Introduction

Sensirion liquid flow meters are calibrated for one or more specific types of liquids. If a different liquid needs to be measured, the sensor performance with that liquid should be verified and it may be necessary to apply a correction to the sensor output. Here, ‘sensor output’ is typically the flow rate, but could also be the accumulated volume if the liquid flow meter is used with the SCC1-RS485 Sensor Cable’s Totalizer function.

This document describes simple methods to determine correction parameters for the flow rate or the volume.

1. Method for Verifying Sensor Performance

The flow range of a given sensor type (e.g. SLQ-QT105) depends on the liquid the sensor is used with. The SLQ-QT105 is calibrated for Isopropyl Alcohol (IPA). The calibration will be correct for IPA and approximately correct for other hydrocarbons with similar thermodynamic properties. For other liquids, the maximum flow range may be considerably reduced. See below:

<table>
<thead>
<tr>
<th>Medium</th>
<th>Maximum Flow Rate</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPA</td>
<td>2000</td>
<td>µl/s</td>
</tr>
<tr>
<td>Ethanol, Methanol, Gasoline</td>
<td>-830</td>
<td>µl/s</td>
</tr>
<tr>
<td>Acetone</td>
<td>-670</td>
<td>µl/s</td>
</tr>
<tr>
<td>Diesel, Petroleum, Veg. Oils</td>
<td>1300 (1600)</td>
<td>µl/s</td>
</tr>
<tr>
<td>Silicon Oil, Ether</td>
<td>&lt; 1600</td>
<td>µl/s</td>
</tr>
<tr>
<td>Water</td>
<td>85</td>
<td>µl/s</td>
</tr>
</tbody>
</table>

Fig. 1: Maximum flow rates for different media

If an unknown medium is dispensed, the sensor’s ability to measure this medium at the desired flow rate needs to be verified. A simple procedure for this is as follows:

1. Determine the operating point (operating flow rate, \( Q_{\text{operating}} \)) you would like to use.
2. Fix a typical dispense time (e.g. 1 second).
3. Measure 3 dispenses of fixed duration with the sensor:
   a. one at the desired flow rate
   b. one at a lower flow rate
   c. one at a higher flow rate
4. Plot the volumes measured by the sensor \( V_{\text{measured}} \) vs. the dispensed volumes \( V_{\text{dispensed}} \) in a diagram, see Fig. 2:
The measured volumes must lie approximately on a straight line which passes through the origin.

2. Sensor Output Correction

Once the sensor performance at the desired flow rate has been verified according to section 1, the correction for the sensor output may be determined. The following use cases may be distinguished:

- The sensor output of interest is the accumulated volume, e.g. in a dispensing application.
  - a) The dispense duration and the flow rate setpoint are fixed.
  - b) The dispense duration is variable, the flow rate setpoint is fixed.
  - c) The dispense duration is fixed, the flow rate setpoint is variable.
  - d) The dispense duration and the flow rate setpoint are variable.

- The sensor output of interest is the flow rate, e.g. in a closed-loop control or in a flow rate monitoring application.
  - e) The flow rate setpoint is fixed.
  - f) The flow rate setpoint is variable.

The suggested correction method for each of the above use cases is suggested according to Table 1:

Table 1: Suggested sensor output correction methods

<table>
<thead>
<tr>
<th></th>
<th>Fixed dispense duration</th>
<th>Variable dispense duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed flow rate setpoint</td>
<td><strong>Cases a) and e)</strong>. Correction method: Multiply sensor output by a constant.</td>
<td><strong>Case b)</strong>. Correction method: Linear fit of volume vs. time (see section 3)</td>
</tr>
<tr>
<td>Variable flow rate setpoint</td>
<td><strong>Cases c) and f)</strong>. Correction method: Linear or Non-linear fit (see section 4)</td>
<td><strong>Case d)</strong>. Correction method: two-dimensional fit. (contact Sensirion for further information)</td>
</tr>
</tbody>
</table>

Fig. 2: Measured volume vs. dispensed volume for variable flow rates (667, 1000, 1667 ul/s) but a fixed dispense time (1s).

5. The measured volumes must lie approximately on a straight line which passes through the origin.
3. Method for Dispense Volume Correction (Variable Duration, Fixed Flow Rate)

3.1 Description of Correction Method

Once the sensor's suitability for the desired medium and flow rate setpoint has been verified according to section 1, the sensor's volume output may be corrected to give the true dispensed volume. In the case that the flow rate is fixed, the following simple procedure gives good results.

1. Measure two dispenses with different dispense durations (e.g. 1 s, 3 s) at the same desired flow rate \( Q_{\text{operating}} \).
2. The result may look like Fig. 3.

![Dispensed volume vs. measured volume for variable dispense times (0.5 s, 1 s, 2 s, and 3 s) but fixed flow rate (1000 µl/s). The medium is a mixture of 10% H\(_2\)O and 90% IPA.](image)

Fig. 3: Dispensed volume vs. measured volume for variable dispense times (0.5 s, 1 s, 2 s, and 3 s) but fixed flow rate (1000 µl/s). The medium is a mixture of 10% H\(_2\)O and 90% IPA.

3. The two points measured in step 1 (solid marks in Fig. 3) determine the relationship between the measured volume and the dispensed volume according to equation (1):

\[
V_{\text{dispensed}} = a \cdot V_{\text{measured}} + b \tag{1}
\]

where the slope \( a \) can be computed from

\[
a = \frac{V_{\text{dispensed}}(3 \text{ s}) - V_{\text{dispensed}}(1 \text{ s})}{V_{\text{measured}}(3 \text{ s}) - V_{\text{measured}}(1 \text{ s})} = 0.7196 \tag{2}
\]

and the offset \( b \) can be computed from

\[
b = V_{\text{dispensed}}(1 \text{ s}) - a \cdot V_{\text{measured}}(1 \text{ s}) = 70.51. \tag{3}
\]

4. The correction parameters \( a \) and \( b \) determined in equations (2) and (3) can now be used to correct the dispense volume for any dispense time at the desired flow rate \( Q_{\text{operating}} \) by using the formula (4):

\[
V_{\text{corrected}} = a \cdot V_{\text{measured}} + b \tag{4}
\]

With the method described in section 3.1, the dispense volumes can be corrected at any fixed flow rate within the flow range of the sensor for the selected medium (see section 1).
3.2 Example: Flow Rate 1000 µl/s, 10% H₂O and 90% IPA

Fig. 4 shows the results of such a correction for a flow rate of 1000 µl/s and the medium being a mixture of 10% H₂O and 90% IPA.

Fig. 4: Left: Dispensed, measured and corrected volumes for different dispense times at fixed flow rate (1000 µl/s) for a mixture of 10% H₂O and 90% IPA. Right: corrected volumes for 8 dispenses at each dispense time and fixed flow rate.

The left plot of Fig. 4 shows the dispensed volumes (measured with a scale), the measured volumes (measured by the sensor without correction), and the corrected volumes (measured by the sensor and corrected using the method of section 3.1).

The right plot of Fig. 4 shows the corrected volumes of 8 dispenses for each dispense time, all computed with the same parameters determined in equations (2) and (3) of section 3.1. The flow rate is fixed at 1000 µl/s. The typical error of the correction is smaller than 1 % for dispense times ≥ 1 s.

For different flow rates the procedure of section 3.1 can be repeated and gives the results presented in the following sections.
3.3 Example: Flow Rate 1667 µl/s, 10% H₂O and 90% IPA

![Graph](image)

**Fig. 5:** Correction parameters for flow rate 1667 µl/s and 10% H₂O 90% IPA

![Bar chart](image)

**Fig. 6:** Dispensed, measured and corrected volumes for flow rate 1667 µl/s and 10% H₂O 90% IPA

![Line graph](image)

**Fig. 7:** Corrected volumes of 8 dispenses at each dispense time for flow rate 1667 µl/s and 10% H₂O 90% IPA
3.4 Example: Flow Rate 667 µl/s, 10% H₂O and 90% IPA

Fig. 8: Correction parameters for flow rate 667 µl/s and 10% H₂O 90% IPA

Fig. 9: Dispensed, measured and corrected volumes for flow rate 667 µl/s and 10% H₂O 90% IPA

Fig. 10: Corrected volumes of 8 dispenses at each dispense time for flow rate 667 µl/s and 10% H₂O 90% IPA
4. Method for Dispense Volume Correction (Fixed Duration, Variable Flow Rate)

4.1 Description of Correction Method

Once the sensor’s suitability for the desired medium and flow rate setpoint has been verified according to section 2, the sensor’s volume output may be corrected to give the true dispensed volume. Depending on the properties of the liquid in use, a linear correction may be sufficient or a higher order correction may be necessary. In general, the lowest order which yields a satisfactory result should be used for the correction.

4.1.1 Linear Correction

In a first step, a linear correction similar to the one presented in section 3.1 may be tried. The procedure is as follows.

1. Fix a dispense duration (e.g. 3 s) and measure the sensor volume output for a set of flow rate setpoints covering the flow range of interest.
2. Copy the result to a spreadsheet program such as e.g. Microsoft Excel. Plot the true dispensed volume vs. the sensor output. The result may look like Figure 11.

3. Use the ‘Add trendline’-function to generate a fit to the data points. Select fit type ‘linear’ and display the fit equation and the $R^2$-value on the chart. The $R^2$-value is an indicator for the quality of the fit: the closer it is to 1, the better is the fit. The fit equation is displayed in the form $y = ax + b$ on the chart.
4. Use the parameters $a$ and $b$ obtained from the fit to calculate the corrected volume from the sensor output by the following formula (5)

$$V_{\text{corrected}} = a \cdot V_{\text{sensor}} + b$$ (5)

The result of this calculation is shown in Figure 12:

The relative error of the correction can be calculated by the following formula (6)

$$E_{\text{correction}} = \frac{V_{\text{corrected}}}{V_{\text{dispensed}}} - 1$$ (6)

If the result is satisfactory, a suitable correction has been reached.

Fig. 11: Example data and linear fit: Dispensed volume vs. measured volume for variable flow rate but fixed dispense time (3 s).

Fig. 12: Result of linear correction
4.1.2 Quadratic Correction

In the present case, a considerable error remains, and it may be worth to refine the correction. Instead of a linear correction, a polynomial of higher order may be used. In step 3 of section 4.1.1, select type ‘polynomial’ with order ‘2’ instead of ‘linear’ to obtain a quadratic fit. The result is shown in Fig. 13:

![B) quadratic fit](image)

From the parameters obtained from the fit, the volume correction can be computed using the formula indicated in the chart, where \( x \) is the sensor volume output and \( y \) the corrected volume. The result is shown in the following Fig. 14:

<table>
<thead>
<tr>
<th>True volume</th>
<th>sensor volume output</th>
<th>corrected sensor output</th>
<th>relative error of correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4</td>
<td>1.46</td>
<td>2.296</td>
<td>-4.4%</td>
</tr>
<tr>
<td>3.3</td>
<td>1.68</td>
<td>3.493</td>
<td>5.9%</td>
</tr>
<tr>
<td>4.3</td>
<td>2.17</td>
<td>4.386</td>
<td>2.1%</td>
</tr>
<tr>
<td>5.2</td>
<td>2.49</td>
<td>5.138</td>
<td>-1.2%</td>
</tr>
<tr>
<td>6.2</td>
<td>2.64</td>
<td>5.996</td>
<td>-3.9%</td>
</tr>
<tr>
<td>7.2</td>
<td>3.02</td>
<td>7.330</td>
<td>1.8%</td>
</tr>
</tbody>
</table>

![Fig. 14: Result of quadratic fit.](image)

The evaluation presented in Fig. 14 shows that the volume correction has improved considerably, but the relative deviations still reach up to 6%.
4.1.3 Cubic Correction

Note that the data in Fig. 11 (and Fig. 13) shows a slight S-shape. A polynomial fit of order 3 can account for such a curve shape. In step 3 of section 4.1.1, select type ‘polynomial’ with order ‘3’ instead of ‘linear’ to compute a cubic fit. The result is shown in Fig. 15:

![Cubic fit](image)

Fig. 15: Cubic fit to the data of Fig. 11. The red ellipses highlight parts of the fit which must not be used for the correction of the sensor output.

The fit curve follows the data points very closely. The good quality of the fit is also evident from the high $R^2$-value.

Note: The fit curve is not monotonic and therefore it must not be used to extrapolate the correction above and below the range of the measured flow rates.

The quality of the correction inside the measured range is evaluated in Fig. 16:

<table>
<thead>
<tr>
<th>true volume</th>
<th>sensor output</th>
<th>corrected sensor output</th>
<th>relative error of correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4</td>
<td>1.46</td>
<td>2.408</td>
<td>0.3%</td>
</tr>
<tr>
<td>3.3</td>
<td>1.88</td>
<td>3.273</td>
<td>-0.8%</td>
</tr>
<tr>
<td>4.3</td>
<td>2.17</td>
<td>4.321</td>
<td>0.5%</td>
</tr>
<tr>
<td>5.2</td>
<td>2.4</td>
<td>5.242</td>
<td>0.0%</td>
</tr>
<tr>
<td>6.2</td>
<td>2.64</td>
<td>6.160</td>
<td>-0.7%</td>
</tr>
<tr>
<td>7.2</td>
<td>3.02</td>
<td>7.214</td>
<td>0.2%</td>
</tr>
</tbody>
</table>

Fig. 16: Result of cubic fit

The error of the correction is below 1% in all 6 data points. The quality of the fit is certainly sufficient so no higher order is required. Moreover, using a fit of too high order may lead to spurious effects and is not recommended.