Mass Air Flow Sensors
Mass Flow Versus Volumetric Flow

Application Sheet

WARNING

MISUSE OF DOCUMENTATION

- The information presented in this application sheet is for reference only. Do not use this document as product installation information.
- Complete installation, operation, and maintenance information is provided in the instructions supplied with each product.

Failure to comply with these instructions could result in death or serious injury.

This application note describes the difference between mass flow in terms of volumetric flow at standard conditions (760 Torr and 0°C) and volumetric flow at nonstandard conditions.

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

In accordance with these standards, Honeywell mass flow sensors are specified as having volumetric flow at calibration reference conditions of 760 Torr and 0°C. This translates to a specific mass flow rate. For example, 200 cm^3/min (volumetric flow) of nitrogen at standard conditions of temperature and pressure calculates to 0.2498 g/min mass flow.

The following formulae are used to find true mass flow in g/min from volumetric flow (Q):

I. 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)
$\hat{m}$ = 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 $V = \frac{nRT}{P}$

Equation 2

Gas density is defined as: $\rho = \frac{m}{V}$

Equation 3

Substitute Equation 1 into Equation 2 to redefine gas density as: $\rho = \frac{m\,P}{n\,R\,T}$

Equation 4

Mass flow is equal to density times volumetric flow rate: $\hat{m} = \rho \bullet Q$

Equation 5

Redefine mass flow using gas density as derived from the Ideal Gas Law. Substitute Equation 3 into Equation 4: $\hat{m} = \frac{m\,P}{n\,R\,T} \bullet Q$

Example 1

Assume a volumetric flow rate of Q = 200 cm^3/min of nitrogen (N_2) at standard pressure of 760 Torr and pressure of 0°C, and solve for true mass flow (g/min):

Given:
Q = 200 cm^3/min
m = 28.0134 grams in 1 mole of N_2
n = 1 mole
P = 1 atm (760 Torr)
R = 82.1 (cm^3 • 1 atm)/(mole • °K)
T = 273.13°K(0°C)
Answer: $\hat{m}$ = .2498 (g/min)

II. 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 voltage 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 .2498 g/min (200 sccm) at the same pressure of 760 Torr (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 $Q = \frac{nRT}{mP} \bullet \hat{m}$

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:
$\hat{m}$ = .2498 (g/min)
m = 28.0134 grams in 1 mole of N_2
n = 1 mole
P = 1.000 atm (760 Torr)
R = 82.1 (cm^3 • 1 atm)/(mole • °K)
T = 273.13°K(0°C) + 25°C = 298.13 • °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.

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 1 and 2).

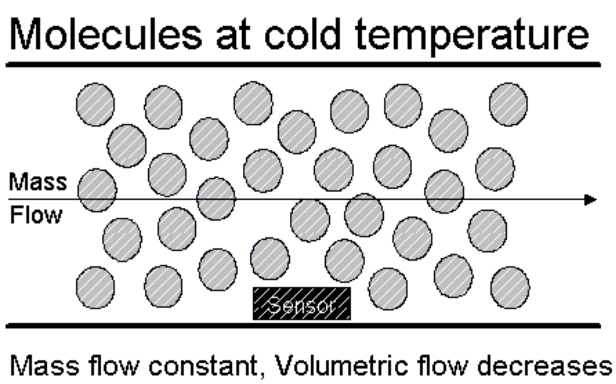

Figure 1

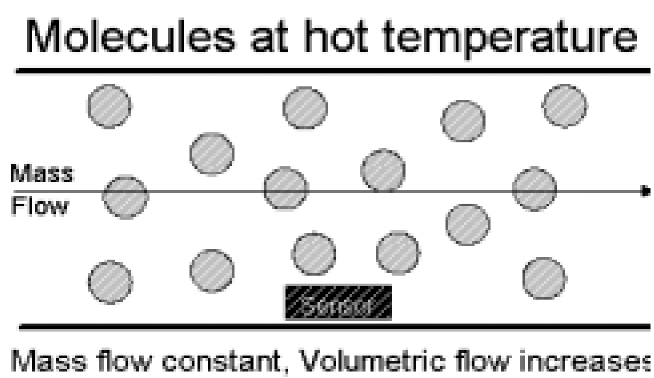

Figure 2

III. 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 (760 Torr, 0°C) versus "X" conditions of temperature and pressure.

This method of determining volumetric flow eliminates the use of gas density values at reference conditions (760 Torr, 0°C) 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 760 Torr (1 atm) and 0°C
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,
$$\frac{mPx}{nRTx} \cdot Qx = \frac{mPs}{nRTs} \cdot Qs$$

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 760 Torr and 0°C.

Given:
Qs = 200 sccm
Ps = 1 Torr or 1 atm
Px = 1 Torr or 1 atm
Ts = 273.13°K (0°C)
Tx = 298.13°K (25°C)

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

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