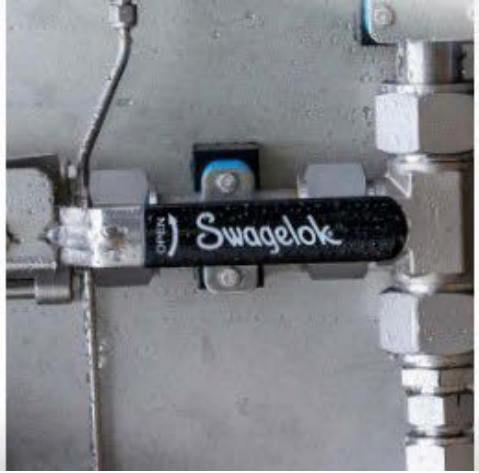


Hydrogen & Safety

Nico Dissel & Marco van den Broek

12 September 2023

Introduction Swagelok

Marco van den Broek

Sales Engineer & H2 Specialist

Nico Dissel

Sales Engineer & H2 Specialist & Trainer

When it comes to hydrogen, it's about

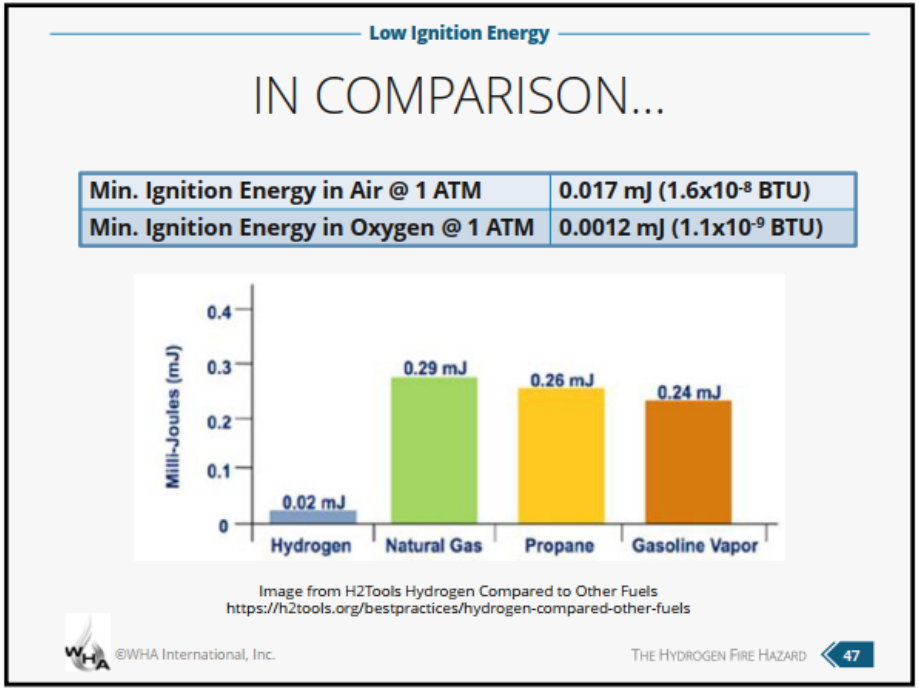
Safety First

Hydrogen Tech Talk Content

- Fire Triangle
- Lessons Learned
- Hydrogen Embrittlement
- Fitting Installation procedure
- Tubing
- Flex Metal Hoses
- Regulators
- Filters
- Needle Valves

Gain the Support You Need from Local Experts

Hydrogen – Low Ignition Energy

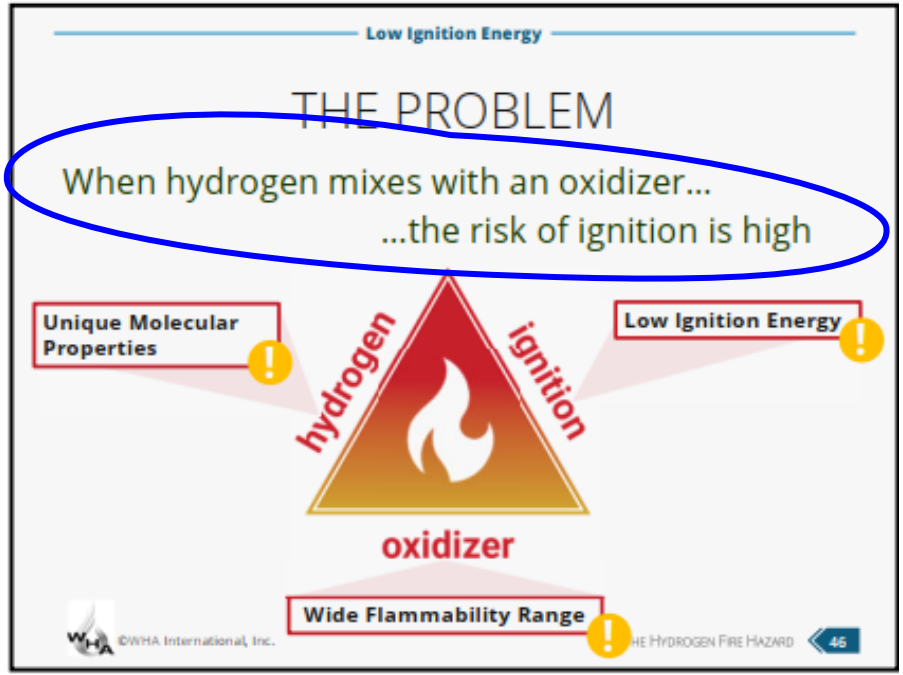


Info from: WHA International, Inc.

The energy required to initiate hydrogen combustion is much lower than that required for other common fuels (e.g., a small spark will ignite it.)

A static discharge from a human can reach 60 mJ or more. A spark that can be felt when touched, has about 20 mJ.

Fire Triangle



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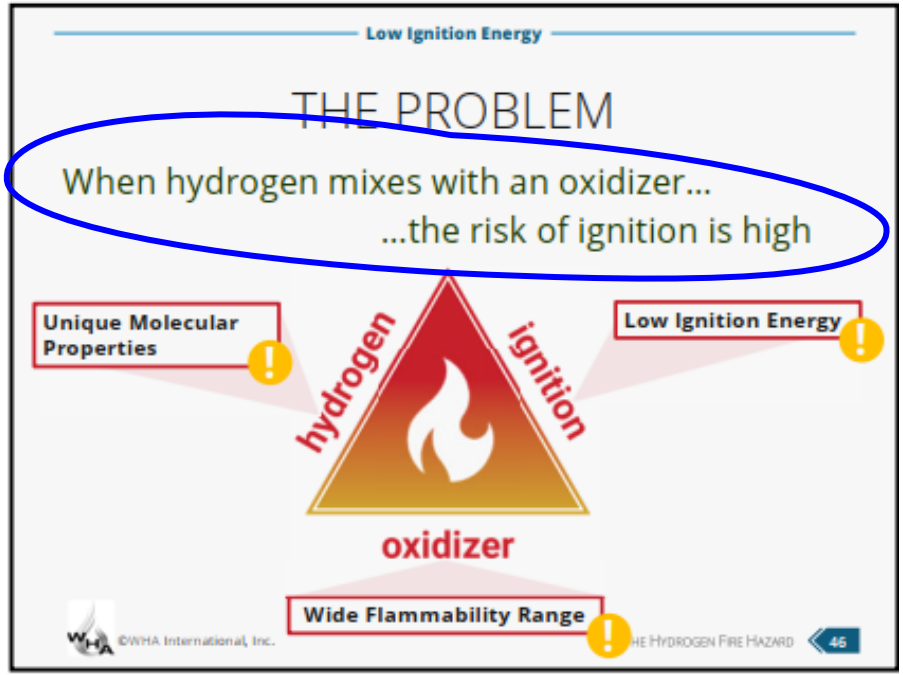
Fire Triangle



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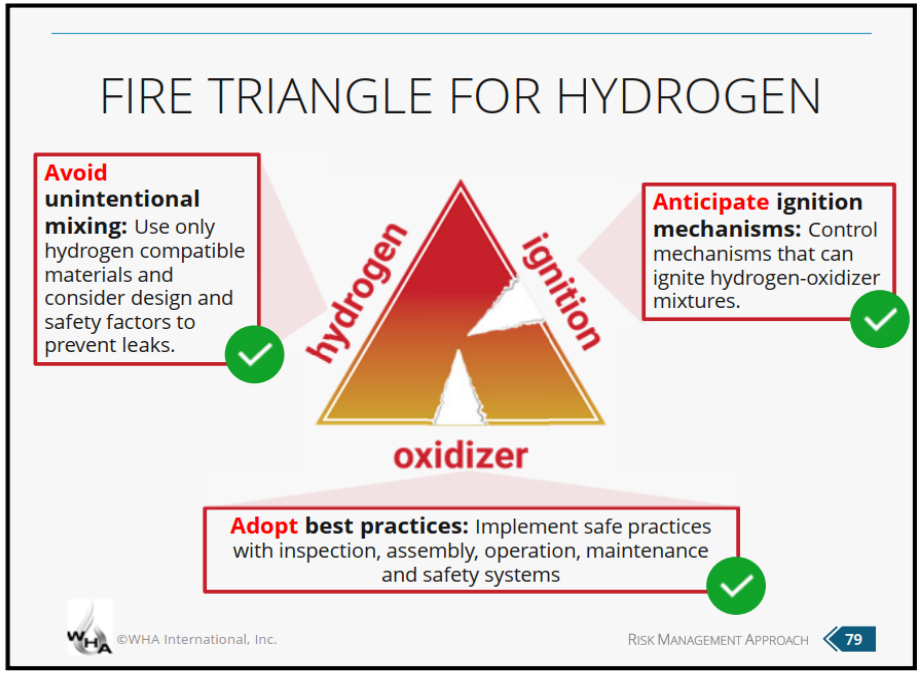


Info from: WHA International, Inc.

Leak Free Systems

KEEP HYDROGEN AWAY FROM OXYGEN

- Prevent external leaks from your hydrogen system to the surrounding environment

KEEP AIR (OXYGEN) AWAY FROM HYDROGEN

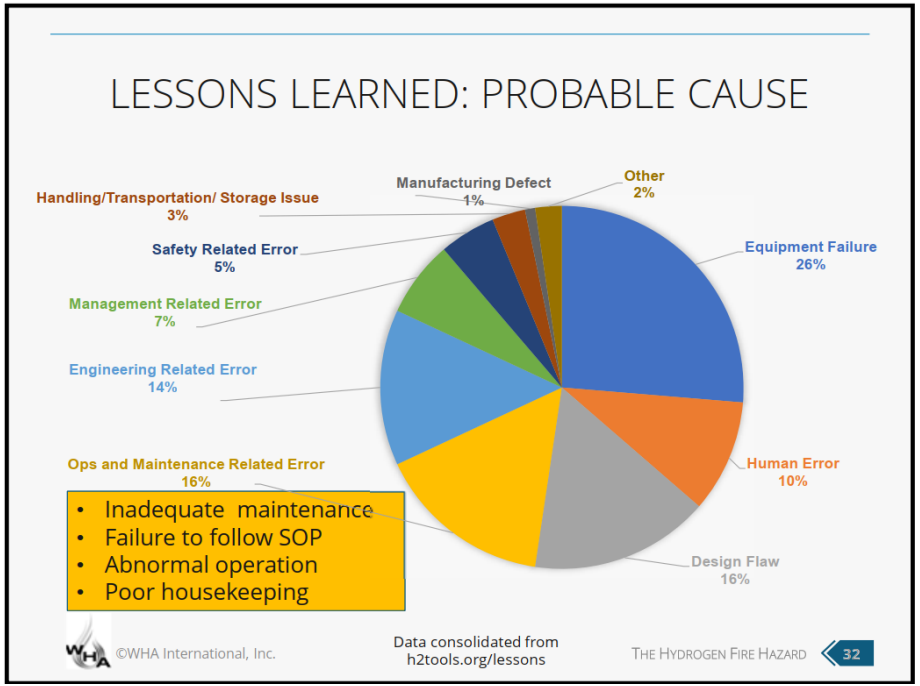
- Prevent in-leakage
- Prevent internal leakage

Leak Free & Safe Systems

How do we achieve a safe and reliable hydrogen system …….?

…….by using components suitable for hydrogen and by applying them correctly!

Lessons Learned



One of the reasons for equipment failure is due to improper installation or design errors

Info from: WHA International, Inc.

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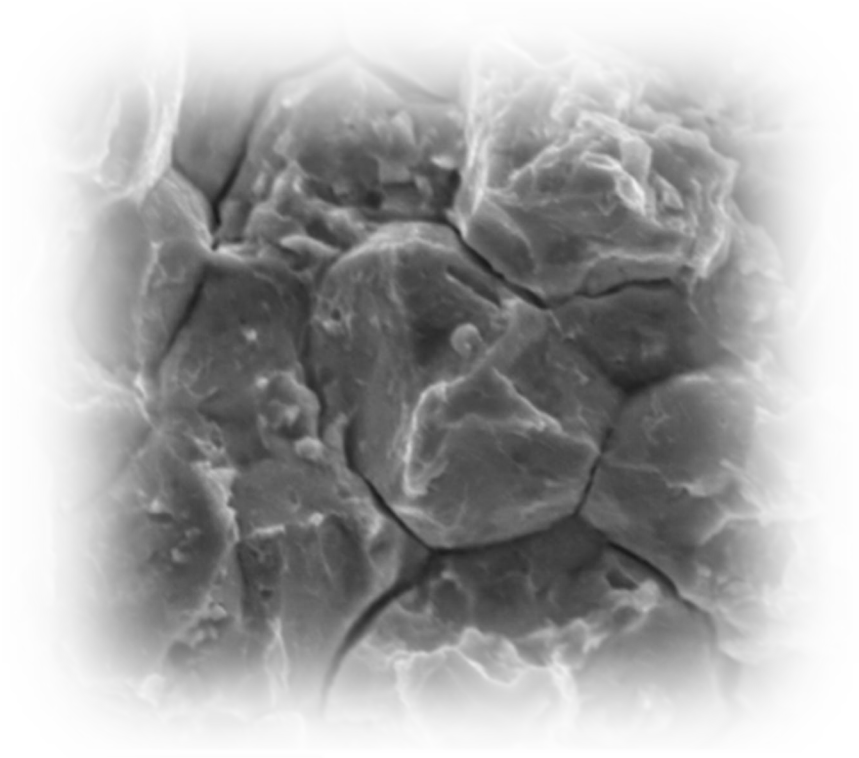
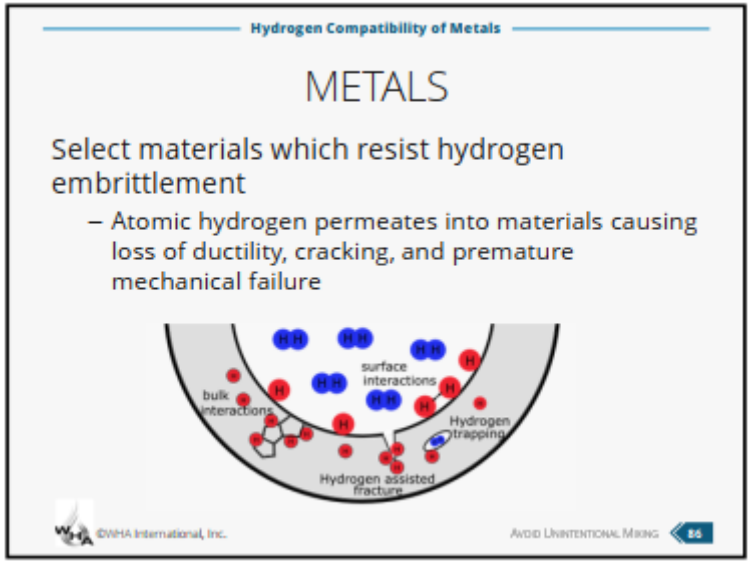
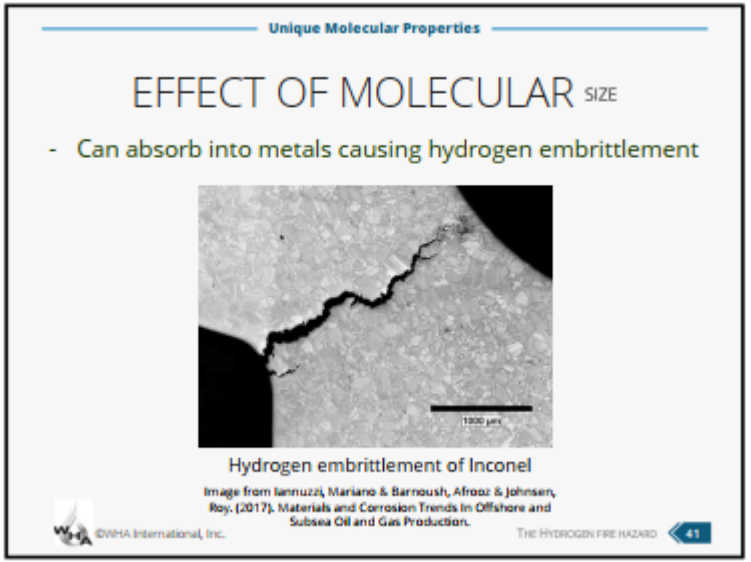
- Hydrogen Embrittlement
- Fitting Installation precedure
- Tubing
- Hoses & Flex Metal Hoses
- Regulators
- Filters
- Valves



Hydrogen Embrittlement

Hydrogen embrittlement, also known as hydrogen-assisted cracking or hydrogen-induced cracking, is a reduction in the ductility of a metal due to absorbed hydrogen and often as a result of an incorrect choice of material.





Hydrogen Embrittlement – Nickel content

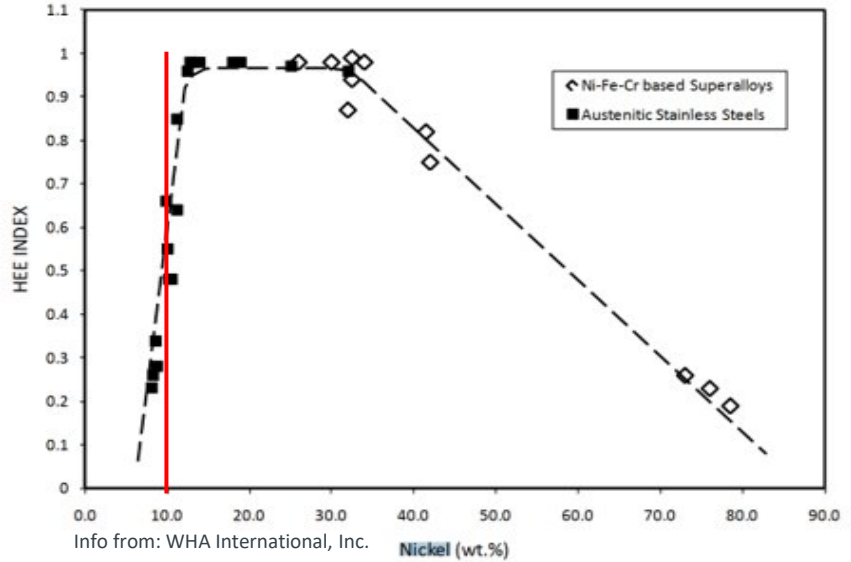


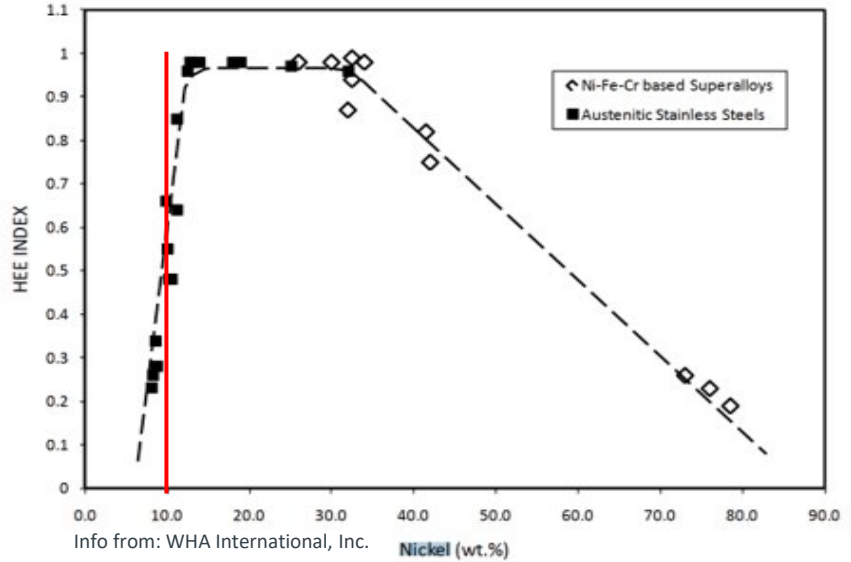
Figure 1: HEE Index for Fe-Ni-Cr superalloys and stainless steels as a function of Ni content (wt.%) (Data is from references in Table 7)
Source: NASA TM-2016-218602

Hydrogen Environmental Embrittlement (HEE) — The degradation of certain mechanical properties that occur while a material is under the influence of an applied stress and intentionally exposed to gaseous hydrogen environment

As the hydrogen gas pressure increases, the susceptibility for hydrogen embrittlement is also increased.

The chance of hydrogen embrittlement can be greatly reduced by using Austenitic Stainless Steel with a Nickel content between 10% and 30%.

Hydrogen Embrittlement – Nickel content



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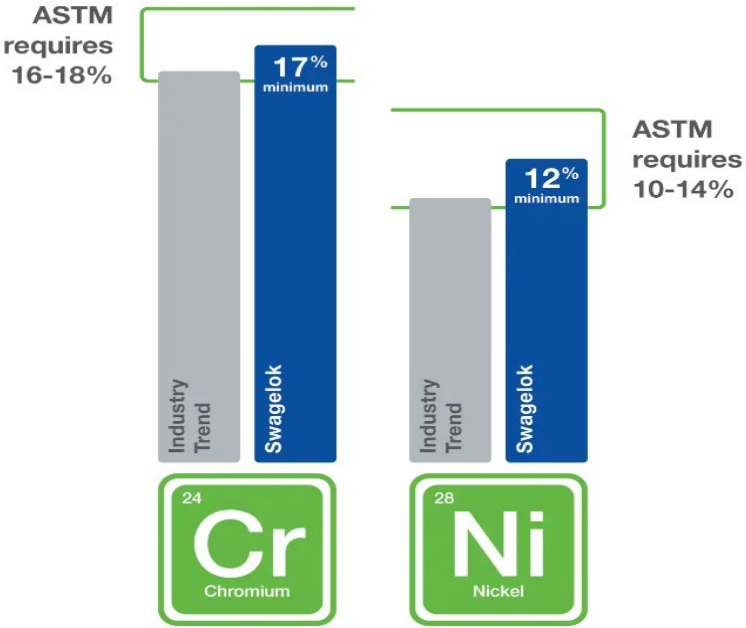


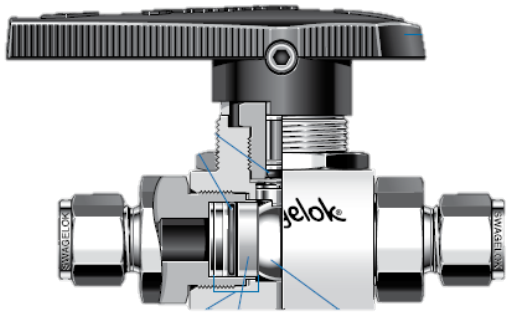
Swagelok 316 stainless steel tube, fittings and instrumentation valves exceed minimum ASTM specifications.

Hydrogen Embrittlement

Swagelok Hydrogen-compatible products have had the materials of construction reviewed for appropriate use with hydrogen.

Swagelok® Hydrogen-Compatible Products

- Metals that are susceptible to hydrogen embrittlement have been replaced with less susceptible materials for compatibility with hydrogen service.
- If in doubt, always contact a Swagelok (field) engineer or specialist so that the correct product selection can be made.



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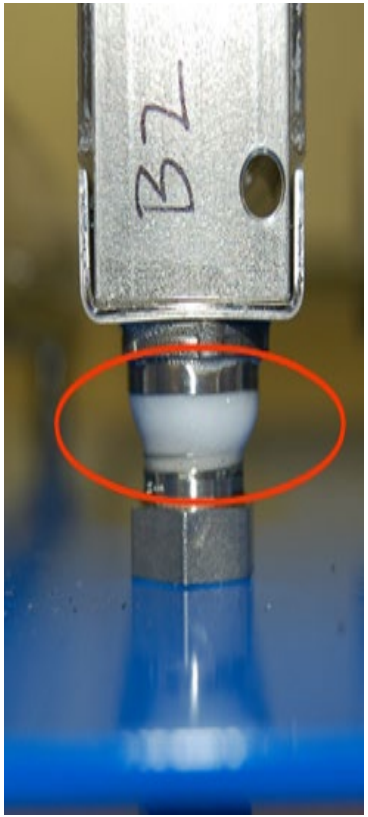
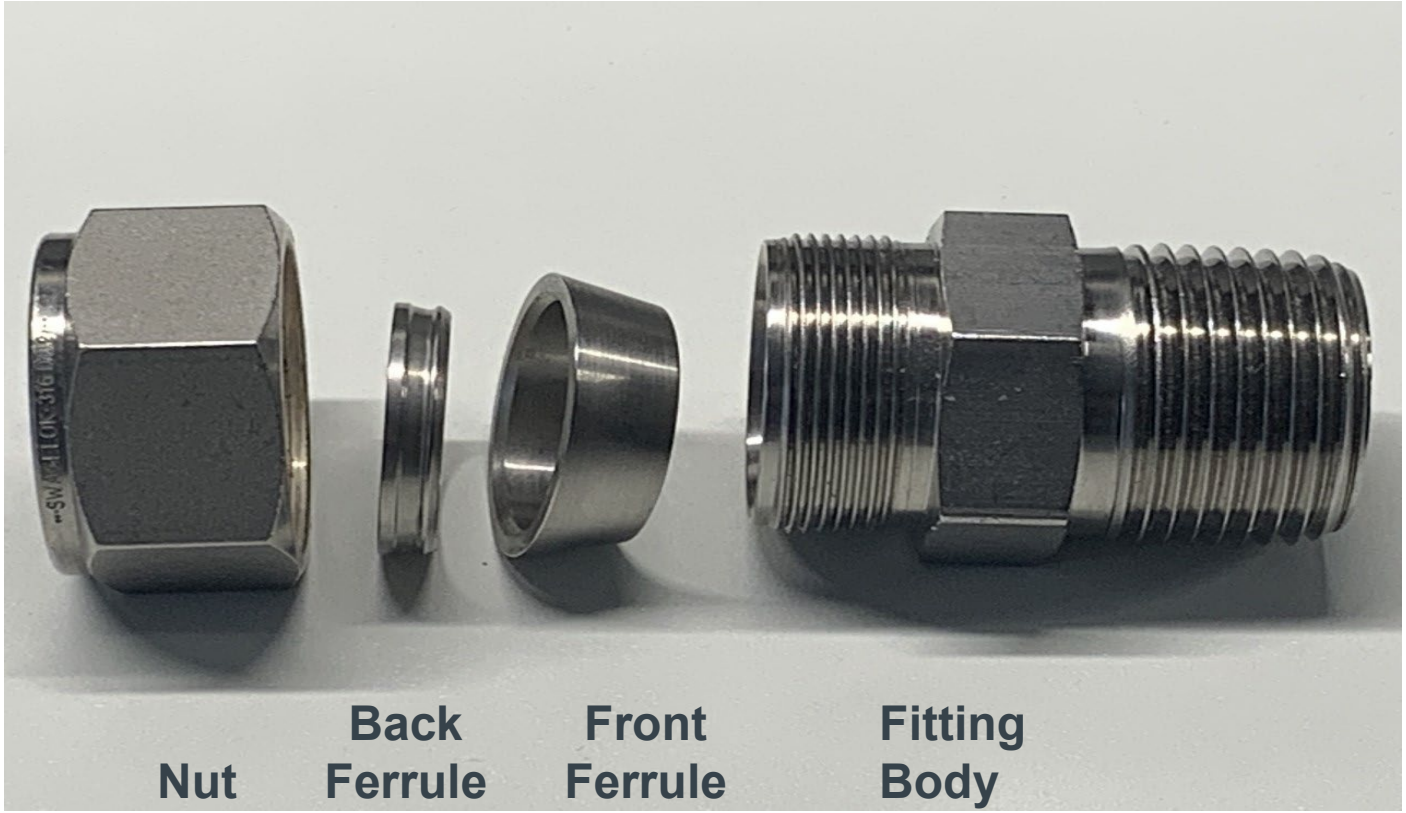
- Valves

Fitting Installation Procedure

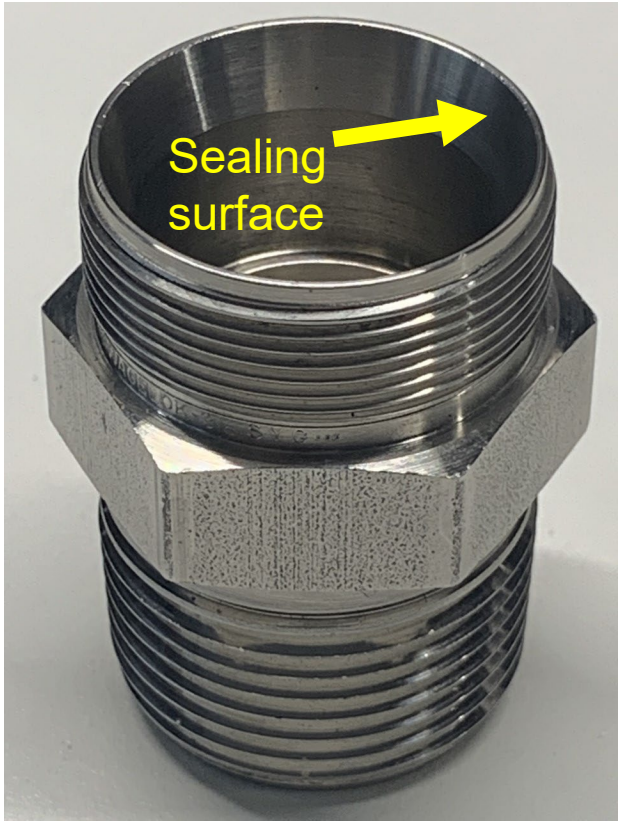


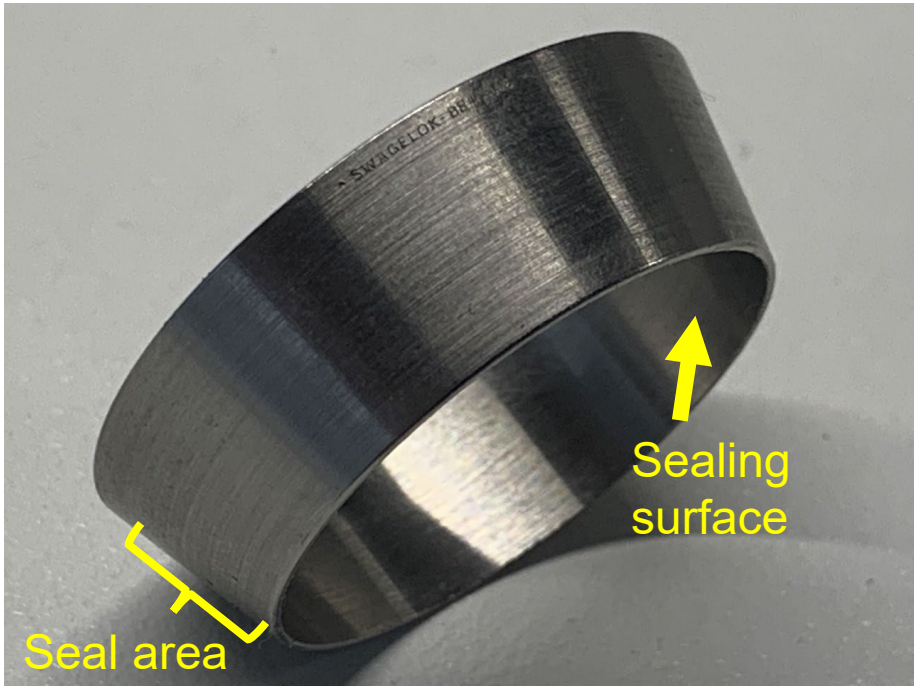
- Most leaks are the result of performing an incorrect installation, incorrect re-installation procedure
- Fortunately, these are often relatively small leaks, but sometimes so small that they only become visible after a few minutes by using a leak detection fluid

Fitting Installation Procedure



Fitting Installation Procedure – Sealing surfaces





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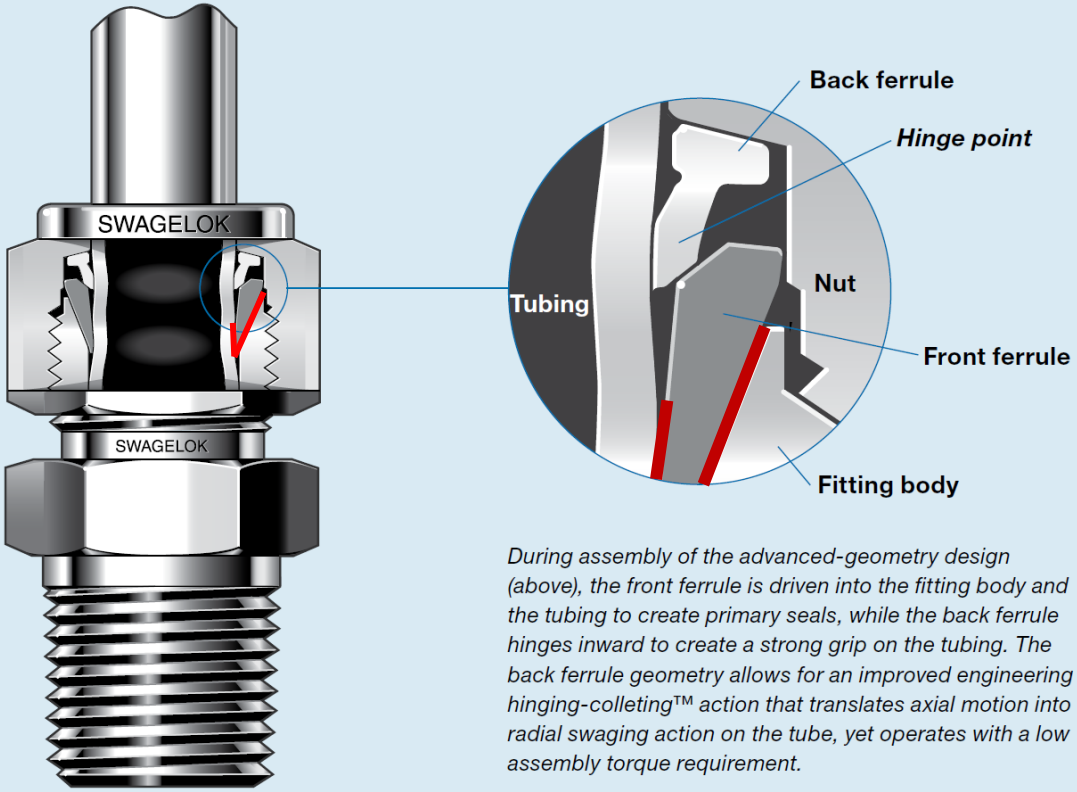
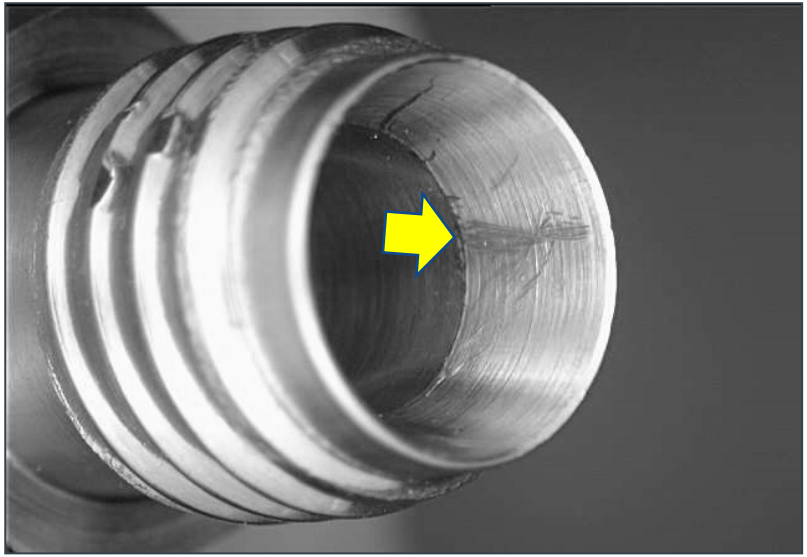
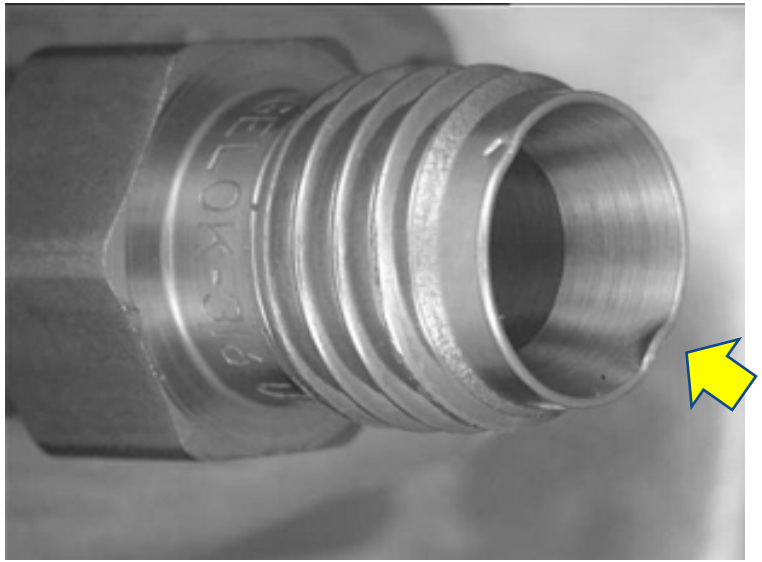


During assembly of the advanced-geometry design (above), the front ferrule is driven into the fitting body and the tubing to create primary seals, while the back ferrule hinges inward to create a strong grip on the tubing. The back ferrule geometry allows for an improved engineering hinging-colleting™ action that translates axial motion into radial swaging action on the tube, yet operates with a low assembly torque requirement.

During installation there is a Burnishing or Polishing action of body bevel by the front ferrule.

Fitting Installation Procedure

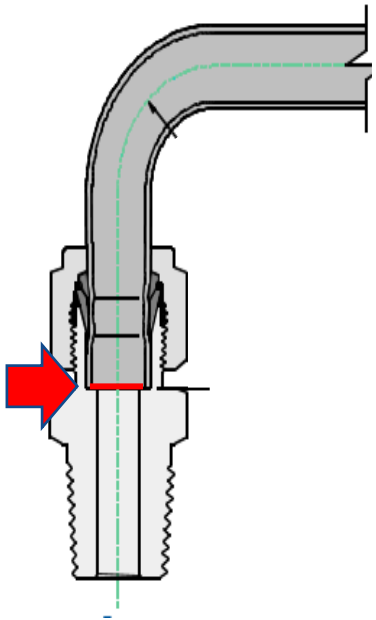




When the seal area is damaged the front ferrule is unable to polish this damage away which most of the times resulting in a leak.

Fitting Installation Procedure – Depth Marking Tool

- Minimum straight lengths of tubing are needed to ensure proper insertion depth into the fitting



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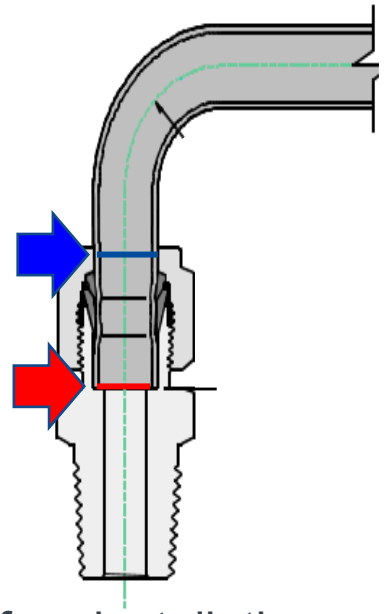


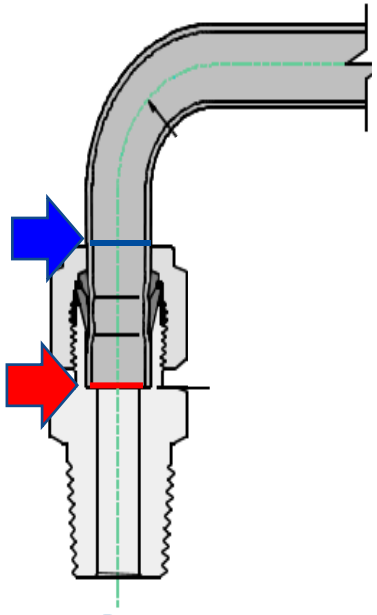
Before installation

Depth Marking Tools

Swagelok depth marking tools help ensure that tubing is bottomed on the shoulder inside the Swagelok tube fitting body.

Fitting Installation Procedure – Depth Marking Tool

- Minimum straight lengths of tubing are needed to ensure proper insertion depth into the fitting



After installation

Depth Marking Tools

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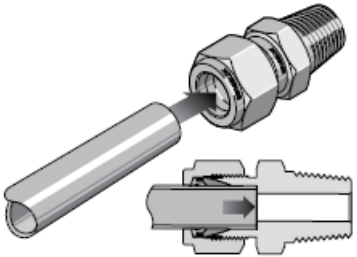
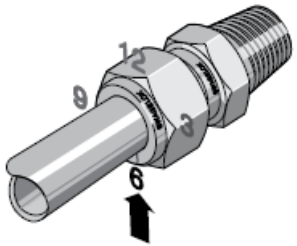
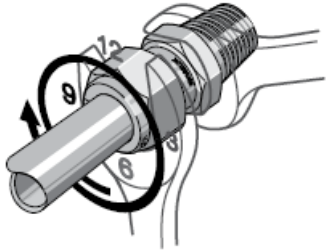
Fitting Installation Procedure



Fully insert the tube into the fitting and against the shoulder; rotate the nut finger-tight.
High-pressure applications and high safety-factor systems: *Further tighten the nut until the tube will not turn by hand or move axially in the fitting.*



Mark the nut at the 6 o'clock position.



While holding the fitting body steady, tighten the nut one and one-quarter turns to the 9 o'clock position.

For 1/16, 1/8, and 3/16 in.; 2, 3, and 4 mm tube fittings, tighten the nut only three-quarters turn to the 3 o'clock position.

3/4 turn from finger-tight when tube diameter is smaller than 1/4 inch or 6 mm

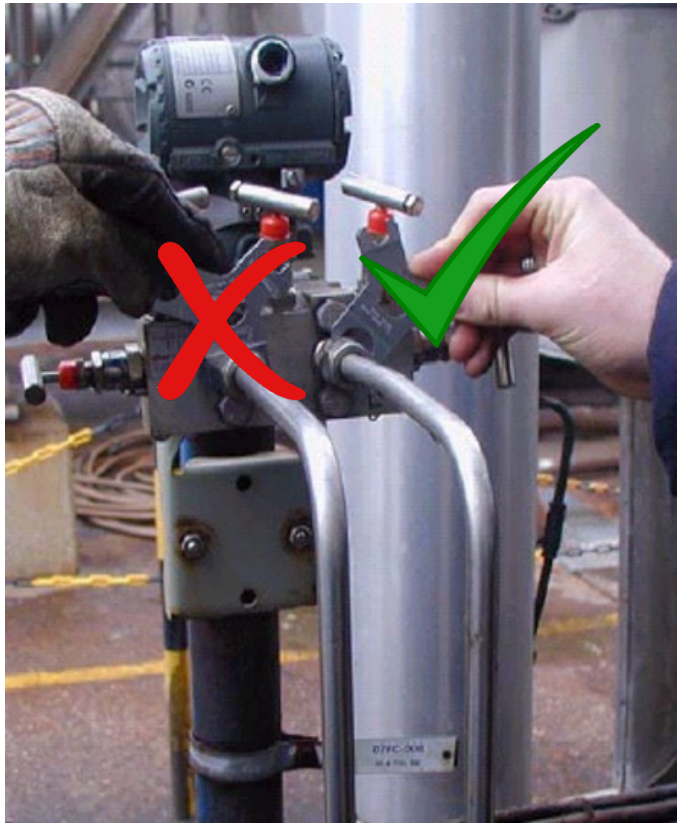
1 ¼ turn from finger-tight when tube diameter is 1/4 inch / 6mm and larger

Fitting Installation Procedure

Swagelok gap inspection gauges assure the installer or inspector that the fitting has been sufficiently pulled up on initial installation. All metal Swagelok tube fittings are gaugeable with the exception of a few forged bodies in aluminum.

If the gauge will not enter the gap, the fitting is sufficiently tightened.

Fitting Installation Procedure



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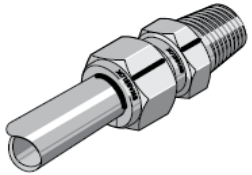
If the gauge will not enter the gap, the fitting is sufficiently tightened.

Fitting Re-assembly Procedure / All Sizes

Reassembly—All Sizes

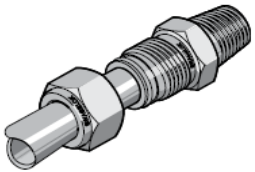
You may disassemble and reassemble Swagelok tube fittings many times.

⚠ **Always depressurize the system before disassembling a Swagelok tube fitting.**



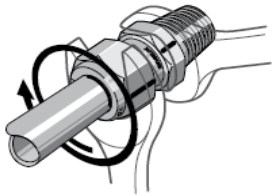
Prior to disassembly, mark the tube at the back of the nut; mark a line along the nut and fitting body flats.

Use these marks to ensure that you return the nut to the previously pulled-up position.



Insert the tube with preswaged ferrules into the fitting until the front ferrule seats against the fitting body.

Over 1 in./25 mm sizes: *If needed, reapply lubricant lightly to the body threads and the rear surface of the back ferrule.*



While holding the fitting body steady, rotate the nut with a wrench to the previously pulled-up position, as indicated by the marks on the tube and flats. At this point, you will feel a significant increase in resistance. Tighten the nut slightly.

⚠ **Do not use the Swagelok gap inspection gauge with reassembled fittings.**

While holding the fitting body steady, rotate the nut with a wrench to the previously pulled-up position, as indicated by the marks on the tube and flats. **At this point, you will feel a significant increase in resistance. Tighten the nut slightly.**

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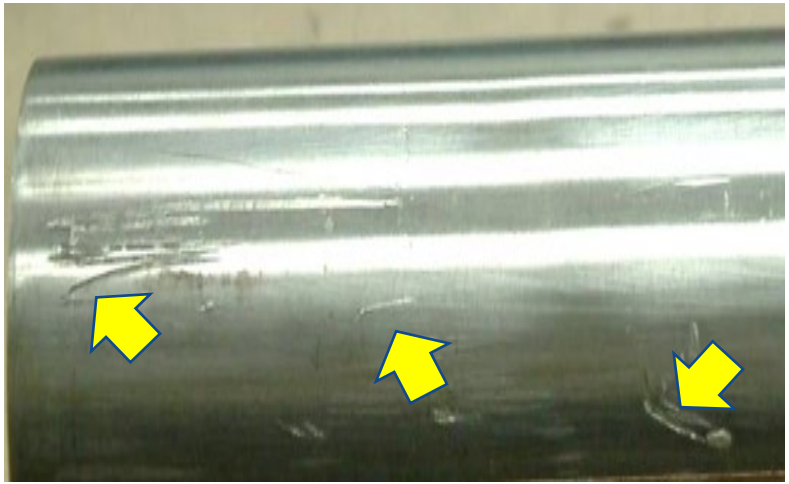
Tubing - Requirements



Damaged and scratched tubing due to improper storage

For a leak-free connection, it is crucial that the tubing meets the following minimum requirements:

- Within the required hardness limits (always check the supplied 3.1 certificate)
- Scratch free
- Correct diameter (fractional versus metric)
- Conform the Swagelok ‘Tubing Data’ information to be find in the’ brochure MS-01-107
- Deburred and cleaned

Tubing - Deburring

The need for deburring tubing is often underestimated. We also often see this during our fitting training sessions. Usually, internal leaks on valve or regulator seats are a reason for not or not properly deburring. **Each loose particle can also become a source of ignition, at the expense of safety.**

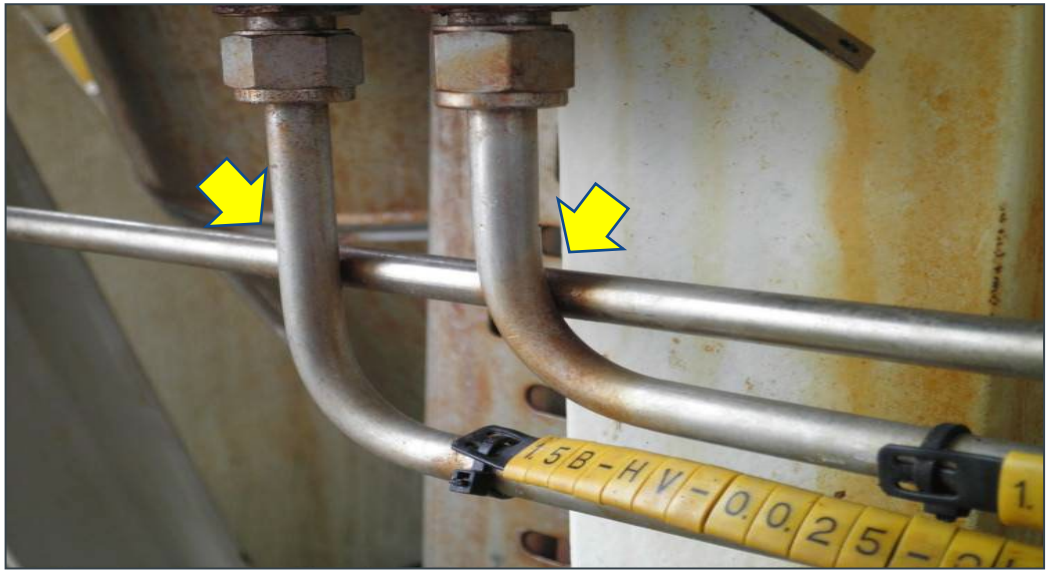
Before deburring

After deburring

Use of a tube cutter

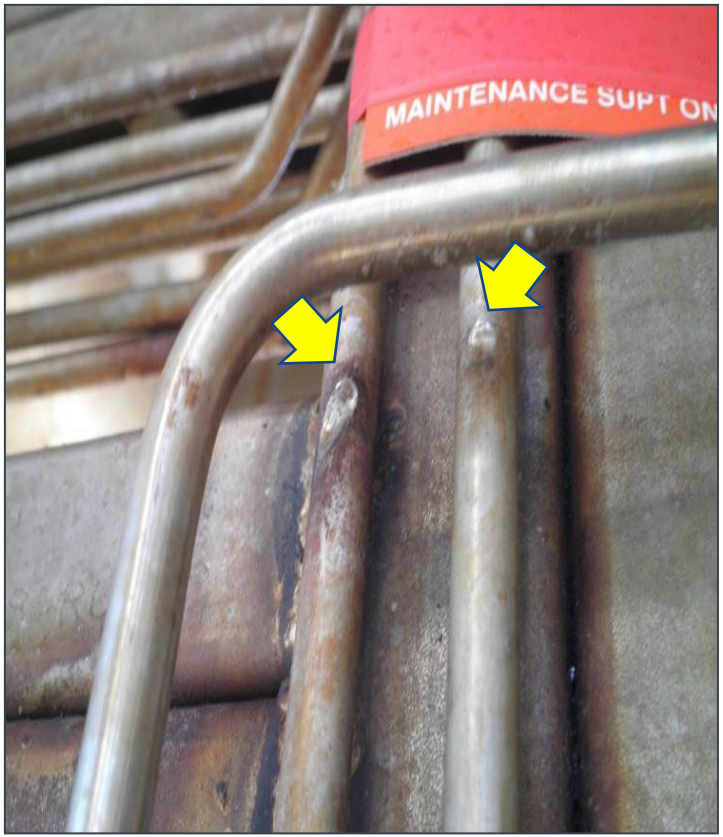
Use of a hacksaw

Tubing - Supporting



During On-Side-Surveys that we carry out, we unfortunately regularly see that tubing is not fully supported, resulting in damage to the tubing.

Tubing - Supporting



- Shearing tubing together can result in a much thinner wall
- In the worst case, the tubing wall can become extremely thin that it tears, and a serious unsafe situation arises when hydrogen can escape at high pressures

Tubing - Supporting

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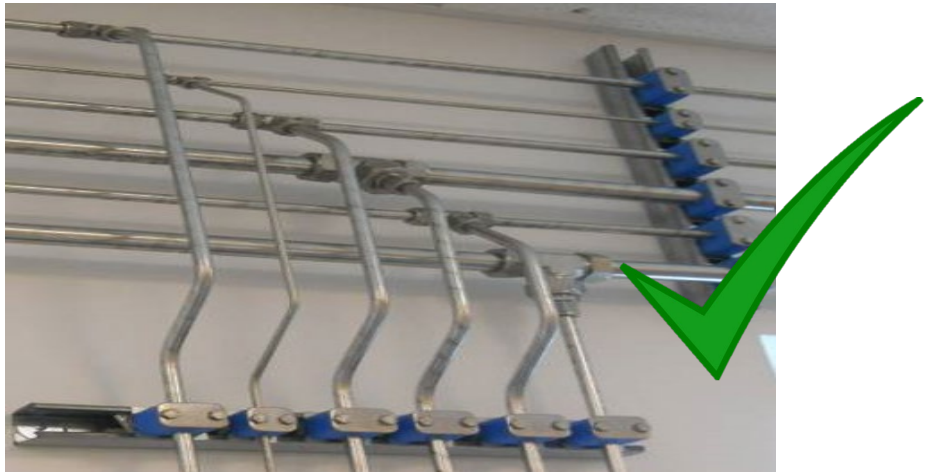
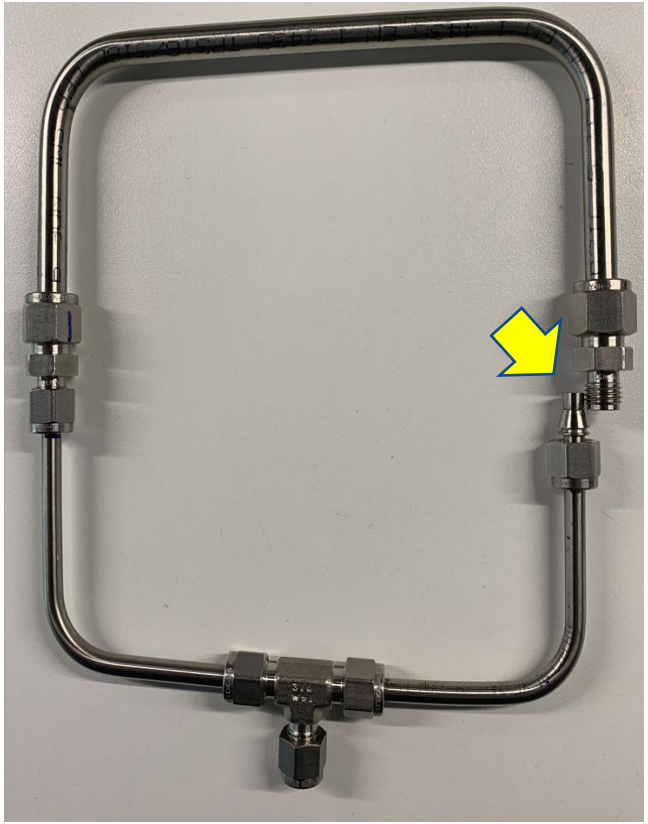
- In the worst case, the tubing wall can become extremely thin that it tears, and a serious unsafe situation arises when hydrogen can escape at high pressures



Tubing - Bending



For an optimal leak-free connection, the tubing that has been bent must be mounted stress-free in the relevant fitting.

Any tension or side load should be avoided.

During our Bending Training, a lot of attention is paid to this. You learn to bend with exactly the right size and tension-free.

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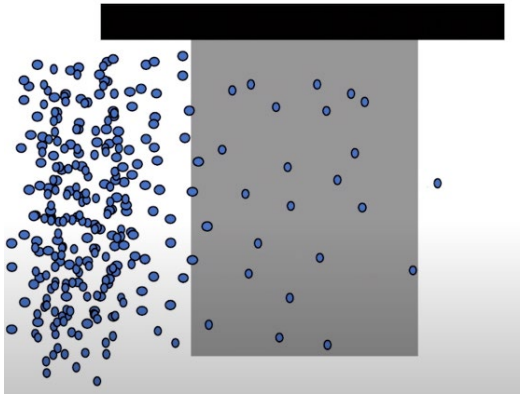
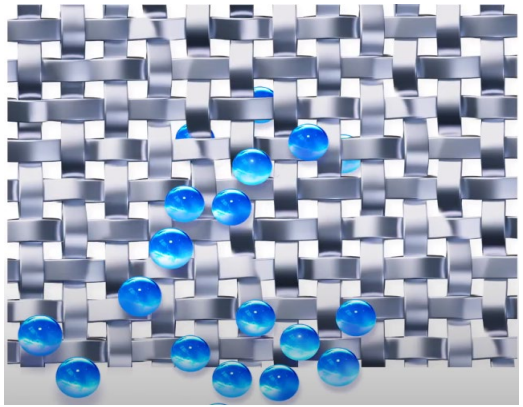
Hoses & Flex Metal Hoses

It can be difficult to select the right hose from the many different types of hoses.

- What is the design pressure?
- Do I need a safety Tie-Down cable?
- What about static discharge?
- What kind of end connections?
- Where is the hose used outside or inside?
- Is the environment corrosive (ig. off & on shore applications)?
- How about the bend radius of hoses?
- What about movement?
- What about permeability?

Hoses & Flex Metal Hoses - Permeability



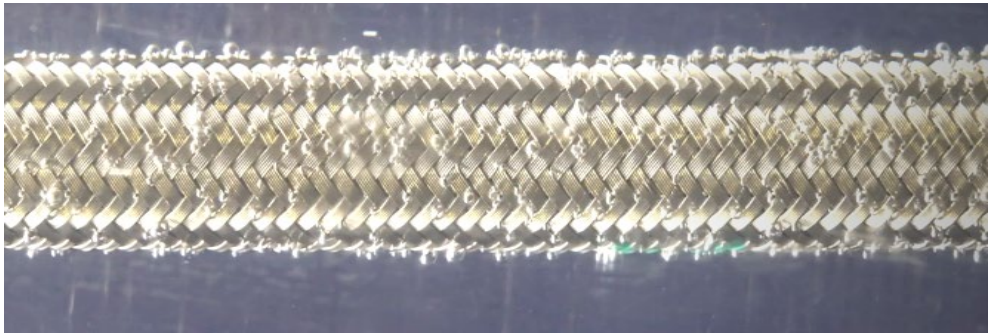


What is Permeation:

The flow of Gas (H2) molecules through a solid material. Usually, it concerns plastic products

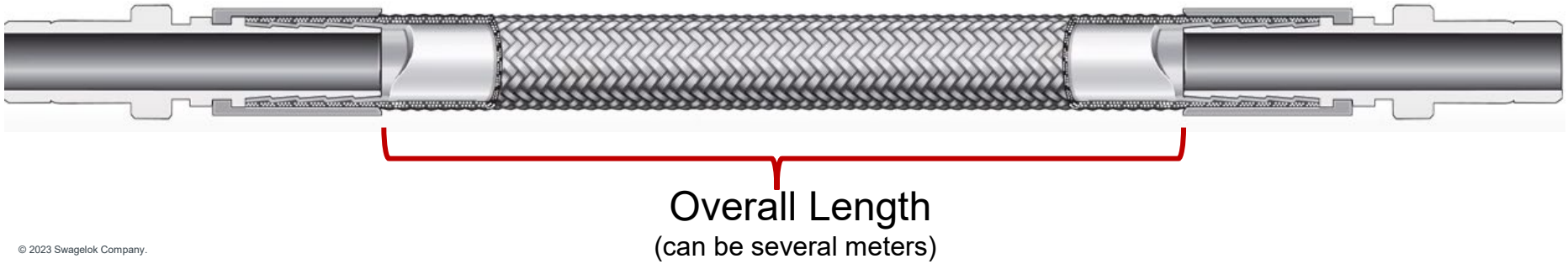
- In fact, every material is permeable
- PTFE hose cores are permeable and not are advised for use with thin gas like Helium and Hydrogen
- The best choice for use in hydrogen **are Flex metal hoses**

Hoses & Flex Metal Hoses - Permeability

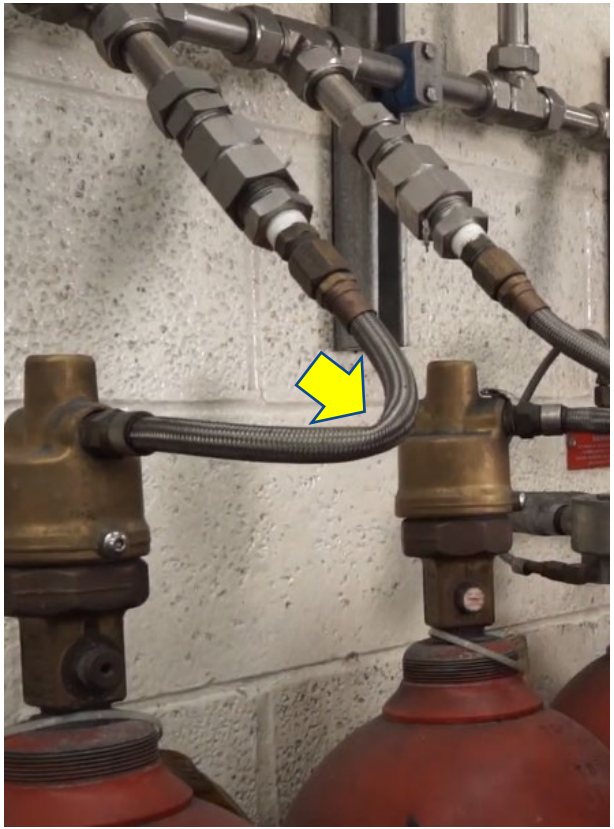


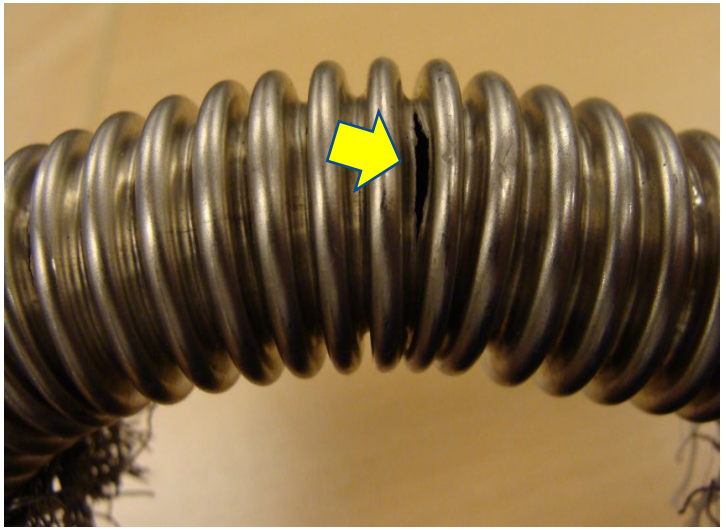
In many situations, permeation need not be an issue. However, for hydrogen systems, permeation is **not allowed**. Any form of permeability (= leakage) creates an unsafe fire-hazardous situation.

Depending on the length of the hose, considerable leakage can occur with a hose with a Teflon or PTFE core.



Hoses & Flex Metal Hoses – Installation issues





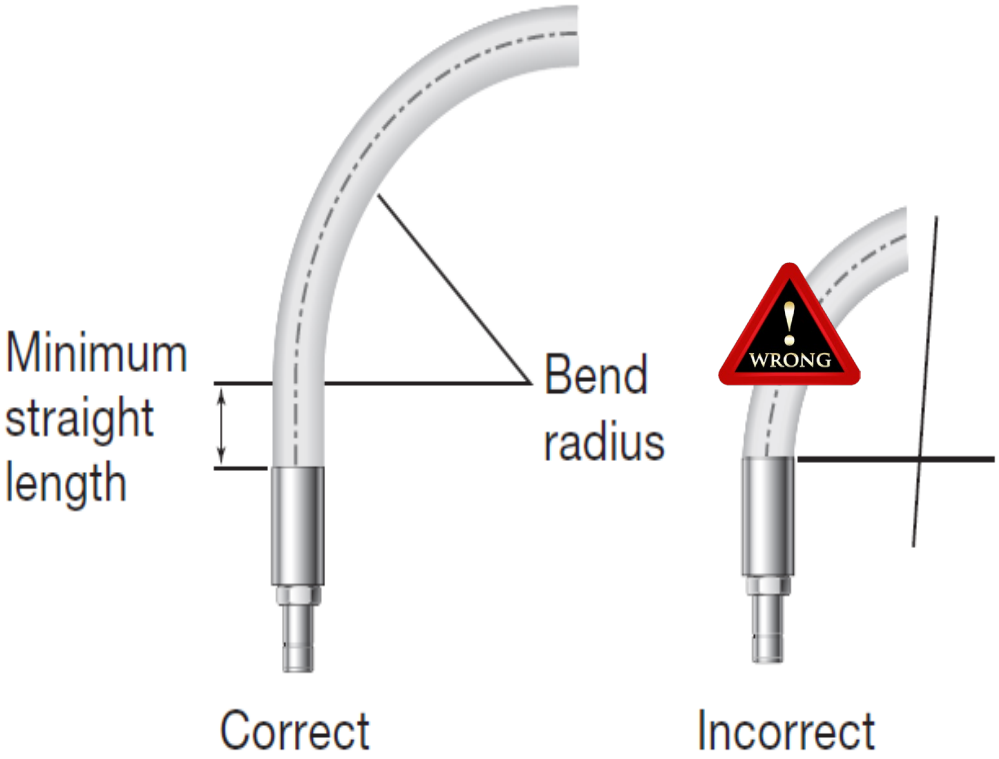
Most leaks are caused by incorrect installation

- Bend radius too small
- Damaged Hose Braid
- Twisted hoses
- Running into structure
- High tension on hoses

Hoses & Flex Metal Hoses – Installation issues

- Avoid any damage to the hose braid
- Hose braid participates in the strength of the hose
- Establish an inspection schedule based on system application and replacement history
- Dirt in the braid can accelerate corrosion processes. Prevent dirt from collecting in the braid and keep it clean

Hoses & Flex Metal Hoses – Installation instructions



Minimum Bend Radius

Follow minimum bend radius requirements for your hose. Installing hose with smaller bends may kink hose and reduce hose life.

Hoses & Flex Metal Hoses – Installation instructions

Correct

Incorrect

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

Hoses & Flex Metal Hoses – Installation instructions

Hose Strain

Elbows and adapters can be used to relieve hose strain

Hoses & Flex Metal Hoses – Installation instructions

Technical Data

Nominal Hose Size in. (mm)	Inside Diameter in. (mm)	Outside Diameter in. (mm)	Minimum Inside Bend Radius in. (cm)		Temperature Range °F (°C)	Working Pressure at 70°F (20°C) psig (bar)	Burst Pressure at 70°F (20°C) psig (bar)	Bulk Hose Weight lb/ft (kg/m)
			Static	Dynamic				
1/4 (6.4)	0.25 (6.4)	0.46 (11.7)	1.25 (3.18)	4.20 (10.7)	–65 to 450 (–53 to 230)	3500 (241)	14 000 (964)	0.13 (0.19)
3/8 (9.6)	0.38 (9.6)	0.57 (14.5)	1.75 (4.44)	4.40 (11.2)		3000 (206)	12 000 (826)	0.17 (0.25)
1/2 (12.7)	0.50 (12.7)	0.76 (19.3)	2.50 (6.35)	6.38 (16.2)		1800 (124)	7 200 (496)	0.24 (0.36)
3/4 (19.0)	0.75 (19.0)	1.00 (25.4)	3.50 (8.89)	4.55 (11.6)		1250 (86.1)	5 000 (344)	0.36 (0.54)
1 (25.4)①	1.00 (25.4)	1.32 (33.5)	5.50 (14.0)	7.15 (18.2)		1000 (68.9)	4 000 (275)	1.1 (1.6)

Pressure-temperature ratings may be limited by the end connections.

① Constructed with two stainless steel braids and no fiber braid reinforcement.

- Every type of hose has, depending on their diameter, a ‘Static’ and a ‘Dynamic’ minimum Bend Radius
- Consider replacing hoses every 3 year regardless of out come of leak checks depending on the application

Hydrogen Tech Talk Content

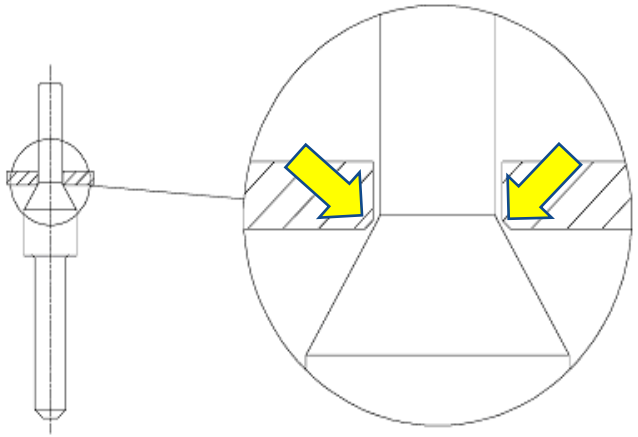
- Fire Triangle
- Lessons Learned
- Hydrogen Embrittlement
- Fitting Installation precedure
- Tubing
- Hoses & Flex Metal Hoses
- Regulators
- Filters
- Valves

Pressure Regulators

The most common causes of a malfunctioning pressure regulator are:

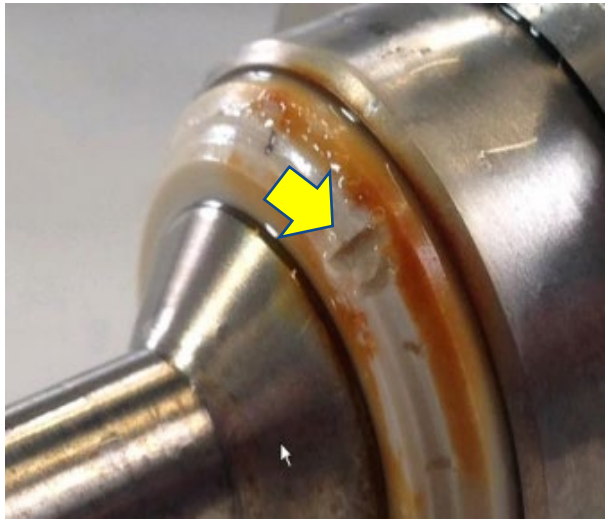
- Damage to the seat and/or membrane/piston because of pressure spikes above the set pressure
- Wrong sizing (design issue)
- Improper use of the regulator
- Dirt particles from the system that can collect on the seat of the regulator, preventing the regulator from closing completely (Creep)

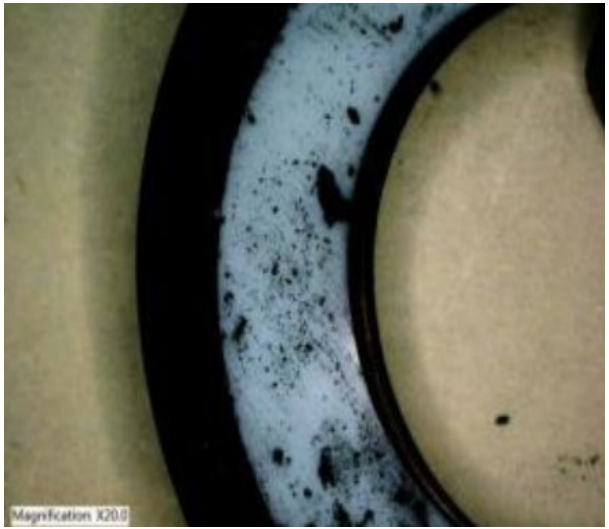
Pressure Regulators - Creep



- ‘Creep’ can cause outlet pressure increases over time. If the poppet does not fully seat in the orifice, inlet pressure may continue to bleed through the orifice
- Over time this leakage can increase the outlet pressure. If no PRV is placed behind the regulator, in the worst case the set pressure can become equal to the inlet pressure

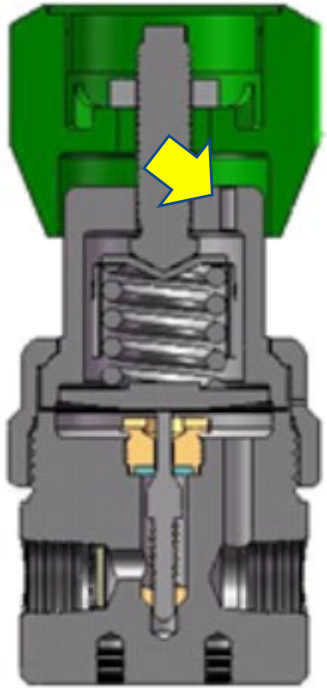
Pressure Regulators - Issues





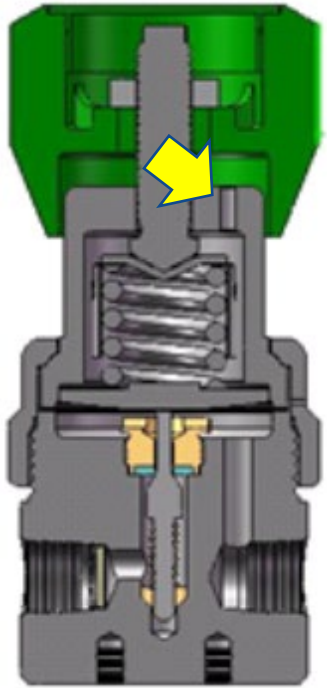
- Most common cause of leakage of the regulator is dirt from the system such as PTFE tape as a result of incorrect applying tape to tapered threads, metal particles due to incorrect deburring or not cleaned tubing after deburring and other debris from the system
- Therefore, the use of a filter that is suitable for hydrogen is recommended

Swagelok K series Pressure Regulators



For the correct performance of the regulator, the spring chamber must always be connected to ambient through the Vent Opening

Swagelok K series Pressure Regulators



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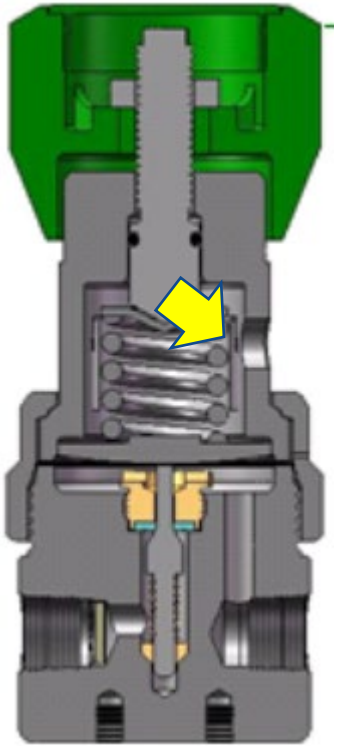

For Hydrogen (and other flammable or toxic gas) applications it is advised to use regulators with a vent opening on the side of the spring chamber in order to safely discharge the hydrogen during a possible leak. Via a threaded connection a tube can be installed to this vent opening to vent in a safely manner.

Swagelok RHPS series Pressure Regulators

- The Swagelok RHPS series reducing pressure regulators are standard equipped with a vent opening on the side of the regulator
- This opening must always remain open!!
- A tube can be connected via a threaded connection to safely discharge the hydrogen gas during a calamity
- This opening should always be connected to ambient for the best performance of the regulator
- How a pressure regulator works and can best be used is explained in the February tech talk

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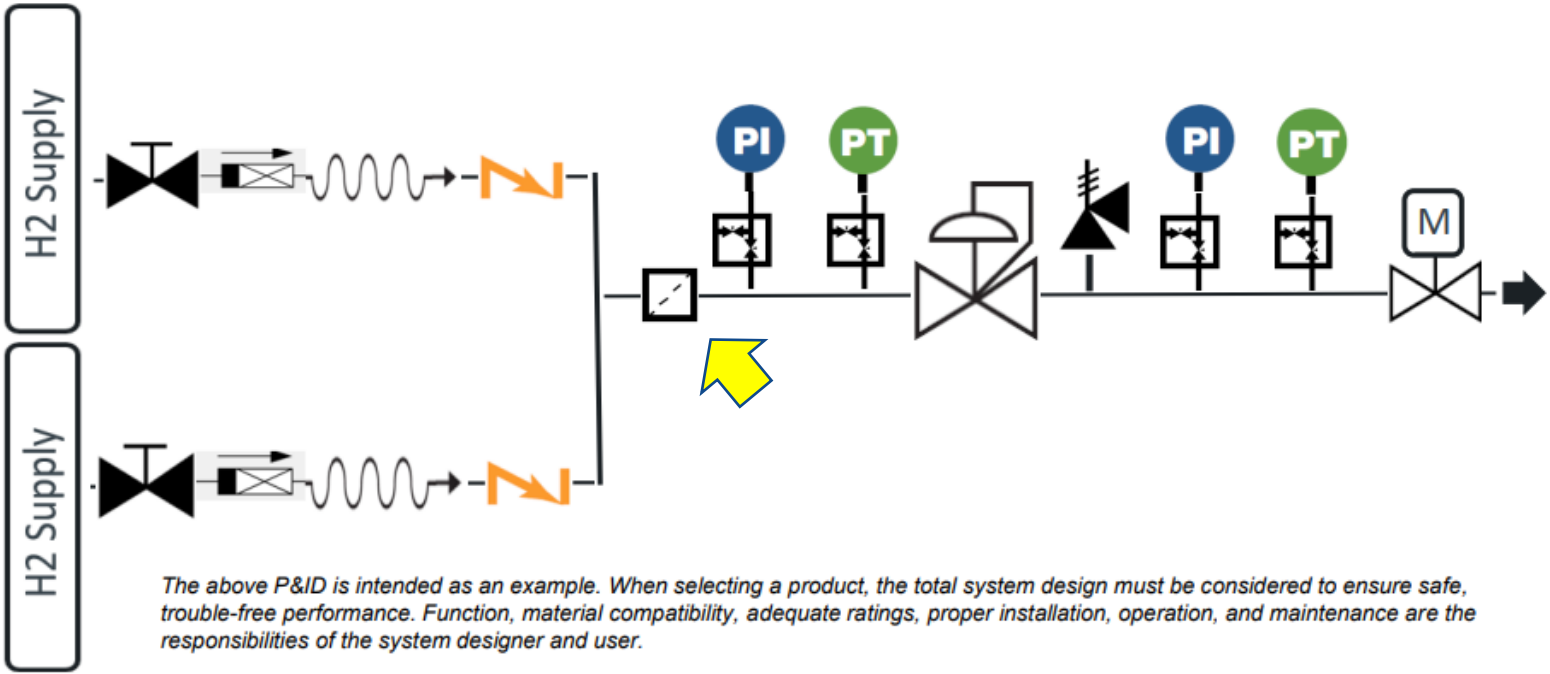
Hydrogen Filters



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.

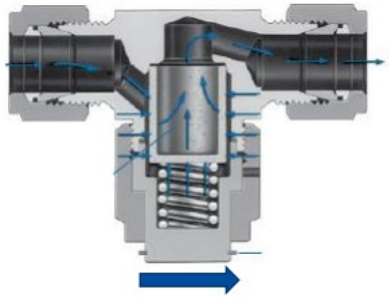
Hydrogen Filters

To prevent problems such as damaged valve seat, regulator seats and other critical system components, the use of a filter is advised!

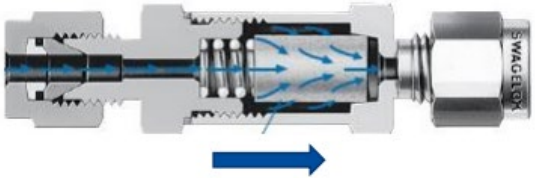
Do I have the correct filter?

- Maximum allowable temperature & working pressure?
- Pore size?
- Filtration Area?
- Hydrogen compatible (ATEX / Static Discharge)?
- Flow capacity?
- Differential Pressure Rating?
- Flow direction?

Hydrogen Filters - Types



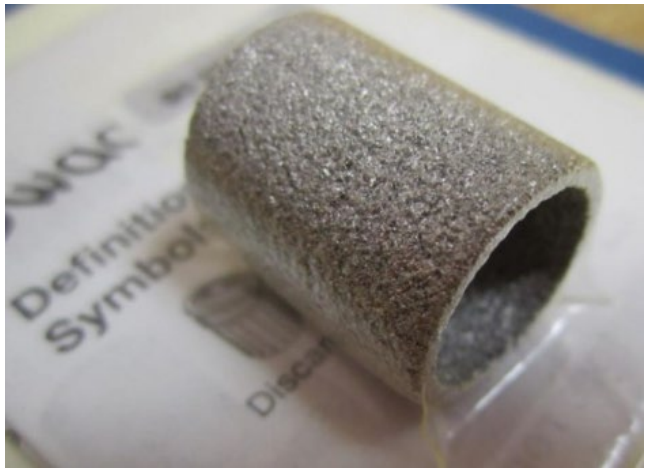
Tee-Type Filter



Inline Filter

- When installing a filter, it is important to pay attention to the correct flow direction, often indicated by an arrow on the body
- Tee Type Filter simplifies element change compared to an in-line filter
- T type Filter element can be replaced without removing body from system
- Unfortunately, we sometimes see that a filter has correctly been placed in the system, but it has never been checked whether the filter element needs to be renewed

Hydrogen Filters - Damage



New Filter Element

Collapsed Filter Element

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)		—

- To high differential pressure across the filter may result in a collapsed filter element. An unfiltered system can cause component seat leakage
- A collapsed filter element can be caused by an excessive flow or a completely contaminated element

Hydrogen Filter - Selection

- For a good and safe working system it is important that the right filter with the right capacity is chosen.
- For large flows, filters with a larger filtration area may be required.
- A larger filtration area often has a longer service life.
- A certain maximum differential pressure applies to each type of filter, which must be checked regularly !!
- Always check the data sheet of the relevant filter.

Hydrogen Filter – Periodic Maintenance

- Periodic maintenance inspection of a filter is crucial for a correctly and safely operating hydrogen system

  - ❖ **Check periodically the differential pressure!**
  - ❖ **Change periodically the element!**

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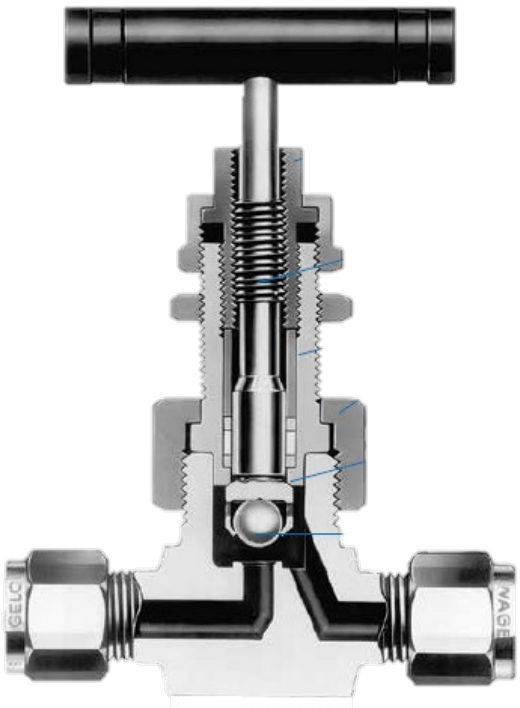
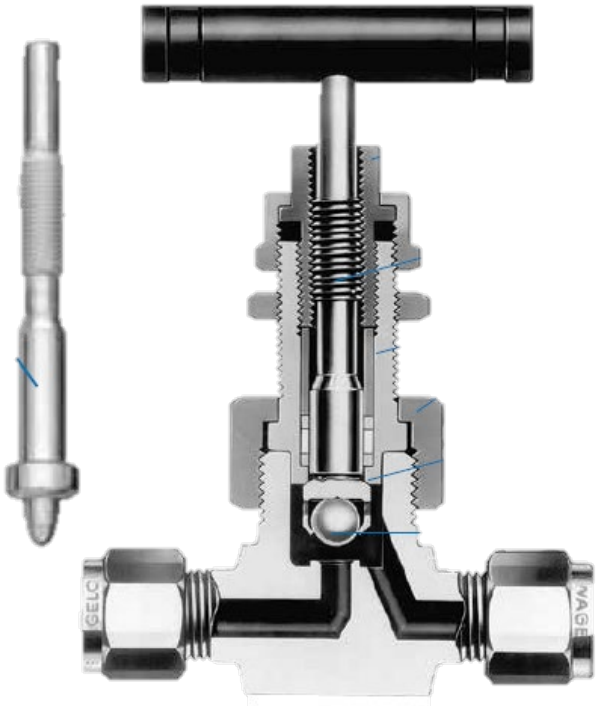
Needle Valves



To allow gas to enter a system in a controlled manner and depending on the pressure, a needle valve is often used instead of a ball valve which has been developed for fully open or fully closed.

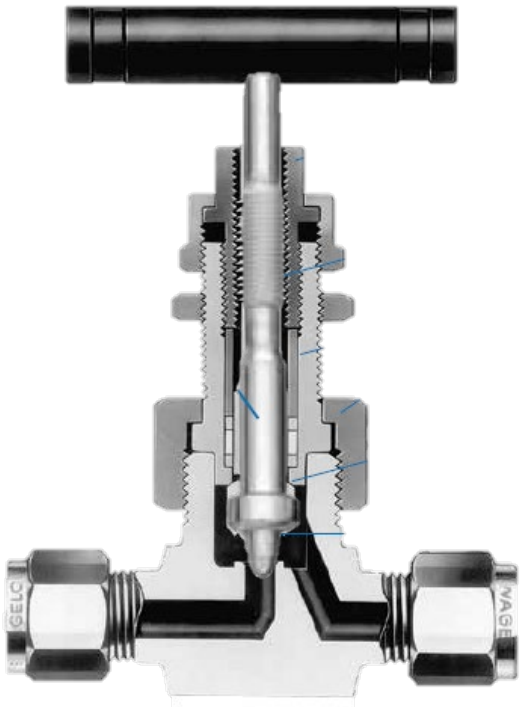
A Needle valve is usually provided with a metal Non Rotating Ball stem tip which is made of a hard material such as a cobalt alloy. Cobalt alloy can be suspectable for hydrogen embrittlement.

Needle Valves



Often the stem tip is replaced by a regulating stem tip with a **soft seat** (PTFE) which is preferred when we have to deal with a thin gas like hydrogen.

Needle Valves

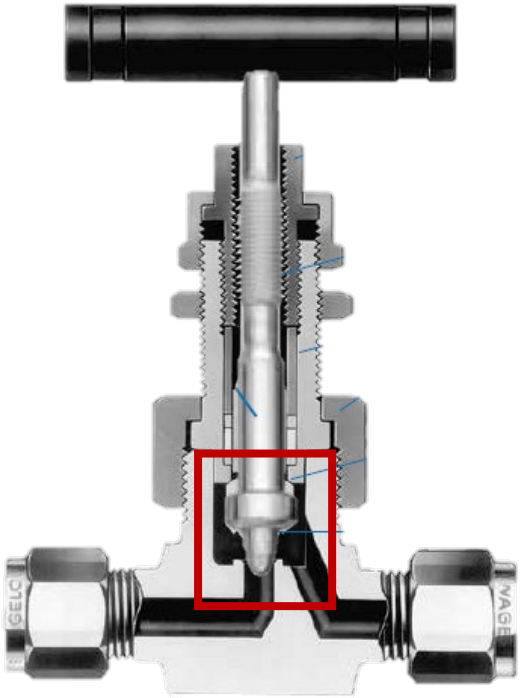


Often the stem tip is replaced by a regulating stem tip with a soft seat (PTFE) which is preferred when we have to deal with gas like hydrogen.

If a soft-seated stem is used, it is important that the torque/force required to close the valve **is just enough to close the valve properly.**

The greater the force with which the valve is closed, the greater the chance that the soft seat in the stem will be damaged, shorten the service life of the valve and can resulting in leakage!!

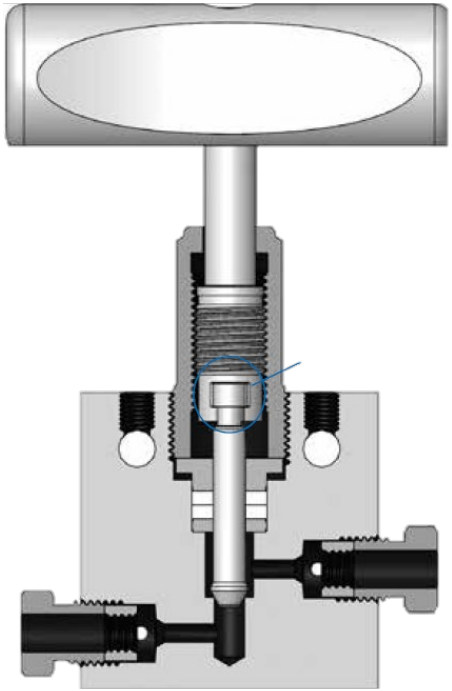
Needle Valves



Soft Stem Tip Seat is damaged due to possible excessive force being applied to the stem when closing the valve.

To increase service life, ensure proper valve performance, and prevent leakage, apply only as much torque as is required to achieve positive shutoff.

Needle Valves – High Pressures



High pressure Needle Valves are standard equipped with a hardened stem-tip material which may be suspectable for hydrogen embrittlement.

For Hydrogen application the stem-tip **need to be changed** into Hydrogen Compatible Stem Material Nitronic® 50

To order valves with factory-assembled Nitronic 50 stem material, add **-N50** to the valve ordering number

Example: NVT4M1VA20**-N50**

Resume

- Fire Triangle
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- Hydrogen Embrittlement
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- Tubing
- Flex Metal Hoses
- Regulators
- Filters
- Needle Valves

Gain the Support You Need from Local Experts

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