Application Note for Sensirion Differential Pressure Sensors (SDP)

Mass Flow Temperature Compensation & Sensor Selection Guide

Summary

Specific applications demand for particular sensor solutions. Sensirion provides a range of differential pressure sensors, and particularly offers two different types of temperature compensations: One optimized for differential pressure measurements, the other for flow measurements in a bypass setup. This application note gives answers to the questions:

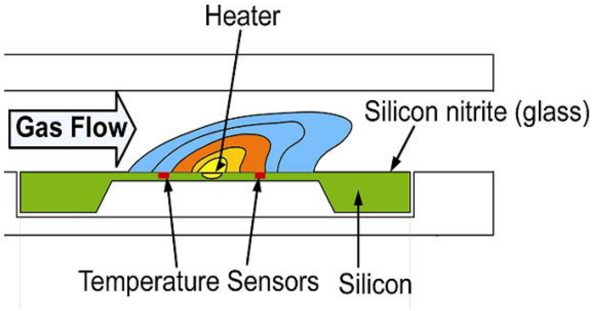
- What is mass flow temperature compensation?
- Which temperature compensation is suitable for a given application?
- When are additional external pressure and temperature compensations needed?

1. Introduction

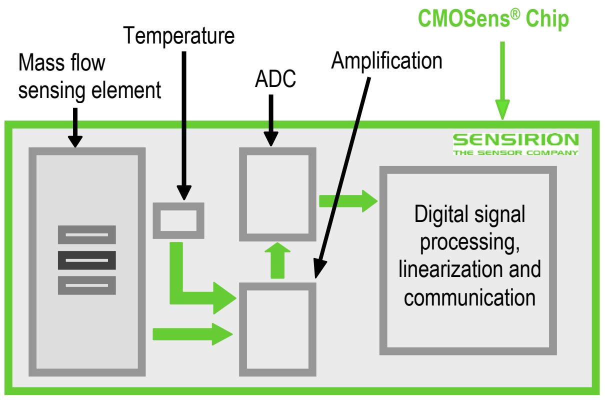
Sensirion offers a whole range of differential pressure sensors with different sizes, pressure ports, interfaces, measurement ranges and configurations. Every single sensor features sophisticated digital temperature compensation. There are two ways how Sensirion corrects for temperature effects; "differential pressure temperature compensation" and "mass flow temperature compensation". This application note explains the difference between the two temperature compensations and helps to select the best sensor or measurement mode for a given application.

2. Measurement technology

In order to measure differential pressure or mass flow, Sensirion uses a thermal mass flow sensing element based on a calorimetric measurement principle. This sensing element is composed of two temperature sensors and a small heating element. The difference between the two temperature sensors correlates with the mass flow passing the chip. A differential pressure across the sensor ports induces a tiny gas flow through the sensor, which is measured by the sensor element.



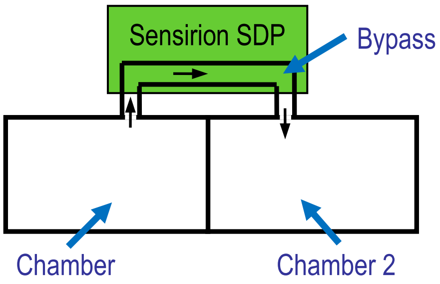
The mass flow sensing element is integrated on a CMOSens® chip allowing the signal to be amplified and digitized on chip for best performance.



3. Typical measurement configurations

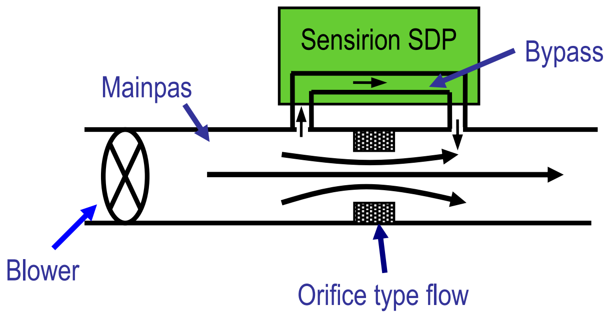
3.1. Differential pressure measurement

In some applications the *differential pressure (dp)* between two chambers (or rooms) is measured. The measurement is commonly expressed in the SI unit “Pascal” or in “inch of water column”.



3.2. Flow measurement

In other applications the differential pressure is measured in a bypass over an orifice in order to derive the *air flow* in the main-pass. The air flow can either be measured in *volume flow* or as *mass flow*.



3.2.1. Volume flow

Volume flow refers to the gas volume per time. The most common units are “liters per minute [l/min]” or “actual cubic feet per minute [acfm]”.

3.2.2. Standard volume flow or Mass flow

Standard volume flow refers to the volume flow at given standard conditions for temperature and pressure. Common units are “standard liters per minute [slm]”, “standard cubic centimeters per minute [sccm]” or “norm liters per minute [ln/min]”.

Because standard volume flow is referenced to a defined temperature T and pressure p, the number of molecules n in the volume V can be calculated using the ideal gas law (pV=nkT). In other words, standard volume flow refers to the number of molecules per time and therefore to the mass per time. For a given gas, a sensor measuring standard volume flow is a mass flow sensor. For clarity we will only use the term mass flow [slm] in this document.

In most applications the mass flow needs to be known instead of the volume flow. For example in heating applications the calorimetric heating value, i.e. the number of gas molecules, is more important than the actual gas volume flow.

Because of its thermal measurement principle Sensirion’s differential pressure sensors are ideally suited to measure mass flow.

4. Temperature Compensations

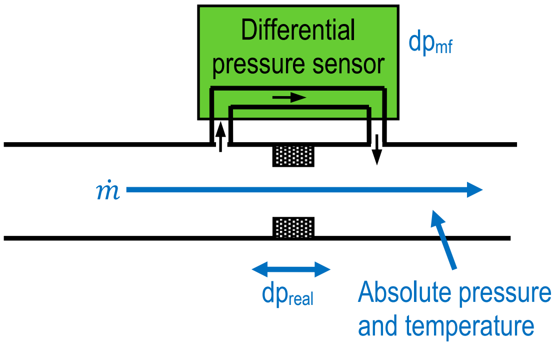
4.1. Temperature compensation for Differential Pressure

With temperature compensation for differential pressure the sensor outputs a signal that is temperature compensated for normal differential pressure measurements. Due to the measurement principle of the sensor, the differential pressure measurement value is dependent on ambient pressure.

4.2. Temperature Compensation for Mass Flow

As explained in chapter 2, Sensirion differential pressure sensors work on a flow-through principle and are intrinsic mass flow sensors. Mass flow temperature compensation delivers a differential pressure value that correlates with the true mass flow.

An example: let's assume a constant mass flow $\dot{m}$ in the use cases below. In these use cases temperature and absolute pressure are varied.



Mass flow	**Absolute pressure**	**Temp**	**dp_{mf}**	**dp_{real}**
constant $\dot{m}$	966mbar	25°C	constant dp_{mf}	$dp_{real} = dp_{mf}$
	966mbar	40°C		$dp_{real} > dp_{mf}$
	1.2bar	5°C		$dp_{real} < dp_{mf}$

One can see that with a constant mass flow the output signal (dp_{mf}) is only a function of the mass flow and otherwise independent of temperature and pressure. In contrast the actual differential pressure (dp_{real}) changes with temperature and pressure and is thus not suited for determining the mass flow.

The reason that in the first use case $dp_{real} = dp_{mf}$ is that the SDP sensors are calibrated at 966mbar and 25°C.

4.3. Choosing the right sensor or measurement mode

Depending on which physical quantity (differential pressure, mass flow or volume flow) is finally needed, either temperature compensation for differential pressure or mass flow is suggested.

For the SDP3x-digital and SDP8xx-digital (I²C) the temperature compensation can be selected by separate measurement commands.

The SDP3x-analog has a configuration pin to select the temperature compensation mode.

In summary:

Measure dp or flow?	Measure dp	Measure flow
Proposed temperature compensation	Temperature compensation for Differential Pressure	Temperature compensation for mass flow

Note: The best way to measure mass flow in a bypass configuration is to use a differential pressure sensor calibrated with a temperature compensation for mass flow, rather than using a mass flow sensor in the bypass channel. The reason is that orifices have a clearly defined flow/dp characteristic that is independent of the sensor in the bypass channel. Therefore, the flow should be determined via a dp-measurement. When using a mass flow measurement in the bypass channel instead, the flow/flow characteristic will depend on manufacturing variations of the mass flow sensor. This would limit sensor interchangeability and can make the manufacturing process more cumbersome.

5. Compensation formulas

Measure dp or flow?	Measure dp	Measure air flow	Measure air flow
Which output needed?	Differential pressure	Mass flow	Volume flow
Proposed Temperature compensation	Temperature compensation for differential Pressure	Temperature compensation for mass flow	Temperature compensation for mass flow
Temperature compensation necessary?	**No** (sensor features automatic internal temperature compensation)	**No** (sensor features automatic internal temperature compensation)	**Yes** (only to calculate the density / can be read out from the most digital SDP sensors)
Pressure compensation necessary?	**Yes**	**No**	**Yes**
Compensation formula	$dp_{eff} = dp_{sensor} \times \frac{966\text{mbar}}{p_{actual}}$ dp_{eff} real dp in Pascal [Pa] dp_{sensor} sensor output in Pascal [Pa] p_{actual} actual system pressure in millibar [mbar]	No compensation needed. $\dot{m} = F(dp_{sensor})$ $\dot{m}$ mass flow in [slm] or [kg/s] $F(dp)$ Flow$_{\text{in mainpass}}$ vs. dp$_{\text{sensor}}$	$Q = F(dp_{sensor})\frac{\rho_{char}}{\rho_{actual}}$ Q actual volume flow $F(dp)$ Flow$_{\text{in mainpass}}$ vs. dp$_{\text{sensor}}$ ρ_{char} density of air at characterization conditions ρ_{actual} actual density of air in system Note: air density can be derived from known absolute pressure and temperature

Table 3: Sensor selection guide and compensation formulas

Please note:

- Sensirion sensors feature a sophisticated temperature compensation to make the differential pressure measurement or the mass flow measurement independent of temperature changes. For high volume OEM applications it would be possible to implement a temperature compensation for measuring volume flow. Contact Sensirion for more information.
- If the real **differential pressure** value is needed, additional absolute pressure information has to be gained in order to compensate for changes in the ambient pressure. In many applications, only the relative change in differential pressure is important, in which case the pressure compensation is not needed.
- Measuring **flow** in a mainpass/bypass configuration: the flow restrictor usually has a specific dp vs. flow characteristic $F(dp_{sensor})$, which needs to be measured once in order to establish the dp versus flow relationship of the complete sensor/mainpass system. See our application note: "Bypass Configuration Differential Pressure Sensor" on our website.
- To convert the mass flow compensated differential pressure signal to **volume flow**, density compensation is needed, and therefore the ambient pressure and the temperature have to be known. The temperature information can be read out from most digital SDP sensors. Consult the datasheet or ask Sensirion for instructions to do so.
- In case one is interested in **volume flow** and decides to omit compensation and accept the reduced accuracy that comes with it, a temperature compensation for differential pressure is recommended. While it is much easier to convert the temperature compensated signal for mass flow to an accurate volume flow measurement, the temperature compensation for differential pressure is actually the closer match if used uncompensated.

6. Comparison with diaphragm-type differential pressure sensors

The measurement principle of the Sensirion differential pressure sensors is different to most other sensors available on the market. While common diaphragm-type sensors use the mechanical deformation of a membrane to measure the pressure difference, Sensirion's SDP sensors thermally measure a small air flow passing through the sensor.

This thermal measurement principle offers a number of advantages. Sensirion SDP series sensors feature high repeatability, small sensor to sensor variation and no zero point drift. The measurement of the zero flow point is extremely accurate and stable, making re-zeroing obsolete and leading to an outstanding dynamic range of measurement.

Different measurement principles ask for different compensations. To help selecting the best sensor solution for a specific application, the following table shows the compensation needed when using **standard diaphragm-type** differential pressure sensors.

Measure dp or flow?	Measure dp	Measure air flow	Measure air flow
Which output needed?	Differential pressure	Mass flow	Volume flow
Temperature compensation necessary?	**Yes** (if the sensor features no internal compensation)	**Yes** (for the temperature dependence of the sensor AND for the temperature dependence of the dp/flow characteristics)	**Yes** (for the temperature dependence of the sensor AND for the temperature dependence of the dp/flow characteristic)
Pressure compensation necessary?	**No**	**Yes**	**Yes** (if the flow restrictor has a non-linear characteristic) **No** (if the flow restrictor has a pure linear characteristic)

Table 4: Compensation needed with **standard diaphragm-type** differential pressure sensors

Revision history

Date	Version	Author	Changes
November 2010	V1.0	PHA/PHU/SAW	Initial release
August 2013	V2	PHA/ANB	Merged with document "DP_AN_SDP_mass_flow_temp_comp_1_1_C2". Other improvements.
January 2016	V3	ANB	Document now applies to all Sensirion's Differential Pressure Sensors
January 2017	V3.1	ANB	SDP600 replaced with SDP800.

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