Hydrogen: From Supply to Point of Use

General Industry, Infrastructure & On-vehicle Applications

Nico Dissel & Marco van den Broek

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Introduction Swagelok

Marco van den Broek

Sales Engineer & H2 Specialist

Nico Dissel

Sales Engineer & H2 Specialist & Trainer

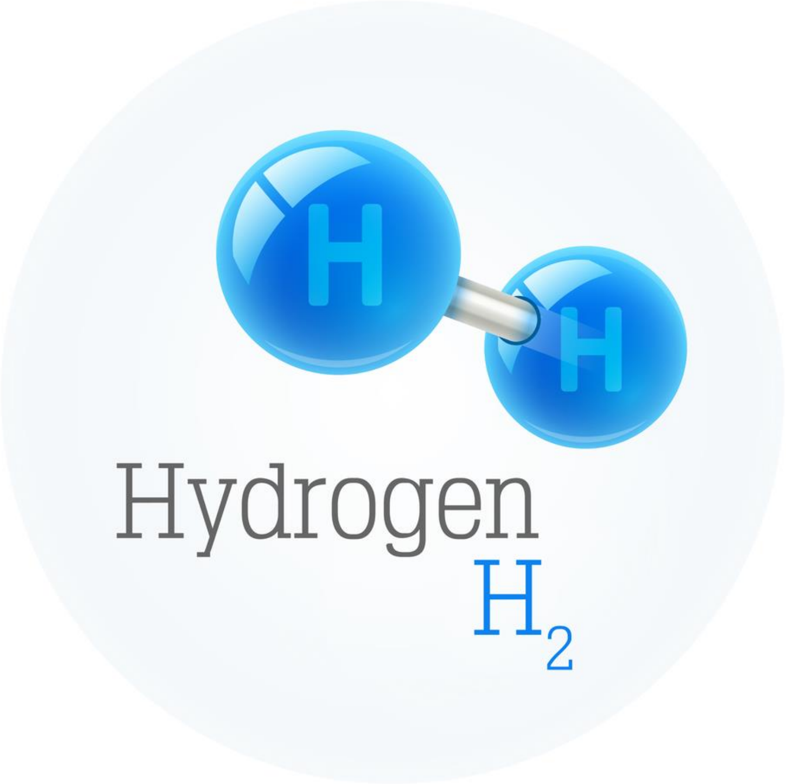
Swagelok and Hydrogen

75 years of experience with Hydrogen compatible products:

- Oil & Gas
- Automotive & Infrastructure
- Clean Energy
- Semicon
- Chemical & Refinery
- Research & development

Hydrogen challenges

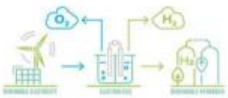
- Small Molecule
- Leak Tightness
- High Pressure
- Vibration
- Temperatures



Clean Energy Pressure Schematic

H2 Production
Electrolysis (PEM / Alkaline)

Electrolyzer



Low Pressure: up to 30 bar
Temp: Ambient
Materials: SS316 / Monel for lye in alkaline electrolyzer

H2 distribution & infrastructure
Processing, storage, distribution & transmission

Pipeline / Grid balancing

Low Pressure: up to 100 bar
High Pressure: TBC
Temp: TBC
Materials: SS316

H2 storage

High Pressure: up to 500 bar
Temp: Ambient
Materials: SS316

Fuel cell

Low Pressure: up to 30 bar
Temp: Ambient
Materials: SS316

H2 Compression & Refuelling
Fixed / Portable refuelling

Virtual Pipeline

High Pressure:
Generally, 300-500 bar
some up to 1000 bar
Temp: -20°C to 85°C
Materials: SS316

Mobile Refueler

High Pressure: up to 1000 bar
Temp: -20°C to 85°C
Materials: SS316

Compressor

High Pressure: up to 1000 bar
Temp: System Specific
Materials: SS316

H2 Compression & Refuelling
Fixed / Portable refuelling

On-site storage

High Pressure:
H35 pressure Class: 525 bar
H50 Pressure Class 687 bar
H70 Pressure Class: 962 bar
Temp: -40°C to 85°C
Materials: SS316

Dispenser

High Pressure:
H35 pressure Class: 525 bar
H50 Pressure Class 687 bar
H70 Pressure Class: 962 bar
Temp: -40°C to 85°C
Materials: SS316

H2 Mobility
On & off road heavy duty vehicles

350 bar vehicle

Low pressure to fuel cell: up to 30 bar
Temp: Ambient
Materials: SS316

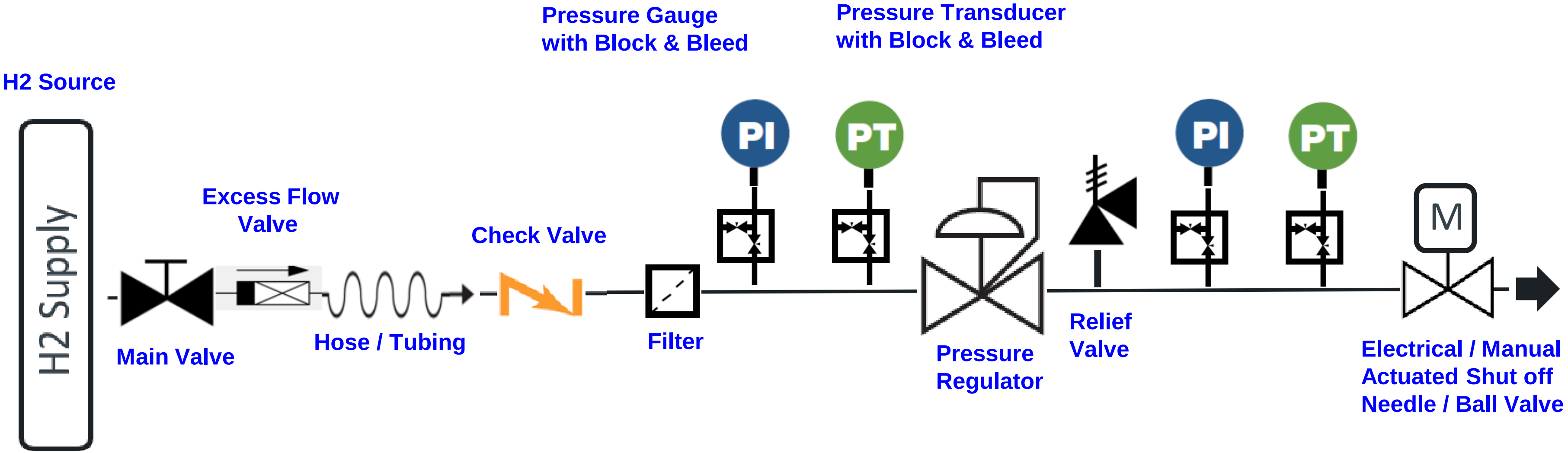
High Pressure fuel system : 437 bar
Temp: -40°C to 85°C
Materials: SS316

700 bar vehicle

Low pressure to fuel cell: up to 30 bar
Temp: Ambient
Materials: SS316

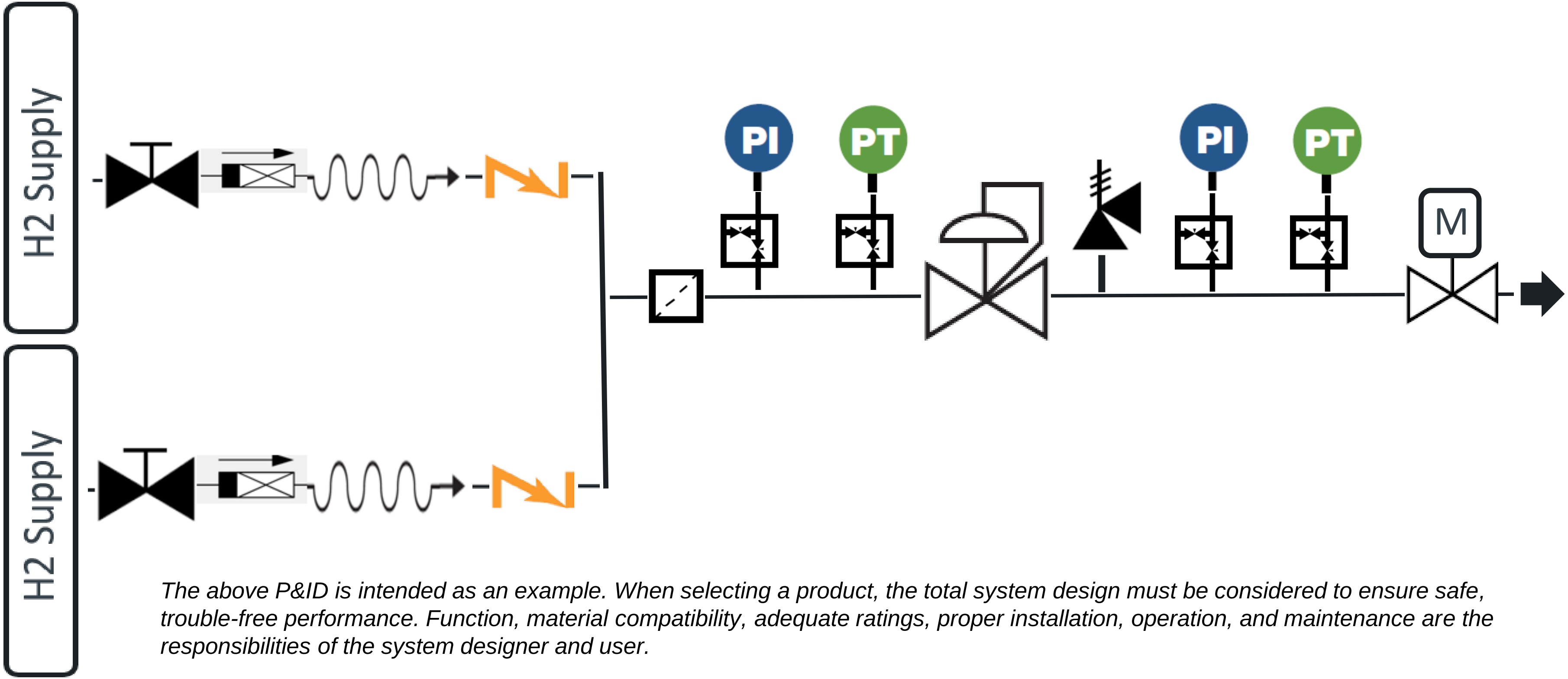
High Pressure fuel system : 962 bar
Temp: -40°C to 85°C
Materials: SS316

From Supply To Point Of Use



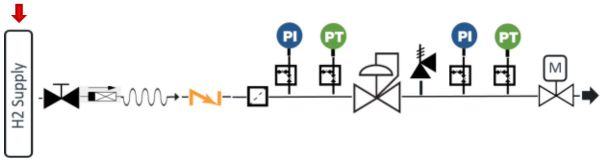
The above P&ID is intended as an example. When selecting a product, the total system design must be considered to ensure safe, trouble-free performance. Function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.

From Supply To Point Of Use

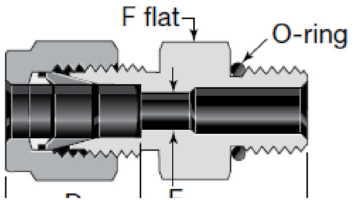


The above P&ID is intended as an example. When selecting a product, the total system design must be considered to ensure safe, trouble-free performance. Function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.

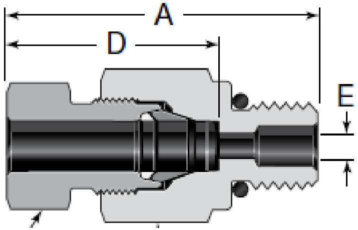
H2 Supply - Tank / Buffer



Hydrogen cylinder
350 / 700 bar



Standard Fitting

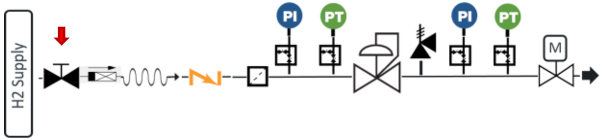


FK Fitting (1378 bar)

- Tanks or Cylinders are often equipped with SAE Thread connections
  - ➢ SAE–Light Duty (Swagelok ST fittings)
  - ➢ SAE–Heavy Duty (Swagelok STH fittings)

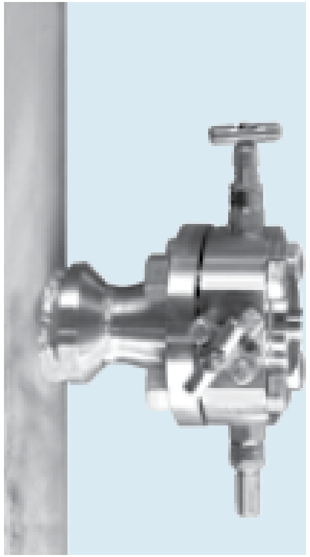
- Use the torque values specified by the cylinder / tank manufacturer
- O ring materials are mainly EPDM (peroxide cured), Highly compouded FKM. Standard FKM can work at low pressures
- EC-79 has expired as of July 2022. No HV35 or HV70 suffix is required

H2 Supply Main Shut off Valve

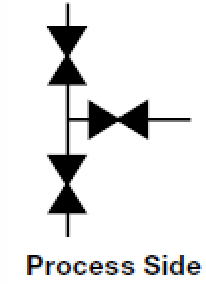


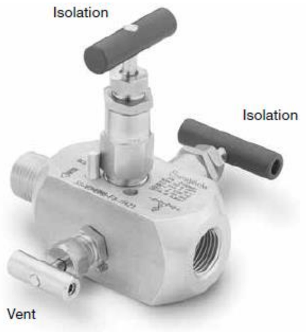
Questions from the field: *“In the context of Safety, we are increasingly moving to the principle of process interface valves and/or Double Block and Bleed shut off vales”*

Double Block & Bleed
(for pressures up to 1378 bar)

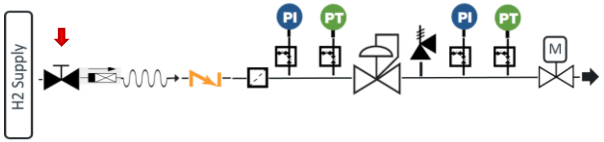


Process Interface valves

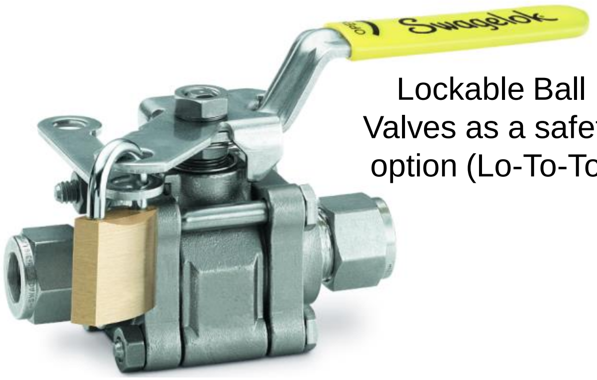




H2 Supply Main Shut off Valve



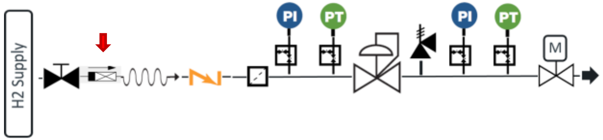
- Swagelok Ball Valves are designed to be used in a fully open or fully closed position (fast opening or closing)
- Needle valves are designed to correctly regulate the flow and prevent any pressure surges in the system (slowly opening or closing)
- Both can be manually activated or electrical activated



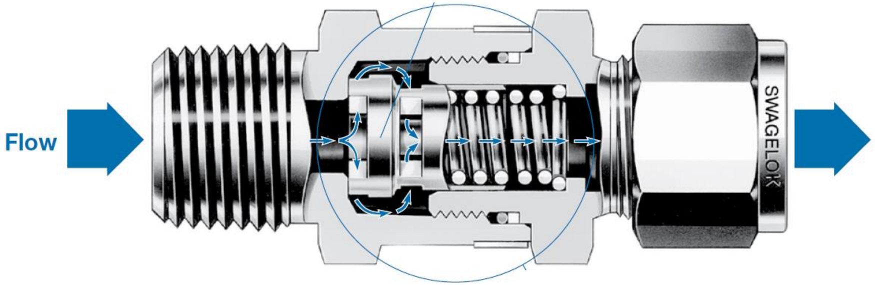
Lockable Ball Valves as a safety option (Lo-To-To)

High Pressure Needle Valve (slow opening)

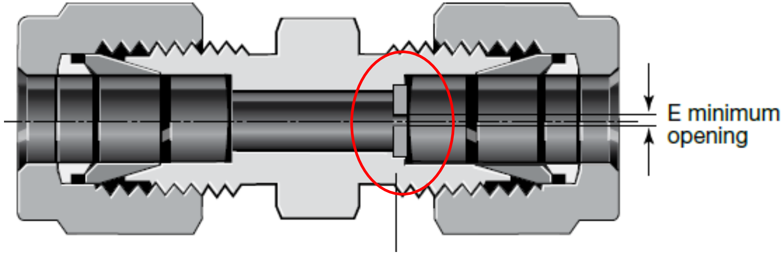
Needle Valve (slow opening manual or electrical / ATEX)



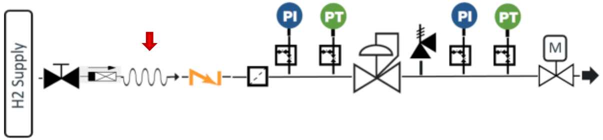
Excess Flow Control



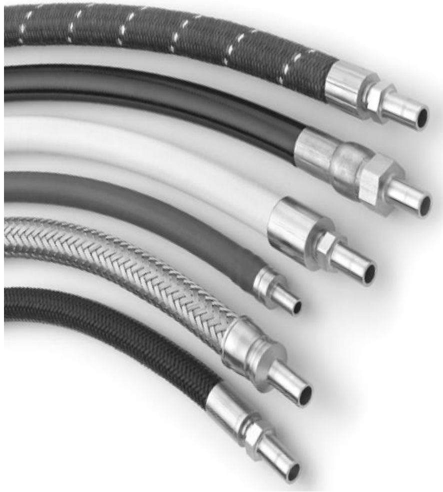
- In case of hose failure or system failure the Excess Flow valve shutt off the system pressure
- Ethylene Propylene O ring (EP)



- Many times an ‘calibrated’ orifice is used to control the system flow. Depending on the flow orifice opening needs to be calulated

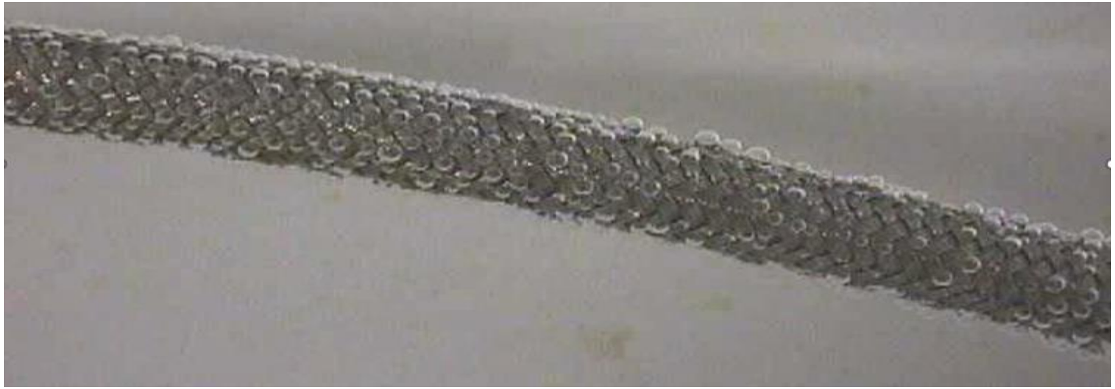


Hoses for use in Hydrogen



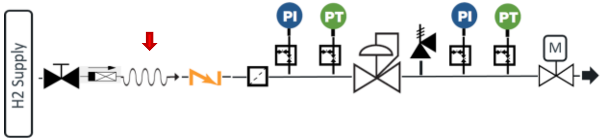
Many type hoses are available

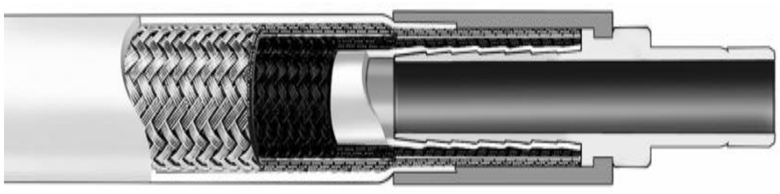
- Hydrogen is the second thinnest gas we know with very small molecules that want to make their way through the hose wall
- The degree of permeability determines whether or not a material is suitable for hydrogen applications



Teflon hose tested with Hydrogen in a water basin

Hoses for use in Hydrogen

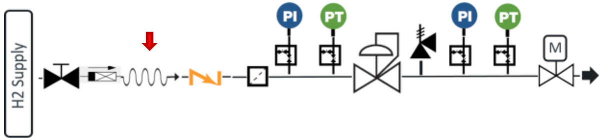




- Typically PFA or PTFE
- Permeable
- Not advised for use with gasses like hydrogen or helium.

- Metal braid end connections welded to the flexible metal hose ends.
- Swagelok Metal series hose assemblies are inboard helium leak tested to a maximum leak rate of 1 × 10–5 std cm3/s

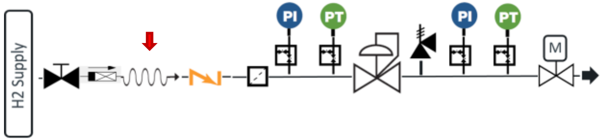
Hoses for use in Hydrogen



Tie Down Cable

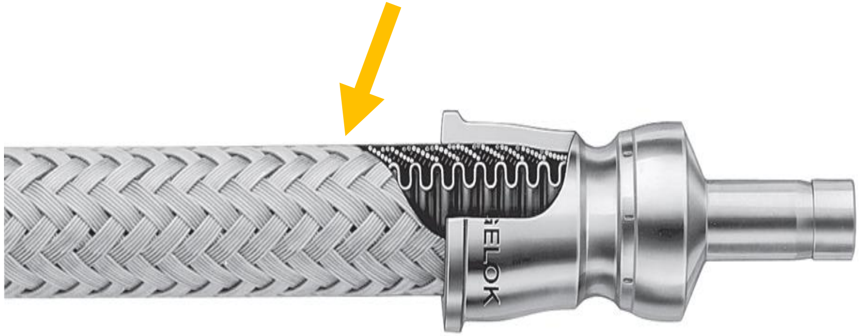
- Connected to the hose and the end connection to protect against end connection separation
- Connected to nearby equipment to protect against end connection failure
- Can also be connected to both

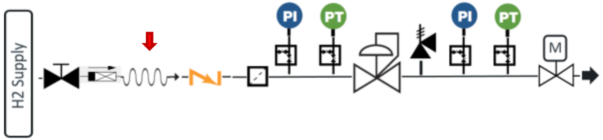
Hoses for use in Hydrogen



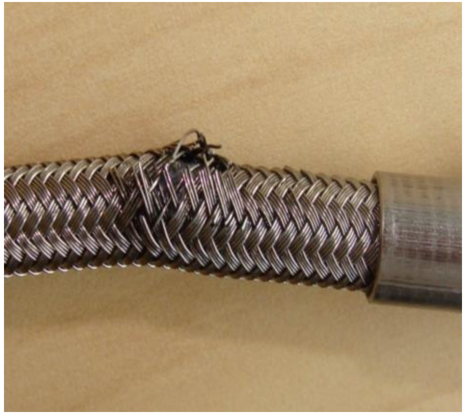
Reinforcement:

- Protects the tube and allows the hose to contain pressure
- Provides kink resistance
- Wire braid.

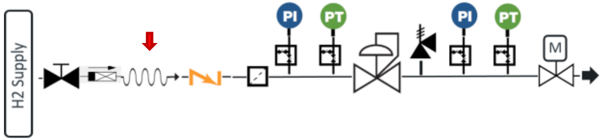


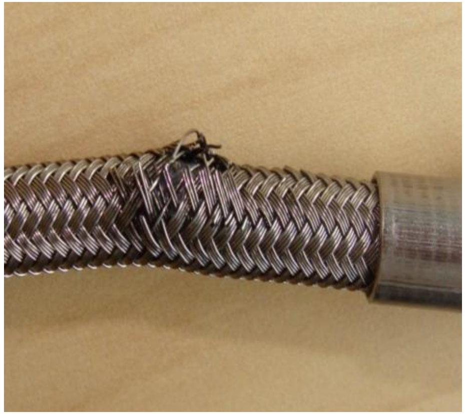


Hose - installation



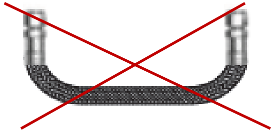
Hose - installation





Hose rupture or leakage may result from bending too close to the hose/fitting connection.

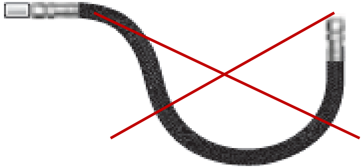
Recommended



Not recommended

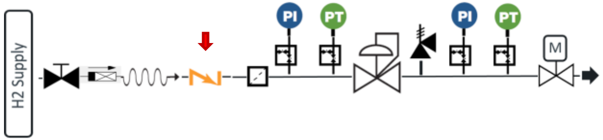
Hose Strain
Elbows and adapters can be used to relieve hose strain.

Recommended



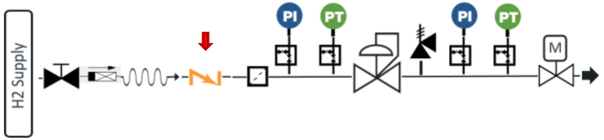
Not recommended

Check Valves



- Check valves are designed for directional flow control only. ***Swagelok check valves should never be used as code safety relief devices***
- Selecting the correct size and specification is important to ensure a smooth, trouble-free and long-term operation
- Determine the correct check valve size by means of the Cv or the flow data as indicated in the brochures
- Avoid chattering of the valve. Chattering occurs when the valve is oversized for the application and is one of the most common causes of check valve failure

Check Valves



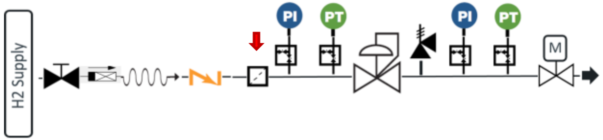
- **Cracking pressure**:
  The inlet pressure at which the first indication of flow occurs and is depending on the available spring options

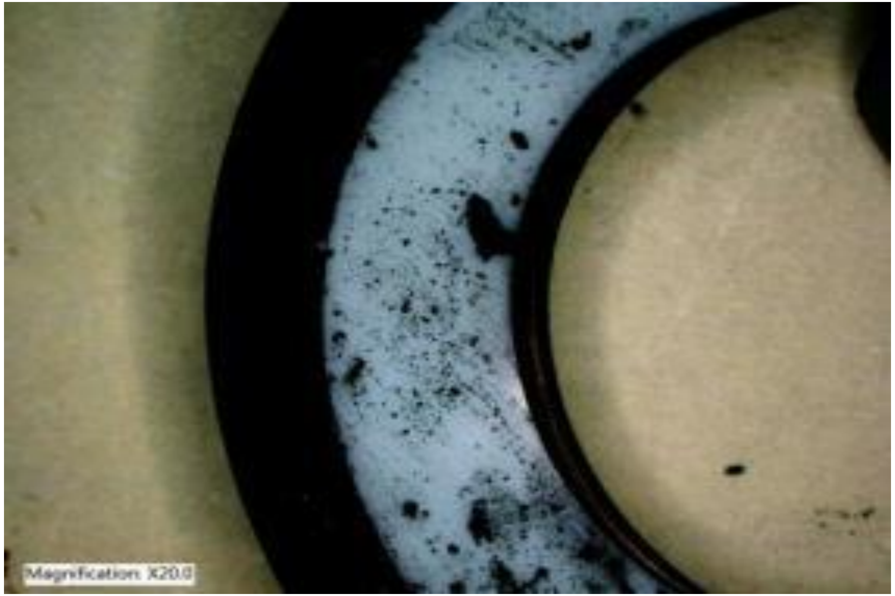
- **Maximum allowable back pressure**:
  The maximum allowable differential pressure between the inlet and outlet pressure

- Pressures up to 1378 bar in combination with the Swagelok FK or Cone & Thread (IPT) integral connection

- **Poppet check valve Seal materials:**
  - Often Ethylene Propylene (EP) or Neoprene (NE)
  - HNBR (Hydrogenated Nitrile Butadiene Rubber) in High Pressures

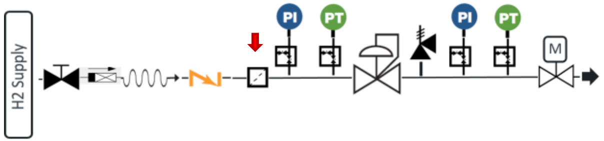
System Filters





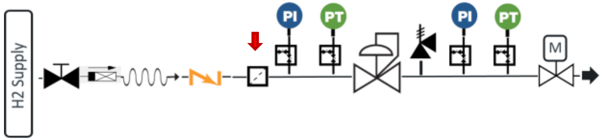
Most common Valve leakage is Stem Tip Seal Leakage caused by system contamination like debris from welding spatters, burs, teflon tape from thread connection etc etc.

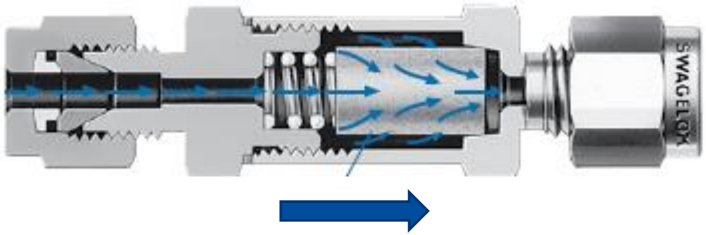
System Filters



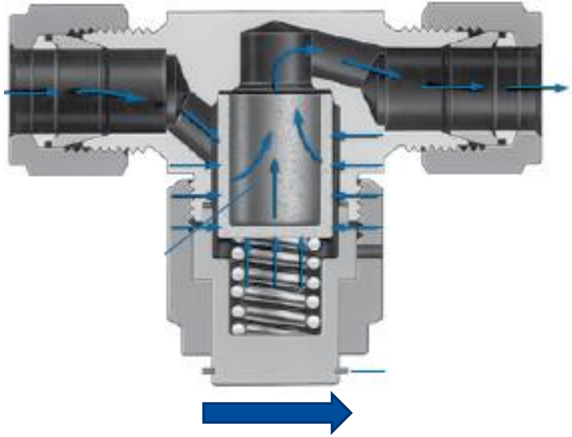
- Filters are crucial parts that can prevent a lot of damage and failure of complete systems
- Every (very) small damage (scratch) can lead to a failure of a component
- Location of a filter in a system is very important
- Pore Size based on the expected particle size
- Required flow through the (clean) filter
- System Working pressure
- Maximum Differential Pressure (Delta P)
- Filtration Area (mm2)
- UHP filter options for lab applications

Filters – Flow Direction





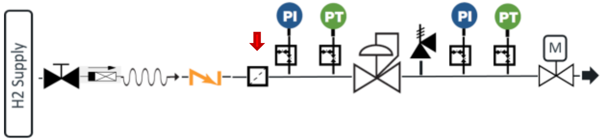
Inline Filter



Tee-Type Filter

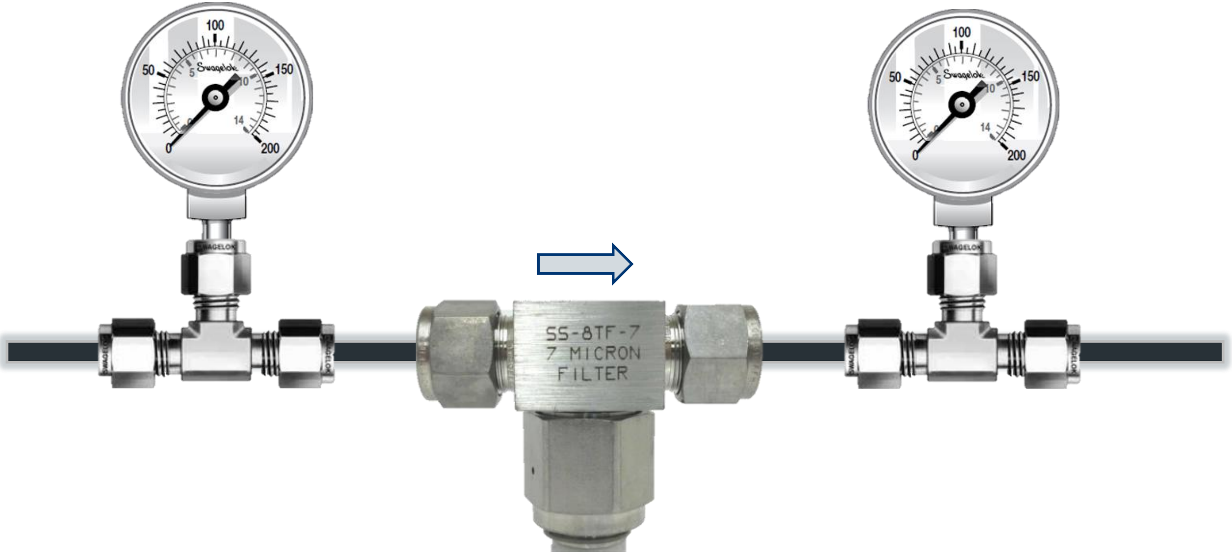
- Note the arrow for the correct flow direction
- Tee Type Filter simplifies element change.
  - ➢ Filter element can be replaced without removing body from system

Filters – Differential Pressure



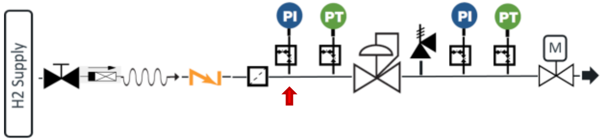
Differential Pressure Ratings

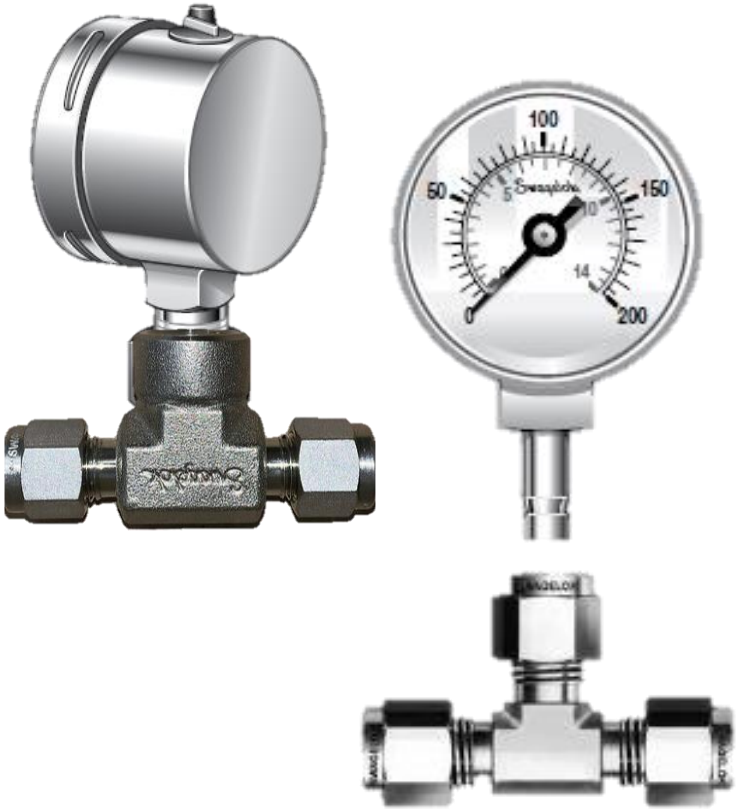
Filter Series	Maximum Differential Pressure psig (bar)		
	Sintered Element	Strainer Element	Pleated Element
FW	600 (41.3)	—	100 (6.8)
F, TF	1000 (68.9)		—



- Trapped particles affect the pressure difference across the element
- The more trapped particles the higher the differential pressure across the element
- System and Filter element can be damaged by clogged filters
- Check regularly the status of the filter element

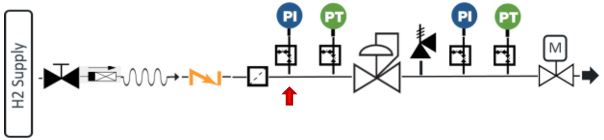
Measurement Devices – PI



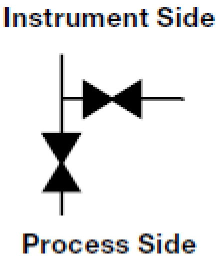


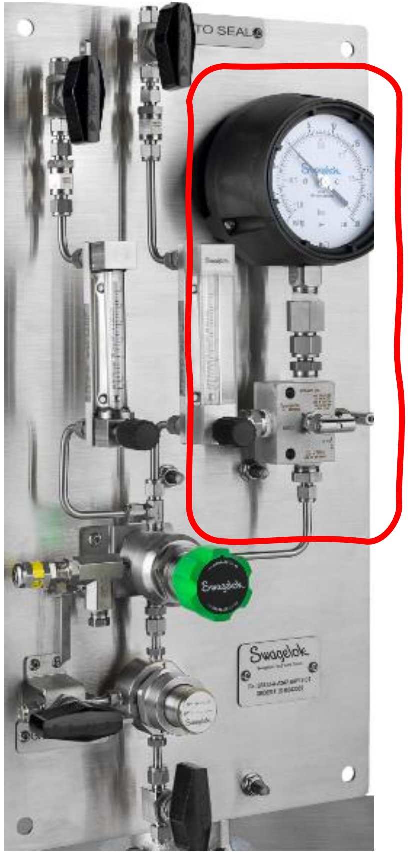
- When installing a gauge with a pipe fitting end connection, it is often difficult to align the dial to the desired position without damaging the gauge
- Gauges with integral Swagelok tube adapters eliminate alignment problems and damage to the gauge connection
- Tube adapter connections can be used many times

Measurement Devices – PI



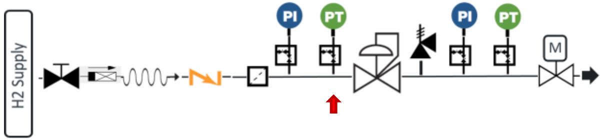
Compact Gauge
Valves

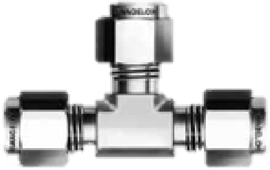




- For the safety of the installer or installer, we recommend never to remove a pressure gauge when the system is still under pressure
- Removal of a pressure gauge for calibration or renewal should be done safely
- The pressure must be released in a safe manner
- By means of a Compact Gauge Valves or Block and Bleed option the pressure can be released safely

Measurement Devices - PT

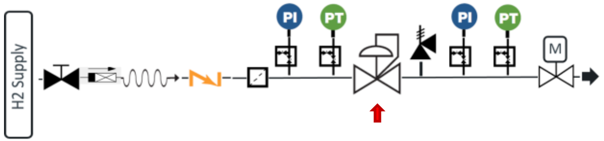




- For the safety of the installer or installer, we recommend never to remove a pressure transducer when the system is still under pressure. In fact, the same rules apply as for the gauges

- Pressure Transducers with integral Swagelok tube adapters eliminate alignment problems
- Should be designed for hydrogen applications
- Gold plated membrane
- Gold plating prevents the possibility that Hydrogen permeation will cause a signal drift
- Approvals: ATEX/IECEx

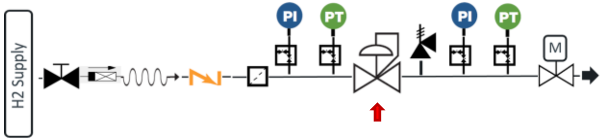
Pressure Regulators

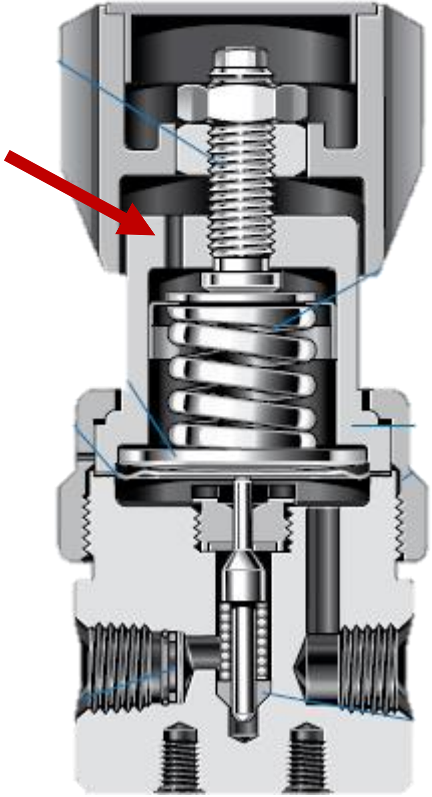


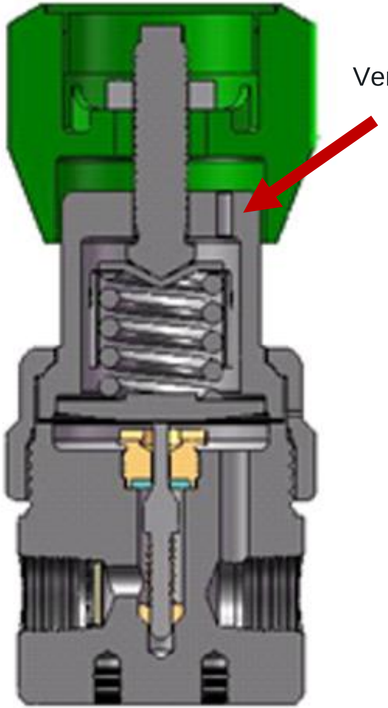
A regulator's main purpose is to maintain a constant pressure on one side of the regulator even though there is a different pressure or fluctuating pressure on the other side. In the case of a pressure-reducing regulator, pressure is controlled downstream of the regulator.

- Type of fluid (Hydrogen gas)
- Pressure source
- Inlet Pressure
- Outlet Pressure
- Flow
- Gas velocity
- Type Regulator
- End Connections
- Anti Tamper option
- Expected temperature
- Seal / Seat / O ring Material

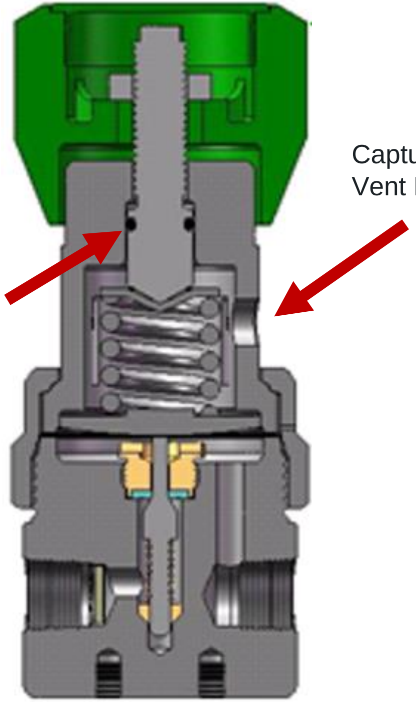
Pressure Regulators
Venting Option





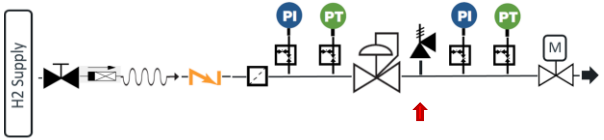


No Captured Vent



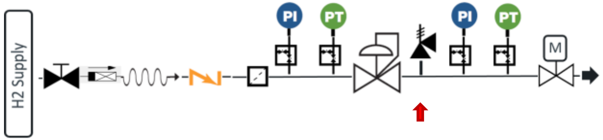
Captured Vent

Relief Valve

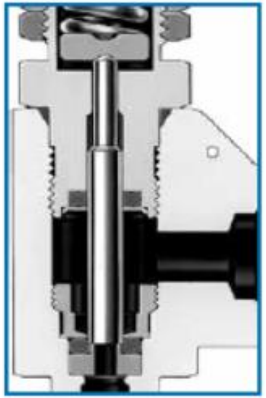


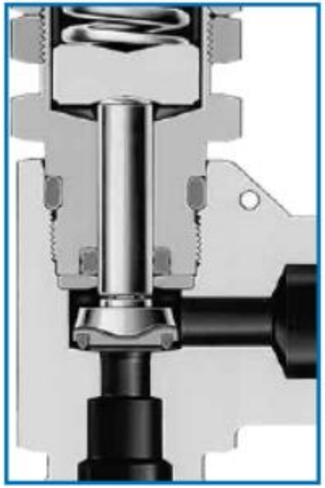
- Relief valves OPEN when system pressure reaches the set pressure and CLOSE when system pressure falls below the set pressure
- Set pressure X% above the MAWP
- Determine capacity of the relief valve based on possible creep caused by the regulator or based on full system flow?
- The effect of system back pressure is depending of the valve design

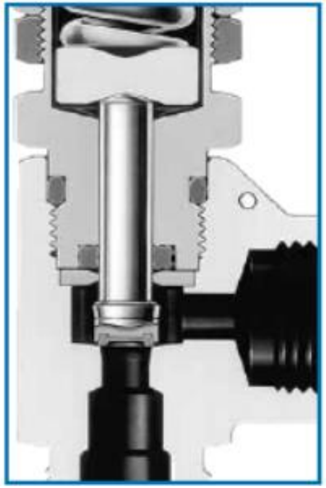
Relief Valve



The effect of system back pressure is depending of the valve design.



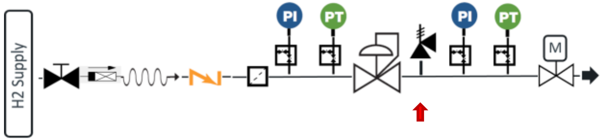




The effect of system back pressure is minimized by the design of these high-pressure valves

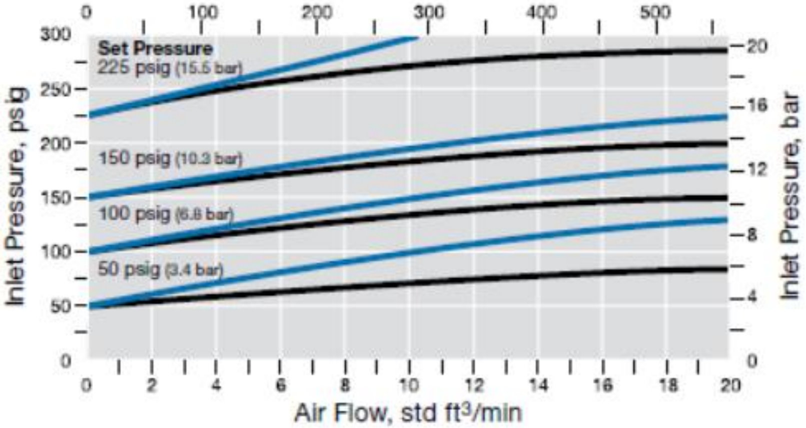
System back pressure increases the set pressure of the valve.

Relief Valve



How to calculate the capacity of a relief valve

- Use the Factory Flow data
- Certified Discharge Coefficient *(Kdr)*



Kdr = 0.027 (for gas)
A = 103.87 mm^2

Example

Check for critical flow:

$Pb/Po \le (2/(k+1))^{(k/(k-1))}$

$Pb / Po = 1 / 175.9 = 5.68 \times 10^{-3}$

$(2/(k+1))^{(k/(k-1))} = (2/(1.4+1))^{(1.4/(1.4-1))} = 0.528$

therefore critical flow

Flow calcuation using critical flow equation

$C = 3.948*sqrt(k*(2/(k+1))^{((k+1)/(k-1))} = 3.948*sqrt(1.4*(2/(1.4+1))^{((1.4+1)/(1.4-1))}$

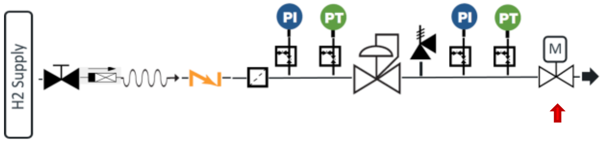
$= 2.703$

Qm = (Po)*(C)*(A)*(Kdr)*{sqrt(M/Z*To)}

$= 175.9$ bara*2.703*103.87mm^2*0.027*{sqrt(28kg/kmol/1*293K)}

= 412 kg/h

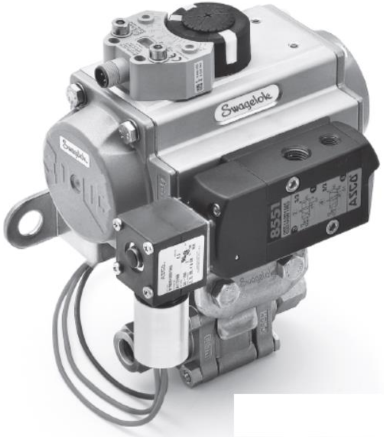
Shutt Off Valve



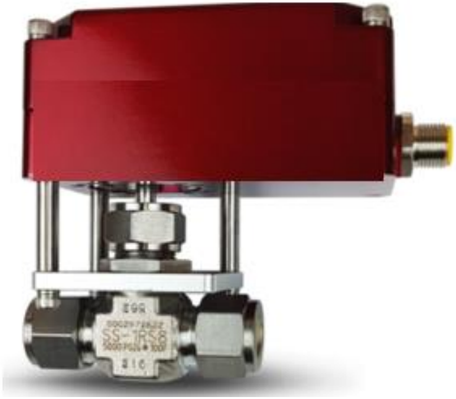
- Pneumatic Actuated only : Fast opening and closing
- Pneumatic with solenoide : Fast opening and closing)
- Fully Electrical : RPM options available
- Manual Operated

- Fully Electrical or Solenoide : Standard or ATEX/ Gasgroup IIC

Pneumatic Actuated only



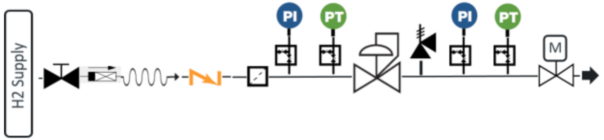
Semi Pneumatic with solenoide



Fully Electrical

Manual Operated Shut off

Stainless Steel Tubing




Stainless Steel Seamless fully Annaeald Tubing

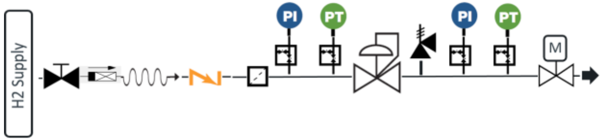

Stainless Steel FK series Medium - Pressure Tubing

- Stainless Steel Tubing 316/316L (dual certified / fully annealed)
- Stainless Steel Seamless FK tubing Fully annealed or Cold-Drawn 1/8-Hard 316 / 316L

Stainless Steel Seamless FK Tubing:

- ➢ Pressures up to 1378 bar
- ➢ 316 is an austenitic stainless steel, it can not be hardened by heat treatment, but can be hardened by cold work
- ➢ Cold-Drawn 1/8-Hard → Larger inside diameter compared to fully annealed FK tubing
- ➢ It is not recommended to weld Cold-Drawn 1/8-Hard FK tubing !!

Stainless Steel Tubing Function of Nickel



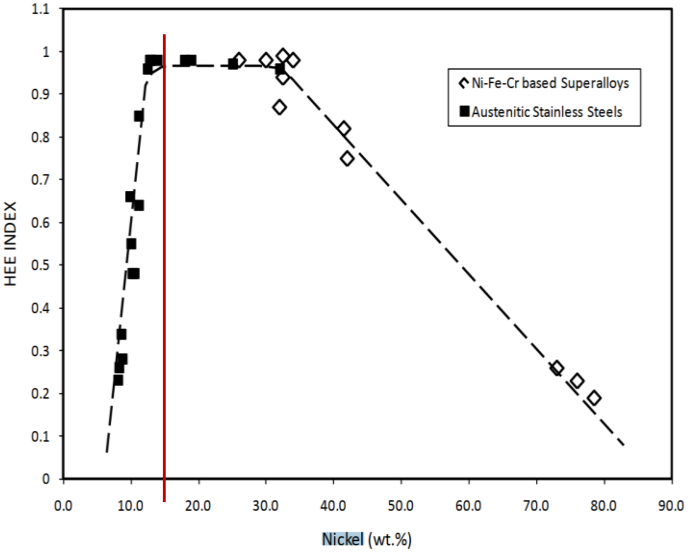
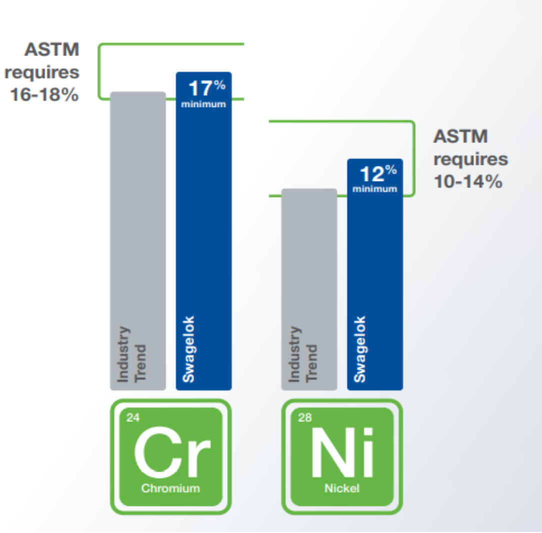


Figure 1: HEE Index for Fe-Ni-Cr superalloys and stainless steels as a function of Ni content (wt.%) (Data is from references in Table 7)

Source: NASA TM-2016-218602

- ASTM requires 16-18% chromium and 10-14% nickel
- Swagelok Stainless Steel tubing minimum content of 17% Cromium and 12% Nickel (more resistant to (pit) corrosion and hydrogen embrittlement)



Introduction Swagelok

Marco van den Broek

Marco.van.den.broek@swagelok.nl

Nico Dissel

Nico.dissel@swagelok.nl

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