Pressure Drop & Vacuum in One Lesson

What is pressure drop? Pressure drop is the amount of line pressure that is permanently lost as gas passes through an instrument in the gas line. This pressure loss is due to the frictional resistance of the components the gas touches. Every instrument and fitting in a line induces some pressure drop; even the pipe walls generate some friction, which causes a small amount of pressure drop.

Pressure drop is determined by calculating the difference between the pressure of the gas when it enters the instrument and the pressure of the gas when it leaves the instrument. The easiest way to make this measurement is to plum the inlet and outlet of the device to a differential pressure gauge, like one of our P-PSID Series gauges. When making these measurements, it is important to consider the following relationships:

- Under laminar flow conditions, pressure drop is proportional to volumetric flow rate. At double the flow rate, there is double the pressure drop.
- Under turbulent flow conditions, pressure drop increases as the square of the volumetric flow rate. At double the flow rate, there is four times the pressure drop.
- Pressure drop decreases as common mode pressure increases.
- Pressure drop increases as gas viscosity increases. Since increasing the temperature of the gas increases its viscosity, pressure drop also increases as gas temperature increases.

To standardize our pressure drop specifications, Alicat's instrument data sheets always denotes the maximum pressure drop at the instrument's full-scale flow when venting to atmosphere under standard conditions. Said another way, our pressure drop specification identifies the minimum amount of inlet pressure to run the instrument at full-scale flows while venting to atmosphere.

Why pressure drop matters

For any gas process to work, the available system pressure must be greater than the total pressure drop of the components in the system at the expected operating flow rates and temperatures. If too little pressure is provided at the inlet of the entire system, there will not be enough gas pressure to pass through all the components of the process at full-scale flows. Likewise, if multiple gases are being used in the same process, pressure drop will be the highest for the most viscous gas.

This principle is a primary driver for Alicat's many valve customizations. The wider the valve orifice, the lower the pressure drop of the valve when it is wide open. However, greatest control precision is achieved when we use the largest portion of the valve's operating range. So our goal when building a flow or pressure controller is to select the smallest valve that will allow full-scale flows of all gases being used in the system.

When customers have little available inlet pressure, or perhaps a very large amount of back pressure, sometimes our standard line of mass flow instruments exhibit too much pressure drop to reach full-scale flows. In these cases, we recommend our Whisper Series of mass flow meters and controllers. By making the flow body design more open and by changing the spacing and configuration of our laminar flow elements, we are able to achieve much lower pressure drops, usually by a factor of ten. The Whisper Series also employs a much more sensitive pressure sensor package to take full advantage of the lower pressure readings.

Why Pressure Drop Matters in Subatmospheric Applications

Michael Hodges-Owen

Pressure drop is an important physical and financial consideration when working with subatmospheric and vacuum applications. Pressure drop is the loss of line pressure caused by frictional resistance in the flow path. Everything causes some degree of frictional resistance on the fluid flowing, such as a valve, fittings and tubing, and this results in the loss of pressure. By determining how much pressure drop each part causes, you can calculate how much pressure you need to run your process. The lower the total pressure drop of the system, the less gas is needed to run it, which saves you money.

How Pressure Drop Works

Static pressure affects the amount of pressure drop across an Alicat mass flow meter, and this is important to consider when choosing a device for use in sub-atmospheric pressures. Alicat devices calculate flow rates by measuring the differential pressure across a laminar flow stack. Since the flow is laminar, we can use the Hagen-Poiseuille equation to calculate the pressure drop caused by an Alicat device. The equation is notated as follows:

$$\Delta P= 8\eta LQ/(\pi r^4)$$

Where:
ΔP = pressure drop
L = length of pipe
η = viscosity of the fluid
Q = volumetric flow rate
r = radius of pipe
π = mathematical constant Pi

Since Alicat mass flow meters measure the pressure drop internally, L and r are constant for each flow device. Assuming the gas viscosity (η) remains the same, the pressure drop increases proportionally to the volumetric flow rate.

$$\Delta P \propto Q\eta$$

Previously, we explained that decreasing your static line pressure increases the volume of gas flowing through your system and therefore your volumetric flow rate. With this thought in mind, the relationship above shows that increasing volumetric flow (as a result of our decrease in static pressure) also increases pressure drop.

For the sake of simplifying this concept, I am going to pretend temperature remains constant or does not exist in the following example. Say I fill up a balloon that has been blown up to perfectly fit through a tube. I then make a road trip up into the mountains with the same balloon and tube, and attempt to fit the balloon through the tube. Since I am at higher elevation, there is less pressure compressing the molecules in the balloon, resulting in the balloon increasing in size and volume. I can still fit the balloon through the tube, but I have to apply more force since it now takes up more volume and generates more resistance against the tube walls. Pressure drop increases as static pressure decreases.

Sizing Flow Meters for Subatmospheric Applications

Understanding this relationship between static pressure and pressure drop will help you select the appropriate mass flow device for your subatmospheric application. The product specification sheets on our website provide the pressure drops for Alicat mass flow meters and controllers at atmospheric pressures. Let's say we need to find a mass flow meter that can measure a maximum of 500 sccm at half an atmosphere (½ atm) of pressure (about 7.4 psia). In a previous post, we saw that 500 sccm becomes 1000 ccm at ½ atm. Since our devices by default are sized for the mass flow rate and not the volumetric flow rate, you will need to increase the size of the device to accommodate the increased volume of the gas.

The solution is to choose a 1000-sccm device (Alicat part number M-1SLPM-D) instead of a 500-sccm device (M-500SCCM-D), and then requesting a custom range of 500 sccm for the mass flow and 1000 ccm for the volumetric flow. Both of these instruments have full-scale pressure drops of 1 psid at 1 atm. At ½ atm, the M-500SCCM-D mass flow meter's pressure drop would theoretically double to 2 psid at full scale, since the volume of the gas has doubled. However, using the larger M-1SLPM-D meter at ½ atm results in the full-scale pressure drop of 1 psid. Essentially, we are doubling the tube size to fit a balloon that has doubled in size. At ¼ atm, you would need the M-2SLPM-D meter with a range of 500 SCCM for mass flow and 2000 for volumetric flow, since the volumetric flow is now 4 times the mass flow.

Mass Flow Meters with Low Pressure Drop

Now, this works if you have enough pressure in your subatmospheric system to lose a whole psi through the flow meter. If we look at the available pressure at ½ atm, the pressure drop across the oversized M-1SLPM-D meter restricts 1 psid, or around 14% of your available pressure. It gets even tighter working at ¼ atm, where the oversized M-2SLPM-D meter again induces 1 psid of pressure drop, which is now 27% of your available pressure. This is not optimal, especially when you are limited in your available pressure.

Ah-ha! Alicat has a solution: Our "Whisper" series of low pressure drop mass flow meters are perfect for this type of scenario, since their pressure drops are very low compared to our standard M-series meters. An oversized MW-1SLPM-D Whisper meter has a pressure drop of only 0.07 psid at ½ atm and 500 sccm, which is now just 1% of your available pressure. Both the standard mass flow meter and the Whisper meter will perform with the same accuracy under these conditions, but using a low pressure drop Whisper will give you a lot more breathing room in terms of pressure loss as you design your subatmospheric system