Selecting valves for pressure swing adsorption

The PSA unit is a demanding process for control valves. Here are guidelines and maintenance strategies for control valves in applications including revamps

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Pressure swing adsorption (PSA) is a process that involves separating impurities from a feed gas mixture to produce a single product gas such as hydrogen, oxygen or nitrogen. PSA is typically used in refineries, air separation units (ASUs), ethylene plants, and ethanol production facilities. PSA equipment is often mounted on skids, allowing it to be tested off-site, and then shipped to the plant or facility for installation.

Feed gas cycles through fixed-bed adsorbers. Forward and reverse flows are used to rapidly switch gases between parallel vessels, and these flows are regulated by control valves (see **Figure 1**). Within the fixed bed adsorber, impurities are removed from the product gas at high pressure and then rejected as the system pressure 'swings' to a lower pressure. Completely adsorbing impurities allows the production of high purity (99.99%) end products.

One of the biggest challenges for control valves in PSA service is that they are expected to cycle as often as every few minutes while providing tight, bidirectional shut-off. Common failures of control valves due to these stringent requirements include:

• Stem or shaft breakage due to deficient pinning design
• Poor valve-actuator-positioner linkages, leading to accelerated component wear and mechanical failures
• Increased leakage through the valve.

In this article, we will discuss best practices for selecting PSA valves to alleviate these issues as well as some proactive maintenance practices to ensure proper operation of these critical assets.

Figure 1 PSA control valves have stringent requirements for stroking frequency and shut-off

Inside the PSA process

The PSA process is based on the principle that adsorbent beds are capable of adsorbing more impurities at a higher gas phase partial pressure than at a lower partial pressure. The impurities are adsorbed in a fixed bed adsorber at high pressure and then rejected as the system pressure swings to a lower level. Hydrogen is not adsorbed.

A PSA process (see **Figure 2**) operates at ambient temperature on a

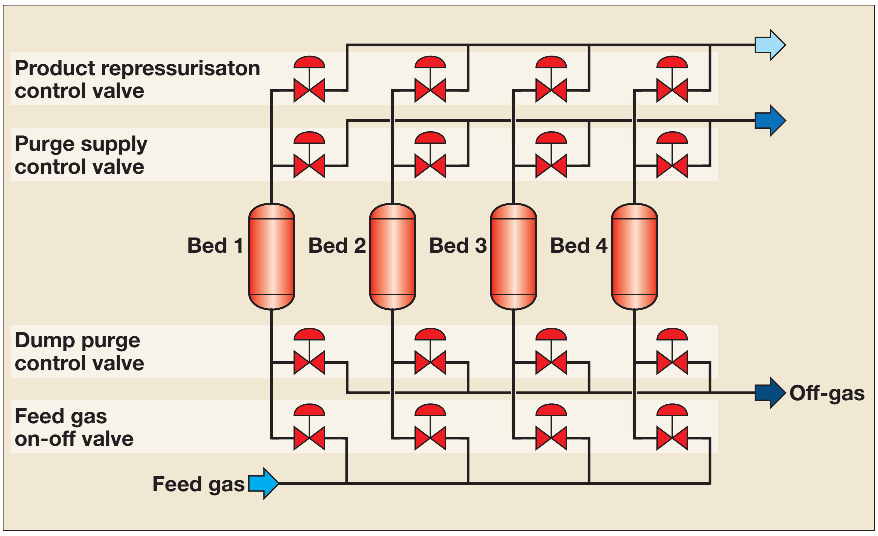

Figure 2 Control valves in a four-bed PSA process

cyclical basis. The PSA process is a semi-batch-type process that uses multiple adsorbers to provide constant feed, product and off-gas flows. The high purity hydrogen product leaves the system close to the feed gas pressure. The off-gas (impurities and hydrogen losses) is available at low pressure as fuel.

A complete pressure swing cycle consists of five basic steps:

1. Adsorption: multiple feed gases are allowed to pass co-currently through the clean adsorbent bed. Impurities are selectively adsorbed, while pure hydrogen product at high pressure exits from the adsorbent bed. The adsorber vessels are on staggered cycles, resulting in a highly flexible purification unit that is not influenced by fluctuations in the composition, temperature and pressure of the feed gas stream. Stored hydrogen can be used for pressure equalisation, repressurisation and purging of other adsorbers.
2. Co-current depressurisation: to recover hydrogen trapped in the void spaces, co-current depressurisation is used to force stored hydrogen into repressurising beds.
3. Countercurrent depressurisation: final depressurisation in the counter-current direction blows impurities into the off-gas stream.
4. Purge at low pressure: the bed is cleaned at low pressure using a hydrogen-rich stream obtained from stored hydrogen. Impurities are removed in the off-gas stream.
5. Repressurisation: after the purge step, pressure is increased back to the adsorption pressure level and the process can restart.

The PSA unit is a demanding process for control valves. The constant production and operating scheme of the PSA unit requires an extremely high number of cycles, which can lead to damaging effects on PSA process equipment. The high number of cycles can lead to production and maintenance concerns with mechanical equipment.

Control valve shut-off is a major concern because it affects PSA unit efficiency. If valve leakage causes contamination from one PSA bed to another, gas purity can be compromised and process inefficiencies will be realised.

Improper selection, installation and maintenance of control valves can be the limiting factor in achieving the PSA process purity and longevity required by process plants today.

PSA valve problems

Emerson performed a detailed analysis of control valves at a large refinery in Oklahoma. The results demonstrated a clear indication of the PSA valve dilemma faced at many process plants today.

The original control valve manufacturer at the refinery recommended routine maintenance on PSA control valves every 100 000 cycles. Due to the high cycle requirements for these valves, this equates to approximately 13 months of operation time between maintenance activities. A change-out of all soft parts, including O-rings in the piston actuator and PTFE disk in the seat ring, was also recommended. The cost to replace soft parts on the refinery's 30 PSA valves was $100 000, labour costs included. Thus, the cost to rebuild each OEM valve every 100 000 cycles was $3333 annually.

Additionally, the main throttling valve was repaired four to five times in the first year of service. The O-ring in its piston and sliding block assembly continued to fail even with routine maintenance. The valve operated every two minutes and cycled on all six beds. This unit was shut down for maintenance five times in two years.

Stem rotation issues were experienced using valves with piston actuators. The root cause of this issue was determined to be the positioner linkage mechanism. Stem rotation increased wear on the valve stem linkage and disconnected the linkage from the positioner, causing valve control issues to occur. Stem rotation also caused the actuator tension bolt to back out or loosen. Because the spring load was not held constant, seat leakage increased and the control valve stroking speeds deviated from acceptable limits. Mechanical problems associated with the piston actuator directly impacted PSA unit timing and process purity.

At this refinery, the most common valve related failure was the actuator. The O-rings in the piston rolled, thus accelerating wear and reducing thrust output to the valve. This directly impacted seat leakage and stroking speeds, adversely affecting unit purity and efficiency. Ultimately, the valves failed to operate properly and the PSA unit had to be brought down to conduct reactive maintenance.

Mechanical breakdown in the actuator can also lead to control valve failure. Internal analysis on the OEM piston actuator determined that high cycling caused fatigue failure.

Further analysis noted a rotary valve failed after only 15 months of high cycle service. The site of failure was the weld on the pins for the shaft/disk connection. As a temporary fix, the pins were welded to maintain shaft/disk connection. Welding these pins is not maintenance friendly.

In this large refinery, as each bed went down due to a valve failure, the entire PSA unit was forced to shut down. The unit had to be modified to operate on five beds instead of six in preparation for valve failures. This reduction in hydrogen throughput led to cutbacks in refinery production to keep available hydrogen in balance. Mechanical failures led to reduced efficiency and had a direct impact on profitability within the refinery. For that reason, control valve reliability became a focal point in reducing PSA unit downtime.

Cutting maintenance costs

Poor reliability and the resulting high cost of maintenance and reduced profitability led the refinery to seek a better solution. An analysis indicated that a control valve capable of 500 000 cycles in PSA service without significant maintenance would have payback of 3.2 years, an acceptable number for this particular refinery. Emerson analysed the application and recommended Fisher GX globe valves for throttling, and Fisher high performance butterfly valves for isolation on the PSA units (see **Figure 3**).

Actuators were a spring and diaphragm design instead of piston actuators used on the OEM valves.

The new valves also used a positioner with performance diagnostics. The globe valve was specified with an ion-nitrated plug/stem.

Refinery engineers decided to install five valves on one skid for testing. The valves were cycled under normal process conditions. During a 24-month test and 200 000 cycles of service, there were no critical maintenance issues and no observable leakage. Based on this experience, all 30 existing valves on the PSA units were replaced with Fisher valves and actuators.

Figure 3 To cure PSA problems at an Oklahoma refinery, Fisher GX globe valves and high performance butterfly valves were installed

Underperforming PSA valves cost another refinery millions of dollars in inefficient operations, as detailed in the next example.

Revamping a refinery

At a refinery in Texas, the PSA skid (see **Figure 4**) was recovering only about 65-70% hydrogen. Plant maintenance personnel worked with Emerson to identify application requirements for the PSA skid. They used diagnostics to analyse the performance of the PSA skid's valves and justify the unit's revamp.

Initially, more than two dozen PSA valves, especially those with coupling wear issues, were repaired. Others were replaced with new Fisher rotary valves specified for high cycle operation, including chromium carbide-coated shafts, Peek bearings and/or durable soft seals. The assemblies included rack and pinion actuators and digital valve controllers.

The smart digital positioners with advanced diagnostic capabilities, in conjunction with software, improved valve monitoring, reduced operating costs and enabled predictive maintenance.

After the installation of 40 new valves in the PSA skid, the PSA unit was recovering hydrogen at an increased rate of 80-84%. In addition, the tail gas compressor was operating with 26% hydrogen compared to the 45% or 50% required before the valve revamp. Increased density of the process flow also improved compressor performance.

Figure 4 This PSA skid was producing only 65-70% hydrogen. Replacing the valves improved production by 20%

On average, there is typically 25 MMSCFD of hydrogen in the feed to the PSA. The 20% improvement in H_2 recovery equated to an additional 3.75 MMSCFD. With a cost of $1500/MMSCFD, this valve project saved about $5600/day, or over $2 million/y.

Selecting control valves

Two types of control valves are suitable for PSA applications: globe and rotary (butterfly) valves. Each should have features specifically designed for stringent leakage requirements and rapid cycling.

Globe valves meet tight shut-off requirements with the use of durable soft seats that enable long-lasting Class VI shut-off per ANSI/FCI 70-2. To further ensure tight shut-off, contours of the unbalanced plug design should only contact the PTFE soft seat when shut-off is required. The seat ring centres the plug as it enters the seat, so the valve establishes a concentric seal. This also helps ensure prolonged valve trim over the life of the valve.

Three important features allow globe control valves to be cycled over a million times and achieve tight shut-off, making them ideal for high cycle applications:

- Reliable actuator performance: special diaphragm materials help reduce common problems such as air oxidation, thermal aging, low temperature embrittlement and loss of retention. Unlike a piston actuator, a spring and diaphragm actuator does not have a large diameter sliding seal that is subject to wear. The double-sided diaphragm within the actuator helps reduce mechanical wear-induced failure.
- Fast stroking speed: the actuator must be able to handle high cycle counts at specific stroke speeds while maintaining tight process control.
- Precise valve positioning: linkageless, non-contact digital valve controllers can achieve precise positioning accuracy and fast response to process changes while increasing reliability of the valve assembly.

Rotary control valves (see **Figure 5**) meet critical shut-off requirements via the use of seal rings with a pressure-assisted sealing action, and with spring-loaded shafts that centre the disk in the seal.

Rotary control valve assemblies can also achieve a million cycles under load conditions with a spring and diaphragm actuator similar to that of the sliding stem spring and diaphragm design. The benefits of these actuator designs include: no O-rings to wear, a defined position on air failure, low actuator pressures for operation, and double-sided diaphragms.

Although both rotary and globe valves can be used for the various PSA applications, globe valves are better suited for installations that require operation at intermediate travels. Globe valves offer improved rangeability when compared to rotary valves, improving stability and allowing users to more closely track controller set-point.

Figure 5 Fisher rotary valve suitable for PSA processes

A critical feature often overlooked when selecting the appropriate valves for PSA service is the diagnostic capability of the positioner. The ideal positioner is one capable of online, in-service, non-intrusive performance testing, real time monitoring, and data capture. This ensures earlier detection of valve degradation and gives technicians the troubleshooting tools necessary to make informed maintenance decisions.

Conclusion

Control valves are critical to the operation and efficiency of a PSA system. The wrong valves can cause expensive maintenance problems, and underperforming valves can adversely affect process efficiency, costing a refinery millions of dollars annually. Selecting the proper control valve for a PSA application should be done in conjunction with the valve manufacturer to ensure the best valves are selected for this difficult application.

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