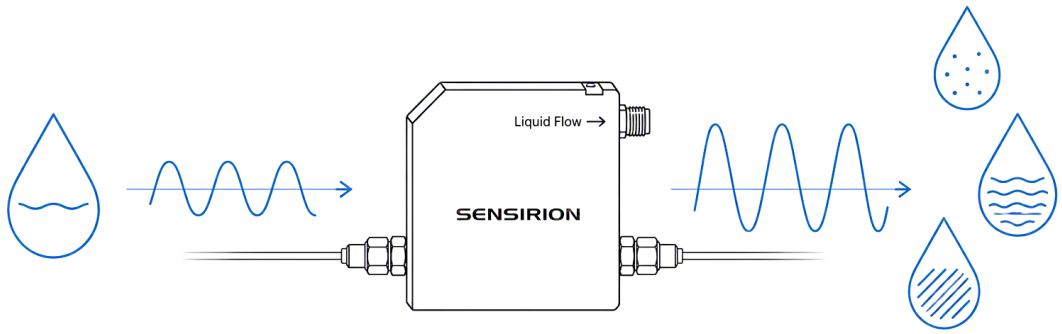
SENSIRION

Flow Rate and Volume Correction

Application Note for Liquid Flow Sensors



This document provides practical guidance for correcting the flow rate and dispensed volume output of Sensirion liquid flow sensors when used with liquids other than the factory calibrated media. It explains how to generate reference measurements, derive correction parameters, and apply the correction in user software for the validated liquid, setup, and operating range.

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1 Introduction

Sensirion liquid flow sensors are factory-calibrated for one or more reference liquids, typically water and/or isopropyl alcohol (IPA). When a sensor is used with another liquid, the sensor still provides a stable and repeatable signal, but the absolute flow rate or accumulated volume can deviate from the real value because the thermal properties of the liquid differ from the calibration medium.

This application note explains practical methods to derive correction parameters that can be applied in the user's software. The goal is not to change the factory calibration stored on the sensor, but to correct the output externally for the validated liquid, flow range, setup, and operating conditions.

2 Flow rate recalibration for different media

Flow rate recalibration is recommended when the sensor output is used as an absolute flow value, for example in flow monitoring or closed-loop pump control. The correction is valid only for the liquid, temperature, sensor type, selected calibration field, and flow range used during the recalibration measurements.

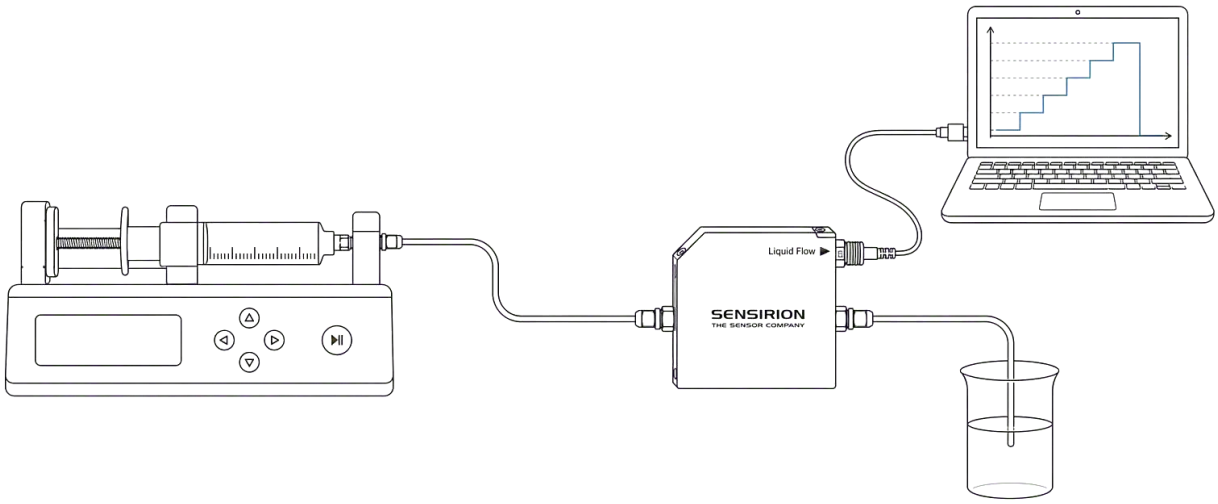


Figure 1. Schematics of set-up for flow rate recalibration process

Generate calibration data for the new liquid by comparing the sensor output with an independent reference measurement at several stable flow points across the relevant operating range. At each point, allow the flow to stabilize before recording the paired sensor and reference values.

1. Choose the available sensor calibration field that most closely matches the thermal behavior of the new liquid. Water calibration may be a suitable starting point for aqueous solutions, while IPA calibration may be suitable for some hydrocarbons or liquids with similar thermal properties. Verify the selected field experimentally over the intended operating range.
2. Generate several stable reference flow points across the defined flow rate range using a suitable pump, preferably a low-pulsation source such as a syringe pump.
3. At each point, record the sensor output and the independently determined reference flow rate to create a table where each entry contains two values:
    - the sensor output measured with the selected calibration field
    - the corresponding reference flow rate measured independently

4. Plot the reference flow rate against the sensor output in a scatter graph. Fit a straight line and assess the residual error across the full range. If the relationship is sufficiently linear to meet the application's accuracy requirements, use a single linear correction equation:

$$Q_{actual} = a \cdot Q_{sensor} + b$$

5. If the deviation is nonlinear but repeatable, evaluate a higher-order polynomial fit or create a look-up table (LUT) as described in Section 2.1. Select the simplest method that meets the accuracy requirement and avoid unnecessarily high polynomial orders that may introduce unrealistic behavior between measurement points.

2.1 Making and using a LUT

If the deviation between measured and reference flow rates is nonlinear, create a look-up table (LUT) that maps each measured sensor output to the corresponding reference flow rate. During operation, the user software uses this table to convert the sensor output into a corrected flow rate by interpolation.

1. Organize the measurement data in ascending order of sensor output, then divide the data into segments. Each segment is defined by two consecutive data points. Use enough calibration points to capture the shape of the deviation over the full operating range, adding more points where the curve changes rapidly or greater accuracy is required.
2. If the LUT is intended as a generic recalibration for multiple sensors of the same type, it is recommended to collect data from several sensors to characterize unit-to-unit variation.
3. Calculate a linear fit for each segment and express the corrected reference flow rate as a function of the measured sensor output. The LUT consists of the sensor-output range and the corresponding correction equation for every segment (see Table 3 and Table 5 as examples).
4. Store the LUT in the user software, not on the sensor. The sensor continues to report the flow rate based on its factory calibration, while the software applies the correction externally.
5. During operation, identify the LUT segment that contains the current sensor output value and evaluate that segment's correction equation to calculate the corrected flow rate.
6. Do not extrapolate outside the measured LUT range. If the sensor output is below the lowest point or above the highest point, extend the calibration data or limit the usable flow range accordingly.
7. Validate the final LUT using reference measurements at additional flow points that were not used to derive the correction. Confirm that the corrected error meets the application's accuracy requirements across the validated operating range.

2.2 Example

This example applies the procedure described in Section 2 to recalibrate a liquid flow sensor for a different liquid. It first derives a single linear flow correction and then develops a LUT-based linear spline correction using the same measurement data.

1. Collect a set of flow rate measurements in the range of interest and compare them to the reference value given by the low-pulsating pump. For optimal accuracy, collect measurements from multiple different sensors and average the result for each flow rate. In this example, the target flow rate range is 10 to 60 ml/min.

Actual Flow (ml/min)	Average Sensor Measured Flow (ml/min)
10	9.52
20	14.61
30	19.71
40	22.93
50	32.68
60	42.07

Table 1. Example measurements for flow rate recalibration

2. Enter the collected data into an Excel spreadsheet and plot the actual flow vs the average flow measured by the sensors.

3. Right click on any data point and select "Add Trendline." Select "Linear" under the trendline options and check the "Display Equation on chart" box. For illustrative purposes, the chart below includes translucent markers that represent the measurements from each individual sensor.

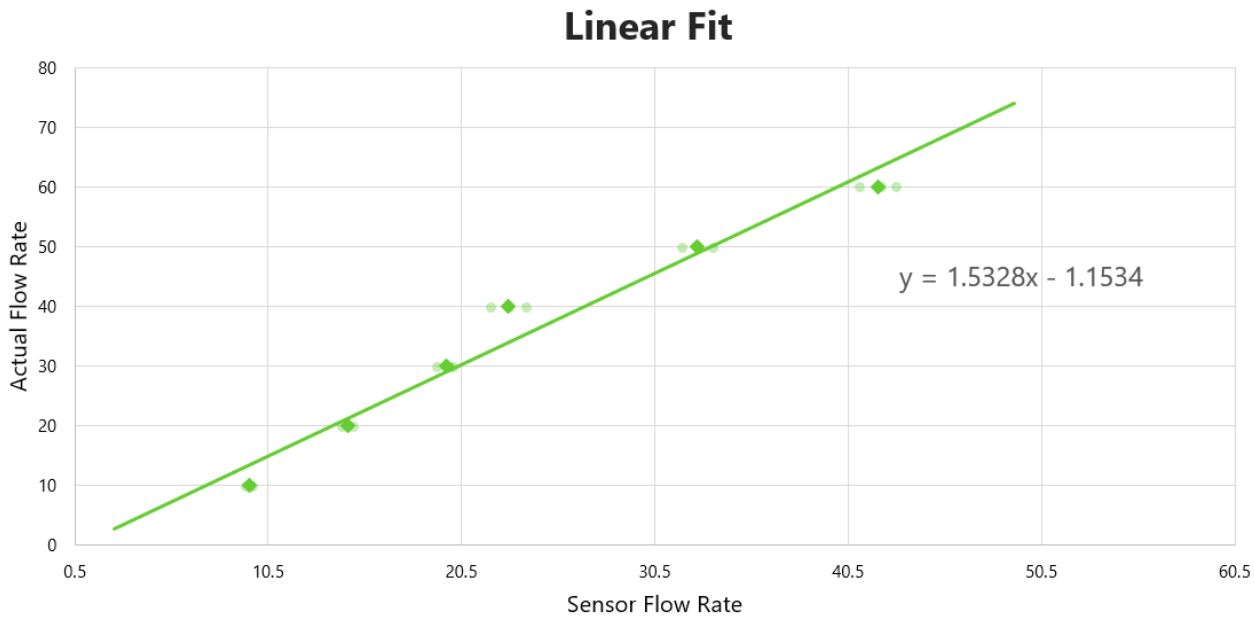


Figure 2. Scatter plot of average flow measurements with linear trendline.

4. The slope and y-intercept of the trendline equation represent the coefficients a and b of the correction equation:

$$Q_{actual} = a \cdot Q_{sensor} + b$$

$$Q_{actual} = 1.53 \cdot Q_{sensor} - 1.15$$

2.2.1 LUT-Based Linear Spline

As an alternative to a linear fit, we will use the previous data to illustrate how to create a look up table (LUT) that more accurately corrects the non-linearities in the new recalibration. Before proceeding, review the previous example, as this one expands on those concepts.

5. To get started, organize the data points from Table 1 into succeeding pairs. The line connecting each set of points will represent a segment in our spline function:

Segment	Data Point Pair (x, y)
1	(9.52,10) and (14.61,20)
2	(14.61,20) and (19.71,30)
3	(19.71,30) and (22.93, 40)
4	(22.93, 40) and (32.68, 50)
5	(32.68, 50) and (42.07, 60)

Table 2. Data point pairs for each spline segment

6. Add the collected data to an excel spreadsheet and create a plot. Right click on the plot and choose Select Data. Add each point pair as a separate series, as shown below. Each series will represent a segment in the spline correction.

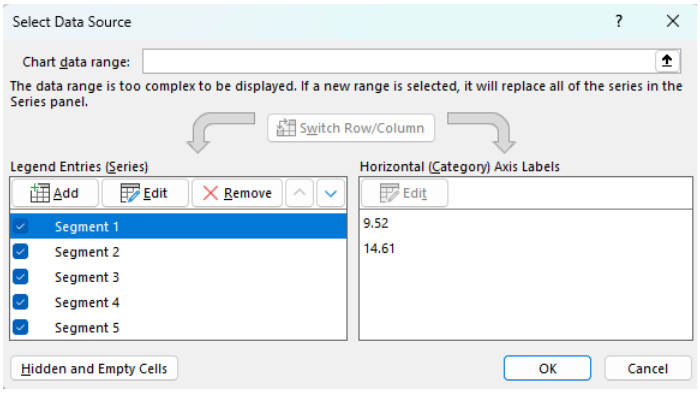


Figure 3. Point pairs added as series in Excel

7. Calculate a line equation for each segment. This can be done by adding a linear trendline to each of the 5 series.

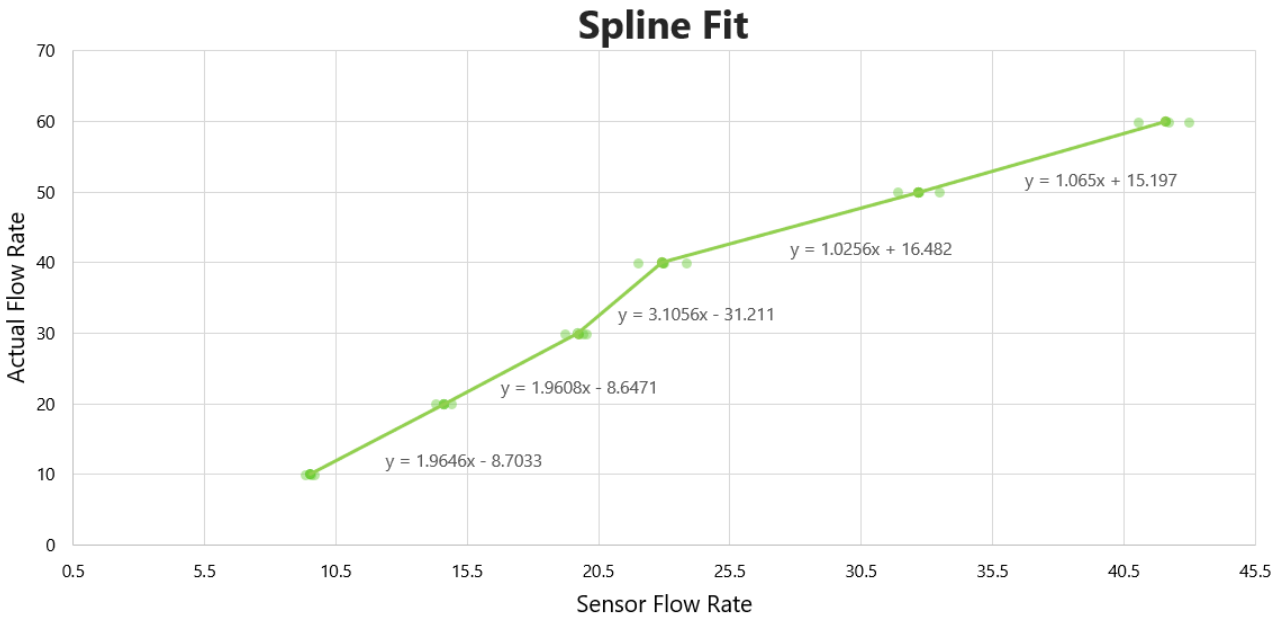


Figure 4. Scatter plot of point pairs with trendlines. Translucent markers represent individual sensor measurements and solid markers represent the average.

8. We are therefore left with 5 linear equations, with each equation representing a segment of the linear spline correction function. Each equation is provided in the table below, along with the range where it is defined.

Range	Correction Equation
$9.52 \leq Q_{sensor} < 14.61$	$Q_{actual} = 1.9646 \cdot Q_{sensor} - 8.7033$
$14.61 \leq Q_{sensor} < 19.71$	$Q_{actual} = 1.9608 \cdot Q_{sensor} - 8.6471$
$19.71 \leq Q_{sensor} < 22.93$	$Q_{actual} = 3.105 \cdot Q_{sensor} - 31.211$
$22.93 \leq Q_{sensor} < 32.68$	$Q_{actual} = 1.025 \cdot Q_{sensor} + 16.482$
$32.68 \leq Q_{sensor} \leq 42.0$	$Q_{actual} = 1.9646 \cdot Q_{sensor} + 15.197$

Table 3. Look up table (LUT) with recalibration equations for each measurement segment

9. The numbers of segments required depends on the data behavior. For example, in this case it may be adequate to use only 2 different segments to represent the flow rate behavior at low and high flow rates. Such LUT and corresponding plot would look like this:

Segment	Data Point Pair (x, y)
1	(9.52,10) and (22.93, 40)
2	(22.93, 40) and (42.07, 60)

Table 4. Data point pairs for spline segments

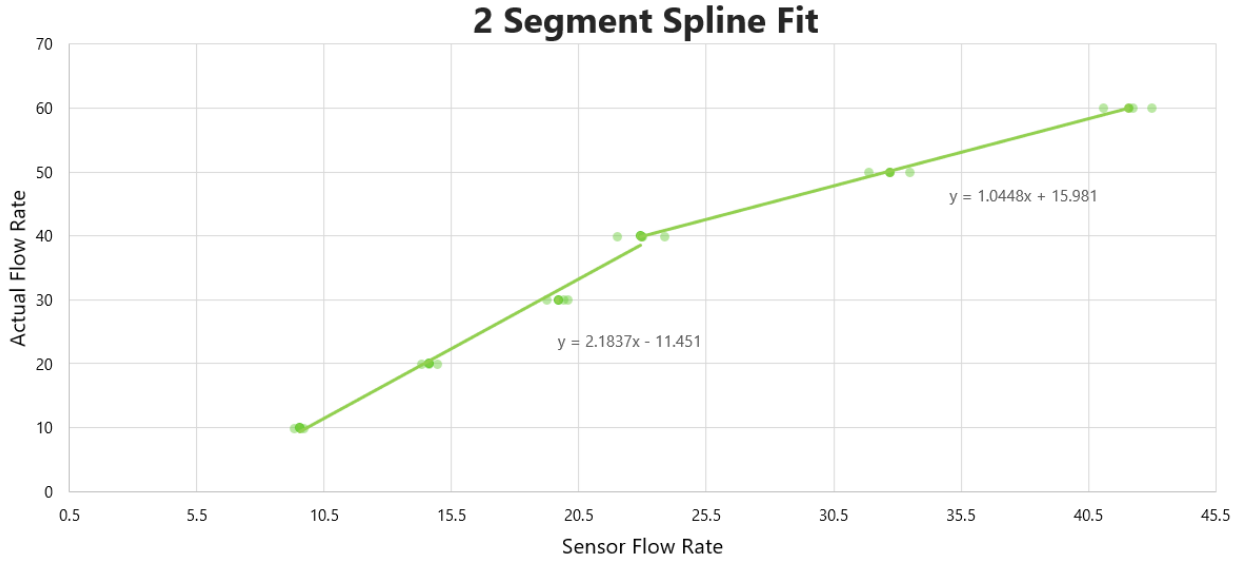


Figure 5. Scatter plot of point pairs with trendlines

10. In this case, the LUT only has two different segments.

Range	Correction Equation
$9.52 \leq Q_{sensor} < 22.93$	$Q_{actual} = 2.1837 \cdot Q_{sensor} - 11.451$
$22.93 \leq Q_{sensor} \leq 42.0$	$Q_{actual} = 1.0448 \cdot Q_{sensor} + 15.981$

Table 5. Look up table (LUT) with recalibration equations for each measurement segment

3 Dispensed volume correction

Dispense applications require the sensor reading to correlate accurately with the actual delivered volume. When the liquid differs from the factory calibration medium, the sensor remains highly repeatable, but the accumulated volume can show a systematic deviation. As with the flow rate recalibration described in Section 2, the measured volume can be corrected in the user software using the methods described below.

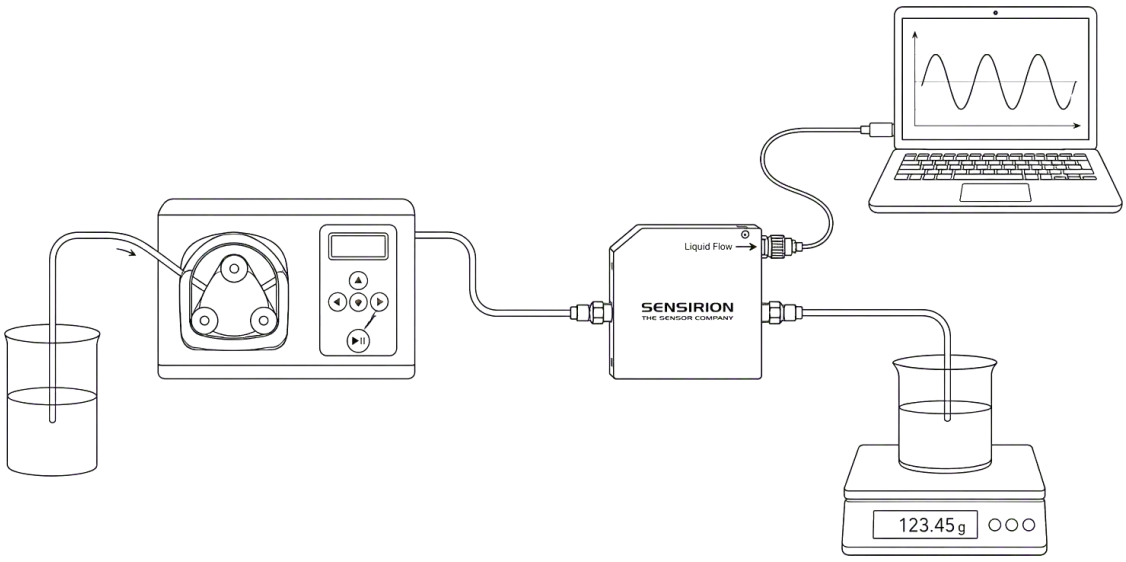


Figure 6. Schematics of set-up for dispensed volume correction process

The simple volume correction described below is valid only for fixed dispense conditions. If the dispense flow rate, dispense profile, fluid, temperature, or relevant fluidic setup changes, repeat the verification and correction procedure. Perform the measurements using the same components and system as in the final application; a syringe-pump setup is not required for this scenario. Compare the volume calculated from the sensor signal with an independently measured dispensed volume, then apply a correction factor in the application software.

1. Set the pump to the fixed flow rate or dispense profile that will be used during normal operation. The correction is valid only for the tested operating condition, so choose a representative setting.

2. Run several measurements at different dispense times. Select dispense times that cover the expected operating range of the application, including the shortest and longest relevant dispense durations. For more statistically significant data, repeat each measurement several times.

3. For each dispense, determine the actual dispensed volume using an independent reference method, such as gravimetric measurement with a suitable balance and fluid density correction.

4. Plot the actual dispensed volume vs. the measured volume from sensor and fit the data with a straight line (or a higher degree polynomial) to determine the correction coefficients. See examples in sections 3.1 and 3.2 for more details.

5. Implement the correction coefficients in your software and repeat several dispense tests within the verified range. Confirm the corrected sensor-based volume against the independent reference measurement before using the correction in the final application.

3.1 Example: linear correction

1. Collect a set of volume points as described in Section 3. In this case, the pump was set to 30 ml/min and different volumes were measured at dispensed times between 5 and 15 seconds. For each dispense time, the measurement was repeated 5 times.

Dispense time (s)	Actual Volume (ml)	Average Sensor Measured Volume (ml)
5	2.5	1.46
7	3.5	1.88
9	4.5	2.17
11	5.5	2.4
13	6.5	2.64
15	7.5	3.02

Table 6. Example measurements for a volumetric correction

2. Enter the collected data into an Excel spreadsheet and plot the actual volume vs the volume measured by the sensor.

3. Right click on any data point and select "Add Trendline." Select "Linear" under the trendline options and check the "Display Equation on chart" box.

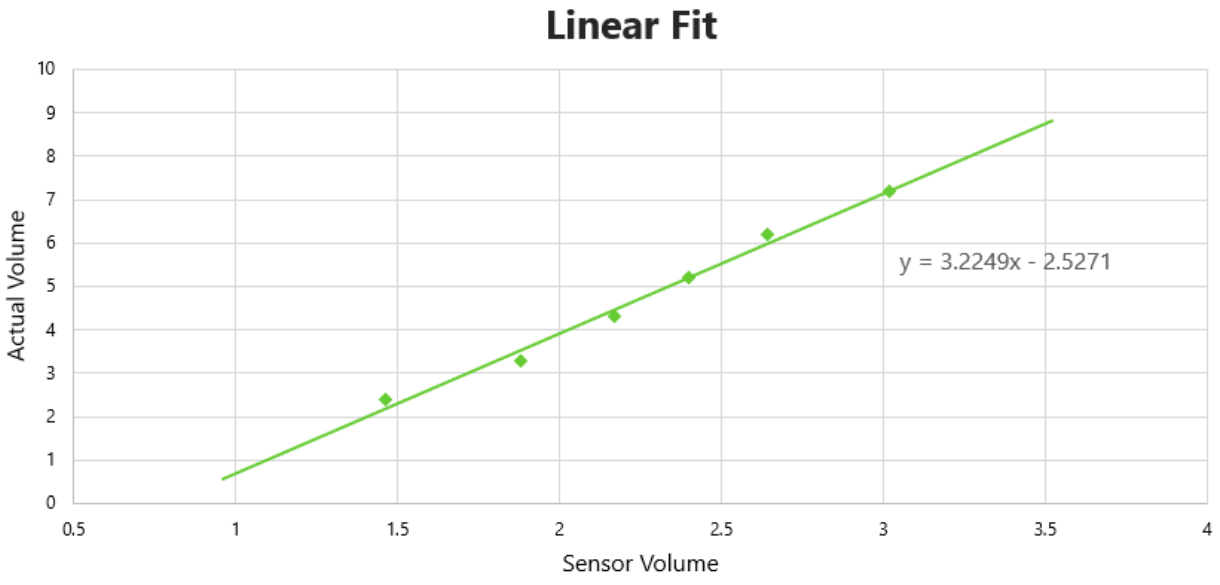


Figure 7. Scatter plot of volume measurements with linear trendline

4. The slope and y intercept of the trendline equation represent the coefficients a and b of the correction equation:

$$V_{actual} = a \cdot V_{sensor} + b$$

$$V_{actual} = 3.2249 \cdot V_{sensor} - 2.5271$$

5. You can verify the accuracy of the correction by calculating the percent error using the following formula.

$$E_{correction} = 100 \cdot \left(\frac{V_{corrected}}{V_{actual}} - 1\right)$$

6. The error calculation from this example yields the following result.

True Volume	Sensor Output	Corrected sensor output	Relative error of correction
2.5	1.46	2.31	-7.75%
3.5	1.88	3.72	6.21%
4.5	2.17	4.69	4.27%
5.5	2.4	5.46	-0.64%
6.5	2.64	6.27	-3.52%
7.5	3.02	7.55	0.64%

Figure 8. Resulting error from linear correction

3.2 Example: polynomial correction

1. Follow steps 1 and 2 from the linear correction example in Section 3.1

2. Right click on any data point and select "Add Trendline." Select "Polynomial" under the trendline options, and enter the desired polynomial order. In this example, we will be generating a 2nd order (quadratic) equation. Check the "Display Equation on chart" box.

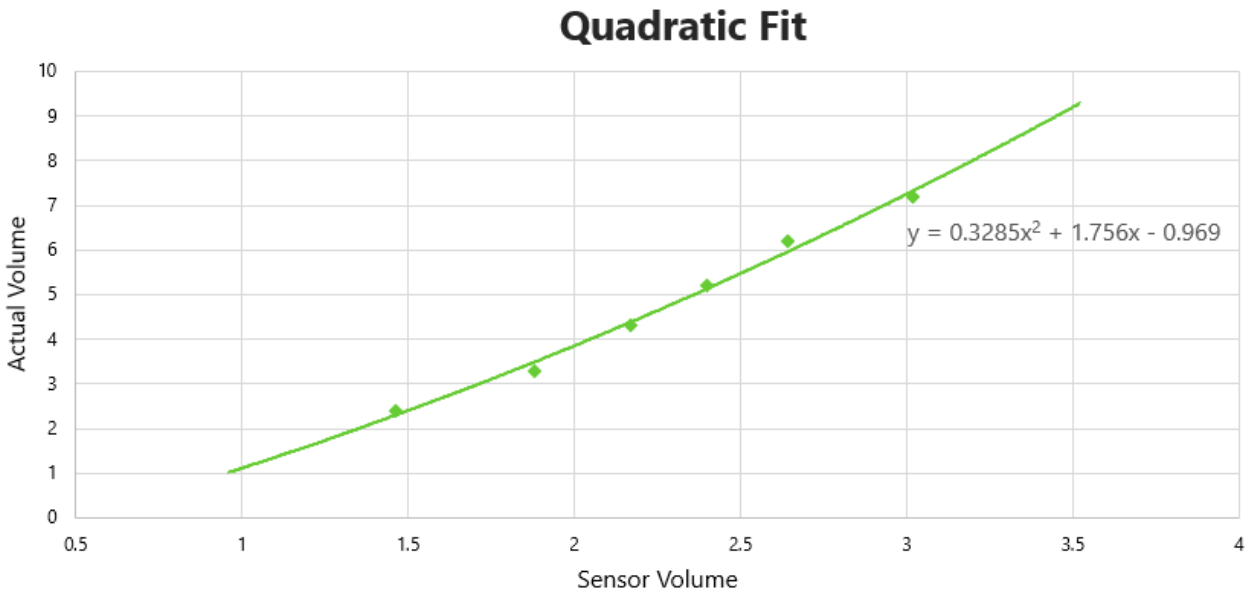


Figure 9. Scatter plot of volume measurements with quadratic trendline

3. The quadratic correction equation can be expressed in the following format, with a, b and c representing the coefficients:

$$V_{actual} = a \cdot V_{sensor}^{2} + b \cdot V_{sensor} + c$$

Using the coefficients obtained from the trendline, the following equation is derived:

$$V_{actual} = 0.3285 \cdot V_{sensor}^{2} + 1.756 \cdot V_{sensor} - 0.969$$

4. You can verify the accuracy of the correction by calculating the percent error using the following formula.

$$E_{correction} = 100 \cdot \left(\frac{V_{corrected}}{V_{actual}} - 1\right)$$

5. The error calculation from this example yields the following result.

True Volume	Sensor Output	Corrected sensor output	Relative error of correction
2.5	1.46	2.39	-4.31%
3.5	1.88	3.69	5.29%
4.5	2.17	4.63	2.88%
5.5	2.4	5.41	-1.67%
6.5	2.64	6.25	-3.87%
7.5	3.02	7.64	1.84%

Figure 10. Error resulting from quadratic correction

4 Conclusions

The examples presented in this application note are intentionally simplified and are intended to illustrate the general recalibration approach when measuring different liquids. In practice, achieving an accurate recalibration becomes more challenging as the thermal properties of the target liquid differ increasingly from those of the selected factory calibration medium. To maximize recalibration accuracy, each sensor should ideally be recalibrated individually, taking advantage of the high repeatability of Sensirion liquid flow sensors. If individual recalibration is not feasible and a generic correction function is required, measurements should be collected from multiple sensors, and the methods described in this application note should be applied to the averaged data.

Sensirion liquid flow sensors are temperature-compensated over their specified operating range, typically 5 to 50 °C. However, when a sensor is recalibrated for a different liquid, the recalibration should be performed at the intended application temperature. If the application operates at multiple temperatures, verify the recalibration at each relevant temperature and evaluate the resulting discrepancies. The sensor's standard temperature compensation does not necessarily compensate for the temperature-dependent behavior of the new liquid or guarantee that one correction remains valid across the full temperature range.

Important Notices

Warning, Personal Injury

Do not use this product as safety or emergency stop devices or in any other application where failure of the product could result in personal injury (including death). Do not use this product for applications other than its intended and authorized use. Before installing, handling, using or servicing this product, please consult the data sheet and application notes. Failure to comply with these instructions could result in death or serious injury.

If the Buyer purchases or uses SENSIRION products for any unintended or unauthorized application, Buyer shall defend, indemnify and hold harmless SENSIRION and its officers, employees, subsidiaries, affiliates and distributors against all claims, costs, damages and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if SENSIRION is allegedly negligent with respect to the design or the manufacture of the product.

ESD Precautions

The inherent design of this component causes it to be sensitive to electrostatic discharge (ESD). To prevent ESD-induced damage and/or degradation, take customary and statutory ESD precautions when handling this product. See application note "ESD, Latchup and EMC" for more information.

Warranty

SENSIRION solely warrants to the original purchaser of this product for a period of 12 months (one year) from the date of delivery that this product is of the quality, material and workmanship defined in SENSIRION's published specifications of the product. Within such period, if proven to be defective, SENSIRION shall as sole and exclusive remedy, in SENSIRION's discretion, repair this product or send a replacement product, free of charge to the Buyer, provided that:

- notice in writing describing the defects shall be given to SENSIRION within fourteen (14) days after their appearance;
- such defects shall be found, to SENSIRION's reasonable satisfaction, to have arisen from SENSIRION's faulty material or workmanship;
- the defective product shall be returned to SENSIRION's factory at the Buyer's expense; and
- the warranty period for any repaired or replaced product shall be limited to the unexpired portion of the original period.

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Headquarters and Subsidiaries

Sensirion AG
Laubisruetistr. 50
CH-8712 Staefa ZH
Switzerland
phone: +41 44 306 40 00
fax: +41 44 306 40 30
info@sensirion.com
www.sensirion.com

Sensirion Taiwan Co. Ltd
phone: +886 2 2218-6779
info@sensirion.com
www.sensirion.com

Sensirion Inc., USA
phone: +1 312 690 5858
info-us@sensirion.com
www.sensirion.com

Sensirion Japan Co. Ltd.
phone: +81 45 270 4506
info-jp@sensirion.com
www.sensirion.com/jp

Sensirion Korea Co. Ltd.
phone: +82 31 337 7700~3
info-kr@sensirion.com
www.sensirion.com/kr

Sensirion China Co. Ltd.
phone: +86 755 8252 1501
info-cn@sensirion.com
www.sensirion.com/cn

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