High Humidity Applications

Applicable to following sensors
SFM3200, SFM3300, SFM3400

Key content
- Neonatal ventilation simulation
- Flow results with and without the use of the heater
- Heater Operation

Summary
Sensirion's autoclavable and washable SFM3x00-AW and single-use/disposable SFM3x00-D sensors are typically used in expiratory and proximal respiratory applications. In these applications, the sensor is in contact with heated and humidified air originating either from the patient or external conditioning devices such as humidifiers. Rainout or condensation of the humid gas occurs in the coolest part of the breathing circuit, which in heated circuits is often the flow sensor. In order to prevent this condensation/rainout in the flow sensor, all SFM3x00-AW/-D sensors are equipped with an external heater.

This document outlines the effect of the heater in a challenging neonatal long-term ventilation case and explains how to utilize the heater depending on the application. The AppNote SFM-22 "Clip-On Cap/Cable Evaluation Kit" outlines the control and implementation of the heater function. The AppNote SFM-23[1] "Effects of Humidity and Gas Mixtures" covers the influence of humidity on the sensor signal.

[1] Available on the www.sensirion.com/vent website after registration. Please refer to the AppNote section on the website.

1 Introduction

For all current gas flow sensors, the proximal use case is particularly challenging due to the close contact with the patient and the high humidity airstream flowing to and from the patient. The SFM3x00-AW/-D flow sensor series features a 0.5 W rated heater resistor located on the top side of the sensor PCB. This heater can be used to elevate the temperature of the flow sensors and thus enable robust and reliable flow measurements in especially challenging environments.
This external heater resistor is intended for two specifically challenging use cases:

1) Prevent the sensor from icing up when the sensor is operated in environments down to - 20 °C (- 4° F) and thus ensure the sensor remains functional.
2) Prevent the humid air from condensing or raining out in the sensor and ensure stable operation even in highly humid environments.

For investigation of the sensor's external heater performance, we chose a challenging neonatal ventilation setup, which requires very small volumes (~5 ml) of humid air to reliably be delivered. Figure 1 illustrates the setup used in this investigation.

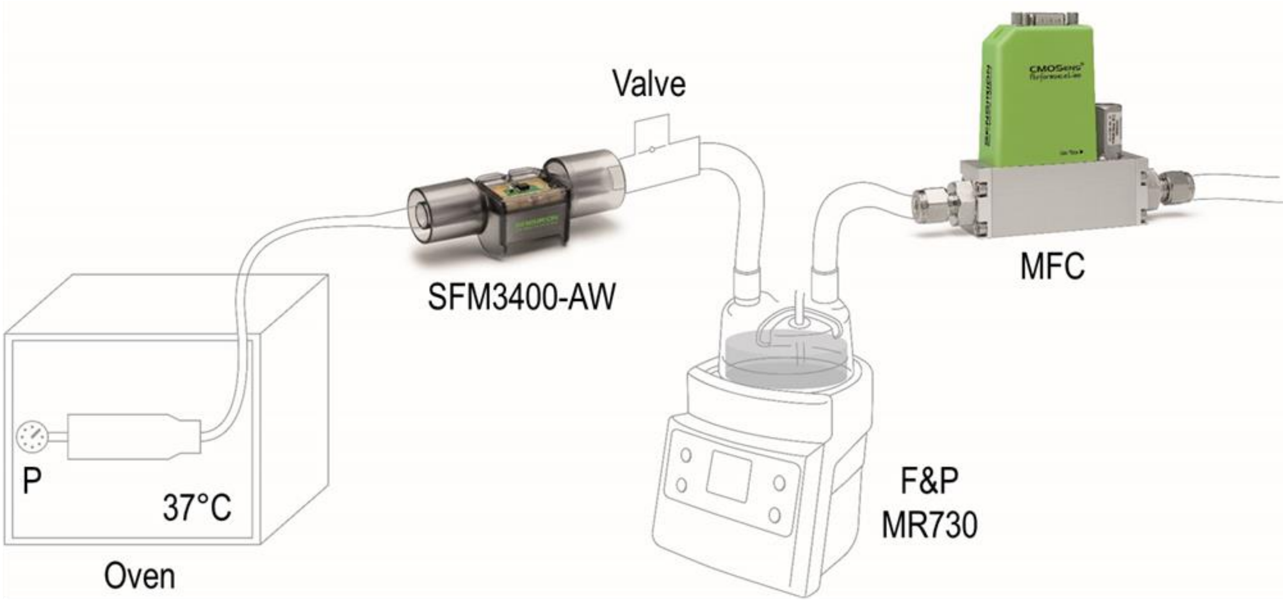

Figure 1. Setup used to simulate neonatal ventilation with 5 ml tidal volume of highly humid air.

Sensirions' mass flow controller (MFC) from the SFC5400 series controls the airflow. For humidification, a standard F&P MR730 humidifier with heated tubes is used and set to maximum humidification. The pneumatically controlled valve switches between inhalation and exhalation at a frequency of 60 times per minute and simulates the high respiratory rate of neonates. The proximal neonatal SFM3400-AW mass flow meter used in a proximal configuration measures the flow from and towards the neonate. A steel cylinder placed inside an oven heated to 37 °C simulates the neonatal lung. At the bottom of the steel cylinder a connected pressure sensor serves as independent flow reference. The SFM3400-AW is connected to the steel cylinder via a small diameter tube which generates the required flow resistance.

2 Flow Operating Principle

The pneumatic valve switches the flow path between inhalation and exhalation 60 times per minute. Figure 2 illustrates the airflow in the inhalation case, from the source through the humidifier and to the lung when the valve is closed. When the valve opens, the air from the simulated lung flows back through the SFM3400-AW flow meter and leaves to the environment through the valve.

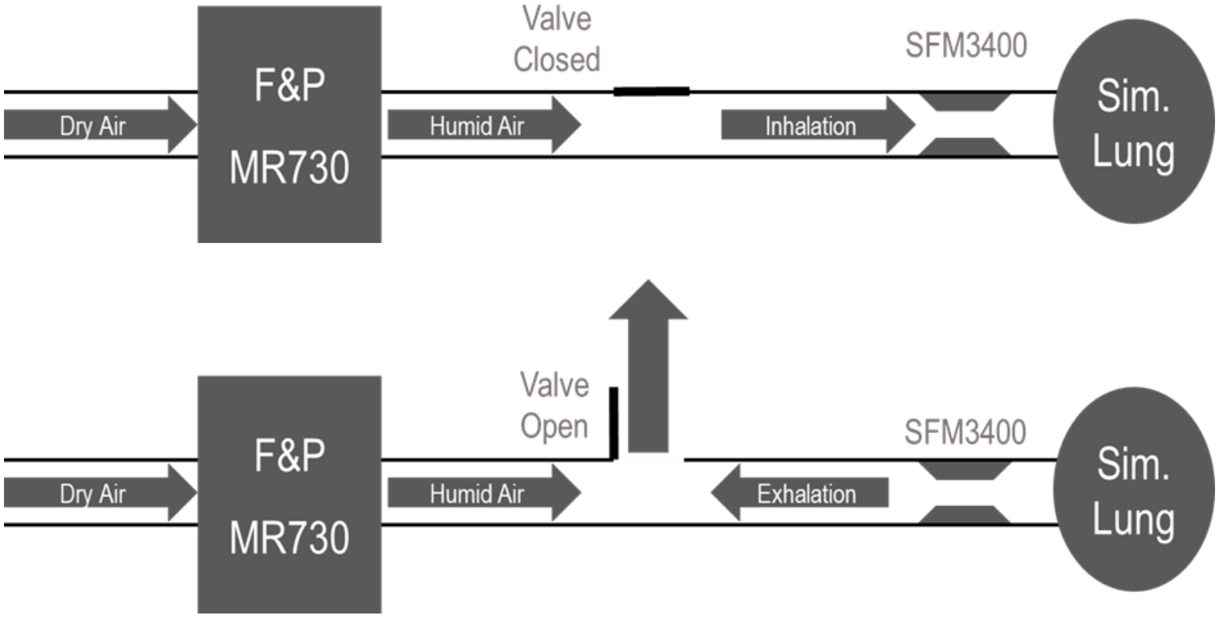

Figure 2. Principle used to simulate neonatal inhalation (top) and exhalation (bottom) of 5 ml tidal volume

3 Flow Results

Without a heater, flow sensors in heated and humidified breathing circuits are commonly the coolest part of the breathing circuit and prone to cause the high humidity airstream to condense or rain out, eventually resulting in errors in flow reading.

Figure 3 shows that it takes close to 3 hours in this environment until the first event of unstable flow readings occur. From this point onwards, several reoccurrences of unstable flow readings continue to occur over the remaining 13 hours. Some being very short positive or negative flow signal spikes and some readings being offsets for several tens of minutes. These “off” readings originate from the accumulated water droplets and cause the sensor signal to spike.

Overall, these around 30 events over the course of 16 hours can be detected by the sensor signal as well as in the observed difference between the inhaled and exhaled volume. Inspecting the sensor after 24 hours revealed that the entire sensor was filled with water and ventilation without emptying the water from the breathing circuit could not have been continued.

Results obtained with the 0.5 W heater turned to the 100% power level are displayed in Figure 4. Measurements reveal nearly perfect flow measurements over the entire course of 16 hours. Solely 4 minor glitches can be observed which each have a duration of only 1-2 seconds and interestingly the pressure sensor reference signal also exhibits these glitches. This indicates that a water droplet in the narrow tubing between the flow meter and the steel cylinder caused these four very short measured drops in tidal volume and they are not an artifact of the sensor, but actually represent less flow entering and leaving the steel cylinder.

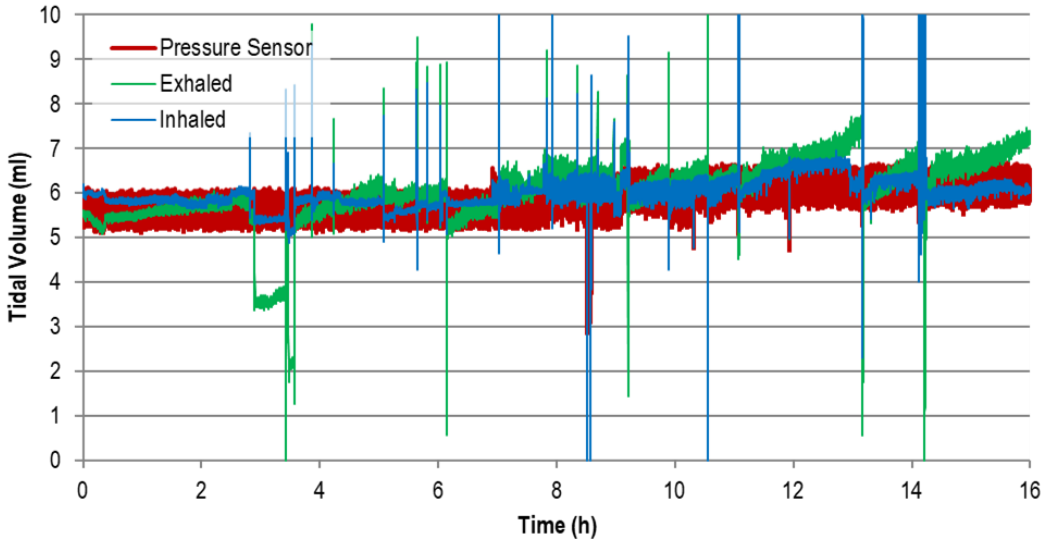

Figure 3. Exhaled, inhaled and reference tidal volume with the heater turned off

At the end of the measurement, it was observed that the sensor's heater had successfully prevented condensation and rainout in the breathing circuit as the coldest part of the otherwise heated circuit had been removed.

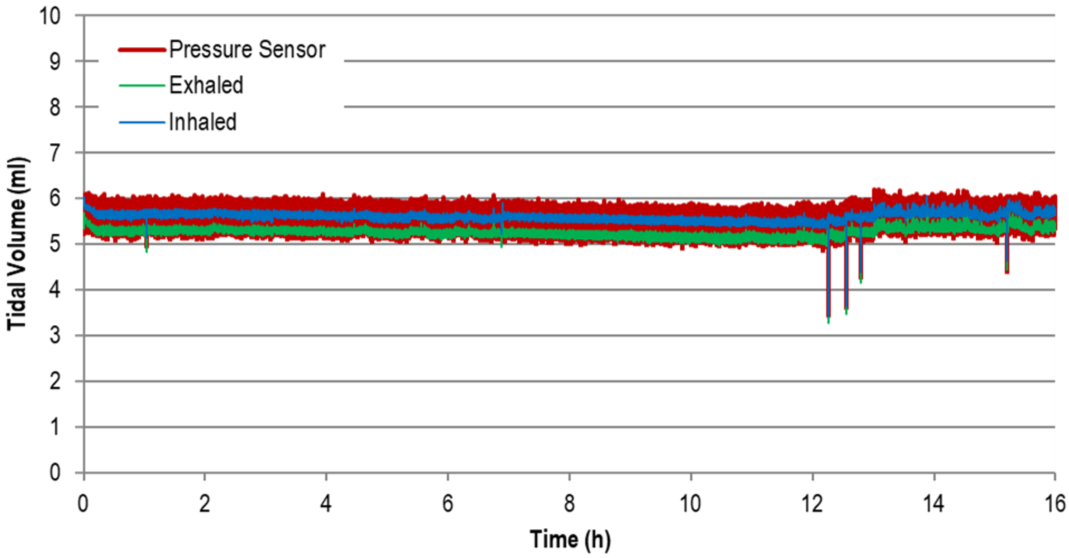

Figure 4. Exhaled, inhaled and reference tidal volume with the heater set to 100% power level

4 Heater Operation

For sake of simplicity, we compared only the 0% and 100% heater level effect on the measurement. The heater power can be varied freely between the off and full power state, while remaining within the 0.5 W specified maximum heater power limit. The recommendation is to use the heater as required by the specific application and its environment as at maximum heater power the accuracy of the sensor decreases by an average of 5%. The relationship between the decrease in accuracy and heater power is linear and therefore if 20% heater power is sufficient to avoid condensation in an AC controlled hospital environment, the accuracy would merely be reduced by an average of 1%. The required heater power can either be determined by experiment or can be stepwise increased as the sensor detects unstable readings as shown in Figure 3.

5 Revision history

Date	Author	Version	Changes
Aug 2018	ALAN	0.1	First Draft
Jan 2021	ALAN	0.2	Minor updates and formatting

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