Choosing the Measurement Basis for your FLS110 Application

Introduction

This application note describes the differences between mass flow, volumetric flow, and molar flow (volumetric flow under standard conditions). When measuring the flow of air or any other gas accurately care it is important to remember that the amount of gas that exists within a certain volume of space depends on the condition and composition of the gas.

Performance in some applications is dependent on volume flow, for other applications mass flow or molar flow is more important. This document discusses the best measurement basis for different applications and how to convert between these different bases and an overview of how to configure the FLS110 firmware to provide readings in the preferred measurement basis for your application. For details of the procedure see the FLS110 datasheet (FL-000038-DS).

1 The differences between volume, mass, and molar flow

Volumetric flow is a common basis for flow measurement. It is defined as the volume of gas passing through a surface per unit time, typically through the cross-section of a pipe or duct.

Mass flow is defined as the mass of gas passing through a surface per unit time. The link between mass flow and volumetric flow is the density of the gas. This depends on:

1. Its composition (e.g., helium is less dense than air under the same conditions)
2. Temperature (increasing temperature reduces the density of a gas)
3. Pressure (reducing pressure reduces the density of a gas).

For many applications the composition of the gas remains consistent enough for practical purposes. Very high levels of humidity, particularly at elevated temperatures, can reduce the density of air to a meaningful degree for precision applications.

Pressure and temperature commonly vary in many applications due to altitude, geographic location and prevailing weather conditions. Without knowledge of the pressure and temperature it is not possible to accurately convert between volumetric and mass flow.

Molar flow is a measure of the number of molecules of gas passing through a surface per unit time. To avoid very large numbers the number of molecules is reported in moles (1 mol = $6.02214076 \times 10^{23}$ molecules). Under the same temperature and pressure conditions all ideal gases occupy the same volume per mole. This is called the molar volume and is 24.4 L at 25°C and 101.325k Pa (1 atm). Most gases behave as ideal gases unless they are at enormous pressure and or cryogenic temperatures.

2 Standard conditions

Molar flow is often defined in units of volumetric flow **under standard conditions**. At a defined temperature and pressure (the standard conditions) the relationship between moles of gas and volume is constant.

In scientific applications standard conditions are called **Standard Temperature and Pressure (STP)** and are usually defined as 0 °C (273.15 K) and 101.325 kPa (1 atm).

In engineering it is common to use 25 °C and 101.325 kPa (1 atm). This allows testing under standard conditions to take place much more easily without requiring refrigeration. These are the standard conditions used to specify performance in the FLS110 datasheet.

3 Measurement bases for different applications

Different applications can benefit from flow measurement using different bases.

3.1 Mass flow

Applications that use air to move particles (such as vacuum cleaners) rely on momentum transport from the airflow to perform their function. In these applications measurement with a mass flow basis may provide better information for optimisation of operational performance than volumetric flow.

Combustion, reaction, and fuel cell applications use oxygen from the air as a reagent. Measuring the mass flow rate of air provides a more direct measure of the mass of oxygen being supplied than volumetric flow.

Drying and heating applications rely on heat and mass transport to and from the airflow. In this case a mass flow measurement basis may be more appropriate as the heat transfer rate of an air flow is dependent on its mass flow rate.

3.2 Volumetric flow basis

Applications that deal with inhaled air (respirators and inhalers) are better served by a volumetric flow measurement as the volume of someone's lungs is independent of the prevailing pressure and temperature conditions.

Similarly, applications that provide air to fill a room or other space (e.g., air purifiers and HVAC systems) or extract air at a given rate (e.g., extractor fans) are also usually best served with volumetric flow measurement.

Calculation of differential pressure readings uses the same mathematical basis as volumetric flow. so, for applications in which the FLS110 is being used to read differential pressure, the volumetric flow / DP basis should be selected.

4 Converting between mass flow, volumetric flow, and molar flow

Definitions:

$\mathrm{P} = \text{Pressure [atm]}$

$\mathrm{V} = \text{Volume } [\mathrm{cm}^3]$

$\mathrm{n} = \text{Number of molecules of gas [mol]}$

$\mathrm{R} = \text{Universal gas constant } [\mathrm{cm}^3\ \mathrm{atm}\ \mathrm{mol}^{-1}\mathrm{K}^{-1}] = 82.057\ \mathrm{cm}^3\ \mathrm{atm}\ \mathrm{mol}^{-1}\mathrm{K}^{-1}$

$\mathrm{R}_{\mathrm{specific}} = \text{Specific gas constant } [\mathrm{cm}^3\ \mathrm{atm}\ \mathrm{g}^{-1}\mathrm{K}^{-1}]$ see table in Appendix A

$\mathrm{T} = \text{Absolute temperature [K]}$

$\dot{\mathrm{m}} = \text{Mass flow } [\mathrm{g\ min}^{-1}]$

$\mathrm{Q} = \text{Volumetric flow } [\mathrm{cc\ min}^{-1}]$

$\rho = \text{Gas density } [\mathrm{g\ cc}^{-1}]$

$\mathrm{M} = \text{Molecular weight (molar mass) } [\mathrm{g\ mol}^{-1}]$ see table in Appendix A

$\dot{\mathrm{n}} = \text{molar flow rate } [\mathrm{mol\ min}^{-1}]$

4.1 Converting from mass flow to volume flow

Gas density defines the relationship between mass flow and volumetric flow:

$$\dot{m} = \rho\dot{V} \quad (1)$$

The ideal gas law allows the density to be calculated:

$$P = \rho R_{specific} T$$

$$\rho = P/(R_{specific} T) \quad (2)$$

The specific gas constant can be found in tables (see Appendix A) or calculated:

$$R_{specific} = R/M \quad (3)$$

Through back substitution of (3) into (2) and (2) into (1):

$$\dot{m} = \frac{PM}{RT}Q \quad (4)$$

4.2 Converting from mass flow to molar flow

The molecular weight (molar mass) of the gas defines the relationship between mass flow and molar flow:

$$\dot{m} = M\dot{n} \quad (5)$$

Substituting (5) into (4) shows that molar flow is proportional to volumetric flow provided pressure and temperature are constant:

$$\dot{n} = \frac{P}{RT}Q \quad (6)$$

5 Setting the measurement basis on the FLS110 for your application

By default, FLS110 standard firmware reports mass flow readings. For applications where it is required, the firmware can be instructed to calculate and report volumetric flow instead. The measurement basis is specified at the time of system characterisation/calibration and should not be changed during operation.

The calculation requires that the flow pressure (p_{flow}) be provided by the application and the measurement basis is set to volumetric flow during system characterisation and/or calibration. Our technical note *FLS110 System Characterisation and Calibration* describes in detail how this is done.

For molar flow applications where the gas composition does not change significantly over time the FLS110 can be used in mass flow measurement mode and calibrated in the molar flow unit of choice.

Appendix A Gas property table

Gas	Molecular Formula	Molecular Weight [g mol^{-1}]	Specific gas constant [cm^3 atm g^{-1} K^{-1}]
Air		29	2.830
Acetylene (ethyne)	C_2H_2	26	3.156
Ammonia	NH_3	17.031	4.818
Argon	Ar	39.948	2.054
Benzene	C_6H_6	78.11	1.051
Butane	C_4H_{10}	58.1	1.412
Butylene (Butene)	C_4H_8	56.11	1.462
Carbon dioxide	CO_2	44.01	1.865
Carbon monoxide	CO	28.01	2.930
Chlorine	Cl_2	70.906	1.157
Ethane	C_2H_6	30.07	2.729
Ethylene	C_2H_4	28.03	2.927
Helium	He	4.02	20.412
Hydrogen	H_2	2.016	40.703
Hydrogen Chloride	HCl	36.5	2.248
Hydrogen Sulphide	H_2S	34.076	2.408
Methane	CH_4	16.043	5.115
Neon	Ne	20.179	4.066
Nitric oxide	NO	30	2.735
Nitrogen	N_2	28.02	2.929
Nitrogen Dioxide	NO_2	46.006	1.784
N-Octane		114.22	0.718
Nitrous Oxide	N_2O	44.013	1.864
Nitrous Trioxide	NO_3	62.005	1.323
Oxygen	O_2	32	2.564
Ozone	O_3	48	1.710
Propane	C_3H_8	44.09	1.861
Propene (propylene)	C_3H_6	42.1	1.949
Sulphur	S	32.06	2.559
Sulphur Dioxide	SO_2	64.06	1.281
Sulphur Trioxide	SO_3	80.062	1.025
Sulphuric Oxide	SO	48.063	1.707
Toluene	C_7H_8	92.141	0.891
Water Vapor, steam	H_2O	18.016	4.555