Choosing The Proper Regulator For High-Purity Applications

By Bill Menz
Pressure regulators are highly technical and specialized fluid-handling components. In the process of regulator selection, the application needs to be defined with consideration given not only to the pressure requirements, but also to the flow rate, gas/liquid composition and temperature. Proper selection can help to avoid undesirable conditions, whereas poor selection can lead to failures.

Regulators are available in a variety of types, designs and materials of construction. There are three main categories of pressure regulators, including pressure reducing, back pressure and vaporizing. Within each of these three classifications, one can choose between piston and diaphragm regulators, and between one- and two-stage regulators.

Once the appropriate type of regulator has been identified based on the application, attention should be given to the materials of construction. The same regulator may be outfitted with different materials for critical components to ensure safe and proper functioning of the regulator over time. A sales and service representative can be helpful in explaining the inner workings of the regulator, so you can make the most educated decision for your particular application. This article focuses to some extent on high-purity applications, in which even the smallest mix of corrosive gases and liquids, or aggressive environmental conditions, warrant the use of a stainless steel regulator.

Pressure-Reducing & ?Back-Pressure Regulators

Regulators are the pivotal point between high and low pressure. It is always the case that the pressure is higher on one side of the regulator than the other. Most common applications require a pressure-reducing regulator, meaning 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.

Figure One 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 ±0.025 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 2.0 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 downstream pressure fluctuations.

Vaporizing Regulators

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-Thomson effect and cause a regulator to freeze. The Joule-Thomson 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, 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- & Two-Stage Regulators

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 in which the inlet pressure is relatively constant. In applications involving large variation, a two-stage regulator with a low SPE can provide more 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 can deliver an outlet pressure range that may be estimated using the following formula: ?P (outlet) = ?P (inlet) x 0.01. In other words, the variability in outlet pressure is 1 percent of the inlet pressure range. In Figure One, 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 drops from 2 to 1.95 bar. The inverse relationship between the high pressure (inlet) rising and low pressure (outlet) dropping is typical of one-stage regulators. The high-pressure rise causes the valve seat to constrict slightly, reducing orifice size and the corresponding outlet pressure.

A two-stage regulator consists of two one-stage regulators combined into one component (Figure Two). The first regulator reduces the high-pressure supply to an intermediate point between the inlet and desired outlet pressure. The second stage reduces the intermediate pressure to the desired outlet pressure. To calculate the variability of outlet pressure for a 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 drops. 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 drops 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.

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 in which two gas cylinders feed one point of entry (Figure Three). 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 is located at the entry point to the system, so that the gas is passing through two regulators at all times.

Diaphragm Regulators

Diaphragm regulators are generally the most sensitive in response to pressure changes, 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, which 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, allowing the poppet to rise into the seat, and reducing the effect of the increasing inlet pressure so as to provide a constant outlet pressure.

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 is to use a solid convoluted diaphragm, which incorporates a fluted configuration around its perimeter, to enhance flexibility.

Perhaps the best seal for diaphragm regulators is metal-to-metal. The diaphragm sits in the regulator body, and is held by the cap assembly without an elastomeric or polymeric seal. Metal-to-metal seals are reliable, and less sensitive to temperature change than elastomeric or polymeric seals. The use of a backing plate between the diaphragm and the cap assembly can guard against diaphragm rupture. The backing plate is a stainless steel disk that can also help to apply uniform pressure across the entire diaphragm surface.

The poppet is critical in a diaphragm regulator. The poppet looks like an inverted funnel with a thin cylindrical stem extending up from the top and down from the bottom. Generally made of a high-grade stainless steel, such as S17400, the poppet is electropolished to provide a high-tolerance seat seal. In a pressure-reducing regulator, the poppet is spring-loaded and held vertically in the inlet channel with the tip in constant contact with the diaphragm. With the poppet pushing up and the diaphragm pushing down, the two work together toward the desired balance. The poppet closes or opens the regulator inlet as its conical shape fits against a precision-machined seat. A damper fitted to the bottom of the poppet supports and centers the poppet to reduce noise and vibration in high-flow conditions.

With stainless steel regulators for high-purity applications, particular attention should be paid to the materials of construction for the diaphragm and poppet seat.

For the diaphragm, a stainless steel, such as Type 316, may not be sufficient, and an alloy like Inconel may be more appropriate due to its greater flexibility and high corrosion resistance. Likewise, the poppet seat is critical. A hard fluoropolymer is not as forgiving and does not seat as well as a softer material. On the other hand, the harder material is more resistant to abrasion. The poppet seat should be modular so an appropriate material (e.g., PEEK, PCTFE) may be chosen based on chemical compatibility, pressure requirements and temperature.

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 a stainless steel inflexible 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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