Flow Curves

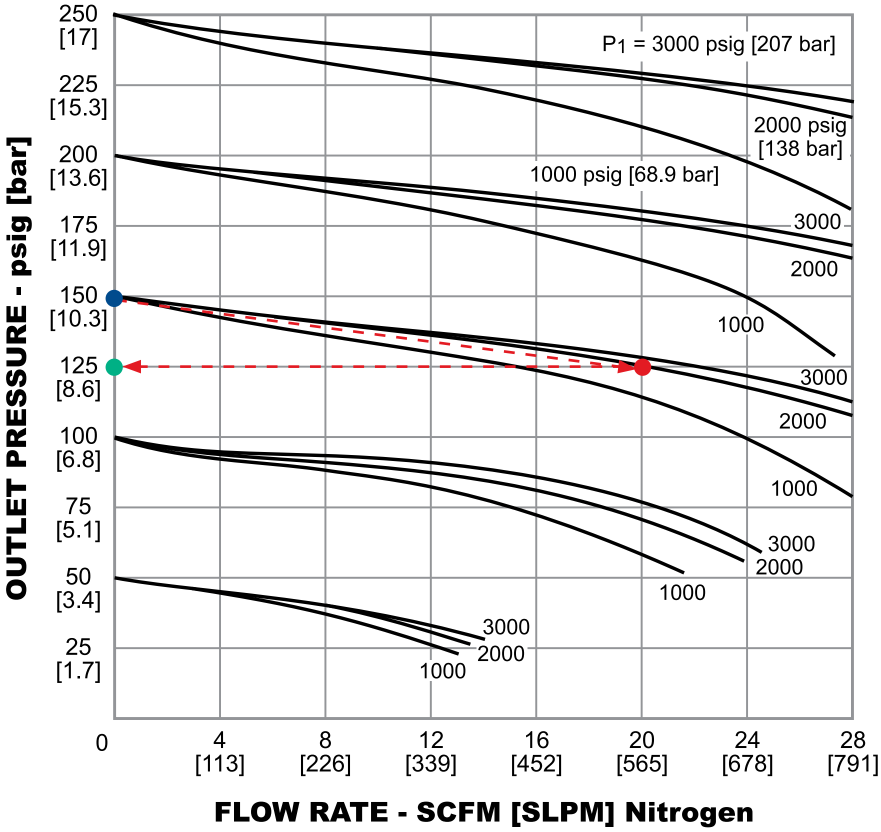
TESCOM flow charts are the graphic representation of test results which show the change in outlet pressure (P_2) with a varying flow rate. All curves are based on using nitrogen at ambient conditions as a media unless otherwise noted. Inlet pressure (P_1) is shown on the right end of each curve.

To use these charts, select the curve to fit the following:

- Regulator model
- Verify C_V of that model
- Comparable inlet pressure (P_1) to your application
- Comparable outlet pressure (P_2) to your application

Determine the maximum dead-ended (zero flow) P_2 pressure permitted by your system. Locate this pressure on the P_2 (vertical) axis. If no curve is plotted for that exact pressure, extrapolate a new curve between the two closest existing curves and follow from the zero flow point to the intersection of the new curve and the vertical coordinate of the desired flow. Read horizontally to locate the corresponding P_2 pressure.

REGULATOR DISCHARGE CHARACTERISTICS CURVES



Example:

Using the flow chart above, determine the droop (P_2 at the 20 SCFM / 565 SLPM condition).

1. Locate maximum outlet pressure (150 psig / 10.3 bar) on P_2 axis with zero (0) flow.
2. Follow the discharge curve until it crosses the vertical line corresponding to 20 SCFM / 565 SLPM.
3. Follow the intersecting point horizontally to the vertical P_2 axis and read the corresponding pressure of 125 psig / 8.6 bar. Hence droop is 25 psig / 1.7 bar (150-125).

Note: You are given that P_1 = 2000 psig / 138 bar, P_2 = 150 psig / 10.3 bar maximum, Q = 20 SCFM.

Flow Curves

In addition to reading the curve, there are components to a flow curve associated with what is happening. Here are some common terms used (see Flow Chart 2):

Lock-up

The outlet pressure increase which occurs above the "set pressure" as the flow is decreased to zero.

Hysteresis

The outlet pressure differential which occurs between flow increase (droop) and flow decrease (lock-up).

Initial Droop

The outlet change (offset) from the "set pressure" which occurs as the flow rate initially increases.

Optimal Flow Range

The flow range that is most suitable for a given regulator at a given pressure scenario.

Choke Flow Range

The point at which the regulator is too small to handle the flow rate being demanded. The regulator will be wide open and no longer regulating pressure.

What is Droop?

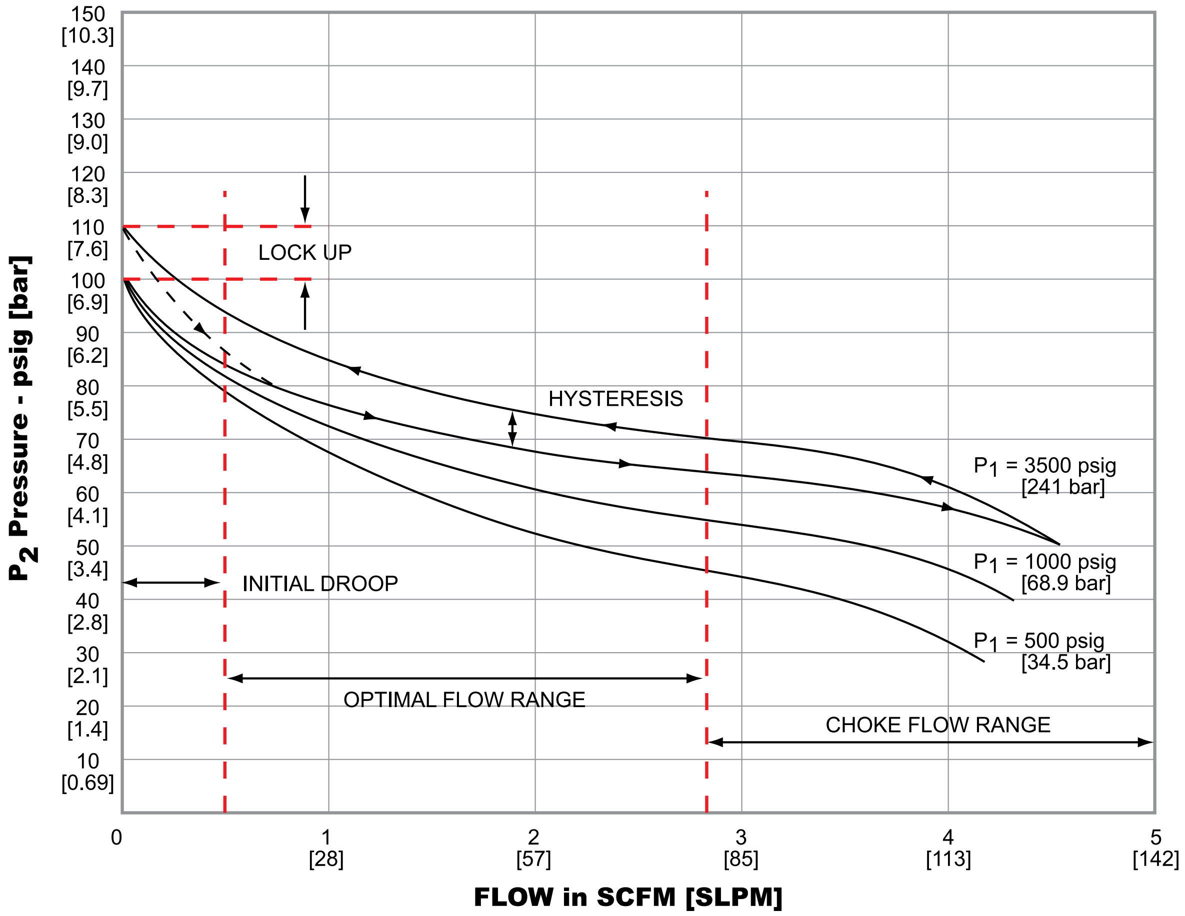
This is the outlet pressure (P_2) change (offset) from the set (static) pressure which occurs as the flow rate increases. We've all heard the term droop used when referring to regulator performance, but most of us never fully understand the meaning of this term. In a pressure reducing regulator, the outlet pressure drops (or droops) as the flow increases. As the flow decreases, the P_2 pressure goes up, or recovers to just above the original setpoint (lock-up). Droop is the result of loading force changes in the regulator, and is caused primarily by the load spring.

How does it work?

To better understand droop, let's evaluate the performance of a regulator for a typical application (see Flow Chart 2). A regulator is needed for nitrogen service, set at 100 psig / 6.9 bar. The gas source is a cylinder, pressurized to 2600 psig / 179 bar (P_1 pressure). Most nitrogen cylinders are packaged at 2200-2600 psig / 152-179 bar when full. If the cylinder sits outside on a gas pad in the heat of the sun, you can assume that the initial cylinder pressure will be on the high side of this range. Small lecture bottles are packaged at lower pressures, but will still exhibit pressure decay as the process consumes the gas. The subject regulator needs to deliver 2 SCFM / 57 SLPM. If you refer to the flow (or droop) curve for the subject regulator you will note that at zero flow, the regulator set point (P_2) is established as 100 psig / 6.9 bar.

We will use the flow curve labeled for P_1=3500 psig / 241 bar to evaluate our subject regulator's performance, since our inlet pressure is 2600 psig / 179 bar. To determine the droop at 2 SCFM / 57 SLPM, follow the 3500 psig / 241 bar flow curve until it intersects the vertical line marked 2 SCFM / 57 SLPM. At this point, draw a horizontal line to the left until it intersects the vertical line marked with P_2 pressures, and read the pressure value on the vertical (P_2) scale. In our example, we find that the outlet pressure has drooped to approximately 68 psig / 4.7 bar. The outlet pressure of this regulator would drop from 100 to 68 psig / 6.9 to 4.7 bar; the droop is 32 psig / 2.2 bar. Moving further along the droop curve to 3 SCFM / 85 SLPM, we see that the P_2 pressure is now 63 psig / 4.3 bar. At approximately 2.8 SCFM / 79 SLPM, the droop curve starts to drop off significantly. This is the point at which the main valve of the regulator is wide-open, and no longer regulating pressure. We call this area of the flow curve the choke flow range. We generally don't consider the choke flow range as part of the regulator's working flow range, so avoid specifying a regulator with a flow requirement that falls into the choke flow range. If we start to reduce the flow from 3 SCFM / 85 SLPM towards zero flow, we note that the P_2 pressure climbs toward the original 100 psig / 6.9 bar set point. Something interesting occurs, however. The P_2 pressure at 2 SCFM / 57 SLPM is approximately 75 psig / 5.2 bar, not the 68 psig / 4.7 bar we observed when the flow was increasing. This condition is known as hysteresis. Other than recognizing it for what it is, hysteresis is usually not an issue in evaluating the performance of a regulator.

Flow Chart 2



To get a full picture of how the regulator will perform in our application, we should take into account the fact that the inlet pressure will decrease as we consume gas from the cylinder—sometimes allowing cylinder pressure to drop to 200 psig / 13.8 bar before changing out the cylinder. Therefore, we should perform a droop evaluation at P_1=500 psig / 34.5 bar to see if the regulator will still meet expectations. Using the flow curve labeled P_1=500 psig / 34.5 bar, we see that the droop at 2 SCFM / 57 SLPM is now approximately 52 psig / 3.6 bar, or nearly half of the original 100 psig / 6.9 bar set point. Clearly, the droop gets worse as the inlet pressure falls. If an outlet pressure of 100 psig / 6.9 bar, +/- 40 psig / 2.8 bar had been specified, we might have considered the subject regulator as suitable for the application if we had only considered its performance when the cylinder is full. But, by conducting an evaluation with a low inlet pressure, we see that the regulator would have not met the application requirements under this condition and therefore would not have specified this regulator.

You can use the flow curves to evaluate droop for gases other than air or nitrogen. Using compensation factors found under Flow Calculations, multiply the flow values by the appropriate multiplier to get a new flow scale for the gas involved. For example, to convert nitrogen flow to hydrogen flow, the multiplier is 3.79; 1 SCFM / 28 SLPM of nitrogen equals 3.79 SCFM / 107 SLPM of hydrogen, 2 SCFM / 57 SLPM of nitrogen equals 7.58 SCFM / 215 SLPM of hydrogen, and so on. The shape of the flow curves remains the same, only the flow scale changes.

What is Creep?

An increase in the outlet pressure subsequent to lock-up, usually a long-term slow pressure increase. This indicates a regulator leak and calls for the immediate removal of the regulator for service. This may be caused when contaminants from upstream of the regulator are deposited on the valve seat or actually damage the seat during flow—this will obstruct the valve stem from sealing on the seat due to surface damage. Should this happen, positive shut-off cannot occur and the downstream pressure will gradually try to reach the same as the inlet pressure (dependent on media flow).

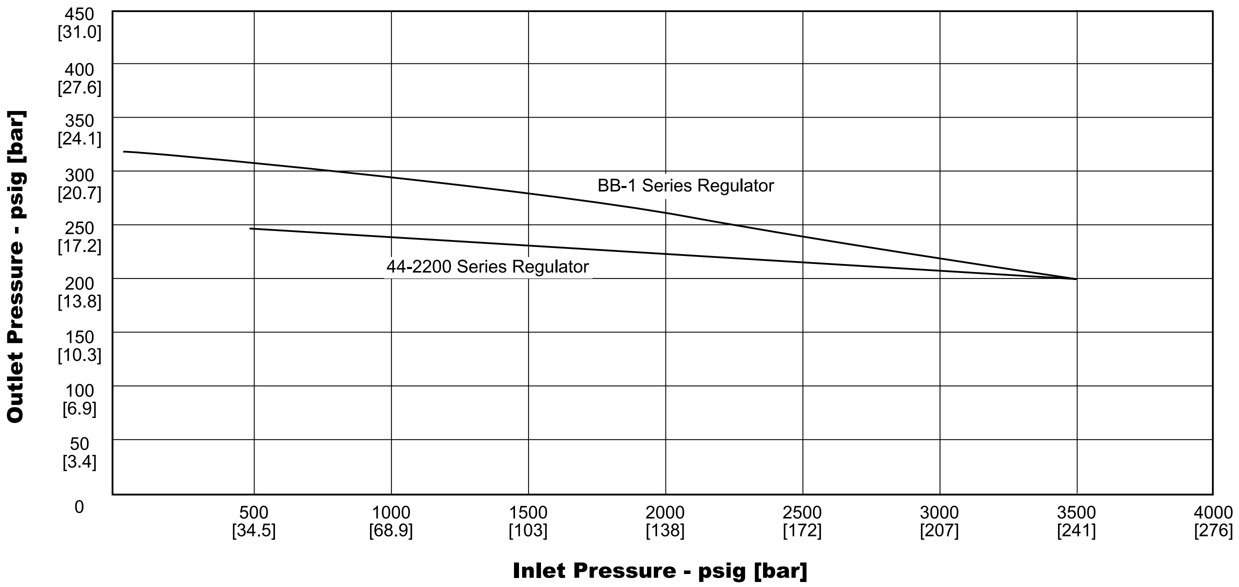
What is the Decaying Inlet Characteristic?

The effect on the set pressure of a regulator due to an inlet pressure change. This is usually an increase in outlet pressure due to a decrease in inlet pressure. Some people work with pressure regulators all of their lives and never know what is really going on inside. TESCOM spends a great deal of time teaching our distributors and customers about the key operating characteristics of pressure regulators. Understanding them and using the flow curves to properly evaluate a regulator's performance for an application is the secret to a trouble-free installation.

Definition

The decaying inlet characteristic is the amount of change in outlet pressure of a pressure reducing regulator as the inlet pressure varies. The decaying inlet characteristic has an inverse relationship between the inlet and outlet pressure of a single-stage regulator; as the inlet pressure goes down, the outlet pressure goes up (see chart below).

DECAY INLET CHARACTERISTIC



Considerations

We must consider decaying inlet when our pressure is a limited source, such as a cylinder or tube trailer. When our source gas comes from a compressor or liquid source such as a dewar, the inlet pressure is fairly stable and the effect of the decaying inlet characteristic on set point is negligible.

How It Works

To see how decaying inlet works, let's consider a few TESCOM regulators for the same application.

Parameters

Our application is a compressed gas that is packaged at 3500 psig / 241 bar. Our process requires a 200 psig / 13.8 bar set point.

Scenario A

We'll look at the BB-1 Series, which is rated for 3500 psig / 241 bar max inlet pressure, and has a 4 psig/100 psig (0.28 bar/6.9 bar) decaying inlet characteristic (4 psig / 0.28 bar rise in outlet pressure per 100 psig / 6.9 bar decrease in inlet pressure). Assuming that we start with full inlet pressure of 3500 psig / 241 bar, and that the source pressure will decay to 500 psig / 34.5 bar before it is either changed out or recharged, the net change on the inlet of the regulator is 3000 psig / 207 bar. If the regulator is initially set for an outlet pressure of 200 psig / 13.8 bar with 3500 psig / 241 bar on inlet, the outlet pressure will rise by 120 to 320 psig / 8.3 to 22.1 bar.

3000 psig change in inlet pressure ÷ 100 psig = Factor of 30
Factor of 30 x 4 psig decaying inlet characteristic = 120 psig increase

207 bar change in inlet pressure ÷ 6.9 bar = Factor of 30
Factor of 30 x 0.28 bar decaying inlet characteristic = 8.4 bar increase

Scenario B

The 44-2200 Series has much lower decaying inlet characteristic 0.75 psig/100 psig (0.05 bar/6.9 bar). Using the same operating conditions is the previous example, we find that these regulators will see a pressure rise of 22.5 psig / 1.6 bar on the outlet, from 200 to 222.5 psig / 13.8 to 15.3 bar. Clearly, we get better outlet pressure stability with these regulators.

Scenario C

To further reduce the decaying inlet effect, we should consider taking the pressure reduction in two steps, or stages. We typically use a two-stage regulator like the 44-3400 Series to do this. The 44-3400 Series is composed of two 44-2200 Series regulators built into the same body and internally connected in series with one another. The decaying inlet characteristic of the 44-2200 Series is 0.75 psig/100 psig (0.05 bar/6.9 bar). The first stage is preset at a nominal pressure of 250 psig / 17.2 bar. The second stage is adjusted to our original 200 psig / 13.8 bar set point. When the source pressure decays from 3500 to 500 psig / 241 to 34.5 bar, the first stage sees a net decrease of 3000 psig / 207 bar on its inlet. The outlet pressure of the first stage will increase by 22 to 522 psig / 1.5 to 36.0 bar. The second stage now sees a net increase of 22 psig / 1.5 bar on its inlet. The outlet of the second stage will go down by 0.17 psig / 0.01 bar (22 psig ÷ 100 psig = 0.22 psig x 0.75 psig = 0.17 psig) (1.5 bar ÷ 6.9 bar = 0.22 bar x 0.05 bar = 0.01 bar). To anyone reading a typical pressure gauge on the downstream side of the two-stage regulator, the decaying inlet characteristic is negligible.

Controlling Decaying Inlet Characteristic

Two-stage pressure regulators are frequently employed as cylinder regulators for packaged specialty gases. The flows are typically low and the two-stage reduction allows the operator to provide stable delivery pressures to the process. There are times when a single-stage regulator is used on the cylinder, which feeds a header in a lab or process facility. Point-of-use regulators are installed along the header, permitting individual users to adjust their pressures accordingly. The use of a single-stage source regulator, along with point-of-use regulators, provides the two-stage reduction necessary for controlling decaying inlet characteristic. For higher flow applications, TESCOM offers regulators with balanced main valves, like the 44-1300 Series. The 44-1300 Series is so highly balanced that its decaying inlet characteristic is a very low 0.1 psig/100 psig (0.007 bar/6.9 bar) with a 0-300 psig / 0-20.7 bar control pressure. For a 3000 psig / 207 bar reduction on its inlet, the 44-1300 Series would yield a 3 psig / 0.21 bar increase on its outlet, nearly transparent to anyone working with this regulator. The 44-1300 Series is often used as a tube-trailer regulator because of its high flow and extremely low decaying inlet characteristic. These qualities allow users to employ only one regulator to provide the required working pressure for their process.

Mistaken Identity

Many times, unknowing regulator users observe the decaying inlet characteristic and mistake it for a leaky regulator. In the non-flowing condition, the user observes that the set point has climbed above the original set point and believes the regulator is creeping. One quick method to confirm that the regulator is not creeping is to observe the gauge reading for a short period of time. If the pressure has stabilized at a few psig above the original set point, then this is probably decaying inlet. If the pressure is slowly climbing and not stabilizing, then the regulator seat is likely contaminated and the regulator must be removed for servicing. By confirming that the source pressure is a compressed source such as a cylinder, you can quickly correlate the drop in inlet pressure to the increase in set point.

Sizing a Regulator

There are several reasons to consider the decaying inlet characteristic when evaluating a regulator. First and foremost, can the system handle the increase in outlet pressure? What if the outlet pressure decays to a point where a relief valve triggers or a rupture disk bursts for example? Secondly, can the process itself tolerate the pressure swing involved? In our BB-1 Series example mentioned earlier, could the process tolerate a 120 psig / 8.3 bar increase on the set point? Are gauges and other instrumentation downstream of the regulator sized to handle this increase in pressure? Our responsibility as application specialists is to consider all possibilities when selecting a regulator for the customer's application. By taking into account the decaying inlet characteristic when you size a regulator, you can avoid any surprises that would otherwise result when the regulator is placed into service.

Flow Calculations

This section is for computing gas and liquid flow through regulators and valves.

C_V

Flow coefficient for regulators and valves that expresses flow capabilities of a unit at full open condition. For liquids, this coefficient is defined as the flow of water at 60°F / 16°C in gallons per minute at a pressure drop of one psig. For gases, this coefficient is defined as the flow of air at standard conditions in standard cubic feet per minute for each psig of inlet pressure.

S_L

Specific gravity of liquids relative to water, both at standard temperature of 60°F / 16°C. (Specific gravity of water = 1.0 at 60°F / 16°C.)

S_g

Specific gravity of a gas relative to air; equals the ratio of the molecular weight of the gas to that of air. (Specific gravity of air = 1.0 at 60°F / 16°C.)

P

Line pressure (psia).

P_1

Inlet pressure expressed in psia.

P_2

Outlet pressure expressed in psia.

ΔP

Differiential pressure (P_1 - P_2).

psia

Absolute pressure which is gauge pressure (psig) plus 14.7 (atmospheric pressure).

Q_L

Liquid flow in gallons per minute (GPM).

Flow Calculations

GASEOUS FLOW FORMULAS*

a. $C_V = \frac{Q_g \times 2\sqrt{S_g}}{P_1}$

Use when P_1 equals or is greater than 2 x P_2.
(Referred to as critical flow)

Example: Determine C_V required for a regulator when inlet pressure (P_1) is equal or greater than two times outlet pressure (P_2) and the following items are known:

Given:

P_1 = 1000 psia

P_2 = 400 psia

Q_g = 400 SCFM

S_g = 1.0 (assume air in this example)

$$C_V = \frac{Q_g \times 2\sqrt{S_g}}{P_1} = \frac{400 \times 2}{1000} = .8\ C_V$$

*Caution: When sizing components for flow applications, attention must also be directed to the size of plumbing. When flow requirements are at low pressures, the plumbing may be the flow limiting item rather than the regulator or valve.

b. $C_V = \frac{Q_g \times \sqrt{S_g}}{\sqrt{\Delta P \times P_2}}$

Use when P_1 is less than 2 x P_2 or P_2 is greater than one-half of inlet pressure.

Note: This is referred to as sub-critical flow.

Example: Determine maximum flow capability through the same regulator (example in a.) using the C_V factor when the following conditions exist:

Given:

P_1 = 1000 psia

P_2 = 600 psia

C_V = 0.8

S_g = 1.0 (assume air in this example)

Solve formula for Q_g:

$$Q_g = \frac{C_V\sqrt{\Delta P \times P_2}}{\sqrt{S_g}}$$

$$= \frac{.8\sqrt{1000\text{-}600 \times 600}}{\sqrt{1}} = \frac{392}{1}$$

Q_g = 392

Flow Calculations

LIQUID FLOW FORMULAS

$$C_V = \frac{Q_L\sqrt{S_L}}{\sqrt{\Delta P}} \quad \therefore \quad Q_L = \frac{C_V\sqrt{\Delta P}}{\sqrt{S_L}}$$

Example: Determine liquid flow (assume water) through a regulator in gallons per minute with the following conditions:

Given:

P_1 = 1000 psia

P_2 = 600 psia

S_L = 1.0

C_V = .08

$$Q_L = \frac{C_V\sqrt{\Delta P}}{\sqrt{SL}} = \frac{0.08\sqrt{1000\text{-}600}}{\sqrt{1}} = \frac{0.08 \times 20}{1}$$

$$= \underline{\underline{1.6 \text{ GPM (Water)}}}$$

CONVERT FLOW FROM CFM TO SCFM

$$Q_g = \frac{Q \times P}{14.7}$$

Example: Convert gas flow expressed in cubic feet per minute (CFM) to units of standard cubic feet per minute (SCFM).

Given:

Q = 20 CFM

P = 294 psia

$$Q_g = \frac{Q \times P}{14.7} = \frac{20 \text{ CFM} \times 294 \text{ psia}}{14.7 \text{ psia}}$$

$$= \underline{\underline{400 \text{ SCFM}}}$$

CONVERT MASS FLOW TO VOLUME FLOW (SCFM) OF AIR

$$Q_g \text{ (Air)} = \frac{M \text{ (any gas)} \times 13.36}{S_g \text{ (any gas)} \times \sqrt{\frac{1}{S_g \text{ (any gas)}}}}$$

Example: Convert mass flow (lb/min) of any gas to volume flow (SCFM) of air

Given: M (He) = 1 lb. min, S_g (H_e) = .138

$$Q_g = \frac{M \times 13.36}{S_g \times \sqrt{\frac{1}{S_g}}} = \frac{1 \times 13.36}{.138 \times \sqrt{\frac{1}{.138}}}$$

$$= \underline{\underline{35.96 \text{ SCFM (Air)}}}$$

EMERSON. Process Management

Flow Calculations

Media Tables

A. Approximate multipliers to use when converting flow (GPM) of water to various liquids:

Crude Oil	1.015 to 1.11
Gasoline	1.15
Hydraulic Oil-Mineral Base	1.12
Hydraulic Oil-Phosphate Ester Base	.95
Hydraulic Oil-Standard Mil 5606	1.10
Hydraulic Oil-Water Glycol Base	.98
Kerosene	1.10
Water	1.00

Example: Determine maximum flow of kerosene through a regulator if maximum water flow capability is 5 GPM.

Kerosene flow = 5 GPM (water) x 1.10 (kerosene multiplier) = 5.5 GPM

B. Approximate multipliers to use when converting flow (SCFM) of air to various gases:

Air	1.000
Ammonia	1.295
Argon	.852
Arsine	.609
Carbon Dioxide	.810
Helium	2.690
Hydrogen	3.790
Hydrogen Chloride	.888
Nitrogen	1.015
Oxygen	.951
Silane	.915

Examples: Determine maximum flow of helium through a regulator if the maximum air flow capability is 300 SCFM.

Helium flow = 300 SCFM (air) x 2.69 (helium multiplier) = 807 SCFM

$$\text{Air flow} = \frac{25\ \text{SCFM}}{2.69} = 9.3\ \text{SCFM of He}$$

C. Approximate specific gravities (S_L) for various liquids:

Crude Oil	.81 to .97
Gasoline	.75
Hydraulic Oil-Mineral Base	.80
Hydraulic Oil-Phosphate Ester Base	1.10
Hydraulic Oil-Standard Mil 5606	.83
Hydraulic Oil-Water Glycol Base	1.05
Kerosene	.82
Water	1.00

To convert the flow from water (specific gravity of 1.0) to a liquid having a specific gravity other than 1.0 use the following formula:

$$Q_L\ (\text{any liquid}) = Q_L\ (\text{water}) \sqrt{\frac{1}{S_L\ (\text{any liquid})}}$$

D. Approximate specific gravities (S_g) for various gases:

Air	1.000
Ammonia	.596
Argon	1.379
Arsine	2.695
Carbon Dioxide	1.529
Helium	.138
Hydrogen	.070
Hydrogen Chloride	1.268
Nitrogen	.967
Oxygen	1.105
Silane	1.195

To convert the flow from air (specific gravity of 1.0) to a gas having a specific gravity other than 1.0 use the following formula:

$$Q_g\ (\text{any gas}) = Q_g\ (\text{air}) \sqrt{\frac{1}{S_g\ (\text{any gas})}}$$

WARNING! Do not attempt to select, install, use or maintain this product until you have read and fully understood the *TESCOM Safety, Installation and Operation Precautions.*