SENSIRION
THE SENSOR COMPANY

Application Note for SFM3000

Inlet conditions

Summary

Most flow sensors use a significant pressure drop to stabilize the flow that goes through the sensor. Since the SFM3000 is designed for a low pressure drop, it uses other techniques to stabilize the flow. But when no precautions are taken, some effects can still make the measurement sensitive to the inlet conditions to the sensor.

It is therefore highly recommended to design the flow path in such a way that turbulence and acoustic noise at the inlet of the low pressure drop sensor are minimized.

This application note describes the main factors to be considered when choosing inlet conditions or designing the flow path leading up to the sensor.

1. Introduction

The SFM3000 delivers a solution for gas flow measurements in circumstances where a low pressure drop of the sensor is required. The demand for low pressure drops implies a reduced settling of the flow within the sensor; this makes low pressure drop sensors inherently more sensitive to inlet conditions.

The inlet conditions have an influence on the flow profile in the sensor and its laminarity and repeatability. It is therefore important to understand that the flow design of the system leading to the sensor can have an impact on the measurement results. We highly recommend testing flow routing and sensor inlet conditions at an early stage of the product or system development.

2. Turbulence and acoustic noise

In an ideal measurement setup the flow in the sensor is fully laminar, the velocity distribution in the pipe clearly defined and stationary, and there are no velocity and pressure fluctuations (except for the change in total flow). Although in the real world this is rarely given, it is important to achieve flow conditions that come close to this. There are two major types of possible interferences that can negatively affect the measurement result: Turbulence and acoustic noise.

Turbulence is a flow regime characterized by chaotic and stochastic property chances. The cause for turbulent flow in the sensor is usually an insufficient design of the flow routing upstream of the sensor.

Acoustic noise can be caused by sound sources like fans and jet nozzles somewhere in the flow routing. Acoustic waves are (periodic) disturbances in the pressure level travelling with the speed of sound. Because the velocity of the gas flow in the sensor is usually below sonic speed, acoustic noise sources originating from upstream or downstream of the sensor can impact the measurement.

Depending on their nature, turbulence and acoustic interferences can either cause symmetric or asymmetric measurement noise, with the latter leading to systematic reading errors.

The following sections show how to test and optimize the system's flow design.

3. Mesh

To stabilize the flow as much as possible and to reduce the influence of inlet conditions, Sensirion delivers the SFM3000 sensor with a metal mesh at the inlet and the outlet of the sensor tube. This mesh smoothens the flow and reduces the impact of pre-sensor flow conditions.

Similar measures can be taken by the user to increase flow stability with limited impact on the pressure drop across the system.

4. Factors influencing the inlet conditions

The laminarity and repeatability as well as the flow profile can be influenced by changing the following factors:

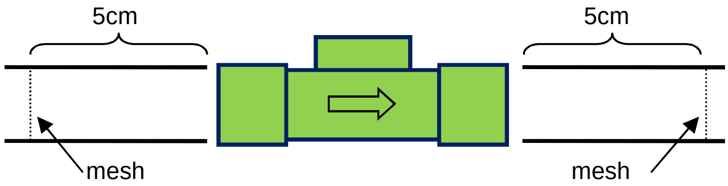
- Lengths and diameter of the tube leading to the sensor
- Bends and kinks leading to the sensor
- Differences in surface texture of the tube and the sensor
- Transition from tube to sensor (gap, step)
- Obstacles or other interferences in the flow path causing turbulences
- Filters in the flow path, especially those that condition the flow profile unevenly
- Jet nozzles, fans and other sources of acoustic noise

Many of such inlet condition alterations will not have significant influence on the measurement. However, in some circumstances major measurement deviations can be caused by these factors or an unfavorable combination of factors.

5. Calibration setup

Sensirion has designed the flow routing at calibration in a way which creates a highly repeatable and laminar flow within the sensor. The most accurate measurements with the sensor can be achieved by choosing a flow design similar to the one at calibration. Thus the calibration setup shall be briefly explained here.

The sensor is positioned horizontally with the connector facing upwards. The piping of the calibration apparatus has the same inner diameter of 18.45mm as the sensor itself. Up- and downstream of the sensor are 5cm of straight steel tubing each with a mesh at the opposite side of the sensor.

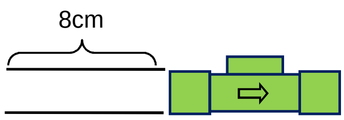


6. Examples: Test of different inlet conditions

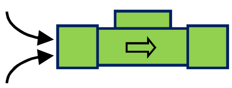
Sensirion has tested a range of typical types of inlet conditions.

These include:

A 8 cm straight inlet tube with 18.45mm inner diameter

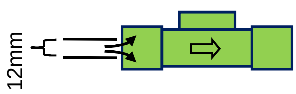


C Open inlet, meaning that the flow is drawn through the sensor and the inlet is open to a larger air volume.



B Commercially available 22mm ISO5356-1:2004 straight connector (intersurgical 1967 straight connector, 22F-22F)

D 12mm nozzle



The following table summarizes the results for those conditions.

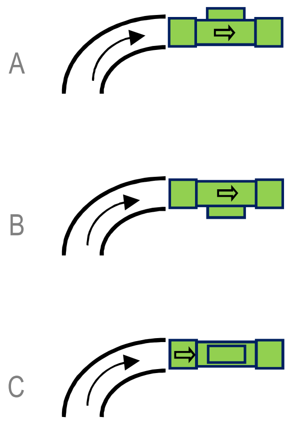
Inlet condition	*Sensor accuracy*
A	*perfect*
B	*perfect*
C	*well within specifications*
D	*high flows slightly (up to 1%) off specifications* *low flows well within specifications*

Conclusion:

- It is strongly advised to avoid an inlet tube with a significantly smaller inner diameter than the sensor. This type of inlet creates a jet nozzle causing an untypical flow profile and significant turbulences.

7. Bends and kinks

Another cause for turbulences and unsymmetrical flow profiles are bends and kinks in the tube right before the sensor inlet. If it is not possible to design the inlet straight, additional testing is recommended. Note that the orientation of the sensor in relation to the bend will influence the measurement. During tests at Sensirion three basic geometries were evaluated and compared with the calibration setup.



The sensor flow reading showed that:
Calibration setup > *A* > *C* > *B* for the same nominal flow, with the measurement of setting A being the closest to the calibration setup and setting B resulting in a reading with the largest deviation from the true flow. All measurements were made with sensors without a mesh at the inlet to increase the sensitivity of the tests.

These results are bound to be dependent on the shape of the bend and the distance between the bend and the inlet. It is possible that a different geometry of the bend would lead to a reading of a too high value in case A and the best measurement result with setting C.

For sensors with a mesh at the inlet these effects are reduced significantly, but can still be significant.

Conclusions:

- Bends and kinks immediately upstream of the sensor should be avoided. If inevitable, extensive testing is recommended.
- Changing the orientation of the sensor in relation to a bend in the inlet can reduce/increase the accuracy of the measurement.

8. Acoustic noise

To date Sensirion encountered two types of interfering noise sources in typical applications of the SFM3000: Fans and jet nozzles. Fans can cause an acoustic noise with a typical frequency related to its rotation.

For jet noise the theory tells us that the acoustic intensity is proportional to the 8th power of the jet velocity, and the typical noise frequency scales linearly with the jet velocity and the inverse of the jet diameter,

$U \propto v^8$, with U the acoustic intensity and v the jet velocity

$f_n \approx v / d$, with f_n the typical noise frequency, v the jet velocity and d the jet diameter

Typically the interference with the measurement peaks at resonance frequencies of the flow system. Measurements at Sensirion suggest that frequencies around 60Hz should be avoided in particular, but depending on the system design and the amplitude of the noise other frequency bands (e.g. much higher frequencies and amplitudes) can show similar effects.

9. Filters

Filters in the flow routing can help calming the flow, but it is also possible that their casing induces new turbulences. Therefore it is suggested to avoid placing a filter straight before the sensor.

In case of acoustic noise, filters have the potential to weaken sonic interference. In systems where acoustic noise is an issue and a filter is used anyway, we recommend placing the filter somewhere in between the sensor and the noise source. However the magnitude of the effect depends on the typical frequency of the noise and the absorption spectrum of the filter.

10. Conclusions and recommendations

The SFM3000 sensor provides low pressure drop flow measurement of outstanding accuracy. As a result of the low pressure drop of the sensor, the flow is not fully stabilized at the sensor interface. The measurement is therefore sensitive to the sensor inlet conditions.

- **Ideal inlet conditions**: Straight piece of tube (5 to 10 cm) with the same inner diameter as the sensor, no steps and gaps, flow stabilizer (laminar flow element or mesh) at the beginning of the straight section leading to the sensor.
- **Testing**: of the whole system (inlet conditions) is recommended.
- **Avoid**: tubes smaller than the inner diameter of the SFM3000 (jet nozzles), strong bends or kinks immediately upstream of the sensor, open inlet, acoustic noise sources.

Revision history

Date	*Author*	*Version*	*Changes*
May 2013	PHA	V0.1	Preliminary draft
June 2013	PHA	V0.2	Reworked draft, sections about filters and acoustic noise added
July 2013	ANB	V1	First release, minor changes

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