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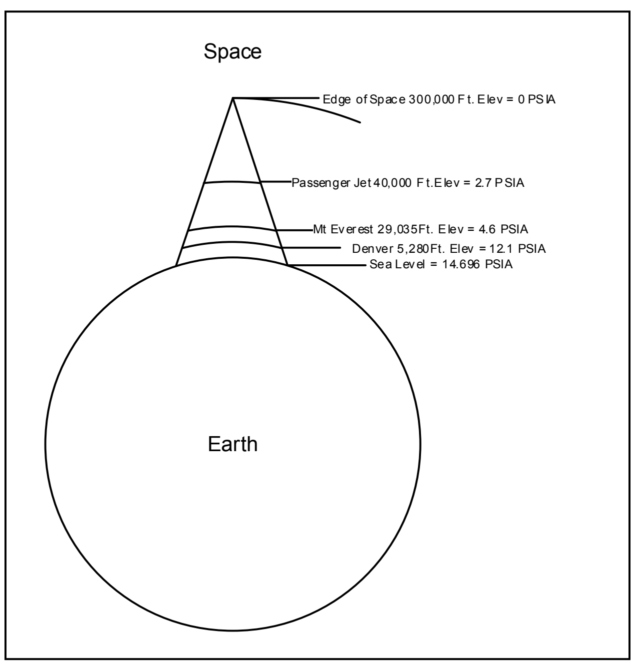
A Layman's Primer on Gas Flow and Alicat Scientific

"In the beginning there was only pipe. For untold eons it sat quiet and solid and still, a constant in the universe. Suddenly, in the flash of an eye, God created a Pressure Difference and so there was Flow. The solid, constant walls of the pipe did not budge and thus resisted this new Flow, and Pressure Drop was born." - Redneck Fluids

What everyone should know about actual absolute real pressure in one paragraph.

You are presently sitting, breathing, and reading surrounded and immersed in your local atmospheric pressure, which is not zero. In space, the pressure really is zero, but here on earth all the air on top of you creates a modest pressure which varies with where you are located heightwise between sea level and space. Generally speaking, the highest atmospheric pressure on earth can be experienced at any ocean beach, and is widely recognized as 14.696 Pounds per Square Inch Absolute (PSIA). We have to tack the "Absolute" on here to let everyone know that we're talking about pressure relative to actual (hence absolute) zero pressure as found in space. You can think of this as the "real" pressure, and in fact that's what it is. For those purists, yes, technically speaking mines, caves, and residents of Death Valley are closer to the center of the earth and do have slightly higher atmospheric pressures, but for most of us surface dwellers, 14.696 PSIA at sea level is the most we'll spend any time in. This pressure is a good baseline pressure, and is widely recognized as the "Standard" pressure condition.



Atmospheric Pressure

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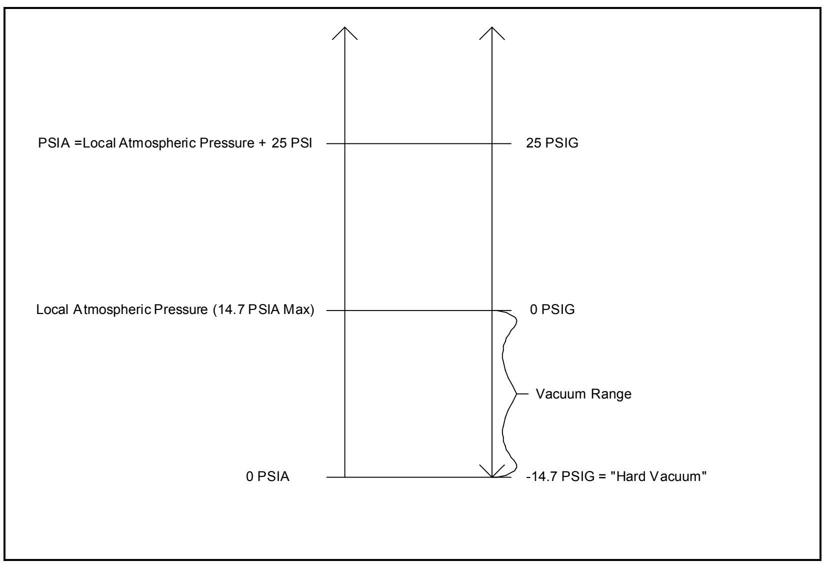
How to make your own personalized pressure.

Because all the air anywhere near your particular location right now is at your own individual atmospheric pressure, and because you don't really feel it, it is convenient and useful to think of it as zero pressure. When you decide to call your local atmospheric pressure zero, and work up (or down) from there, then you work in what is referred to as a Gauge (or Gage…no one knows why) Pressure scale. When you check your tire pressure, fill your basketball, or inflate your rubber ducky, you generally use Pounds per Square Inch Gauge (PSIG) to measure the pressure. We have to tack the "Gauge" on here to let everyone know that we're talking about pressure relative to local atmospheric pressure. This makes sense because when you let all the air out of your neighbor's tire, the pressure will drop down to local atmospheric pressure and won't go any lower (unless you go to the added measure of shooting the tire up toward space). In the gauge pressure world view, any pressure below local atmospheric pressure is called a vacuum, and real actual absolute zero pressure like you find in space is called "hard vacuum".



Absolute Scale vs Gauge Scale

Other pressure Units of Measure you'll eventually have to learn anyway.

As a general rule, any quantity that can be measured will be measured by different people, for different reasons, different ways, at different times. Invariably, this means different Units of Measure, or Engineering Units. In the United States, the most common unit of pressure is pounds per square inch or PSI. In much of the rest of the metric oriented world, the most common unit is variations of the pascal, either kilopascal (kPa) or Megapascal (MPa). In early history, after the cave man but before the Volkswagon Beetle, many pressure measurements were made with manometers, which consisted of a U shaped tube with liquid in the bottom of the U. When a pressure was applied to one side of the tube, the liquid in the other side of the tube would rise some easily measured and comparable distance. Thus was born the somewhat unusual pressure units of inches

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or millimeters of water (inH20, mmH20). Some enterprising individual realized that if you used a denser liquid, you could use smaller manometers to measure higher pressures and so we also have pressure units of inches or millimeters of mercury (inHG, mmHg). For some reason unknown to this author, mercury based pressure units usually (though not always) infer vacuum applications. It is also common to measure pressures in "atmospheres", or multiples of the standard atmospheric pressure. Just for comparison's sake, let us compare values of different common units at standard absolute atmospheric pressure:

1 absolute atmosphere = 14.696 PSIA
101.325 kPa
1.013 Bar
406.8 inH20
29.92 inHg
760 mmHg
and 760 torr among other things.

Slightly less profuse, but no less important, are temperature units of measure. In the United States, we typically use degrees Fahrenheit to describe the temperature, which is a bizarre scale that makes most of the rest of the world snicker and scratch their heads. Zero on the Fahrenheit scale was as cold as you could get an ice and salt mixture (think home made ice cream), and the high end of the scale was 96 degrees, which was originally taken to be the temperature of the human body (incorrectly). Most of the rest of the world uses the much more sensible water based Celsius scale, defined by zero degrees Celsius where pure water freezes and 100 degrees Celsius where pure water boils at sea level (standard pressure!!). The Celsius scale is sometimes referred to as Centigrade because it is defined as100 degrees between water freezing and water boiling.

Just as we have an absolute pressure scale, there is also an absolute temperature scale. The absolute temperature engineering unit is a Kelvin. This scale, invented by Lord Kelvin (possibly a half brother to Lord Vader), uses the theoretical lowest temperature possible in the universe, where there is an absolute absence of any energy, as it's zero point. Welcome to the dark side baby. The size of a Kelvin is equal to the size of a Celsius degree, so the conversion is a simple numerical offset. For the record, there is also an absolute temperature scale that starts at the same place as the Kelvin scale, but has degree Fahrenheit size units called Rankins, but we don't want to go there…ice cream salt!?…hee hee hee.

Water Freezes at: 0 Degrees Celsius
32 Degrees Fahrenheit
273.15 K (for Kelvin)

From	To Fahrenheit	To Celsius	To Kelvin
Fahrenheit (F)	F	(F - 32) * 5/9	(F - 32) * 5/9 + 273.15
Celsius (C or ^{o})	(C * 9/5) + 32	C	C + 273.15
Kelvin (K)	(K - 273.15) * 9/5 + 32	K - 273.15	K

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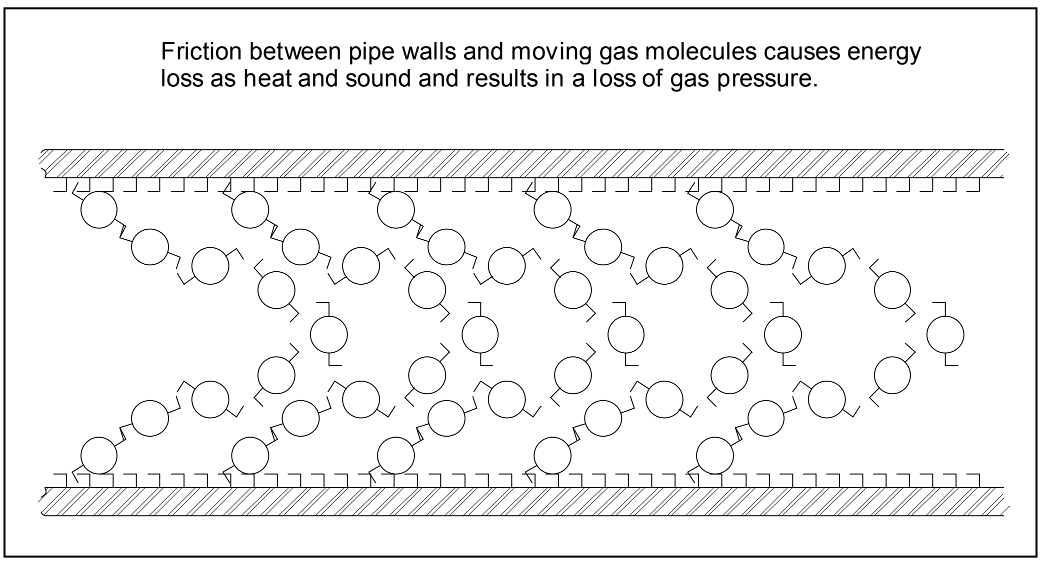
Flow and what causes it.

Gas flow in a pipe is created by a difference in pressure. This difference in pressure is normally created by a mechanical compressor which increases pressure above local atmospheric pressure, or by a mechanical vacuum pump which reduces pressure below local atmospheric pressure. Sometimes a really heavy compressor is used to pressurize gas into a cylinder (commonly referred to as bottled gas) which can be used to create flow. This is especially common with gases other than air. In any case, you have to put work (pronounced “mon” – “ey”) into making a change in pressure to create flow.

Pressure Drop and what it causes.

Piping is very useful stuff for directing flow to where you want it, but the fixed walls of the piping cause a drag on the flow. This drag gives off energy as heat and sound (this is the same energy you paid good money for in compressing the gas) and reduces the pressure of the gas. This phenomenon, which is common to every piping system, is called Pressure Drop. Every piece of pipe, every fitting, every component in the piping system that the gas comes into contact with causes Pressure Drop. As the flow moves along pressure is constantly dropping. Because they’ve paid good money to create flow, and because they want to get as much as possible out of that investment, it is not uncommon to find customers who are very keen on minimizing pressure drop in their systems.



Friction Causes Pressure Drop

You can reduce the amount of pressure drop by keeping your piping runs straight, reducing the number of components and fittings, and keeping the diameter of the piping as large as possible.

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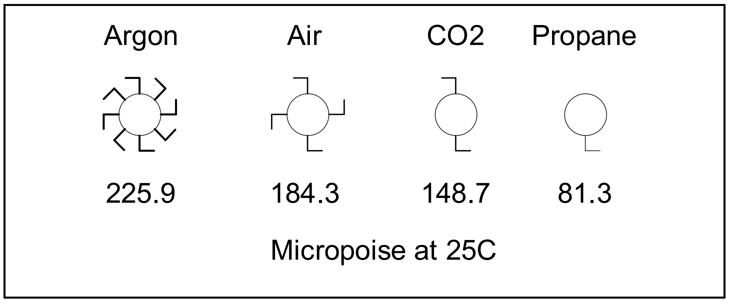
Gas Viscosity Visualized: Molecular Velcro!

The molecules of different kinds of gases have different propensities to stick to each other and to other molecules. This propensity is affected by the temperature of the gas. If you think of gas molecules as having little hooked arms, you can imagine high viscosity gases such as Argon (226 micropoise at 25 degrees Celsius) as having a lot of stout little hooked arms and low viscosity gases such as Propane (81 micropoise at 25 degrees Celsius) as having much fewer and less stout little hooked arms.



Visualizing Viscosity

The viscosity is a property of the gas, but its numeric value depends on the temperature of the gas. As the temperature of the gas increases, the extra energy causes the gas molecules to move about more and more, increasing the rate of collisions and increasing the likelihood that the molecules will stick together. Thus, in gases, the viscosity actually increases with temperature. This is somewhat counterintuitive, because most people are more familiar with liquid viscosities (think honey for instance), which become less viscous with higher temperatures. Fortunately for us, the relationship between temperature and gas viscosity is generally quite linear (true of gases, but not so for liquids). In particular, for most gases, their viscosity changes about one quarter of one percent per degree C of temperature change. This makes it simple to calculate the viscosity if you know the temperature.

A Tale of Two Flows

The flow of a fluid, be it a gas or a liquid, is very complicated. Millions upon millions of moving molecules are interacting with one another and their environment. Fortunately, nature provides a couple of different kinds of flow, and one is a lot easier to work with than the other. The two kinds of flow are <u>laminar</u>, and <u>turbulent</u>. Anyone who has ever witnessed the smoke from a cigarette in a still room has witnessed both kinds of flow. The heat of combustion carries the smoke upward in a smooth laminar flow for 4 to 8 inches before the smoke "breaks" and forms intricate and unique curls and waves. The curly, wavy, portion of the flow is turbulent, and it is much more difficult to get useful information about the flow once it breaks into turbulence because it is fairly unpredictable.

A very bright scientist, whose last name was undoubtedly Reynolds, worked out a calculation that yields a "Reynolds Number" which describes flow in terms of its

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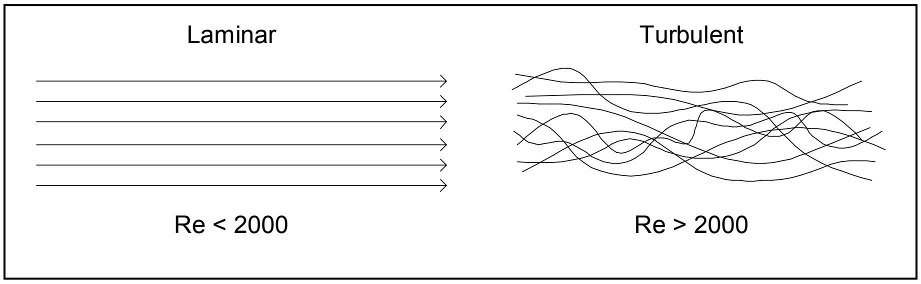
complexity. In very general terms, flows with Reynolds Numbers below about 2000 are laminar in nature, and flows with Reynolds Numbers in excess of about 2000 are considered turbulent.



Two Types of Flow

For completeness sake, the Reynolds Number is defined as:

$$Re = \rho VL/\mu$$

Where ρ = Gas Density, V=Average Gas Velocity, L=A Constant determined by the geometry of the passage, and μ=Gas Viscosity. From this relationship we see that increasing the gas density or velocity increases the Reynolds Number (and thus the likelihood of turbulent flow) and increasing the gas viscosity decreases the Reynolds Number. For a given gas in a given pipe at a given temperature, L and μ are roughly fixed constants.

Swing your partner round and round? Are You Dense?!!

Gas density is determined by the number of molecules of gas (and the weight thereof) that are in a given fixed volume space, say your skull for instance. If you were standing on a beach (14.696 PSIA), the temperature was a balmy 25 Degrees Celsius, and we removed your brain and let the cavity left behind fill with air, you would become an airhead. In addition, the air in your head would have a density of 1.1839 grams per liter of space. Different gases have different densities at standard conditions because different gas molecules are different sizes.

While density is a property of the gas, the actual value is affected by the temperature and the pressure. Rising temperature decreases gas density (think hot air balloon) and rising pressure increases gas density (think politician). If your recently vacated brain space were exactly 1 liter in volume, but gas molecules were free to enter and exit your ears, at 25C and 14.696 PSIA, the combined total of all the air molecules in your head would weigh 1.1839 grams.

Temperature effect on density: If you went into a hot green house on the beach, the increased temperature would cause the air molecules to move around more rapidly, and a bunch of them would have to exit, much like what would happen if a square dance erupted spontaneously in a crowded building. If everyone wanted to swing their partner

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round and round, a bunch of them would have to move outside to get it done, leaving the number (and thus the weight) of people remaining inside lower.

Pressure effect on density: If the cops came along and pressured everyone back inside the building and the dancing stopped, the density in the building would return to where it started. If they also added a bunch of people who just happened to be walking by, then the density would increase even more.

Just when you thought your head was gonna explode, let's assume that the above squ(air) dance was attended by average sized adults. Imagine how it would change if it were attended by members of Overeaters Anonymous with Richard Simmons calling the moves (Butane weighs 2.38 grams per liter), or by a convention of anorexic dwarf pygmy midgets (Helium weighs 0.16 grams per liter).

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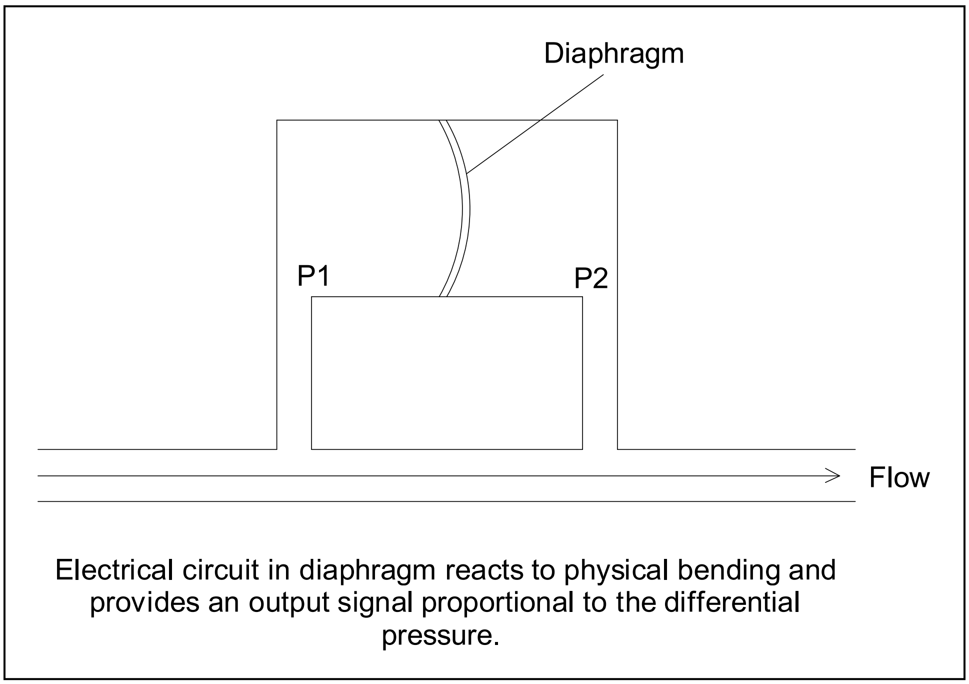
The Alicat Scientific Part

Okay, so gas flows…but how do we measure it?

As it turns out, if you pay heed to a few things we've talked about above and hold a few things constant, the pressure drop can be used to determine the rate of the flow. The heart of an Alicat Scientific flow meter is a simple differential pressure sensor, which is used to measure the pressure drop between two points in the flow. In addition, the properties of the circuitry on the diaphragm of the differential pressure sensor can be manipulated to infer the temperature of the gas. Don't ask us how we do this, because we'd have to kill you if we told you. It's enough that you know that we do it.



Differential Pressure Sensor Measures Pressure Drop

Getting It Our Way: Forcing The Flow To Be Laminar

In order to make use of the differential pressure signal to determine the flow rate, the flow must be in a laminar state. All Alicat Scientific flow meters utilize a special flow passage designed to keep the flow inside the meter in a laminar state (Reynolds Number less than 2000). This ensures that the relationship between the pressure drop and the flow rate is linear. This special flow passage, called a Laminar Flow Element or LFE Stack, is created with stacks of thin, smooth, hard plates with very thin spacers between them. The gas flow is forced through the long, thin, smooth spaces between the plates, so that wall friction dominates the flow. As long as the number and size of the spaces between the plates is carefully designed to match the expected gas flow range, the result is a smooth laminar gas flow which yields a pressure drop between the two legs of the differential pressure sensor that is consistent with the range of the sensor. The standard differential

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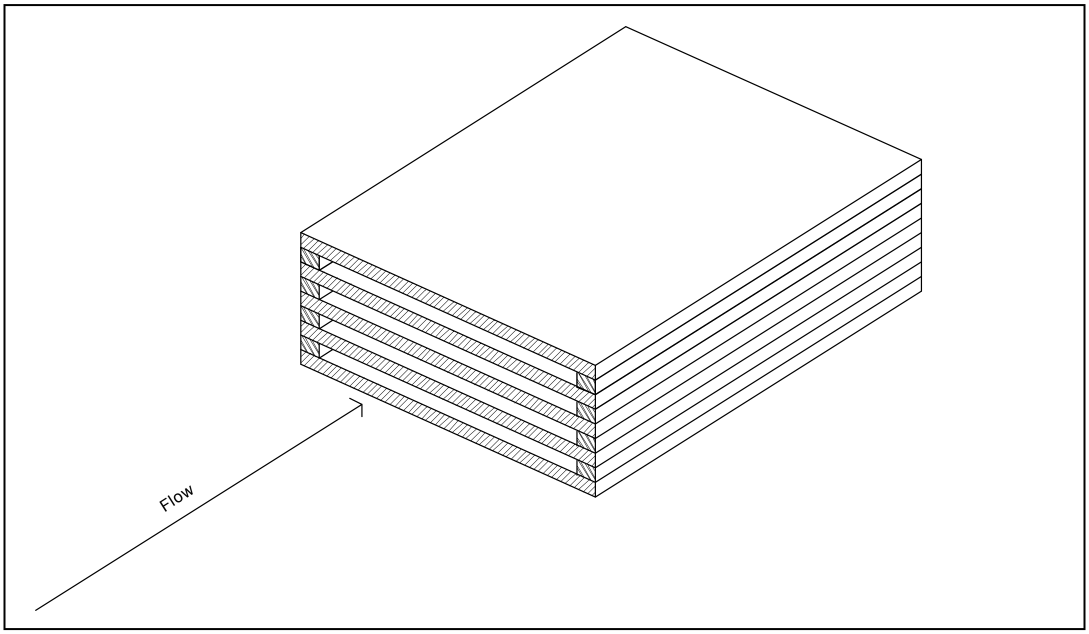
pressure sensor has a full scale range of about 1 PSI of differential pressure, though others are available and sometimes used for special configurations.

Our LFE Stack: Ins and Outs, Ups and Downs

You can imagine an Alicat Scientific LFE stack as being like sheets of plywood stacked on top of each other with 2x4's between them along two edges.



Laminar Flow Element (LFE Stack) Repesentation

The picture above is somewhat misleading in that the spacers between the plates in a real LFE stack are very thin. This does a great job of forcing the flow to be laminar, but it also catches any sizable particulates that might be in the flow. Any foreign material that gets caught in the LFE stack can cause a change in the effective flow area (which we are counting on to remain a fixed constant after calibration) and/or interrupt the laminar flow (which we are counting on to maintain a linear output). This means that it is very important to keep the gas flow clean if the meter is to maintain its calibration.

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The Math: The Abridged Version for Volumetric Flow

The Alicat flow meter owes its operating principle to Jean Poiseuille (1797-1869), a physician who worked to understand the flow of blood in the human body. He developed a set of equations that described the relationship between flow, viscosity, pressure drop, and the length and area of the pipe. Today, the volumetric flow rate in an Alicat flow meter is calculated by using Poiseuille's Law. The equation we use is:

$$\text{Volumetric Flow} = (P_1 - P_2)\pi r^4 / 8\eta L$$

Where:
P_1 = Upstream Pressure
P_2 = Downstream Pressure
r = Effective Radius of Restriction
η = Viscosity of Fluid (gases are fluids too!)
L = Length of restriction between P_1 and P_2.

Once the flow meter is constructed, the effective radius of restriction "r" (related to the cross sectional area) and the length of the restriction "L" become fixed constants. Because they are both constant, they can be combined as one constant $K = r^4/8L$. The differential pressure sensor gives us P_1-P_2, and the viscosity η is a property of the fluid (gas) and is known, so that leaves us with only K that we don't know exactly. We don't know K exactly because each meter has slight variations in the thickness of the plates and spacers that make up the LFE Stack. That is why we have to calibrate the meters with a known flow standard. Doing this essentially gives us the value needed for K for each individual meter. The math is reduced to:

$$\text{Volumetric Flow} = K((P1-P2) / \eta)$$

Providing the flow is laminar, this works every time.

The Alicat House

Volumetric Flow is the foundation by which Alicat Scientific does all flow measurement and control. However, volumetric flow is severely limited in practical applications because it is at the whim of changes to the density of the gas. Just like the foundation of a house, you wouldn't really want to live on only the foundation. The only time a simple foundation is going to be a comfortable place to live is when the weather is pleasant and stays that way. In most of the real world, the weather is always changing. In a few instances where you will be using the meter only on the end of the line (so the line pressure will be near atmospheric) and the gas will be at nearly constant room temperatures, you can actually get a small financial benefit from using a volumetric only meter. We usually sell these to Hawaiian folk bands who perform open air concerts from their houseless foundations.

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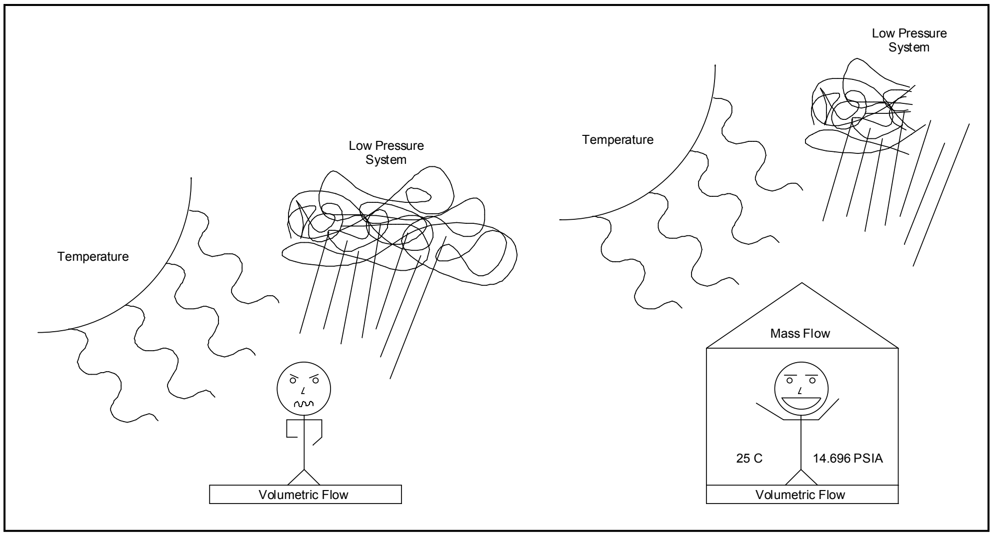

Seriously now, volumetric flow is affected by the density of the gas, and the density is in turn affected by gas temperature and gas pressure. A volumetric flow meter measures and reports what the volumetric flow rate is at its particular location. However, we know that with flow comes pressure drop, and that the line pressure is constantly changing in a real piping system. Therefore, it turns out that if you put identical volumetric flow meters in different places in the same piping system, they'd all give you different measurements. How helpful is that? The moral of the story is that you should generally not buy or sell a volumetric flow meter without carefully considering the application. They are really only useful when they are operated at near atmospheric conditions, which means low pressures and room temperatures.

Why Mass Flow Is Not Mass Flow, And What It Actually Is.

You can imagine mass flow to be the completed house, sitting on the foundation of volumetric flow. It's structure keeps the conditions inside the house close to comfortable atmospheric conditions. In fact, our mass flow house keeps them at exactly atmospheric conditions. It does this by measureing the conditions outside and compensating so that the inside stays just right. Our standard conditions are 25 degrees Celsius, and 1 atmosphere of absolute pressure. Our mass flow meters measure the volumetric flow rate, measure the temperature of the gas flow, measure the absolute pressure of the gas flow, and calculates and reports what the flow would be IF it were at our standard conditions, instead of it's current conditions. What this allows you to do is compare flow rates either from time to time or from place to place and know that you are comparing flow rates independent of changes in gas density. If I look at the people in a mass flow house and they change from blue in the morning to red in the afternoon, I can safely conclude that they have super smurf transformer powers, and not that it was cold in the morning and warm in the afternoon. The conditions inside of the house would be the same and comparable from morning to afternoon.

An Actual Volumetric Flow vs. Mass Flow Example: At room temperature and low pressures the volumetric and mass flow rate will be nearly identical, however, these rates

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will diverge rapidly with changes in temperature and/or pressure because the temperature and pressure of the gas directly affects the volume. For example, assume a volumetric flow reading was used to fill balloons with 250 mL of helium, but the incoming line ran near a furnace that cycled on and off, intermittently heating the incoming helium. Because the volumetric meter simply measures the volume of gas flow, all of the balloons would initially be the same size. However, if all the balloons are placed in a room and allowed to come to an equilibrium temperature, they would generally all come out to be different sizes. If, on the other hand, a mass flow reading were used to fill the balloons with 250 standard mL of helium, the resulting balloons would initially be different sizes, but when allowed to come to an equilibrium temperature, they would all turn out to be the same size.

The problem with mass flow is that while everyone calls it mass flow, it is not technically a mass flow rate. A mass flow meter reports the mass flow in engineering units of "Standard" volumes per unit time. The "Standard" implies that it has been corrected to some "standard" set of conditions. For Alicat Scientific, those standard conditions (as we've pretty well beaten into the ground by now) are 25 degrees Celsius and 14.696 PSIA. Common mass flow units include Standard Liters Per Minute (SLPM), Standard Cubic Feet per Minute (SCFM), Standard Cubic Centimeters per Minute (SCCM), and Standard Cubic Feet per Hour (SCFH). Do you see any mass related terms in there? Not a one. In truth, we should probably call mass flow meters something more logical like maybe standard flow meters, or standardized flow meters, but I guess the term "mass" does have fewer syllables. In any case, that's what EVERYONE calls them.

The only logic behind this choice of names is that it IS simple to get from a "mass flow rate" to a real mass flow rate. If you have a flow rate, all you need is the gas density to calculate an actual mass flow rate. With a standardized mass flow rate, instead of having to figure out what the density of the gas is at the temperature and pressure it happens to be at, all you have to know is the density of the gas at standard conditions. Instead of having to have a table with thousands of different combinations of temperatures and pressures, you only need the density at one condition. If you look at a gas density table in any text book, they will give you the density of different gases at one or two "standard" conditions.

Once the corrected mass flow rate at standard conditions has been determined and the density at standard conditions is known (see the density table at the back of our manual), a true mass flow can be calculated as detailed in the following example:

Mass Flow Meter Reading = 250 SCCM (Standard Cubic Centimeters/Min)
Gas: Helium
Gas Density at 25C and 14.696 PSIA = .1636 grams/Liter
True Mass Flow = (Mass Flow Meter Reading) X (Gas Density)
True Mass Flow = (250 CC/min) X (1 Liter/ 1000 CC) X (.1636 grams/Liter)
True Mass Flow = 0.0409 grams/min of Helium

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Construction 101: How We Build The House

Okay, we have a foundation, and we know how we made it. We know we want a house, so what do we have to do to get there? It turns out we only need a couple of tools and a bit of simple math. The tools are the measured temperature of the gas, and the measured pressure of the gas. With these two things, and a knowledge about what these two things do to the density of a gas, we can determine the so called mass flow rate. The relationship between mass, volume, and density is:

Mass = Volume x Density

As you will no doubt remember from your square dance lessons, increasing the temperature decreases the gas density, and increasing the pressure increases the gas density.

Using ideal gas laws, the effect of temperature on density is as follows: (This is glossing over the laws, but just like in Arkansas, it is more important that you know that it IS illegal to sleep with a sheep than WHY it is illegal to sleep with a sheep.)

$$\rho_a / \rho_s = T_s / \mathbf{T_a}$$

Where: ρ_a = density @ flow conditions
$\mathbf{T_a}$ = absolute temp @ flow *condition in °Kelvin*
ρ_s = density @ standard (reference) conditions
T_s = absolute temp @ standard (reference) *condition in °Kelvin*
ºK = ºC + 273.15 Note: ºK=ºKelvin

Using ideal gas laws, the effect of pressure on density is as follows:

$$\rho_a / \rho_s = \mathbf{P_a} / Ps$$

Where: ρ_a = density @ flow conditions
$\mathbf{P_a}$ = absolute pressure at flow conditions
ρ_s = density @ standard (reference) conditions
Ps = Absolute pressure @ standard (reference) conditions

So, we now apply our bit of math to get:

$$\text{Mass Flow} = (\text{Volumetric Flow}) \times (T_s / \mathbf{T_a}) \times (\mathbf{P_a} / Ps)$$

Notice that the measured gas temp is in the bottom of the fraction and the measured absolute pressure is in the top of the fraction. This is because the temperature and pressure affect the density in opposite ways. Recall that increasing temperature makes a gas less dense, and increasing pressure makes a gas more dense.

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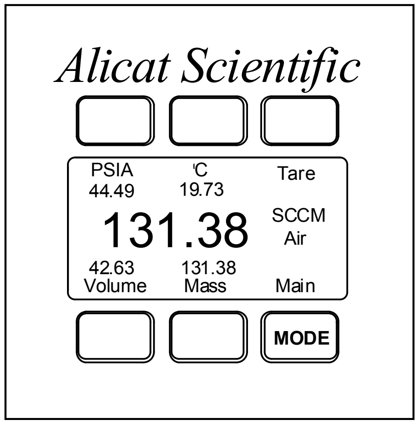
The Obligatory Example To Prove That It Works

We should probably chug through a fast example to make sure all of this math actually works. If you look at one of our mass flow meter screens, you will see that it displays the volumetric flow rate, the temperature, the absolute pressure, and the mass flow rate. The mass flow rate is calculated from the volumetric flow, temperature, and absolute pressure shown on the display.



The first order of business and one of the most easily overlooked is that to do the math, we have to calculate with absolute temperatures and pressures. Our display shows absolute pressure, so we can use that as is, but it shows temperature in degrees Celsius. To convert to an absolute temperature, we take our reading in degrees C and add 273.15 to get an absolute temperature in Kelvin (K). So:

T_s = 25.00C + 273.15 = 298.15 K
T_a = 19.73C + 273.15 = 292.88 K

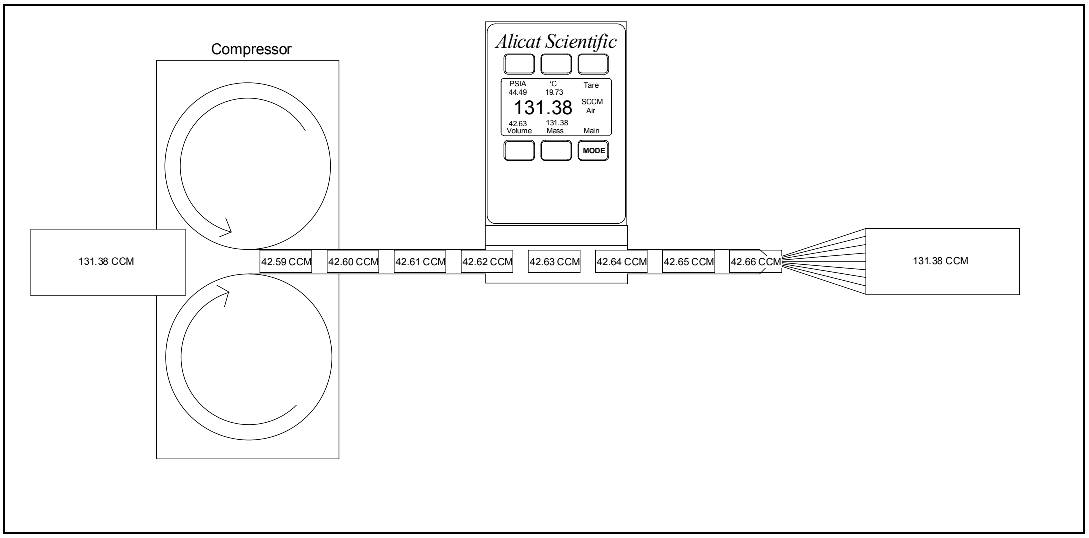
Then the mass flow calculation is simply:

Mass Flow = (Volumetric Flow) x (T_s / **T_a**) x (**P_a** / Ps)

Mass Flow = 42.63 CCM x (298.15K / **292.88K**) x (**44.49PSIA** / 14.696PSIA)

Mass Flow = 42.63 CCM x (1.0179937) x (3.0273543) = 131.37831 **SCCM**

Reality Check. Does this make sense? The gas has about three times as much pressure as it would at standard conditions. It is denser than gas at standard pressure, and so it has more gas molecules per cubic centimeter than gas just floating around at sea level. The gas is at just a slightly lower than standard temperature, so the temperature effect on the density is small, and in this case makes it just slightly more dense than the same gas at a standard 25C. Because of both its pressure and temperature, the gas comes out to be just a bit more than three times more dense than the same gas would be under our standard conditions. This tells us that because of the extra pressure and slightly reduced temperature, the gas flow which would be 131.38 CCM at standard conditions has been squeezed down to a paltry 42.63 CCM of volume flow, which is what our nifty volumetric meter is measuring.



Meter Sizing

Approximately once per week we get a call from someone who looks at the picture above and thinks, “Gee, why don’t I just buy me a 50 ccm full scale volumetric meter instead of a 200 SCCM mass flow meter and save myself some dough??” This is somewhat frustrating because the question to answer size ratio is so large. It’s a one sentence question with a one page answer. The general idea though, is that we size all flow meters for the highest volumetric flow we expect them to handle near standard conditions. As we’ve discussed, mass flow is roughly equivalent to volumetric flow near standard conditions. We “size” them by calculating the flow area that would be necessary to give us a differential pressure that is consistent with our differential pressure sensor and a Reynolds number that guarantees a laminar flow under these conditions. If the Reynolds Number gets above a certain point, generally accepted as approximately 2000, the flow will become non-laminar. The Reynolds Number for a given Newtonian fluid flow is defined as:

$$Re = \rho VL/\mu$$

Where:
- ρ = density
- V = average velocity
- L = Constant determined by length and geometry of passage
- μ = viscosity

From this relationship we see that increasing the gas density or velocity increases the Reynolds Number, and increasing the gas viscosity decreases the Reynolds number. For a given gas in a given meter at a given temperature, L and μ are roughly fixed constants. This means that we need to watch the gas density and the gas velocity carefully.

In the above example, our 200 SCCM mass flow meter is sized appropriately for 200 SCCM of flow, or about 200 CCM of volumetric flow near standard conditions. When we raise the pressure, the density goes up, so the Reynolds number goes up, so that is

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bad. However, when we raise the pressure, the volume goes down, and since the area is fixed, the velocity goes down, so that is good. These two factors roughly offset one another and the Reynolds number stays reasonable.

If instead we tried to use a meter sized for 50 SCCM of mass flow, or approximately 50 CCM of volumetric flow near standard conditions, we would have a problem. The increased pressure would increase the Reynolds number exactly as before. But now if we try to cram the same volume as before through this smaller area the velocity would have to increase, which would increase the Reynolds number. Instead of offsetting each other, the increased density and the increased velocity team up to push the Reyolds number too high. The resulting flow is no longer laminar, thus making the differential pressure interpretation meaningless.

Gas properties also need to be taken into account in deciding whether you can use a volumetric flow meter at a particular line pressure. Helium, which has a relatively low density and a relatively high viscosity at standard conditions, can generally get away with higher pressures in a volumetric flow meter. Propane, on the other hand, has a relatively high density and relatively low viscosity making it a considerably more difficult gas to measure at higher pressures in a volumetric flow meter. In air, most Alicat Scientific volumetric flow meters make valid full scale measurements up to 10-15 PSIG line pressure. Keep in mind though the other limitations of volumetric flow discussed previously.

In Summary: Distilling The Last 15 Pages Into Something Useful

In order to give you an accurate mass flow rate, Alicat Scientific needs…6 things:

1. *The gas viscosity.* This is a property of the gas. When you select the gas from the menu, you insert the selected gas's viscosity into Poiseuille's Law.
2. *The differential pressure.* This is measured with a differential pressure sensor inside the Laminar Flow Stack, which keeps the flow laminar.
3. *The absolute line pressure.* This is measured with an absolute pressure sensor in each unit.
4. *The line temperature.* This is measured with a temperature sensor in each unit.
5. *Laminar flow.* This is achieved by appropriately sizing the flow area and passing the flow through the Laminar Flow Stack.
6. *Physics and a fancy calculator.* The calculation of Poiseuille's Law to determine volumetric flow, and the calculation of mass flow from temperature and pressure information, is performed by a fast microprocessor in each unit.

In summary: Money buys a Compressor/Vacuum Pump which makes Pressure Difference and causes Flow but Pipe Walls Don't Move so there is Friction which results in Pressure Drop. A Differential Pressure Sensor and the Gas Viscosity in Poiseuille's Law gets Volumetric Flow that is nice but affected by Gas Density which is in turn affected by Gas Temperature and Gas Pressure which are measured to determine that which is not actually Mass Flow. Any questions?