

Stability and control: Pressure regulation for hydrogen systems



Nico Dissel & Aidan Lourier

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Introduction Swagelok



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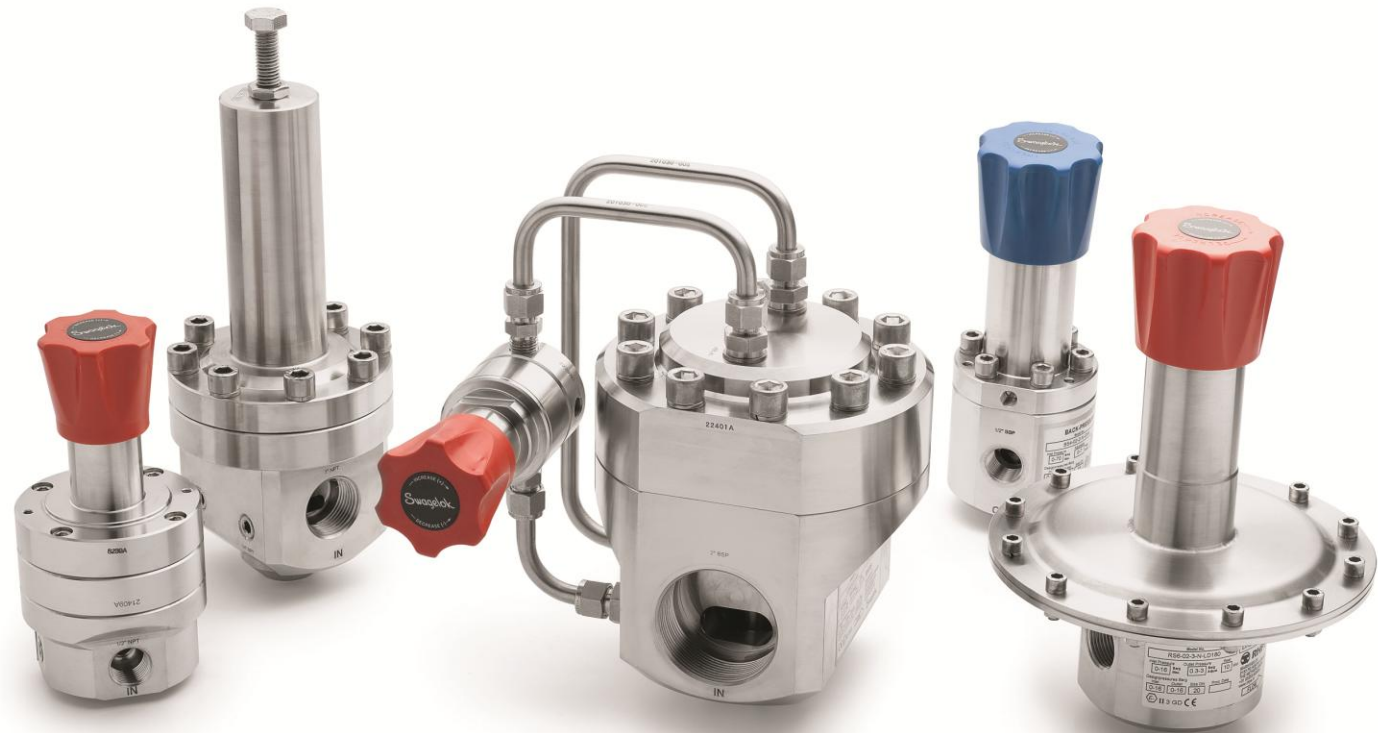
Why this TechTalk?

Swagelok



Agenda

- Type of regulators (reducing & back pressure)
- Regulator main components (loading, sensing and control element)
- Droop curve
- How to flatten the droop curve
- High pressure regulator
- Electronic pressure control
- Hydrogen embrittlement
- Chrome & Nickel content



Swagelok Pressure Regulators – By Types

- **Pressure-Reducing**
 - Spring-Loaded
 - Dome-Loaded
- **Back Pressure Regulators**
 - Spring-Loaded
 - Dome-Loaded
- **Specialty**
 - Vaporizing regulators
 - Automatic switching regulators
 - Tank-blanketing regulators



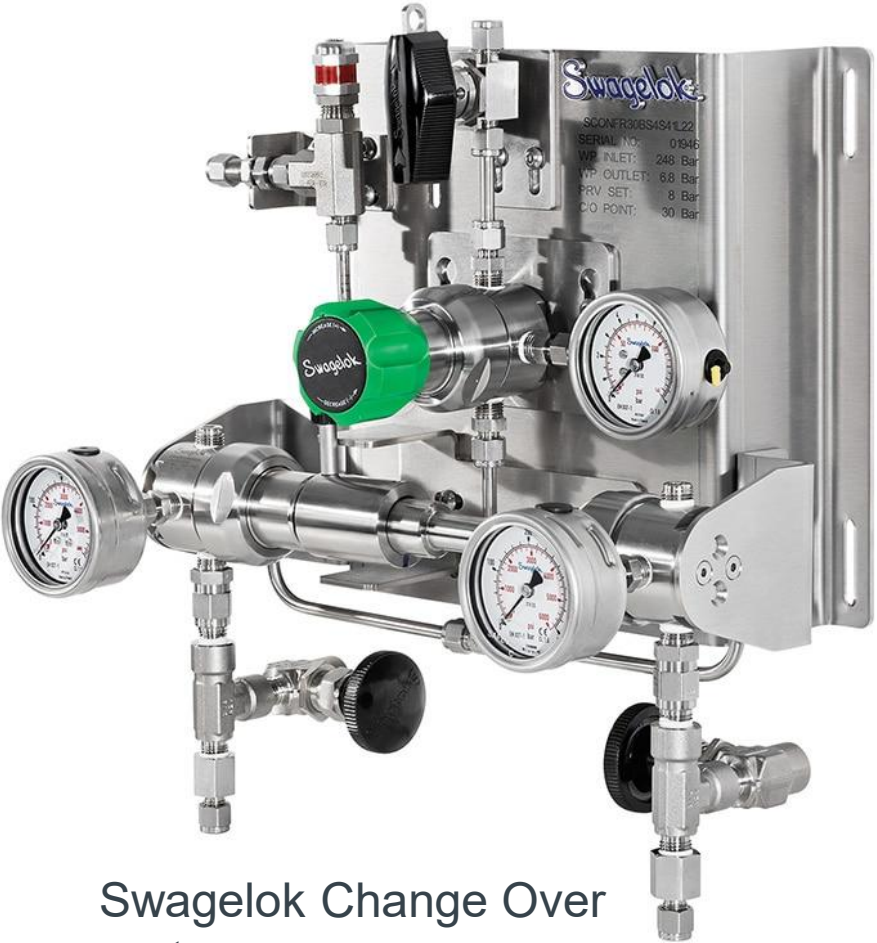
Swagelok Pressure Regulators – By Types



K Series Regulator
(1/4 inch – 1/2 inch)



Swagelok
Liquid
Sampling
system



Swagelok Change Over
system

Swagelok Pressure Regulators – By Types

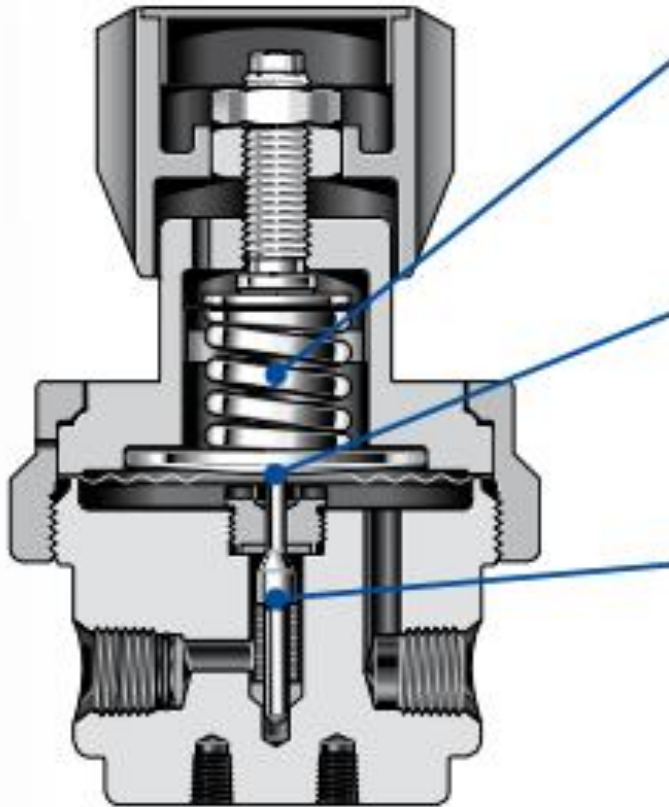


Process Regulators
(1/4 inch – 4 inch)



How Pressure Regulators Work

Understanding a regulator's functionality begins with familiarity of its component parts:

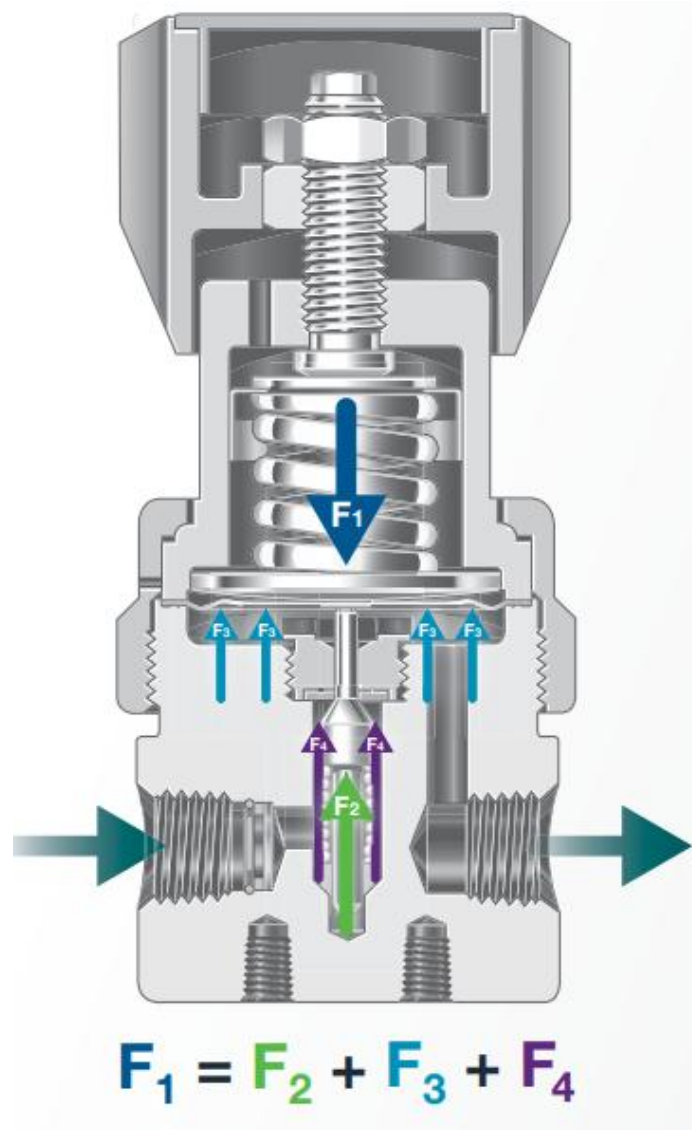


A loading element. Regulators may be spring-loaded or dome-loaded. The loading element applies a downward, balancing force on top of the diaphragm.

A sensing element, typically a diaphragm or piston. The sensing element allows the poppet to rise and fall in the seat, controlling inlet or outlet pressure.

A control element, including a seat and poppet. The seat contains pressure and prevents fluid from leaking to the opposite side of the regulator when flow is closed. Together with the seat, the poppet regulates pressure by maintaining a fine gap between the two while a system is flowing

How Pressure Regulators Work



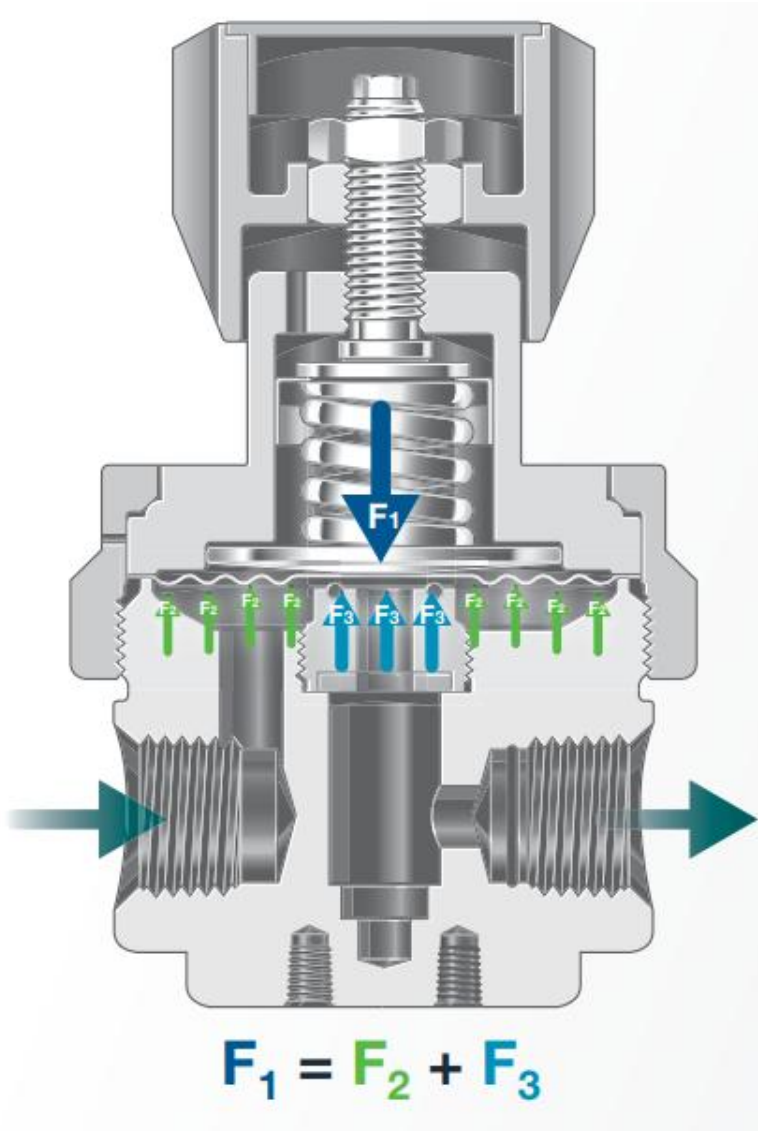
Pressure-Reducing Regulators

A pressure-reducing regulator decreases pressure and keeps it as constant as possible as inlet pressure and flow rate vary. Four different forces must be balanced.

These include loading force (**F1**), inlet spring force (**F2**), outlet pressure force (**F3**), and inlet pressure force (**F4**).

Total loading force must be equal to the combination of inlet spring force, outlet pressure force, and inlet pressure force

How Pressure Regulators Work



Back-Pressure Regulators

A back-pressure regulator keeps inlet pressure below a set pressure. It can either open when exposed to excess pressure or close when pressure drops below a desired level.

These regulators must balance spring force (**F1**), inlet pressure force (**F2**), and outlet pressure force (**F3**), as shown.

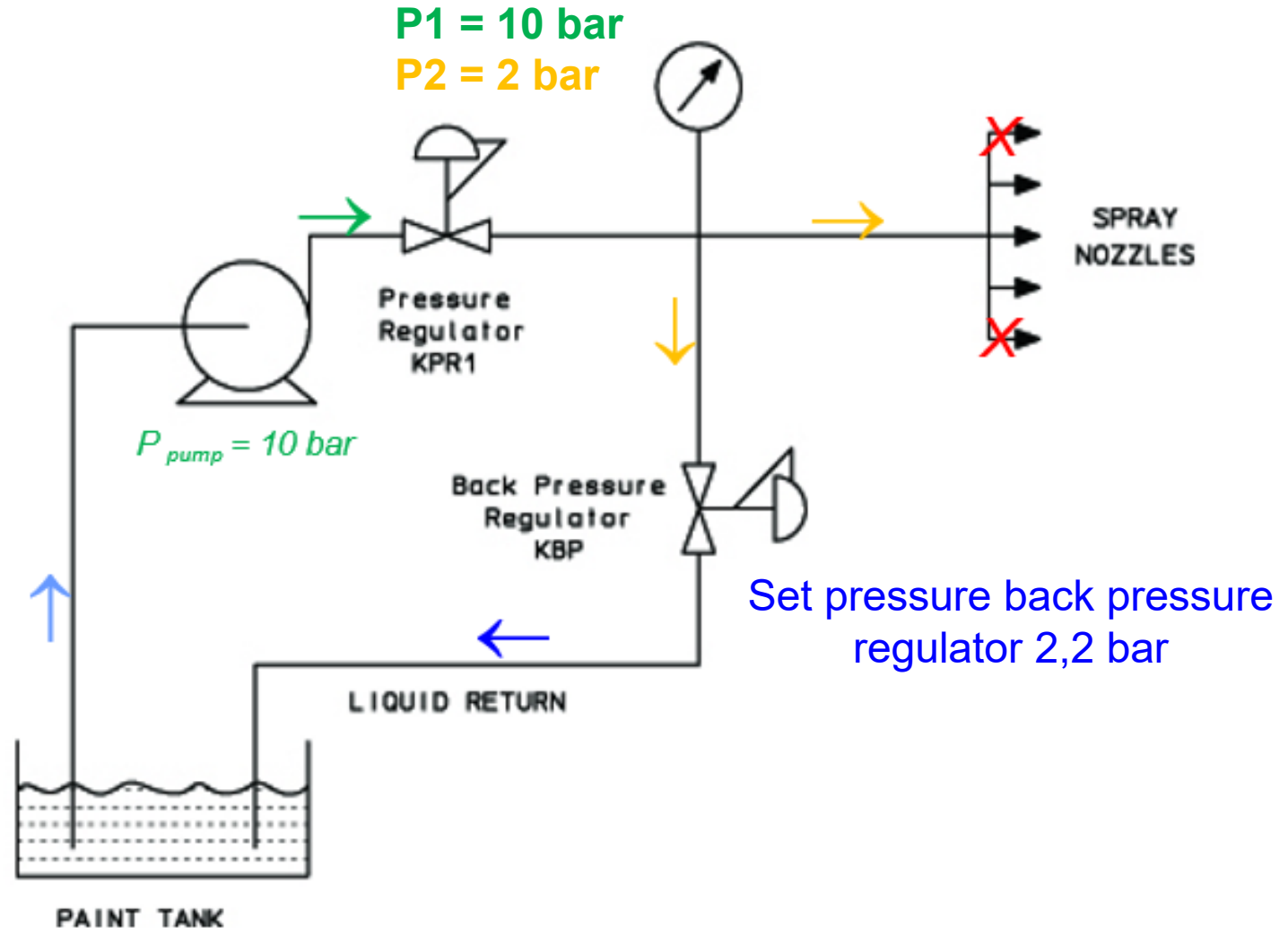
Here, the spring force must equal the combined force of the inlet pressure force and the outlet pressure force.

How Pressure Regulators Work

Spray nozzles are open allowing paint to flow to the application.

Spray nozzles close building pressure in line.

KBP relieves pressure (paint) back to paint tank



How to Choose a Regulator

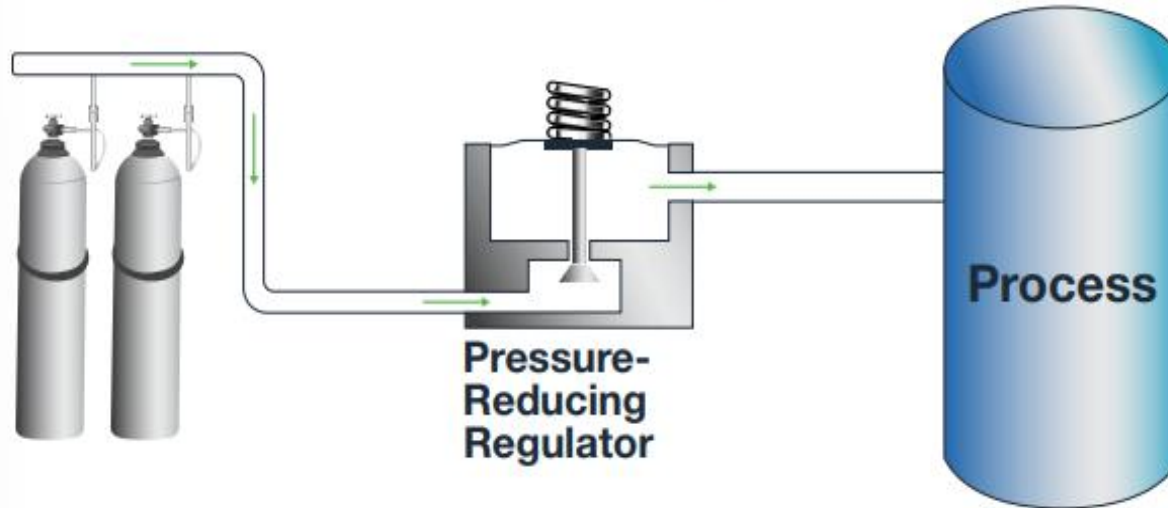
How to Choose a Regulator

- Assess Your Process Condition
- Determine What You Need to Control
- Get to Know Regulator Behaviors
- Identify the Appropriate Loading Element
- Follow Best Practices



How to Choose a Regulator

Whether you need a pressure-reducing or back-pressure regulator depends on your process requirements:

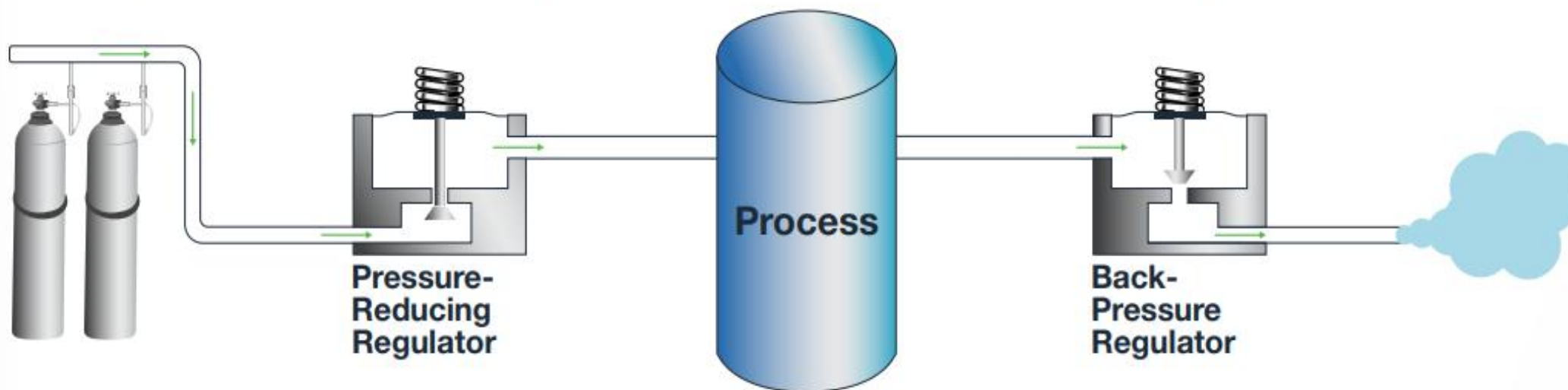


If you need to reduce pressure from a high-pressure source before system media reaches the main process, a **pressure-reducing regulator** will be the correct choice.

Used in the right context, these regulators can help you maintain desired pressures throughout your system.

How to Choose a Regulator

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If you need to reduce pressure from a high-pressure source before system media reaches the main process, a **pressure-reducing regulator** will be the correct choice.

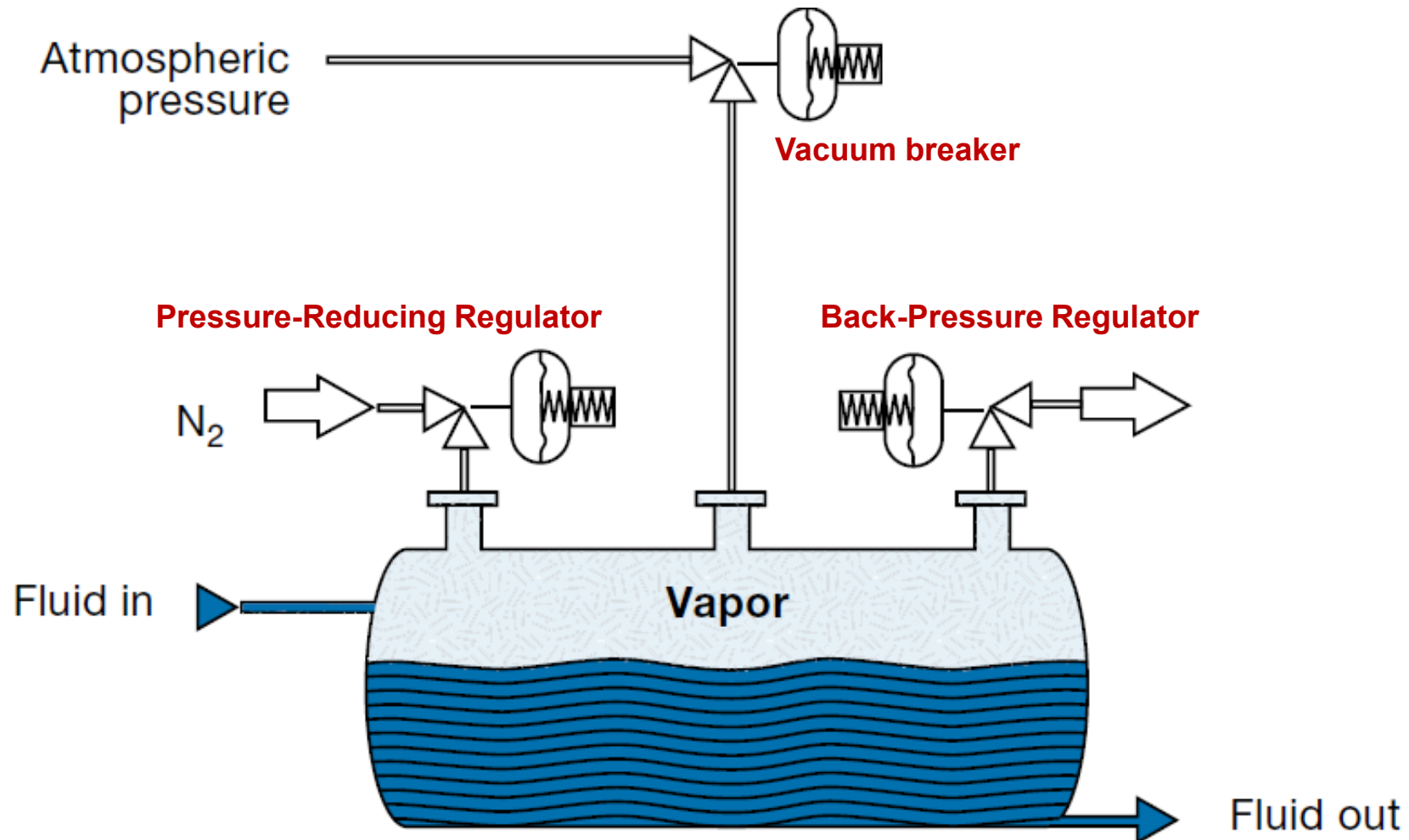


If you need to control and maintain upstream pressure and prevent unwanted pressure increases, a **back-pressure regulator** is typically the right choice.

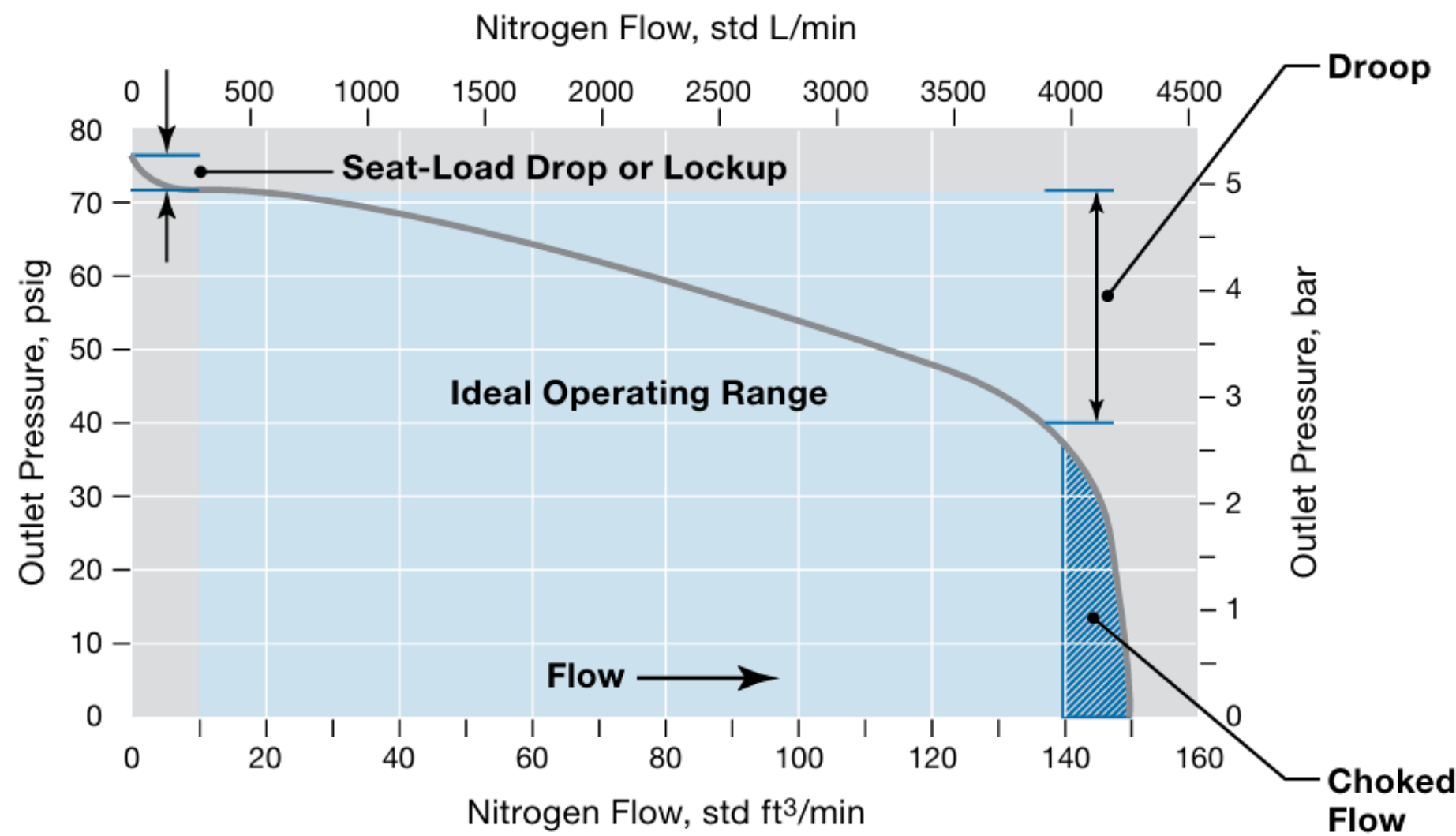
Used in the right context, these regulators can help you maintain desired pressures throughout your system.

How to Choose a Regulator

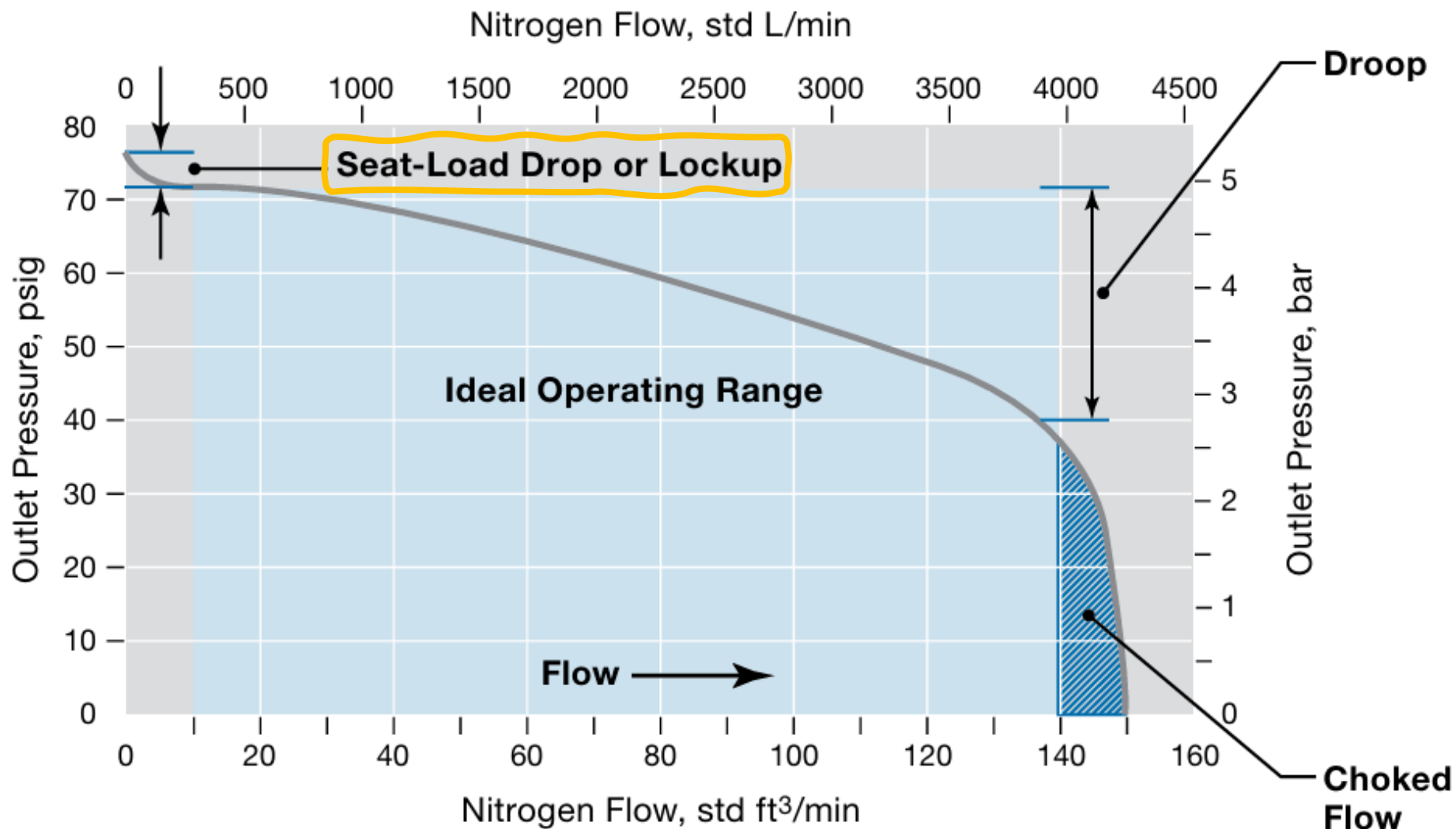
Pressure-Reducing Regulators versus Back-Pressure Regulators



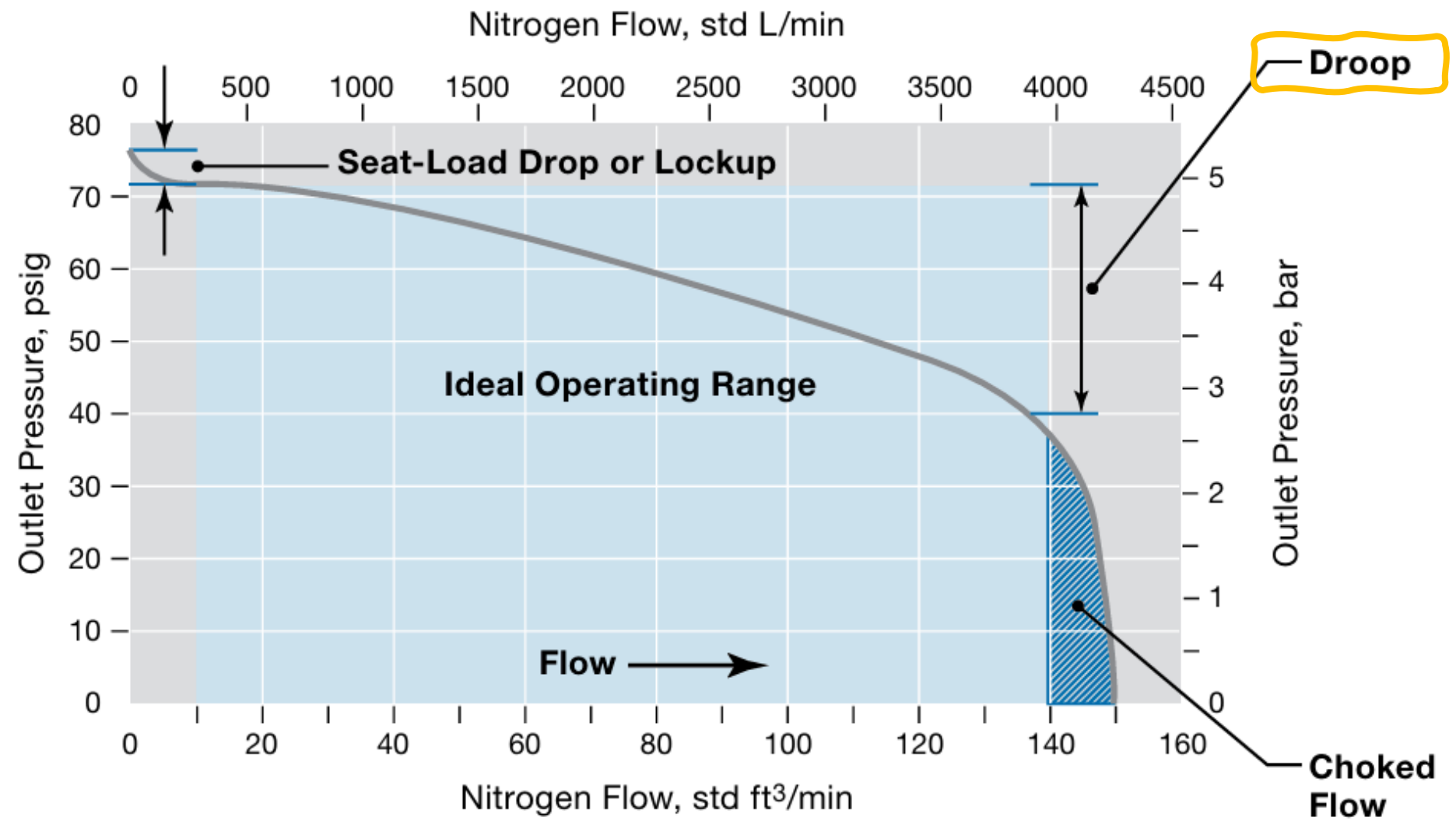
Pressure Regulator Droop Curve



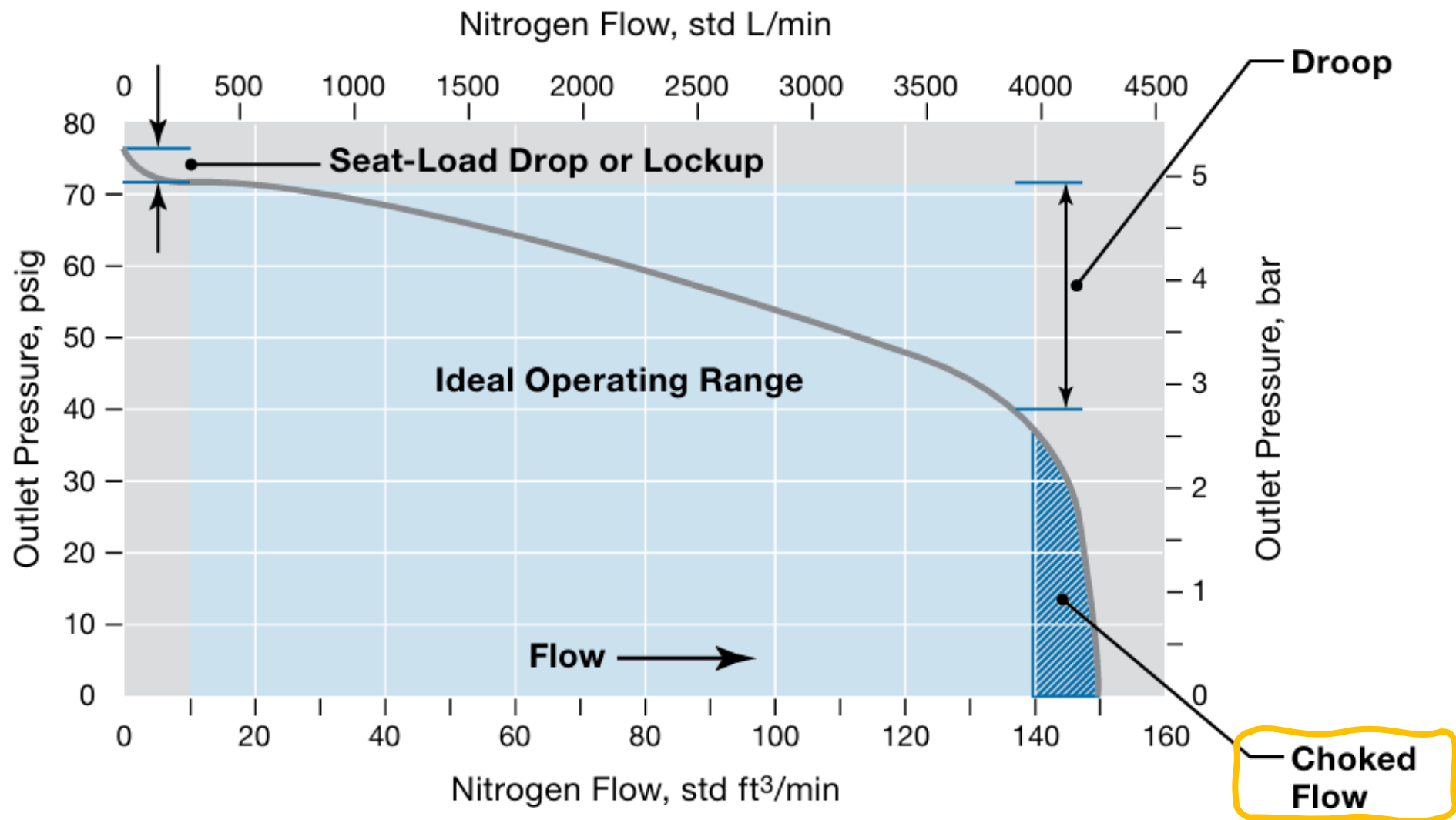
Pressure Regulator Droop Curve



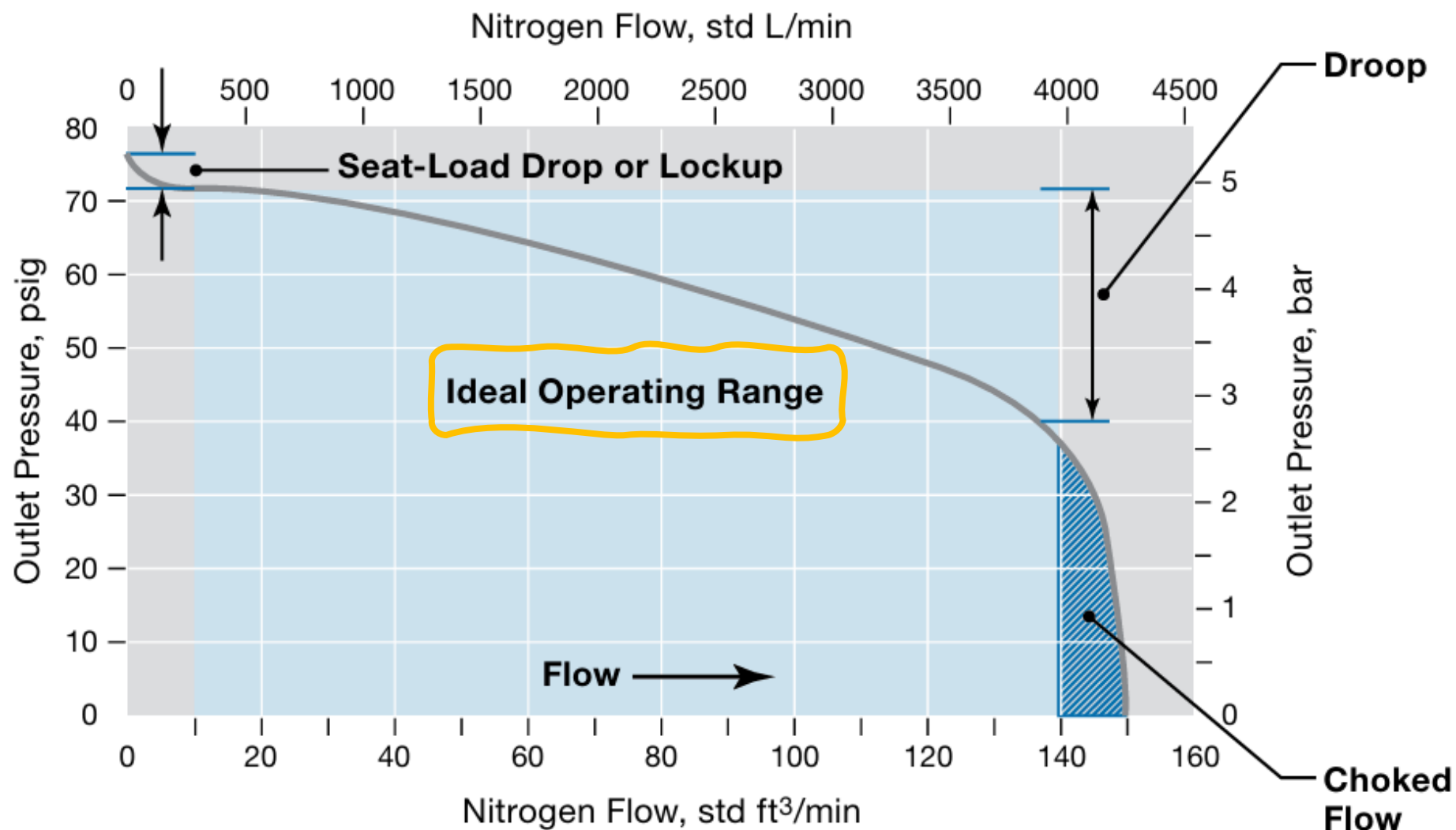
Pressure Regulator Droop Curve



Pressure Regulator Droop Curve

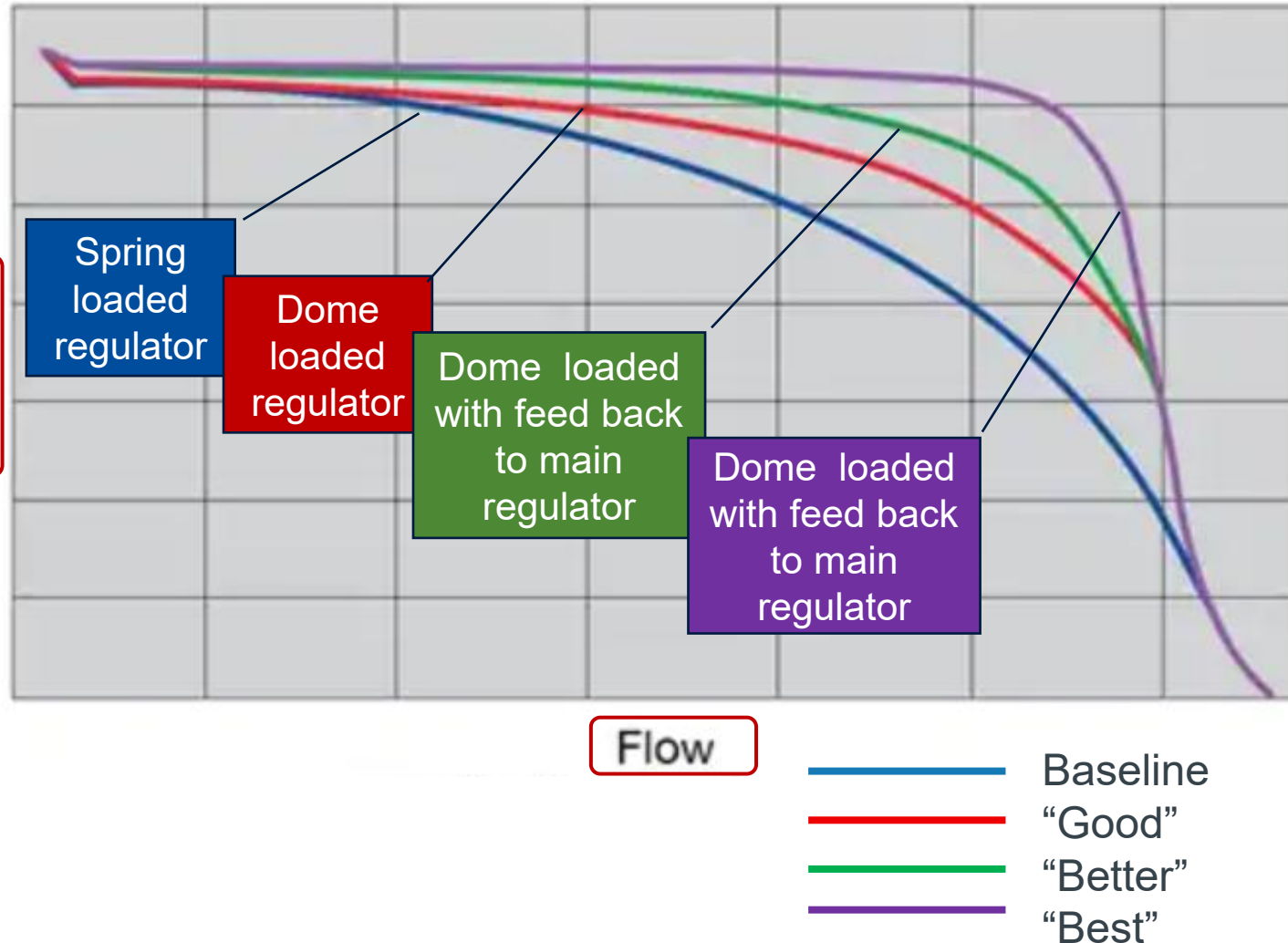


Pressure Regulator Droop Curve



How to flatten the Pressure Regulator Droop Curve

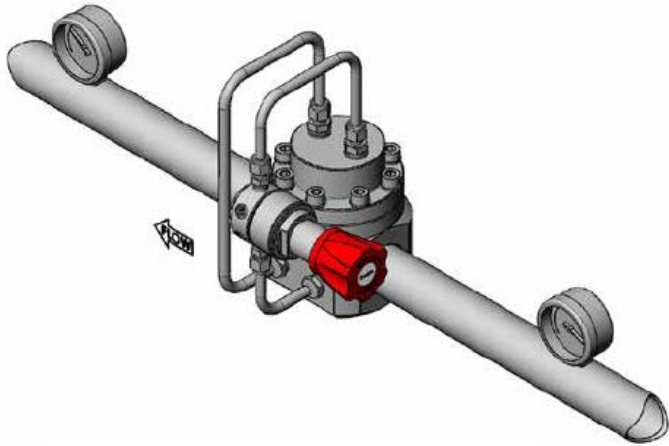
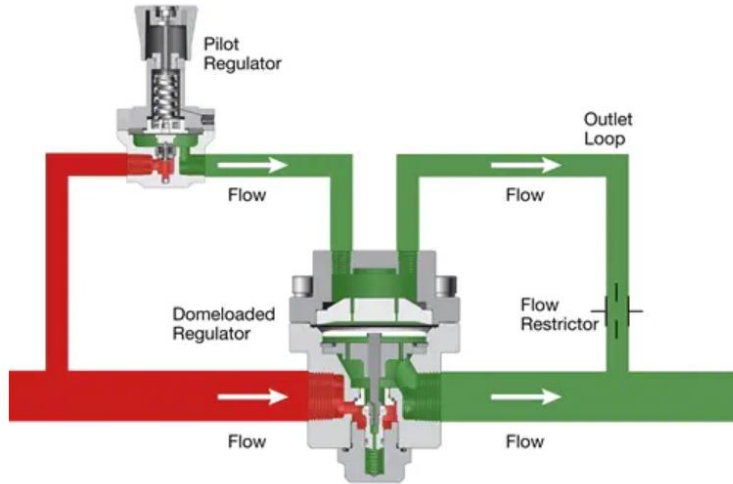
How to Flatten a Regulator Flow Curve to Reduce Droop



Consistent pressure control is essential to the safe operation of industrial fluid systems. Maintaining a reliable downstream pressure with a regulator can help minimize flow rate changes, especially in a high-flow system. However, in order to sustain pressure control and minimize droop, external components may be necessary additions to your fluid system.

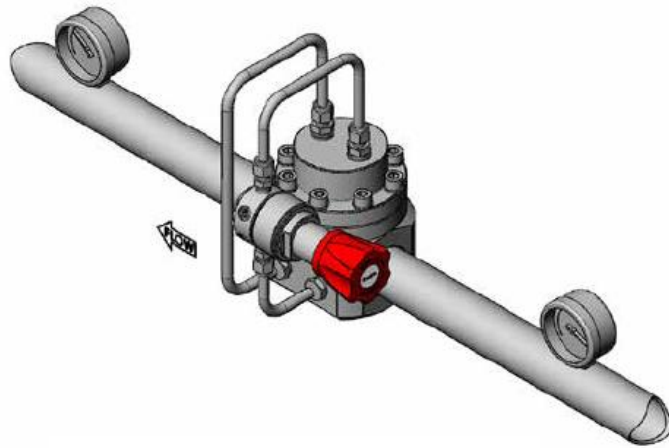
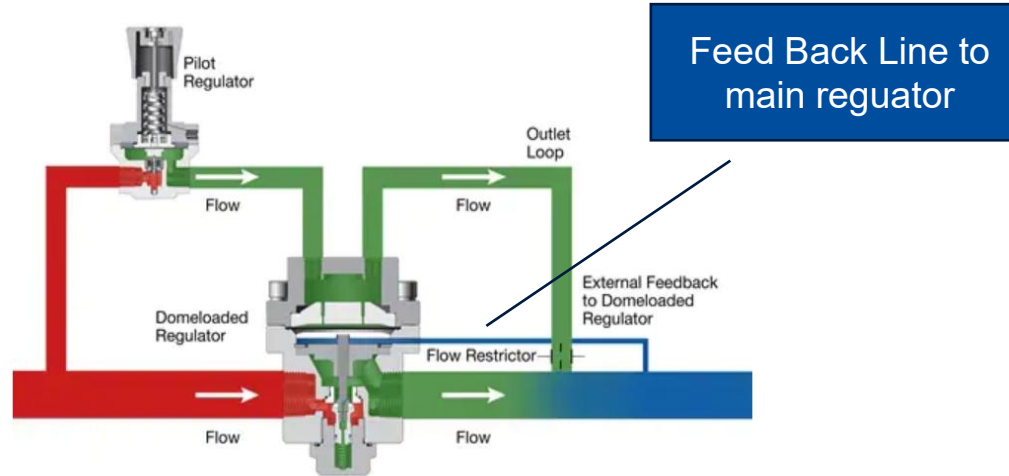
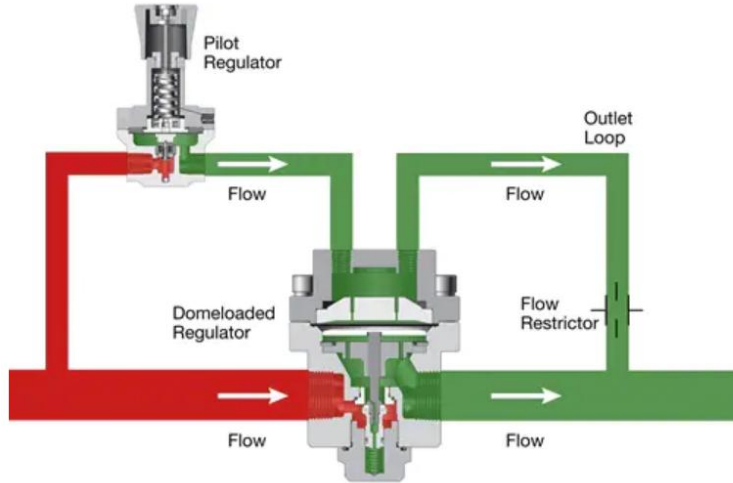
Droop is defined as a decrease in outlet pressure as downstream flow increases.

How to flatten the Pressure Regulator Droop Curve

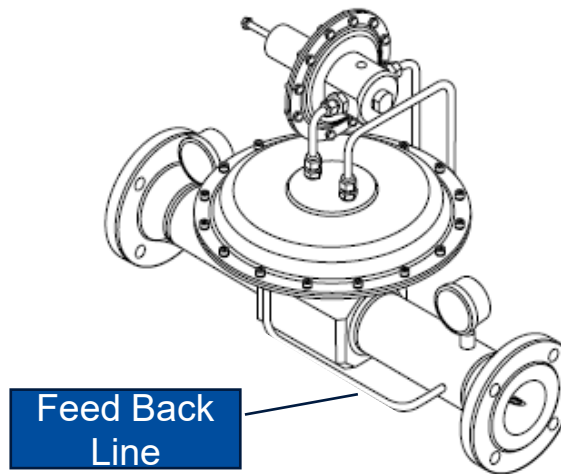


Dome Loaded Regulator

How to flatten the Pressure Regulator Droop Curve



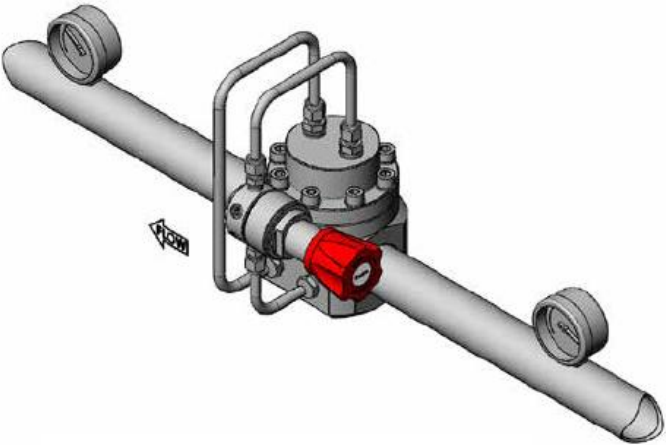
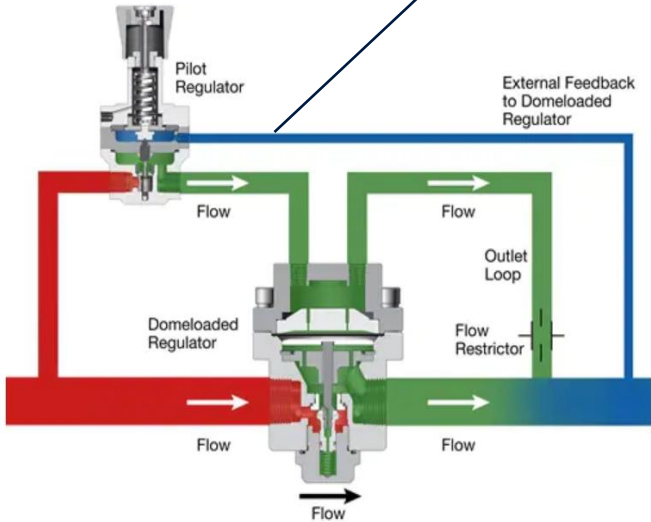
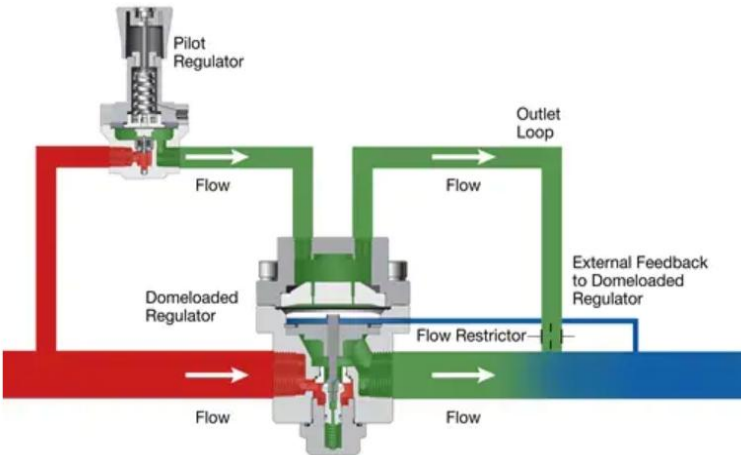
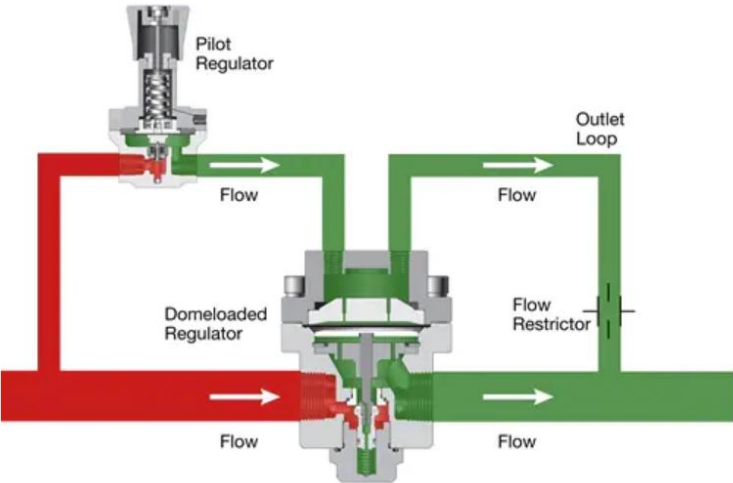
Dome Loaded Regulator



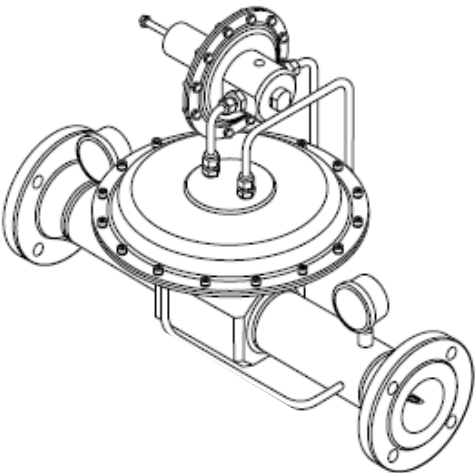
Dome Loaded Regulator with External
Feed back to main Regulator

How to flatten the Pressure Regulator Droop Curve

Feed Back Line to pilot regulator

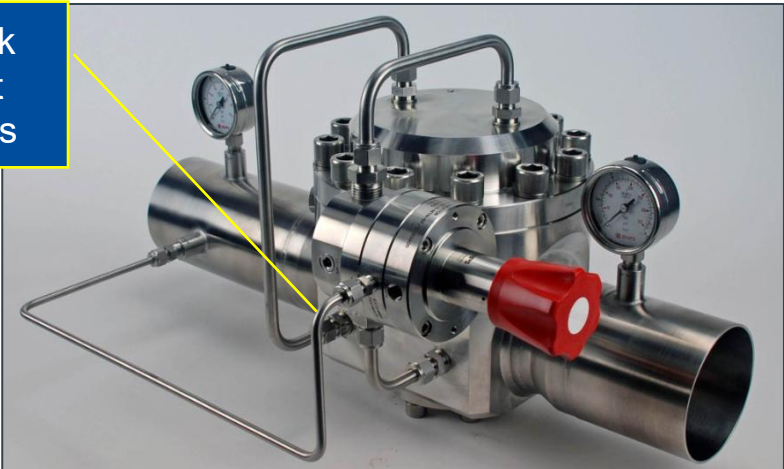


Dome Loaded Regulator



Dome Loaded Regulator with External Feed back to Dome Regulator

Feed Back Line Pilot Regulators



Dome Loaded Regulator with External Feed back to Pilot Regulator

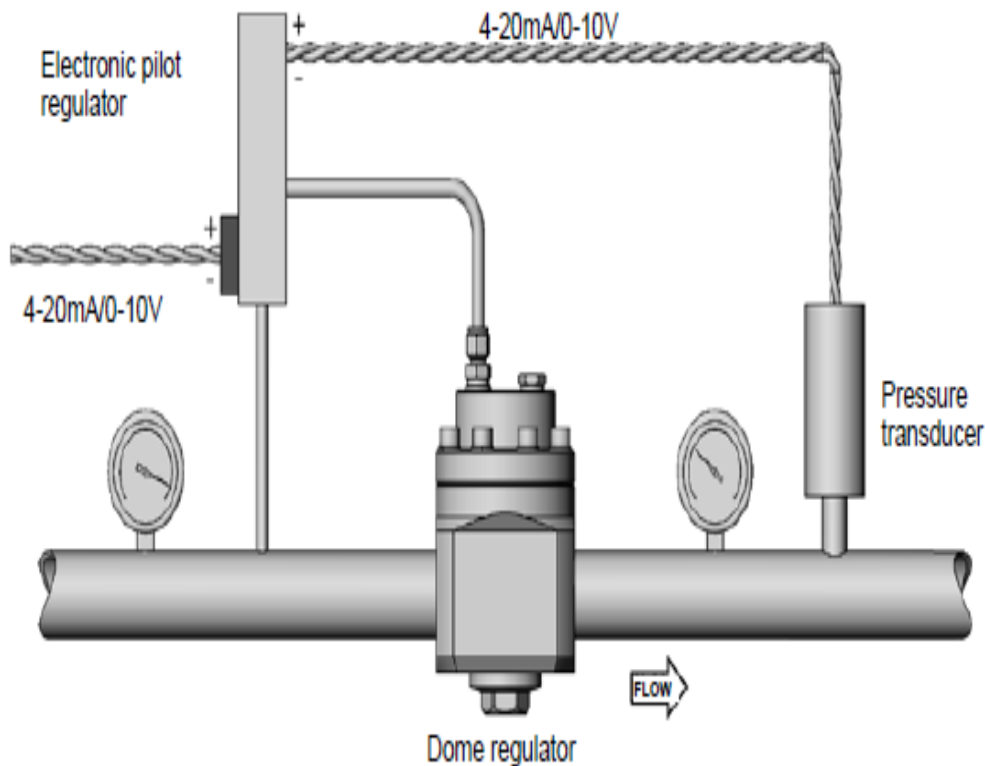
How to flatten the Pressure Regulator Droop Curve

Electronic Pressure Control

When maintaining pressure where flow change is critical, more sophisticated setups incorporating feedback loops, pilot regulators, and other methods can help.

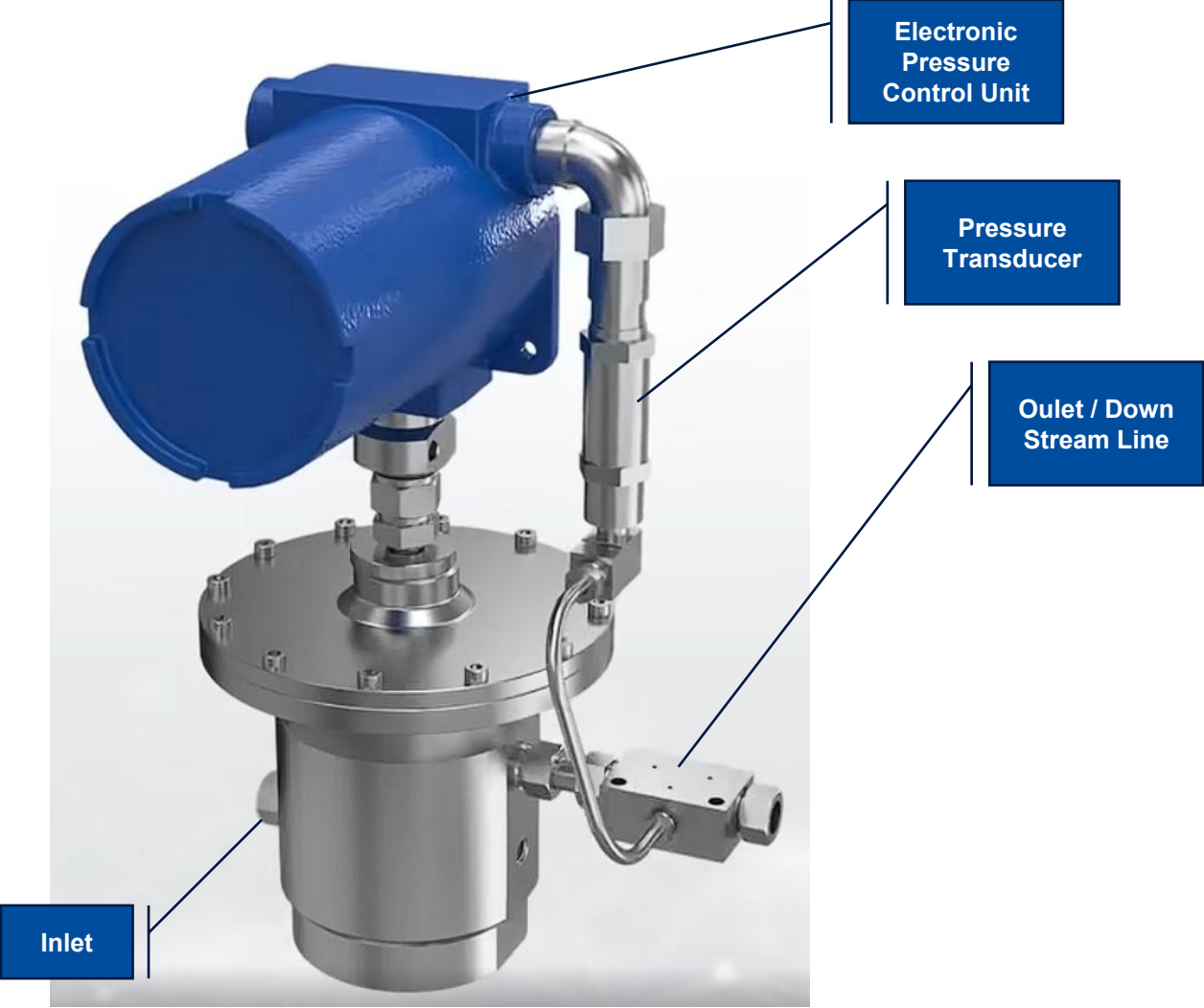
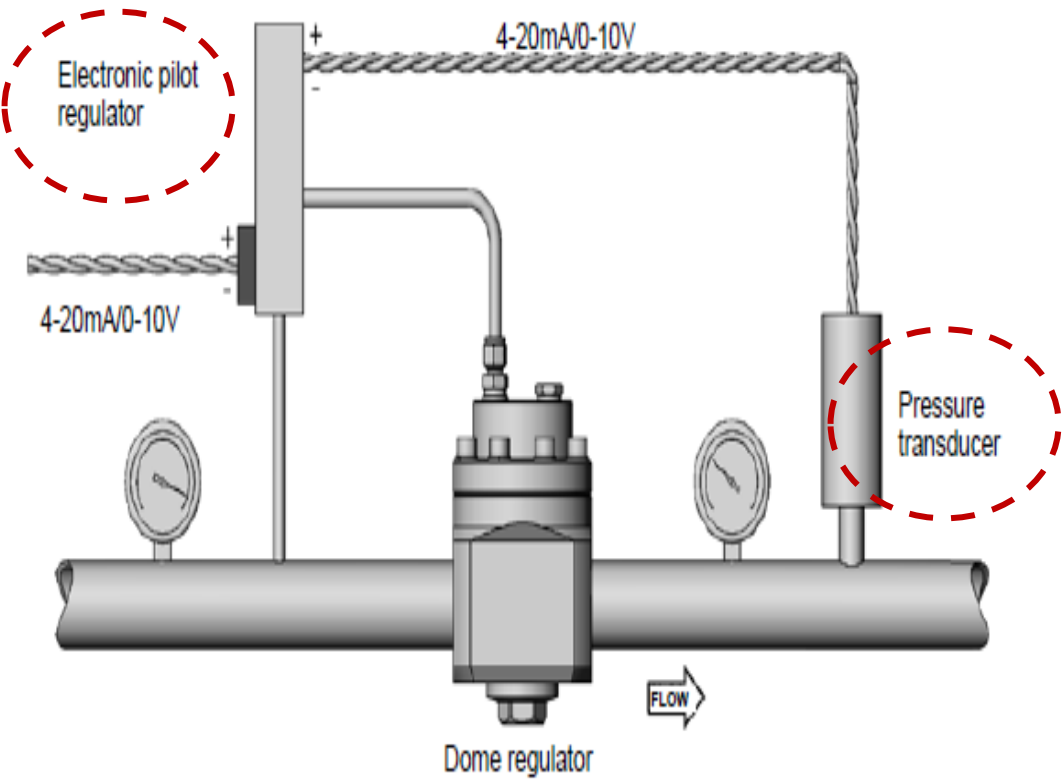
Electronic Pressure Controller is designed to regulate the pressure of a gas in proportion to the command signal by monitoring pressure from its installed pressure transducer. These are typically installed in conjunction with a ratio regulator to extend its functional pressure control range.

Electronic Control Schematic

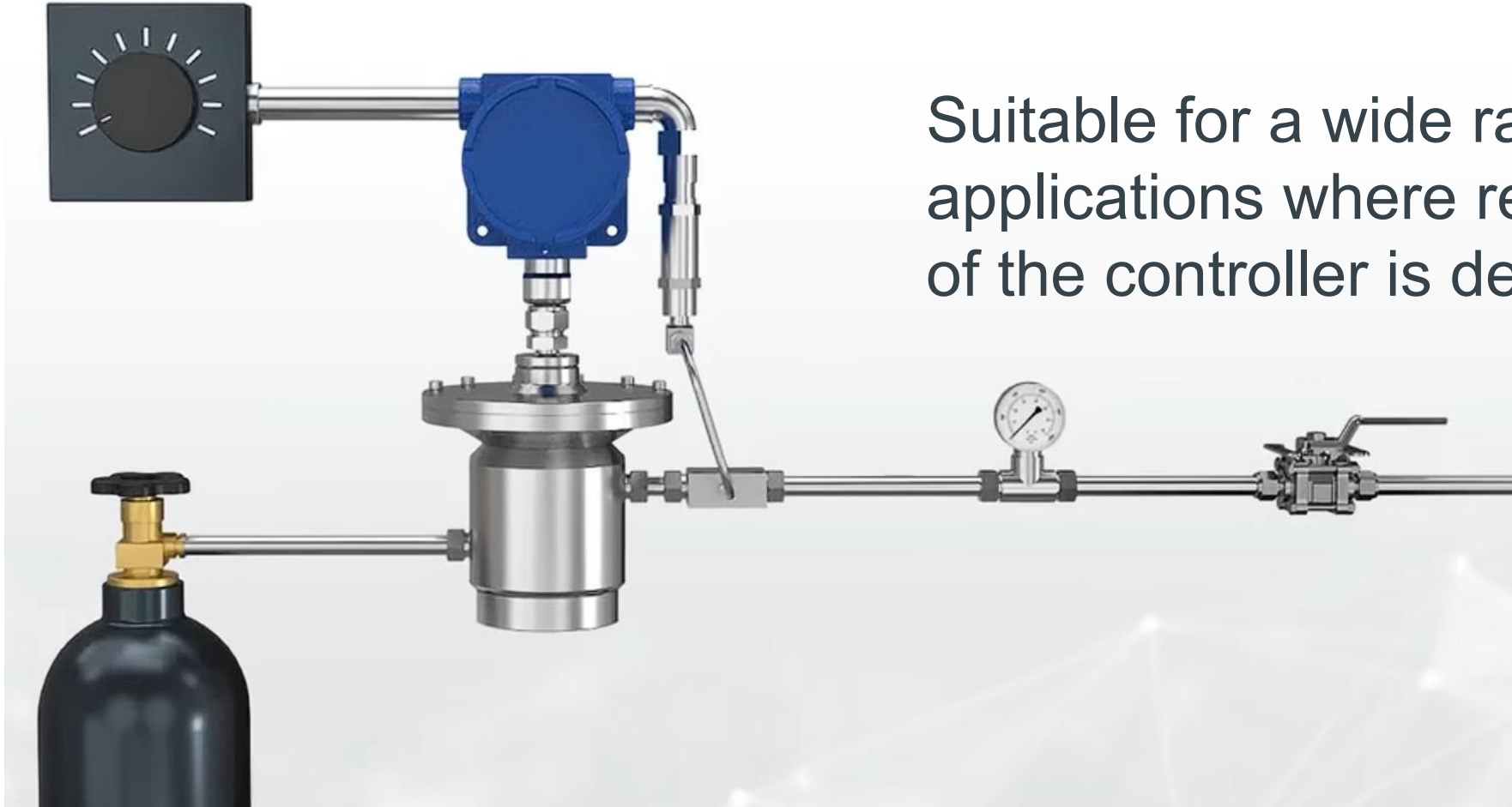


Electronic Pressure Control

Electronic Control Schematic

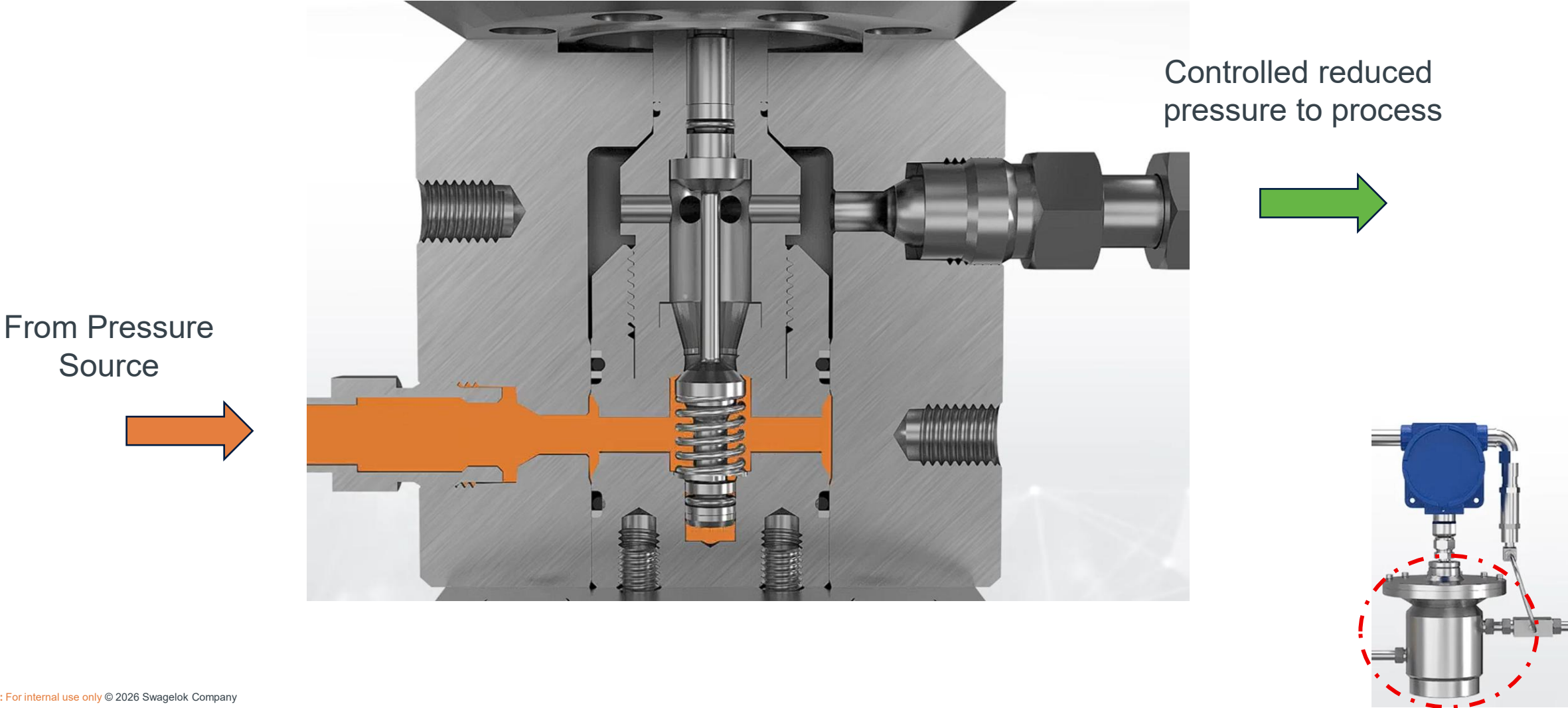


Electronic Pressure Control

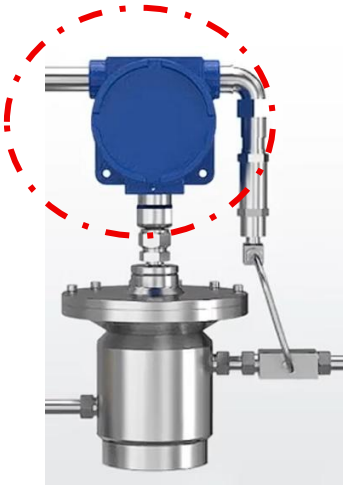
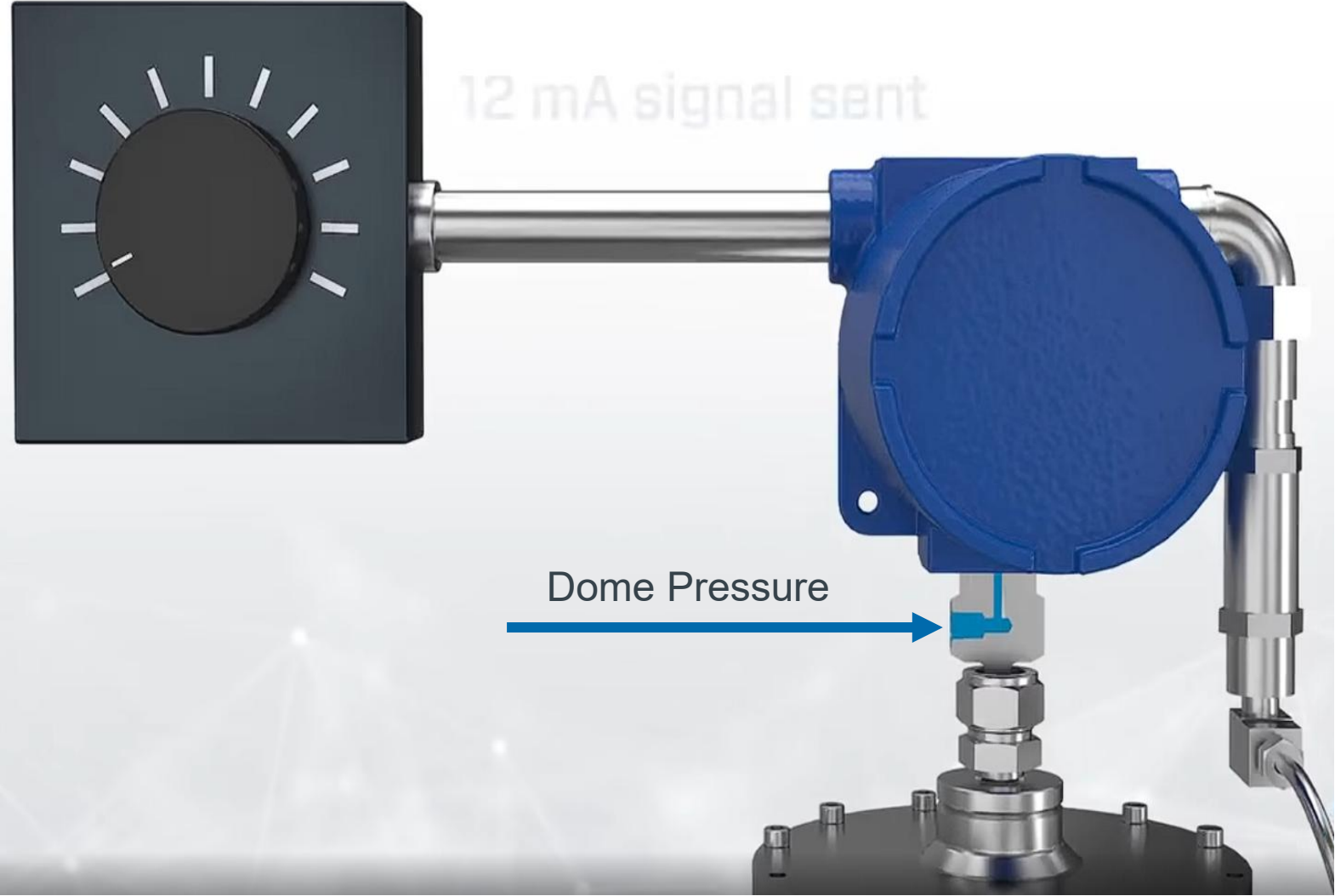


Suitable for a wide range of industrial applications where remote operation of the controller is desired.

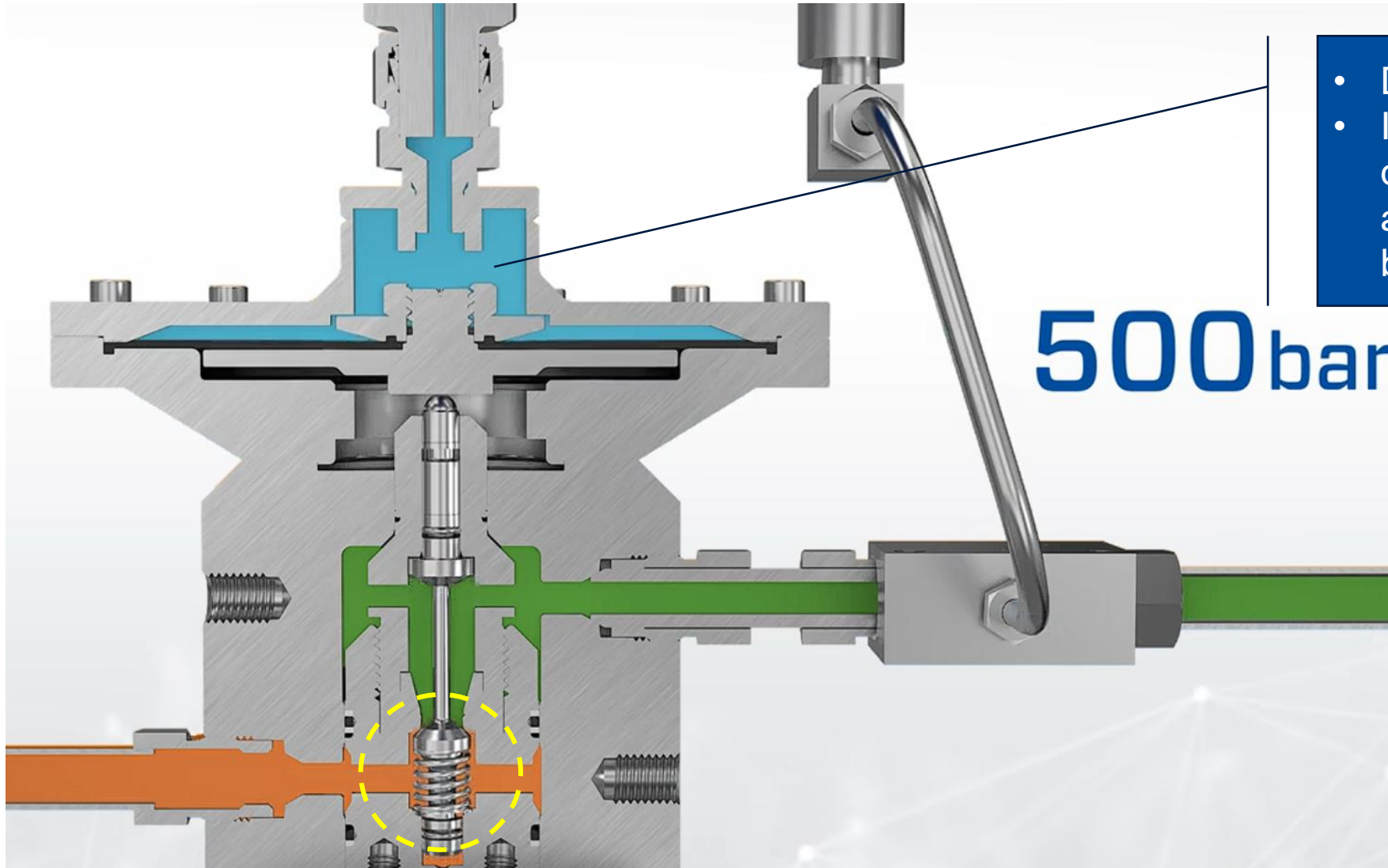
Electronic Pressure Control



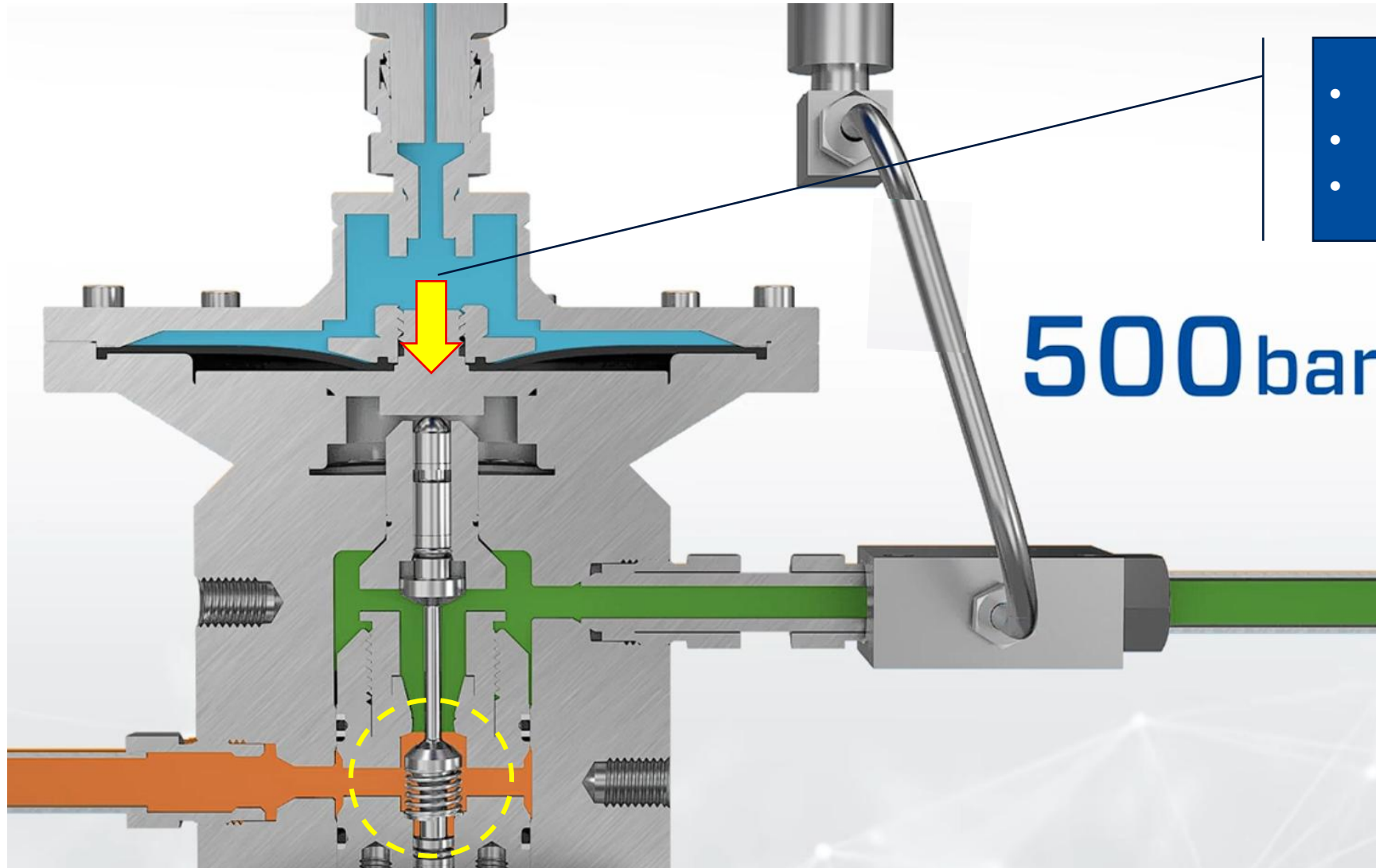
Electronic Pressure Control



Electronic Pressure Control



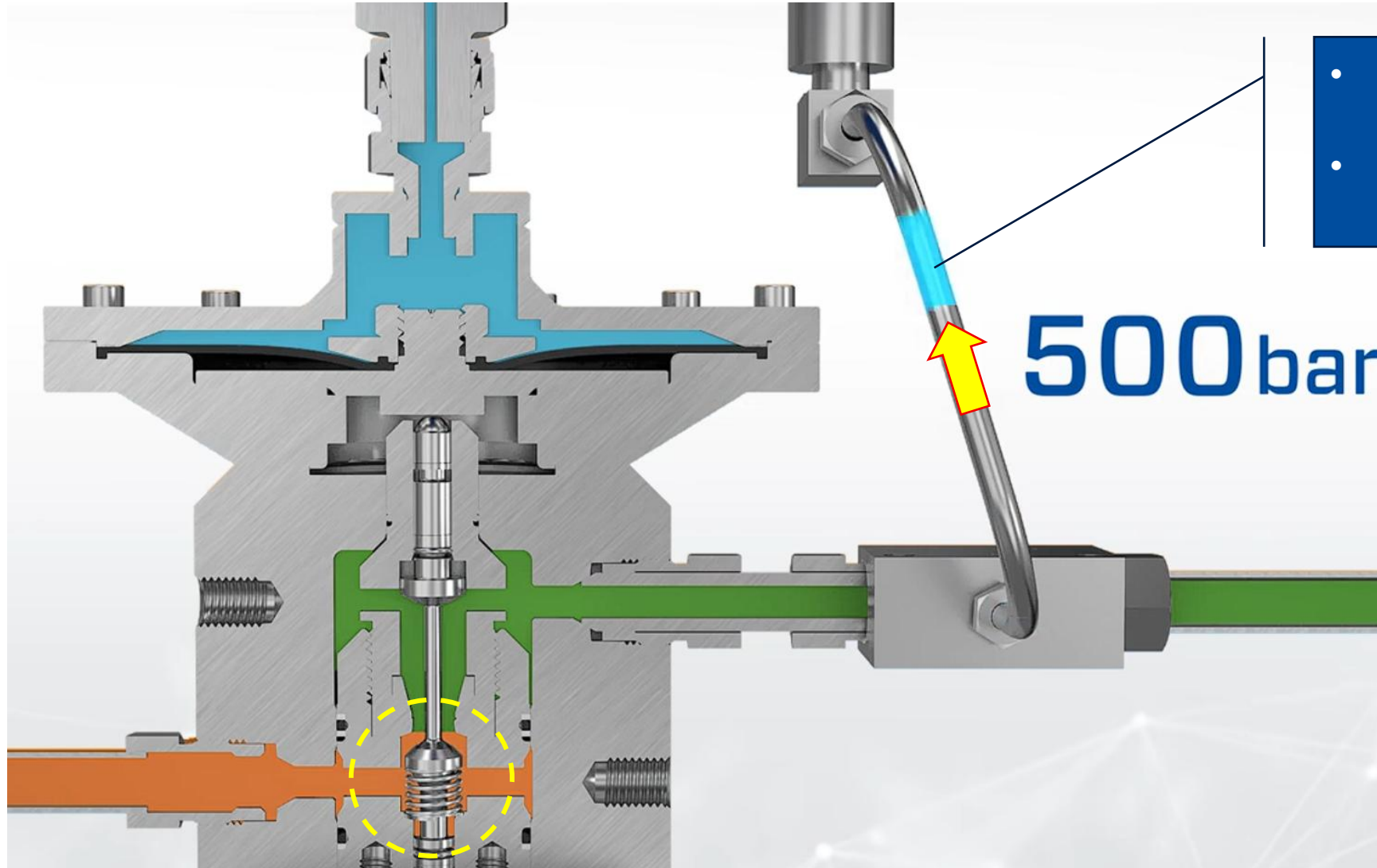
Electronic Pressure Control



- Dome Pressure increases
- Poppet opens
- Pressure to process increases



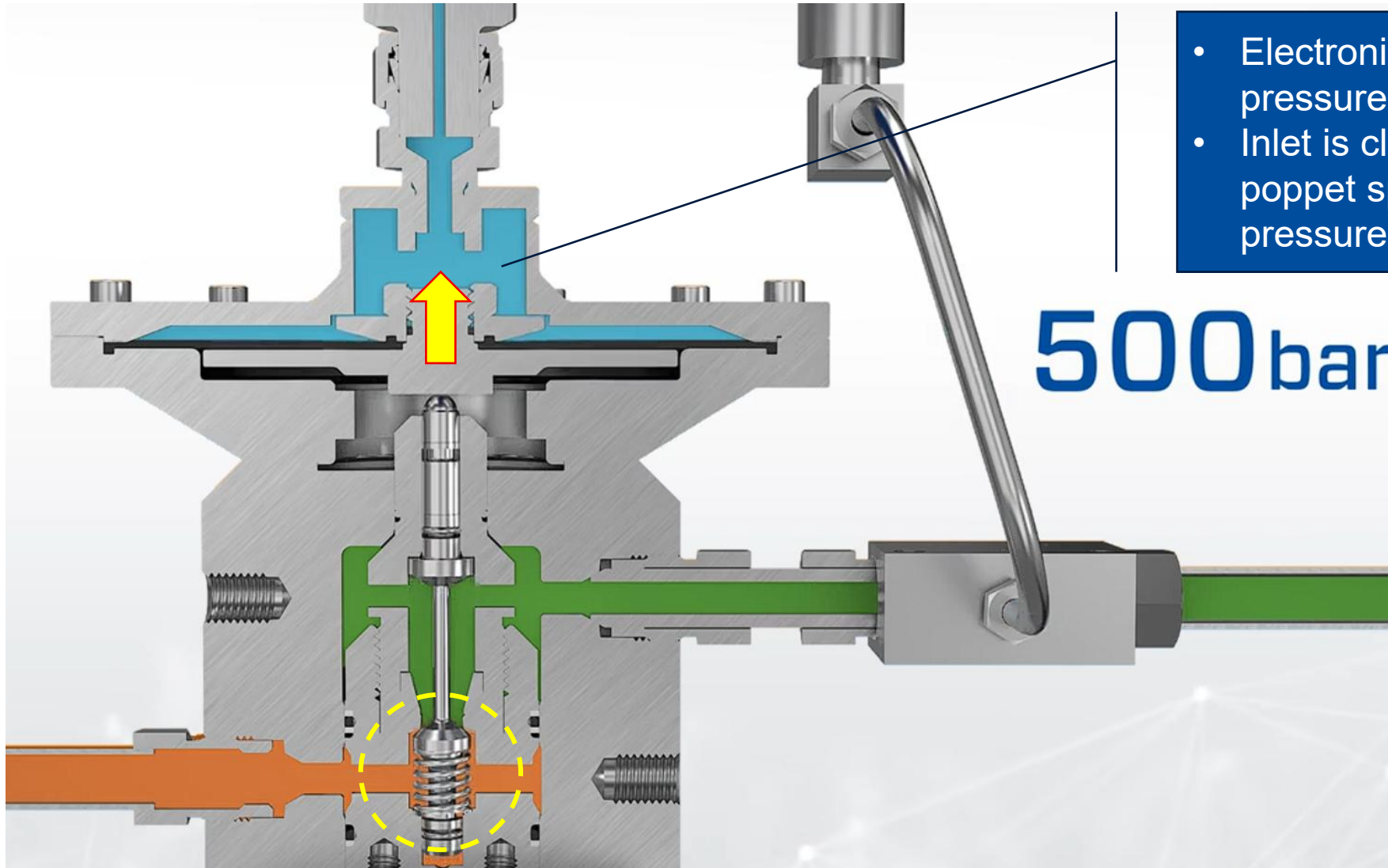
Electronic Pressure Control



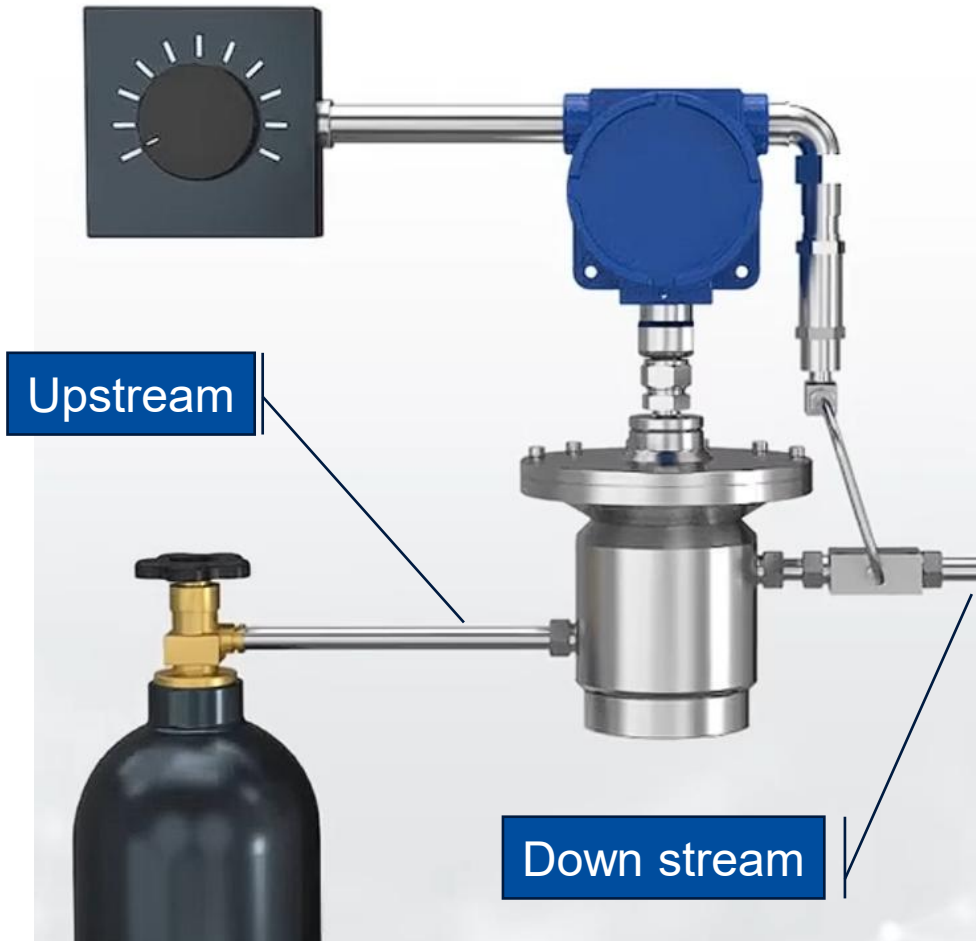
- Set pressure of 500 bar has been reached
- Transmitter send signal to Electronic Pressure Controller



Electronic Pressure Control



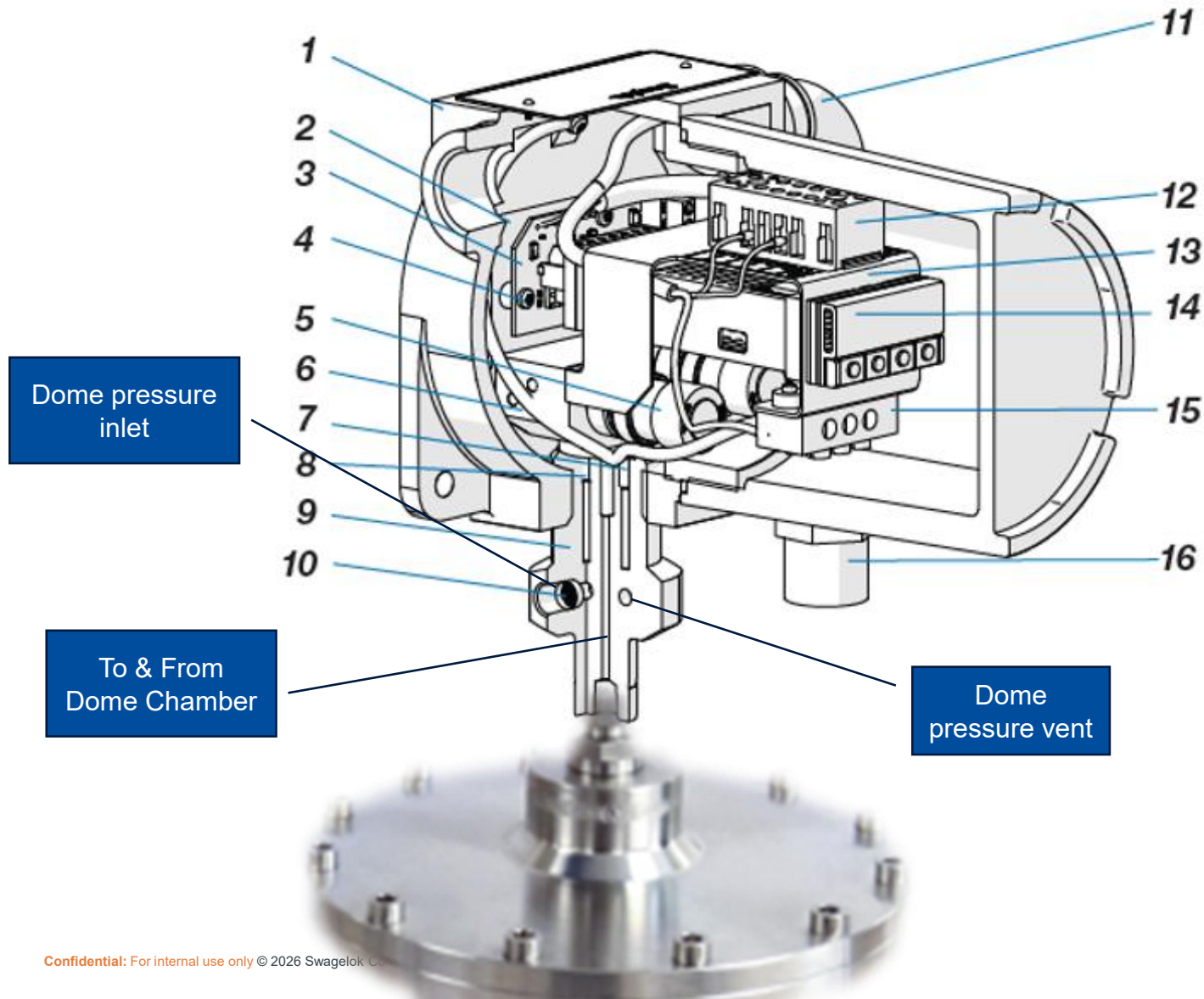
Electronic Pressure Control



What if upstream pressure drops?

- Tank pressure drops
- Downstream pressure rises (**SPE**)
- Transducer reads pressure sends signal
- Control signal adjusts dome pressure, adjusts piston
- Downstream pressure back to system set pressure

Electronic Pressure Control



High Pressure Reducing Regulator

High Pressure-Reducing, Ratio-Loaded Regulators – SFRA Series

Applications

Suitable for a wide variety of industrial applications where remote operation of the regulator is suitable.

Features

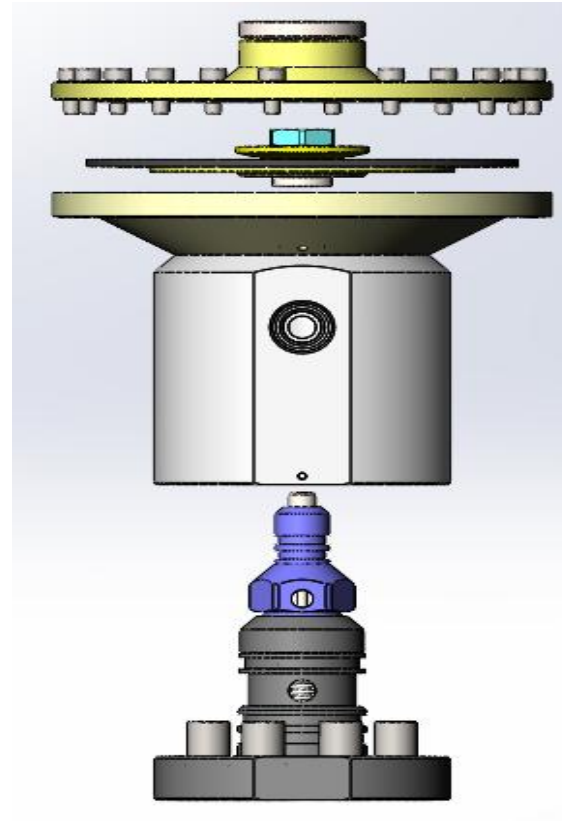
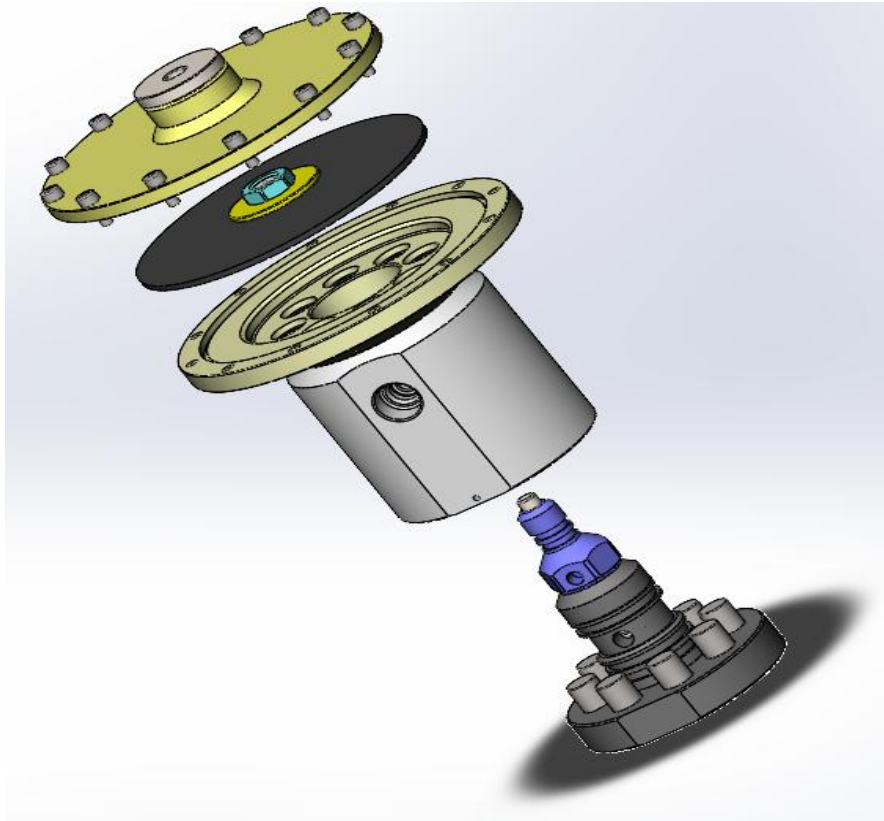
- Balanced poppet
- Piston sensing
- Modular design
- Body material construction 316 SS
>12% Ni
- Patented removable cartridge design
allows servicing without the need
to remove the product from the
dispenser system

Options

- Special cleaning
- PID control unit using
4-20mA signal
- North American HAZLOC certified
- ATEX & IECEx Hazardous location
certified

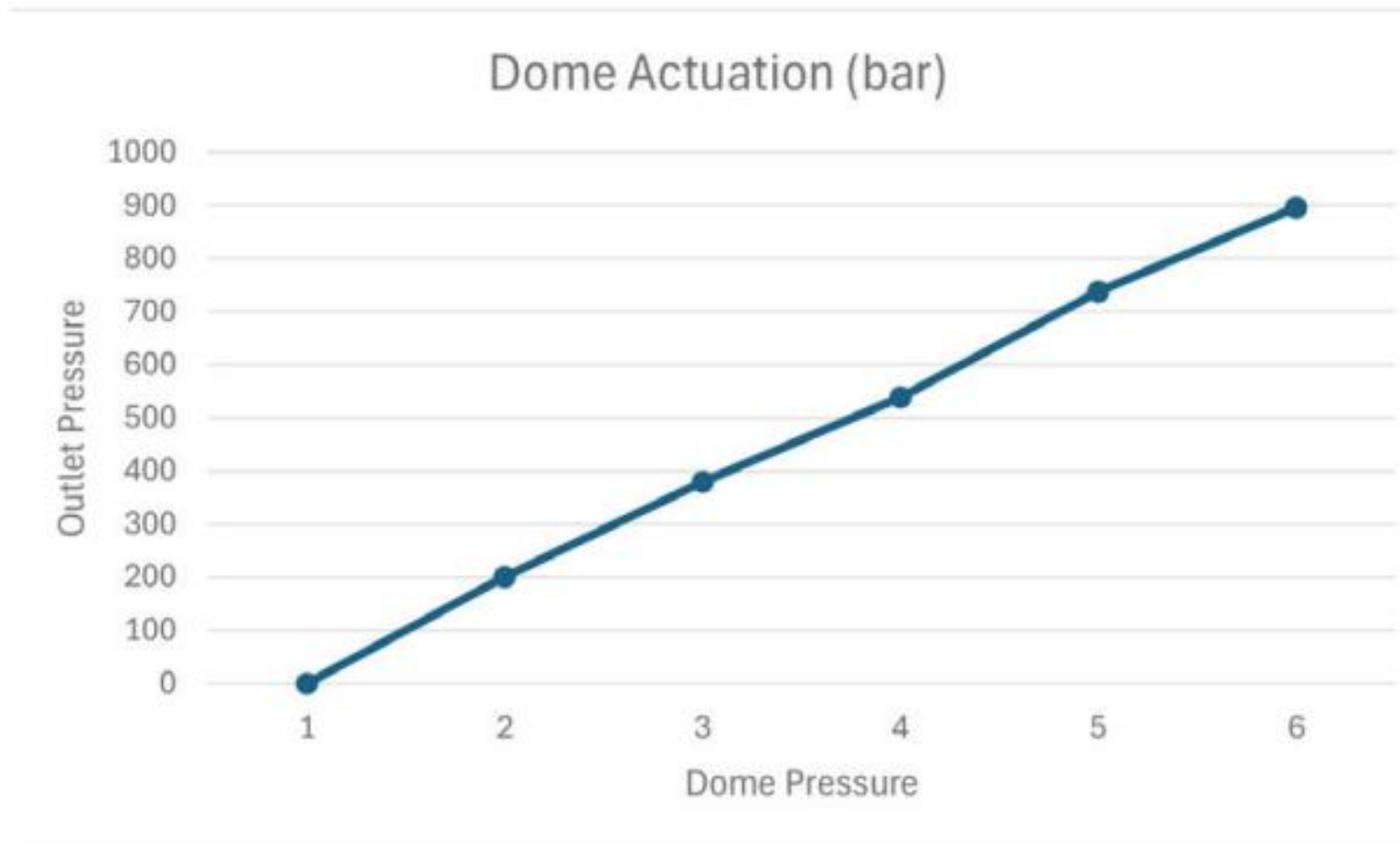


Maintenance



Patented removable cartridge design allows servicing without the need to remove the product from the dispenser or other system

High Pressure Ramp Regulator for H2 filling



High Pressure-Reducing, Ratio-Loaded Regulators SFRA Series



Designed for high flow $C_v = 1.95$ capable of 300g/s flow*

High Pressure Ramp Regulator for H2 filling



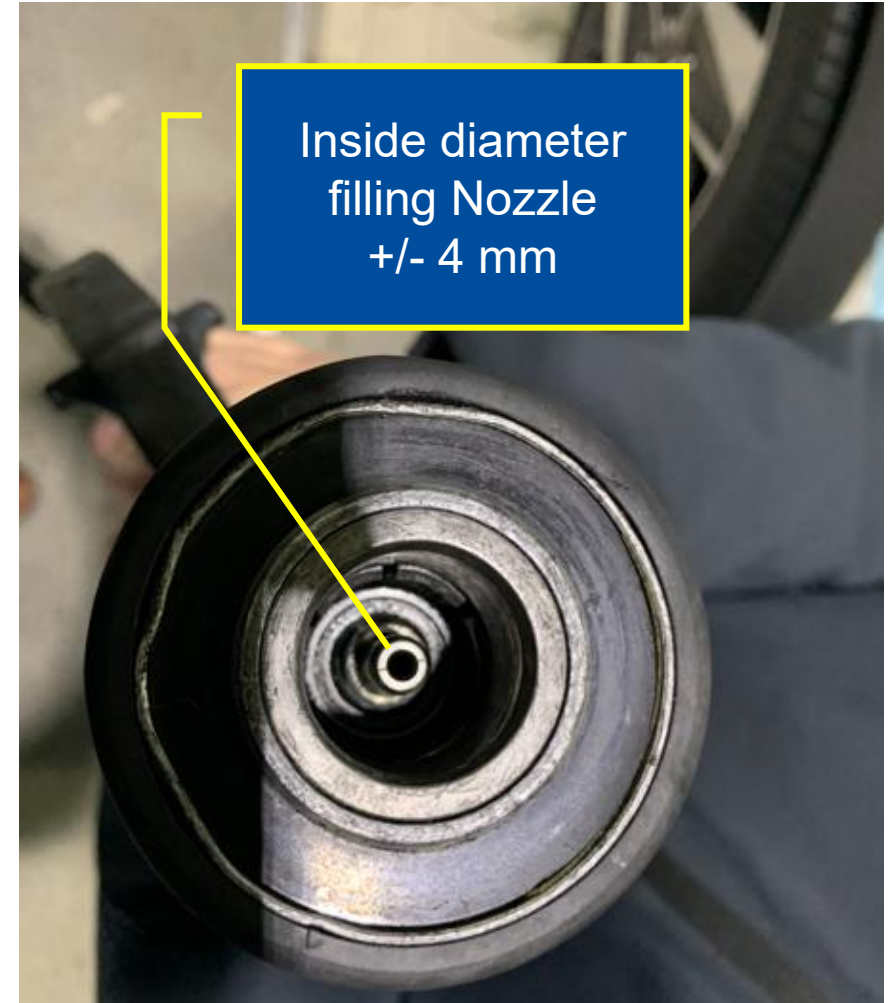
One of the systems where maintaining flow with extreme changing pressure and temperature rates is crucial is a Hydrogen Fuel Filling Station.

Swagelok® Ramp Regulator for Hydrogen Applications

Designed for use in hydrogen refueling station applications, a ramp regulator is designed to handle rapid thermal and pressure changes that can impact system integrity.



High Pressure Reducing Regulator for H2 filling



High Pressure Ramp Regulator for H2 filling

When refueling with hydrogen (gaseous, 700 bar for passenger cars), you have to deal with cryogenic (very low) temperatures at the pump, which ensure that the temperature in the vehicle's tank doesn't rise too high.

- Refueling (pre-cooled): For fast refueling, hydrogen gas is cooled significantly to approximately -33°C to -40°C before it enters the car's tank.
- Temperature in the tank: Despite cooling, the hydrogen heats up due to the high-pressure compression. Regulations state that the temperature in the vehicle's tank may not exceed $+85^{\circ}\text{C}$ during refueling.
- Hydrogen expands and heats up as it flows from the fueling system to the vehicle (Joule-Thomson effect). Without pre-cooling to -40°C , the temperature in the vehicle's tank would exceed 85°C , which is dangerous for the tank materials.
- **This means that the Ramp Regulator must be able to function safely and properly under extreme conditions such as extreme high pressure, flow, low temperature and must be resistant against Hydrogen embrittlement**



High Pressure Ramp Regulator for H2 filling

- H2 High pressure, high flow fueling
- Allows control of ramp to SAE JS2601 fueling protocol
- Designed for high flow $C_v = 1.95$ capable of 300g/s flow
- Body material construction 316SS >12% Ni



ISO 19880-1 Chapter 7, Hydrogen Fueling Diagram ©

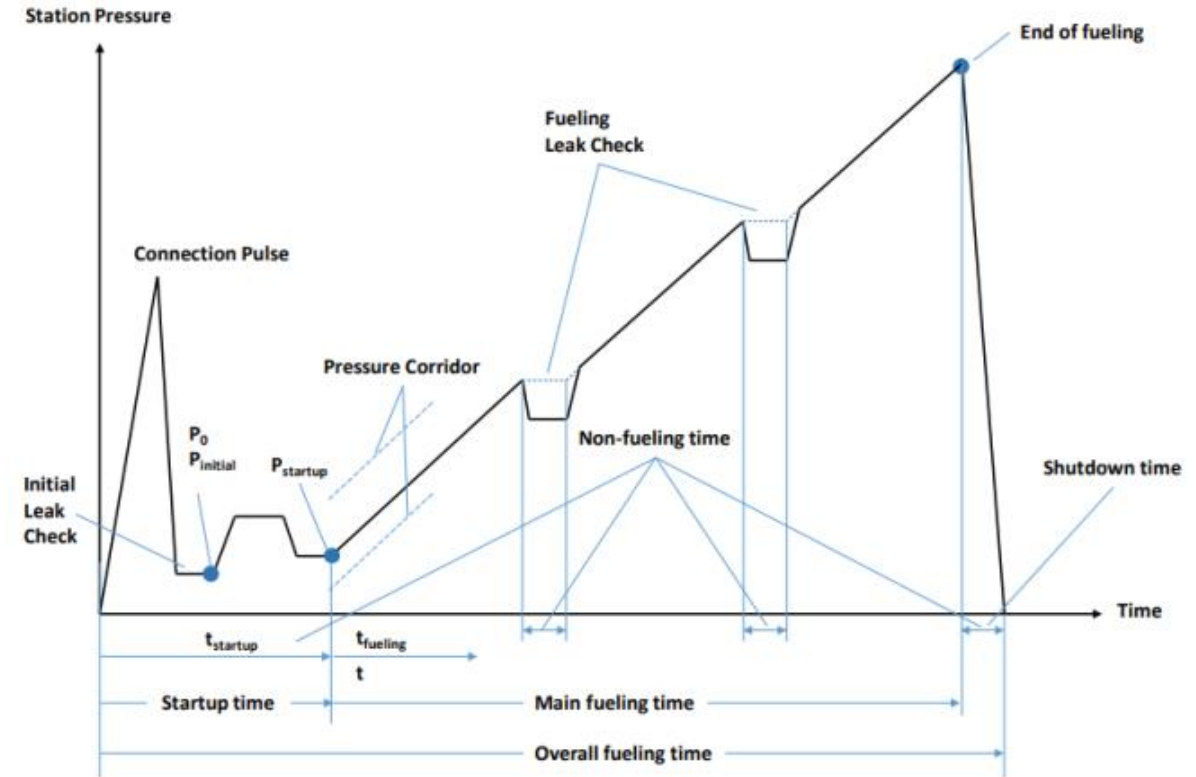
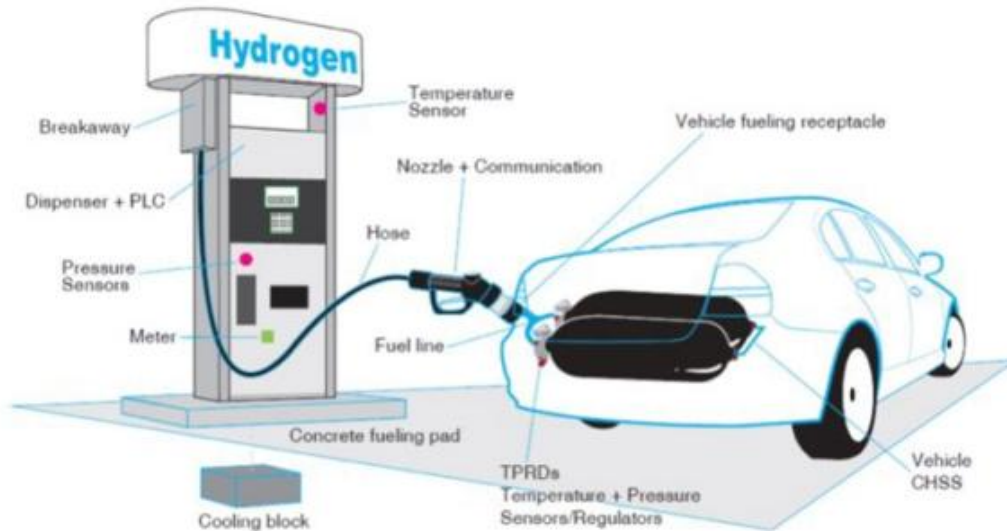


Figure 1 - Representative hydrogen fueling time diagram

High Pressure Components

Components used in hydrogen systems must deliver optimum levels of safety, reliability and performance because:

- ❖ **Small-molecule hydrogen gas** can escape from even the smallest connection gaps, leading to leaks and safety concerns
- ❖ **High-containment pressures** (up to 1050 bar [15 229 psi]) require high-performance components where traditional options simply are not suitable
- ❖ **Hydrogen embrittlement and degradation** can impact critical system components, compromising the materials' integrity and potentially leading to failures



Hydrogen Embrittlement

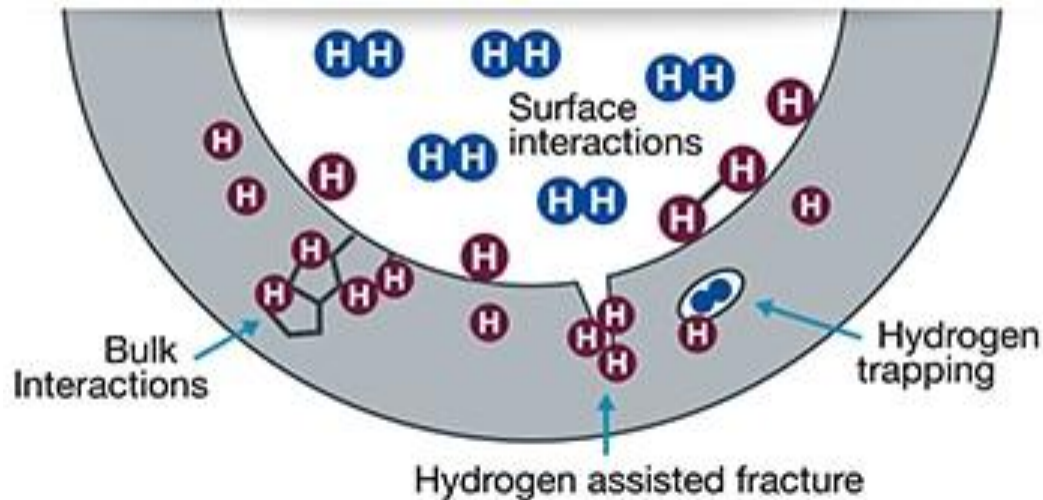


Figure 2: Hydrogen molecules can dissociate to atomic hydrogen and penetrate metals.

- Hydrogen embrittlement is a form of hydrogen corrosion that causes a reduction in fatigue- and fracture- resistance of metal.
- Hydrogen molecules (blue icons in Figure 2) can dissociate to atomic hydrogen (purple icons in Figure 2) and penetrate a metal.
- Hydrogen atoms accumulate at stress concentrators such as crack tips or microstructural features like grain boundaries, inclusions, or precipitates.
- In certain cases, atomic hydrogen can reform as diatomic hydrogen.

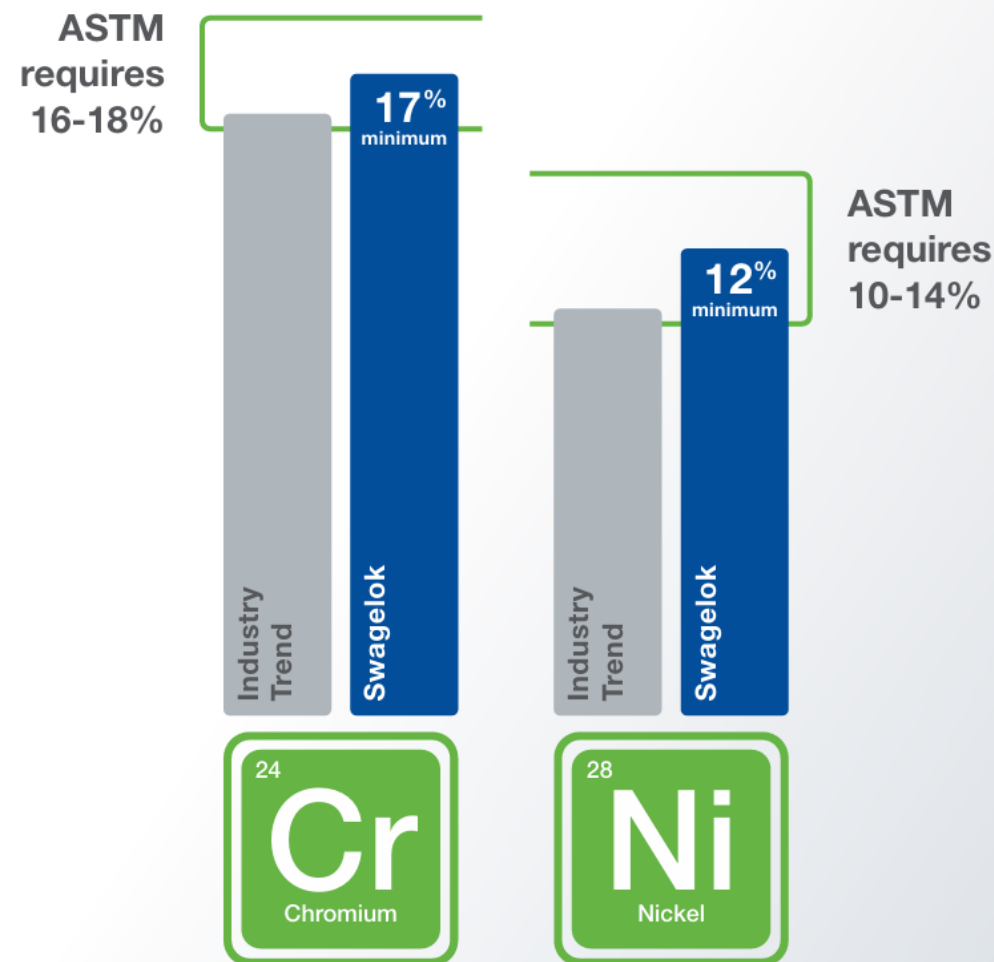
Swagelok Material Composition – Cr/Ni

Higher, tighter range alloy content than required per ASTM A-479

- Nickel 12% Minimum (versus 10% required).
- Chromium 17% Minimum (versus 16% required).

Which provides:

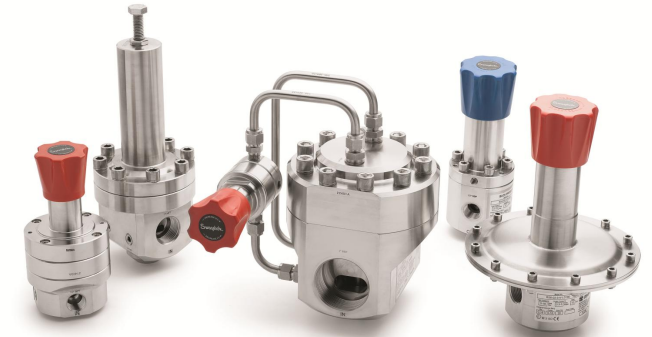
- More consistent intra-heat component manufacturing
- Greater resistance to hydrogen-assisted fracture



Swagelok 316 stainless steel tube fittings and instrumentation valves exceed minimum ASTM specifications.

Summary

- Type of regulators (reducing & back pressure)
- Main regulator components (loading, sensing and control element)
- Droop curve
- How to flatten the droop curve
- High pressure regulator
- Electronic pressure control
- Hydrogen embrittlement
- Chrome & Nickel content



Questions?



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