Pressure Regulators: How to Pick the Best One for High-Purity Use

By Bill Menz

Pressure regulators are highly technical and specialized fluid handling components. When selecting a regulator, make sure to define application needs with consideration not only to pressure requirements but also to flow rate, gas/liquid composition, and temperature. Proper selection can avoid undesirable conditions such as droop and creep while poor selection can lead to failures such as improper pressure control and contamination of gas streams.
Regulators are available in a variety of types, designs, and materials of construction. The three main categories are pressure-reducing, back-pressure, and vaporizing. Within each classification, there are piston and diaphragm regulators as well as one- and two-stage regulators. Let’s review these below.

Pressure-Reducing and Back-Pressure Styles

Regulators control pressure. They are the pivotal point between high and low pressure. It will always be the case that the pressure will be higher on one side of the regulator than on the other. Most common applications require a pressure-reducing regulator, which means the inlet pressure undergoes a mechanically controlled pressure drop, resulting in a relatively constant pressure at the outlet. In some cases, the reverse may be required. In such cases, a back-pressure regulator is used to mechanically control the outlet pressure so that a relatively constant pressure is maintained at the inlet.

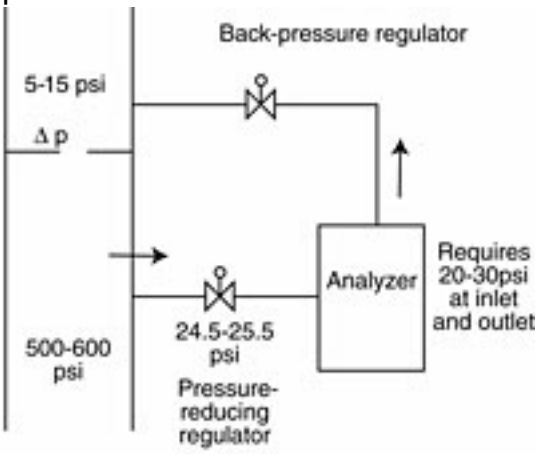

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Figure 1 (Click image for larger version.)

Figure 1 shows an analyzer system with pressure-reducing and back-pressure regulators performing typical functions. Note that the pressure-reducing regulator is receiving high pressure (37.5+/-2.5 bar) from the process line and reducing pressure to a stable supply pressure (2+/-.025 bar, with a one-stage regulator) as the gas flows into the analyzer. In this application, the analyzer system needs to

maintain a pressure of 2 bar. Because of pressure fluctuations in the process stream where the sample is being returned, a back-pressure regulator is employed. It maintains a stable pressure on the inlet side and shields the analyzer from the downstream pressure fluctuations.

Vaporizing Models

A vaporizing regulator is a pressure-reducing regulator used either to prevent condensation or induce vaporization. A steam or electric heating element is part of the vaporizing regulator. The reason for preventing condensation is to forestall rapid pressure drop that could result in the Joule-Thompson effect and cause a regulator to freeze up. The Joule-Thompson effect is caused by a gas losing heat as it undergoes a complete or partial condensation. A vaporizing regulator applies heat at the point of the pressure drop, preventing the condensation and consequent regulator freezing from occurring.
In other cases, such as are typical for gas chromatograph applications, it may be desirable for a liquid to be vaporized. In this instance, the vaporizing regulator applies heat to vaporize the liquid to a gas.

One and Two Stages

An important consideration in choosing between a one- and two-stage regulator is the variation in the inlet pressure supply. The manner in which a regulator adjusts to variations in the high pressure supply is known as supply pressure effect (SPE). In general, one-stage pressure-reducing regulators are suitable for most applications where the inlet pressure is relatively constant. In applications where the high pressure supply is subject to large variations, a two-stage regulator with a low SPE will provide the most stable low-pressure delivery.
The degree of variation that can be expected in the outlet pressure differs between one- and two-stage regulators. A high-quality one-stage regulator will deliver an outlet pressure range that may be estimated using the following formula: (delta symbol)P (outlet) = (delta symbol)P (inlet) x 0.01. In other words, the variability in outlet pressure is 1 percent of the inlet-pressure range. In Figure 1, the inlet pressure varies by 5 bar (35 to 40 bar), so 5 bar x 0.01 equals an outlet pressure variation of 0.05 bar. If the outlet pressure is set for 2 bar, and the inlet pressure rises from 35 to 40 bar, the outlet pressure will drop from 2 to 1.95 bar. The inverse relationship between the high pressure (inlet) rising and the low pressure (outlet) dropping is typical of one-stage regulators. The high pressure rise causes the valve seat to constrict slightly, reducing the regulator orifice size and the corresponding outlet pressure.

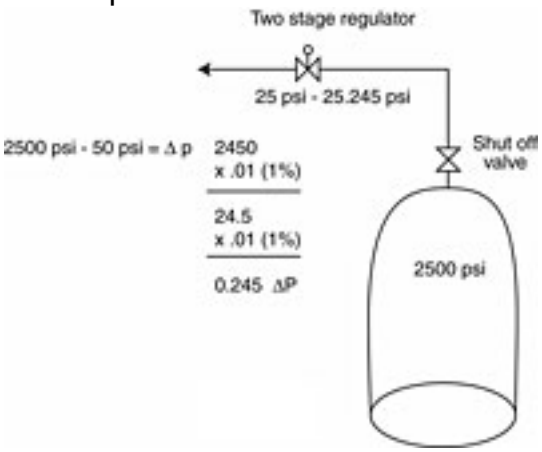

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Figure 2 (Click image for larger version.)

A two-stage regulator consists of two one-stage regulators in series and combined into one component (Figure 2). The first regulator reduces the high pressure supply to an intermediate point between the inlet pressure and the desired outlet pressure. The second stage reduces the intermediate pressure to the desired outlet pressure. To calculate the variability of outlet pressure for a high-quality two-stage regulator, the inlet pressure difference is multiplied by 0.0001 or by 1 percent for each regulator (0.01 x 0.01 = 0.0001).

In a typical application for a two-stage regulator, a gas cylinder is emptied at a near constant outlet pressure. As the cylinder empties, pressure at the regulator inlet will drop. If, for example, the pressure drops from 175 to 5 bar, the inlet pressure variation is 170 bar. If a two-stage regulator is used with a target outlet pressure of 2 bar, then the outlet pressure will drop from 2 to 1.983 bar. On the other hand, if the same gas cylinder were outfitted with a one-stage regulator, the pressure would increase from 2 to 3.7 bar.

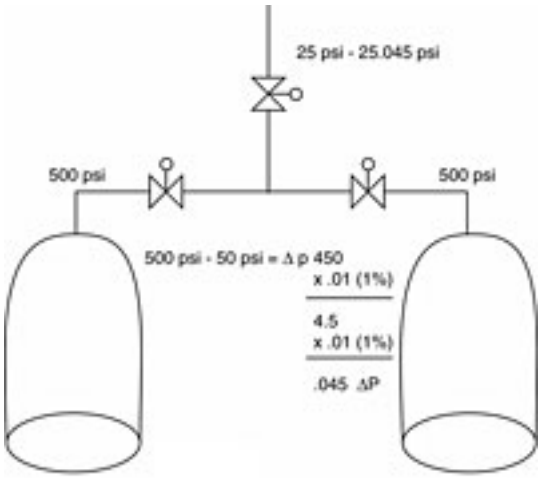

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Figure 3 (Click image for larger version.)

While a two-stage regulator is handy, two one-stage regulators may work just as well or better in some applications. One example is a cross-over arrangement, where two gas cylinders feed one point of entry (Figure 3). One cylinder is used until its pressure drops below a certain point. The second cylinder then goes into service. This specialized configuration places a one-stage regulator with each of the two cylinders. An additional regulator (often referred to as a line regulator) is located at the entry point to the system so that at all times the gas is passing through two regulators.

Diaphragm Regulators

Diaphragm regulators are generally the most sensitive in response to changes in pressure, especially in low-pressure applications. Depending on their rating, they may be used with inlet pressures up to 248 bar and controlled outlet pressures up to 35 bar. In a diaphragm regulator, a thin metal diaphragm flexes as the high pressure inlet varies. This flexure causes the regulator poppet to move in and out of the regulator seat. This compensating action is what causes the downstream pressure to remain constant. As inlet pressure rises, the diaphragm flexes up, which allows the poppet to rise into the seat and reduces the effect of the increasing inlet pressure so as to provide a constant outlet pressure. As the inlet pressure drops,

the force on the diaphragm is reduced so that it flexes down and pushes the poppet out of the seat. This action allows for a flow increase through the regulator, which in turn creates a stabilizing pressure at the outlet. The flexibility of the diaphragm is vital to the long-term performance of the regulator.
Flexibility is attained in one of two ways: perforation or convolution. The diaphragm can be perforated and then coated in PTFE or another flexible material. In this design, the PTFE may erode, in which case a leak can occur since the diaphragm is designed with holes in it. An alternative design is to use a solid convoluted diaphragm, which is a diaphragm with a fluted configuration around its perimeter to enhance flexibility. Perhaps the best seal for a diaphragm regulator is a metal-to-metal seal. In this design, the diaphragm sits in the regulator body and is held in place by the cap assembly without the aid of an elastomeric or polymeric seal. A metal-to-metal seal provides a reliable seal and is less sensitive to changes in temperature than elastomeric or polymeric seals.

Piston Regulators

Piston regulators are generally used in applications with outlet pressures higher than 35 bar, although they may also be suitable for lower pressures. In a piston regulator, pressure is controlled by means of a spring-loaded piston, which is an inflexible stainless steel disk that lies flat in the vertical cylinder of the regulator. The piston seals against the cylinder walls by means of an elastomeric O-ring seal. The thickness of the piston, along with the O-ring seal, allows a piston regulator to achieve higher working pressures than diaphragm regulators.
Compatibility of the O-ring material with the regulated process stream is an important consideration when specifying piston regulators, particularly in high-purity service. Likewise, the surface finish of the inside chamber is critical so that the O-ring seal between the piston and the cylinder wall can move up and down freely, thereby increasing the overall sensitivity of the regulator. The operation of a piston regulator is very similar to that of a diaphragm regulator. Adjusting the knob to achieve a higher outlet pressure causes the piston to push down on the poppet, which moves it out of the seat and creates a higher outlet pressure.
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