White Paper

Pressure Regulator Selection Strategy

How to use a flow curve to ensure effective regulator specification

The best way to select a regulator for your application is to examine its flow curve, which is often provided by the manufacturer. “Flow curve” is a misleading name. You could call it a “pressure curve” instead, since regulators control pressure, not flow.

The curve represents the range of pressures that a regulator will maintain given certain flowrates in a system. When selecting a regulator, you are not just looking for the right size – you’re looking for a set of capabilities, which is a function of the regulator’s design. A flow curve illustrates the regulator’s range of capabilities at a glance. Once you understand a flow curve – and we’ll explain how – it is easy and very quick to read.

Unfortunately, a more common way to select a regulator is to consult its flow coefficient (Cv). If the system flow is within range of the Cv, some people may believe that the regulator is the right size – but that is not necessarily true. The Cv represents the regulator’s maximum flow capacity. At maximum flow, a regulator can no longer control pressure. It you’re expecting flowrates to reach the regulator’s Cv, it is probably not the right regulator for your system. Let’s discuss how to read a flow curve. We’ll cover the basics first and then some of the complexities, including droop, choked flow, seat load drop or lockup, hysteresis, and accumulation.

Regulator Flow Curve Terminology

Accumulation: The increase in inlet pressure required to obtain a specified flowrate for a back pressure regulator.

Choked-Flow Area: The area of a flow curve in which flow demand is greater than the pressure controlling capabilities of the regulator.

Droop: The outlet pressure change from the set pressure that occurs as a flowrate increases for a pressure-reducing regulator.

Hysteresis: The difference between flow curves for increasing and decreasing flow.

Lock-Up: The outlet pressure increase that occurs as flow is decreased to zero.

Seat Load Drop: The initial pressure drop experienced when a regulator starts from a no-flow state.

The Basics

A regulator’s main purpose is to maintain a constant pressure on one side of the regulator even though there is a different pressure or fluctuating pressure on the other side. In the case of a pressure-reducing regulator, you control the downstream pressure. In the case of a back-pressure regulator, you control the upstream pressure.

For now, let’s talk in terms of pressure-reducing regulators since they are more common. Later, we will provide some direction for selecting back-pressure regulators.

A flow curve illustrates a regulator’s performance in terms of outlet pressure (Y axis) and flowrate (X axis). Flow is not controlled by the regulator. It is controlled downstream by a valve or flowmeter. The curve shows you how a regulator will respond as flow in the system changes.

Let’s look at the top curve in Figure 1. The curve starts at 400 pounds per square inch gauge (PSIG) (27.5 bar). This is the original set pressure for the regulator. No adjustments are made to the regulator, yet the curve shows a change in pressure.

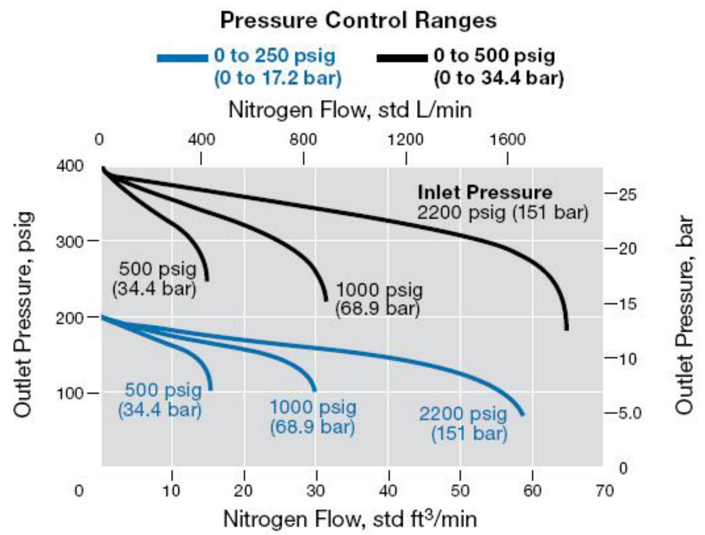

Figure 1. *Manufacturers often provide multiple flow curves for the same regulator at different inlet pressures to provide a range of the regulator’s operating capabilities.*

The regulator is making adjustments, trying to maintain the original set pressure as flow changes – but it is not perfect. No regulator is. As a system’s flow increases, pressure downstream of the regulator drops. The important question is: How much does it drop?

When reading a flow curve, first identify the range of flows that you can expect to see in your system. Mark these on the graph. Then, look to see what the corresponding changes in outlet pressure will be. Is that range of pressure acceptable to you? If not, you need to look for a different regulator.

When reading a flow curve, first identify the range of flows that you can expect to see in your system. Mark these on the graph. Then, look to see what the corresponding changes in outlet pressure will be. Is that range of pressure acceptable to you? If not, you need to look for a different regulator. Ideally, you want to operate the regulator on the flattest part of the curve. There, the regulator will maintain relatively constant pressures even with significant changes in flow. At the far ends of the curve, there are steep drops, where pressure will change dramatically with even the slightest change in flow. You do not want to operate the regulator at these locations.

Any given regulator can produce a nearly infinite number of curves, so you need to make sure you are looking at the right one. For every set pressure, there will be a different curve. In Figure 1, there are two main sets of curves – one based on a set pressure of 400 PSIG (27.54 bar) and one for a set pressure of 200 PSIG (13.7 bar). It is helpful when a manufacturer provides more than one set of curves representing the range of set pressures possible with a particular regulator. If your set pressure lies between the curves, you can interpolate. Note that the two curves are close to the same shape but in different locations on the graph.

There is one additional variable that affects the shape of a curve – inlet pressure (i.e., pressure going into a pressure-reducing regulator on the upstream side). Note that for each of the two sets of curves in Figure 1, there are three curves representing a range of inlet pressures.

In sum, to locate the right curve for your system, look for: (1) the right set pressure; (2) the right inlet pressure; and (3) the right range of flows.

Finally, make sure you are looking at the right units. Pressure readings are provided most commonly as PSIG or bar. Flowrate units vary depending on the system media, so be sure to note whether the regulator is rated for liquid or gas service. Liquid flow is typically expressed as gallons per minute (gal/min) or litres per minute (L/min), while gas flow is conveyed as standard cubic feet per minute (std ft3/min) or standard litres per minute (std L/min).

Curves are usually created using air or nitrogen (for gas service) or water (for liquid service). If your system medium is a gas, you may need to make an adjustment in the manufacturer's curve. Gases compress at different rates, so you may need to multiply the flow curve's units by a gas correction factor. For example, hydrogen's correction factor is 3.8, meaning 3.8 molecules of hydrogen have the same volume as one molecule of air. Therefore, the point on a flow curve showing an airflow volume of 100 std ft3/min (2,831 std L/min) indicates a comparable hydrogen flow of 380 std ft3/min (10,760 std L/min). The curve stays the same, but the flow scale will change.

For liquids, the difference in flow between water and a different medium is not as dramatic due to the incompressibility of the liquids.

Droop, Choked Flow, and Other Complexities

As mentioned above, it is best to operate along the flattest – or most horizontal – part of a flow curve. Indeed, the ideal flow curve would be a flat line. However, no regulator can produce a perfectly flat line over the full range of pressures because the internal components of the regulator have limitations. In a spring-loaded regulator, longer springs produce flow curves with broader horizontal sections. Dome-loaded regulators, which use a trapped volume of gas instead of a spring, produce even broader horizontal sections. Electrically controlled pneumatic-loaded regulators and dome-loaded regulators with external feedback produce the broadest horizontal sections.

When selecting a regulator, you are not just looking for the right size – you're looking for a set of capabilities, which is a function of the regulator's design. A flow curve illustrates the regulator's range of capabilities.

Typically, a flow curve consists of three parts: (1) a relatively flat part in the middle; (2) a steep drop on the far left; and (3) a steep drop on the far right. The flat part in the middle is not perfectly flat. Usually, it slopes downward, and this is called droop. As flow increases, pressure will drop some – or a lot depending on the regulator design. While droop is relatively modest along the flat part of the curve, it is quite steep at the far ends of the curve.

Choked flow occurs on the far right of the curve. See the choked-flow area in Figure 2, where pressure begins to droop sharply at 140 std ft3/min (3,964 std L/min). Eventually, near 150 std ft3/min (4,247 std L/min), pressure drops to zero. At this point, the flow demand has exceeded the pressure-controlling capabilities of the regulator. Here, the regulator is wide open and is no longer regulating pressure. It has essentially changed from a pressure controlling device to an open orifice. Increasing downstream flow at this point or beyond renders the regulator ineffective. It is not advisable to operate a regulator in the choked-flow area due to the sharp pressure drop.

Note that Cv is measured at the regulator's fully choked point, and that's why it is not an especially useful measurement. It is a poor indicator of a regulator's overall performance.

Seat load drop occurs on the far left of the regulator curve (Figure 2), where there is initially a steep drop in pressure. If you are reading the curve from left to right, imagine that the system is in a no-flow state.

The regulator is set to a certain pressure, but there is no flow. Then imagine that an operator slowly opens a downstream valve to initiate flow. Right away, there is a sharp drop in pressure because it is difficult for a regulator to maintain pressure at this location. If your regulator is operating along this steep drop in the curve, you may hear chattering or pulsating as the regulator fluctuates between flow and no-flow conditions.

Now let's read the curve from right to left. Imagine that the system is operating along the flat part of the curve. Then imagine that an operator is slowly closing a downstream valve, reducing flow to near zero. We are moving up the curve. As we near the no-flow state, the regulator has difficulty maintaining the set pressure. Again, you may hear chattering. Eventually, the regulator snaps shut, stopping flow. This is called lock-up.

The terms seat load drop and lock-up are essentially interchangeable. Sometimes people use lock-up to describe both conditions. It is not advisable to operate a regulator in this area.

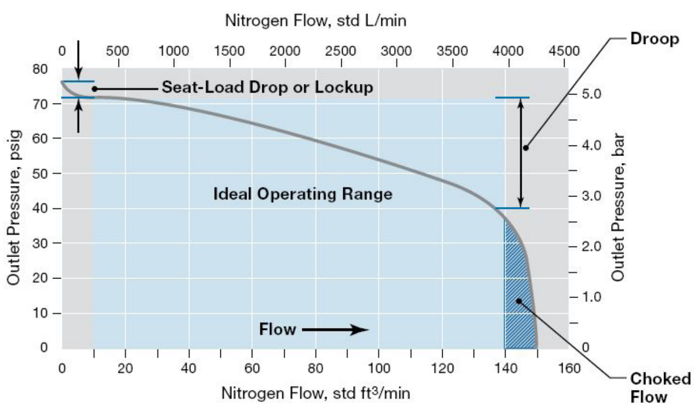

Figure 2. *This typical flow curve for a pressure-reducing regulator demonstrates several phenomena, including the ideal operating area, droop, choked flow, seat load drop or lock-up, and flow coefficient (Cv).*

Hysteresis

It matters whether you are reading a flow curve from left to right or right to left. When reading left to right, flow is increasing. And the reverse is true when reading from right to left. Depending on whether flow is increasing or decreasing, the curve will be slightly different. Outlet pressure will not follow the same "droop line," nor end at the original set pressure. This phenomenon, which is illustrated in Figure 3 (above), is called hysteresis. The upper line is for decreasing flow, while the bottom line is for increasing flow.

Hysteresis, which results from dynamic friction forces within the regulator, is usually not an issue when evaluating the performance of a regulator. However, it can be a point of confusion during system operation. Suppose an operator sets up a system to deliver and outlet pressure of 50 PSIG (3.4 bar) at 110 ft3/min (3,115 L/min). The next day, he notices that the pressure is now 50.5 PSIG (3.48 bar), but the flow is still 110 ft3/min (3,115 L/min). Hysteresis is to blame. It is likely that something in the system temporarily created more flow demand downstream. Moving from left to right on the curve, the temporary flow increase slightly reduced the outlet pressure. Then, as the flow demand returned to 110 ft3/min (3,115 L/min), hysteresis cause the outlet pressure to return to a point slightly higher than the initial set point. likely that something in the system temporarily created more flow demand downstream. Moving from left to right on the curve, the temporary flow increase slightly reduced the outlet pressure. Then, as the flow demand returned to 110 ft3/min (3,115 L/min), hysteresis cause the outlet pressure to return to a point slightly higher than the initial set point.

This scenario illustrates the need for operators to periodically check systems to ensure regulators are set to the proper outlet pressures. It is recommended to approach your set pressure from a lower pressure. Another best practice is to employ pressure gauges in a system to help fine tune regulator settings to achieve desired operating pressures.

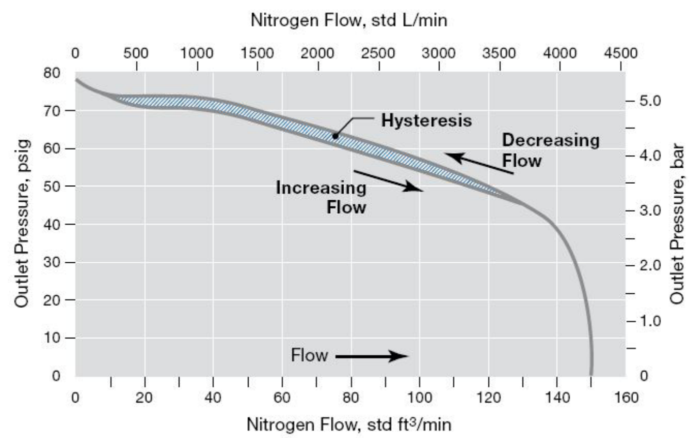

Figure 3. *The phenomenon of hysteresis reveals that outlet pressures will be higher at the same flow volume when decreasing flow compared to when increasing flow. (Note: Hysteresis shown larger than actual for demonstration purposes.)*

Back Pressure Regulators and Accumulation

Flow curves for back-pressure regulators reveal a phenomenon known as accumulation (Figure 4), which is the opposite of droop. Because a back-pressure regulator controls inlet pressure, pressure will go up as flow increases instead of down as in a pressure-reducing regulator. The phenomenon occurs because the back-pressure regulator acts as a restriction and essentially limits flow at the inlet. Your objective is the same as it is with pressure-reducing regulators – i.e., to operate on the flat part of the curve.

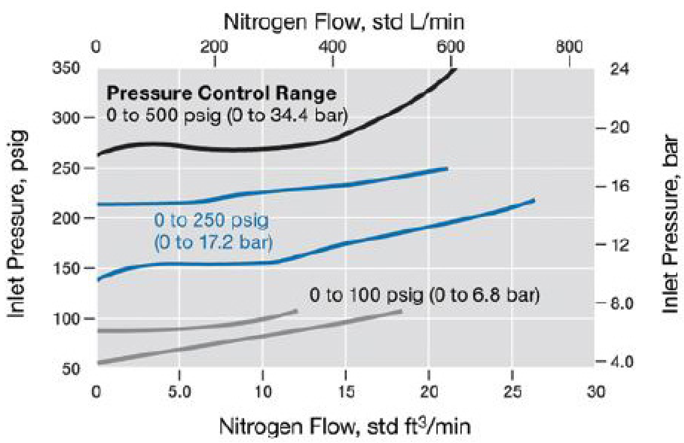

Figure 4. *The flow curve for a back-pressure regulator indicates accumulation, which is the opposite of droop.*

Regulator Flow Curve Generator

Swagelok has developed a new tool that will give you a unique flow curve based on a set of user-specified application parameters for Swagelok RHPS Series regulators. The tool allows you to:

- View the performance of one regulator in up to four different applications
- Compare the performance of up to four different regulators in the same application
- View any combination of regulators and applications, adding up to a total of four, on the same graph

Access the Regulator Flow Curve Generator

Best Practices

When selecting a regulator for your application, consult the flow curve, not the Cv. Make sure you are looking at the right curve. Does it reflect the pressure you will set your regulator to (your "set pressure")? Does it reflect the right inlet pressure range? Are you working with the right units? Do you need to calculate any adjustments if your system medium is a gas? Once these issues have been addressed, you can start reading your curve. On the curve, identify the range of flows you can expect in your system. Given that range, the curve will tell you what pressures you can expect the regulator to maintain. Ideally, you want the regulator to operate along the relatively flat part of the curve. That's where the regulator will perform most consistently. You want to avoid operating the regulator on the far ends of the curve where undesirable conditions like lock-up and choked flow occur.

If a flow curve is not available, or if you need help selecting a regulator, consult with our knowledgeable associates who can provide guidance on properly sizing a regulator for your application.

Contact Us

Please visit our website at safst.swagelok.com.

For expert guidance on selecting pressure regulators, complete our Service Request Form.