INTRODUCTION

This application note describes the difference between mass flow in terms of volumetric flow at standard conditions (1013.25 hPa, 0 °C) and volumetric flow at nonstandard conditions.

Mass flow is a dynamic mass per time unit measured in grams per minute (g/min). By referencing a volumetric flow (cm^3/min) to its known temperature and pressure, an exact mass flow can be calculated. It is common in the industry to specify mass flow in terms of volumetric flow at standard (reference) conditions.

In accordance with these standards, Sensortechnics' mass flow sensors are specified as having volumetric flow at calibration reference conditions of 1013.25 hPa and 0°C. These conditions are referred to as standard conditions and calibration units for these sensors are sccm (standard cubic centimeters per minute) or slpm (standard liters per minute).

Note:
Attention must be paid regarding the stated reference conditions when flow sensors are specified in standard volumetric flow such as sccm or slpm.
Standard temperature and pressure (STP) is usually defined as being at 0°C (273.15 K) and 1013.25 hPa (1 atm). However, standard temperature may also be specified as 20°C or 25°C. Sometimes these reference conditions may also be referred to as normal temperature and pressure (NTP).
Special industrial branches may even have their own definitions, e.g. the gas industry may reference flow volume to a temperature of 70°F.

1. CALCULATING TRUE MASS FLOW FROM VOLUMETRIC FLOW

A volumetric flow at standard conditions translates to a specific mass flow rate.

For example, 200 cm^3/min of nitrogen at standard conditions of temperature and pressure (200 sccm) calculates to 0.2498 g/min mass flow as will be shown below.

Definitions:

P = Pressure [hPa][atm]
V = Volume [cm^3]
n = Number of molecules of gas [mole]
R = Universal gas constant [(cm^3•atm)/(mole•K)]
T = Absolute temperature [K]
ρ = Gas density [g/cm^3]
m = Mass [g]
$\dot{m}$ = Mass flow [g/min]
$\dot{V}$ = Volumetric flow [cm^3/min]
$\dot{V}_S$ = Volumetric flow at standard conditions [cm^3/min]

The ideal gas law,

$$PV = nRT$$

can be solved for the gas volume to get:

$$V = \frac{nRT}{P} \qquad (1)$$

Gas density is defined as:

$$\rho = \frac{m}{V} \qquad (2)$$

Substituting equation (1) into equation (2) redefines gas density as:

$$\rho = \frac{mP}{nRT} \qquad (3)$$

Mass flow is equal to density times volumetric flow rate:

$$\dot{m} = \rho \cdot \dot{V} \qquad (4)$$

With equation (3) mass flow can be redefined as:

$$\dot{m} = \frac{mP}{nRT} \cdot \dot{V} \qquad (5)$$

For a volumetric flow rate of $\dot{V}_S$ = 200 cm^3/min at standard conditions of 273.15 K and 1 atm the true mass flow then calculates to

$$\dot{m} = 0.2498 \quad g/min$$

$\dot{V}_S$ = 200 cm^3/min
m = 28.0134 grams in 1 mole N_2
n = 1 Mol
P = 1 atm (1013.25 hPa)
R = 82.1 (cm^3•atm)/(mole•K)
T = 273.15 K (0 °C)

2. CALCULATING VOLUMETRIC FLOW FROM TRUE MASS FLOW

Sensortechnics' flow sensors are mass flow devices rather than volumetric ones. At a constant mass flow, these sensors will give a constant output voltage even if the measured air or gas volume changes due to pressure or temperature changes.

Confusion may result when mass flow sensors are used with volumetric devices, such as rotometers or pith-ball indicators. Accurate volumetric flow calculations for mass flow devices require consideration of both temperature and pressure ranges.

In contrast to mass flow sensors volumetric devices indicate different flow rates at varying temperatures and pressures. Simple calculations can be used to show the relationship between mass flow and nonstandard volumetric flow.

For example, an FBAM200DU sensor with a mass flow rate of 0.2498 g/min (200 sccm) at standard pressure of 1013.25 hPa but nonstandard temperature of 25°C has a 5 V output voltage, indicating a standard flow rate of 200 sccm. The rotometer, however, would indicate a nonstandard volumetric flow rate.

By rearranging equation (5) the corresponding volumetric flow at nonstandard conditions of 25°C can be calculated for the mass flow measured by the FBAM200DU.

$$\dot{V} = \frac{nRT}{mP} \cdot \dot{m} \qquad (6)$$

$$\dot{V} = 218.3 \ \ cm^3/min$$

$\dot{m}$ = 0.2498 g/min
m = 28.0134 g in 1 mole N_2
n = 1 mole
P = 1 atm (1013.25 hPa)
R = 82.1 (cm^3•atm)/(mole•K)
T = 298.15 K (25 °C)

In this example the mass flow rate of 0.2498 g/min at standard conditions, which corresponds to a volumetric flow of 200 sccm, translates to a nonstandard volumetric flow of 218.26 cm^3/min for an increased gas temperature of 25 °C.

This increase reflects the fact that as temperature rises, gas expands, placing more distance between gas molecules (see Fig. 1). More distance between molecules means less mass in a given volume. If mass flow is kept constant, and temperature increases, volume flow increases to pass the same amount of mass (molecules) across the sensor.

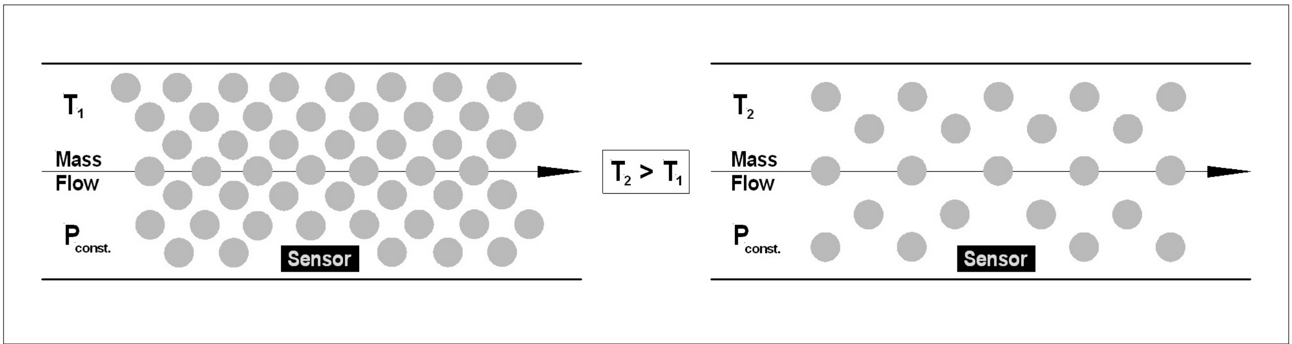

Fig. 1: Increased volumetric flow due to temperature increase $T_2 > T_1$, constant mass flow and pressure.

3. CALCULATING NONSTANDARD FROM STANDARD VOLUMETRIC FLOW

The actual, nonstandard volumetric flow $\dot{V}_x$ can be found with standard volumetric flow $\dot{V}_s$ (P_s= 1013,25 hPa, T_s= 0 °C) when the actual temperature and pressure of the measured gas (T_x, P_x) is known.

This method eliminates the use of gas density values at reference and actual conditions.

Further definitions:

$\dot{V}_s$	=	Volumetric flow at standard conditions
$\dot{V}_x$	=	Volumetric flow at nonstandard conditions
T_s	=	Temperature at standard conditions
T_x	=	Temperature at nonstandard conditions
P_s	=	Pressure at standard conditions
P_x	=	Pressure at nonstandard conditions
$\dot{m}_s$	=	Mass flow at standard conditions
$\dot{m}_x$	=	Mass flow at nonstandard conditions

If mass flow is held constant over temperature and pressure, then the following is true:

$$\dot{m}_S = \dot{m}_X$$

Therefore,

$$\frac{mP_X}{nRT_X} \cdot \dot{V}_X = \frac{mP_S}{nRT_S} \cdot \dot{V}_S$$

Solving for $\dot{V}_x$ yields:

$$\dot{V}_X = \dot{V}_S \cdot \frac{P_S}{P_X} \cdot \frac{T_X}{T_S} \qquad (7)$$

The actual, nonstandard volumetric flow at 25 °C is found to be

$$\dot{V}_X = 218.3\ \ cm^3/min$$

$\dot{V}_s$	=	200 cm^3/min
P_s	=	1 atm (1013.25 hPa)
P_x	=	1 atm (1013.25 hPa)
T_s	=	273.15 K (0 °C)
T_x	=	298.15 K (25 °C)