

Swagelok Regulator Flow Curve Article

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HOW TO READ A REGULATOR FLOW CURVE

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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 easily call it a “pressure curve” instead, since a regulator controls pressure, not flow. The curve represents the range of pressures that a regulator will maintain given certain flow rates 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 one 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 (C_v). If the system flow is within range of the C_v , some people may believe that the regulator is the right “size.” But that is not necessarily true. The C_v represents the regulator’s maximum flow capacity. At maximum flow, a regulator can no longer control pressure. If you’re expecting flow rates to reach the regulator’s C_v , 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 lock-up, hysteresis, and accumulation.

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 flow rate (X axis). Flow is not controlled by the regulator. It is controlled downstream by a valve or flow meter. 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.

The regulator is making adjustments, trying to maintain the original set pressure as flow changes. But, it is not perfect. No regulator is. As system 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 pressures 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. Flow rate 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 liters per minute (L/min), while gas flow is conveyed as standard cubic feet per minute (std ft³/min) or standard liters per minute (std L/min).

Curves are usually created using air or nitrogen (for gas service) or water (for liquid service). If your system media 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 volume 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 air flow volume of 100 std ft³/min (2831 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 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 springloaded regulator, longer springs produce flow curves with broader horizontal sections. Domeloaded regulators, which use a trapped volume of gas instead of a spring, produce even broader horizontal sections. Electrically controlled pneumatic-loaded regulators and domeloaded regulators with external feedback produce the broadest horizontal sections.

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 a curve. See the choked-flow area in Figure 2, where pressure begins to droop sharply at 140 std ft³/min (3964 std L/min). Eventually, near 150 std ft³/min (4247 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 to 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 C_v 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.

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 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, 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 an outlet pressure of 50 psig (3.4 bar) at 110 ft³/min (3115 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 (3115 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 (3115 L/min), hysteresis caused 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.

BACK-PRESSURE REGULATORS AND ACCUMULATION

Flow curves for back-pressure regulators reveal a phenomenon known as **accumulation** (see 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. This 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: to operate on the flat part of the curve.

CONCLUSION

When selecting a regulator for your application, consult the flow curve, not the C_v . 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 media 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 a knowledgeable sales and service representative who can provide guidance on properly sizing a regulator for your application.

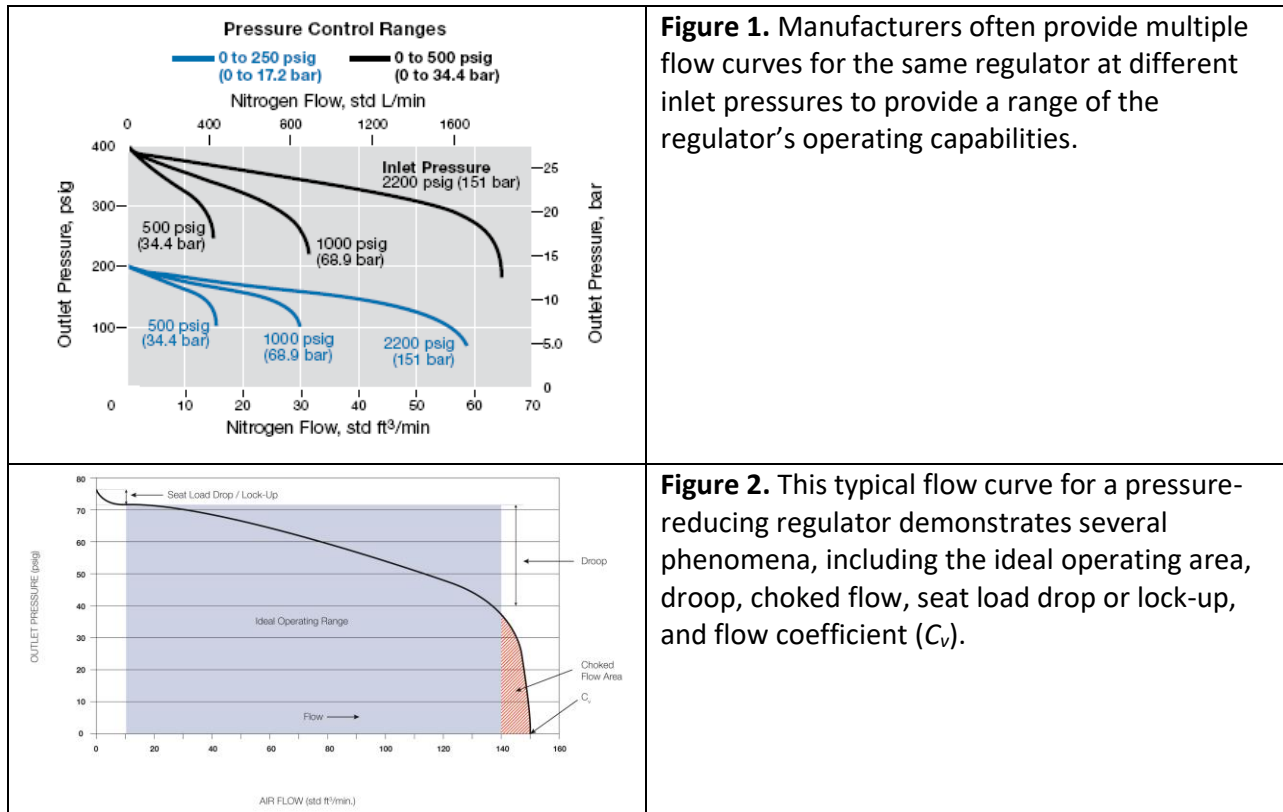
SIDEBAR: REGULATOR FLOW CURVE TERMINOLOGY

- **Accumulation:** The increase in inlet pressure required to obtain a specified flow rate 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 flow rate 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.

ABOUT THE AUTHOR *(To be updated based on org announcement)*

As manager, field engineering, Bill Menz leads a team of engineers dedicated to supporting application, service and training of Swagelok products. He has worked closely with distributors and end users to define market trends, growth opportunities, new product needs, and applications for Swagelok’s analytical and process instrumentation products. Bill has more than 13 years of experience gained through a variety of engineering and marketing roles with Rosemount Analytical. Bill graduated from the University of Cincinnati with a bachelor of science degree in chemical engineering. He can be reached at Bill.Menz@Swagelok.com.

FIGURES AND CAPTIONS



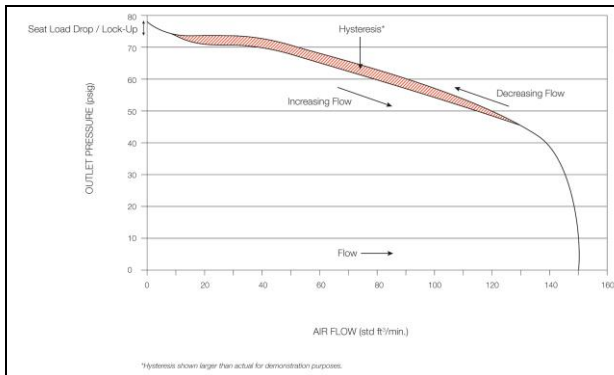


Figure 3. The phenomenon of hysteresis reveals that outlet pressures will be higher at the same flow volume when decreasing flow compared to when increasing flow. *Hysteresis shown larger than actual for demonstration purposes.*

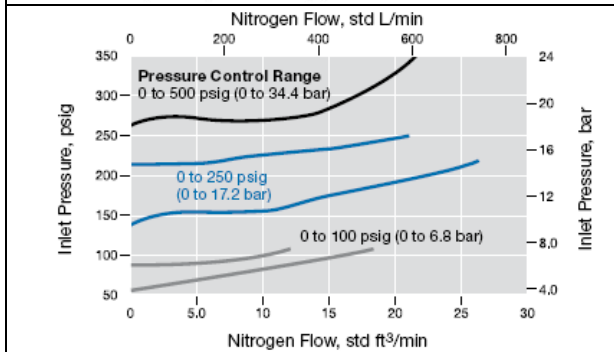


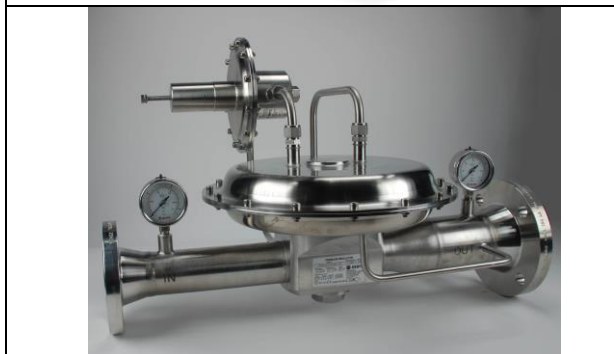
Figure 4. The flow curve for a back-pressure regulator indicates accumulation, which is the opposite of droop.



Optional: Flow curves for springloaded pressure regulators feature broad horizontal sections.



Optional: Domeloaded regulators produce flow curves with very broad horizontal sections, because they use a trapped volume of gas internally.



Optional: A domeloaded regulator with external feedback produces the broadest horizontal sections for a purely mechanical pressure regulator.