Technical Note

Mass Flow Sensors: Mass Flow versus Volumetric Flow and Flow Rate Unit Conversions

1.0 Introduction

This technical note explains the following:

- How mass flow is measured with volumetric units at standard conditions.
- How to convert between volumetric units at standard conditions of 0 ºC, 1 atm, and nonstandard temperature and pressure conditions.
- How to convert between volumetric units at standard conditions of 0 ºC, 1 atm, and an alternative standard temperature and pressure conditions.
- How to convert from volumetric units to mass units.

Honeywell mass flow sensors use a silicon sense die construction known as a microbridge to measure the rate of mass transfer in a fluid.

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

The temperature and pressure reference conditions of the volumetric unit do not imply nor do they require the pressure and temperature conditions of the measured fluid to be the same; they are simply part of the volumetric unit that is required to specify mass from a measured volume.

Honeywell mass flow sensors are generally specified as having volumetric flow units at standard reference conditions of 0°C and 1 atm. This is indicated on volumetric units with the "S" prefix. For example:

SCCM "Standard Cubic Centimeters (per) Minute"
Reference Conditions: 0 °C, 1 atm

SLPM "Standard Liters (per) Minute"
Reference Conditions: 0 °C, 1 atm

If a certain application requires nonstandard reference conditions, the units will be specified in the device datasheet without the “S” prefix and the reference conditions will be called out. The “@” symbol will be used to indicate the volumetric unit reference conditions for temperature and flow. For example:

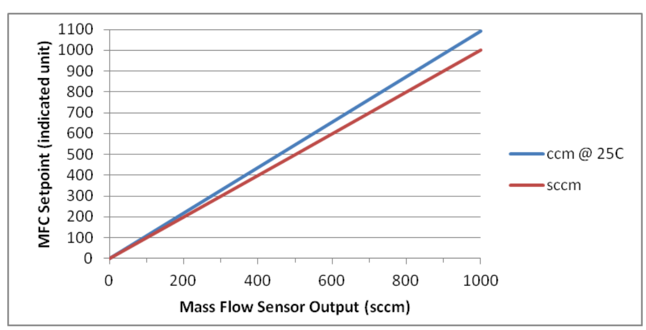
CCM @ 21°C, 101.325 kPa
LPM @ 20 °C, 1013.25 mbar

When designing an application around a mass flow sensor, it is critical to use consistent reference conditions for volumetric units throughout the system. There is no industry standard for the reference conditions indicated by “SCCM” or “SLPM”, they must be explicitly determined.

Consider a Honeywell mass flow sensor which has output calibrated for a full scale of 1000 SCCM. If this sensor is used in a system with a mass flow controller that has a Full Scale of 1000 SCCM (defined by the manufacturer as using a reference condition of 25°C, 1 atm), then without converting units, the system error will be more than 9% of reading.

Rather, the mass flow controller output should be converted to Honeywell Standard SCCM by scaling the output, or the sensor output could be converted to CCM @ 25 °C, 1 atm by using the inverse scale factor, as shown in Figure 1.

Figure 1. Mass Flow Controller Setpoint versus Mass Flow Sensor Output



Mass Flow versus Volumetric Flow and Flow Rate Unit Conversions

2.0 Finding True Mass Flow (g/min) from Volumetric Flow (Q) Definitions

P = Pressure
V = Volume (cm^3)
n = Number of moles of gas
R = Gas constant .0821 (liters • atm/mole • °K) or
82.1 (cm^3 • atm/mole • °K)
T = Absolute temperature in Kelvin (°K)
ρ = Gas density (g/cm^3)
m = Mass in grams (g)
m = Mass flow (g/min)
$\hat{m}$ = Mass flow (g/min)
Q = Volumetric flow
Qs = Volumetric flow at standard conditions (SCCM)

Equation 1

Using the Ideal Gas Law, PV = nRT, solve for:
Volume (V), or:

$$\mathbf{V = \frac{nRT}{P}}$$

Equation 2

Gas density is defined as:

$$\mathbf{\rho = \frac{m}{v}}$$

Equation 3

Substitute Equation 1 into Equation 2 to redefine gas density:

$$\mathbf{\rho = \frac{mP}{nRT}}$$

Equation 4

Mass flow is equal to density times volumetric flow rate:

$$\mathbf{\hat{m} = \rho \cdot Q}$$

Equation 5

Redefine mass flow using gas density as derived from the Ideal Gas Law. Substitute Equation 3 into Equation 4:

$$\mathbf{\hat{m} = \frac{mP}{nRT} \cdot Qx}$$

Example 1

Assume a volumetric flow rate of Q = 200 cm^3/min of nitrogen (N_2) at standard temperature of 0 °C and 1 atm, and solve for true mass flow (g/min):

Given:
Q = 200 cm^3/min
m = 28.0134 g in 1 mole of N_2
n = 1 mole
P = 1 atm
R = 82.1 (cm^3 • 1 atm)/(mole • °K)
T = 273.15 °K(0 °C)
Answer:

$\hat{m}$ = 0.2498 (g/min)

3.0 Finding Volumetric Flow (Q) from True Mass Flow (g/min)

Microbridge products are specified in “standard” volumetric flow (Qs) such as standard cubic centimeters per minute (SCCM) or standard liters per minute (SLPM) which can be translated into true mass flow as indicated above.

The microbridge sensor is a mass flow device rather than a volumetric one. At a constant mass flow, the microbridge device will give the same output even if there are temperature or pressure changes. Because the microbridge sensor senses mass flow, confusion may result when mass flow sensors are used with volumetric devices, such as rotometers or pith-ball indicators. Accurate mass flow calculations for volumetric devices require consideration of both temperature and pressure ranges.

At varying temperatures and pressures, these other volumetric devices indicate different flow rates than those indicated by microbridge sensors. Simple calculations can be used to show the relationship between mass flow and “nonstandard” volumetric flow.

An AWM3100V with a mass flow rate of 0.2498 g/min (200 SCCM) at the same pressure of 1.0 atm but at a different temperature, 25 °C, has a 5 Vdc output voltage, indicating a standard flow rate(Qs) of 200 SCCM. The rotometer, however, would indicate a nonstandard volumetric flow rate, (Q).

Use Equation 5 to rearrange the formula for the volumetric flow value to calculate the rotometer nonstandard volumetric flow rate.

Equation 6

$$\mathbf{Q = \frac{nRT}{mP} \cdot \hat{m}}$$

Use the following given values to calculate volumetric flow rate (Q). Multiply the R value by 1000 to convert the number to cm^3:

Given:
$\hat{m}$ = 0.2498 (g/min)
m = 28.0134 grams in 1 mole of N_2
n = 1 mole
P = 1.000 atm
R = 82.1 (cm^3 • 1 atm)/(mole • °K)
T = 273.15 °K(0 °C) + 25 °C = 298.15 • °K

Answer: Q = 218.26 cm^3/min

In this example, the standard volumetric flow rate (Qs) is 200 cm^3/min while nonstandard volumetric flow rate increases to 218.26 cm^3/min.

Mass Flow versus Volumetric Flow and Flow Rate Unit Conversions

This increase reflects the fact that as temperature increases, gas expands, placing more distance between gas molecules. More distance between molecules means less mass in a given volume as temperature increases. If mass flow is kept constant, and temperature increases, volume flow increases to pass the same amount of mass (molecules) across the sensor (see Figures 2 and 3).

Figure 2. Molecules at Cold Temperature: Mass Flow Constant, Volumetric Flow Decreases

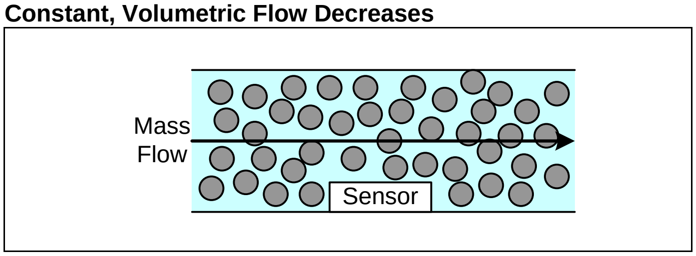
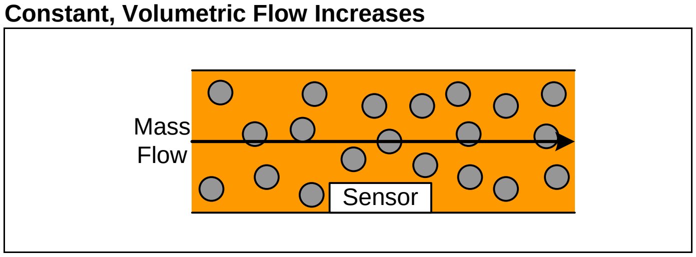


Figure 3. Molecules at Hot Temperature: Mass Flow Constant, Volumetric Flow Increases



4.0 Finding volumetric Flow (Qx) from "Standard" Volumetric Flow (Q_S):

Nonstandard volumetric flow can be found with standard volumetric flow using the ratio of temperature and pressure at referenced conditions (0 °C, 1 atm) versus "X" conditions of temperature and pressure.

This method of determining volumetric flow eliminates the use of gas density values at reference conditions (0°C, 1 atm) versus "X" conditions of temperature and pressure.

FURTHER DEFINITIONS

Qx = Volumetric flow at X conditions of pressure and temperature
Qs = Volumetric flow at standard conditions of 0 °C and 1 atm
Tx = Temperature at "X" conditions in °Kelvin (°K)
Ts = Temperature at standard conditions in °Kelvin (°K)
Px = Pressure at "X" conditions in °Kelvin (°K)
Ps = Pressure at standard conditions in °Kelvin (°K)

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

$$\hat{m}_s = \hat{m}_x$$

That is,

$\hat{m}_s$ mass flow, at standard conditions is equal to

$\hat{m}_x$ mass flow at nonstandard X conditions of temperature and pressure.

Therefore,

$$\frac{mPx}{nRTx} \cdot Qx = \frac{mPs}{nRTs}$$

Equation 7: Solving for Qx yields:

$$Qx = Qs \cdot \frac{Ps}{Px} \cdot \frac{Tx}{Ts}$$

Equation 7

Equation 7 calculates volumetric flow (Qx) at "X" conditions from volumetric flow (Qs) at reference conditions of 0 °C and 1 atm.

Given:
Qs = 200 SCCM
Ps = 1 atm
Px = 1 atm
Ts = 273.15 °K (0 °C)
Tx = 298.15 °K (25 °C)

Answer:

$$Qx = Qs \cdot \frac{Ps}{Px} \cdot \frac{Tx}{Ts} = 218.3\ cm^3/min$$

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