

Swagelok Tube Fitter's Manual



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Tube fittings, valves, and other fluid system components illustrated in this manual are the subject of pending or issued U.S. and foreign patents.

The contents of this manual are intended to provide reference information to assist the user. However, it is important that total system design be considered to ensure safe, trouble-free performance. Component function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.

Preface

Wherever gases and liquids flow, Swagelok® tube fittings are preferred for their robust performance, reliability and availability. Swagelok tube fittings have attained leadership in industry because of outstanding design principles in combination with superior metallurgy, close manufacturing tolerances and quality assurance within each stage of the manufacturing process. In addition, our network of local authorized sales and service centers helps you optimize your supply chain, offering off-the-shelf delivery, inventory management, and support throughout the world.

These fittings have been used successfully on demanding applications in such fields as semiconductor, alternative fuels, chemical and petrochemical, oil and gas, fossil and nuclear power, pulp and paper, and aerospace. Our Continuous Improvement efforts have allowed Swagelok tube fittings to set the standard for excellence since 1947.

As industry requirements have grown and changed over the years, so too has the content of this manual. We have expanded the manual to include information on selecting tube fittings for severe service requirements, metallurgy, innovations in product design, and advanced manufacturing processes. Yet the information you have always counted on, such as troubleshooting, tubing specifications, and pressure ratings is still here.

To improve the accessibility of information in this manual, we have added a QR code, as shown below. This code links you to important information, such as supplemental publications or videos. Simply use your mobile device's QR code reader application or go to www.swagelok.com/TFM to access the content.



For more information, please refer to this video of leak-tight performance. www.swagelok.com/TFM

The success of your fluid system is dependent not only upon specifying Swagelok tube fittings, but also upon proper installation and use of high-quality tubing. We believe that the combination of these factors will go far to help ensure leak-tight connections.

The information contained in this manual is a result of extensive field research and laboratory studies conducted by our research and development engineers, as well as by our customers. We would like to thank the many pipe fitters, system design and instrument engineers, and shop floor personnel whose extensive help, suggestions, contributions and comments made this book possible.

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Chapter 1

The Swagelok Tube Fitting

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The Swagelok Tube Fitting Advantage

The Swagelok tube fitting is a flareless, mechanical grip-type fitting consisting of a body, nut, front ferrule, and back ferrule. It is the industry-leading two-ferrule, mechanical grip-type tube fitting and has set the standard for performance and reliability. All components are manufactured to exacting tolerances from the highest quality material, providing a tube fitting that will perform in a wide array of markets and applications. The design has evolved over the years to keep up with changing industry needs.



For more information, please refer to this video of the design.
www.swagelok.com/TFM

Swagelok tube fittings are offered in a variety of configurations, sizes, and materials that are designed to handle some of the most severe field applications. Learn more about Swagelok's leak-tight performance.



For more information, please refer to this video of leak-tight performance.
www.swagelok.com/TFM

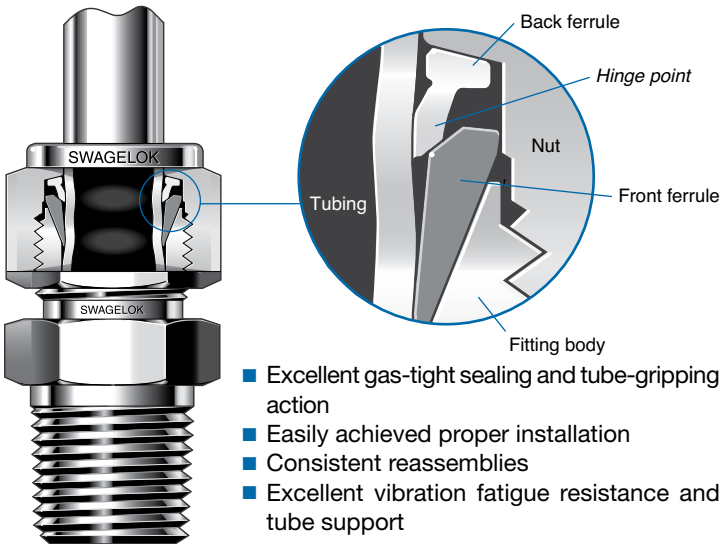


Figure 1-1 The Swagelok tube fitting advantage.

How the Swagelok Tube Fitting Works

The Swagelok tube fitting is a sequential-phase, controlled-action sealing and gripping device. Superior design, rigid manufacturing tolerances, and strict quality assurance programs produce an all-metal sealing and holding device that performs leak-tight when properly installed.



For more information, please refer to this video of how the pull-up works.
www.swagelok.com/TFM

Consisting of a nut, back ferrule, front ferrule, and body, the Swagelok tube fitting functions as follows:

1. Tubing is inserted into the completely assembled fitting until it bottoms against the shoulder of the fitting.
2. The nut is tightened 1 1/4 turns from finger-tight. During this tightening, a number of different movements take place within the fitting in a preplanned sequence.



For more information, please refer to this video of *How It Works*.
www.swagelok.com/TFM

- a) Through threaded mechanical advantage, the nut moves forward, driving the back ferrule forward.
- b) The back ferrule drives the front ferrule forward.
- c) The front ferrule is forced inward by the fitting body bevel.
- d) The front ferrule takes up the tolerance between its inside diameter and the outside diameter of the tube.
- e) As the front ferrule moves forward and inward, its trailing edge is lifted by the back ferrule to a sealing position with the fitting body bevel.
- f) As greater resistance is encountered because more tubing is deformed and a greater area of body bevel and front ferrule is in contact, the back ferrule is driven inward to form a grip, or hold, on the tubing.
- g) At 1 1/4 turns of wrench pull-up, the nut has moved 1/16 in. forward. Within this 1/16 in. movement, the sequence of sealing and holding has been accomplished.
- h) One of the unique abilities of this proven design is the ability to seal and hold on a wide variety of tubing materials, wall

thicknesses, and hardnesses. Because the amount of back ferrule grip is determined by the tube's resistance to front ferrule action, grip is much tighter when heavy wall tubing is encountered. This is an important design feature because heavy wall tubing is often used in service conditions such as high pressure or other unusual stresses, vibration, pulsation, or shock. Thus, the Swagelok tube fitting, by design, grips much more securely on heavy wall tubing than it does on thin wall tubing used for more moderate service (Figure 1-2).

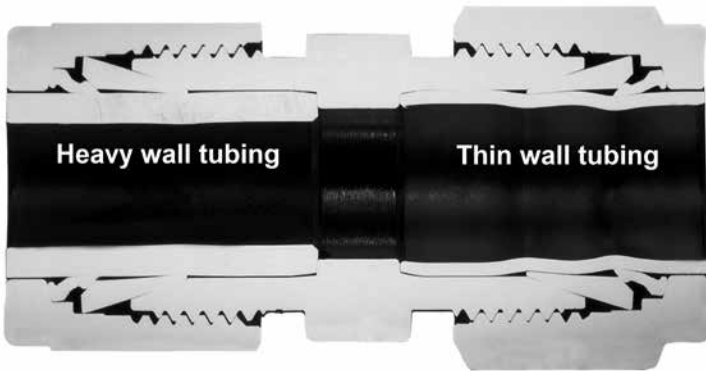


Figure 1-2 Compensating action of the Swagelok tube fitting.

Enhanced Factors of Performance: The Big Three

Tube Grip

The patented recessed and contoured geometry of the Swagelok back ferrule creates the hinging and colletting™ action that grips the tube. The hinging and colletting action allows for more material of the back ferrule to be in close contact with the tube adjacent to the tube grip. This material provides direct and axial support to the tube-gripping function.

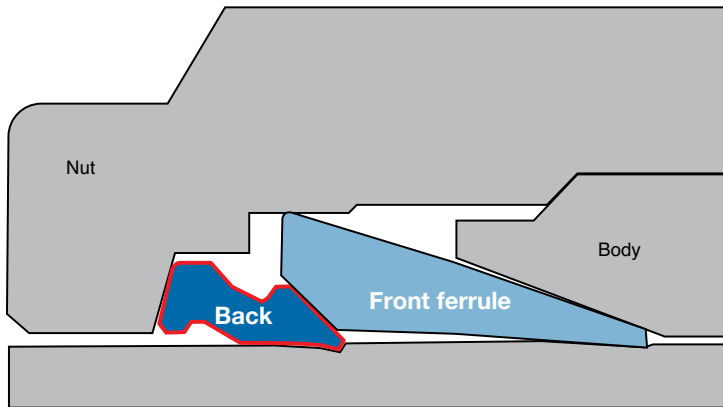


Figure 1-3 The hinging and colleting™ action provides more material of the back ferrule in close contact with the tube adjacent to the tube grip.

Gas Seal

A gas seal is achieved by the burnishing or polishing that occurs between the front ferrule and the tube fitting body and the front ferrule and the tubing. This burnishing action accompanies concentrated zones of contact, as shown in yellow.

The back ferrule drives the front ferrule a sufficient distance to achieve the gas seal. Once this is accomplished, the back ferrule will no longer progress against the front ferrule. By controlling the movement of the back ferrule just enough to ensure a leak-tight seal, the Swagelok tube fitting limits the stroke and deformation on the front ferrule.

We refer to this controlled movement of the ferrules as compensating action. Compensating action allows the tube fitting to overcome tubing variables such as materials, hardness, wall thickness, and dimensions, while achieving a leak-tight seal.



For more information, please refer to this video of the tube fitting and gas seal. www.swagelok.com/TFM

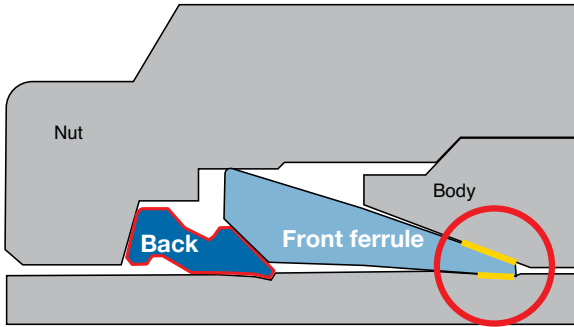


Figure 1-4 Gas seal between front ferrule and the tube. Concentration of burnished zone shown in yellow.

Vibration Resistance

To reduce the effects of bending, deflection, and vibration, the mid portion of the back ferrule adjacent to the tube-gripping nose collets and applies a compressive stress against the tube that isolates, dampens, and protects the stress riser at the nose of the back ferrule.

The live-loading, spring action and residual elasticity of the front and back ferrules compensate for thermal cycling and thermal and mechanical transients (rapid changes). The elasticity of the ferrules responds and maintains a seal through these transients. This design has a protected stress riser through our patented back ferrule geometry, which reduces the damaging effects of system dynamics.

Materials

Material Standards

Material	Bar Stock ^①	Forgings ^②	Designator
316 stainless steel	ASTM A276, ASME SA479, EN 1.4401/ 1.4404	ASTM A182, ASME SA182, EN 1.4401	SS
Alloy 400	ASTM B164	ASTM B564, ASME SB564	M
Alloy 600	ASTM B166, ASME SB166	ASTM B564, ASME SB564	INC
Alloy 625	ASTM B446 ^③	ASTM B564, ASME SB564 ^④	625
Alloy 825	ASTM B425	ASTM B564, ASME SB564	825
Alloy C-276	ASTM B574	ASTM B564	HC
6-Moly	ASTM A479	ASTM A182	6MO
Aluminum	ASTM B211	ASTM B247	A
Brass	ASTM B16, ASTM B453	ASTM B283	B
Carbon steel	ASTM A108	—	S
PFA ^⑤	—	ASTM D3307 Type I	PFA
PTFE	ASTM D1710	ASTM D3294	T
Alloy 2507 ^⑥	ASTM A479	ASTM A182	2507
Titanium (grade 4)	ASTM B348	ASTM B381	TI

① Straight fittings and tube adapters.

② Elbows, crosses, and tees.

③ All straight fittings and tube adapters and 1/4 and 3/8 in.; 6 and 10 mm elbows, crosses, and tees.

④ Elbows, crosses, and tees larger than 3/8 in. and 10 mm.

⑤ See the Swagelok *PFA Tube Fittings* catalog, MS-01-05.

⑥ See the Swagelok *Gaugeable Alloy 2507 Super Duplex Tube Fittings* catalog, MS-01-174.

Additional Processing

Fitting bodies are processed for improved performance, as shown. No additional processing is required for alloy 625, alloy 825, brass, 316 stainless steel, 6-Moly stainless steel, and PTFE materials.

Fitting Body Material	Process
Aluminum	Anodized, hydrocarbon film
Alloy 400, alloy C-276, alloy 600	Hydrocarbon film
Carbon steel (except weld bodies)	Zinc plating
Carbon steel (weld bodies)	Hydrocarbon film chemical conversion coating
Titanium	Anodized

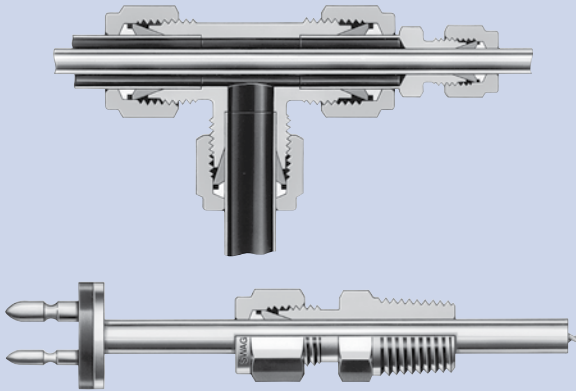
- Over 1 in./25 mm fittings are supplied with a package of fluorinated-base with PTFE and tungsten disulfide lubricant for use in fitting assembly.
- Over 1 in./25 mm stainless steel fittings use stainless steel ferrules with PFA coating. Applications above 450°F (232°C) **require** silver-plated front ferrules and uncoated back ferrules. To order fittings with silver-plated front ferrules and uncoated back ferrules, add **BM** to the fitting ordering number.

Example: SS-2400-6**BM**

- All carbon steel Swagelok tube fittings are supplied with 316 stainless steel back ferrules.

Bored-Through Swagelok Tube Fittings

For many years, Swagelok tube fittings have been successfully used for introducing thermocouples or other types of probes into piping systems. There is one physical difference between a bored-through fitting and a standard fitting. When a fitting body is bored-through, the shoulder of the Swagelok tube fitting is removed and the ferrules will not meet the same resistance as when the tubing is properly bottomed.



Swagelok bored-through male connectors accommodate thermocouples or dip tubes. Most male connectors are available as a bored-through fitting, but male connectors whose pipe thread end is small relative to the tube fitting end—such as **-600-1-2** or **-8M0-1-2RT**—cannot be bored through.

Swagelok bored-through reducers and standard Swagelok tees can be used to create a heat exchanger tee.

To order bored-through fittings, add **BT** to the ordering number.

Example: SS-400-1-4**BT**

Bored-through fittings have a reduced pressure rating.

Figure 1-5 Bored-through fittings for thermocouples, dip tubes, and heat exchanger tees.

The most obvious effect is that pressure rating is reduced. In general, we have multiplied the allowable working pressure of the tubing, as found on the Tubing Data Sheet, by the following factors:

Size (in.)	Size (mm)	Factor
Up to 1/2 in.	Up to 12 mm	0.75
Above 1/2 in. to 3/4 in.	Above 12 mm to 18 mm	0.50
Above 3/4 in.	Above 18 mm	0.25

All other requirements for correct installation of Swagelok tube fittings need to be observed for bored-through fittings:

- Correct tube material
- Hardness and wall thickness
- Correct pull-up
- Temperature limitations

First, for sizes 1/16 and 1/8 in. (4 mm and below), always tighten the nut until the tube will not turn by hand or move axially in the fitting, then complete the required assembly procedure.

Because many bored-through fitting applications involve thermocouples with different types of filler materials, the user should verify the suitability of the thermocouple with the Swagelok fitting.

With over 1 in. and over 25 mm bored-through fittings, the tubing is inserted through the fitting body, and pull-up must be done with wrenches and inspected with the multihead hydraulic swaging unit (MHSU) gap gauge.

A Checklist for Excellence in Tube Fitting Selection

Design

- The tube fitting will be a controlled-phased, sequential-gripping device consisting of four machined components—the body, front ferrule, back ferrule, and nut—that are produced by a single manufacturer and engineered to work in a wide range of system conditions.
- The back ferrule will have a uniform surface hardening. This surface hardening will be a low-temperature carburization, avoiding carbide formation. It will follow a disclosed and auditable process procedure.
- There will be no machined ferrule stops. Assembly of parts will provide for ferrule movement during tightening. The tube fitting components will be engineered to provide appropriate controlled-phased, sequential ferrule movement during tightening. Upon proper installation, the tube fitting will be capable of disassembly and reassembly, producing a leak-tight seal.
- The back ferrule will hold the tube with a hinging colletting action. This radial hinging colletting action of the back ferrule will grip the tube adjacent to and outboard from the swaging point to enhance the vibration endurance.
- The hinging colletting action will cause the mid portion of the back ferrule to press onto the tube while keeping the back end of the

back ferrule away from the tube surface. The back ferrule will not bow during assembly.

- The sealing and gripping actions of the fitting will provide a compensating action between ferrules that will accommodate the allowed ranges of tube wall thickness, diameter, and material hardness. For example, on thin wall tubing, the back ferrule will grip the wall of the tube with less indentation than is necessary on heavy wall tubing. The front ferrule will move farther down the body ramp to burnish or polish a seal on the tube more than is needed on a heavy wall tube.
- The stainless steel material, from which tube fitting bodies and components are made, will be restricted to a minimum chromium content of 17.0 % and a minimum nickel content of 12.0 % for improved corrosion resistance, and to a maximum carbon content of 0.05 %, which provides better corrosion-resistant weldability.
- The tube fitting nut will be internally plated with a high-purity silver to eliminate galling during assembly.

Performance

- The tube fitting will produce a leak-tight seal in pressure or vacuum service.
- The tube fitting manufacturer will specify the allowed ranges of tube wall thickness, diameter, and material hardness.
- The tube fitting will function on standard ASTM stainless steel tubing, fully annealed according to ASTM A269 or A213.
- The tube fitting will contain pressure up to a minimum of four times (4×) the working pressure of the tube without fitting material rupture when properly installed.

Installation

- The manufacturer should offer a wide variety of tools for tube fitting installation.
- The manufacturer will provide clear instructions for proper tube fitting installation.
- The tube fitting will not apply torque to or twist the tubing during original or subsequent assembly of the connection.
- The fitting should use geometry or defined axial movement of the nut for assembly.
- The tube fitting will not require fitting disassembly for inspection after assembly.

Quality Assurance

- All tube fitting metal components will be stamped to identify manufacturer and material.
- All tube fittings will have a gaugeable shoulder to check for sufficient pull-up on initial installation. The gaugeable shoulder will allow a gap inspection gauge to be inserted between the hex of the nut and hex of the body shoulder. Consistently, the gap inspection gauge will not fit between the nut and shoulder hexes of a sufficiently tightened fitting on the initial installation.
- The tube fitting manufacturer will be certified to produce fittings under an N Stamp Program accredited by ASME.
- The tube fitting manufacturer will have a Statistical Quality Control program, which will have an acceptance quality limit (AQL) level of 1.5.

Note: Additional information may be referenced in *Zero Acceptance Number Sampling Plans*, 5th Edition, written by N.L. Squiglia, published by ASQ Press.

- The tube fitting manufacturer will be committed to Statistical Control of Processes for manufacture of all critical dimensions.
- The tube fittings will be procured from the tube fitting manufacturer's distribution network supported and trained by the manufacturer.
- No component of any other tube fitting manufacturer will be interchanged or intermixed with the four components (body, nut, front ferrule, and back ferrule) of the tube fitting.

Why Close Tolerances Are Important

The Swagelok tube fitting consists of four components, as shown here. In actual practice, there is a fifth component, the tubing. Various organizations publish tolerance data, notably ASTM in the United States. In general, Swagelok has found that international specifications follow the same approximate guidelines as shown in ASTM standards.

The tolerances published for tubing partially control the tolerancing of tube fittings. For example, a common tubing outer diameter (OD) variable in ASTM A269 for 1/2 in. OD stainless steel is $1/2 \times 0.005$ in. Therefore, the tube OD can vary from 0.495 in. to 0.505 in. Obviously, the bore of the nut, ferrules, and body must be large enough to accept this tubing. Beyond this, we must hold the closest bore tolerance achievable. At the same time, however, the ferrule system must allow for the fact that the tube OD could be as small as

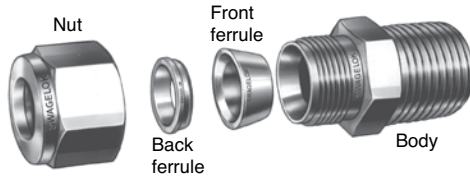


Figure 1-6 Swagelok tube fitting: four components.

0.495 in. Therefore, very stringent quality control is essential just to overcome the sizeable variation in tube OD.

Besides OD tolerances, there are tolerances in tube wall thickness, ovality, and hardness. All these variables must be overcome in only 1 1/4 turns of the nut.

Therefore, we must keep our tolerances within an extremely tight range to ensure consistent performance. We have been told that our quality is “too good” for some applications. We continue to say, “It is never good enough,” and we are constantly looking for ways to do it better.

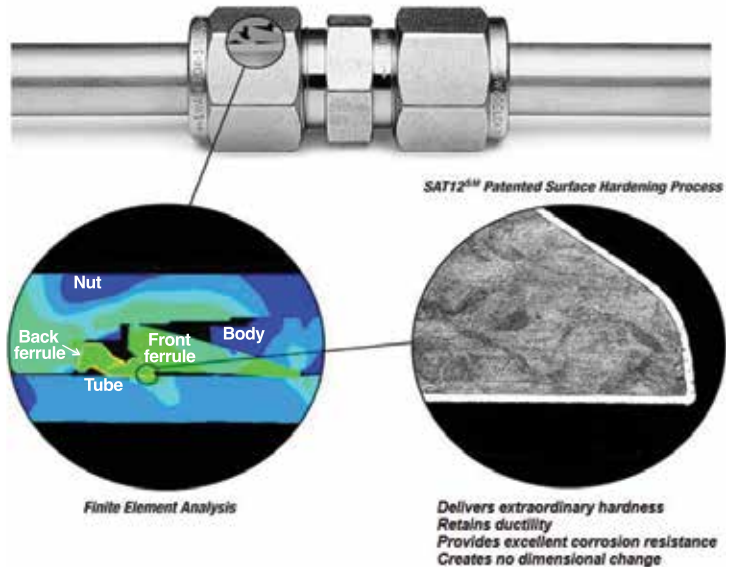


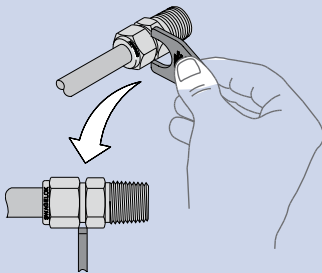
Figure 1-7 SAT12 patented surface hardening process.

Gaugeability

Swagelok's tube fittings are developed with such stringent control over all variables that a gap inspection gauge can be used to ensure proper tightening when the fittings are first installed.

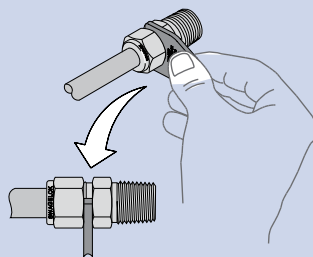
On initial installation, the Swagelok gap inspection gauge assures the installer or inspector that a fitting has been sufficiently tightened.

Position the Swagelok gap inspection gauge next to the gap between the nut and body.



Correct

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



Incorrect

If the gauge **will** enter the gap, additional tightening is required.

Figure 1-8 Ensure proper tightening with Swagelok gap inspection gauge.

Interchange and Intermix of Tube Fitting Components

Over the years, many manufacturers have stated that their products are interchangeable and can be intermixed with Swagelok tube fittings.

Swagelok recommends no intermix/interchange of Swagelok tube fitting components with other manufacturers' components.

- No industrial design standard exists for two ferrule tube fittings. Each company makes components to its own design and not to any recognized standards.
- Interchanging and intermixing tube fitting components can result in unpredictable performance, environmental releases, increased costs, and can be dangerous in critical applications.

Chapter 2

Tubing: Specification and Ordering

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Tube Specification and Ordering

General Comments and Suggestions

Careful selection, specification, purchase, and handling of tubing are essential to the successful use of Swagelok tube fittings.

Several general rules apply:

- Metal tubing must always be softer than the fitting material. For example, stainless steel tubing should never be used with brass fittings.
- When tubing and fitting are made of the same material, the tubing must be fully annealed. Mechanical, structural, or ornamental grade tubing should never be used for fluid systems.
- Extremely soft or pliable tubing such as Tygon® or PVC tubing should always use an insert. Seals on the outside diameter (OD) of tubing require a certain amount of tube resistance for tight sealing.
- Extremes of wall thickness should be checked against our suggested minimum and maximum wall thickness limitations. Swagelok tube fittings are not recommended for tube wall thicknesses outside the ranges shown in the following tables for each size. A wall too thin will collapse under ferrule action and may not resist enough to allow the ferrules to coin out surface defects. A wall thickness greater than the maximum suggested does not increase the allowable working pressure.
- Tubing surface finish is very important to proper sealing. Tubing that is deeply embossed (such as copper water tube); has a visible weld seam on its OD; or has flat spots, scratches, or draw marks may not seal properly when used with a fitting sealing on the tubing OD.
- Oval tubing that will not easily fit into fitting nuts, ferrules, and bodies should never be forced into the fitting. Such forced tube entry will scrape the tube OD surface at the maximum diameter, making sealing difficult.
- Laminated or multiwall tubing, such as braided hose, should generally not be used with Swagelok tube fittings. Because the Swagelok fitting seals on the tube OD, system fluid may leak between hose or tube layers, causing ballooning and possible wall rupture.

Tubing for Gas Service

Gases such as air, hydrogen, helium, and nitrogen have very small molecules that can escape through even the smallest leak path. Some surface defects on the tubing can provide such a leak path.

As the tube OD increases, the likelihood of scratches or other surface defects also increases. The most successful connection for gas service will occur if all installation instructions are carefully followed and the heavier wall thicknesses of tubing are selected from the tables shown below.

A heavy wall tube resists ferrule action more than a thin-wall tube and allows the ferrules to coin out minor surface imperfections. Thinner wall tubing offers less resistance to ferrule action during pull-up and reduces the chance of coining out surface defects, such as scratches.

For the greatest safety factor against surface defects in any gas system, use a wall thickness no less than the ones listed in the tables shown here.

Fractional Sizes, in inches

Tube OD	Minimum Nominal Wall Thickness	Tube OD	Minimum Nominal Wall Thickness
1/8	0.028	3/4	0.065
3/16	0.028	7/8	0.083
1/4	0.028	1	0.083
5/16	0.035	1 1/4	0.109
3/8	0.035	1 1/2	0.134
1/2	0.049	2	0.180
5/8	0.065	×	×

Metric Sizes, in millimeters

Tube OD	Minimum Nominal Wall Thickness	Tube OD	Minimum Nominal Wall Thickness
3	0.8	18	1.5
6	0.8	20	1.8
8	1.0	22	2.0
10	1.0	25	2.2
12	1.0	28	2.5
14	1.2	30	3.0
15	1.5	32	3.0
16	1.5	38	3.5

Metal Tube Selection and Specification



Please refer to the Swagelok Tubing Data Sheet (MS-01-107) for additional tubing information.
www.swagelok.com/TFM

When using a Swagelok tube fitting, it is important to remember that the fitting performance can be greatly compromised by the use of poor quality tubing. The Swagelok tube fitting consists of four components as shown here. They come to you fully inspected and assembled.

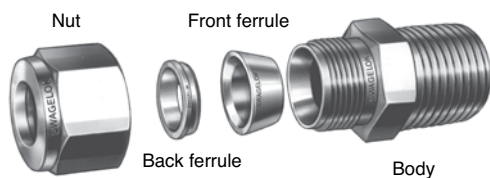


Figure 2-1 Swagelok tube fitting: Four components.

Tubing is considered to be the fifth important component when considering tube fittings and tubing selection for a fluid system.

Despite its importance, tubing selection is often treated as an afterthought. It is counterproductive to use low quality tubing in the design of a critical fluid system.

Purchasing tubing to ASTM, or equivalent specifications, is a start toward tubing quality. However, most such specifications allow rather wide latitudes when considering several important factors. For example:

- ASTM A269, a commonly used stainless steel tube specification, refers one to ASTM A1016 General Requirements, which include:

13. Straightness and Finish

13.1 Finished tubes shall be reasonably straight and have smooth ends free of burrs. They shall have a workmanlike finish. Surface imperfections (Note 1) may be removed by grinding, provided that a smooth curved surface is maintained, and the wall thickness is not decreased to less than that permitted by this or the product specification. The outside diameter at the point of grinding may be reduced by the amount so removed.

Note 1—An imperfection is any discontinuity or irregularity found in the tube.



Figure 2-2 Fifth component: Quality tubing.

- ASTM A269 allows *ovality* of the tube to be two times the OD tolerance of ± 0.005 in. or ± 0.010 in. for thin-walled tube.

However, the specifications lack standards. What, or who, defines a *workmanlike* finish? How deep or how flat must the grinding be? In the second specification, if this ovality were to be ± 0.010 in. (0.510 in. by 0.490 in. for 1/2 in. OD tubing), the tube would not fit into most tube fittings.

In conclusion, the mere use of ASTM specifications does not actually indicate that you have a quality piece of tubing. Tubing quality depends on the integrity and the quality consciousness of the tubing supplier.

To be sure of selecting tubing with quality good enough to perform properly when used with the precision-made Swagelok tube fitting, we suggest that the following variables be considered:

- Tubing material and method of manufacture
- Tubing wall thickness and OD
- Tubing surface finish
- Tubing hardness
- Tubing concentricity
- Tubing ovality

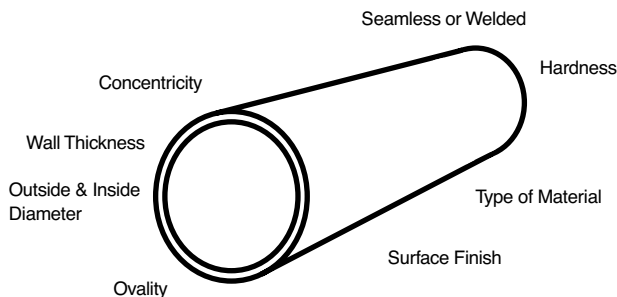


Figure 2-3 Tubing variables to be considered when selecting tubing.

Specify Limits on Your Tubing Purchase Order

Often, a user can specify certain limits on a tubing purchase order, particularly on large purchases, at no extra cost. These limits may well be considerably narrower than those permitted in ASTM specifications. For example, Restricted OD Tolerances: Typical ASTM tubing specifications shown here permit various plus and minus tolerances. Some users will not accept tubing with a *minus* tolerance because it is more difficult to seal undersize tubing. Also, for tubing 1/8 in. OD and smaller, we suggest restriction to ± 0.003 in. Please refer to Figure 2-5, ASTM Tolerance—Tube OD, on page 27.

Restricted Surface Finish Tolerances

As mentioned previously, ASTM specifications are ambiguous and unclear on the subject of finishes. In particular, when stainless steel welded and drawn tubing is specified, poor quality of weld or weld bead removal can cause sealing problems when the tube and tube fitting are assembled.

- Poor welding usually results in a visible depression (concavity), which ferrules cannot seal.
- Poor weld bead removal results in a raised (slag) portion or in a flat spot at the weld.

Any of these conditions may result in a leak when flareless tube fittings are assembled.

A rule to consider that may be written in welded tube specifications is:

“Weld bead on the tube OD should not be visible to the naked eye.” Locate the weld seam on the tube ID. Then inspect the OD at that location. You should not be able to see the weld on the OD if it is high quality tubing.

Please refer to Chapter 5, Troubleshooting, page 152, Trouble #5.

Hardness Restrictions:

All flareless tube fittings require that the tubing be softer than the fitting material. Various terms are used to describe tubing hardness. In general, metal tubing should be fully annealed to work properly with Swagelok tube fittings. Most stainless steel tubing is restricted to a maximum Rockwell hardness of 90 HRB.

Suggested Ordering Information by Material

The following are suggested tubing specifications for specifying the best quality tubing for leak-free tubing systems.

Aluminum Tubing: High quality drawn and seamless aluminum alloy tubing, ASTM B210 or (Type 6061-T6) or equivalent.

Carbon Steel Tubing: High quality, soft, annealed, seamless carbon steel hydraulic tubing, ASTM A179 or equivalent. Hardness not to exceed 72 HRB or 130 HV. Tubing is to be free of scratches and suitable for bending and flaring. Other acceptable specifications: ASTM A161, ASTM A556 grade A2, ASME SA179, AMS 5050, and SAE J524b.

Copper Tubing: High quality, soft, annealed, seamless copper tubing to ASTM B75, EN 1057, or equivalent. Also soft annealed (Temper O) copper water tube, type K or type L to ASTM B88. If copper water tube to ASTM B88 is used, it should be ordered without OD embossing. Such deep embossing interferes with ferrule action. Even the areas where there is no embossing are sometimes flattened by blank dies.

Stainless Steel Tubing: High quality, fully annealed (Type 304, 304/304L, 316, 316/316L, 317, 317/317L) (seamless or welded and drawn) stainless steel hydraulic tubing, ASTM A269 or A213, A632, EN ISO 1127, or equivalent. Hardness not to exceed 90 HRB or 200 HV. Tubing to be free of scratches, suitable for bending and flaring. OD tolerances not to exceed ± 0.003 in. for 1/16 in. and 1/8 in. OD tubing and equivalent metric sizes. Dual-certified grades such as 304/304L, 316/316L, and 317/317L meet the minimum chemistry and the mechanical properties of both alloy grades.

Note: Certain austenitic stainless tubing has an allowable ovality tolerance double the OD tolerance and may not fit into Swagelok tube fittings.

Alloy 400 Tubing: High quality, fully annealed, seamless alloy 400 hydraulic tubing, ASTM B165 or equivalent. Hardness not to exceed 75 HRB or 137 HV. Tubing to be free of scratches, suitable for bending and flaring. OD tolerances not to exceed ± 0.005 in.; for 1/16 and 1/8 in. tubing, OD tolerances are not to exceed ± 0.003 in.

Alloy 600 Tubing: High quality, fully annealed, cold-drawn #1 temper alloy 600 seamless alloy tubing, ASTM B167 or equivalent. Hardness not to exceed 92 HRB or 198 HV. Tubing to be free of scratches, suitable for bending and flaring. Order to OD and wall thickness only, not to inside diameter, average wall specification. OD tolerances not to exceed ± 0.005 in.

Alloy 625 Tubing: High quality, fully annealed, seamless alloy 625 tubing, ASTM B444, grade 1 or 2, or equivalent. Hardness not to exceed 25 HRC or 266 HV. Tubing to be free of scratches, suitable for bending and flaring.

Alloy C-276 Tubing: High quality, fully annealed alloy C-276 tubing, ASTM B622 or equivalent. Hardness not to exceed 100 HRB or 248 HV. Tubing to be free of scratches, suitable for bending and flaring. OD tolerances not to exceed ± 0.005 in.

Titanium Tubing: High quality, fully annealed, seamless or welded and drawn grade 2 titanium tubing, ASTM B338 or equivalent. Tubing to be free of scratches, suitable for bending. OD tolerances not to exceed ± 0.005 in.

Alloy 2507 Super Duplex Tubing: High quality, fully annealed alloy 2507 super duplex tubing, ASTM A789 or equivalent. Hardness not to exceed 32 HRC. Tubing to be free of scratches, suitable for bending and flaring.

Alloy 825 Tubing: High quality, fully annealed, seamless alloy 825 tubing, ASTM B163, ASTM B423, or equivalent. Fully annealed welded alloy 825 tubing, ASTM B704, class 1 or equivalent. Hardness not to exceed HR15T90 or 201 HV. Tubing to be free of scratches, suitable for bending and flaring. Wall thickness tolerances not to exceed ± 10 %.

Alloy 254 Tubing: High quality, fully annealed, seamless or welded and drawn alloy 254 hydraulic tubing, ASTM A269 or ASTM A213, or equivalent. Hardness not to exceed 96 HRB. Tubing to be free of scratches, suitable for bending and flaring.

Plastic Tubing

Many different types of plastic tubing are available for use in a wide range of fluid applications. The most common types are listed below with certain characteristics and limitations and suggested ordering information.

Nylon Tubing: Nylon tubing is a tough tubing material that is readily available for a wide variety of low-pressure tubing systems. Typical uses are on low-pressure hydraulics or air fluid power systems and in laboratory piping. Because of its good flexibility and abrasion resistance, it is often used for instrument air, lubrication, beverage, and fuel lines. Size ranges generally run from 1/8 in. OD to 1/2 in. OD. Nylon tubing is usually rated by short-time burst rating, commonly from 1000 to 2500 psig (68 to 172 bar). Working pressure is generally 250 to 625 psig (17 to 43 bar) using a 4:1 design factor. Working temperature range is 75 to 165°F (24 to 74°C).

Swagelok metal tube fittings may be used up to the maximum working pressure of nylon tubing.

Suggested ordering information: OD is not to exceed ± 0.005 in. from nominal OD for 3/16 to 1/2 in. tubing and is not to exceed $\pm .003$ in. for 1/8 in. OD.

Polyethylene Tubing: This inexpensive, flexible tubing is widely used in laboratories, instrument air lines, and other applications. It is more flexible than nylon but not as abrasion resistant. It is generally very corrosion resistant, so it is very good for air service in corrosive environments.

It is rated by burst pressure from 250 to 500 psig (17 to 34 bar) and working pressure from 60 to 125 psig (4 to 9 bar) with a 4:1 design factor. It is generally rated to a maximum temperature of 140°F (60°C).

Swagelok metal tube fittings may be used to the maximum working pressure of such tubing. No insert is required unless the tubing OD is larger than 1/2 in.

Suggested ordering information: OD is not to exceed ± 0.005 in. from nominal OD for 3/16 to 1/2 in. tubing and is not to exceed ± 0.003 in. for 1/8 in. OD.

Polypropylene Tubing: An excellent flexible tubing that is much stronger than polyethylene. It is rated by burst pressure from 1600 to 2400 psig (110 to 165 bar) and working pressure from 400 to 600 psig (28 to 41 bar) with a 4:1 design factor. It has unusually good

temperature characteristics and is generally rated to a maximum temperature of 250°F (121°C).

Swagelok metal tube fittings are satisfactory for use on polypropylene tubing.

Suggested ordering information: OD is not to exceed ± 0.005 in. from nominal OD for 3/16 to 1/2 in. tubing and is not to exceed ± 0.003 in. for 1/8 in. OD.

PFA and PTFE Tubing: This tough tubing is used in a wide variety of fluid handling operations. It has excellent properties that resist corrosion. It has good temperature capabilities to 400°F (204°C). Standard metal Swagelok tube fittings may be used on PTFE or PFA tubing. When PTFE fittings are used on PTFE tubing, there is very little holding power because of the very low coefficient of friction when a PTFE fitting tries to hold a length of PTFE tubing. However, the PFA Swagelok tube fitting, when used with Swagelok PFA tubing (and grooved with the Swagelok groove cutter), will hold to the rated working pressure of the tubing. Consult your Swagelok representative for pressure rating information on this combination.

Suggested ordering information: OD is not to exceed ± 0.005 in. from nominal OD for 3/16 to 1/2 in. tubing and is not to exceed ± 0.003 in. for 1/8 in. OD.

- PTFE fittings with PTFE tubing.
- PTFE ferrules with SS or plastic tubing and SS body and nut.
- Nylon ferrules with SS or plastic tubing and SS body and nut.

Tube O.D. in.	Suggested Allowable Working Pressure (psig)
1/8	35
1/4	25
3/8	25
1/2	15
5/8	10
3/4	5
1	5

Soft PVC Tubing: This tubing is used for flexibility and corrosion resistance in many laboratory, medical, food, and pharmaceutical applications. It is normally rated at approximately 165°F (74°C). When used with Swagelok metal or plastic tube fittings, a serrated insert must be used. The insert supports the tube wall from the inside so that ferrules can grip and seal the tubing. Swagelok hose connectors may also be used with this type of tubing (see Chapter 6 for details). Reinforced soft PVC tubing is also available. An inner braid is imbedded in the tube wall to increase strength and working pressure.



Figure 2-4 Tubing insert.

Swagelok tube fittings should **NOT** be used with reinforced soft PVC tubing because of possible leakage from the end of the tube around the braid, within the tube wall. An inside diameter seal, such as a Swagelok hose connector, should be used.

Suggested ordering information: OD is not to exceed ± 0.005 in. from nominal for 3/16 to 1/2 in. tubing and is not to exceed ± 0.003 in. for 1/8 in. OD.

Tubing Standards

The following list covers the commonly encountered metal tubing specifications for tubing to be used with Swagelok tube fittings.

For OD tolerances, refer to the table shown here.

Tube OD (in.)	Swagelok Tube Size	Decimal Equivalents (in.)	Stainless Steel		Carbon Steel ASTM A179	Copper ASTM B75	Aluminum ASTM B210
			ASTM A213 and A249	ASTM A269			
1/16*	100	0.0625	±.004 in.	±.005 in.	±.004 in.	±.002 in.	±.003 in.
1/8*	200	0.125	±.004 in.	±.005 in.	±.004 in.	±.002 in.	±.003 in.
3/16	300	0.1875	±.004 in.	±.005 in.	±.004 in.	±.002 in.	±.003 in.
1/4	400	0.250	±.004 in.	±.005 in.	±.004 in.	±.002 in.	±.003 in.
5/16	500	0.3125	±.004 in.	±.005 in.	±.004 in.	±.002 in.	±.003 in.
3/8	600	0.375	±.004 in.	±.005 in.	±.004 in.	±.002 in.	±.003 in.
1/2	810	0.500	±.004 in.	±.005 in.	±.004 in.	±.002 in.	±.003 in.
5/8	1010	0.625	±.004 in.	±.005 in.	±.004 in.	±.002 in.	±.004 in.
3/4	1210	0.750	±.004 in.	±.005 in.	±.004 in.	±.0025 in.	±.004 in.
7/8	1410	0.875	±.004 in.	±.005 in.	±.004 in.	±.0025 in.	±.004 in.
1	1610	1.000	±.006 in.	±.005 in.	±.005 in.	±.0025 in.	±.004 in.
1 1/4	2000	1.250	±.006 in.	±.005 in.	±.006 in.		
1 1/2	2400	1.500	±.006 in.	±.010 in.	±.006 in.		
2	3200	2.000	±.010 in.	±.010 in.	±.010 in.		

Notes:

Certain austenitic stainless tubing has an allowable ovality tolerance double the OD tolerance. Such oval tubing may not fit into Swagelok precision tube fittings.

* ±0.003 in. maximum recommended for 1/16 and 1/8 in. OD tubing when used with Swagelok tube fittings

Figure 2-5 ASTM Tolerance—Tube OD.

Stainless Steel Tubing	
ASTM A213 Seamless ferritic and austenitic alloy steel boiler, superheater, and heat-exchanger tubes.	Standard to which seamless austenitic stainless steel tubing may be purchased for general service. Hardness 90 HRB maximum. OD tolerances are determined by ASTM A1016. Satisfactory for use with Swagelok stainless steel tube fittings.
ASTM A249 Welded austenitic steel boiler, superheater, heat-exchanger, and condenser tubes.	Standard to which welded austenitic stainless steel tubing may be purchased for general and high temperature service. Hardness 90 HRB maximum. OD tolerances determined by ASTM A1016. A draw pass to blend the weld groove into a smooth tube OD is necessary for satisfactory use with Swagelok tube stainless steel fittings.
ASTM A269 Seamless and welded austenitic stainless steel tubing for general service.	Standard to which both welded and seamless austenitic stainless steel tubing may be purchased for general, corrosion-resisting, and low- and high-temperature service. Hardness 90 HRB maximum. Should be purchased cold finished and is satisfactory for use with Swagelok stainless steel tube fittings in the cold finished condition.
ASTM A1016 General requirements for ferritic alloy steel, austenitic alloy steel, and stainless steel tubes.	Covers general requirements for steel and stainless steel welded or seamless tubing. Many of its requirements are mandatory in such specifications as A213 and A249. Except for A269, all these specifications cover OD tolerances by reference to A1016. Tubing is not purchased to ASTM A1016. It is purchased to other specifications that get their general requirements from A1016.
ASTM A632 Seamless and welded austenitic stainless tubing (small diameter) for general service.	Covers stainless steel tubing that may be purchased for small diameter work from 0.050 to 1/2 in. OD. Wall thicknesses are 0.005 to 0.065 in. Can be either seamless or welded and drawn. Often used for small instrument tube requirements. Has closer OD and inside diameter (ID) tolerances (plus 0.002 in. minus 0.000 in. OD, plus 0.000 in. minus 0.002 in. ID).
Carbon Steel Tubing	
ASTM A161 Seamless low-carbon and carbon-molybdenum steel tubes for refinery service.	Standard to which cold-drawn, seamless carbon steel tubing may be purchased for elevated pressure-temperature service. Carbon content is 0.10 % to 0.20 %. Hardness 70 HRB maximum. OD tolerances are determined by ASTM A450. Only the cold-drawn, low-carbon variety is satisfactory for use with Swagelok steel tube fittings.

<p>ASTM A179 Seamless cold-drawn, low-carbon steel heat-exchanger and condenser tubes.</p>	<p>Standard to which cold-drawn, seamless carbon steel tubing may be purchased for general service. Carbon content is 0.06 % to 0.18 %. Hardness 72 HRB maximum. OD tolerances are determined by ASTM A450. Satisfactory for use with Swagelok steel tube fittings.</p>
<p>SAE J524b Seamless low-carbon steel tubing, annealed for bending and flaring.</p>	<p>Similar to A179, maximum carbon content is 0.18 %. Hardness 65 HRB maximum. However, in 3/8 in. OD and smaller sizes with a wall thickness less than 0.065 in., no hardness test is required. Satisfactory for use with Swagelok steel tube fittings.</p>
<p>Copper Tubing</p>	
<p>ASTM B68 Seamless copper tube, bright annealed.</p>	<p>Covers annealed seamless copper tubing suitable for use in refrigerators, oil lines, gasoline lines, etc., where tube absolutely free of scale and dirt is required. Should be specified as “soft annealed,” temper 060 for use with Swagelok brass fittings. Wall thickness and diameter tolerances are determined by ASTM B251.</p>
<p>ASTM B75 Seamless copper tube.</p>	<p>Covers seamless copper tube for general purposes. Should be specified as annealed temper 060 for use with Swagelok brass fittings. Wall thickness and diameter tolerances are determined by ASTM B251.</p>
<p>ASTM B88 Seamless copper water tube.</p>	<p>Covers seamless copper water tube suitable for general plumbing. It comes in Type K, Type L, and Type M. Sizes 3/8 to 12 1/8 in. OD (1/4 to 12 in. nominal). Should always be specified as annealed temper 0 for use with Swagelok brass fittings. OD and wall thickness tolerances are specified in ASTM B88, but OD tolerances generally follow ASTM B251 guidelines. Type K is the heaviest wall, Type L is medium wall, and Type M is very thin wall. Type M is normally available only in hard temper straight lengths and has a wall too thin to be used with Swagelok brass fittings. Both Type K and Type L are available either in 20 ft. straight lengths or 60 ft. coils and soft annealed. Type K or L is usually satisfactory for use with Swagelok brass fittings, but wall thickness may not be sufficient for gas service. NOTE: Beware of tubing that is marked by embossing into the OD. Such depressed lettering can interfere with proper ferrule sealing. Water tube is normally sized by “nominal” OD, not actual OD, so actual OD should be determined when using with Swagelok tube fittings.</p>

<p>ASTM B251 General requirements for wrought seamless copper and copper alloy tube.</p>	<p>This is the general specification for copper tubing that governs many requirements for ASTM B68 and B75 copper tubing. It covers wall thickness and OD tolerances applicable to ASTM B68 and B75 tubing.</p>
<p>Other Alloy Tubing</p>	
<p>ASTM B210 Aluminum alloy seamless tubes.</p>	<p>Covers drawn seamless aluminum tubes in straight lengths and coils. Alloy 6061 in T4 and T6 tempers is suggested and is indicated in our Tubing Data Sheet. For Swagelok tube fitting use with other aluminum alloy tubing, consult your Swagelok representative.</p>
<p>Alloy 400 ASTM B165 Nickel-copper alloy (UNS N04400) seamless pipes and tubes.</p>	<p>Covers alloy 400 seamless tubing. Should be specified “annealed” for use with Swagelok alloy 400 fittings. Hardness 75 HRB maximum (annealed). OD tolerance is ± 0.005 in. up to 5/8 in. OD. Over 5/8 in. OD allows ± 0.0075 in., so tubing should be ordered to a special tolerance of ± 0.005 in. for best results with Swagelok alloy 400/405 fittings.</p>
<p>Alloy 600 ASTM B167 Nickel-chromium-iron alloy (UNS N06600) seamless pipes and tubes.</p>	<p>Covers alloy 600 tubing. Should always be specified “cold-drawn annealed” for use with Swagelok alloy 600 fittings. Hardness 92 HRB maximum. OD tolerance is ± 0.005 in. up to 5/8 in. OD. Over 5/8 in. OD allows ± 0.0075 in., so tubing should be ordered to a special tolerance of ± 0.005 in. for best results with Swagelok alloy 600 fittings.</p>
<p>Titanium ASTM B338 Seamless and welded titanium and titanium alloy tubes for condensers and heat exchangers.</p>	<p>Covers titanium tubing that may be used with Swagelok titanium fittings. Swagelok tube fittings are manufactured from grade 4 titanium. Tubing should be ordered as grade 2 to perform properly with Swagelok titanium fittings. Grade 2 titanium is approximately 98.75 % pure titanium.</p>
<p>Alloy C-276 ASTM B622 Seamless nickel alloy pipes and tubes (UNS N10276 or UNS N10665).</p>	<p>Covers several nickel alloys, but in particular, it covers alloy C-276 tubing such as would be used with Swagelok alloy C-276 tube fittings. OD tolerance is ± 0.005 in. up to 5/8 in. OD. Over 5/8 in. OD allows ± 0.0075 in., so tubing should be ordered to a special tolerance of ± 0.005 in. for best results with Swagelok alloy C-276 fittings.</p>

<p>Alloy 2507 Super Duplex ASTM A789 Seamless and welded ferritic/austenitic stainless steel tubing for general service.</p>	<p>Covers fully annealed alloy 2507 Super Duplex tubing, such as would be used with Swagelok alloy 2507 Super Duplex tube fittings. Hardness not to exceed 32 HRC. Tubing to be free of scratches, suitable for bending and flaring.</p>
<p>Alloy 825 ASTM B163 Seamless nickel and nickel alloy condenser and heat-exchanger tubes.</p>	<p>Covers fully annealed seamless alloy 825 tubing, ASTM B163, ASTM B423, or equivalent, such as would be used with Swagelok alloy 825 tube fittings. Fully annealed, welded alloy 825 tubing, ASTM B704, class 1 or equivalent. Hardness not to exceed HR15T90 or 201 HV. Tubing to be free of scratches, suitable for bending and flaring. Wall thickness tolerances not to exceed $\pm 10\%$.</p>
<p>ASTM B423 Nickel-iron-chromium-molybdenum-copper alloy seamless pipes and tubes.</p>	
<p>ASTM B704 Welded UNS N06625, UNS N06219, and UNS N08825 alloy tubes.</p>	
<p>Alloy 254 ASTM A269 Seamless and welded austenitic stainless steel tubing for general service.</p>	<p>Covers fully annealed seamless or welded and drawn alloy 254 hydraulic tubing, ASTM A269 or ASTM A213, or equivalent, such as would be used with Swagelok 6-Moly tube fittings. Hardness not to exceed 96 HRB. Tubing to be free of scratches, suitable for bending and flaring.</p>
<p>ASTM A213 Seamless ferritic and austenitic alloy steel boiler, superheater, and heat-exchanger tubes.</p>	
<p>Alloy 625 ASTM B444 Nickel-chromium-molybdenum-columbium alloys (UNS N06625 and UNS N06852) and nickel-chromium-molybdenum-silicon alloy (UNS N06219) pipes and tubes.</p>	<p>Covers fully annealed seamless alloy 625 tubing, ASTM B444, grade 1 or 2, or equivalent, such as would be used with Swagelok alloy 625 tube fittings. Hardness not to exceed 25 HRC or 266 HV. Tubing to be free of scratches, suitable for bending and flaring.</p>

Chapter 3

Tubing and Tube Fitting Handling and Installation

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Tubing Handling

Careful handling of tubing, from receiving to installation, will promote leak-free systems.

Good handling practices will reduce scratches, gouges, and nicks, which can interfere with proper sealing (particularly on gas service).

Never Drag Tubing Off Racks

- The weight of the tube as it is dragged over the edge of a truck bed or tube rack may be sufficient to score or scratch outside diameter (OD) surfaces.
 - Scratches can occur if an OD burr is left on the tubing.
 - Tubing should never be dragged across rough surfaces such as cement, dirt, asphalt, or sand.

Never Drop Tubing

- Tubing can be damaged if dropped onto a hard surface.
 - This may create dents, making tubing out-of-round.
 - Forcing out-of-round tubing into the fitting may result in leakage.

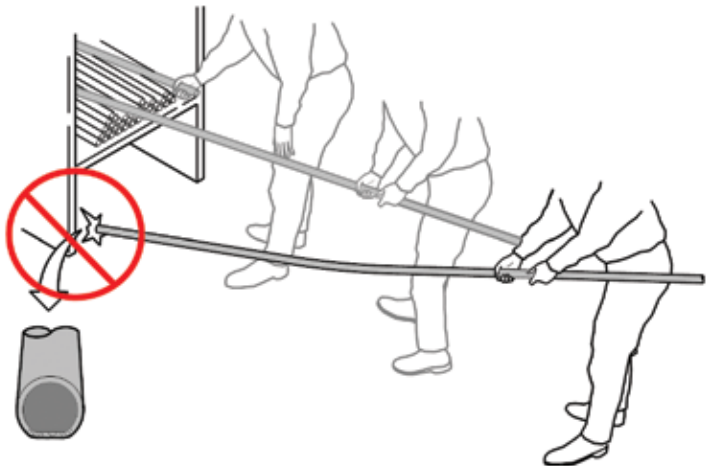


Figure 3-1.

Tubing System Layout

When installing a system, the first step is to draw a layout of the system to determine the number of tube fittings and the length of tubing required.

- Measure all dimensions from the end of tubing and between tubing centerlines.
- Treat all bends as if they were square corners.

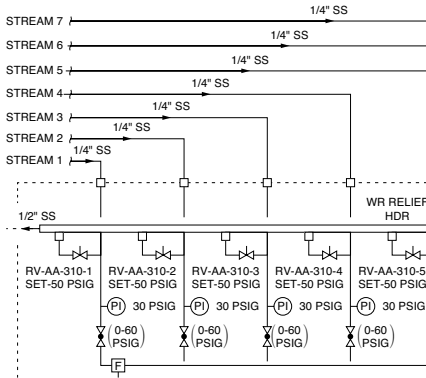


Figure 3-2.

Other considerations:

Provide Good Accessibility for Fittings

- Easy installation
- Easy maintenance

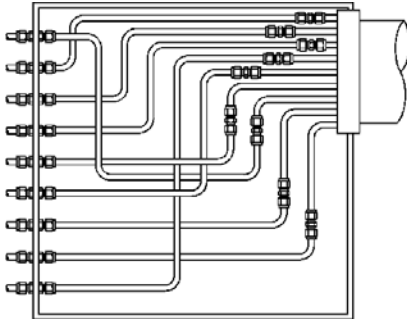
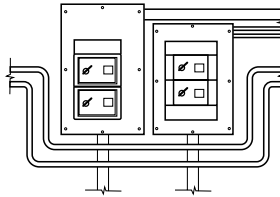


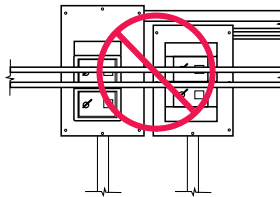
Figure 3-3.

Proper Tubing Placement

- Avoid placement directly in front of access doors, bolts, and equipment.
- Do not prevent access to controls.
- Allow access for repair or maintenance.



Correct

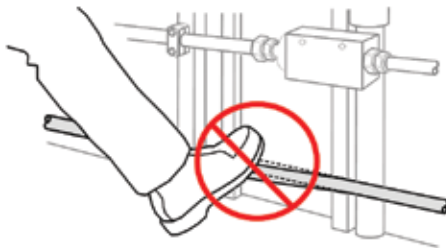


Incorrect

Figure 3-4.

Avoid Locating Tubing in “Foot Rail” Positions

- Low level runs of tubing may be inappropriately used as a foot rest, which may lead to damaging the tube.
- Low tubing may create a trip or safety hazard.



Incorrect

Figure 3-5.

Avoid Locating Tubing in “Hand Rail” Positions

- High runs of tubing may be inappropriately used like a hand rail, which may lead to damaging the tube.
- Tubing may be inappropriately used as a support for other objects, which may lead to damaging the tube.

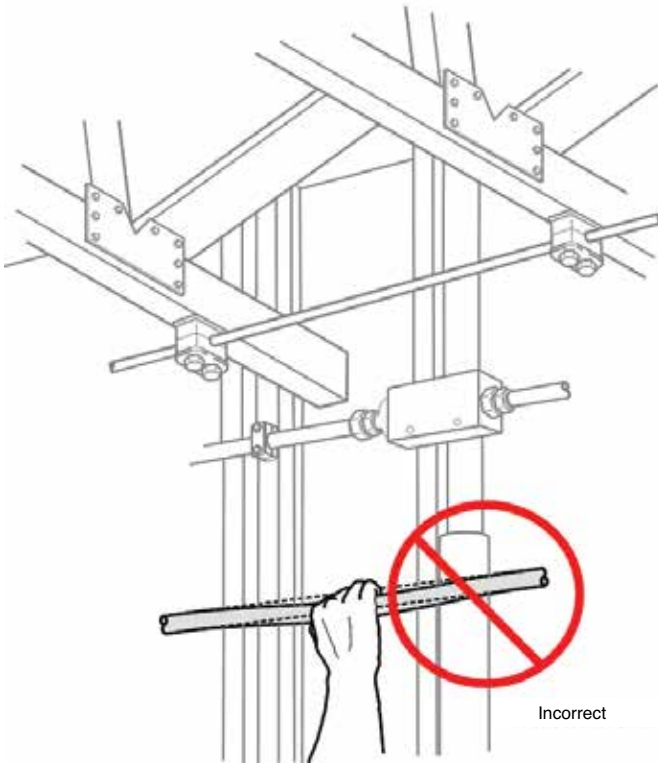


Figure 3-6.

Provide Proper Support

- Proper support limits the effects of impulse and vibration on fluid systems.
- Use resilient supports on tubing.
- Long runs of tubing should be supported to prevent sagging.

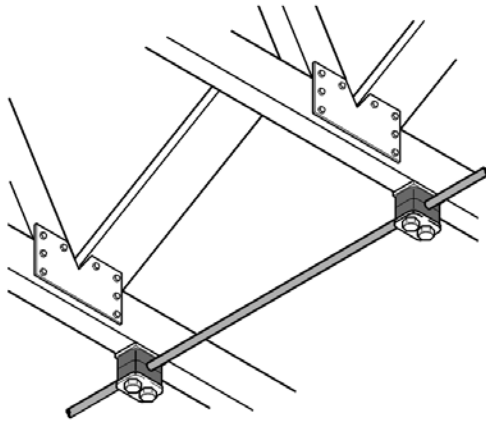


Figure 3-7 Resilient supports.

- Tubing should not support weight of valves, fittings, regulators, etc. Components should be mounted.
- Fluid density and tube size determine the frequency of supports.
- All tubes should be clamped on both sides of a bend, as close to the bend radius as possible.

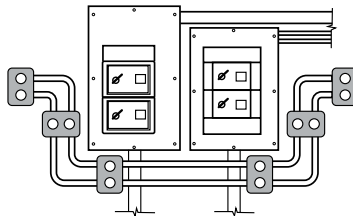


Figure 3-8 Bent tubes clamped on both sides.



For further information, refer to the Standard Practice ANSI/MSS SP-58-2009, replacing SP-69. www.swagelok.com/TFM

Fluid systems may be subjected to repeated impulse and vibration. Appropriate system design can limit the effects of impulse and vibration by including a proper tube support system that limits the movement of tubing and fluid components. The types and location of tube supports will depend on the design of the fluid system in

question. Supports are especially important around elbows, tees, bends, and heavy in-line objects such as valves. There are several published guidelines that outline support selection and spacing of tubing in systems based on different industry practices and experiences.

The Manufacturers Standardization Society (MSS) of the Valve and Fittings Industry Suggested Spacing for Supports

Tubing Diameter OD in	Tubing Diameter OD mm	Distance between Clamps ft.	Distance between Clamps m
3/16 to 3/8	4 to 10	3	0.9
1/2 to 7/8	15 to 22	5	1.5
1 to 1 1/4	25 to 30	7	2.1

Maximum Horizontal Pipe Hanger and Support Spacing

Nominal Pipe or Tube Size in.	Nominal Pipe or Tube Size mm	Standard Wt. Steel Pipe				Copper Tube			
		Water Service ft.	Water Service m	Vapor Service ft.	Vapor Service m	Water Service ft.	Water Service m	Vapor Service ft.	Vapor Service m
1/4	6	7	2.1	8	2.4	5	1.5	5	1.5
3/8	10	7	2.1	8	2.4	5	1.5	6	1.8
1/2	15	7	2.1	8	2.4	5	1.5	6	1.8
3/4	20	7	2.1	9	2.7	5	1.5	7	2.1
1	25	7	2.1	9	2.7	6	1.8	8	2.4
1 1/4	32	7	2.1	9	2.7	7	2.1	9	2.7
1 1/2	40	9	2.7	12	3.6	8	2.4	10	3.0
2	50	10	3.0	13	3.9	8	2.4	11	3.3

Stack Tubing Vertically

- Avoids collection of dirt, corrosives, and contaminants.
- If tubing must be ganged horizontally, the tubing should be covered.

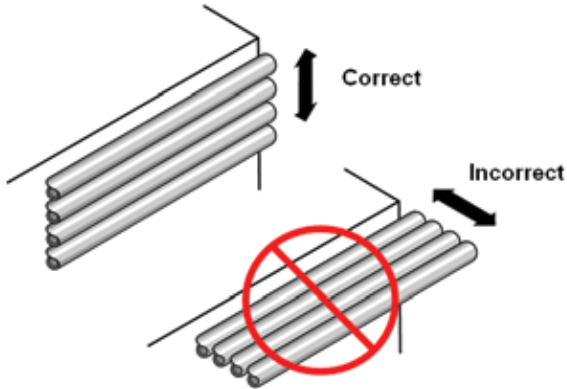


Figure 3-9.

Utilize Expansion Loops

- Conserves space, allowing runs to be placed closer together
- Allows for expansion or contraction due to temperature changes
- Provides access for assembly or disassembly

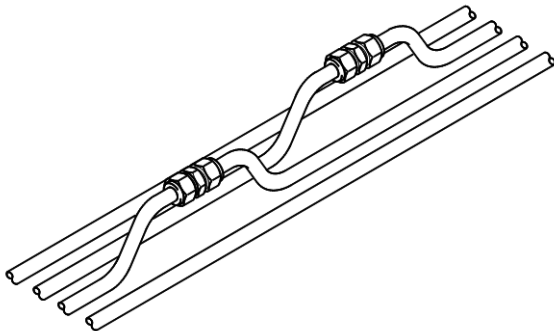


Figure 3-10.

Do Not Spring Tubing into Position

Avoiding springing results in these benefits:

- Allows proper bottoming of tubing
- Allows for system to be easily maintained
- Prevents side-load stresses and allows for expansion

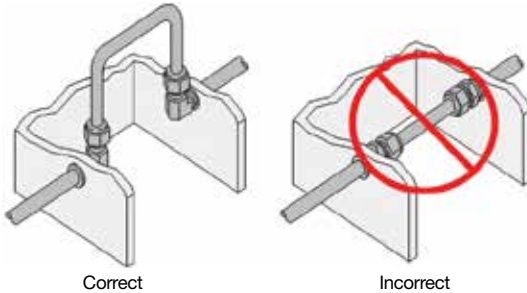


Figure 3-11.

Additional tubing considerations:

- Metal tubing material should be softer than fitting material. For example, stainless steel tubing should not be used with brass fittings.
- When tubing and fitting are made of the same material, the tubing must be fully annealed. Mechanical, structural, or ornamental grade tubing should never be used for fluid systems.
- Always use an insert with extremely soft or pliable plastic tubing.
- Extremes of wall thickness should always be checked against the suggested minimum and maximum wall thickness limitations.
- Surface finish is very important to proper sealing. Tubing with any kind of depression, scratch, raised portion, or other surface defect will be difficult to seal, particularly in gas service.
- Tubing that is oval and will not easily fit through fitting nuts, ferrules, and bodies should never be forced into the fitting.

Advantages of Tubing versus Pipe

- Tubing can be more cost effective than pipe for connecting fluid system components.

Ease of Installation

- Standard wrenches
- No threading
- No flaring

- No soldering or brazing
- No welding

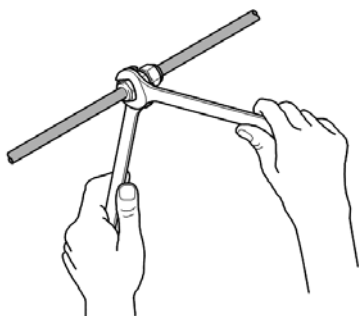


Figure 3-12.

Better Strength-to-Weight Ratio

- Threading on pipe reduces the effective wall thickness.
- Thinner-walled tubing may be used to similar pressure ratings as pipe.
- Tubing is typically lighter, making it less expensive to transport and easier to assemble and fabricate.

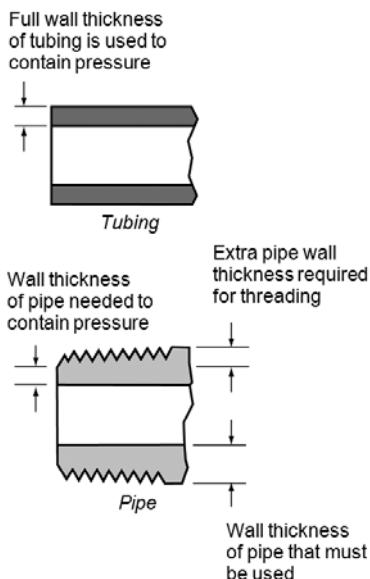


Figure 3-13.

Fewer Connections Required

- Decreases the number of potential leak points
- Can be bent around obstructions

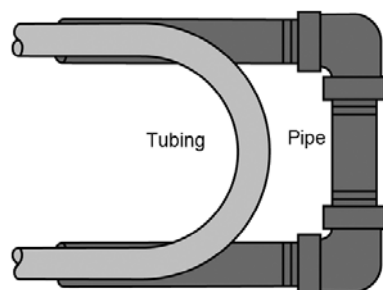


Figure 3-14.

Lower Pressure Drop

- Sharp right angle bends are reduced.
- Smooth transitions reduce turbulence.

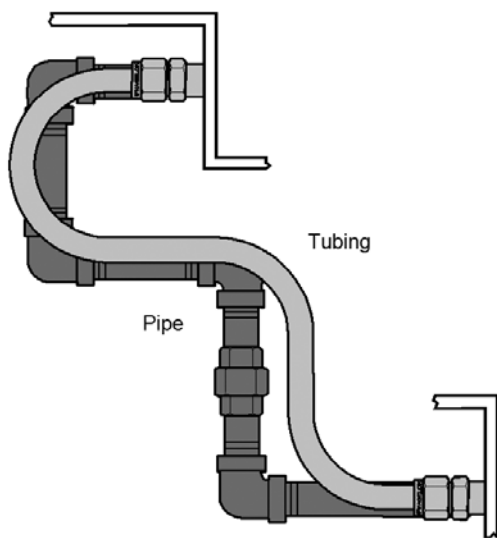


Figure 3-15.

Tube-Straightening Techniques

Straightness of tubing is important from two standpoints.

- Where the tube enters the fitting, it is necessary to have a straight run long enough to allow the tube to bottom in the fitting body.
- Also, straight tubing is easier to support properly and makes access for maintenance simpler. Straight tube runs are also more attractive and reduce support installation time.

Softer tube materials such as copper and aluminum are often furnished in coils, and some straightening must be done to make the tubing ready for use.

How to Uncoil Tubing

Take the end of the tubing and, with one hand, hold it down on a flat surface such as a table top, wooden plank, floor, or sidewalk. If the flat surface is rough, put padding down to protect the end of the tubing from scratches.



Figure 3-16.

Begin rolling the coil away from the end of the tubing with the other hand.



Figure 3-17.

Slide the first hand along the tubing, following the coil in such a manner that the tubing lies flat on the flat surface. Unroll the coil rather than pulling the tubing end out sideways from the coil. Uncoiling from the side of the roll can twist or weaken the tubing and will tend to throw the tubing out of round.



Figure 3-18.

Do not uncoil more tubing than is necessary, because repeated uncoiling and recoiling will distort, harden, and stiffen coiled tubing.

Soft coiled copper tubing is sometimes unrolled and then stretched to straighten it. Stretching can slightly harden the tube. Therefore, this practice is not recommended, but if it is performed, tubing should be stretched no more than 1 % or 6 in. per 50 ft. of coil. If tubing is stretched beyond this, OD reduction takes place and can cause sealing problems.

Another common field method to straighten copper tubing is to lay the tubing on a smooth floor or bench and use a wooden board flatwise to strike the high spots. Do not strike too hard or flat spots will be formed. Soft tubing is easily dented and may collapse at a dent when it is being bent.

Stainless Steel Tubing: Coils

Stainless steel tubing may also be ordered in coils. In this instance, you may require mechanical assistance to straighten the tubing. Swagelok offers the Five-Roll Straightener, which is designed either for hand-held operation or to be mounted to a spool stand for more automated tube straightening.



Please refer to the Swagelok Five-Roll Straightener User's Manual (MS-CRD-0147) for operating instructions. www.swagelok.com/TFM

Tube Bending

Bend Terminology

Blueprints, engineering drawings, and bend templates typically indicate the position of a tube bend as the point where the centerlines of two straight sections of tube intersect.

The straight sections are referred to as “legs,” whereas the intersection point of the two legs is called the vertex.

There are three points commonly used to dimension bends:

- Beginning end of the tube
- Vertex of the bend
- Finishing end of the tube

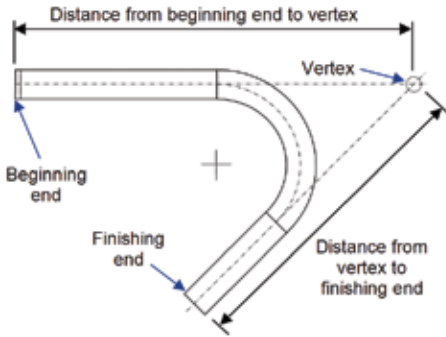


Figure 3-19.

In multiple bend layouts, distances between bends are usually dimensioned vertex-to-vertex along the tube centerlines.

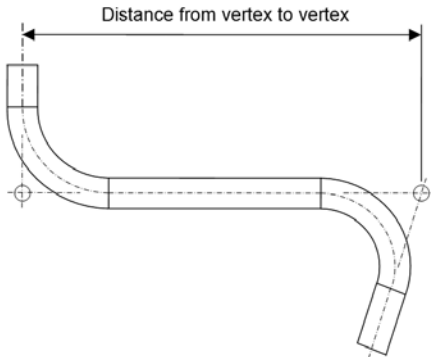


Figure 3-20.

Sometimes bends are dimensioned using the theoretical beginning and ending points of the bends.

Bends dimensioned in this manner will often require the operator to calculate the actual vertex-to-vertex lengths.

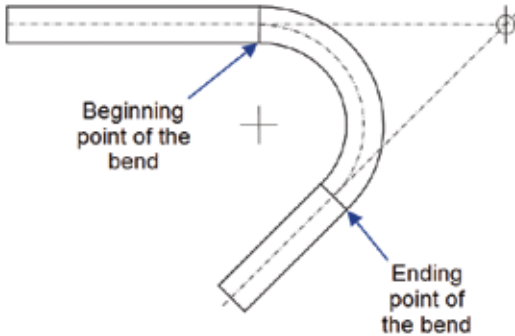


Figure 3-21.

180° Bends

The legs of 180° bends are parallel and, as a result, do not have a vertex. For layout purposes, the intersection of a line tangent to the midpoint of the 180° bend (B) is treated as if it were the vertex of the bend. The length of a leg containing a 180° bend is measured from the beginning point of the leg (A), along the centerline, and then extended to a point perpendicular to a line tangent to the midpoint of the 180° bend (B). It is not measured directly from (A) to (B).

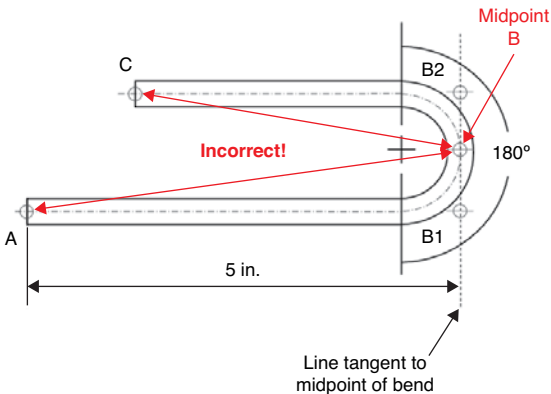


Figure 3-22.

In the example below, the length of the leg from (A) to (B) is correctly dimensioned at 5 in. along a straight line from (A) to (B1). In the same way, a leg dimensioned from (B) to (C) would be measured parallel to the leg from (B2) to (C), not at an angle from (B) to (C).

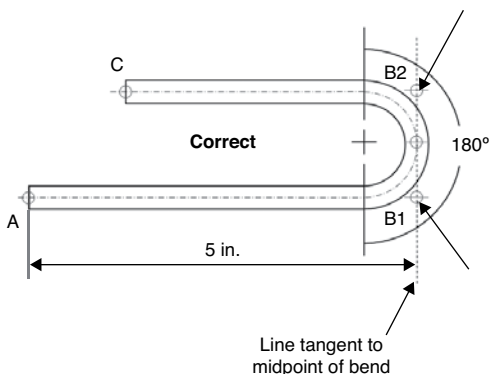


Figure 3-23.

Bend Radius

The radius of tube bends is defined as the radius to the center of the tube. This table shows commonly used bend radii on currently available tube benders.

Tube material, wall thickness, and type of equipment used will influence the smallest bend radius that can be attained.

TYPICAL TUBE BEND RADIUS

Tube OD	Radius
1/8 in.	3/8 in.
1/4 in.	9/16 in.
3/8 in.	15/16 in.
1/2 in.	1 1/2 in.
5/8 in.	1 1/2 in.
3/4 in.	1 3/4 in.
7/8 in.	2 in.
1 in.	4 in.
1 1/4 in.	5 in.
1 1/2 in.	6 in.
2 in.	8 in.

Offset Bends

The purpose of an offset bend is to change the centerline of the run, usually to avoid an obstruction. In an offset bend, two bends of the same angle (E) are placed back-to-back on opposite sides of the tube.

In many applications, the length of the offset (O) may be provided or known rather than the actual vertex-to-vertex length (L) between the bends.

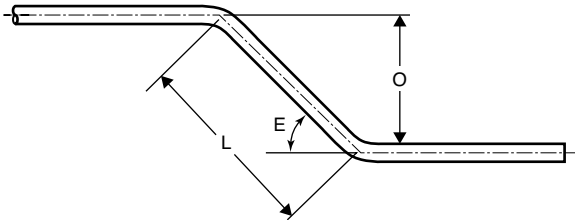


Figure 3-24.

It is important to be aware of offset dimensions, as it is easy to mistake the length of the offset as the vertex-to-vertex length. This may lead to the bends being placed too close together.

The vertex-to-vertex length (L) can be easily calculated by multiplying the amount of offset (O) by the offset bend allowance, which is the cosecant* of the bend angle (E).

Offset Bend Angle (E)	Offset Bend Allowance
22 1/2°	2.613
30°	2.000
45°	1.414
60°	1.154

Example:

Offset Bend Angle (E)	Offset Dimension (O)	×	Offset Bend Allowance	=	Length of Offset (L)
22 1/2°	30 mm	×	2.613	=	78 mm
30°	2.0 in.	×	2.0	=	4 in.
45°	65 mm	×	1.414	=	92 mm
60°	9.5 in.	×	1.154	=	10.96 in. (approximately 11 in.)

* Cosecant is a trigonometric term describing the inverse of the sine of an angle. It is a ratio of the length of the hypotenuse of an angle to the length of the opposite side.

Springback

Springback occurs when a material is bent from its original form. The bent tube will elastically “spring back” slightly toward its original pre-bent form as the pressure exerted on it during the bending process is released.

As a tube is bent around a bend radius, it will conform to the radius of the bend die; however, once the pressure is released, the tube will spring away from the bend die. For example, a stainless steel tube bent 180° using a bender with a 3/4 in. bend radius (1 1/2 in. diameter) may spring open to as much as 1 5/8 in. diameter after bending.

The amount of springback will vary depending on variables such as the bend radius, tube material, diameter, and wall thickness.

Springback can also vary with the bend angle, with a larger bend angle exhibiting more springback than a smaller angle. In extreme cases, springback can be so great that large bend angles may not be achievable using the hand bender.

There are two ways to compensate for springback:

- The operator can anticipate the amount of springback by bending the tube past the angle indicated on the bend die. As the bend pressure is released, the tube will spring open slightly.
- The bender can be manufactured with the angle marks on the bend die offset to compensate for a predetermined amount of springback. The Swagelok hand tube bender is designed in this manner, with the angle marks offset approximately 3° to compensate for the springback typically observed when bending

stainless steel. When bending softer tube, such as copper and aluminum, do not bend all the way to the angle mark!

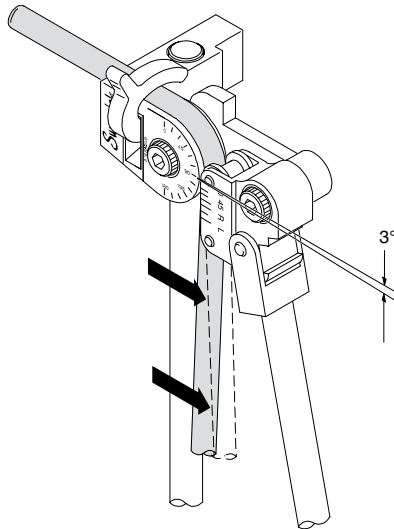


Figure 3-25.

Regardless of the method used to overcome springback, it is recommended to use caution when bending and to verify the actual bend angle using a protractor or angle indicator. It is much easier to reload the tube into the bender and bend it a little more than it is to try to unbend it!

Stretch

The term “stretch” is used to describe the difference between a bend marked and bent using conventional trigonometry (theory) against what is actually produced.

In practice, tubing often appears to lengthen slightly, or stretch, as it is bent.

NOTE: In some cases the tubing may also appear to get shorter, or shrink (usually the result of a mismarked bender die or bend reference mark).

Regardless of the reason, whether the resulting piece is longer or shorter than desired, without accounting for stretch, the location of the bend is likely to be wrong.

Bend data provided by Swagelok accounts for the stretch typically observed while using Swagelok benders.

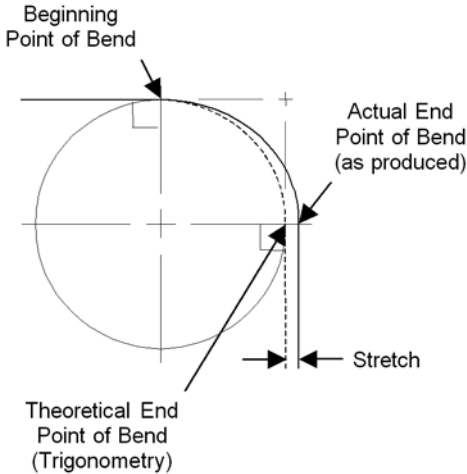


Figure 3-26.

Marks Used in Bend Layout

The biggest challenge for the tube bender operator is to make sure the bend is made in the right location and in the right direction. Three marks are commonly used:

- Reference mark
- Bend marks
- Directional marks

Reference Mark

The reference mark is placed at one end of the tube and is used to indicate the end of the tubing from where all measurements were made.

Bend Marks

Bend marks are used to indicate the location of the bend on the tube. Use of bend marks will vary depending on the layout method used.

Always make bend marks neatly all the way around the tube to make sure they will be visible when changing direction.

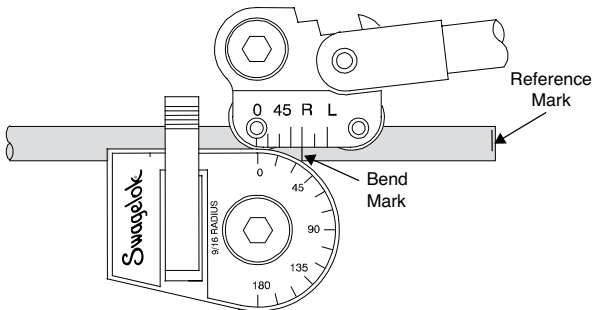


Figure 3-27.

Directional Marks

When making multiple bends on a single piece of tube, it is important to make sure that each bend is made in the correct direction.

Directional marks help ensure that the bend is made in the intended direction.

The directional mark is placed across the bend mark on the outside surface, or heel, of the intended bend.

Directional marks provide two visual reminders for the operator:

- The directional mark will be visible when the tube is correctly positioned in the bender.
- As the rollers are placed against the tube, they will contact the directional mark.

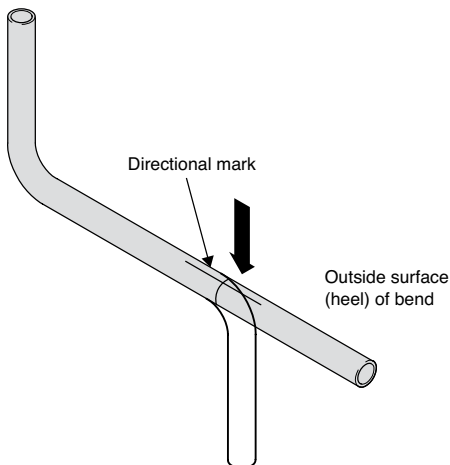


Figure 3-28.

The Measure-Bend Method

The measure-bend method of tube bending is a popular method. Accuracy is largely dependent on the operator's ability to position the tube in the tube bender.

Directions

1. Estimate the overall length of tubing required by adding the length of each of the sections together.

For example, the estimated length of tube needed to complete the elbow pictured below is 5 in. or 125 mm.

However, there are two special circumstances that will require additional calculations:

- Offsets
- 180° bends

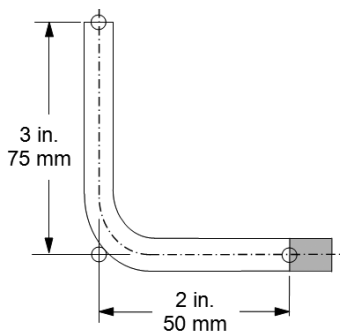


Figure 3-29.

Offsets

As explained earlier, offsets require the length of tube (L) to be calculated.

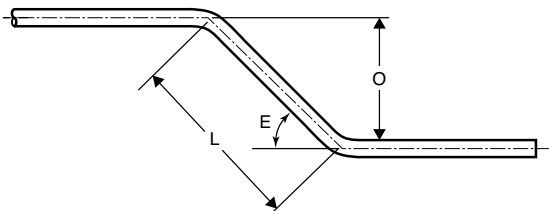


Figure 3-30.

180° Bends

Unlike other bends where the legs intersect at the vertex, the legs of 180° bends are parallel.

As a result, consideration must also be made for the tube consumed by the bend. This can be done by multiplying the bend radius by a factor of 1.25 and then adding this amount to the sum of the legs.

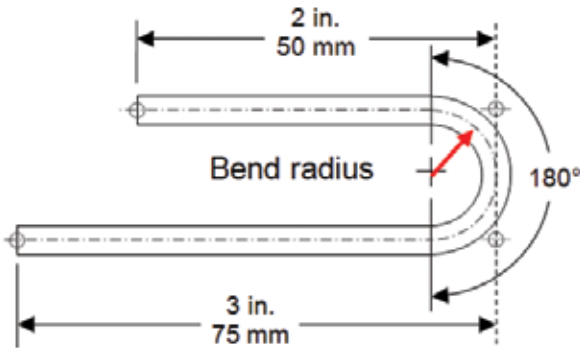


Figure 3-31.

2. Make a reference mark at the end of the tube from which your measurements will begin.

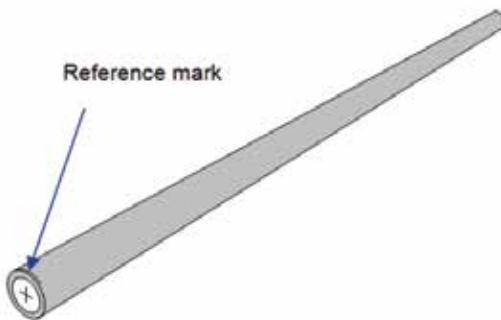


Figure 3-32.

3. Measure from the reference mark and make a bend mark neatly all around the tube at a distance equal to the length of the first leg.

This indicates the vertex of the 90° bend.

Example: The bend mark is placed 3 in. or 75 mm from the reference end of the tube.

4. Bend the tube 90°.

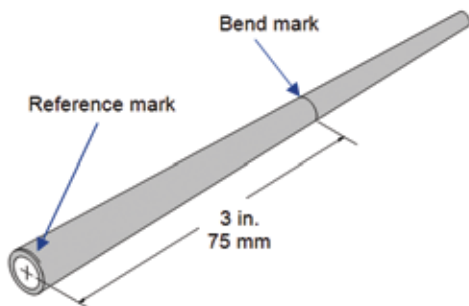


Figure 3-33.

5. Measure 2 in. or 50 mm from the vertex of the first bend and make a mark equal to the length of the second leg. This indicates the cut length.
6. Cut the tube to length.

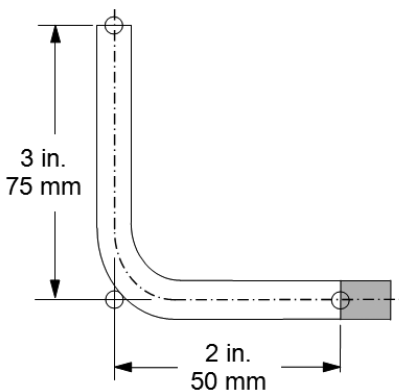


Figure 3-34.

Note: If a 5 in. or 125 mm long piece of tube is used to make this layout, the tube will be too long by a little more than the tube diameter.

Bent Tube Is Stronger Than Straight Tube

Once the tube material has been bent beyond its elastic limit, the thickness of the tube wall on the inside of the bend will be compressed, while the tube wall on the outside of the bend will be stretched, or thinned. This results in work hardening of the bent material. Work hardening increases the strength of the material.

If a length of tube containing a bend is capped with a Swagelok tube fitting and then pressurized to the bursting point of the tube, the tube will visibly expand along the straight lengths much more than it will at a bend, and when it eventually bursts, it will burst in a straight length (typically along the longest straight length).

The work hardening that occurs during bending increases the strength of this stretched material more than enough to offset the loss of strength resulting from the thinning of the wall.

However, if a bend is made in the wrong location or in the wrong direction, it cannot be unbent. This makes it critical to learn how to correctly bend tube.

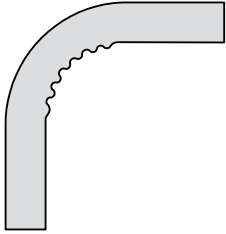
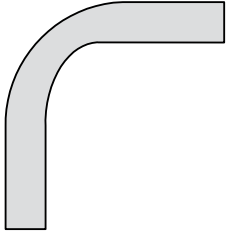
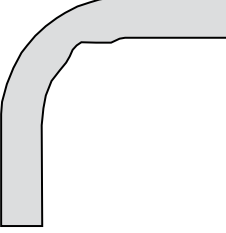
In this figure, tubing bursts on the straight portion showing an increased tensile strength of material at the bend.



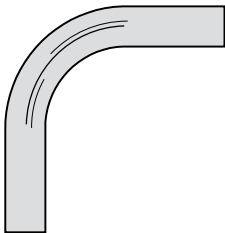
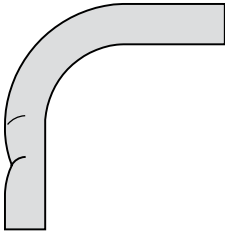
Figure 3-35.

Contact your local authorized Swagelok Sales and Service Center for tube bending training.

Tube Bending Defects

Defect	Causes	Solutions
 Wrinkled Bend	Undersized bend radius	Increase bend radius
	Tube wall thickness too thin	Increase wall thickness
 Flattened Bend	Bender is intended for use with a larger tubing diameter	Use the correct size bender for the tubing being bent
	Tubing is collapsing during bending	Increase wall thickness
	Pressure die is flattening the tubing during the bending operation	Use a bender equipped with rollers instead of a pressure die
 Kinked Bend	Bender is intended for use with a larger tubing diameter	Use the correct size bender for the tubing being bent
	Premature bending caused by link not remaining vertical prior to bending	Make sure the link is vertical before placing rollers on tubing

continued

Defect	Causes	Solutions
 <p>Scored Bend</p>	Bender is intended for use with a smaller tubing diameter	Use the correct size bender for the tubing being bent
	Damaged bender die	Repair bender die or replace bender
	Dirt or foreign matter in bender die/shoe or roller	Clean bender die/shoe or roller
	Frozen roller	Replace damaged roller or bender
 <p>Excessive Tube Deformation</p>	Improper alignment	Make sure that the bender die and bend shoe are aligned
	Excessive pressure on the tube latch (generally visible on softer tubing only)	Reduce latch pressure

Swagelok Tube Benders

Swagelok offers three styles of tube benders: the hand tube bender, the bench top tube bender (manual and electric), and the electric tube bender. Together, the three styles of tube benders cover tubing sizes from 1/8 to 2 in. and 3 to 50 mm.

Hand Tube Bender

The Swagelok hand tube bender (HTB) is a compression type tube bender. Each bender is designed to bend a particular tubing size in a variety of wall thicknesses.



Figure 3-36.

Vise Clamp Block

The vise clamp block allows you to clamp the bender in a vise. This feature is especially helpful when bending tubing of a hard material or heavy wall thickness or long pieces of tubing that need to be supported.

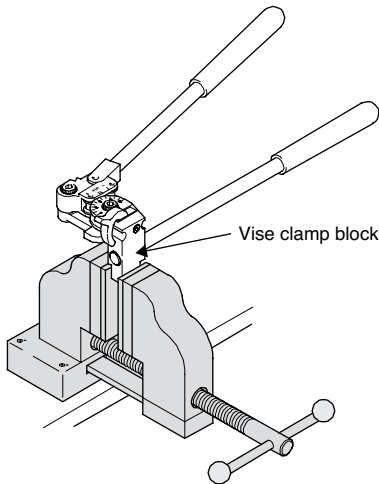


Figure 3-37.

Straight Tube Length Mark

On Swagelok hand tube benders, the straight tube length mark indicates the minimum length of straight tube required to allow the tube to be bottomed in the Swagelok tube fitting.

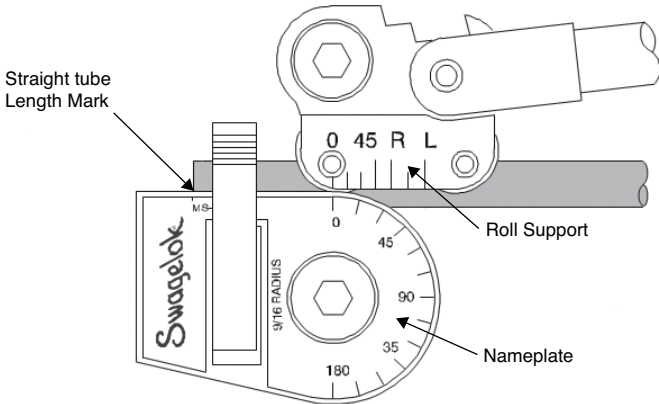


Figure 3-38.



Please refer to the Swagelok Hand Tube Bender (HTB) User's Manual (MS-13-43) for more information and operating instructions. www.swagelok.com/TFM

Bench Top Tube Bender

The Swagelok bench top tube bender (BTTB) is a rotary draw type tube bender. Swagelok offers bench top tube benders in both electric and manual units.

Each bender comes equipped with either aluminum or steel bend shoes and roller sets. Each shoe/roller set is designed to bend a particular tubing size in a variety of wall thicknesses. Steel bend shoes should be used to bend heavy-walled tubing and for high-production applications.



Figure 3-39.



Please refer to the Swagelok Bench Top Tube Bender (BTTB) User's Manual (MS-13-145) for set-up, calibration, and operating instructions. www.swagelok.com/TFM

Electric Tube Bender

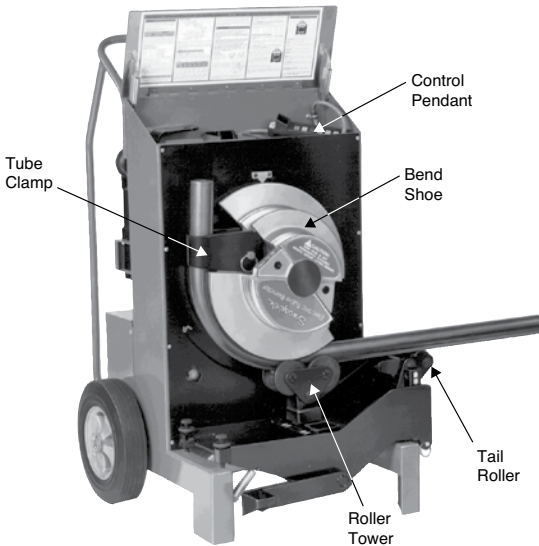


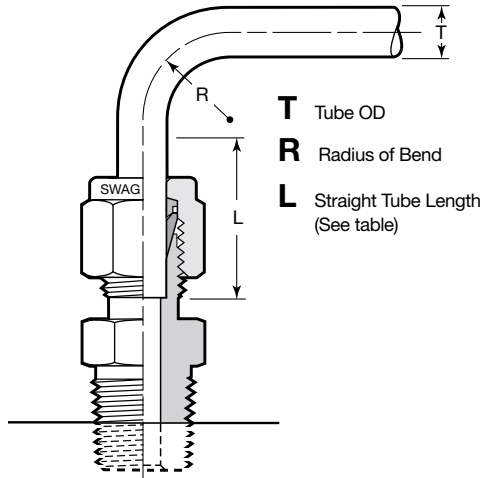
Figure 3-40.



Please refer to the Swagelok Electric Tube Bender (ETB) User's Manual (MS-13-138) for operating instructions. www.swagelok.com/TFM

Minimum Straight Tube Length

When installing fittings near tube bends, a minimum length of straight tube is required to allow the tube to be bottomed in the Swagelok tube fitting.



- T** Tube outside diameter
- R** Radius of tubing bend as required or minimum allowed for specified wall thickness and tube size as recommended by bender manufacturer
- L** Straight tube length required from end of tube to beginning of bend

Figure 3-41.

Bends Near Tube Fittings

Tube bends that are too close to a fitting installation may be a source of leaks, and care must be used on such installations. Several precautions should be taken:

- Leave a length of straight tube so that the deformed section at a bend does not enter the fitting.
- Inspect, for proper roundness, the length of tube that will be inserted into a fitting. Out-of-round tubing could scratch when entering the fitting and result in leaks.
- Long runs of tubing should be supported, as should all other components.
- When a section of bent tubing is being connected, be certain that the tube is in proper alignment with the fitting before doing any

tightening. Springing the tube into position with the fitting can result in excessive stress on the tubing and the connection.

- Proper bends in the tubing and proper alignment will ensure a good, trouble-free connection.

Swagelok Tube Fitting Minimum Straight Tube Length Requirements (by Tube OD)											
Tube OD in.	1/4	5/16	3/8	1/2	5/8	3/4	7/8	1	1 1/4	1 1/2	2
Min. Length	13/16	7/8	15/16	1 3/16	1 1/4	1 1/4	1 5/16	1 1/2	2	2 7/16	3 1/4
Tube OD mm	6	8	10	12	14	15	16	18			
Min. Length	21	22	25	29	31	32	32	32			
Tube OD mm	20	22	25	28	30	32	38	50			
Min. Length	33	33	40	40	52	51	60	83			



Please refer to the Bench Top Tube Bender (BTTB) User's Manual (MS-13-145) to determine the appropriate bend radius for your application. www.swagelok.com/TFM

For example, to determine the minimum vertex-to-vertex distance between two 90° bends using a 1/4 in. hand tube bender:

Bend deduction for bend at beginning of leg	9/16 in.
Bend deduction for bend at end of leg	+ 9/16 in.
Tube clamp requirement	+ 1 1/8 in.
<hr/>	
Minimum vertex-to-vertex distance	2 1/4 in.

Or, to determine the minimum vertex-to-vertex distance between a 45° bend and a 135° bend using 25 mm tubing and a steel bend shoe (bend shoe radius = 82 mm)

Bend deduction for 45° bend	36 mm
Bend deduction for 135° bend	+ 201 mm
Tube clamp requirement	+ 108 mm
<hr/>	
Minimum vertex-to-vertex distance	345 mm

It is important to understand that although the tube clamp requirement will remain constant for the bender or bend shoe, the minimum vertex-to-vertex distance will change depending on the bend angles at the beginning and end of the configuration.

Training and Education

At Swagelok, training is more than an academic exercise; it is an action that focuses on results. The purpose of the Swagelok Tube Bending Qualification Program is to learn how to bend tube within the limitations of the Swagelok tube benders, as well as provide several tips and shortcuts that will help to take some of the mystery out of tube bending.

There are multiple options to learn more about tube bending:

1. Attend the Basic Tube Bending course at your local Swagelok sales center—complete with hands-on exercises.
2. Take the online tube bending course at Swagelok University.
3. Attend an advanced tube bending class taught by Swagelok experts.

Contact your Swagelok Authorized Sales and Service representative or visit the Swagelok.com website for details about the Tube Bending Qualification Programs available.



Please refer to www.swagelok.com/TFM for details.

Tube Preparation

Proper tube preparation is critical when making up tube fitting assemblies. Most assemblies will be constructed of short lengths of tube that have been carefully measured, marked, and cut from longer lengths of tube. Prior to learning how to install a Swagelok tube fitting, it is important to learn how to prepare the tube being used in an assembly. Two common tools are used to cut tube. These are (1) the tube cutter and (2) the hacksaw. Once cut, burrs created during the cutting process must be removed.

Tube Cutter

Tube cutters do not remove material, but rather “push” material aside and down.

The Swagelok tube cutter is designed to cut tubing materials from 3/16 to 1 in. and 6 to 25 mm OD.

Always use a sharp wheel, since this is the best way to minimize burring. Using a dull wheel will also expand and work harden the tube end. Replace wheel when cutting becomes difficult or end of tube begins to expand.



Figure 3-42 Swagelok tube cutter.

Tube Cutter Instructions

1. Position tubing between rollers and cutting wheel.
2. Turn handle until wheel touches tube.
3. Advance handle an additional 1/16 turn. (The handle knobs are spaced in 1/8-turn increments. Use them as reference points.)



Figure 3-43 Align the cutter wheel with the measurement mark.

4. Rotate cutter around tube. After every second rotation, advance handle 1/16 turn. (For softer materials, advance the handle after each rotation.)

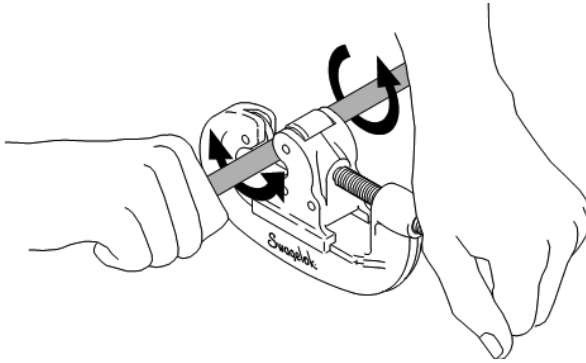


Figure 3-44 Turn the tube cutter completely around the tubing.

5. Continue until tubing is cut through.

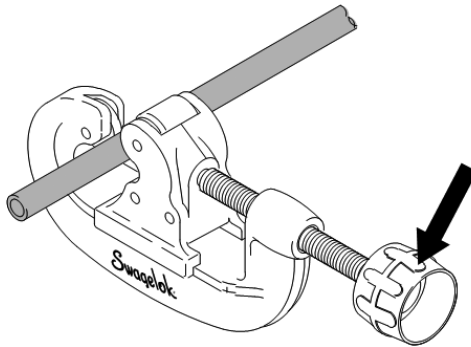


Figure 3-45 Tighten the handle 1/16 turn every second rotation.

Hacksaw

If a tube cutter of the proper size is not available, a hacksaw may be used. Tube should always be cut to length with a square cut. When using a hacksaw to cut tube, a Swagelok tube sawing guide should be used to facilitate a square cut and to keep the tube from flattening out. Hacksaw blades should have at least 24 teeth per inch.

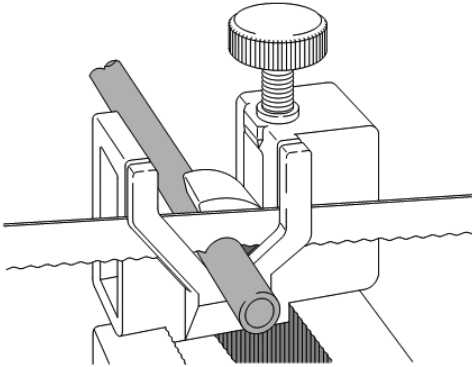


Figure 3-46 Swagelok tube sawing guide and hacksaw.

Tube Deburring

During the cutting process, tube cutters push burrs into the inside diameter (ID) of the tube, and hacksaws will burr both the ID and the OD of the tube. Regardless of which method is used to cut the tube, these burrs must be removed.

Deburring is important for proper fitting function as well as for clean, leak-free systems. If burrs are not removed from the OD of the tube, they could prevent the tube from being fully inserted through the nut and ferrules or against the shoulder of the fitting body. ID burrs could also break off and cause damage to components in other parts of the system by lodging in small holes or vents or by scratching valve seats or soft seals such as O-rings.

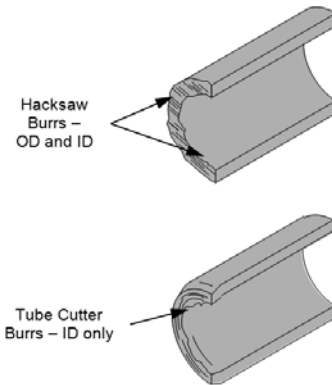


Figure 3-47 Hacksaw and tube cutter burrs.

Deburring Tools

Outside deburring can be accomplished with a smooth file. Inside and outside deburring can be accomplished using Swagelok deburring tools.

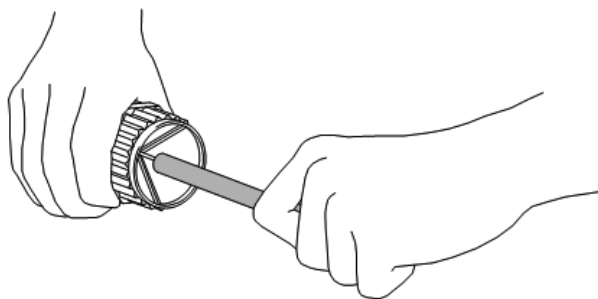


Figure 3-48 OD deburring with a Swagelok deburring tool.

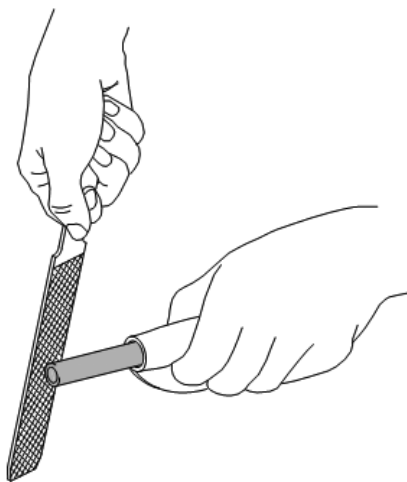


Figure 3-49 OD deburring with a file.

The Swagelok tube deburring tool (part ordering number MS-TDT-24) is used to deburr steel and stainless steel (or other softer tubing) from both the inside and outside diameters. The tool is used for deburring the inside and outside diameters of 3/16 to 1 1/2 in. (4 to 38 mm) tubing.

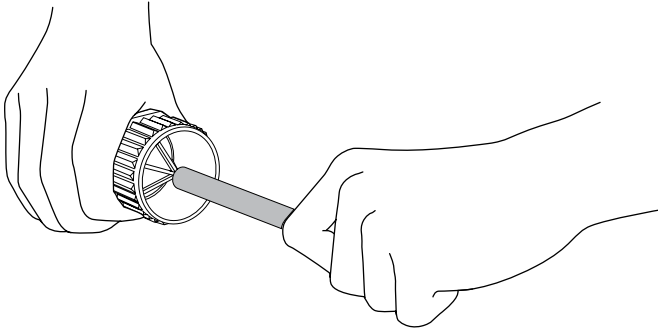


Figure 3-50 ID deburring with a Swagelok deburring tool.

Inside deburring can easily be accomplished using the Swagelok deburring tool with rugged, heavy-duty, die-cast housing and steel blades for long life (part ordering number MS-44CT-27). This tool is used for deburring the inside diameter of 1/4, 3/8, and 9/16 in. stainless steel tubing.

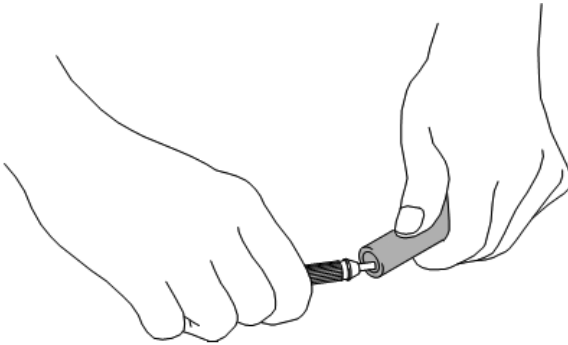


Figure 3-51 ID deburring with a Swagelok deburring tool.

Tube Facing Tool

The Swagelok tube facing tools are designed to machine flat, smooth, square, burr-free, and chamfer-free tube ends and Micro-Fit® miniature tube butt weld fittings. The tools can be used on 316 stainless steel, carbon steel, titanium, and most nickel-based alloys.

Collets are available to ensure precise mounting of tubes and quick change without the use of tools. Micro-Fit collets require a Micro-Fit insert holder, which is included with each tube facing tool.



Figure 3-52.



For more information, please refer to:

- Tube Facing Tools Catalog (MS-02-426) and
 - Tube Facing Tool User's Manual (MS-13-215).
- www.swagelok.com/TFM

Swagelok offers four tools to fit most needs: the TF16, TF24, TF40, and TF72 series.

Some of the features include:

- Tube sizes of 1/8 to 4 1/2 in. and 3 to 114.3 mm
- Maximum wall thickness of 0.118 in. or 3 mm
- Portable and lightweight design for mobility and easy operation
- Corded and cordless tools
- Graduated microfeed advancement for controlled material removal
- High-performance coated tool bit with two cutting edges
- Heavy-duty industrial motor with easy speed adjustment and control
- No tools required to change the collet sets to different sizes
- Removable bench mount bracket included with corded tools
- Clear safety shield or guards to protect operator from the cutting area
- Optional holder to enable bevel cutting
- Storage and shipping case included
- CE marked cordless tools also feature:
 - Robust lithium ion battery packs with capacity display
 - Electronic overload protection with integrated temperature monitoring
 - Air-cooled technology for quick charging and long service life

Handling of Tube Fittings

Swagelok tube fittings come to you completely assembled, finger-tight, and ready for immediate use. Avoid disassembling the tube fittings prior to installation. Doing so can result in dirt or foreign material getting into the fitting, which can interfere with sealing.

This illustration shows a cutaway of the ferrules inside the tube fitting contacting the tube and a cross-sectioned view at the nose portion of the back ferrule that has gone through the carburization process.

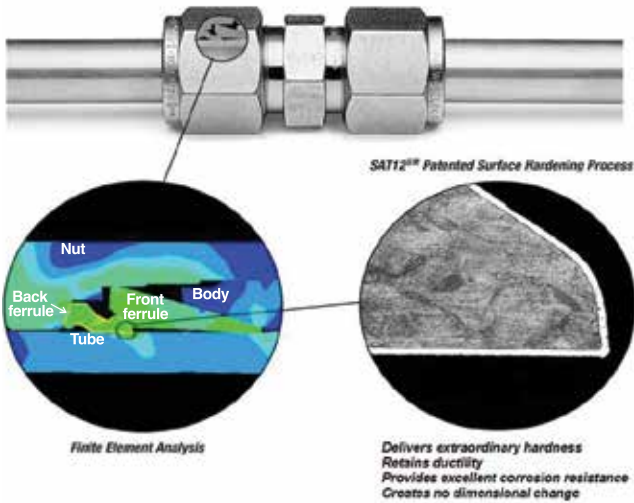


Figure 3-53.

The diffusion has gone into the surface of the ferrule and is not a layer applied on top of the ferrule. That white ribbon is the consistent effect of carbon diffused into the surface providing incredible hardness and corrosion resistance, without dimension change, while retaining ductility.

Prior to installation:

- Make sure the proper-sized fitting for the tubing you are using has been selected.
- Never mix metric components with fractional components.

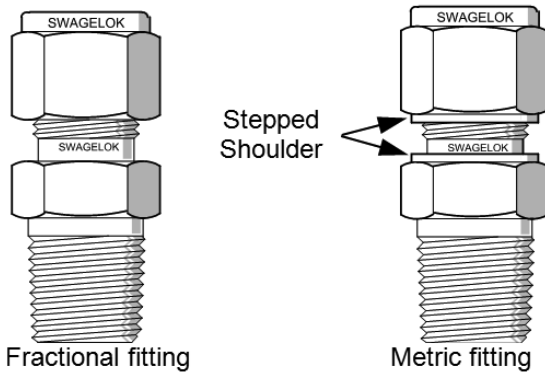


Figure 3-54.

Swagelok Tube Fitting Safety Considerations

- Do not bleed system pressure by loosening fitting nut or fitting plug.
- Do not assemble or tighten fittings when system is pressurized.
- Make sure that the tubing rests firmly on the shoulder of the tube fitting body before tightening the nut.
- Use the correct Swagelok gap inspection gauge to ensure sufficient pull-up upon initial installation.
- Do not mix fitting components (ferrules, nuts, and fitting bodies) with those of other manufacturers.
- Do not mix materials unless defined by Tubing Data - Engineered Combinations MS-06-117.
- Never turn fitting body. Instead, hold fitting body and turn nut.
- Avoid unnecessary disassembly of unused fittings.
- Use only long reducers in female Swagelok end connections.

Manual Installation of Swagelok Tube Fittings up to 1 in. or 25 mm

Safe practices and proper installation are imperative to the performance of the Swagelok tube fitting, especially in critical applications.

For 5/8, 3/4, 7/8 and 1 in.; 16, 18, 20, 22 and 25 mm tube fittings, in all materials except for aluminum and brass, it is a best practice to preswage the ferrules onto the tube adapter using a Swagelok multihead hydraulic swaging unit (MHSU) to lower installation time and increase ease of installation (see Multihead Hydraulic Swaging Unit (MHSU), Setup and Operating Instructions, MS-12-37).

1. Fully insert the tube into the fitting and against the shoulder; rotate the nut finger-tight.

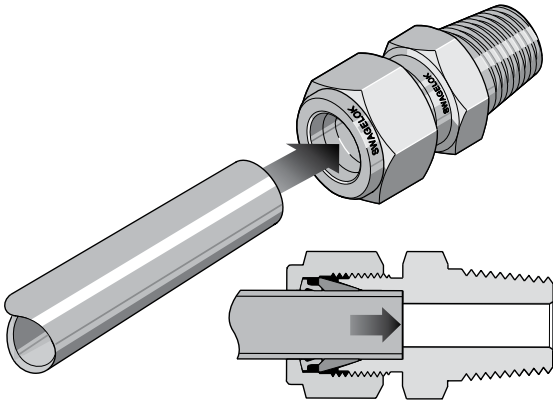


Figure 3-55 Insert tubing into tube fitting.

2. Mark the nut at the 6 o'clock position.
This will be your reference starting position..

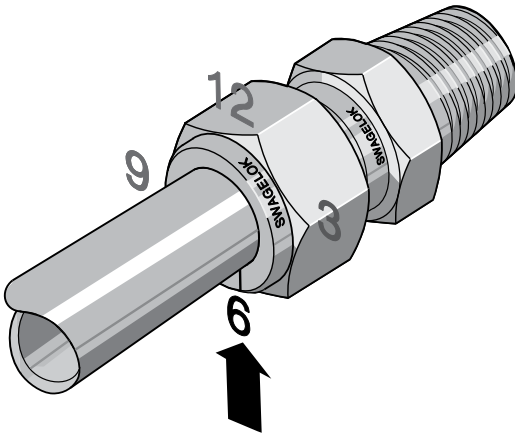


Figure 3-56 Mark the nut at 6 o'clock.

3. While holding the fitting body steady, tighten the nut 1 1/4 turns to the 9 o'clock position.

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

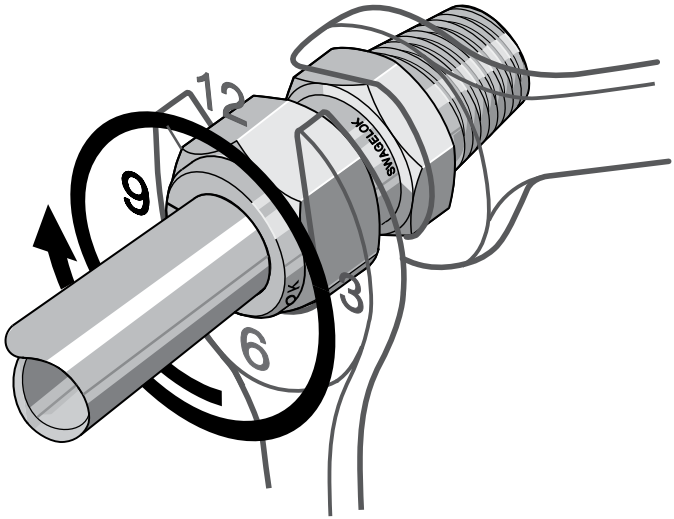


Figure 3-57 Tighten the nut 1 1/4 turns.

For Assembly in High-Pressure Applications and High Safety Factor Systems for Tubing Diameters 1 in. (25 mm) and Smaller, please refer to Chapter 4.

Best Practice: Using the Depth Marking Tool (DMT)

The Swagelok DMT is designed to provide safe installation of tubing into Swagelok tube fittings. Following is a procedure using the DMT to ensure proper bottoming of the tubing on the shoulder inside the Swagelok tube fitting body.

The DMT should only be used on tubing intended for use with Swagelok tube fittings. Intermix or interchange of Swagelok tube fitting parts with parts made by other manufacturers should never occur.

Tubing should be cut cleanly and fully deburred on both the outside diameter (OD) and inside diameter (ID) prior to using the DMT.

1. Insert the tube into the DMT until it has fully bottomed in the tool.

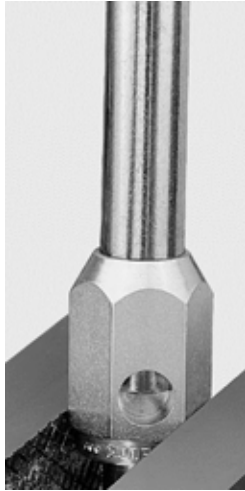


Figure 3-58 Tubing fully bottomed in DMT.

2. Mark the tube at the top of the DMT with a pen, pencil, or adequate marking device. Use marking pens with low-chloride ink when marking any stainless steel component, particularly those to be used in nuclear and high-safety applications. Many marking pens are manufactured with permanent ink that contains chlorides, which cause stress corrosion cracking in austenitic stainless steel.



Figure 3-59 Marking the tube.

3. Remove the tube from the DMT and insert into the Swagelok fitting until it is fully bottomed inside the fitting body. Inspect the mark on the tube prior to fitting assembly. If any portion of the mark on the tube can be seen above the fitting nut, the tube has not fully inserted into the fitting.



Figure 3-60 Removing the tube.



Figure 3-61 Visual inspection of mark.

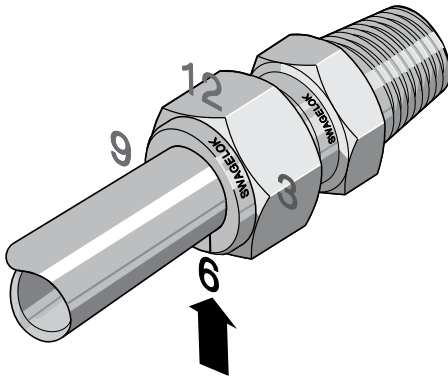


Figure 3-62 Mark the nut at the 6 o'clock position.

4. While holding the fitting body steady, install the fitting by using the installation instructions, including using the gap inspection gauge as shown beginning on p. 81.

Best Practice: Low-Chloride Markers

Many marking pens are manufactured with permanent ink that contains chlorides. Chlorides are a cause of stress corrosion cracking in austenitic stainless steel.

Many manufacturers of marking pens offer products with low-chloride ink. Their use is advised when marking any stainless steel component, particularly those to be used in nuclear and high-safety applications.

No Disassembly Inspection

There is no need to disassemble a Swagelok fitting to inspect the connection after assembly. Exhaustive tests and on-the-job performance have proven that disassembly is not needed as long as the fitting has been assembled in accordance with the installation instructions.

Gaugeability: Manual Installation

On initial installation, or when using a gaugeable preswage tool, the Swagelok gap inspection gauge assures the installer or inspector that a fitting has been sufficiently tightened.

*Gap inspection gauges should **not** be used on reassembled connections.*

Gap gauges manufactured for individual sizes can be used to inspect fittings installed using either installation method.

- The thicker end of the gauge is used for fittings installed using finger-tight method.
- The thinner end of the gauge is used for fittings installed when using the installation methods in high-pressure applications and high safety factor systems to assure the installer or inspector that the fitting has been sufficiently tightened on initial installation.

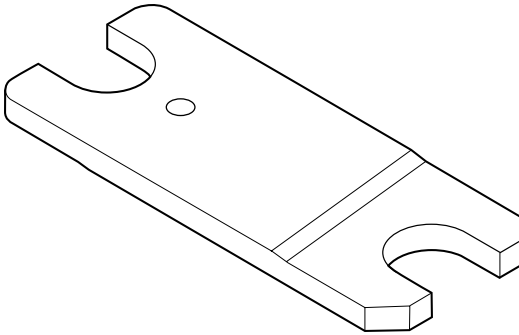


Figure 3-63 Two-sided gap inspection gauge for manually installed fittings.

Multisided gauges are also available, providing the convenience of three gauges in one (fractional sizes 1/4, 3/8, and 1/2 in.), or four gauges in one (metric sizes 6, 8, 10, and 12 mm).

These gauges can be used to inspect initial makeup on fittings installed using the finger-tight method.

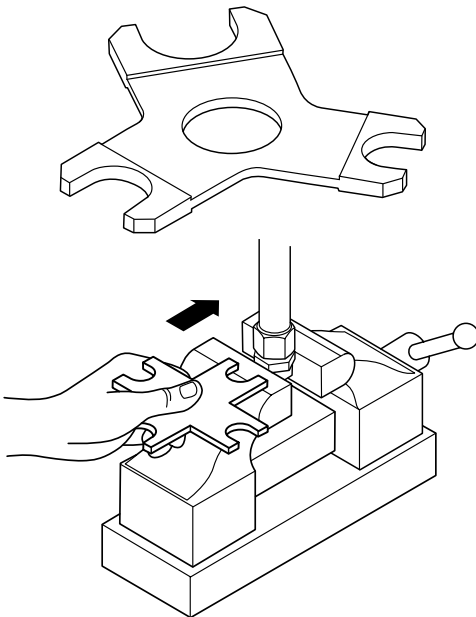


Figure 3-64 Multisided gap inspection gauges.


How the Gap Inspection Gauge Is Used



For more information, please refer to this video of the procedure. www.swagelok.com/TFM

Position the Swagelok gap inspection gauge next to the gap between the nut and body and gently attempt to push it into the gap.

Be sure to choose the correct Swagelok gap inspection gauge for the size of the fitting being inspected, as well as the method of assembly.

CAUTION:  **Always depressurize a system before adjusting the tightness of a tube fitting connection.**

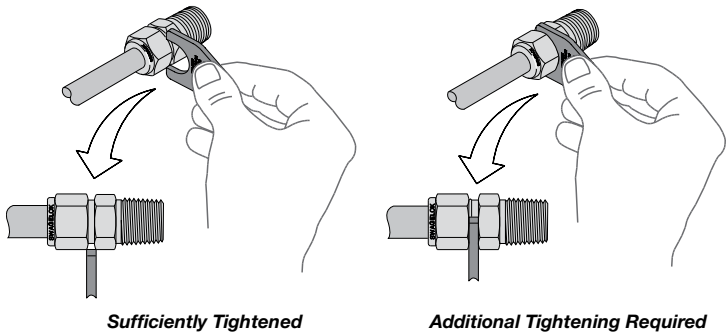


Figure 3-65 Gap inspection gauge procedure.

- If the gauge will **not** enter the gap, the fitting is sufficiently tightened.
- If the gauge will enter the gap, additional tightening is required.

Reassembly

You may disassemble and reassemble Swagelok tube fittings many times.

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

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

Reassembly Procedure



For more information, please refer to this video of the procedure. www.swagelok.com/TFM

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

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

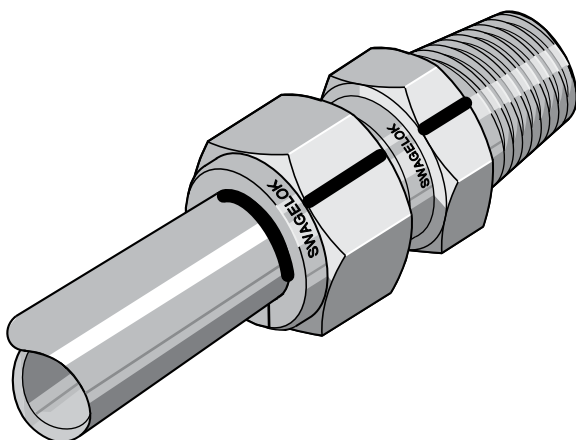


Figure 3-66 Prior to disassembly, mark the tubing and flats.

2. Insert the tubing or tube adapter end connection with preswaged ferrules into the fitting until the front ferrule seats against the fitting body.

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

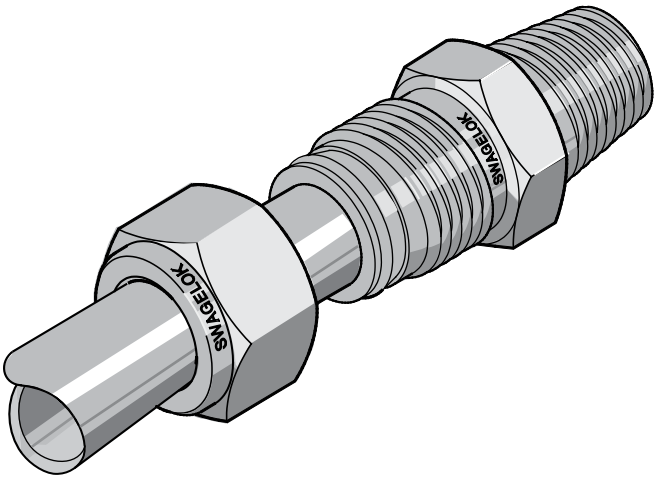


Figure 3-67 Insert tube with preswaged ferrules into the fitting body.

3. 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 tubing and flats. At this point, you will feel a significant increase in resistance. Tighten the nut slightly.

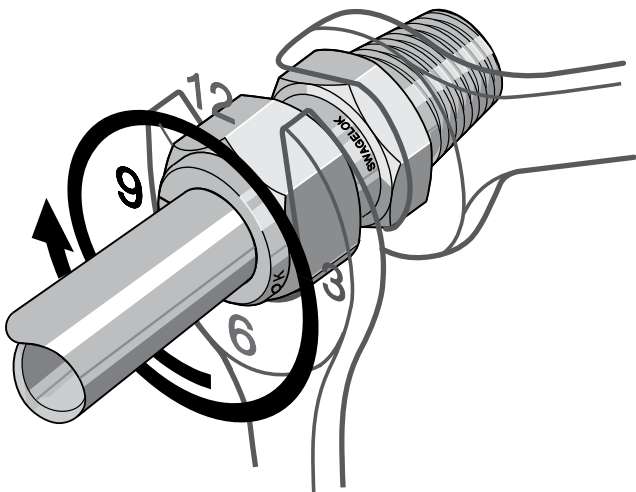


Figure 3-68 Rotate nut to pulled-up position; tighten slightly.

Preswaging Tools

For Swagelok tube fitting installations in close quarters, the Swagelok preswaging tool is a convenient accessory allowing the preswaging of ferrules onto the tube when working in a more open or safe area. After using the tool, follow the retightening instructions discussed earlier in the manual.

- Preswaging tools have a finite life. After frequent use, ask your Swagelok representative to have them checked.
- Dirt, chips, and other metal inclusions can interfere with proper swaging action. The tool should be thoroughly cleaned after each use.

Preswaging Operation

This illustrates tubing with a union connected high above ground. If a run of tubing were to be connected, it would be difficult to pull up the second end of the union.

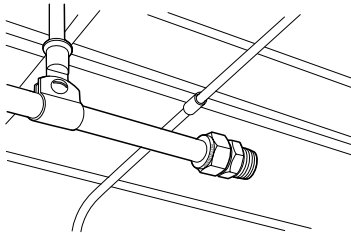


Figure 3-69.

Assemble the Swagelok nut and ferrules onto the preswaging tool. Insert tubing through the ferrules into the preswaging tool until it rests firmly on the shoulder of the preswaging tool body. Tighten the nut 1 1/4 turns from finger-tight (sizes 1/16, 1/8, and 3/16 in.; 2, 3, and 4 mm require only 3/4 turn).

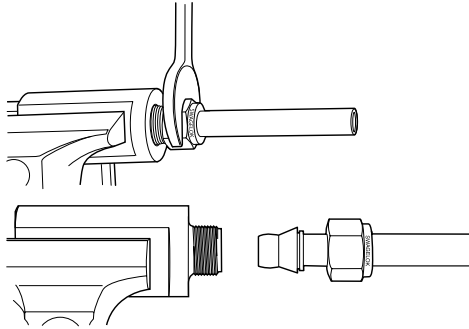


Figure 3-70.

The nut is loosened, and the tubing with preswaged ferrules is removed from the preswaging tool.

The connection can now be made by following the retightening instructions.

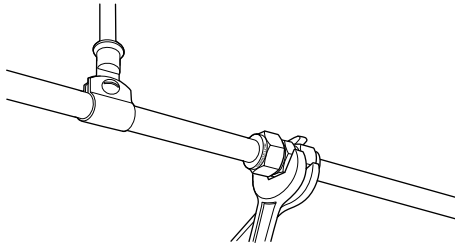


Figure 3-71.

Completed installation.

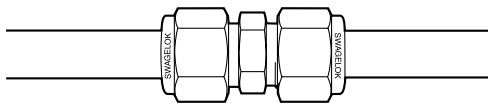


Figure 3-72.

NOTE: Oversized or very soft tubing may occasionally stick in the tool after pull-up. If this happens, remove the tube by gently rocking it back and forth. *Do not turn or twist* the tube with pliers or other tools because this may damage sealing surfaces.

Hydraulic Swaging Using the Air-Actuated Hydraulic Swaging Unit

The Swagelok Air-Actuated Hydraulic Swaging Unit (AHSU) requires only one unit with interchangeable tooling to swage 1/4 to 1/2 in. and 6 to 12 mm Swagelok tube fitting end connections; it is not intended for use with tube adapter or machined ferrule connections.



Please refer to the AHSU Operations Manual (MS-12-38) for more information. www.swagelok.com/TFM

When properly used, the AHSU provides Swagelok tube fittings that are 100 % gaugeable when installed. In addition, use of the AHSU:

- Places no initial strain on the nut or fitting body threads or on body seal surfaces
- Requires no threading of the nut on or off the tooling
- Reduces assembly and installation time and operator error

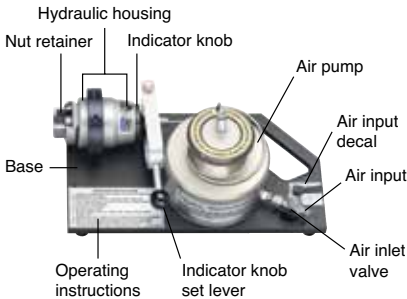


Figure 3-73.

Hydraulic Swaging Using the Multihead Hydraulic Swaging Unit

The Multihead Hydraulic Swaging Unit (MHSU) provides Swagelok tube fitting installations that are 100 % gaugeable upon initial installation.

The Swagelok MHSU is available with interchangeable die heads to install 1/2 to 2 in. and 12 to 50 mm Swagelok tube fittings to tubing. It **MUST** be used to install 1 1/4, 1 1/2, and 2 in. and 28, 30, 32, 38, and 50 mm Swagelok tube fitting end connections to tubing. In addition, the MHSU can also be used to pull up Swagelok tube fittings to tube adapter end connections from 1/2 in. or 12 mm up to 1 in. or 25 mm.



Please refer to MHSU Operations Manual MS-12-37. www.swagelok.com/TFM

The MHSU also:

- Places no initial strain body threads or body seal surfaces.
- Is available with a tube marking feature to indicate when tubing is properly bottomed.
- Reduces assembly and installation time.

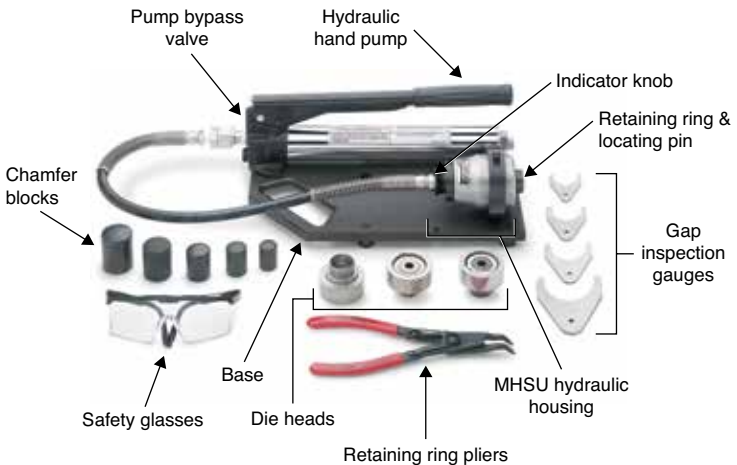


Figure 3-74.

Recommended Minimum Wall Thickness of Tubing for Use with the MHSU

Use of tubing below the recommended minimum wall thickness may result in the tube sticking in the die head.

Swagelok Tube Fittings		
Tooling Size	Steel, Alloy 400, Grade 2 Titanium	Stainless Steel, Alloy (600, 6-moly, 825, and 625)
	Tubing Wall	
Dimensions, in.		
1/2	0.049	0.065
5/8	0.065	
3/4		
7/8		
1		0.083
1 1/4	0.083	0.095
1 1/2		
2	0.095	0.109

Swagelok Tube Fittings		
Tooling Size	Steel, Alloy 400, Grade 2 Titanium	Stainless Steel, Alloy (600, 6-moly, 825, and 625)
	Tubing Wall	
Dimensions, mm		
12	1.5	1.5
14		
15		1.8
16		
18		
20	2.0	2.0
22		
25		
28	2.2	2.2
30		
32		
38		
50		2.5

For other materials, contact your local Swagelok Authorized Sales and Service Center.

Intermix/Interchange of Swagelok Components

Leak-tight seals that will withstand high pressure, vibration, vacuum, and temperature changes depend on close tolerances and consistent, exacting quality control in conjunction with good design principles. The critical interaction of precision parts is essential for reliability and safety. Components of other manufacturers may look like Swagelok tube fitting components, but they cannot be manufactured in accordance with Swagelok engineering standards, and they do not benefit from innovations in design and manufacture defined by more than 100 active Swagelok tube fitting patents issued worldwide.

■ Interchange

A tube fitting manufactured from one company that has been installed on a piece of tubing and that is then disassembled, and the tubing, nut, and ferrules from that installed fitting are reassembled into the body of another manufacturer.

■ Intermix

Tube fitting components, which include the nuts, ferrules, and bodies, from two or more fitting manufacturers that are mixed together and then assembled to make a complete fitting component.

- Swagelok recommends NO intermix/interchange of Swagelok tube fitting components with other manufacturers' components.
 - No industrial design standard exists for two ferrule tube fittings. Each company makes components to its own design and not to any recognized standards.
 - Interchanging and intermixing tube fitting components can result in unpredictable performance, environmental releases, increased costs, and can be dangerous in critical applications.

The Swagelok Limited Lifetime Warranty

Swagelok products are backed by The Swagelok Limited Lifetime Warranty. For a copy, contact your authorized Swagelok representative.

System Configuration Tools

Installation of a Swagelok Tube Adapter End Connection

The Swagelok tube adapter end connection is designed to connect to a Swagelok tube fitting end connection in much the same manner as tube.

Tube adapter end connections come to you in one of two ways, depending on their size:

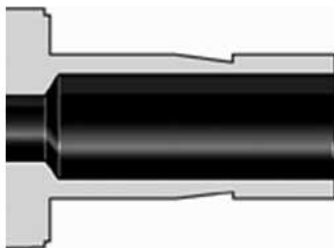


Figure 3-75 Swagelok tube adapter end connection (diameters up to and including 1 in./25mm).

- Tube adapters up to and including 1 in./25 mm are grooved. The groove is positioned to receive the ferrules during installation. It simulates the action of the ferrules as they would perform on annealed tube.
- Tube adapters over 1 in./25 mm are furnished with nut and preswaged ferrules.

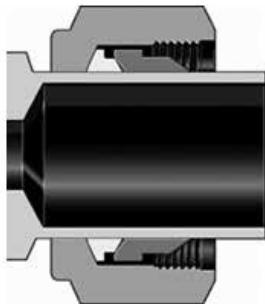


Figure 3-76 Swagelok tube adapter end connection (diameters larger than 1 in./25 mm).

Tube Adapters up to 1 in./25 mm

Safe practices and proper installation are imperative to the performance of the Swagelok tube fitting, especially in critical applications.

For 5/8, 3/4, 7/8 and 1 in.; 16, 18, 20, 22 and 25 mm tube fittings, in all materials except for aluminum and brass, it is a best practice to preswage the ferrules onto the tube adapter using a Swagelok multihead hydraulic swaging unit (MHSU) to lower installation time and increase ease of installation (see Multihead Hydraulic Swaging Unit (MHSU), Setup and Operating Instructions, MS-12-37).

1. Install the end opposite the tube adapter end.

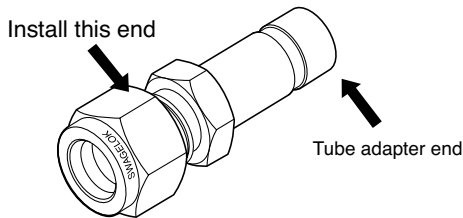


Figure 3-77 Install the end opposite the tube adapter end first.

2. Insert the tube adapter into the Swagelok tube fitting. Make sure that the tube adapter rests firmly on the shoulder of the tube fitting body and that the nut is finger-tight.
3. Mark the nut at the 6 o'clock position.
4. While holding the fitting body steady, tighten the nut 1 1/4 turns to the 9 o'clock position.



Figure 3-78 Insert the tube adapter end connection into the Swagelok tube fitting end connection.

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

Tube Adapters over 1 in./25 mm

Install the end opposite the tube adapter end.

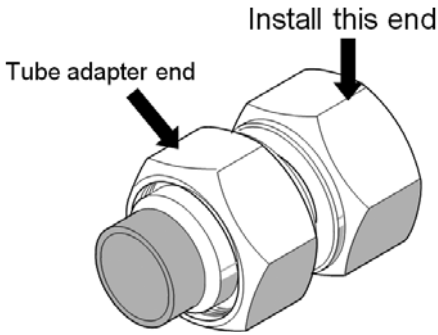


Figure 3-79 Install the end opposite the tube adapter first.

1. Tube adapters over 1 in./25 mm are furnished with nut and preswaged ferrules. Remove the nut and ferrules from the Swagelok tube fitting end connection.
2. Apply the lubricant packaged with the fitting lightly to the Swagelok tube fitting body threads.

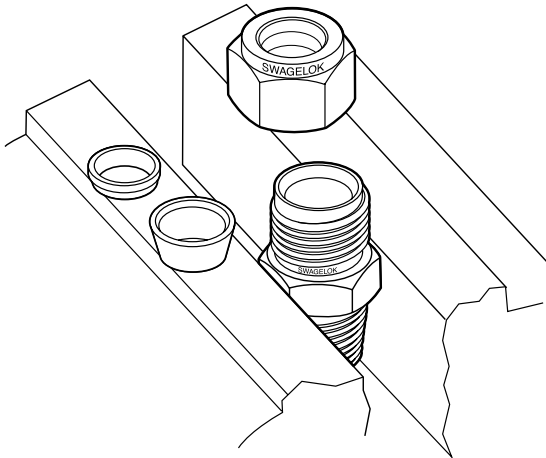


Figure 3-80 Remove the nut and ferrules from the tube fitting end connection.

3. Insert the tube adapter with preswaged ferrules into the fitting until the front ferrule seats against the fitting body; rotate the nut finger-tight.

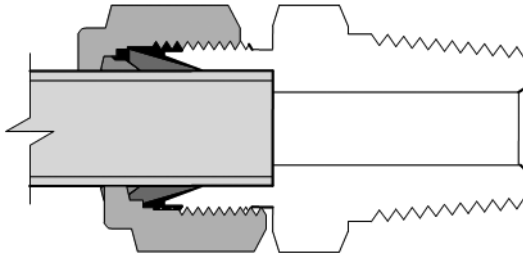


Figure 3-81 Make sure the tube adapter rests firmly on the shoulder of the tube fitting body.

4. Mark the nut at the 6 o'clock position.
5. While holding the fitting body steady, tighten the nut 1/2 turn to the 12 o'clock position.

Do not use the Swagelok gap inspection gauge with preswaged tube adapter connections over 1 in./25 mm.

Installation of a Swagelok Machined Ferrule End Connection

During installation the nut pushes the machined ferrule securely against the seat in the tube fitting end connection. This provides a leak-tight seal.

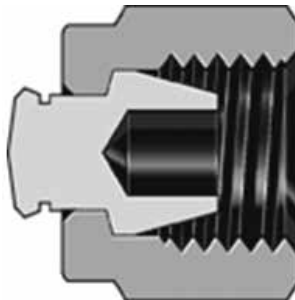


Figure 3-82 Swagelok Machined Ferrule.

The machined ferrule end connection is most commonly found on two components:

- Plug
- Port connector

Each requires a slightly different preparation for installation:

Plug

1. Remove and discard the nut and ferrules from the Swagelok tube fitting end connection.

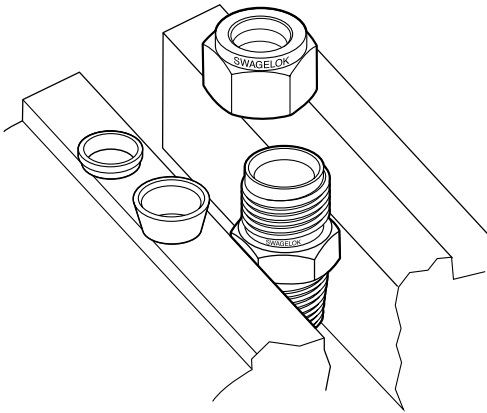


Figure 3-83 Remove the nut and ferrules from the tube fitting end connection.

2. Turn the nut onto the fitting so that it is finger-tight.

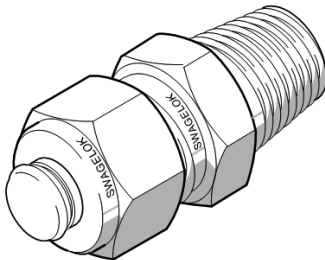


Figure 3-84 Install the nut onto the fitting to finger-tight.

3. While holding the fitting body steady, tighten the nut 1/4 turn. For 1/16, 1/8, and 3/16 in. or 2, 3, and 4 mm tube fittings, tighten the nut 1/8 turn.

For over 1 in./25 mm installation, see page 63 in MS-01-140.

Do not use the Swagelok gap inspection gauge with plug assembly.

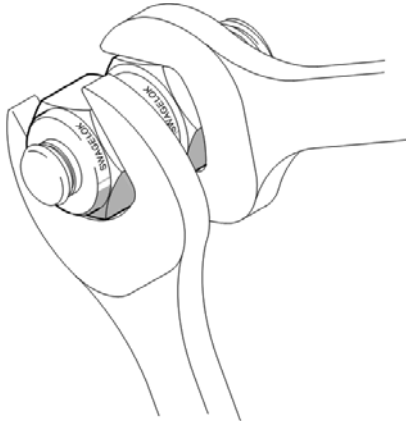


Figure 3-85 Tighten the nut.

Port Connector

Machined Ferrule End

1. Remove the nut and ferrules from the Swagelok tube fitting end connection. Discard the ferrules.

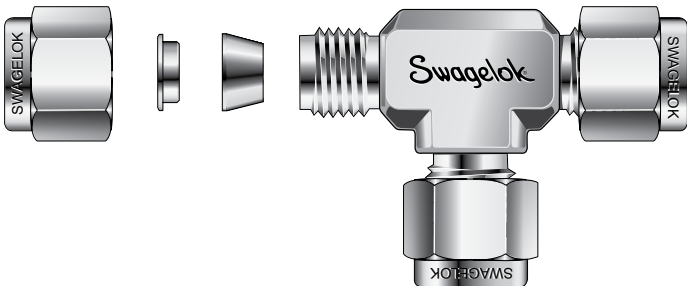


Figure 3-86 Remove the nut and ferrules from the tube fitting end connection.

2. Slip the nut over the machined ferrule end of the port connector.

Over 1 in./25 mm sizes:

The nut is preassembled on the port connector.

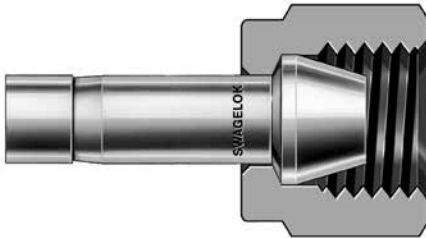


Figure 3-87 1 in./25 mm and under.

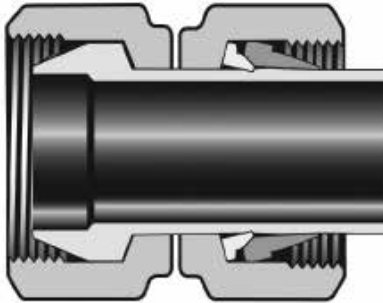


Figure 3-88 Over 1 in./25 mm.

3. Insert the port connector into the end connection and finger-tighten the nut.

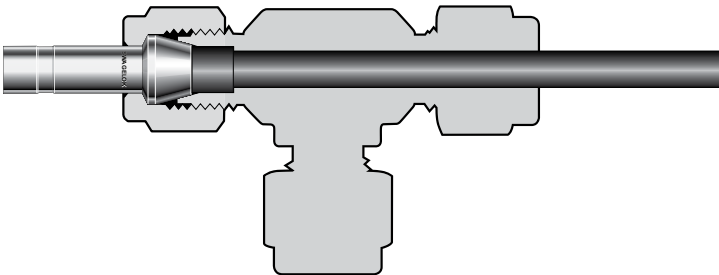


Figure 3-89 Insert the port connector.

4. While holding the fitting body steady, tighten the nut 1/4 turn. For 1/16, 1/8, and 3/16 in. or 2, 3, and 4 mm tube fittings, tighten the nut 1/8 turn.

Do not use the Swagelok gap inspection gauge with machined ferrule ends.

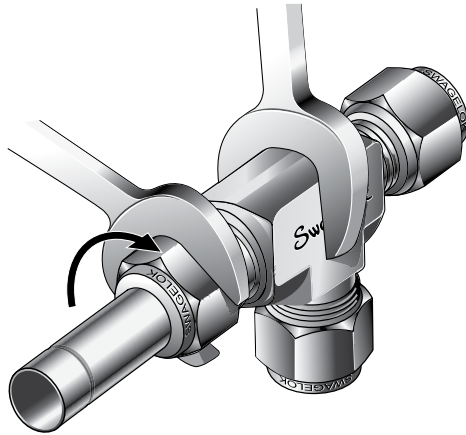


Figure 3-90 Tighten the nut.

Tube Adapter End

1. Insert the tube adapter until it rests firmly on the shoulder of the Swagelok tube fitting body. Finger-tighten the nut.

Over 1 in./25 mm sizes:

Remove and discard the nut and ferrules from the end connection, and then insert the tube adapter.

2. Mark the nut at the 6 o'clock position. While holding fitting body steady, tighten the nut 1 1/4 turns to the 9 o'clock position.

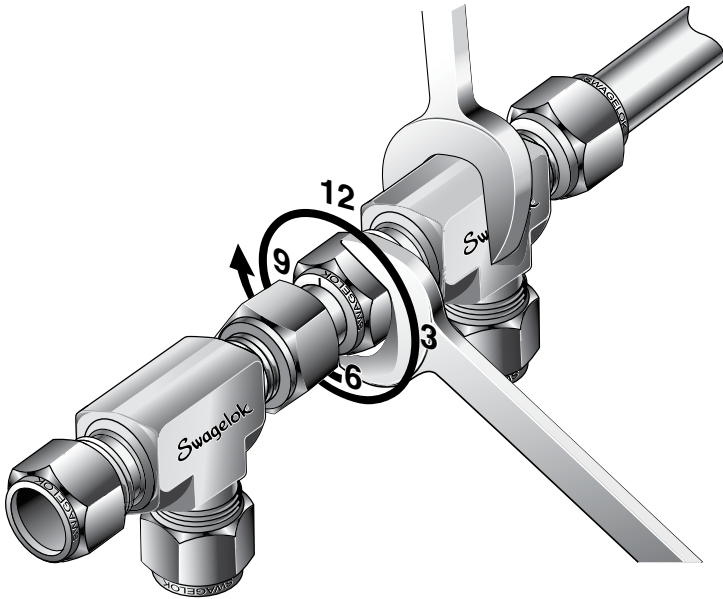


Figure 3-91.

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

For preswaged over 1 in./25 mm tube fittings, tighten the nut 1/2 turn to the 12 o'clock position.

Do not use the Swagelok gap inspection gauge with preswaged tube adapter connections over 1 in./25 mm.

Bulkhead Connections

Unions



Figure 3-92.

Bulkhead connections are used when fluid is to be transferred through a panel wall.

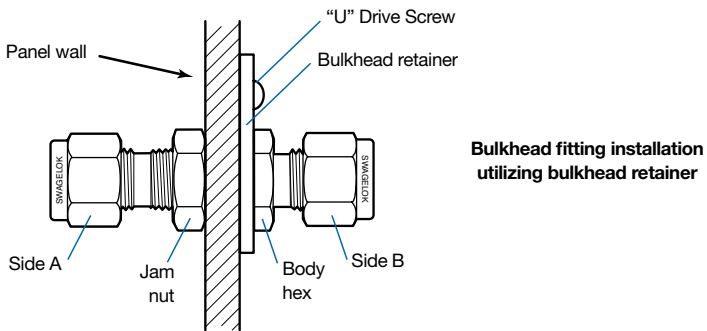


Figure 3-93.



Please refer to the Gaugeable Tube Fittings and Adapter Fittings catalog MS-01-140 for more information.
www.swagelok.com/TFM

SAE or MS Straight Thread Ports (Installation)

Hydraulic equipment often uses SAE/MS straight thread ports instead of pipe threads. Such ports require a Swagelok tube fitting using an O-ring seal. A wide variety of Swagelok tube fittings, adapters, reducers, and plugs are readily available in steel, stainless steel, and other alloy materials with SAE/MS straight threads.



Please refer to the Gaugeable Tube Fittings and Adapter Fittings catalog MS-01-140 for more information.
www.swagelok.com/TFM

Straight fittings have an O-ring, which is directly driven into the tapered port to make a seal.

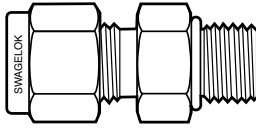


Figure 3-94 Male SAE/MS Connector.

Positionable elbows and tees have an elongated male thread, a jam nut, metal washer, and elastomer O-ring.

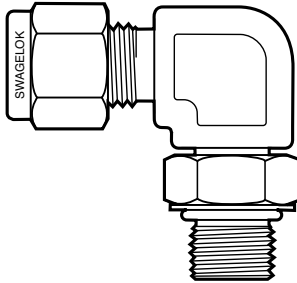


Figure 3-95 90° SAE/MS Positionable Male Elbow.

1. Lubricate the O-ring with a lubricant that is compatible with the system fluid, environment, and O-ring material. (Standard O-ring material is fluorocarbon FKM. Other O-ring materials are available on request.)
2. Turn the fitting into the straight thread boss until the metal back-up washer contacts the face of the boss and forces the O-ring into the tapered port.
3. Position the fitting by backing it out (not more than 1 turn counterclockwise) until the Swagelok end is oriented in the proper direction.
4. Hold the wrench pad with a back-up wrench and tighten the locknut until the washer is against the face of the boss, forcing the O-ring into the tapered port.

Contact your Swagelok Authorized Sales and Service Center for assembly torque specifications.

SAE/MS Straight Thread Positionable Elbows and Tees (Installation)

Positionable elbows and tees are compatible with SAE J1926 or MS16142 female straight thread O-ring bosses.

NOTE: Although O-ring sealed ports are excellent for tight sealing, remember that O-rings do have some inherent disadvantages:

- Some elastomer compounds are attacked by certain system fluids.
- Elastomer compounds sometimes harden and crack under certain field conditions. Both system fluid and environment must be considered.
- Elastomer compounds are easily damaged by sharp surfaces, burrs, or chips.
- Special tools are required to make SAE/MS ports.

O-Ring Seals

O-ring seal fittings include a 70 durometer Buna N O-ring. Other straight-thread fittings with O-rings include a 90 durometer fluorocarbon FKM O-ring. Other O-ring materials are available upon request. O-rings are coated with a thin film of silicone-based lubricant. Removal of factory-applied lubricants may alter performance.

Medium-Pressure Tube Fittings, FK Series

The simple two-piece design of the Swagelok medium-pressure tube fittings and adapters consists of a female fitting body and preassembled cartridge containing the male nut and color-coded front and back ferrules on a disposable plastic arbor. The preassembled cartridge ensures installers correct ferrule orientation, visual confirmation of ferrule presence, and proper installation into the female body. Components are released only after the nut is threaded finger-tight on the fitting body. The Swagelok medium-pressure tube fitting offers a leak-tight gas seal and vibration resistance in applications up to 20 000 psig (1 378 bar).

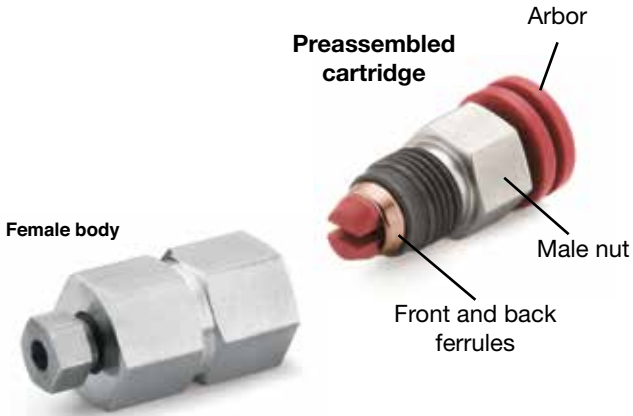


Figure 3-96.



Please refer to the Swagelok Medium- and High-Pressure Fittings, Tubing, and Valves Catalog MS-02-472 for more information. www.swagelok.com/TFM

Medium- and High-Pressure Products: IPT Series

The IPT series is a wide product line of medium- to high-pressure fittings, valves, and other fluid control devices.



Figure 3-97.

Training and Education

Contact your authorized Swagelok representative for details about the *IPT Series Medium- and High-Pressure Products*.

Coned and Threaded Fittings, IPT Series

Swagelok IPT series coned and threaded fittings are available in both medium- and high-pressure designs. The medium-pressure fittings are designed to withstand pressures up to 20 000 psig (1378 bar) and are available in a variety of sizes from 1/4 to 1 1/2 in.

The high-pressure fittings can accommodate pressures up to 60 000 psig and are available in sizes from 1/8 to 1 in.

For both fittings the standard material of construction is 316 cold-worked stainless steel. This material is required for higher yields in tensile strength for higher pressure applications.



Figure 3-98.

Coned and threaded fittings have three basic components. These components are a gland, collar, and body. These components work together with coned and threaded tubing to create a leak-tight seal. Coned and threaded fittings seal at the interface between the angle of the coned tubing and the angle of the seat within the fitting body.

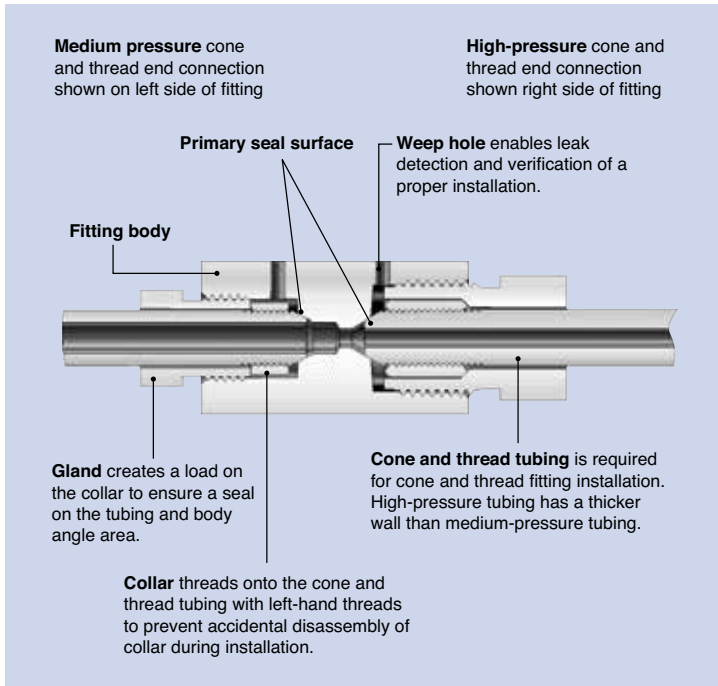


Figure 3-99.

Assembly

Safe, leak-tight operation of any medium- or high-pressure system depends on preparing and installing the coned and threaded connections correctly.

These instructions apply to 1/4, 3/8, 9/16, 3/4, and 1 in. medium-pressure cone and thread fitting sizes and 1/4, 3/8, and 9/16 in. high-pressure cone and thread fitting sizes.

1. Lubricate all male threads with an anti-seize lubricant, such as a Swagelok Goop® product. Lubricate the cone end of the tubing with a system-compatible lubricant.

2. Slide the coned and threaded (C&T) tubing into the gland.
3. Thread the collar counterclockwise (left-hand thread) onto the C&T tubing.
4. Continue threading until one to two full threads are exposed at the cone end of the tubing. This will indicate proper position of the collar.
5. Insert the C&T tubing with collar into the fitting body.
6. Make sure the cone end of tubing rests firmly on the angled seat of the fitting body.
7. Thread the gland into the fitting body until finger-tight. Hold the fitting body steady and tighten the gland to the required torque shown.

Fitting Size in.	Required Torque ft·lb (N·m)
1/4	20 (27.2)
3/8	30 (40.7)
9/16	55 (74.6)
3/4	90 (123)
1	150 (204)

Medium-Pressure C&T Fitting

Fitting Size in.	Required Torque ft·lb (N·m)
1/4	25 (33.9)
3/8	50 (67.8)
9/16	110 (150)

High-Pressure C&T Fitting



Please refer to the Swagelok Medium- and High-Pressure Fittings, Tubing, and Valves Catalog MS-02-472 for more information. www.swagelok.com/TFM

Pipe End (Installation)

Pipe threads are the most common end connections found in industry. Pipe threads always need a sealant because the design creates gaps between male and female threads.

Swagelok End Connections with Tapered Threads

Swagelok manufactures end connections with two types of tapered pipe threads.

- Swagelok NPT end connections are manufactured with NPT tapered threads.
- Swagelok RT end connections are manufactured with ISO 7/1 tapered threads.

NPT (National Pipe Tapered)

- Thread taper $5\ 1^{\circ}47'$
- Truncation of roots and crests are **flat**
- Pitch measured in **threads per inch**
- **60°** thread angle

ISO 7/1

- Thread taper $5\ 1^{\circ}47'$
- Truncation of roots and crests are **rounded**
- Pitch measured in **threads per inch**
- **55°** thread angle

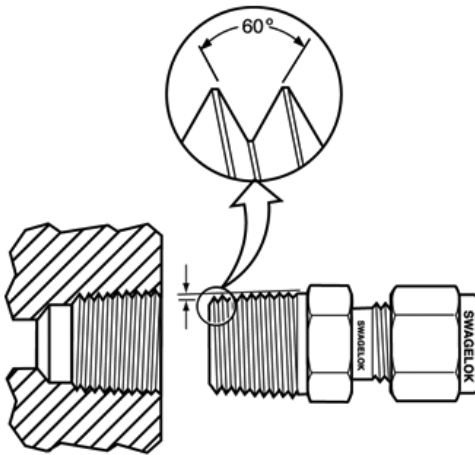


Figure 3-100.

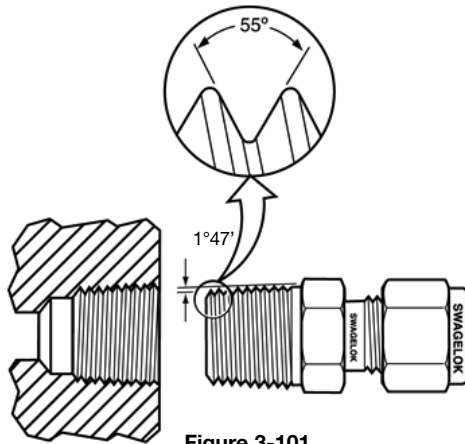


Figure 3-101.

Product Marking: RT and NPT End Connections

RT

All products containing a Swagelok RT end connection are marked **ISO7**.

Fittings with an RT end connection and either a Swagelok tube fitting or tube adapter end connection are also marked **RT** on the hex or wrench flat.

NPT

NPT end connections on Swagelok components are generally not marked.

However, Swagelok fitting components with both NPT and RT end connections will be marked **NPT** and **ISO7**, with arrows pointing to the corresponding end to which each mark refers.

Thread Sealants

Threaded Fitting Installation

Proper sealing depends on many variables, including quality and cleanliness of threads, temperature, component material, installation torque, specific gravity of system media, and system operating pressures.

When assembling a Swagelok product containing a threaded connection, the threaded connection should always be assembled prior to the other connection because of the rotation required to assemble the threaded connection.

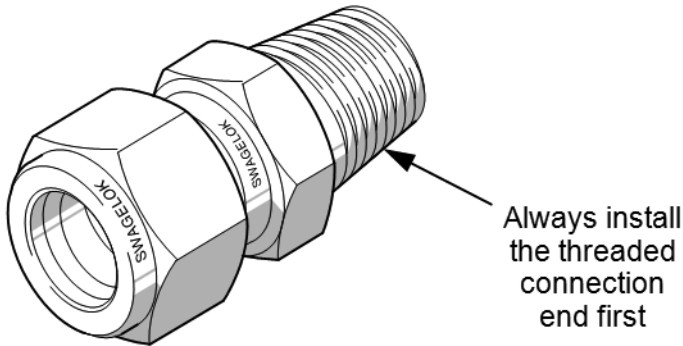


Figure 3-102.

Thread Sealant

Tapered threads always need a sealant to seal system fluids and prevent galling of the threads during installation.

Swagelok PTFE tape and liquid products such as SWAK™ anaerobic pipe thread sealant and PTFE-Free pipe thread sealant help to achieve both the sealing and lubricating functions required of tapered threads.

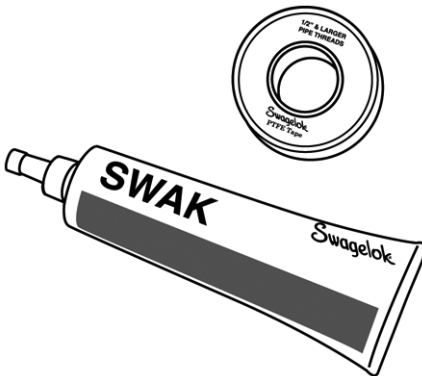


Figure 3-103.

Swagelok PTFE Tape

For service up to 450°F (232°C), Swagelok PTFE tape helps to achieve leak-free connections. PTFE tape is wrapped around male pipe threads. As the threads are tightened, the PTFE tape fills voids at the flank, crest, and root of the threads to provide a seal.

Swagelok PTFE tape conforms to Commercial Item Description A-A-58092, a U.S. standard specifying the chemical, density, and elongation properties of PTFE tape permitted for use by U.S. government agencies.


Swagelok SWAK

Swagelok SWAK anaerobic thread sealant provides reliable sealing on metal pipe threads for service in applications between -65 and 350°F (-53 and 176°C). It also acts as a lubricant during assembly, resisting galling or seizing of threads. SWAK sealant is applied as a paste to the male threads. Once the threaded components are assembled it hardens or cures to form a reliable seal. SWAK pipe thread sealant with PTFE is a semi-liquid, packaged in a squeezable plastic tube with a ribbon applicator.

Some fluids and materials are NOT compatible with SWAK sealant. Please contact your Swagelok Authorized Sales and Service Center for more information.

Swagelok PTFE-Free

For some applications, Swagelok PTFE-Free pipe thread sealant may provide an alternative liquid thread sealant. For service in applications between -65 and 300°F (-53 and 148°C), it seals metal pipe threads upon assembly while providing lubrication to resist galling or seizing of threads.

WARNING:  **Do not use Swagelok PTFE-Free pipe thread sealant in systems containing a strong oxidizer. A chemical reaction, including spontaneous combustion, can occur.**

Assembly Using Liquid Thread Sealants

Following are instructions on how to use two types of liquid sealant:

- Swagelok SWAK anaerobic pipe thread sealant
- Swagelok PTFE-Free pipe thread sealant

1. Remove the thread protector from the male threads. Remove the bits of plastic that may have been scraped onto the threads from the inside of the thread protector using a clean, dry, soft-bristled brush.



Figure 3-104.

2. Where possible, place the component containing the female threads into a vise.



Figure 3-105.

NOTE:

- Tighten the jaws **ONLY** on the flats.
- Tighten just enough to securely hold the component because overtightening could result in damage to the component.

Use a back-up wrench in applications where a vise cannot be used.

3. Knead the tube of sealant (with the cap in place) to blend the contents prior to use.
4. Remove the cap from the ribbon applicator.



Figure 3-106.

5. While viewing the male threads from the open end, or face, of the threaded connection, locate the point where the root of the thread (dashed line) blends into the thread chamfer near the face of the fitting. This point is referred to as the **scratch mark**.

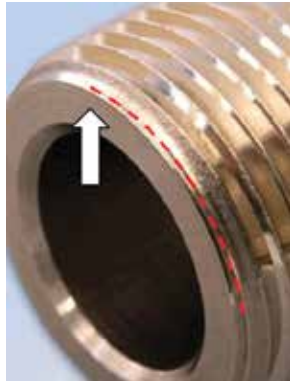


Figure 3-107.

- Place the tip of the ribbon applicator on the crest immediately behind this point.


CAUTION:  **Do not apply sealant prior to this point because excess sealant could get into the fluid system!**



Figure 3-108.

- Apply sealant to fill the next three threads.




Figure 3-109.

- Use a solvent such as acetone to remove any excess sealant.
- Replace the cap before storing the tube.



Figure 3-110.

10. Tighten the male end connection into the female end connection until finger-tight.

CAUTION:  **Use an appropriately sized wrench. An oversized wrench will permit overtightening and might lead to galling of the threads.**


11. Tighten the male end connection until wrench-tight.

There is no standard for torque or number of turns. ANSI/ASME B1.20.1-1983 states, “NPT taper pipe threads are intended to be made up wrench-tight and with a sealant whenever a pressure-tight joint is required.” Do not overtighten so much as to strip the threads!



Figure 3-111.

If the tapered end connection is on an elbow, tee, cross, valve, or pressure gauge, assembly may not result in the desired alignment of the component. Use a tube adapter to get proper alignment.

CAUTION:  **Once tight, do not loosen the connection! Doing so could mean leakage at the pipe thread.**

Assemblies made up using SWAK sealant must be allowed to cure for at least 24 hours at room temperature before pressurizing the connection.

Assemblies made up using PTFE-Free sealant may be pressurized immediately.

Assembly Using PTFE Tape

1. Remove the thread protector from the male threads.



Figure 3-112.

2. Where possible, place the component containing the female threads into a vise.

NOTE:

- Tighten the jaws **ONLY** on the flats.
 - Tighten just enough to securely hold the component because overtightening could result in damage to the component.
- Use a back-up wrench in applications where a vise cannot be used.



Figure 3-113.

3. While viewing the male threads from the open end, or face, of the threaded connection, locate the point where the root of the thread (dashed line) blends into the thread chamfer near the face of the fitting. This point is referred to as the **scratch mark**.

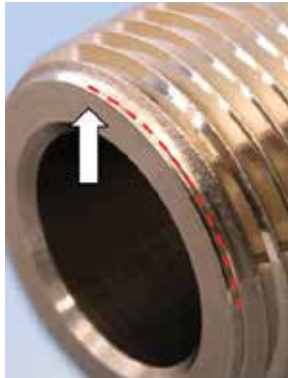


Figure 3-114.

4. Place the edge of the tape on the crest immediately behind this point.
 - Use 1/4 in. wide tape on 1/8, 1/4, and 3/8 in. male tapered pipe threads.
 - Use 1/2 in. wide tape on larger male pipe threads.



Figure 3-115.

5. While keeping the edge of the tape parallel to the face of the fitting, wrap the tape in the direction of the thread spiral (clockwise for right-hand threads) **two to three** revolutions.



Figure 3-116.

NOTE:

If the tape is applied in the opposite direction of the thread spiral, it is likely to fall off as the male component is tightened into the female component.



Figure 3-117.


6. Draw the free end of the tape around the threads tautly so that it conforms to the threads. Cut or tear off excess tape.

Do not cut across the threads.



Figure 3-118.

Firmly press the tape into the threads. Properly applied PTFE tape will exhibit the following:

CAUTION:  **The tape must not overhang the first thread because the tape could shred and get into the fluid system.**

- The space between the face of the connection and the edge of the tape closest to it will be even, with the edge intersecting the thread immediately behind the scratch mark.
- The number of wraps will be consistent, with no gaps, folds, or creases in the tape.



Figure 3-119.

- All crests will be covered. There will be no slices or gouges in the tape.




Figure 3-120.



Figure 3-121.

- Tape must be clear of dirt and debris.

7. Tighten the male end connection into the female end connection until finger-tight.

CAUTION:  **Use an appropriately sized wrench. An oversized wrench will permit overtightening and might lead to galling of the threads!**

8. Tighten the male end connection until wrench-tight.

There is no standard for torque or number of turns. ANSI/ASME B1.20.1–1983 states, “NPT taper pipe threads are intended to be made up wrench-tight and with a sealant whenever a pressure-tight joint is required.” Do not overtighten so much as to strip the threads! If the tapered end connection is on an elbow, tee, cross, valve, or pressure gauge, assembly may not result in the desired alignment of the component.

Once tight, do not loosen the connection! Doing so could mean leakage at the pipe thread.

Chapter 4

Severe Service

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Severe Service

Fittings connect some of a plant's most essential and costly equipment. Because fluid mobility is an integral part of a plant's most critical systems, these applications are often custom-designed and highly engineered, making them significant financial investments. Years of successful performance in the field and rigorous testing have validated the performance of Swagelok tube fittings. These tube fittings have been engineered to perform reliably in a wide range of critical applications, from ambient conditions to the extreme, high-pressure, high-temperature, or highly-corrosive environments. Swagelok tube fittings are used in severe service applications across many industries.

Safety Considerations for Severe Service Systems

- Do not bleed the system by loosening the tube fitting nut or the fitting plug.
- Do not assemble or tighten fittings when the system is pressurized.
- Make sure that the tubing rests firmly on the shoulder of the tube fitting body before tightening the nut.
- Use the correct Swagelok gap inspection gauge to ensure sufficient tightening upon initial installation.
- Never allow problems to go unreported.
- Always use proper thread sealants on tapered pipe threads.
- Do not mix materials or fitting components from various manufacturers—tubing, ferrules, nuts, and fitting bodies.
- Never turn the fitting body. Instead, hold the fitting body and turn the nut.
- Avoid unnecessary disassembling of unused fittings.
- Use only long reducers in female Swagelok end connections.
- Metal tubing material should be softer than fitting material. For example, stainless steel tubing should not be used with brass fittings.
- Use fully annealed tubing when tubing and fittings are made of the same material.
- Always use an insert with extremely soft or pliable plastic tubing.
- Check extremes of wall thickness against fitting manufacturer's suggested minimum and maximum wall thickness limitations.
- Check the surface finish of the tubing. Surface finish is very important to proper sealing. Tubing with any kind of depression,

scratch, raised portion, or other surface defect will be difficult to seal, particularly in gas service.

- Check tubing for ovality. Tubing that is oval and will not easily fit through fitting nuts, ferrules, and bodies should never be forced into the fitting.



Refer to the Swagelok Tubing Data Sheet (MS-01-107) for more information about tubing selection. www.swagelok.com/TFM

Severe Service Requirements

For severe service requirements, there are tools and methods to ensure that installation is correct.

- Depth marking tool (DMT)
- Specific high-pressure and high safety factor instructions
- Gap inspection gauge

Please refer to Depth Marking Tool instructions in Chapter 3 starting on page 78.

Assembly in High-Pressure Applications and High Safety Factor Systems for Tubing Diameters 1 in. (25 mm) and Smaller

This procedure is specific to tubing diameters 1 in. (25 mm) and smaller, and it varies only slightly from the standard procedure.

1. First, fully insert the tubing into the fitting and against the shoulder. Rotate the nut finger-tight.
2. Next, due to variations of tubing diameters, a common starting point is desirable. Therefore, further tighten the nut until the tubing will not turn by hand or move axially within the fitting.
3. Next, mark the nut at the 6 o'clock position. Finally, while holding the body steady, tighten the nut 1 1/4 turns to the 9 o'clock position.

As was mentioned previously, 1/16, 1/8, and 3/16 in. or 2, 3, and 4 mm tube fittings require only a 3/4 turn of the nut for sufficient tightening.

Gap Gauge

Swagelok gap inspection gauges assure the installer or inspector that the fitting has been sufficiently tightened on initial installation.



Figure 4-1 Gap inspection gauge.

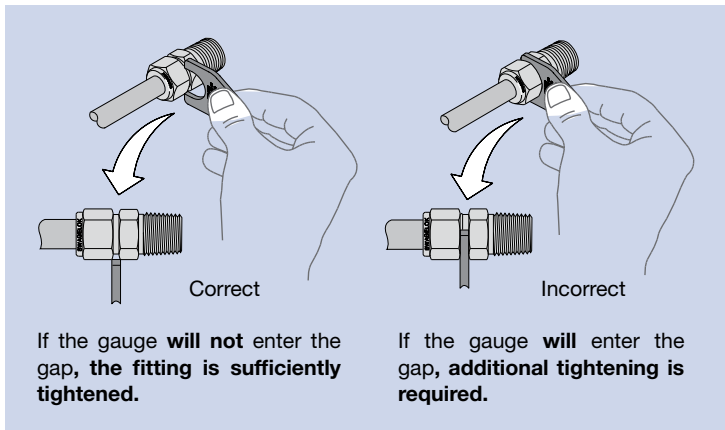


Figure 4-2 Position the Swagelok gap inspection gauge next to the gap between the nut and body.

High-Pressure Gas Systems

What is high pressure? It depends on the consequences of failure. Pressurized gas systems contain a large amount of stored energy. Because light gas can leak through the most minute leak path, the sealing of high-pressure, relatively light gases becomes difficult.

Small scratches, gouges, nicks, or weld seams on the tubing OD may easily create a leak path. These deformities can sometimes cause problems even when the very best Swagelok tube fittings are used.

The general suggestions for this severe service all apply to high-pressure gas systems. In particular, tubing wall thickness should be carefully considered, and no less than the minimum wall for *gas service*, as shown here, should be used.

Tubing for Gas Service

Fractional Sizes, in inches

Tube OD	Minimum Nominal Wall Thickness	Tube OD	Minimum Nominal Wall Thickness
1/8	0.028	3/4	0.065
3/16	0.028	7/8	0.083
1/4	0.028	1	0.083
5/16	0.035	1 1/4	0.109
3/8	0.035	1 1/2	0.134
1/2	0.049	2	0.180
5/8	0.065		

Metric Sizes, in millimeters

Tube OD	Minimum Nominal Wall Thickness	Tube OD	Minimum Nominal Wall Thickness
3	0.8	18	1.5
6	0.8	20	1.8
8	1.0	22	2.0
10	1.0	25	2.2
12	1.0	28	2.5
14	1.2	30	3.0
15	1.5	32	3.0
16	1.5	38	3.5

Minimum wall for gas service

To achieve the best results in achieving an absolutely leak-tight seal on high-pressure gas systems, consider these recommendations:

- Order good-quality hydraulic tubing with proper hardness and a surface finish free of scratches or other defects. Be sure that minimum wall thickness for gas service is used.
- Cut tubing cleanly, deburring both the ID and OD.
- Insert tubing fully into the Swagelok tube fitting. Make sure that the end of the tube rests firmly on the internal shoulder of the fitting.
- Follow the assembly instructions starting on page 75.
- Check each connection with the Swagelok gap inspection gauge.
- Never bend the tube after it has been inserted into the fitting.
- If special cleaning treatments are required, consider the use of specially cleaned Swagelok stainless steel or alloy fittings with silver-plated ferrules.
- Consider use of VCO® or VCR® fittings if you are unable to get proper surface finish on tubing. Because tube is welded to the fitting, the tube surface finish and hardness do not affect the seal.

Five Categories of Compressed Gases

Compressed gases are generally classified in the five categories listed here.

- **Corrosive:** Gases that attack and damage materials and actually remove some of the material by chemical attack. Such chemical attack is usually more severe with the presence of water. Care in material selection is vital.
 - Examples: Hydrogen chloride, hydrogen sulfide
- **Flammable:** Gases that form a flammable mixture in air at 12 % or more concentration. Changes in temperature, pressure, and concentration may cause wide changes in flammability.
 - Examples: Hydrogen, methane
- **Inert:** Gases that generally do not react with ordinary materials at commonly used temperatures and pressures. *Generally noncorrosive, nontoxic.* Not hazardous except when used in confined spaces. Air can be displaced, making life support difficult. Adequate air supply and ventilation should be considered.
 - Examples: Helium, argon
- **Oxidant:** Gases that do not themselves burn but that support combustion.
 - Example: Oxygen

- **Toxic:** Gases that produce deadly or harmful effects on humans by chemical attack.
 - Examples: Arsine, phosphine

Oxygen Systems

Oxygen has unique and hazardous properties. Handling it, either in the liquid or gaseous state, is a specialized field. Design and safety are the responsibility of oxygen system users, who should obtain qualified professional assistance to establish design specifications and operating practices for the safe use of oxygen.



Please refer to the Swagelok Oxygen System Safety technical bulletin (MS-06-13) for additional information.
www.swagelok.com/TFM

Toxic, Flammable, Explosive Gases

Industries such as chemical, semiconductor, and analytical instruments regularly handle gases that are particularly hazardous. The care listed for high pressure gases above should be exercised for such system fluids.

In addition to the items listed in the “High-Pressure Gas Systems” section earlier, you should also consider the following:

- Tube surface finish and careful deburring are essential. In assembly, extra care should be used in fully bottoming the tube in the fitting body before pull-up.
- If gas bottles or cylinders are used, they should always be fully secured in use, storage, and transit. The tremendous stored energy in such containers has caused severe damage and injuries in many recorded accidents, usually caused by dropping or tipping the container and breaking off the cylinder valve.

Steam Piping

Steam is one of the most erosive of system fluids. High-velocity steam can erode metals as hard as stainless steel in a very short time. Dry, superheated steam is less erosive than wet steam.

Unless water chemistry is carefully controlled, corrosive inclusions add to the erosive properties and make steam a difficult fluid to handle.

When installing Swagelok tube fittings for steam service, the following precautions should be taken:

- Material selection should be based on pressure, temperature, and environmental conditions. Both fitting and tubing must have compatible thermal properties.
- Steam should be considered a gas for purposes of wall thickness determination.
- Deep scratches or gouges of tube OD must be avoided. A very slight steam leak through such a defect will become a larger leak as erosive steam etches a deeper valley in the tubing.
- If steam temperatures are above 400°F (204°C), consider the use of Silver Goop® high-temperature thread lubricant on fitting nut threads.

Tracing

Tracing is a method of providing heat or cold input to raise, lower, or maintain temperature in process piping systems and equipment. Swagelok tube fittings are commonly used to connect steam tracing tubing to prevent freeze-up in cold weather. Some heat transfer fluids other than steam, such as Therminol® or Dowtherm®, are also used. Tracing can also be applied to piping and equipment that contain materials that could solidify or become extremely viscous, even in summer months.

This method is not covered in depth since the amount of tracing required will vary with the application. An engineering analysis is recommended on viscous fluid tracing requirements. The severity of winters in a particular locale usually determines the need and methods of tracing. Individual plant practices and preferences also influence requirements. The methods suggested in this manual are for guidance only.

Process lines and equipment can be protected from freezing by using tubing as the tracing lines. Common steam tracing line sizes of copper tubing are:

- 1/4 in. OD × 0.035 in. wall
- 3/8 in. OD × 0.049 in. wall
- 1/2 in. OD × 0.065 in. wall

The heavier wall tubing is preferred because the thicker wall gives improved performance during a cool-down period from full steam temperature and increases temperature cycling ability. It is during that time that thin wall tubing tries to shrink away from the fitting. Once this occurs, any slight scratch becomes a potential leak path. The tubing should be a fully annealed quality.

Tracer Installation on Process Lines

Locating Horizontal Tracers: Several techniques have been developed for positioning the tracing lines in the best manner for suitable heat transfer. Always supply steam to tracers on the high end of a sloping process line to prevent back-up of condensate. As a general guide, small tracers should not exceed 60 ft. in length, and the limit for all other sizes should be about 150 ft.

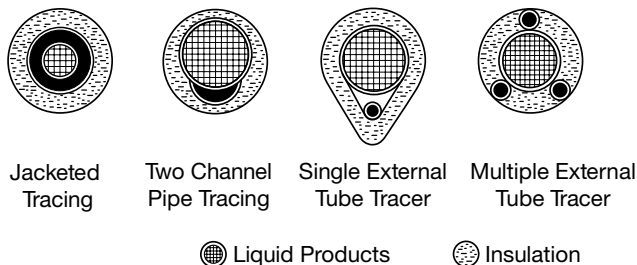


Figure 4-3 Tracer location on horizontal or sloping lines.

Tracer Installation on Vertical Lines

Locating Vertical Tracers: A single tracer on a vertical, or nearly vertical, process line can be spiral wrapped. Multiple tracers on vertical lines should be equally spaced for the most efficient heat

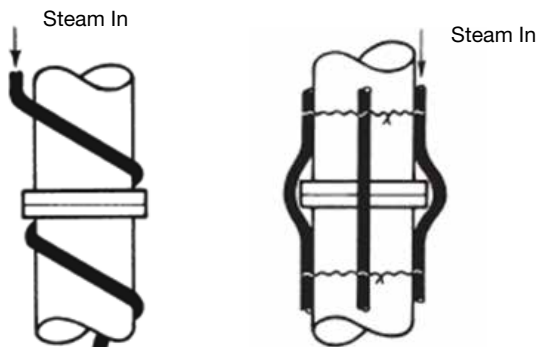


Figure 4-4 *Left:* Single tracer, spiral wrapped.
Right: Multiple tracers, equally spaced.

Vertical lines with spiral-wrapped tracers do not require additional attachment.

transfer.

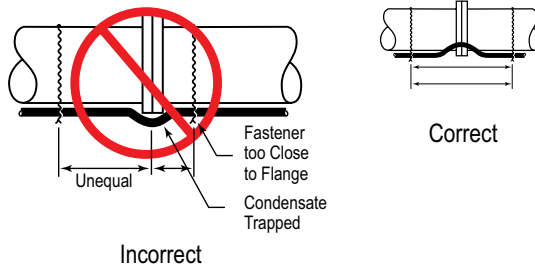


Figure 4-5 Left: Side view. Right: Top view.

Tracer Installation on Horizontal Lines

Horizontal lines with:

- 1/4 in. (6 mm) OD tracers should be fastened every 1 1/2 ft. (45 cm)
 - 1/2 in. (12 mm) OD tracer lines should be fastened every 2 ft. (60 cm)
- Fasteners should be equally spaced on each side of flanges. Always use a large radius bend around the flange on a flat plane so that the loop is not below or above the level of the horizontal tube run.

The table below provides suggested information on the size and number of tracers for process lines of various sizes:

Process Pipe Size	Tracer Size ²	No. of Tracers ²	Max. Tracer Length	Max. Tracer Length Between Traps ¹
1½ in. and smaller	¼ 0.035 in. or ⅜ 0.049 in. wall copper tubing	1	60 ft.	60 ft.
2 in. and 2½ in.	0.065 in. wall, ½ in. OD copper tubing	1	150 ft.	150 ft.
3 in. to 4 in.	0.065 in. wall, ½ in. OD copper tubing	2	150 ft.	150 ft.
6 in. and 8 in.	0.065 in. wall, ½ in. OD copper tubing	3	150 ft.	150 ft.
10 in. and 12 in.	0.065 in. wall, ½ in. OD copper tubing	4	150 ft.	150 ft.

Process Pipe Size	Tracer Size ²	No. of Tracers ²	Max. Tracer Length	Max. Tracer Length Between Traps ¹
40 mm and smaller	6 × 0.80 mm, 8 × 0.90 mm, or 10 × 0.90 mm wall copper tubing	1	18 m	18 m
50 mm and 65 mm	12 × 1.20 mm wall copper tubing	1	45 m	45 m
80 mm to 100 mm	12 × 1.20 mm wall copper tubing	2	45 m	45 m
150 mm and 200 mm	12 × 1.20 mm wall copper tubing	3	45 m	45 m
250 mm and 300 mm	12 × 1.20 mm wall copper tubing	4	45 m	45 m

1. Use individual traps for each tracer line. Never attach tracer lines to one trap via a manifold.
2. Or as required by individual needs.

Tracer Attachment to Process Lines

Single tracer lines may be fastened to the pipe with wire, bands, or tape. Care should be taken to use wires or bands that are galvanically compatible with the pipe or tracer tubes. Tapes for stainless steel tubes and pipes should not contain chlorides or halides, since these can cause corrosive failures of the tracer or pipe. There are several manufacturers of glass fiber tapes that are free of such corrosives and good for temperatures up to 500°F (260°C).

Care must be taken with some process fluids in stainless steel pipe to make sure that local spot overheating does not cause very rapid pipe corrosion on the inside of the pipe at the point the tracer contacts the outside. Such action can be prevented by a layer of insulation between the pipe and the tracer tube. Consult process data for details.

Multiple Tracers

When attaching multiple tracer lines to a process line, fasten each tracer individually to the process line. This will prevent the tracer lines from sliding to the bottom of the process line.

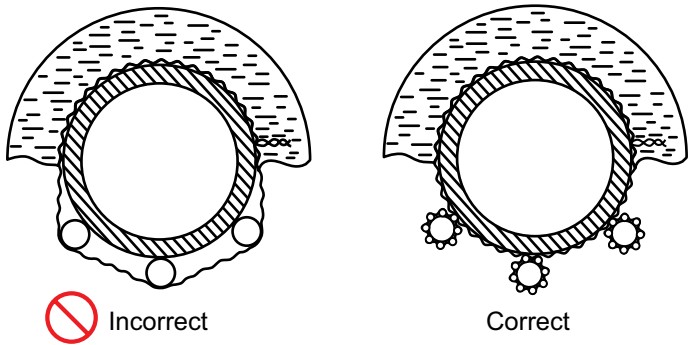


Figure 4-6 Attachment of multiple tracers to a process line.

Expansion: Tracer tubing will expand as the temperature increases. The process piping will also expand when heat is transferred. The rates of expansion of the tracer tubing and the process line will usually differ because of unlike coefficients of expansion of the two materials and the temperature differential between the tracer and the process line. Sufficient slack in the tracer lines and expansion bends is required to prevent the tracer tubing from stretching or kinking.

Before Selecting a Tracing Method

Consider the following:

The capability of any given tracing installation must be matched carefully with the requirements of the system to be traced. Here are some important factors to consider:

- Extreme care should be used on installations where difficult bends and complicated valve manifolds are encountered.
- The choice of tracing techniques can be narrowed by temperature requirements, particularly where high temperatures are needed or where temperatures must be held within precise limits.
- The length and diameter of the process piping to be traced provide an indication of the liquid volume to be maintained at a specified temperature. Therefore, these dimensions should be measured accurately to help estimate tracing system heat requirements.
- Heat loss depends, to a large degree, on the location of the piping to be traced. For example, different tracing methods would be needed for two identical installations if one were outdoors in a cold environment and the other were indoors. Another pertinent factor in estimated heat loss is the type and thickness of the

insulation that covers the pipe and tracing.

- The choice of tracing techniques is limited if the installation is an existing process pipe that may not be moved or disconnected. New installations seldom present this problem.
- Some tracing methods will be ruled out if hot spots on a pipe would be incompatible with the process to be traced (causing unsafe conditions, for instance). Special installation may be needed.
- Heat source for the tracing system must be constant. Steam, for example, must be available even during shutdown.

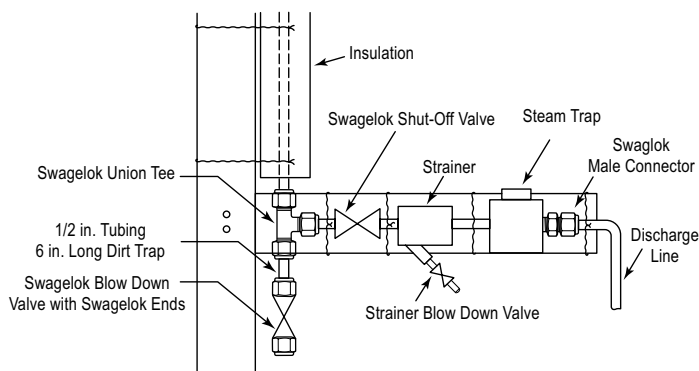


Figure 4-7 Proper installation of steam trap system.

Steam Trap Installation

The efficiency of tracer systems depends on the proper installation of steam traps. It is suggested that the following guide rules be used:

- Insulate the steam tracer line to within 2 lineal ft. of the trap inlet.
- Always install a strainer in front of the steam trap to protect the seating surfaces of the trap.
- Install a 6 in. long section of 1/2 in. OD tubing to provide a dirt trap in front of the steam trap. Large pieces of dirt or contamination accumulate in the dirt trap, thus increasing the service life of the steam trap.
- Install the steam trap, control valves, and strainer as close to the ground as practical.
- Use 1/2 in. OD tubing for the discharge line. This line should be as short as possible and should discharge into a condensate recycle collection header. Make sure the discharge line is not a safety hazard.

- Provide proper support for wiring the horizontal discharge line and accessories.
- Suggested arrangement of components is shown in the steam trap installation graphic.

System Start-Up Instructions

Leak Test

All new tracer lines should be pressurized with air and checked for leaks with SNOOP® or REAL COOL SNOOP® leak detectors. After performing any needed repairs, the system is ready for start-up with steam.



Please refer to the Leak Detectors, Lubricants, and Sealants catalog (MS-01-91) for additional sealant information. www.swagelok.com/TFM



Figure 4-8 Snoop liquid leak detectors.

Tube Fittings

Swagelok brass tube fittings are suggested for use on copper tracer lines (trace steam temperature up to 400°F [204°C]), since they provide easy, reliable, leak-tight connections. In many cases, stainless steel tracing systems may be required due to the external environment.

For ease of maintenance, insulation should not be placed over the Swagelok tube fittings because each Swagelok tube fitting is a union joint. Access to the fittings allows easy replacement of corroded or damaged tube sections.

Wherever possible, locate the Swagelok tube fittings at the process pipe flanges or other uninsulated areas.

When a Swagelok tube fitting must be used in an insulated area, provide a small window in the insulation for accessibility as shown here.

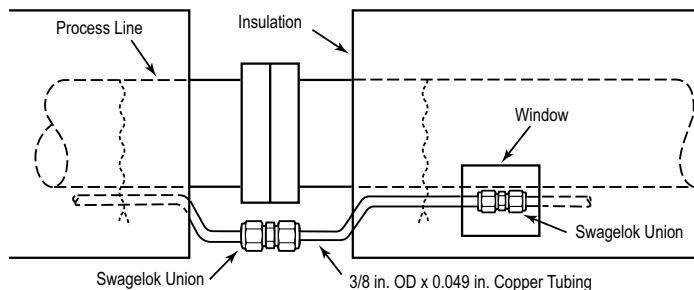


Figure 4-9 Fitting window in an insulated area.

Tracer Installation on Process Equipment

Two methods are available for installing tracers on irregularly shaped equipment such as valves, pumps, and instruments. The two methods are:

1. Spiral wrapped
2. Flat grid

1. Spiral Wrapping Method

Approximately 6 in. should be maintained between coils when the spiral wrapping method is used. Use Swagelok unions to permit removal of the equipment without uncoiling the tracer line.

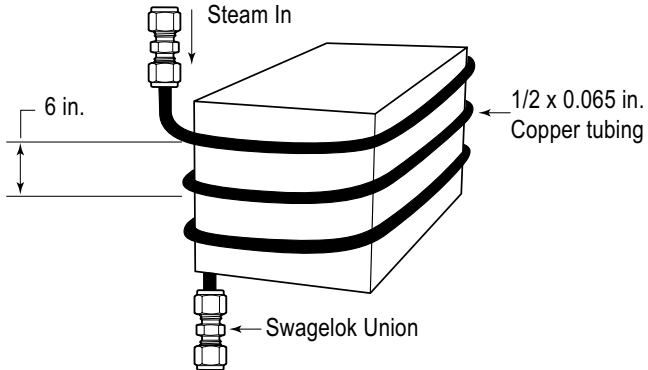


Figure 4-10 Spiral wrapping of irregular shaped process equipment.

When equipment must be frequently removed for servicing, the loop method of spiral wrapping is recommended, as illustrated here.

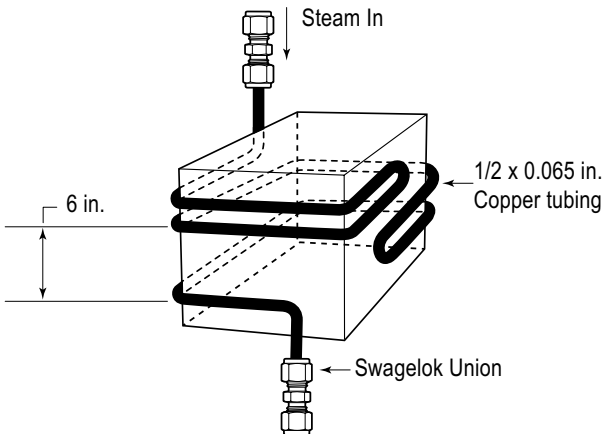


Figure 4-11 Spiral loop wrapping of process equipment for easy removal.

2. Flat Grid Method

For flat or irregular surfaces, 1/4 in. OD tracer tubing should be used. The tubing should be bent to form a grid and shaped to the surface. A 6 in. spacing should be maintained between coils, as illustrated here.

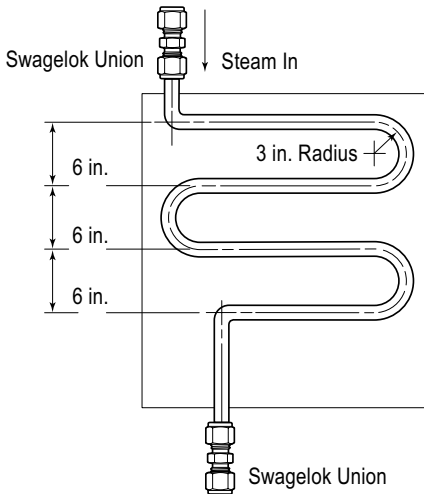


Figure 4-12. Flat grid method.

Heat Transfer Fluids

Commercial heat transfer fluids are readily available. Liquid phase and vapor phase fluids cover a wide range of operating temperatures up to about 750°F (399°C).

One of the chief advantages of such fluids is that high-pressure equipment, steam traps, and water conditioning equipment are not necessary. Thus a high-temperature system does not need to operate at high pressures like a steam trace system.

Heat transfer fluids are generally difficult to seal. Care should be exercised when fittings are used for such systems. In particular, wall thickness of tubing should be selected in line with gas pressure suggestions provided earlier in this chapter.

When selecting materials for heat transfer fluid systems, follow the suggestion of the fluid manufacturer.

Ultra-Clean Systems

Today's high-technology demands call for ever-more-stringent cleanliness requirements. Standard production Swagelok tube fittings are carefully degreased, but for certain electronic, aerospace, and ultra-pure gas systems, special cleaning may be required. A number of different methods may be used, depending on system requirements and fitting materials. Swagelok specially cleaned fittings are packaged individually in sealed plastic bags. Consult your Swagelok representative for details. If Swagelok tube fittings are specially cleaned in the field, we suggest the following:

- Cleaning of the nut or back ferrule should be avoided because only the body and front ferrule are wetted parts.
- Galling and possible leakage may occur when absolutely dry parts are brought together under the high loads necessary to seal. Therefore, use specially cleaned, silver-plated Swagelok front ferrules, or apply a system-compatible anti-gall material.

Vacuum Systems

Swagelok tube fittings are widely used on industrial vacuum applications. The importance of keeping all action moving in an axial direction with absolutely no torque or rotary motion in making a seal is demonstrated in applying Swagelok tube fittings to vacuum work.

Any scoring of the sealing surfaces could prevent a helium leak-tight seal. The axial motion, when making and remaking joints with Swagelok tube fittings, results in pressing the sealing surfaces together so that there is no scoring of any surfaces and, therefore, helium leak-tight joints can be made over and over again. Extreme care should be used in the handling of tubing for vacuum service to ensure successful use in your system. Scratches on tube surfaces can cause problems.

In vacuum work, cleanliness is absolutely essential. All tubing used should be degreased and then dried thoroughly. If this is not done, oils and moisture may vaporize as pressure is reduced and the system will appear to leak even though it is tight. Tube fittings for vacuum work should also be specially cleaned.

When using stainless steel or other special alloys that have tendencies to gall, we suggest that only the body and front ferrule be degreased as these are the only items that are within the system. The nut and back ferrule are outside the sealed system, and special lubricants that have been applied to prevent galling should not be removed.

Swagelok can supply specially cleaned Swagelok tube fittings. Stainless steel and other special alloys use specially cleaned, silver-plated front ferrules to prevent galling of specially cleaned parts. Swagelok metal tube fittings with PTFE ferrules can also be used for quick, easy industrial vacuum connections. Consideration must be given to the cold-flow and outgassing properties of PTFE and the greatly reduced holding power of PTFE ferrules.

Because of partial dependence on tube OD surface finish, when using "OD seal" fittings such as Swagelok tube fittings, we find that when systems are operating in the ranges of very-high or ultra-high vacuum range (below 10^{-6} torr), all-welded systems are the most reliable. Swagelok tube or weld fittings (see Chapter 6) have been used in many such systems. Where systems require breakdown for cleaning or maintenance, VCO® or VCR® fittings are suggested (see Chapter 6).

Swagelok Ultra-Torr Vacuum Fittings are ideal for making quick, easily removed vacuum seals, such as connecting to helium leak detectors or connecting metal to glass tubing. So, both Swagelok tube fittings and other style fittings, such as Swagelok VCO, VCR, etc., can be used on vacuum systems. Caution should be used if fitting components contain elastomers or plastics, especially if the vacuum system will see temperatures in the bakeout range. In bakeout applications, one should not mix metals when system temperatures will be increased unless coefficients of expansion are considered.

For example:

Assume a 316 stainless steel fitting (coefficient of expansion $11 \times 10^{-6}/\text{in.}/\text{in.}/^{\circ}\text{F}$) was installed on alloy 400 tubing (coefficient of expansion $7.8 \times 10^{-6}/\text{in.}/\text{in.}/^{\circ}\text{F}$).

When the temperature is raised, the stainless steel would increase in size at a greater rate than the tubing. The fitting would become loose on the tubing because of a property of the material (coefficient of expansion) coupled with the temperature change.

On the other hand, if alloy 400 is put on stainless and raised to a high temperature, the joint becomes tighter. However, the stainless steel tubing increases in size at a greater rate than the alloy 400 fitting and may yield the fitting, and a leak could result upon returning to lower temperatures. Mixing materials is not recommended (i.e., using different materials for fittings and tubing) unless an engineering analysis is made of temperature variation.

For your convenience, coefficients of expansion for materials commonly employed in tube fitting applications are shown here.

Material	Coefficient of Expansion in./in./°F
Stainless Steel (304 and 316)	8.5×10^{-6}
Alloy 400	7.7×10^{-6}
Brass	9.3×10^{-6}
Aluminum	12.1×10^{-6}
Carbon Steel	7.0×10^{-6}
Copper	9.3×10^{-6}

Temperature Rating: Operating temperature ratings are dependent on application and installation methods, cycle life required, and other variables. Consult your Swagelok representative for additional information. Use Swagelok PTFE tape on pipe threads in a vacuum system to create a seal. VAC-GOOP® lubricant is suggested for use in the vacuum system on bolts and surfaces where it is desired to prevent galling.

Vibration

Systems such as compressor or pump piping often have stringent requirements regarding the fittings' resistance to vibration. Well-designed fittings such as Swagelok tube fittings have built-in vibration protection.

In applications where severe vibration is present, the best protection is to properly support the tubing near the fitting. Limiting the amplitude of the vibration increases fitting and tube connection life. It is particularly important in vibration applications to install fittings exactly according to suggested installation instructions. The bottoming of the tube against the shoulder of the fitting body should receive careful attention. If the tube is fully bottomed, the tube OD ahead of the ferrules is increased during pull-up, creating a more rigid assembly. We have conducted extensive tests on vibration service, particularly on stainless steel fittings. The results are summarized in Product Test Reports.



Refer to Tube Fitting Performance Product Test Reports (MS-06-108) and search for the following test results: PTR-976 and PTR-3222. www.swagelok.com/TFM

See Chapter 3 for tubing support information details.

Swagelok

Disassembly/Reassembly

One of the key qualities that distinguishes a well-designed tube fitting from the ordinary is the ability to take frequent disassembly and reassembly service without losing sealing integrity. In instrument systems or temporary laboratory experiments, where constant cleaning or maintenance is required, a tube fitting with good disassembly/reassembly abilities may often save its price many times over.

Swagelok tube fittings have earned their reputation since 1947 by their ability to seal difficult fluids repeatedly, after many disassembly and reassembly cycles. Swagelok test programs are described in Chapter 7.

As in any application, the original installation will often determine just how many disassembly/reassembly cycles a connection can take while remaining leak free. Swagelok's tests indicate that 25 disassembly/reassembly cycles are not unusual with proper care, although customers routinely report far more than just 25 disassembly/reassembly cycles.

The compensating action of the two Swagelok ferrules promotes longtime service under disassembly/reassembly conditions.

Impulse/Shock

Impulse or pressure cycling is caused by many factors, but primarily by quick-opening valves in hydraulic systems. It causes considerable stress on a tubing system. The Swagelok two-ferrule design absorbs such stress and allows the use of off-the-shelf tube fittings for such service. Proper support of tube runs, as close as possible to the fitting, will prolong the life of tubing connections. Proper assembly of tubing and fitting is essential. Tube wall (within the limits shown in Chapter 9) should be carefully considered, and an additional design factor should be considered where severe impulses are present. Swagelok's impulse testing is described in Chapter 7.

One example is a quick-closing valve that causes very rapid pressure changes.

Shock may take many forms in tubing systems. It normally is considered as any type of a sudden, violent stress that may affect a tubing system.

An example would be the shock that must be absorbed if an ambient temperature component is quickly immersed in liquid nitrogen. Another type of shock is a sudden jolt near a forging

hammer or other heavy equipment that causes a sudden, but short-lived, shock condition.

Temperature cycling, particularly very rapid cycling, is another form of shock.

Elevated Temperature Service

For purposes of definition, high temperature is considered to be above 100°F (40°C). A number of different factors must be considered when tubing and fittings are used at elevated temperatures.

Materials

The first consideration is the material required to resist high temperatures and temperature excursions over a long period of service. Temperature limits of most fitting and tubing materials are listed in ANSI piping codes, including specific conditions regarding tubing materials and methods of manufacture.

This table shows the general range of maximum temperatures for the given materials.

Aluminum	400°F	204°C
Copper	400°F	204°C
Steel	375°F	191°C
304SS/316SS	1000°F	538°C
316SS *	1200°F	649°C
Alloy 400	800°F	427°C

Maximum temperatures by material

* The 316-ELT material meets the ASME B31.1 requirements for service up to 1200°F.

Tensile Strength

The second consideration is that as temperature increases, the tensile strength of metal decreases. Thus the allowable working pressure of tubing is lower at *elevated* temperatures than at room temperature.

This table lists the factors used to determine tubing pressure ratings at *elevated* temperatures. Multiply working pressure rating by the factors shown for temperature indicated.

°F	Aluminum	Copper	Steel	304SS	316SS	Alloy 400
200	1.00	0.80	0.95	1.00	1.00	0.88
400	0.40	0.50	0.86*	0.93	0.96	0.79
600				0.82	0.85	0.79
800				0.76	0.79	0.76
1000				0.69	0.76	
1200				0.30	0.37	
1400						

* Based on 375°F max.

Factors to determine tubing pressure ratings

Wall Thickness

Finally, as temperatures increase, some fluids that are normally liquids can become gases. It is important to use the minimum wall thickness recommended for gas service as listed on pp. 19 and 213 for these applications.

Cryogenic Service

For purposes of definition, cryogenic temperatures will be considered as temperatures substantially below room temperature. The primary consideration is similar to the primary consideration for elevated temperatures: material characteristics.

Plastic Materials

In general, plastic and elastomer materials are not satisfactory for cryogenic applications. Plastics have much higher thermal coefficients of expansion than metals. Therefore, plastic components used as sealing members at room temperature will shrink markedly when temperatures are lowered, causing leakage. Many plastics also have some porosity, which allows water absorption. Water will solidify when temperatures are lowered and make the tube or fitting material brittle. Plastic manufacturers should be consulted before using plastics in cryogenic service.

Elastomer Materials

Most elastomers harden at low temperatures and may crack. Care should be exercised in selecting elastomer seals when cryogenic temperatures are required. Elastomers also have much higher thermal coefficients of expansion than metals. Used as sealing members at room temperature, they will shrink markedly when temperatures are lowered. This shrinkage may result in leakage.

Metal Materials

The most commonly used materials in cryogenic piping systems are aluminum and austenitic stainless steel. Alloy 600, alloy 400, and titanium are also selected for some applications. It is particularly important to use the same alloy for both tube fitting and tubing so that thermal coefficients are the same. Tube wall thicknesses should be selected from the minimum wall for gas service as shown in tables earlier in this chapter. It should be remembered that minimum walls for gas service should be considered even if cryogenic liquids are the system fluid. If at some time the system is brought up to ambient temperatures, the liquid will become a gas.

Chapter 5

Troubleshooting

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Introduction

This section is designed to guide you through the installation of trouble-free fittings. The information is not exhaustive. Should you encounter a problem that is not covered in this section, please contact the local Swagelok Authorized Sales and Service Center for assistance.



To locate your local Swagelok Authorized Sales and Service Center www.swagelok.com/TFM

Troubleshooting

Trouble	Possible Cause	Recommended Corrective Measures
1. Tubing will not fit into fitting.	<p>Burrs on tubing from tube cutting operation.</p> <p>Flattened tubing from bearing too hard with hacksaw in cutting or using dull hacksaw.</p> <p>Tubing out of round from bending.</p> <p>Tubing is the wrong size for fitting. This seldom occurs, but infrequently a piece of 3/8 in. tubing may be used with a 5/16 in. fitting by mistake.</p> <p>Tubing is oversize. Poor-quality tubing may exceed the allowed tolerances for tubing.</p> <p>Tubing end raised due to dull tube cutter wheel.</p>	<p>Deburr tubing. Use outside diameter (OD) deburring tool.</p> <p>Use caution in cutting soft tubing with hacksaw.</p> <p>Swagelok tube fittings are manufactured to tolerances to accept the upper limit of allowed tubing diameters used in tubing manufacture. If tubing is bent too far out of round by improper bend, the tubing will not fit into the tube fitting. Use caution with bends when near the end of tubing.</p> <p>Make sure you use the proper size fitting for each diameter tubing.</p> <p>Check OD of tubing.</p> <p>Determine if it is fractional or millimeter size tubing.</p> <p>Buy good quality tubing. For 1/16 or 1/8 in. fittings, tubing should be ± 0.003 in. on the OD tolerance.</p> <p>Replace with good sharp wheel or use good-quality hacksaw for cutting. Use OD deburring tool.</p>

Trouble	Possible Cause	Recommended Corrective Measures
<p>2. Fitting cannot be pulled up proper amount of turns.</p>	<p>This could happen with steel or stainless steel tubing that is very hard and not intended for fluid system applications.</p> <p>Interchange of other manufacturers components.</p> <p>Components have been cleaned, removing proprietary lubricants.</p> <p>Dirt or other contaminants on threads.</p> <p>Tube wall is too heavy.</p> <p>Galled threads on nut or body.</p>	<p>Buy fully annealed, hydraulic or pressure type steel and stainless steel tubing of recommended hardness.</p> <p>Use only Swagelok tube fittings. DO NOT INTERCHANGE.</p> <p>Never remove lubricants from nut. If special cleaning is required, clean body and front ferrule only. In stainless steel and special alloys, use specially cleaned, silver-plated front ferrules.</p> <p>Protect all thread and seal surfaces from contamination.</p> <p>Use tubing within suggested wall thickness.</p> <p>Replace complete fitting.</p>
<p>3. Leakage at pipe thread.</p>	<p>Fittings not sufficiently tightened with mating thread.</p> <p>Pipe threads require a sealant to make a leak-free connection.</p> <p>Pipe threads damaged from galling of materials during installation.</p> <p>Poor-quality pipe thread either on female or male end.</p>	<p>Tighten fittings.</p> <p>Swagelok PTFE tape should be used on all pipe threads to provide leak-tight sealing. SWAK anaerobic pipe thread sealant with PTFE is also an excellent pipe thread sealant.</p> <p>Good pipe thread sealants such as Swagelok PTFE tape or SWAK also help prevent galling of pipe threads. Discard galled components.</p> <p>Use high quality pipe threads, such as on Swagelok fittings. These pipe threads are precision-manufactured, but this is not sufficient to make a leak-tight connection with a pipe thread on other equipment. Use a good sealant.</p>

Trouble	Possible Cause	Recommended Corrective Measures
4. Leakage at flare joint.	Poor flares. Cracked or split flare.	Use Swagelok tube fittings.
5. Tubing leaks at fitting after initial installation.	<p>Not using Swagelok tube fittings. Fittings not pulled up properly.</p> <p>Tubing not bottomed in fitting body.</p> <p>Tubing has deep longitudinal scratches or is nicked or otherwise damaged.</p> <p>Fitting body was rotated, instead of nut, galling seat and/or front ferrule.</p> <p>Fitting not tightened according to installation instructions because of inaccessible location.</p> <p>Fitting was used as vise or anchor to bend tubing by hand.</p> <p>Interchange of other manufacturers' components.</p> <p>Poor weld bead removal on welded and drawn tubing. Raised bead or flat spots interfere with proper sealing.</p>	<p>Use Swagelok tube fittings. Follow installation instructions. Check for hard tubing or galling. Use good-quality annealed tubing. Check for sufficient pull-up with a Swagelok gap inspection gage.</p> <p>Cut off ferrules and replace. Insert tube until it fully bottoms against shoulder of fitting body.</p> <p>Handle tubing with care. Replace tubing or cut off damaged section and reconnect.</p> <p>Always connect fittings by rotating the nut while holding body stationary.</p> <p>Preswage or use the Multihead Hydraulic Swaging Unit (MHSU), then snug 1/2 turn. See preswaging and hydraulic swaging instructions in Chapter 3.</p> <p>Replace tubing. Never use the fitting as a holding device for bending. This will deform the tubing inside of the fitting and pull the tube away from the seal.</p> <p>Use only Swagelok tube fittings. DO NOT INTERCHANGE.</p> <p>Use high-quality, annealed, welded and drawn hydraulic stainless steel tubing. If OD weld is easily seen with the naked eye, leakage may result.</p>

Trouble	Possible Cause	Recommended Corrective Measures
<p>6. Tubing leaks at fitting after system installation.</p>	<p>Damage caused by mechanical means outside the system.</p> <p>Corrosion is eating away fitting or tubing.</p> <p>Cracking of tubing due to overstressing while making flare for a flare fitting.</p> <p>Interchange of other manufacturers' components.</p>	<p>Replace tubing and fitting. Relocate where damage is less likely to be a problem. Check tubing supports.</p> <p>Inspect connection for corrosion. If present, check corrosion compatibility of fluid, tubing, and fitting materials and ambient atmosphere. Consider galvanic action as a possible cause or microbial influenced corrosion (MIC) in marine applications.</p> <p>Swagelok tube fittings should be used to replace such fittings and avoid this difficulty.</p> <p>Use only Swagelok tube fittings. DO NOT INTERCHANGE.</p>
<p>7. Copper tubing leaks at fitting after operation above 400°F (204°C).</p>	<p>Copper tubing becomes very weak above 400°F (204°C). This is an inherent characteristic of the function of fitting performance. Codes limit copper tubing to 400°F (204°C).</p>	<p>Heavier wall copper tubing will help in some cases in which the temperature is close to 400°F for temperature cycling, but copper tubing should not be used above 400°F (204°C). Stainless steel tubing and fittings can be used.</p>
<p>8. Tubing is deformed after system has been in operation.</p>	<p>Excessive pressure. Tubing of insufficient tensile strength or wall thickness was used.</p> <p>Freeze-up of water or condensate in steam tracing.</p>	<p>Use stronger material or heavier wall tubing. Use Swagelok FK or IPT fittings</p> <p>Prevention through proper installation, operation, and maintenance.</p>
<p>9. Polyethylene tubing slips from fitting.</p>	<p>Check ferrule material—PTFE ferrules not satisfactory or possible undersized tubing.</p>	<p>Use metal Swagelok tube fittings with polyethylene tubing whenever possible. If tubing is very soft, use an insert.</p>

Trouble	Possible Cause	Recommended Corrective Measures
10. PTFE tubing slips from fitting.	Slippery characteristic of PTFE material.	Use all metal fittings whenever possible. PTFE fittings have very low pressure ratings.* NOTE: * The Swagelok PFA tube fitting, when used with Swagelok PFA tubing (which has been grooved with the Swagelok groove cutter), will hold to the rated working pressure of the tubing. Consult your Swagelok representative for pressure rating information on this combination.
11. Glass tubing breaks when connecting fitting.	Metal ferrule used improperly.	Use Swagelok Ultra-Torr vacuum fittings. With Swagelok tube fittings, use a plastic front and back ferrule.
12. Tubing leaks at reconnection following maintenance.	Fitting not properly retightened. Dirt got into fitting or on ferrules while disconnected. Interchange of other manufacturers' components.	Follow instructions. Observe cleanliness practices whenever disconnecting and reconnecting. Clean out foreign material and inspect fitting for damage. If ferrules or seat are damaged, replace the damaged parts. Use only Swagelok tube fittings. DO NOT INTERCHANGE.
13. Flows are too low in system.	Obstruction in system. Single-ferrule fitting has oversized, restricting tube inside diameter (ID). System sized too small.	When assembling a system, be cautious so that gravel, dirt, sand, or other foreign materials do not get in tubing or fitting. Use only Swagelok tube fittings. Check to determine if system should be constructed of a larger diameter tubing.

Trouble	Possible Cause	Recommended Corrective Measures
14. Fittings cannot be taken apart after high temperature operation.	Pipe threads have welded together. Nut threads have welded to threads on tube fitting body.	SILVER GOOP® lubricant may be used on high-temperature alloys for operation at high temperatures to 1200°F (649°C). While SILVER GOOP® may prevent galling, it will not be a sealant. We know of no good thread sealant for use above 450°F (204°C).
15. Fittings gall or leak after special cleaning by customer.	Proprietary lubricants have been removed.	There are a number of different special cleaning options available. Contact your local Swagelok Sales and Service Center to determine which is best for you.

Chapter 6

Special Purpose Fittings

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Special Purpose Fittings

In previous chapters, we discussed the Swagelok general purpose, flareless, mechanical grip-type tube fitting. Swagelok also offers special purpose fittings that have certain characteristics, making them desirable for specific applications.

Weld Fittings

Swagelok produces a complete range of tube and pipe weld fittings. Swagelok weld fittings provide permanent welded connections for critical applications involving corrosive fluids, shock from pressure surges, temperature cycling, system vibration, and ultra-pure applications.

Swagelok offers a variety of weld connections. They include:

- Tube socket weld (TSW)
- Pipe socket weld (PSW)
- Male pipe weld (MPW) pipe to tube weld
- Male tube weld (MTW) tube to tube weld
- Automatic socket weld (ASW)
- Automatic tube butt weld (ATW)
- Tube butt weld (TBW)

Standard material of construction is dual Cert 316/316L stainless steel. 316L is also available, as well as other alloy materials.



Figure 6-1 Weld fittings.

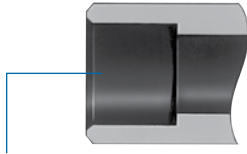


Refer to the Swagelok Weld Fittings catalog (MS-01-149) for additional information.
www.swagelok.com/TFM

Tube Socket Weld Fittings (TSW)

Tapered socket speeds layout, assembly, and alignment.

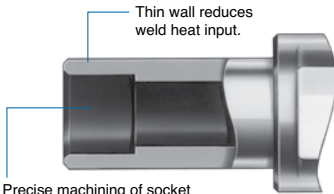
Accurate socket depth ensures proper tube support and consistent assembly.



Precise machining of socket ensures proper tube fit.

Figure 6-2 Tube socket weld fitting.

Automatic Tube Socket Weld Fittings (ASW)



Thin wall reduces weld heat input.

Precise machining of socket ensures proper tube fit.

Figure 6-3 Automatic tube socket weld fitting.



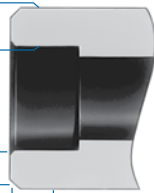
Figure 6-4 Union tee.

Pipe Socket Weld Fittings (PSW)

Weld end can be butt or socket welded.

Precision machining of all surfaces ensures consistent welding to pipe.

Heavy wall, plus strength of material, ensures long life in severe service applications.



Socket depth equals or exceeds requirements of ASME B16.11 and ensures proper pipe support.

Figure 6-5 Pipe socket weld fitting.

Adapters

37 1/2° chamfer ensures proper weld (not included on 1/4 in. size).

Male weld end can be butt or socket welded.

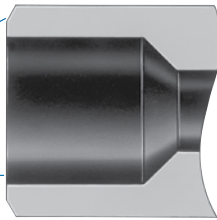


Figure 6-6 Adapter.

Pipe to Tube Weld (MPW)

Used to reduce from a pipe butt weld or pipe socket weld to a smaller tube size.

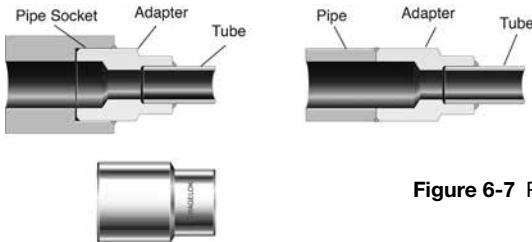


Figure 6-7 Pipe to tube weld.

Tube to Tube Weld (MTW)

Used to reduce from a tube butt weld or tube socket weld to a smaller tube size.

Swagelok tube butt weld (TBW), automatic tube weld (ATW), automatic socket weld (ASW), and Micro-Fit® weld fittings are designed for systems welded manually or with automatic welding equipment, like the Swagelok® Welding system.

Standard material for Micro-Fit fittings is 316L VAR (vacuum arc re-melt). Other grades of stainless steel and other alloy materials can also be offered.

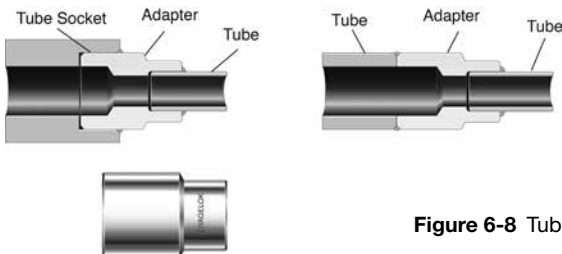


Figure 6-8 Tube to tube weld.

Tube Butt Weld Fittings (TBW)



Figure 6-9 Union elbow.

Standard surface finish is average 10 μm . (0.25 μm) R_a .
Controlled surface finish is available for ultrahigh-purity systems.

Tube ends are machined with a square face and corners to enhance alignments and maintain tube wall uniformly.



Precisely finished diameter matches tubes diameter.

Figure 6-10 Tube butt weld fitting.

Automatic Tube Butt Weld Fittings (ABW)



Figure 6-11 Union tee.

Standard surface finish is average 10 μm (0.25 μm) R_a .
Controlled surface finish is available for ultrahigh-purity systems.

Precisely finished diameter matches tubes diameter.



Integral filler ring aids in alignment.

Figure 6-12 Automatic tube butt weld fitting.

Subsea Weld Fittings

Subsea applications have extreme environmental conditions in settings where space is at a premium. Swagelok subsea weld fittings are available in 316L stainless steel, alloy 2507, and alloy 625 to withstand those harsh conditions. Tees and elbows are made from forgings, giving them a lower profile than those made from extrusions. Weld tangent lengths of up to 2 inches are standard to facilitate on-site repairs, reducing system downtime and scrap costs.

Our subsea weld fittings are designed to meet the requirements of demanding applications such as:

- Subsea Christmas tree
- Umbilical termination assembly
- Steel flying lead
- Hydraulic distribution manifold
- Subsea ROV control panels
- Subsea control modules
- Wellhead control panels
- Hydraulic control panels

Refer to the *Swagelok Subsea Weld Fitting* catalog (MS-02-481) for additional information.



Micro-Fit Fittings

(Miniature Tube Butt Weld)

Swagelok Micro-Fit weld fittings are designed for tubing systems requiring light weight, close component spacing, and cleanliness. These miniature fittings equal the flow rate and service ratings of larger fittings designed for the same size tubing. They are available in standard fractional and metric sizes.

Rounded body block helps prevent damage to other components during system fabrication or maintenance.

Material heat code is roll stamped to ensure raw material traceability.



Marking identifies manufacturer, material, and, when applicable, ultrahigh-purity cleaning.

Micro-Fit Fittings

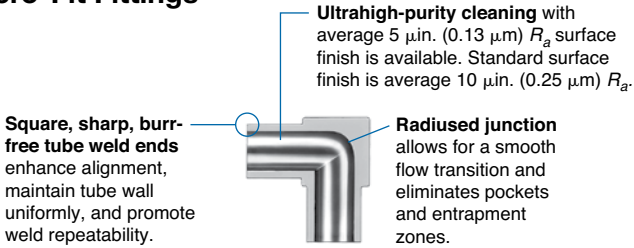


Figure 6-13 Micro-Fit fittings.

Welding System

The Swagelok welding system M200 power supply offers precision and control combined with easy-to-use touch-screen operation for orbital welding.

It can be used to weld a variety of tubing and valves and fittings with weld end connections. The Swagelok welding system uses the gas tungsten arc welding (GTAW) process, which is commonly referred to as TIG (tungsten inert gas) welding. During the welding process, the components to be welded are held stationary in a fixture while an electric arc is mechanically rotated around the weld joint. Various weld heads are available that allow the Swagelok welding system to accommodate outside diameter sizes ranging from 1/16 in. to 4 in. and from 2 mm to 114.3 mm.



Figure 6-14 Swagelok welding system: M200 power supply.



Refer to the Swagelok Welding System catalog (MS-02-342) for additional information.

www.swagelok.com/TFM

Face Seal Fittings

VCR Metal Gasket Face Seal Fitting

Swagelok VCR metal gasket face seal fittings offer the high purity of a metal-to-metal seal, providing leak-free service from critical vacuum to positive pressure. The seal on a VCR assembly is made when the gasket is compressed by two highly polished beads during the engagement of a male nut or body hex and a female nut.

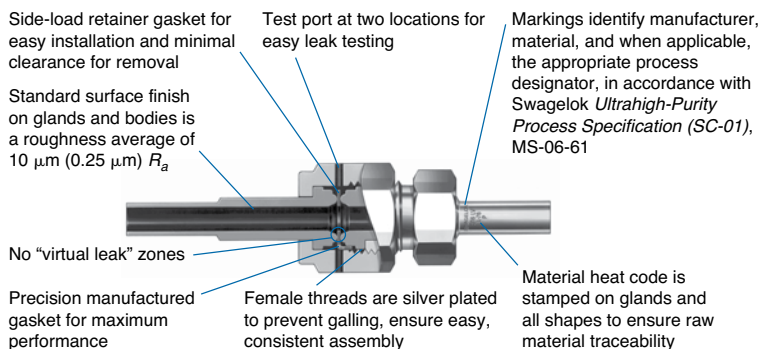


Figure 6-15 VCR metal gasket face seal fitting.



Reference the Swagelok VCR Metal Gasket Face Seal Fittings catalog (MS-01-24) for additional information. www.swagelok.com/TFM

VCO O-Ring Face Seal Fittings

Swagelok VCO O-ring face seal fittings are designed for rapid assembly and disassembly in pipe, tube, and welded systems. Because of their unique design, zero clearance installation and removal is possible where space is limited. Sealing is accomplished with a captive O-ring in the body component. Assemblies can be used from high pressure to critical vacuum, within a wide range of temperatures.



Refer to the Swagelok VCO O-Ring Face Seal Fittings catalog (MS-01-28) for additional information. www.swagelok.com/TFM

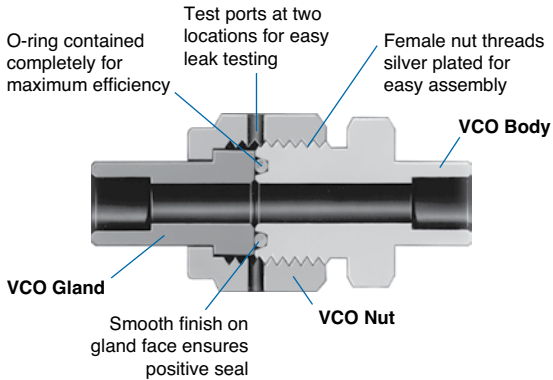


Figure 6-16 VCO O-ring face seal fitting.

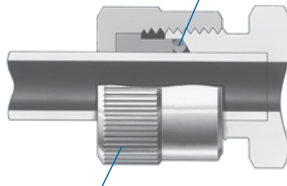
Ultra-Torr Vacuum Fittings and Tubing

Swagelok Ultra-Torr fittings are designed to provide a vacuum-tight seal with quick, finger-tight assembly on glass, metal, or plastic tubing. The Ultra-Torr fitting design has been helium leak tested to a maximum leak rate of 4×10^{-9} std cm^3/s at ambient temperature. The leak rate increases as temperature increases due to permeation through the O-ring.



Refer to the Swagelok Vacuum Fittings catalog (MS-01-32). www.swagelok.com/TFM

Seal performance is maintained through repeated disconnects. O-ring seals to glass, metal, or plastic tubing.



Knurled nut for easy, finger-tight assembly.

Figure 6-17 Vacuum fitting.

Fittings for Very Soft Plastic Tubing

Many types of soft plastic tubing are used in laboratory or low-pressure air systems because of their purity, transparency, flexibility, and smooth interior surface.

Swagelok metal or plastic tube fittings are suitable for use on this tubing. The only additional requirement for use on plastic tubing is an insert. The insert is used to support the tubing so that it will not collapse when the ferrules deform the tube.

Another connection for such service is the Swagelok hose connector (HC). This hose-type fitting has a specially designed serrated shank that properly stretches the tube for optimum sealing. An optional sleeve may be used when the system pressure is more than 50 % of the maximum working pressure of the tube.

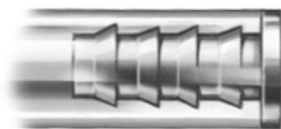


Figure 6-18 Insert.



Figure 6-19 Insert used in Tygon® tubing with Swagelok male connector.



Figure 6-20 Male hose connector for soft PVC tubing with sleeve.



Refer to the Swagelok Hose and Flexible Tubing catalog (MS-01-180). www.swagelok.com/TFM

Fittings for Harder Plastic Tubing

Fittings for polyethylene, polypropylene, PTFE, and PFA tubing are available in a wide range of Swagelok tube fitting sizes and materials. Metal fittings can be used on these types of tubing. PFA Swagelok tube fitting, when used with Swagelok PFA tubing (and grooved with the Swagelok groove cutter), will hold to the rated working pressure of the tubing. Metal Swagelok tube fittings will also hold the rated working pressure of the PFA tubing. Consult your Swagelok representative for pressure rating information on this combination.

Cone and Thread Fittings

Swagelok IPT Series cone and thread fittings are available in medium pressure (MP), with a maximum working pressure of 20 000 psig (1378 bar), and high pressure (HP), with a maximum working pressure of 60 000 psig (4136 bar). All fittings are supplied complete with gland and collars. Antivibration assemblies are also available. Swagelok offers safety heads in a flat or angled design for our cone and thread fittings. The rupture discs must be purchased separately. They are available in 316SS and other alloy materials.

Line filters are another available option. They come standard with two mesh filters. Filter elements available are 0.5, 2, 5, 10, 20, 40, and 100 μm sizes.



Figure 6-21 Swagelok medium-pressure cone and thread fittings.



Figure 6-22 Swagelok high-pressure cone and thread fittings.



Refer to the Medium- and High-Pressure Fittings, Tubing, Valves, and Accessories catalog (MS-02-472).
www.swagelok.com/TFM

JTC Tube Fittings

The Swagelok jacketed tube connector (JTC) is a fitting designed to provide a leak-tight connection on the end of single-jacketed tubing, eliminating the need for sleeves and sealing tape. The JTC is a patent-pending design that combines Swagelok's proven tube fitting technology with an innovative environmental seal on the tubing jacket.

This integral connector consists of a Swagelok tube fitting that provides a leak-tight seal on the stainless steel core of the jacketed tubing and the JTC seal O-ring and jacket seal nut, which provide a watertight seal on the outside diameter (OD) of the jacketed tubing.

Additional features of the Swagelok JTC include:

- Ease of assembly: Knurled jacket seal nut allows for easy, hand-tight assembly.
- Repeated reassembly: Seal performance is maintained through repeated reassemblies of the connector.
- Visual confirmation: Jacket seal nut covers vent O-ring when leak-tight assembly is achieved.
- Vent port: Prevents accidental pressurization of jacket cavity.



Figure 6-23 Swagelok jacketed tube connector (JTC).

Snubber Fittings (Gauge Protectors)

Swagelok snubber fittings protect gauges and instruments from system pressure surges and shocks. Pressure damping (snubbing) is accomplished through the use of a porous sintered 316 stainless steel element. When a Swagelok snubber is installed upstream from a pressure-sensitive instrument, the response rate of the instrument is reduced and generally varies with the initial pressure drop across the porous metal element, and the snubber allows the instrument to smoothly come to line pressure.



Figure 6-24 Swagelok gauge protector.

Elements

With five basic elements available, snubber fittings can meet the requirements of fluid applications ranging from light gases to liquids with viscosities above 1000 SUS (Saybolt universal seconds)

(220 cSt [mm²/s]). Element designators are stamped on all fittings for proper identification.



Refer to the Swagelok Pressure Gauges Catalog (MS-02-170). www.swagelok.com/TFM

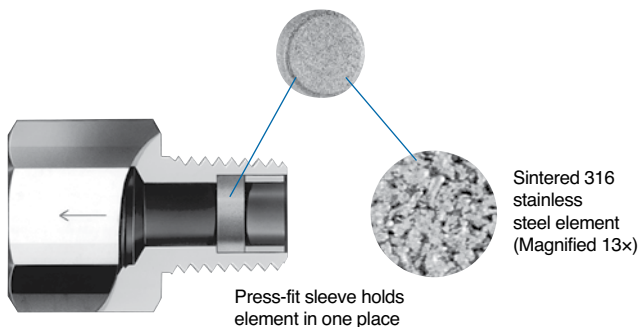


Figure 6-25 Five basic elements available.

Gaugeable Chromatograph and Column End Fittings

Swagelok chromatograph and column end fittings are suitable for liquid or gas chromatography. They are offered in sizes from 1/16 to 1/2 in. Swagelok chromatograph and column end fittings are rated to the working pressure of tubing as listed in Swagelok *Tubing Data*, MS-01-107.



Refer to the Swagelok Gaugeable Chromatograph and Column End Fittings catalog (MS-02-173). www.swagelok.com/TFM



Figure 6-26 Swagelok chromatograph and column end fittings.

Orifice Plates

Swagelok orifice plate fittings allow for pressure adjustments by reducing the orifice size with a plate predrilled to the specified dimensions.

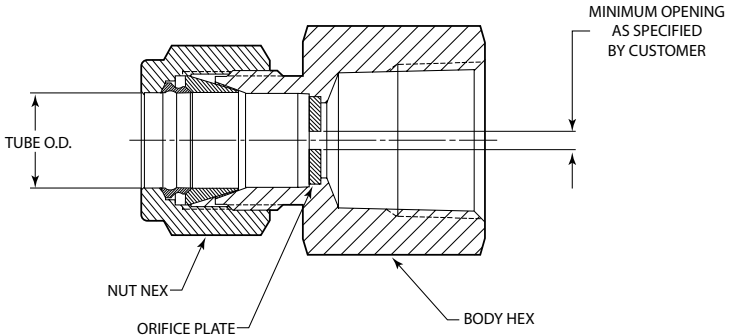


Figure 6-27 Orifice plate.

Wire Drilled Fittings

Swagelok offers wire drilled fittings. These fittings are typically used in safety applications where the wire is tied to the nut and the body to prevent the fitting from being disassembled.

Contact your local Swagelok Authorized Sales and Service representative for more information.

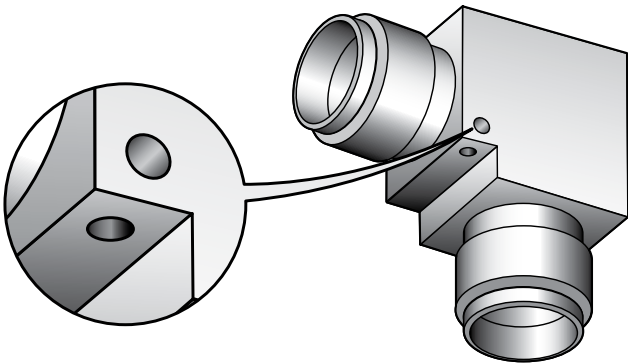


Figure 6-28 Wire drilled elbow.

Flange Adapters and Lap Joint Connectors

Swagelok offers flanges that meet the design standards of ASME, DIN, EN, and JIS. They are one-piece, integrally machined forged bodies and are available in a full range of flange sizes and pressure classes as well as sealing options (flat face, raised face, ring type joint [RTJ], and tongue and groove).

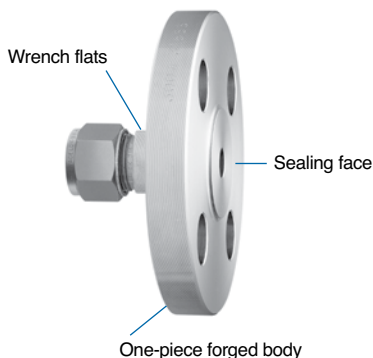


Figure 6-29 Flange adapter.

Swagelok tube fitting lap joint connectors provide easy connections between process and instrumentation lines. They are designed to be used with lap joint pipe flanges. They are available with either smooth or serrated surface finish for sealing. Lap joint connectors are compatible with ANSI B16.5 lap joint flanges.



Figure 6-30 Lap joint connector.



Refer to the Swagelok Flange Adapters catalog (MS-02-200). www.swagelok.com/TFM

Chapter 7

Testing and Evaluation of Tube Fitting Performance

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Testing and Evaluation of Tube Fitting Performance

In this chapter, we discuss the basic principles of establishing a tube fitting performance test program as an important and ongoing process for all fluid systems.

Reasons for a Tube Fitting Performance Test Program

Testing is performed for four basic reasons.

- Prevent material leakage loss.
- Prevent environmental contamination.
- Maintain a pressure differential
- Ensure operational reliability of the system.

Overview

Over the years, tubing systems have become more complex, creating the need for more thorough testing in addition to a wider and deeper evaluation of tube fitting performance. The goal of leak testing is to eliminate safety hazards and the high costs of leakage in fluid systems.

When reviewing leak test results or establishing a leak test program, it is important to select tests that fairly represent actual usage. We begin our discussion on how to conduct effective tests and then continue with an overview of common tests performed. Because Swagelok Company has been in the fluid systems industry since 1947, the observations, data, and recommendations offered here are the results of that experience. Leak testing at Swagelok includes in-house testing, customer-specific tests, industry standard testing, and external or independent tests.



View the Swagelok Tube Fittings Extreme Testing Video.
www.swagelok.com/TFM

Test Program Planning

Consider the following prior to requesting a test or planning your own testing program.

1. Are you trying to prove a predetermined outcome?

Assumption testing is when a certain result is assumed and then tests are designed to find the data to support the assumption.

For example, a department has been directed to cut the cost of tube fittings. Cost reductions are to be accomplished by proving, through testing, that a less expensive fitting is capable of replacing a more expensive fitting. The result of the finding is assumed, therefore negating any test results.

2. Do test results trump long-term experience?

Controlled laboratory test conditions may return better, or worse, results compared to what is actually found in the field.

For example, a new fitting is tested in the laboratory with specific results. However, the history of hundreds or even thousands of fittings in the field contradicts the limited laboratory test results.

3. Will an independent test laboratory be used?

Independent test laboratories may be enlisted to perform tests; however, the samples should always be purchased through the normal supply chain without mention that they are to be used in a testing environment.

For example, the customer is considering replacing a current fitting and has asked for two other manufacturers' fittings to be tested. The samples should always be purchased through the normal supply chain in order to maintain an objective and fair testing procedure.

4. Will valid statistical sampling be employed?

An organization may have over 100 000 tube connections in use each year but test only a small sample of 5 to 10 connections in one or two sizes.

For example, the laboratory testing arrives at one conclusion but doesn't substantiate the test results with the performance in the field. It is possible that the testing parameters thought to reflect the usage of the 100 000 tube connections in the field were not properly documented or conveyed to the test laboratory, causing erroneous conclusions to be drawn.

5. Will extrapolation be used to minimize test costs?

Specific fitting sizes and materials are successfully in service. When the organization expands their fluid system, new materials are ordered but in different fitting sizes and different materials, assuming that the new materials will perform as well as the tried and tested fittings have performed in the past. This assumption can be dangerous.

For example, brass fittings have been tested on copper tubing in

1/4 and 3/8 in. sizes. However, the new fluid system mandates that steel or stainless steel is to be used in sizes from 1/4 to 1 in. Instead of testing the new materials and sizes, an assumption is made that because the current fittings perform so well, the new fittings will work equally as well.

6. Will field-use conditions be simulated?

Laboratory tests may lack validity simply because of the focus and training of the technicians performing the tests. Whereas a laboratory technician is careful to set up the test to the manufacturer's specifications, field technicians of various levels of training and experience can introduce improper installation at any time.

For example, field conditions involve varying pressures, temperatures, impulsing, vibration, and disassemble/reassemble conditions, in addition to tube material, wall thickness, concentricity, condition, and hardness variations that can affect a fitting's performance.

Careful consideration of these six questions may help avoid errors in new test programs or will reveal errors in tests that have been completed and published.

The best test of any component, such as a tube fitting, is repeated use in large numbers under various installation and operating conditions in the field.

Planning the Test Program

When planning the test, be sure to factor in careful selection of fittings, tubing, sizes, materials, and configurations to be tested. Remember, the same considerations can apply to the evaluation of completed and published tests.

1. Obtain fittings.

The fittings to be used for testing should always be purchased through the normal supply chain without mention that they are to be used in a testing environment. This ensures that the sampling is taken from the average supply that will be available for the final solution.

2. Obtain tubing.

The tubing to be used for testing should either be tubing used in the plant or purchased through the normal supply chain without mention that it is to be used in a testing environment. When stainless steel tubing is required, both welded-and-drawn and seamless should be tested, unless only one or the other is used exclusively in actual plant

service. When a manufacturer recommends *only* seamless tubing, *all* tests should be conducted on seamless tubing. Additionally, testing only seamless tubing when the plant requirement is actually welded-and-drawn tubing can skew test results.

It is important to test more than one wall thickness.

For example, if fittings are to be used on 0.035, 0.049, 0.065, and 0.083 in. wall thickness, at least 0.035 and 0.083 in. should be tested (minimum and maximum wall).

All tubing tests should use an identical method each time. When competitive tests are conducted, the two sides of each tube cut should also be put into the competitive fittings to ensure all variables are equal for each manufacturer fitting used in the test.



Figure 7-1 Thick- and thin-wall tubing.

3. Select sizes.

When establishing your test pattern, remember that the larger the seal, the larger the potential leak. Test the largest fitting you anticipate installing more times than testing the smallest fitting you plan to install. If the test succeeds on the larger 1 in. fitting, it is likely that it will work on the smaller 1/8 in. fitting. The reverse is not true.

4. Select materials.

Test fittings in all materials you expect to install. A brass fitting may work well, but the same fitting in steel or stainless steel may fail. The fact that it works in stainless steel does not necessarily indicate that it will work in other alloys such as alloy 400 or alloy 2507.

5. Select fitting configurations.

Test several configurations. Elbows, tees, and crosses are made from forgings, which normally are softer than the bar stock used in straight fittings. Therefore, different factors may affect sealing and holding ability, as well as thread life. Testing several configurations negates the possibility of all test fittings being made on the same machine on the same day with the same tools. For example, testing for quality control of four different configurations is a more valid testing pattern than testing four fittings of one configuration. Nuts and ferrules are more likely to come from different manufacturing lots.

The components shown here in each size, material, and wall thickness should give you a representative test for quality and consistency.

This assortment will make six connections: four bar stock fitting connections and two forged body fitting connections. This approach ensures a valid test of consistency because the fittings would be made on various machines at various times.

Testing different configurations also provides an excellent quality control check on a manufacturer in terms of holding critical tolerances throughout the product line. Such tolerances are discussed under disassemble/reassemble testing.

Another test of quality control and consistency is to take apart all the fitting components and measure the components as listed here.

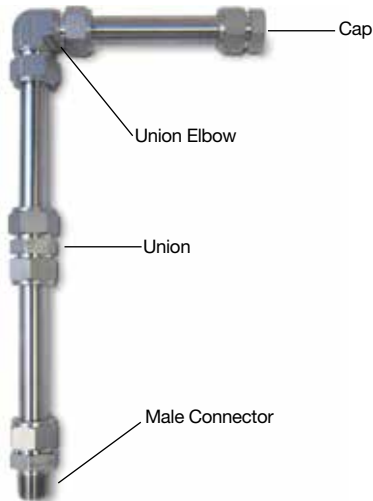


Figure 7-2 Typical test set-up.

	Body	Front Ferrule	Back Ferrule	Nut
Inside bore diameter	X	X	X	X
Skirt diameter	X			
Outside diameter		X	X	
Length		X	X	X

Quality Control

- Measure the total spread of measurements of each manufacturer to check consistency and quality control.
- Never average the variations in any critical dimension. Maximum deviation from highest to lowest measurement of such dimensions will reveal a great deal about a manufacturer’s quality control.
- Thorough planning in the above areas is time well spent in ensuring a comprehensive, objective, and valid test program, and information gained may determine that further tests are not needed.

The best test of any component, such as a tube fitting, is repeated use in large numbers under various installation and operating conditions in the field.

Implementing the Test Program

Next, we discuss nine types of tube fitting tests. Some can be performed by the user without major expense, whereas others are more practically performed by manufacturers due to the time and expense involved.

Gas Leak Tests

Gas leak tests evaluate seal integrity. Inert gas, such as nitrogen or helium, should be used. Air is acceptable. Test pressures should be at least equal to the working pressures recommended by tubing manufacturers. Various test methods can be used depending on cost, equipment availability, and sensitivity desired. These include

bubble checking (underwater); using a leak detector fluid such as Snoop at all connections; or more sensitive methods such as ultrasonic, halogen torch, or mass spectrometer helium leak detectors using a probe, as shown below.



Figure 7-3 Snoop leak test.



Figure 7-4 Sniffer test of helium pressurized system.

A very important facet of gas leak testing is to determine in advance what will be considered a leak. The test pressure and a realistic leak rate should be decided based on the maximum plant requirements and the limitations of the fittings and tubing. The test pressure may be determined by multiplying the plant pressure times an appropriate safety factor, for example:

$$1000 \text{ psig (68 bar)} \times 2 \text{ (2:1)} = 2000 \text{ psig (138 bar)}$$

A common error is to not report a leak if it can be stopped by additional tightening. If a fitting is assembled and reassembled according to instructions, it should not leak. The necessity of this approach is to simulate field conditions where leaks are expensive.

For example, a system with 100 connections is tested as a system. Leaks are located and isolated, and repairs or replacements are made. All these steps are costs, and the cost of failures is high, even if leaks can be stopped by additional tightening.

If you can stop a leak by further tightening, you still need to consider it a leak.



Refer to Tube Fitting Performance Product Test Reports (MS-06-108) and search for the following test result:

- PTR-1388
- PTR-3221

www.swagelok.com/TFM

Tube fitting performance can be evaluated using three specific types of test criteria. These tests allow a tube fitting to be evaluated under varying dynamic conditions. Product Test Reports (PTRs) for Swagelok tube fittings are available upon request.

Vacuum Tests

Vacuum tests are excellent tests of seal integrity. Any fitting that must rely on internal system pressure to help effect a seal will usually fail vacuum tests.

Vacuum tests are advisable where vacuum is in regular use, particularly ultra-high vacuum in sophisticated instruments. The equipment is expensive, but so is the cost of failures. Usually, helium leak detectors of the mass spectrometer type are used.

A fitting-tube assembly is attached to the test port, vacuum is pulled internally, and a helium gun is used to squirt helium at all seal points.



Refer to Tube Fitting Performance Product Test Reports (MS-06-108) and search for the following test result: PTR-1369. www.swagelok.com/TFM

Disassemble/Reassemble Tests

A tube fitting's ability to stand many make/break cycles is perhaps the best measure of comparison among competitive products. These tests can be extremely important in instrumentation fitting applications where periodic maintenance requires making, breaking, and remaking tube connections. Therefore, disassemble/reassemble tests should be performed very carefully. When equated to field usage, disassemble/reassemble test results can greatly reduce in-service tube fitting costs. But such tests will not relate to field usage unless they incorporate the following two vital procedures:

1. Use a variety of configurations (elbows, tees, crosses, unions, bulkhead unions, male and female connectors) to ensure a fair representation of quality parts has been tested, as discussed earlier.
2. Randomly reassemble nut-ferrule-tubing assemblies with different bodies to simulate field conditions.



Figure 7-5 Typical disassemble/reassemble test.

Let's examine the second procedure in more detail and consider what really happens in the field.

For example, analytical instruments such as chromatographs have column changes, where the nut-ferrule-tubing assemblies are removed with columns. The fitting stays attached to the instrument. Another column with nut-ferrule-tubing assembly is connected to the same body.

In another example, process or measuring instruments, such as controllers or transmitters, are dropped from a system with fitting bodies attached, while the nut-ferrule-tubing assemblies stay on the same tubing. Other instruments with different fitting bodies are installed as replacements. Here the bodies are changed, but the nut and ferrule systems stay. You can see that in these realistic disassemble/reassemble situations, the same nut-ferrule-tubing combination seldom sees the same body twice. Therefore, disassemble/reassemble testing with the same nut-ferrule-tubing assembly repeatedly into the same body does not simulate field disassemble/reassemble conditions.

The Importance of Disassemble/Reassemble Testing

There are several reasons why disassemble/reassemble testing is one of the best ways to check the quality control of any fitting manufacturer.

- Due to sealing ferrule design, galling takes place at the body seal area (particularly in stainless and other corrosion-resistant alloys), and another ferrule trying to seat in the damaged body seal area often causes a leak—another simulation of what happens in the field.
- Regarding the sealing mechanism, several different nut-ferrule-tube combinations must seal at different points on the body seal area (because it is necessary to coin or groove the body seal at a slightly different spot each time), and leakage often results.
- Thread integrity during repeated disassemble/reassemble cycles is an important indication of sound quality control, as well as good design.
- Uniform unblemished sealing surfaces indicate good surface quality control. In any metal-to-metal sealing device, good surface finish is a necessity. But a smooth surface finish is only

a beginning. If that surface is greatly degraded during original or subsequent disassemble/reassemble cycles, especially with several different bodies, there is a good chance of field failure. Tests and calculated data show that leakage varies by a cube function as seal smoothness degrades. A 50 % improvement in the sealing surface provides an 800 % improvement in seal integrity.



Refer to Tube Fitting Performance Product Test Reports (MS-06-108) and search for the following test results:

- PTR-383
- PTR-395

www.swagelok.com/TFM

Rotary Flex Vibration Tests

The specialized equipment costs of such tests usually make them impractical for the user to design. Swagelok's tests use a minimum of a 1750 rpm motor with a deflection block that adjusts the center line deviation of the tube assembly under test.



Figure 7-6 Vibration test stand.

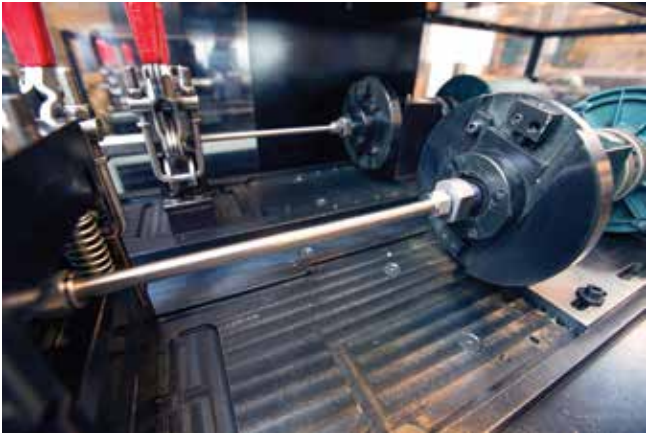


Figure 7-7 Adjustable tube deflection for vibration tests.

An internal tube pressure is selected (maximum working pressure of the tubing).

Motor rotation causes the motor end of the capped tube to move in a circle whose radius is the tube deflection from center line.

The test sample should be flexed until one of the following occurs:

- The fitting leaks.
- The tube fractures.
- Ten million cycles are achieved.

An in-line pressure transducer stops the test if fitting leakage or tube fatigue fracture occurs.

We have seen other tests where a 90° bend in the tubing is placed between the test fitting and the adjustable block. This causes indeterminate test results; the applied stress cannot be measured or estimated. Best practice is to follow the guidelines of ASME B31J, Standard Test Method for Determining Stress Intensification Factors (*i*-Factors) for Metallic Piping Components.



Refer to Tube Fitting Performance Product Test Reports (MS-06-108) and search for the following test result: PTR-3222. www.swagelok.com/TFM

Tensile Pull Tests

These tests usually are performed only by fitting manufacturers because of costs and equipment requirements. Tensile pull tests are used to check the holding ability of fitting connections rather than sealing ability.

Results allow calculation of the internal pressure needed to cause separation, where the tube actually could blow out of the fitting. Most quality tube fittings will hold tubing to hydraulic pressures approaching yield or burst of the tubing. Hydraulic burst testing is discussed later in this chapter.



Refer to Tube Fitting Performance Product Test Reports (MS-06-108) where you can search for the following test result: PTR-4060. www.swagelok.com/TFM



Figure 7-8 Tensile pull test.

Rotation Tests

These tests sometimes are performed to determine what torque would be required to twist a piece of tubing so severely as to break the ferrule-tubing seal and cause leakage. Although we can test fittings this way, the test rarely would be equated to a field type of malfunction.

Hydraulic Impulse Tests

Hydraulic impulse tests commonly are run by fitting manufacturers to determine the ability of the tube and fitting assembly to resist severe and sudden pressure impulses without failure.

Swagelok's impulse method is to shock the assembly under test with an impulse of $1.5 \times \text{tubing maximum working pressure}$. A quick-opening valve is used to achieve the shock at a frequency of 35 to 40 cycles per minute for 100 000 pressure cycles.

Hydraulic impulse tests provide valuable bits of test information but not as valuable as actual field use.



Refer to Tube Fitting Performance Product Test Reports (MS-06-108) and search for the following test result: PTR-2849. www.swagelok.com/TFM



Figure 7-9 Hydraulic impulse test.

Hydraulic Burst Tests

Hydraulic burst tests are an excellent test of tube grip performance but a poor test of sealing ability.

Burst tests can be significant when designed properly to test the fitting. In Swagelok's own general program tests, the tubing is restricted from burst by clamping blocks, thereby forcing a failure at the fitting-to-tubing engagement.

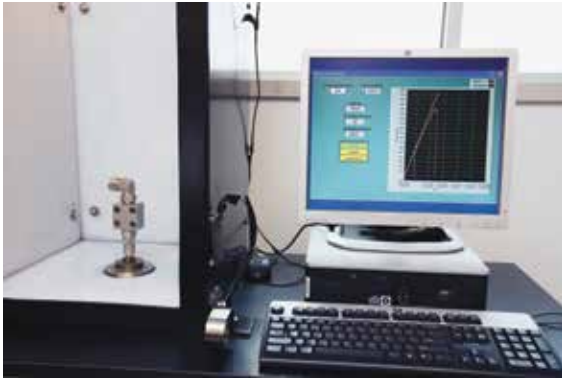


Figure 7-10 Hydraulic burst test.

The pressure is gradually increased, and pressure is recorded when one of the following occurs that prevents applying higher pressure:

- Loss of tube grip
- Material rupture
- Leakage

Results are then compared to the tubing working pressure.



Reference Tube Fitting Performance Product Test Reports (MS-06-108) and search for the following test result: PTR-3220. www.swagelok.com/TFM



Figure 7-11 Tubing yield before burst.



Figure 7-12 Tube burst.

Thermal Cycling Tests

Temperature cycling is one of the toughest services a tube fitting must experience.

Examples:

- Steam
- Cryogenics
- Arctic or tropical environments
- Heat transfer fluids such as liquid metals
- Space simulation
- Analytical instrument ovens, chambers, columns

The cost of setting up a test facility is usually prohibitive, except for a major fitting manufacturer or a government-funded research program.

As mentioned previously, most large users of tube fittings have their own testing laboratories in the form of their existing in-plant applications. In the case of thermal cycling, most process plants have some or all of the services listed earlier.



Reference Tube Fitting Performance Product Test Reports (MS-06-108) and search for the following test results:

- PTR-386
 - PTR-392
 - PTR-2835 (high temperature)
 - PTR-2836 (low temperature)
- www.swagelok.com/TFM



Figure 7-13 1000 psig (68 bar) gas test at 1000°F (538°C).

Factors Affecting Seals

In general, seal integrity between fitting components is severely affected by temperature excursions. Factors directly affecting seals include:

- Relative wall thicknesses (thin tube wall versus relatively heavy fitting wall thickness)
- Differential thermal coefficients of expansion (copper tube versus brass fitting)
- Length of tube support within the fitting (affecting heat transfer as tube cools faster than fitting)
- Rate of temperature change (Thermal shock or very rapid temperature change is a much more severe test than temperature excursion made slowly.)

Effects of Steam

Among all temperature cycling applications, steam is perhaps the most common fluid and, in many ways, the most difficult. Its erosive properties are well known, and these properties often preclude the luxury of retightening if a leak does occur. A high-velocity, erosive steam leak passing through a very small orifice usually increases the original leak rate greatly and, therefore, the cost of leaks. Extra tightening seldom stops that first steam leak (particularly on copper steam-trace tubing) because the high-velocity steam etches a deeper and deeper path in the soft tubing under the sealing ferrule.

Evaluating Product Test Reports (PTR)

It is important to understand the testing parameters when evaluating Product Test Reports. The first question to ask is whether all fittings used the same parameters. It would not be considered a comparable test if the test duration was shorter or if water or hydraulic oil was used instead of the lighter gases such as nitrogen, air, or helium. Also, as stated earlier, laboratory installations tend to be more focused and cautious than field installations.

The best test of any component, such as a tube fitting, is repeated use in large numbers under various installation and operating conditions in the field.

Intermix/Interchange

Many manufacturers claim that their fitting components are interchangeable and/or intermixable with Swagelok tube fittings. These claims are sometimes accompanied by some test data. However, these tests are often subject to many of the pitfalls mentioned earlier in the chapter (lack of objectivity, governed by predetermined results, lack of statistical validity, extrapolation, etc.).

It should be noted that many users of tube fittings have developed their own tests of tube fitting component interchangeability. It is generally agreed that component interchange is not a recommended or accepted practice.

Behind this is the fact that there is no third-party commercial design standard that governs component design and dimension for Swagelok and other ferrule-type tube fittings. The lack of a third-party design standard means that test results would not be repeatable.

See Chapter 1, page 15, for more information on tube fitting intermix/interchange.

Summary

Plan test programs with fittings, tubing, materials, and configurations that will ensure objectivity and statistical validity, while avoiding predetermined results and extrapolation. Pay close attention to the same considerations when evaluating test results from outside sources.

Recognize the fact that existing plants represent the most reliable test labs possible. Those who ignore field operating results and rely on limited lab test programs are overlooking their most valuable input.

Chapter 8

Threads

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Introduction

Proper sealing of threads depends on many variables: quality and cleanliness of threads, temperature, component material, installation torque, specific gravity of system media, and system operating pressures.

The type of thread used for a connection can enhance the quality of the seal. This chapter lists the most common threads and their typical use. It is important to note that even experienced workers sometimes have difficulty identifying threads, regardless of their thread identification procedure and the quality of their gauges.

Screw Thread Terminology

Threads have peaks and valleys, referred to as **crests** and **roots**, respectively. The surface between the crest and root is called the *flank*.

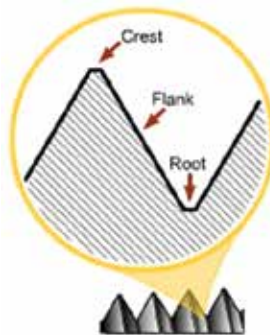


Figure 8-1 Thread terminology.

Threads also have a *pitch* and an *angle* as shown here.

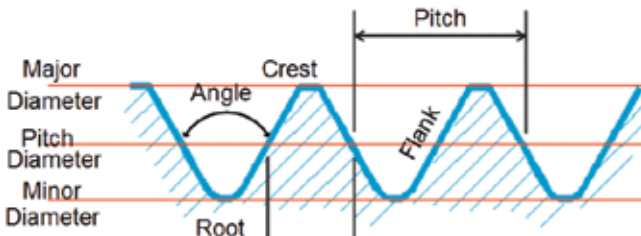
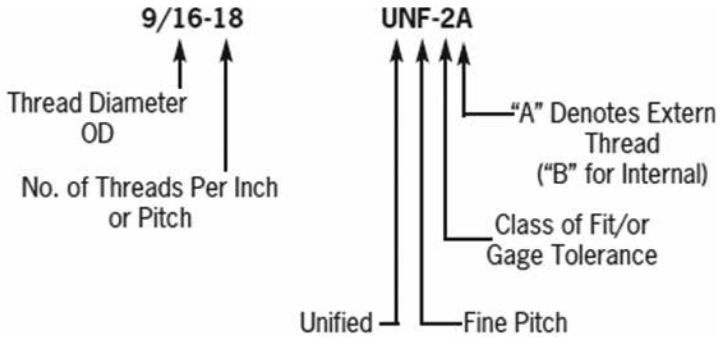


Figure 8-2 The pitch of a thread.

Screw threads are the workhorse of the threaded product industry. Almost all tube fittings and valves use these for nut and fitting end threads, valve stems, lock nuts, jam nuts, etc.



There is always a 60° included angle in this thread.

Figure 8-3 Typical designation.

Whether a thread is:

- UNC (coarse), or
- UNF (fine), or
- UNEF (extra fine),

is the relationship of threads per inch to thread diameter.

For example:

- 5/16–18 is a UNC thread
- 5/16–24 is a UNF thread
- 5/16–32 is a UNEF thread

But the determination of *coarse*, *fine*, or *extra fine* is not merely threads per inch, but the relationship of threads per inch to thread diameter.

For example:

- 1/4–20 is a UNC (coarse) thread
- 7/16–20 is a UNF (fine) thread
- 3/4–20 is a UNEF (extra fine) thread

Screw threads are straight (not tapered). They are described in terms of thread OD and threads per inch. An example is a nominal 3/8 in. SAE port using a 9/16–18 UNF-2A thread.

All Swagelok tube fittings use American National screw threads in which a nut and threaded body work together to advance the nut and swage the ferrules onto the tube.

Pipe Threads

There are two general categories of threads, *tapered* and *parallel*. This refers to how the threads are applied to the end connection in relation to the center of rotation of the thread form.

Tapered Threads

Tapered threads are applied at an angle, most commonly $1^{\circ}47'$ (which reflects a taper of 1/16 in. per foot). Tapered pipe threads are designed to seal between the flanks of the threads. However, manufacturing tolerances and truncation limits for crests and roots will rarely create a leak-tight seal.

- Tapered pipe threads work by interference fit. The tolerances for angles, lengths, heights, etc., cannot be held closely enough to make a seal.
- Male pipe threads cannot be manufactured to tolerances that will seal on a taper with female pipe threads without a sealant.

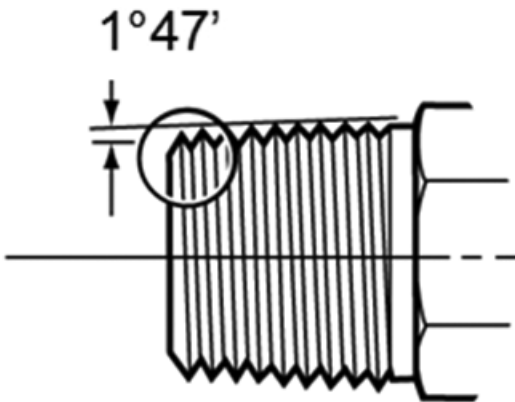


Figure 8-4 Tapered (dynamic).

For this reason, a good thread sealant is always needed to fill in the gaps between the crests and roots and to prevent system fluids from penetrating the connection. The sealant, such as Swagelok PTFE tape, will fill the voids between the threads. The thread sealant will also act as an anti-galling lubricant between the sealing surfaces. Leakage due to thread galling is prevalent with threads made of stainless steel and other nickel alloys that are more prone to seizing.

Swagelok manufactures end connections with two types of tapered pipe threads.

These are NPT and ISO 7/1.

National Pipe Tapered (NPT)

- Thread taper = $1^{\circ}47'$
- The truncated areas of roots and crests are flat
- Pitch measured in threads per inch
- 60 thread angle

Standards:

- ANSI/ASME B1.20.1
- SAE AS71051

National Pipe Tapered (NPT) is made to specifications outlined in ANSI B1.20.1. This is the pipe thread used on the pipe end of all Swagelok tube fittings when the abbreviation NPT is used in the Swagelok Product Binder.

Swagelok manufactures NPT pipe ends that exceed the standards of ANSI B1.20.1 (Pipe Threads, except Dryseal). Some type of pipe thread sealant is always required. Swagelok PTFE tape is made specifically for pipe thread sealing. Swagelok SWAK is an anaerobic pipe thread sealant with PTFE. For further information, consult your authorized Swagelok representative.

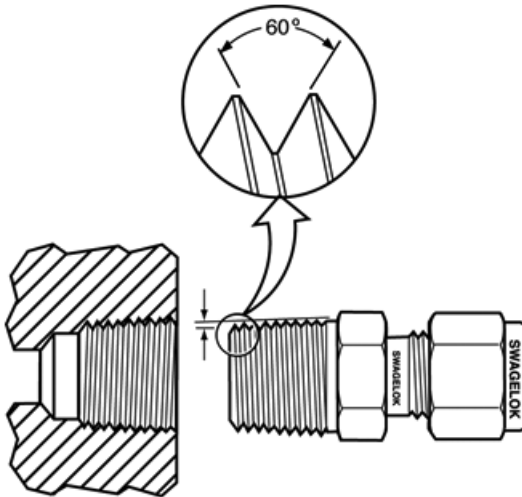


Figure 8-5 NPT.

National Pipe Tapered Dryseal (NPTF)

NPTF is made to specifications outlined in ANSI B1.20.3. This pipe end is used on some hydraulic equipment and is sometimes specified on military hardware.

In "Dryseal" threads, the roots of the threads are more truncated than the crests so that an interference fit causes the roots to crush the crests of the mating threads, leading to galling. Supposedly, when made up, the crests, roots, and flanks are always in full contact, but this can cause galling, particularly without lubrication or a sealing compound on stainless steel or nickel alloys.

Swagelok tube fittings are not manufactured with Dryseal Pipe Threads.

ISO 7/1 (British Standard Pipe Taper)

- Swagelok RT
- Thread taper = $1^{\circ}47'$
- The truncated areas of roots and crests are rounded
- Pitch measured in threads per inch
- 55° thread angle

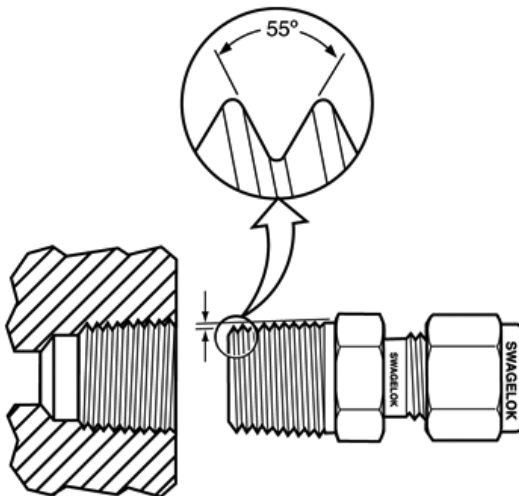


Figure 8-6 ISO 7/1 (British Standard Pipe Taper).

Standards:

- BS EN 10226-1
- JIS B0203
- BS 21
- DIN 2999

ISO tapered threads are equivalent to DIN 2999, BSPT, and JIS B0203.

In applications, ISO threads are used similarly to NPT threads. However, care should be used that ISO and NPT threads are not mixed. ISO threads have a 55° angle versus 60° for NPT. Thread pitch is usually measured in millimeters but may be expressed in inches. In many sizes, the number of threads per inch is different, and the root and crest configurations are different from NPT.

Comparison Chart: Tapered Pipe Threads

Nominal Size	Threads per Inch	Pipe Outside Diameter (OD)	Included Thread Angle	Pitch	
1/16 in.	NPT/NPTF	27	0.313 in.	60°	0.037 in.
	ISO	28	0.312 in.	55°	0.036 in.
1/8 in.	NPT/NPTF	27	0.405 in.	60°	0.037 in.
	ISO	28	0.398 in.	55°	0.036 in.
1/4 in.	NPT/NPTF	18	0.540 in.	60°	0.056 in.
	ISO	19	0.535 in.	55°	0.053 in.
3/8 in.	NPT/NPTF	18	0.675 in.	60°	0.056 in.
	ISO	19	0.672 in.	55°	0.053 in.
1/2 in.	NPT/NPTF	14	0.840 in.	60°	0.071 in.
	ISO	14	0.843 in.	55°	0.071 in.
3/4 in.	NPT/NPTF	14	1.050 in.	60°	0.071 in.
	ISO	14	1.060 in.	55°	0.071 in.
1 in.	NPT/NPTF	11-1/2	1.315 in.	60°	0.087 in.
	ISO	11	1.331 in.	55°	0.091 in.
1 1/4 in.	NPT/NPTF	11-1/2	1.660 in.	60°	0.087 in.
	ISO	11	1.669 in.	55°	0.091 in.
1 1/2 in.	NPT/NPTF	11-1/2	1.900 in.	60°	0.087 in.
	ISO	11	1.900 in.	55°	0.091 in.
2 in.	NPT/NPTF	11-1/2	2.375 in.	60°	0.087 in.
	ISO	11	2.374 in.	55°	0.091 in.

Parallel Threads

Parallel (sometimes referred to as straight) threads are applied parallel to the centerline.

- Unlike tapered threads, which seal as the flanks of the threads are drawn together, there is no interference between the flanks, crests, and roots of parallel threads.
- Almost all tube fittings and valves use parallel threads for nut and fitting end threads, valve stems, lock nuts, jam nuts, etc.

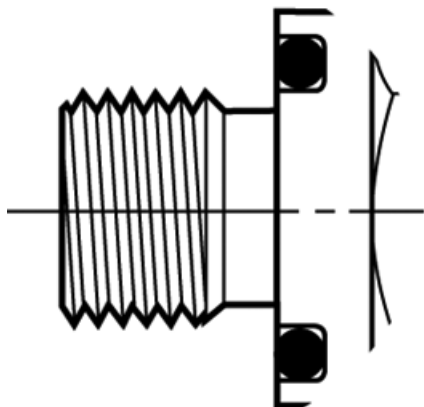


Figure 8-7 Parallel (mechanical).

Swagelok manufactures products using a variety of fractional and metric parallel threads. While the two most common parallel thread series are unified screw threads and ISO 228/1, metric (ISO 261) screw threads are also a common option on some Swagelok components.

Unified Screw Thread

- Swagelok ST, O-Seal
- 60° thread angle
- Pitch measured in threads per inch
- The truncated areas of roots and crests are flat

Standard:

- ANSI/ASME B1.1
- SAE/MS straight thread

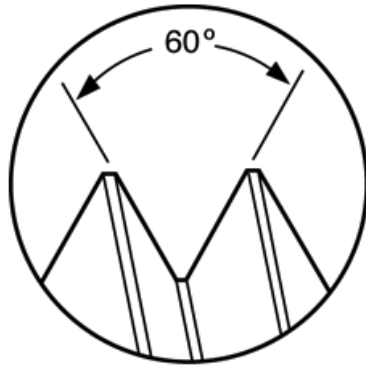


Figure 8-8 Unified screw thread with 60° thread angle.

ISO 228/1 Parallel Pipe Thread (British Standard Pipe Parallel)

- Swagelok RP, RS, RG, RJ
- 55° thread angle
- Pitch measured in threads per inch
- The truncated areas of roots and crests are rounded

Standard:

- JIS B0202
- BSPP

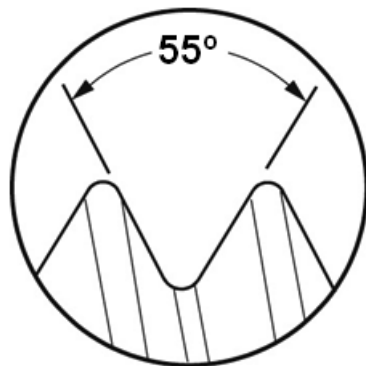


Figure 8-9 ISO 228 with 55° thread angle.

ISO parallel threads are equivalent to DIN ISO 228/1, BSPP, and JIS B0202. These pipe threads are similar in configuration to 7/1 threads except there is no taper. Therefore, they do not work by thread interference like the tapered pipe threads of ISO 7/1 or NPT. A gasket or O-ring is normally used to seal into the parallel female threaded component. In some cases, the body is tightened until a face on the hex is imbedded into the female threaded component. Surface flatness perpendicular to the axis of the threads is essential.

Metric (ISO 261)

- 60° thread angle
- Pitch measured in millimeters
- The truncated areas of roots and crests are flat and of different width

Standard:

- ISO 68-1
- JIS B0205
- ANSI/ASME B1.13M

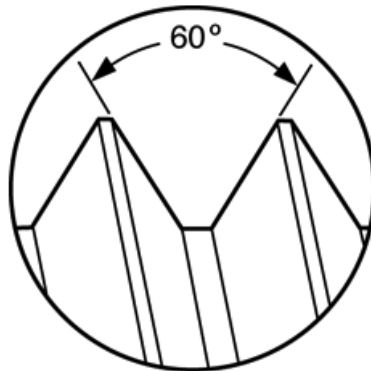


Figure 8-10 Metric (ISO 261) with 60° thread angle.

Unlike tapered threads, parallel threads are not sealing threads. Even the use of good-quality thread sealants will not provide reliable seals for these threads. Four methods of sealing ISO 228/1 male threads to female ports are as follows.

1. A metal-to-metal seal is made between the face of the body hex and the face of the female threaded component (Swagelok "RP" thread).

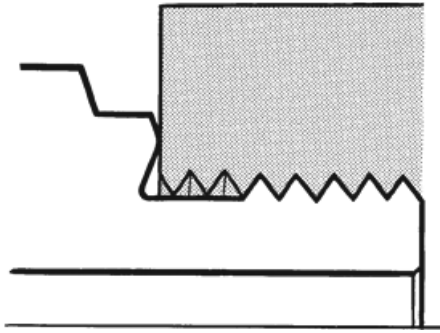


Figure 8-11 Metal-to-metal seal.

2. A metal gasket (usually copper) makes the seal between the face of the body and the face of the female threaded component (Swagelok "RP" thread).

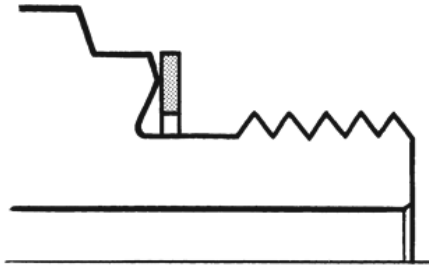


Figure 8-12 Metal gasket seal.

3. A self-centering taper is used at the hex, which centers a composite washer (usually metal and elastomer) to seal to the surface surrounding the female thread (Swagelok "RS" thread).

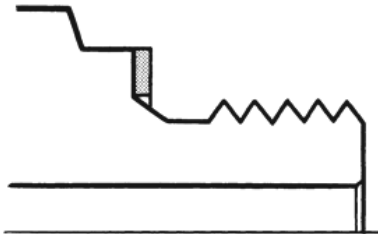


Figure 8-13 Composite washer seal.

- A gasket is dropped into the flat bottom of the female thread. The face of the male thread exerts a load on the gasket to seal (Swagelok "RG" thread).

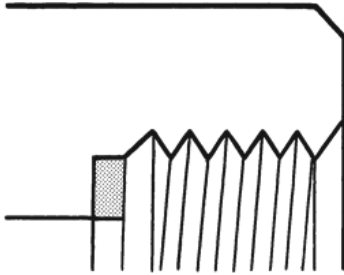


Figure 8-14 Gasket to seal.

Unified Screw Threads

- 60° thread angle
- Pitch measured in inches
- The truncated areas of root and crest are flat
- Diameter measured in inches

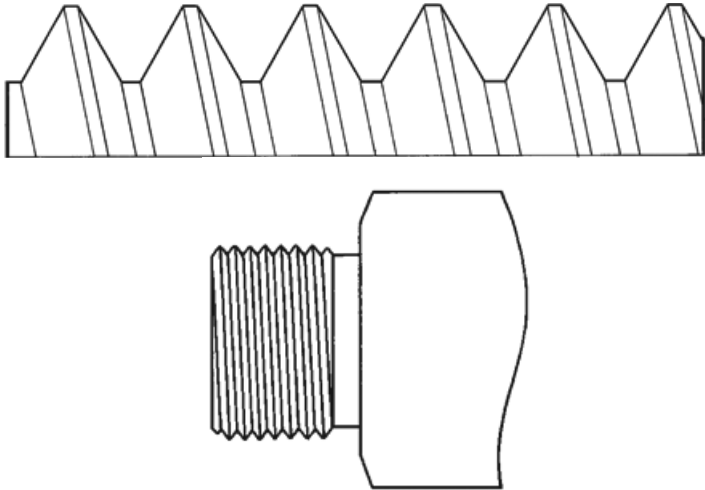


Figure 8-15 American Standard Unified Screw Thread.

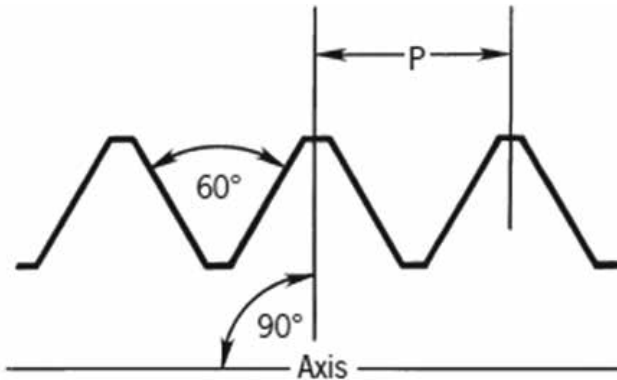


Figure 8-16 Straight threads.

Unified screw threads are commonly used in the hydraulics industry and in military hardware. Swagelok SAE/MS Straight Thread Fittings are used to seal to SAE/MS ports by means of elastomer O-rings.

Thread sizes and other dimensions of SAE ports per SAE J1926 Standard are shown below:

SAE/MS Internal Straight Thread Boss

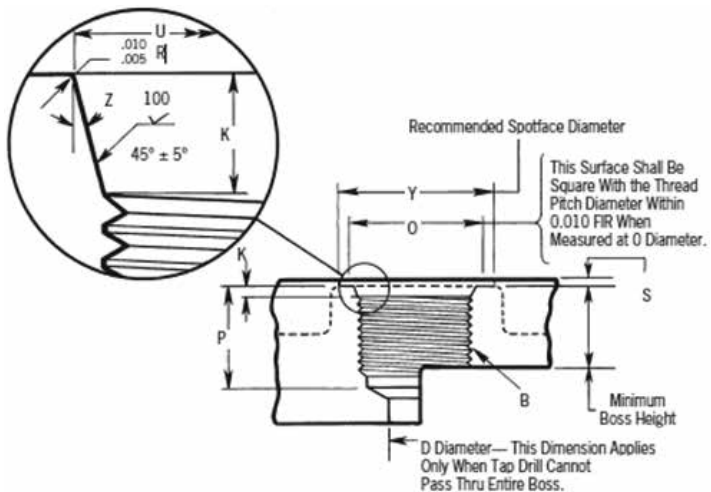


Figure 8-17 SAE/MS Internal Straight Thread Boss.

SAE J1926/1 Port Dimensions

Nom Tube OD	B Straight Thread		J Full Thread Depth	K +0.015 -0.00	O Dia	P\$ Min	S†† Max	U* Dia +0.005 -0.000		Z ±1 Deg			
	Thread Size	Pitch Dia						D Dia	P\$ Min		S†† Max	Y† Dia	
		Min											Max
1/8	5/16-24	0.2854	0.2902	0.277	0.062	0.390	0.074	0.438	0.468	0.062	0.358	0.674	12
3/16	3/8-24	0.3479	0.3528	0.340	0.125	0.390	0.074	0.500	0.468	0.062	0.421	0.753	12
1/4	7/16-20	0.4050	0.4104	0.383	0.172	0.454	0.093	0.563	0.547	0.062	0.487	0.832	12
5/16	1/2-20	0.4675	0.4731	0.446	0.234	0.454	0.093	0.625	0.547	0.062	0.550	0.911	12
3/8	9/16-18	0.5264	0.5323	0.502	0.297	0.500	0.097	0.688	0.609	0.062	0.616	0.989	12
1/2	3/4-16	0.7094	0.7159	0.682	0.391	0.562	0.100	0.875	0.688	0.094	0.811	1.186	15
5/8	7/8-14	0.8286	0.8356	0.798	0.484	0.656	0.100	1.000	0.781	0.094	0.942	1.344	15
3/4	1 1/16-12	1.0084	1.0158	0.972	0.609	0.750	0.130	1.250	0.906	0.094	1.148	1.619	15
7/8	1 3/16-12	1.1334	1.1409	1.097	1.115	0.750	0.130	1.375	0.906	0.094	1.273	1.777	15
1	1 5/16-12	1.2584	1.2659	1.222	1.240	0.844	0.130	1.500	0.906	0.125	1.398	1.934	15
1 1/4	1 5/8-12	1.5709	1.5785	1.535	1.553	1.078	0.132	1.875	0.906	0.125	1.713	2.288	15
1 1/2	1 7/8-12	1.8209	1.8287	1.785	1.803	1.312	0.132	2.125	0.906	0.125	1.962	2.564	15
2	2 1/2-12	2.4459	2.4540	2.410	2.428	1.781	0.132	2.750	0.906	0.125	2.587	3.470	15

All dimensions in inches.

* Diameter U shall be concentric with thread pitch diameter within 0.005 full indicator reading (FIR) and shall be free from longitudinal and spiral tool marks. Annular tool marks up to 100 µin. maximum shall be permissible.

• Maximum recommended spotface depth to permit sufficient wrench grip for proper tightening of the fitting or locknut.

† If face of boss is on a machined surface, dimensions Y and S need not apply.

§ Tap drill depths given require use of bottoming taps to produce the specified full thread lengths. Where standard taps are used, the tap drill depths must be increased accordingly.

Note: MS16142 ports are almost identical to SAE ports except for spotface dimensions.

Metric Screw Threads (ISO 261)

- 60° thread angle
- Pitch measured in millimeters
- The truncated areas of root and crest are flat and of different width
- Diameter measured in millimeters

Metric screw threads are straight (not tapered) and are often used to connect to metric threaded equipment. The system is similar to the unified screw thread system mentioned previously, but it is specified as follows. A 10 mm OD \times 1.5 mm pitch thread would be designated as shown in the following figure:

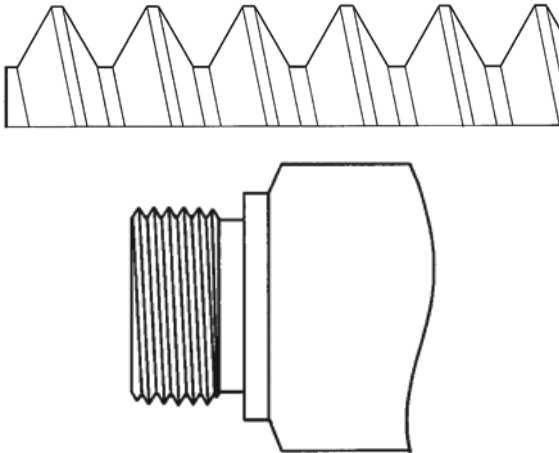


Figure 8-18 International Organization for Standardization (ISO) metric.

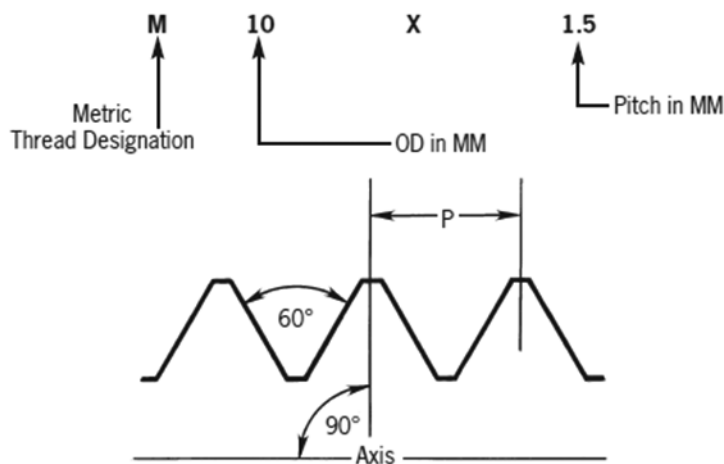


Figure 8-19 Typical designation.

Either a gasket or O-ring is used to seal male metric screw threaded components to female threaded components.

Additional Items to Consider

- When assembling a Swagelok product containing a threaded connection, the threaded connection should always be assembled prior to the Swagelok tube fitting end because of the rotation required to assemble the threaded connection.
- Tapered threads always need a sealant to seal system fluids and prevent galling of the threads during installation. Refer to Chapter 3 section on thread sealants to learn more about how to apply sealants.



Refer to the Swagelok Thread and End Connection Identification Guide (MS-13-77) for additional information.
www.swagelok.com/TFM

Chapter 9

Pressure Ratings

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Tube Calculations and Pressure Ratings

Tubing outside diameter (OD) and inside diameter (ID) are related by the following formulas:

- Tube OD = 2t + Tube ID
- Tube ID = Tube OD - 2t
- Where **t** = Tube wall thickness

Proper wall thickness of tubing to contain internal pressure may be found by using one of the Allowable Pressure Tables in the Tubing Data Sheet (MS-01-107). All tubing pressure ratings are based on ASME Code for Pressure Piping, B31.3-2012.



Refer to the Swagelok Tubing Data Sheet (MS-01-107) for pressure rating of various materials and tubing wall thicknesses. www.swagelok.com/TFM

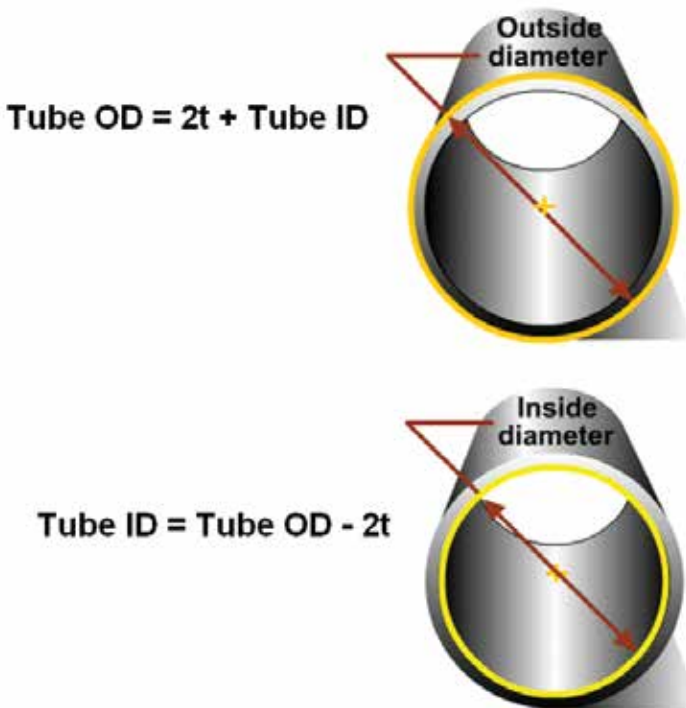


Figure 9-1 Definitions of tube OD and ID.

All pressure ratings are based on minimum wall and maximum OD within the applicable ASTM tubing specifications. A conservative rating is thus established based on worst-case conditions. Because various ASTM specifications have different OD and wall thickness tolerances, use of tubing purchased to ASTM specifications other than those specified in the Tubing Data Sheet (MS-01-107) may cause some changes from the pressure ratings shown in the tables.

As an example, we will use 3/8 in. OD \times 0.049 in. wall seamless stainless steel tubing purchased to ASTM A269 specification.

Nominal OD	0.375
Actual OD	0.370 to 0.380 in. (± 0.005 in.)
Nominal wall	0.049 in.
Actual wall	0.042 to 0.056 in. (± 15 %)

Pressure rating based on nominal wall OD = 5820 psi (401 bar)

Pressure rating based on minimum actual wall (0.042 in.) and maximum actual OD (0.380 in.) = 4860 psi (335 bar)

(Truncated in table to lower 100 psi = 4800 psi [331 bar])

No allowance is taken for corrosion or erosion in the Tubing Data Sheet. As used in this chapter, the term *maximum allowable pressure* is defined as the maximum pressure a system will encounter. The allowable system pressure should be based on the maximum pressure that one can reasonably expect the system will see. Then the system designer, with knowledge of other system variables, can assign an adequate design factor based on familiarity with the system.

Gas Service

Gases (air, hydrogen, helium, nitrogen, etc.) have very small molecules that can escape through even the most minute leak path. Some surface defects on the tubing can provide such a leak path. As tube OD increases, so does the likelihood of a scratch or other surface defects interfering with proper sealing.

The most successful connection for gas service will occur if all installation instructions are carefully followed and the heavier wall thicknesses of tubing shown with no shading in the Tubing Data Sheet are selected.

A heavy wall tube resists ferrule action more than a thin-wall tube and, therefore, allows the ferrules to coin out minor surface imperfections. A thin-wall tube will collapse, thus offering little resistance to ferrule action during pull-up. This reduces the chance of coining out surface defects, such as scratches. For performance reliability against surface defects in any gas system, use a wall thickness no less than the following:

Tubing for Gas Service Tables

Fractional sizes in inches

Tube OD	Minimum Thickness Nominal Wall	Tube OD	Minimum Thickness Nominal Wall
1/8	0.028	3/4	0.065
3/16	0.028	7/8	0.083
1/4	0.028	1	0.083
5/16	0.035	1 1/4	0.109
3/8	0.035	1 1/2	0.134
1/2	0.049	2	0.180
5/8	0.065		

Metric sizes in millimeters

Tube OD	Minimum Thickness Nominal Wall	Tube OD	Minimum Thickness Nominal Wall
3	0.8	18	1.5
6	0.8	20	1.8
8	1.0	22	2.0
10	1.0	25	2.2
12	1.0	28	2.5
14	1.2	30	3.0
15	1.5	32	3.0
16	1.5	38	3.5

Suggested Allowable Working Pressures for Stainless Steel and Copper

Table 1 — Fractional Stainless Steel Seamless Tubing

Allowable working pressures are calculated from an S value of 20 000 psi (137.8 MPa) for ASTM A269 tubing at -20 to 100°F (-28 to 37°C), as listed in ASME B31.3, and ASTM A213 tubing at -20 to 100°F (-28 to 37°C), as listed in ASME B31.1, except as noted.

For Welded Tubing

For welded and drawn tubing, a derating factor must be applied for weld integrity:

- For double-welded tubing, multiply working pressure by 0.85
- For single-welded tubing, multiply working pressure by 0.80

Tube OD in.	Tube Wall Thickness, in.										Swagelok Fitting Series						
	0.010	0.012	0.014	0.016	0.020	0.028	0.035	0.049	0.065	0.083		0.095	0.109	0.120	0.134	0.156	0.188
	Working Pressure, psig																
	Note: For gas service, select a tube wall thickness outside of the shaded area. (See Gas Service, page 212.)																
1/16	5600	6800	8100	9400	12 000												100
1/8						8500	10 900										200
3/16								5400	7 000	10 200							300
1/4											4000	5 100	7 500	10 200 ⁽¹⁾			400

Table 3—Fractional Copper Tubing

Allowable working pressures are calculated from an S value of 6000 psi (41.3 MPa) for ASTM B75 and ASTM B88 tubing at -20 to 100°F (-28 to 37°C), as listed in ASME B31.3 and ASME B31.1.

Tube OD in.	Tube Wall Thickness, in.										Swagelok Fitting Series
	0.028	0.030	0.035	0.049	0.065	0.083	0.095	0.109	0.120	0.134	
	Working Pressure, psig (See Gas Service, page 212.)										
1/8	2700	3000	3600								200
3/16	1800	1900	2300	3400							300
1/4	1300	1400	1600	2500	3500						400
5/16			1300	1900	2700						500
3/8			1000	1600	2200						600
1/2			800	1100	1600	2100					810
5/8				900	1200	1600	1900				1010
3/4				700	1000	1300	1500	1800			1210
7/8				600	800	1100	1300	1500			1410
1				500	700	900	1100	1300	1500		1610
1 1/8					600	800	1000	1100	1300	1400	1810

Suggested Ordering Information

High-quality, soft annealed seamless copper tubing, ASTM B75 or equivalent. Also soft annealed (Temper O) copper water tube, type K or type L to ASTM B88.

Table 4—Metric Copper Tubing

Allowable working pressures are calculated from an S value of 41.3 MPa (6000 psi) for ASTM B75, ASTM B88, and EN 1057 tubing at -28 to 37°C (-20 to 100°F), as listed in ASME B31.3 and ASME B31.1.

Tube OD mm	Tube Wall Thickness, mm										Swagelok Fitting Series
	0.8	1.0	1.2	1.5	1.8	2.0	2.2	2.5	2.8	3.0	
	Working Pressure, bar Note: For gas service, select a tube wall thickness outside of the shaded area. (see Gas Service , page 212.)										
6	110	140	170	220							6M0
8		100	120	160							8M0
10		80	100	130							10M0
12		60	80	100	130	140					12M0
14		50	60	90	110	120					14M0
15			60	80	100	110	120				15M0
16				70	90	100	110	120			16M0
18				60	80	90	100	110			18M0
20				60	70	80	90	100	110		20M0
22				50	60	70	80	90	100		22M0
25				40	50	60	70	80	90	100	25M0
28					40	50	60	70	80	90	28M0

Suggested Ordering Information

High-quality, soft annealed seamless copper tubing, ASTM B75 and EN 1057 or equivalent. Also soft annealed (Temper O) copper water tube, type K or type L to ASTM B88.

For other tubing materials and the latest information, refer to the Swagelok Tubing Data Sheet (MS-01-107).

Factors Used to Determine Tubing Pressure Ratings at Elevated Temperatures

Temperature		Tubing Materials							
°F	°C	Aluminum	Copper	Carbon Steel ^①	304, 304/304L ^②	316, 316/316L ^②	317, 317/317L ^②	321 ^③	347 ^③
200	93	1.00	0.80	0.95	1.00	1.00	1.00	1.00	1.00
400	204	0.40	0.50	0.87 ^①	0.93	0.96	0.96	0.96	0.96
600	315				0.82	0.85	0.85	0.85	0.85
800	426				0.76	0.79	0.79	0.79	0.79
1000	537				0.69	0.76	0.76	0.76	0.76

^① Based on 375°F (190°C) max.

^② Dual-certified grades such as 304/304L, 316/316L, and 317/317L meet the requirements for the lower maximum carbon content of the L grades and for the higher minimum yield and tensile strength of the non-L grades.

^③ Based on the lower derating factor for stainless steel, in accordance with ASME B31.3.



For temperature factors for other tubing materials, refer to the Swagelok Tubing Data Sheet (MS-01-107) factors. www.swagelok.com/TFM

To determine allowable pressure at elevated temperatures, multiply allowable working pressure for a specific material and size by the factor from the Elevated Temperature Factors table. Both values are found in the Tubing Data Sheet.

Example:

Type 316 stainless steel 1/2 in. OD \times 0.049 in. wall at 1000°F (538°C)
 3700 psig \times 0.76 = 2812 psig (255 bar \times 0.76 = 193 bar).

Allowable working pressure for 1/2 in. OD \times 0.049 in. wall type 316 stainless steel tubing is therefore 2812 psig (193 bar) at 1000°F (538°C).

Pipe End Pressure Ratings

Many Swagelok tube fittings have a male or female pipe end. As described below, these ends often have a lower pressure rating than the maximum pressure rating of the tube fitting end.

The ratings shown in the Gaugeable Tube Fittings and Adapter Fittings catalog (MS-01-140) are based on ANSI B31.3. Female pipe ends generally have ratings lower than male pipe in a given size because the inner and outer diameters of female threads are larger than those of male pipe ends. To have the same pressure ratings for male and female pipe threads of the same nominal size, a female threaded fitting would need a heavier wall and would thus be too bulky and heavy to be practical. To keep material and manufacturing costs down, most of the tube fitting industry has adopted wall thicknesses on female pipe threads that result in lower pressure ratings on the female ends than on the male ends.



Refer to the Gaugeable Tube Fittings and Adapter Fittings catalog (MS-01-140) for the ratings. www.swagelok.com/TFM

Note: Sealing Tapered Pipe Threads

A good-quality sealant is always required when sealing NPT or ISO tapered pipe threads. A good sealant will also act as a lubricant, reducing the galling tendency of many materials when subjected to the high loads of the interference fit between a male and female pipe thread.

Swagelok PTFE tape is an excellent thread sealant for temperatures up to 450°F (232°C.) SWAK anaerobic pipe thread sealant is also an excellent thread sealant for use to 350°F (180°C.)

Refer to the section on thread sealants in Chapter 3 to learn more about how to apply sealants.

Chapter 10

The Hidden Costs of Leakage

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Introduction

This chapter discusses why leakage is a serious consideration in the design, construction, and operation of fluid control systems. Components must be leak-tight to ensure the reliable performance of fluid systems.

What Is Leakage?

The uncontrolled flow into or out of a pipe or tube system, such as leakage to the atmosphere

Causes of Leakage

- Unreliable metal-to-metal seals
- Improperly installed tube fittings
- Poor tubing selection and preparation



Figure 10-1 Leakage.

Leak Testing Terminology and Principles

Leak rate: The rate of fluid leakage flow per unit of time under known conditions. Properly expressed in units of volume per unit of time (L/min, std cm³/s).

Leakage: Leaks can be referred to as *real* or *virtual*.



Figure 10-2 Leakage.

Real leak (also referred to as *true, mechanical, orifice, or capillary* leak): Occurs when a pressure barrier fails to contain or isolate a system fluid from the surrounding environment. Real leaks can be the result of cracks or gaps between sealing surfaces or permeation through seal materials. There are three types of real leaks:

1. **Inboard:** Flow into a fluid system from outside containment, such as dirt getting into a fluid system.
2. **Outboard:** Flow out of containment into the environment.
3. **Internal:** Flow across an internal pressure barrier within containment. This type of leak is commonly associated with valve seats.

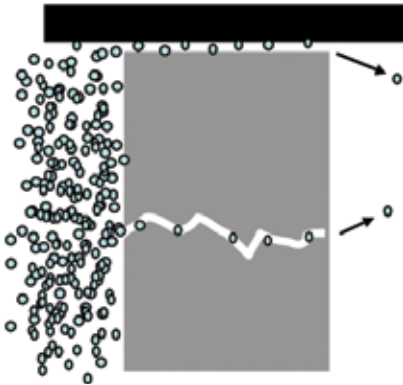


Figure 10-3 Real leak.

Virtual leak: A release of internally trapped fluid into a fluid system due to material **outgassing**, absorbed or adsorbed fluids, entrapment in cracks, or dead legs.

Outgassing: The escape of gas from a material in a vacuum.

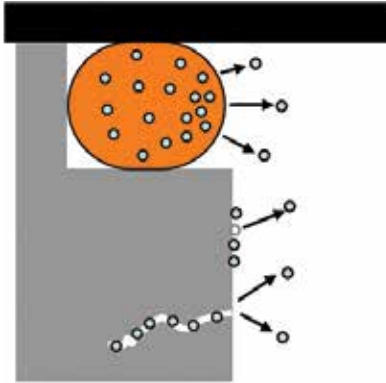


Figure 10-4 Virtual leak.

Permeation: The passage of fluid into, through, and out of a pressure barrier having no holes large enough to permit more than a small fraction of the molecules to pass through any one hole. This leakage is typically associated with PTFE hoses.

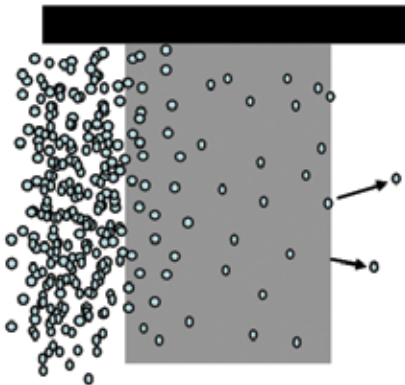


Figure 10-5 Permeation leak.

Be aware that a leak detector using a gas such as helium cannot tell the difference between the helium that gets detected from a real leak and that from a virtual leak, permeation, or outgassing.

One way of detecting system leaks is to use SNOOP liquid leak detector, as shown in the following illustrations.

NOTE: Numerous small bubbles can be observed at the back of the nut.

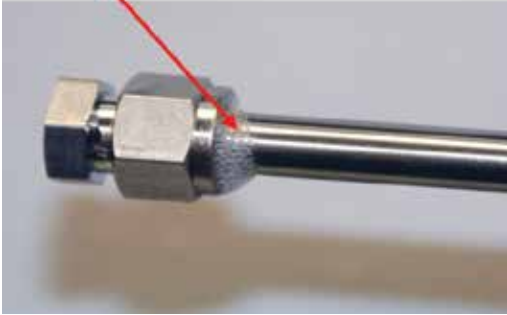


Figure 10-6 Small leak being identified by Snoop liquid leak detector.



Figure 10-7 Medium-sized leak.

Snoop liquid leak detection fluid illustrates a leak in the medium range; larger, more frequent bubbles are escaping from the back of the nut. The important thing to remember with Snoop versus detecting leaks with simple soap and water is that the Snoop will continue producing bubbles for a short period of time after being applied, whereas the soap and water may only give you one set of bubbles to observe before dissolving.



Figure 10-8 Larger leak displays large bubbles.

A large leak identified with Snoop may display large bubbles, similar to the photograph above, or Snoop may be completely blown off the nut by the escaping media. If a large leak is suspected, use caution when checking for leakage.

Leakage Formula

The leakage formula was created in an effort to determine how much leakage may exist throughout a system.

Q = Leak rate, ft³/s

ΔP = Pressure drop, ($P_1 - P_2$), psi

H = Height of gap between sealing surfaces, in.

W = Circumference of seal, in.

96 = Mathematical constant

μ = Absolute viscosity, lb·s/ft²

L = Length of leakage path, in.

$$Q \approx \frac{\Delta P \times H^3 \times W}{96 \times \mu \times L}$$

Figure 10-9 Leakage formula.

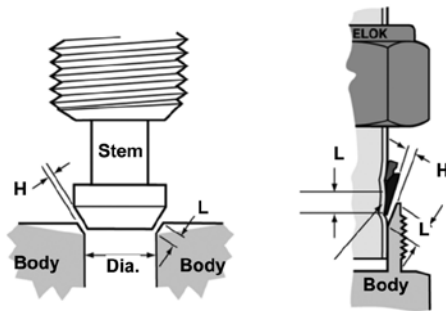


Figure 10-10 Previously assembled Swagelok tube fitting (shown disassembled).

Swagelok tube fittings and valves are designed and manufactured to create a long, smooth seal that performs properly in a variety of customer applications. The gap (H) and length (L) are the only factors in the formula Swagelok can control. Gap can be a problem if tubing surface finish is poor. Because we cannot control operating pressure, seal diameter, or fluid viscosity, we must work within the parameters of gap and length of seal to make good, reliable, repeatable seals.

The sealing material, surface finish, and load as a result of installation impact the leak rate regardless of the system conditions involved in valve and fitting installations.

Seals are designed to prevent leaks from occurring, and there are two basic types of seals: static and dynamic.

Static seals are not intended to be broken or penetrated during service. Tube fittings generally use static seals. Leaks from static seals are commonly associated with vibration, overpressurization, or degradation of the seal material due to chemical attack.

Dynamic seals must seal effectively where motion is involved, which is more common in valve operation.

Leakage costs industry billions of dollars each year. These losses are in many forms:

1. **Lost fluid:** It is estimated that millions of gallons of hydraulic oil are lost each year from oil circulating and hydraulic systems just through leakage.

2. Equipment damage: Loss of lubrication due to leakage can damage equipment.
3. Lost production: Loss of lubrication or hydraulic line leakage can shut down machines and stop production.
4. Energy conservation: Power is used to pressurize hydraulic systems and to compress air.
5. Unsafe work places: Oil drippage can cause accidents.
6. Degraded environment: Fugitive emissions (leakage) can be expensive, illegal, and dangerous and can lead to a lowering of the quality of life for workers and the surrounding population.
7. Product contamination: Food, beverage, pharmaceutical, or other plants making products for human consumption cannot have hydraulic or other contaminants in their system.

When process gases, analyzer gases, nitrogen, helium, and hydrogen are considered, the cost of leakage alone can make the difference between profit and loss. This is in addition to the fire or explosion danger and the damage to the quality of life. As well, improperly calibrated or operating instruments can result in off-specification product.

What Is Energy Management?

Energy management is the process by which energy costs and system leakage are controlled.

This can be accomplished by:

- Identifying and reducing energy loss from system leakage
- Efficiently and cost-effectively reducing the potential for loss of energy
- Improving overall fluid system component efficiency and performance

Managing energy means energy savings.

Energy management impacts you by:

- Establishing an efficient leak detection and repair program
- Documenting energy savings
- Reducing downtime
- Lowering overall system costs, which translates into increased profitability
- Decreasing maintenance costs



Figure 10-11 Detect and identify leaks.

Reducing downtime, lowering overall system costs, and decreasing maintenance costs can all be achieved by effectively documenting energy savings. The *Swagelok Energy Emission Survey* program is designed to identify the presence of leakage in gas systems at a facility. A Swagelok Authorized Sales and Service representative can assist in performing a *Swagelok Energy Emission Survey*. The following are conditions to consider prior to conducting a survey.

1. Preparation is essential. In creating an effective survey, it is necessary to:
 - a. Plan
 - b. Document
 - c. Verify
2. Documentation is a requirement. Using appropriate data collection forms will improve the accuracy in recording results.
3. Validation of survey results by a site representative is mandatory.
4. Site representatives will be made aware of visual identification of fittings from other manufacturers to more accurately authenticate the results.
5. Survey site selection is to be determined by the site representative.
6. All tube fitting and instrumentation or small process valve end connections and packing, regardless of the brand, should be surveyed.
7. Results of survey data collection will be presented, in person, to site representatives.

Request the results of energy surveys from your local Swagelok Authorized Sales and Service Center.

Appendix A

Flow/Pressure Charts and Conversions

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Determining Inside Diameter of Tubing	234
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Calculations for Gas Systems (Charts 11 through 20)	235
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Determining Inside Diameter of Tubing

The ID of tubing is set by flow requirements, permissible pressure drop, and maximum allowable velocity.

- Charts 1 through 10 are provided on the following pages.
- Charts 11 through 20 are provided for sizing tubing for gas flow.

These charts give pressure drop for 100 ft. of tubing for both water and air flow. By using the formula provided, it is also possible to obtain the pressure drop of fluids other than water and gas.

To allow for pressure drops in bends and fittings, the equivalent lengths in Table A can be used when obtaining equivalent length of tubing for pressure drop calculations. To obtain equivalent length of tubing, total all straight lengths and then add lengths for each bend, elbow, or tee from Table A.

Equivalent Feet of Straight Tube

Tubing OD (in.)	90° Elbow (ft.)	90° Bend (ft.)	180° Bend (ft.)	45° Bend (ft.)	Tee Branch (ft.)
1/4	1	1/2	1	1/2	1
3/8	1 1/2	1/2	1	1/2	1 1/2
1/2	2	1/2	1	1/2	2
5/8	2 1/2	1	2	1/2	2 1/2
3/4	3	1	2	1/2	3
1	4 1/2	1	2	1/2	4 1/2
1 1/4	5	2	4	1	5
1 1/2	6	2	4	1	6
2	9	2	4	1	9

Table A

Calculations for Liquid Flow (Charts 1 through 10)

Example 1

Water is to flow through 50 ft. of tubing at 4 gallons per minute (GPM). Water velocity is not to exceed 5 ft. per second. The maximum allowable pressure drop is 5 psig. What diameter of tubing can be used?

- Pressure drop for 100 ft. would be two times the allowable pressure drop for 50 ft., that is, 10 psi.
- By looking at Charts 1 through 9, it can be determined that only 3/4 in. or 1 in. OD tubing can be used because the pressure drop

would be over 10 psi for a 4 GPM flow in smaller tubing. From Chart 5, for 4 GPM flow rate, the pressure drop per 100 ft. of any of the 3/4 in. OD tubes would be satisfactory.

- The smallest ID on Chart 5 is 0.560 in. An ID of 0.560 in. on Chart 10 shows velocity of 5 ft. per second for 4 GPM. Therefore, any of the 3/4 in. tubing can be used, and wall thickness selection would be determined by pressure requirements.

Example 2

Suppose the maximum pressure drop of Example 1 was 1 psig. Find the proper size tubing.

- For 100 ft., maximum pressure drop would be 2 psi.
- The 3/4 in. tubing is now too small as determined by Chart 5. Looking at Chart 6, it can be seen that 1 in. OD tubing of wall thickness less than 0.100 in. can be used because it will have less than a 2 psi pressure drop.

For liquids with specific gravity near water, the equivalent water flow rate can be calculated and then used to find pressure drop. An example follows:

Example 3

Acetone at 1/10 GPM is to flow through 100 ft. of tubing with a pressure drop not to exceed 5 psi.

equivalent flow rate of water = flow rate of other liquid multiplied by $\sqrt{\text{S.G. other liquid}}$

$$\begin{aligned} \blacksquare Q_w &= Q_{\text{acetone}} \sqrt{\text{specific gravity of acetone}} \\ &= (1/10 \text{ GPM}) \sqrt{0.792} \\ &= 0.089 \text{ GPM water} \end{aligned}$$

- Chart 2 shows that 1/4 in. OD tubing of wall thickness 0.049 or less will be of sufficient ID to produce less than a 5 psi drop with a water flow of 0.089 GPM.

Calculations for Gas Systems (Charts 11 through 20)

Pressure drop is directly proportional to length, inversely proportional to absolute pressure, and directly proportional to absolute

temperature. Using this information, the pressure drop formula for use with Charts 11 through 20 is:

$$\Delta P_L = \frac{\Delta P}{100} \frac{L}{100} \left(\frac{114.7}{14.7 + P} \right) \left(\frac{460 + t}{530} \right)$$

where ΔP_L — refers to pressure drop (in psi) of air per L feet of tubing at conditions of pressure (P in psig) and temperature (t in °F)

$\frac{\Delta P}{100}$ — refers to pressure drop at 100 psig, 70°F for 100 ft. of tubing

In order to use Charts 11 through 20, it is necessary to obtain equivalent conditions at 100 psig. This is most easily explained by example problems shown here.

Example 1

What is the pressure drop for 6 CFM of 100 psig air at 70°F for 100 ft. of 3/4 in. 0.095 wall tubing?

Solution: From Chart 15, read 7.5 psi pressure drop

Example 2

Same problem as Example 1 but for 200 ft. of tubing

Solution: Pressure drop is directly proportional to length. Therefore, if 7.5 psi is the pressure drop for 100 ft., $2 \times 7.5 = 15$ psi is drop for 200 ft.

Example 3

Same problem as Example 1 but for 50 ft. of tubing

Solution: Pressure drop is directly proportional to length. Therefore, if 7.5 psi is the pressure drop for 100 ft., $1/2 \times 7.5 = 3.75$ psi is the drop for 50 ft. of tubing.

Example 4

10 CFM free air is to pass through 75 ft. of tubing at 80 psig inlet pressure and 75°F. The diameter of the proper tubing is to be found knowing the maximum allowable pressure drop is 6 psi.

Solution:

1. Find the pressure drop for 100 ft. of tubing at 70°F and 100 psig so that the charts may be used.

$$\Delta P = 6 = \frac{\Delta P}{100} \left(\frac{75}{100} \right) \left(\frac{114.7}{14.7 + 80} \right) \left(\frac{460 + 75}{530} \right)$$

$$\frac{\Delta P_L}{100} = 6.55 \text{ psi drop per 100 ft. at 100 psig at } 70^\circ\text{F}$$

2. Change flow rate at 80 psig and 75°F to the flow rate at 100 psig and 70°F.

$$Q_{\text{air}} \text{ at } 100 \text{ psig, } 70^\circ\text{F} = Q_{\text{air}} \text{ at } 80, 75 \left(\frac{14.7 + 80}{114.7} \right) \left(\frac{530}{460 + 75} \right) \\ = 8.18 \text{ CFM}$$

3. On Chart 16, note that all 1 in. tubing will give a pressure drop of less than 6.55 psi at 8.18 CFM flow at 100 psig.

Example 5

Helium is to pass through 100 ft. of tubing at 25 psig inlet pressure and 70°F. The flow rate of free helium is 8 CFM. What is the pressure drop in 3/8 in. 0.035 in. wall tubing?

Solution:

1. Find the equivalent air flow so that air flow charts may be used.
flow rate of air = flow rate of helium $\sqrt{\text{specific gravity of helium}}$

$$Q_{\text{air}} = Q_{\text{He}} \sqrt{(\text{S.G.}) \text{ He}}$$

$$Q_{\text{air}} = 8 \text{ CFM} \sqrt{0.138} = 3 \text{ CFM}$$

2. Change flow rate at 25 psig to the flow rate of air at 100 psig.

$$Q_{\text{air}} \text{ at } 100 = Q_{\text{air}} \text{ at } 25 \left(\frac{14.7 + 25}{114.7} \right) = 1.0 \text{ CFM}$$

3. See Chart 13 and find that the pressure drop of 100 psig air at 1.0 CFM is 6 psi for 100 ft. of tubing.
4. Solve for pressure drop in the problem by using the pressure drop formula.

$$\Delta P = \frac{P}{100} \left(\frac{L}{100} \right) \left(\frac{114.7}{14.7 + P} \right) \left(\frac{460 + t}{530} \right) \\ = 6 \left(\frac{100}{100} \right) \left(\frac{114.7}{14.7 + 25} \right) \left(\frac{530}{530} \right) \\ = 6 (2.9) = 17.3 \text{ psi pressure drop}$$

Example 6

8 CFM of 15 psig, 70°F air is to pass through 10 ft. of 1/2 in. OD, 0.049 wall tubing. What is the pressure drop?

Solution:

1. Change flow rate at 15 psig to flow rate at 100 psig.

$$Q_{\text{air}} \text{ at } 100 = Q_{\text{air}} \text{ at } 15 \left(\frac{14.7 + 15}{114.7} \right) = 8 \left(\frac{29.7}{114.7} \right) = 2.07$$

- From Chart 14, pressure drop at 100 psig is found to be 6 psi for 100 ft. of tubing.
- Change this pressure drop to the condition of the problem.

$$\begin{aligned}\Delta P &= \frac{\Delta P}{100} \left(\frac{L}{100} \right) \left(\frac{114.7}{14.7 + P} \right) \left(\frac{460 + t}{530} \right) \\ &= 6 \left(\frac{10}{100} \right) \left(\frac{114.7}{14.7 + 15} \right) \left(\frac{530}{530} \right) \\ &= 6 \times 1/10 \times 3.86 = 2.3 \text{ psi drop}\end{aligned}$$

Chart 1: 1/8 in. OD Tubing

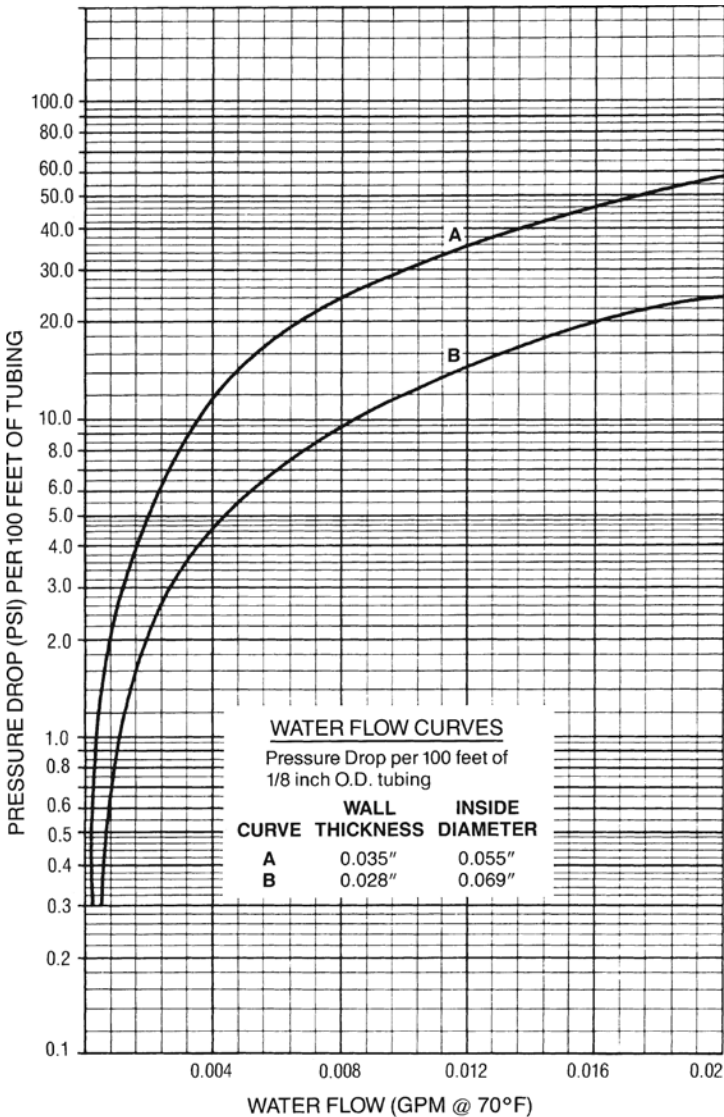


Chart 2: 1/4 in. OD Tubing

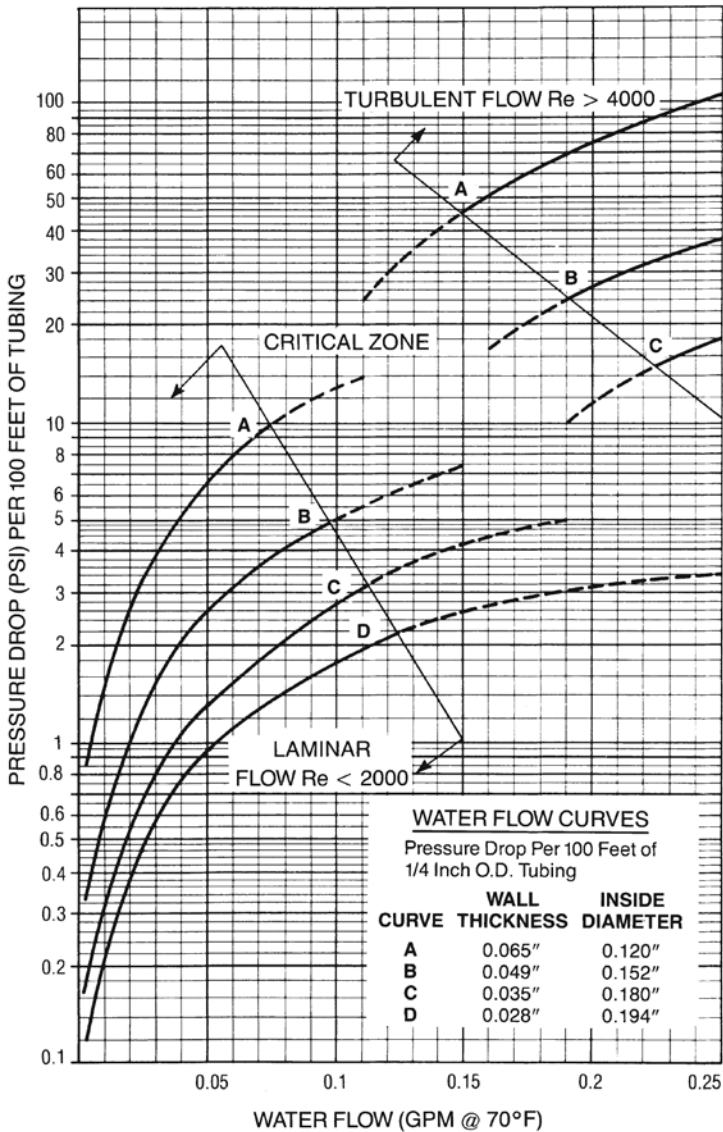


Chart 3: 3/8 in. OD Tubing

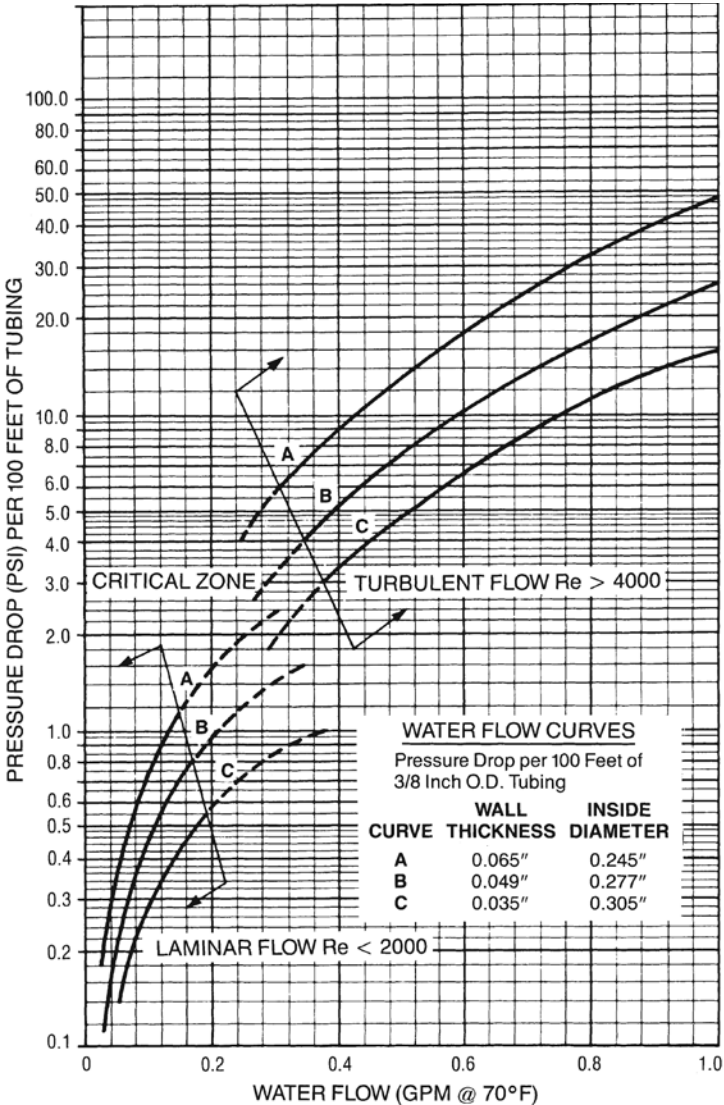


Chart 4: 1/2 in. OD Tubing

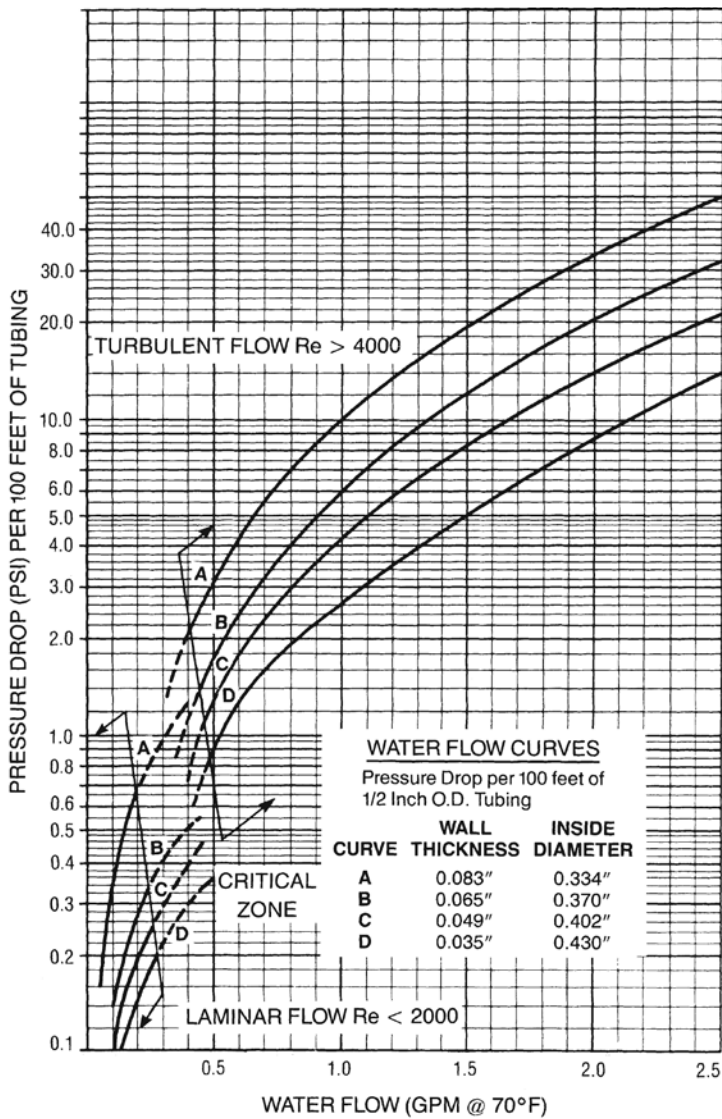


Chart 5: 3/4 in. OD Tubing

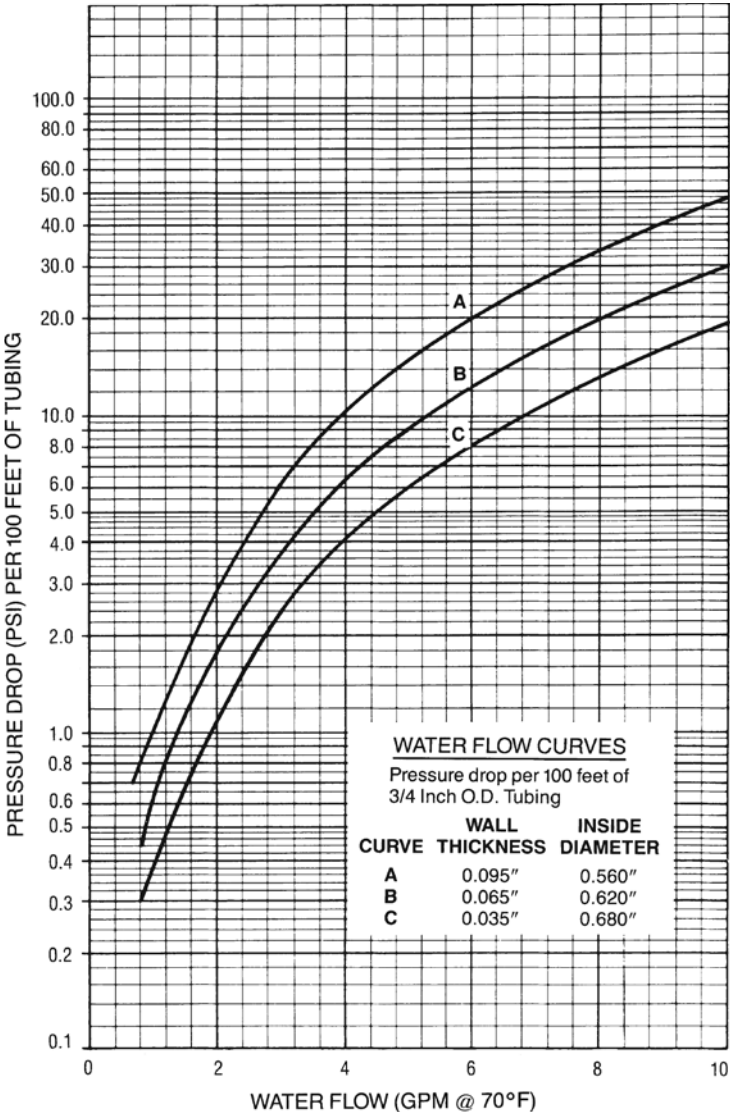


Chart 6: 1 in. OD Tubing

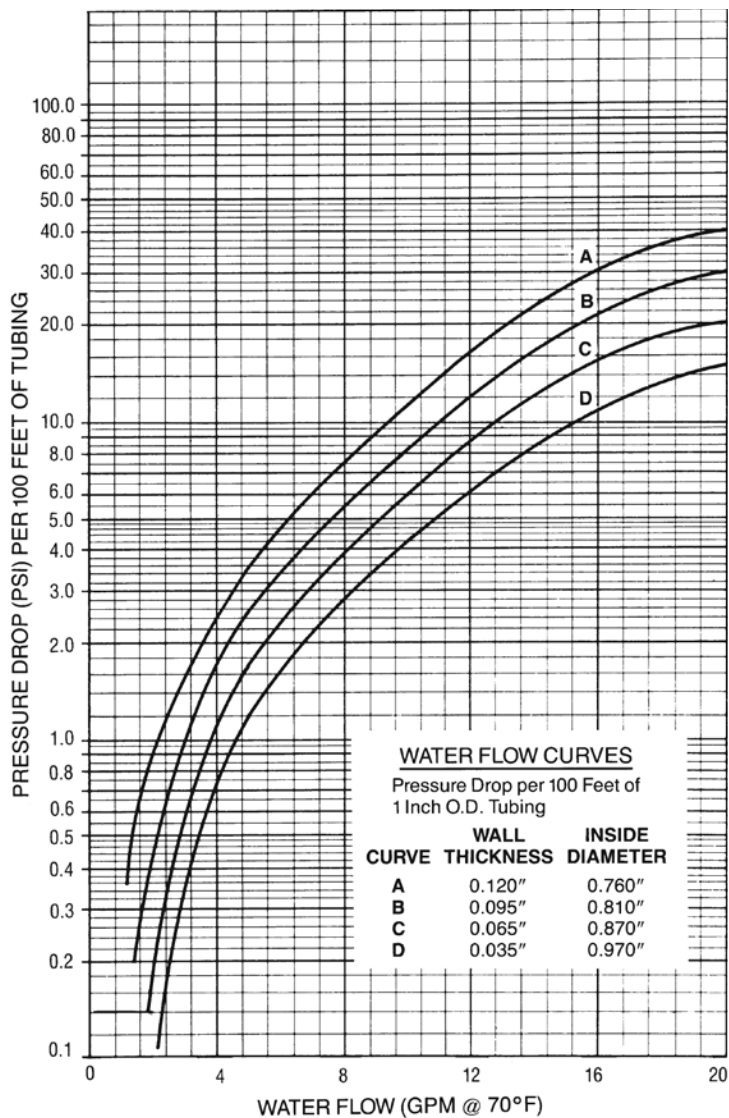


Chart 7: 1 1/4 in. OD Tubing

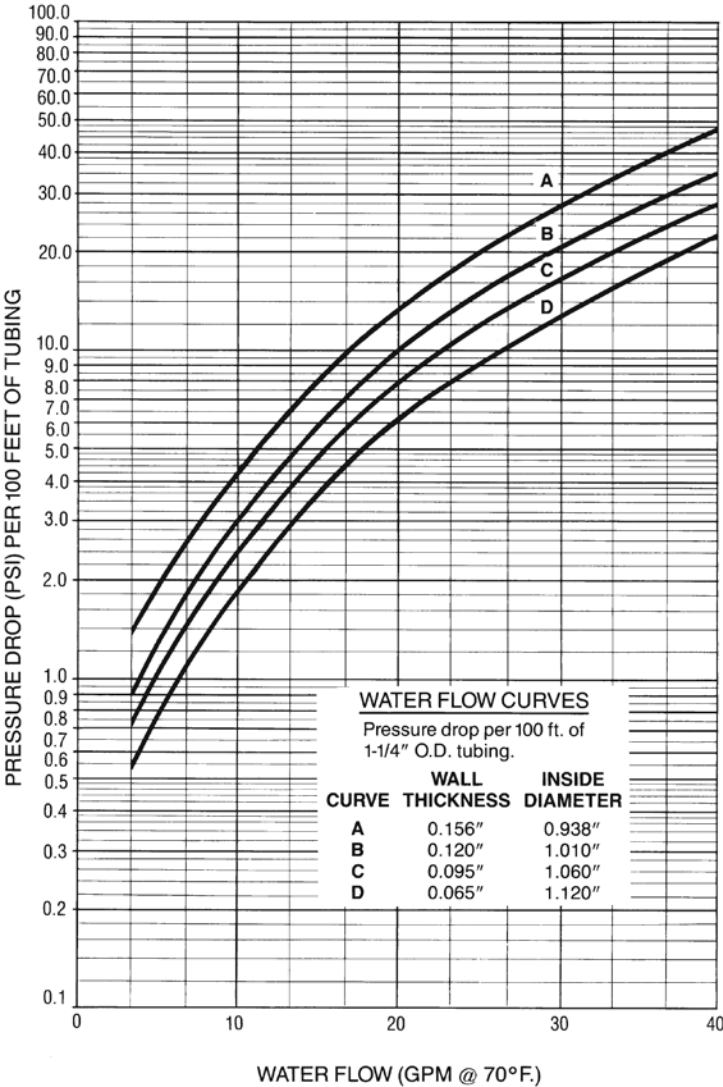


Chart 8: 1 1/2 in. OD Tubing

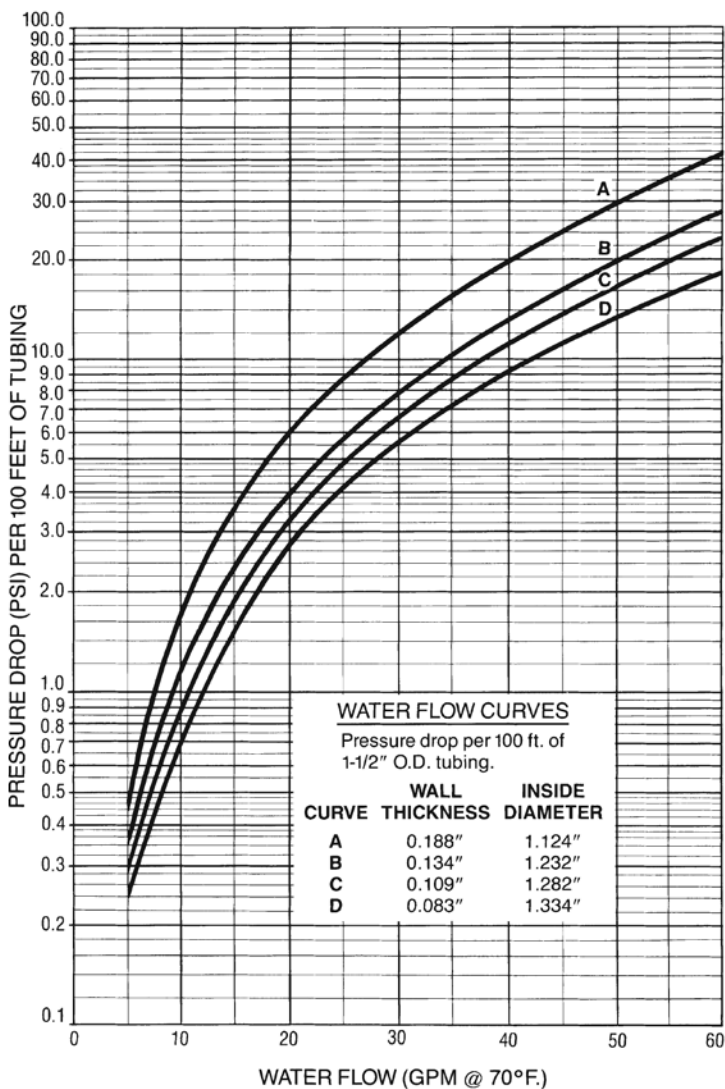


Chart 9: 2 in. OD Tubing

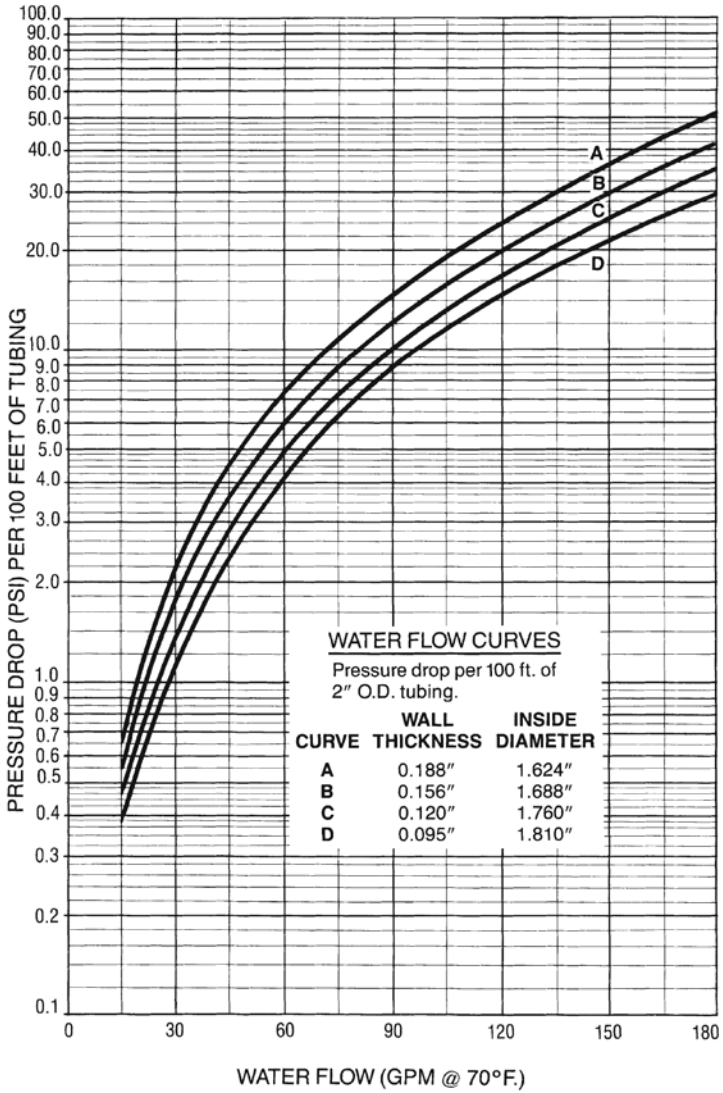


Chart 10:
Mean Velocity versus Tube Inside Diameter for Various Water Flows

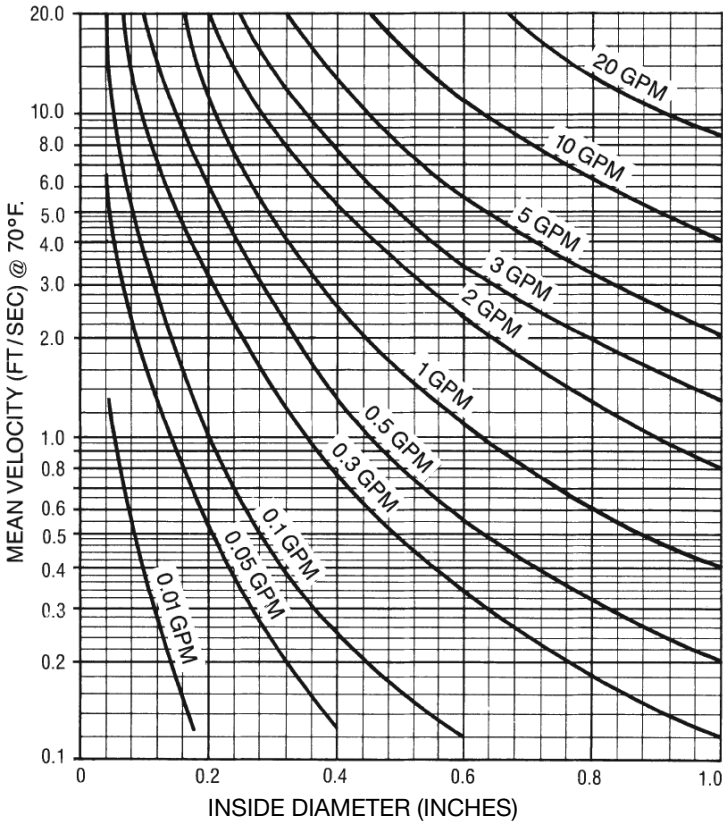


Chart 11:
1/8 in. OD Tubing

STANDARD AIR FLOW (CFM AT 14.7 PSIA @ 70°F)

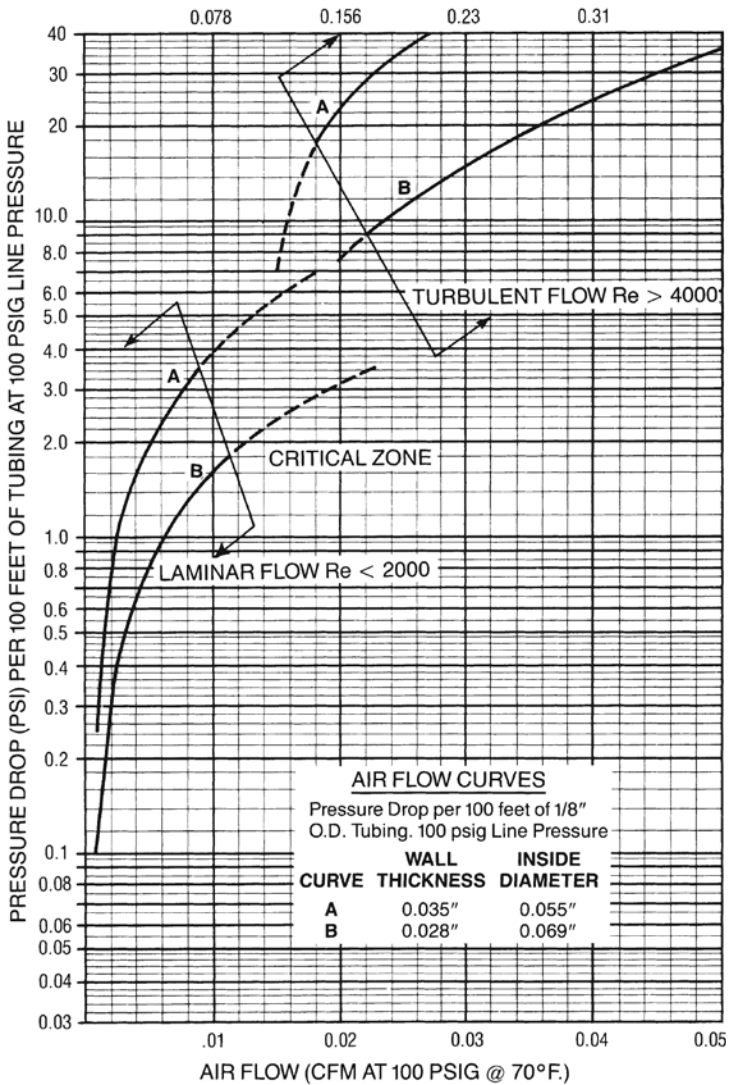


Chart 12: 1/4 in. OD Tubing

STANDARD AIR FLOW (CFM AT 14.7 PSIA @ 70°F)

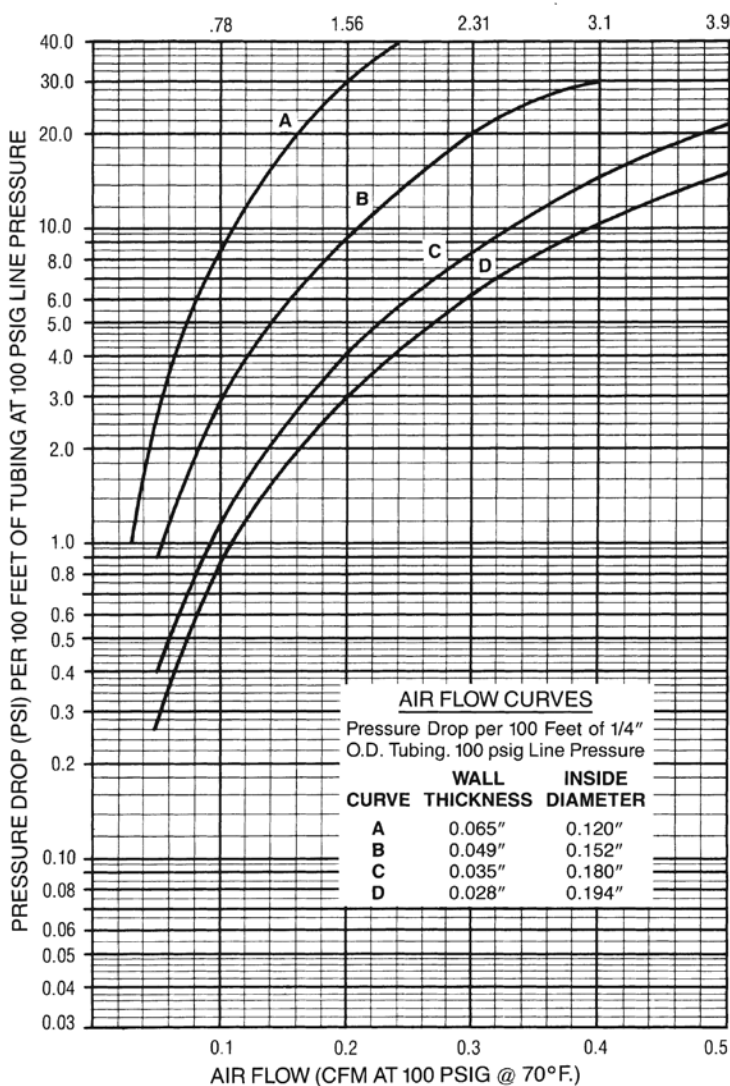


Chart 13: 3/8 in. OD Tubing

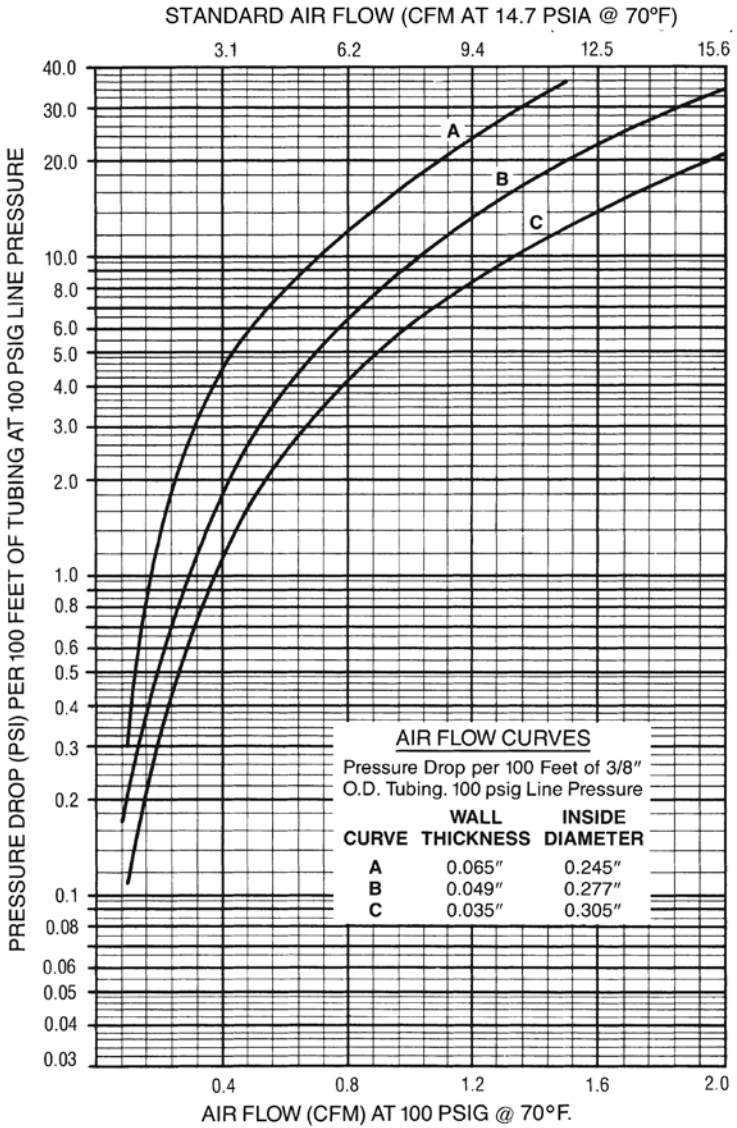


Chart 14: 1/2 in. OD Tubing

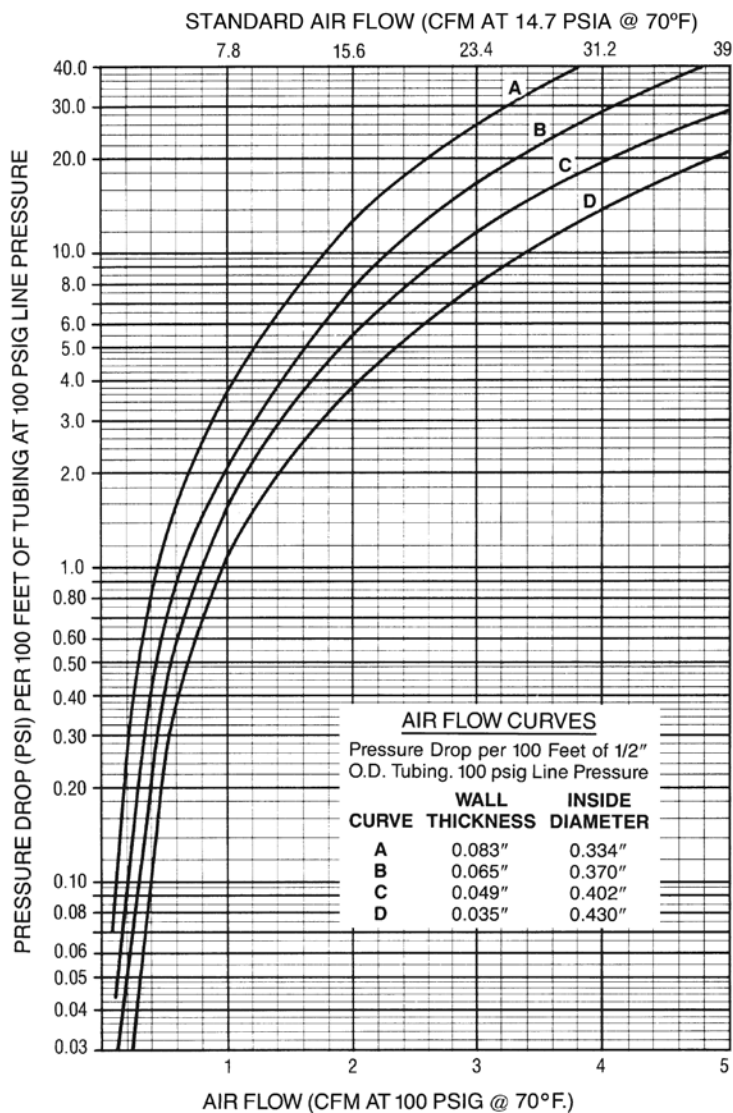


Chart 15: 3/4 in. OD Tubing

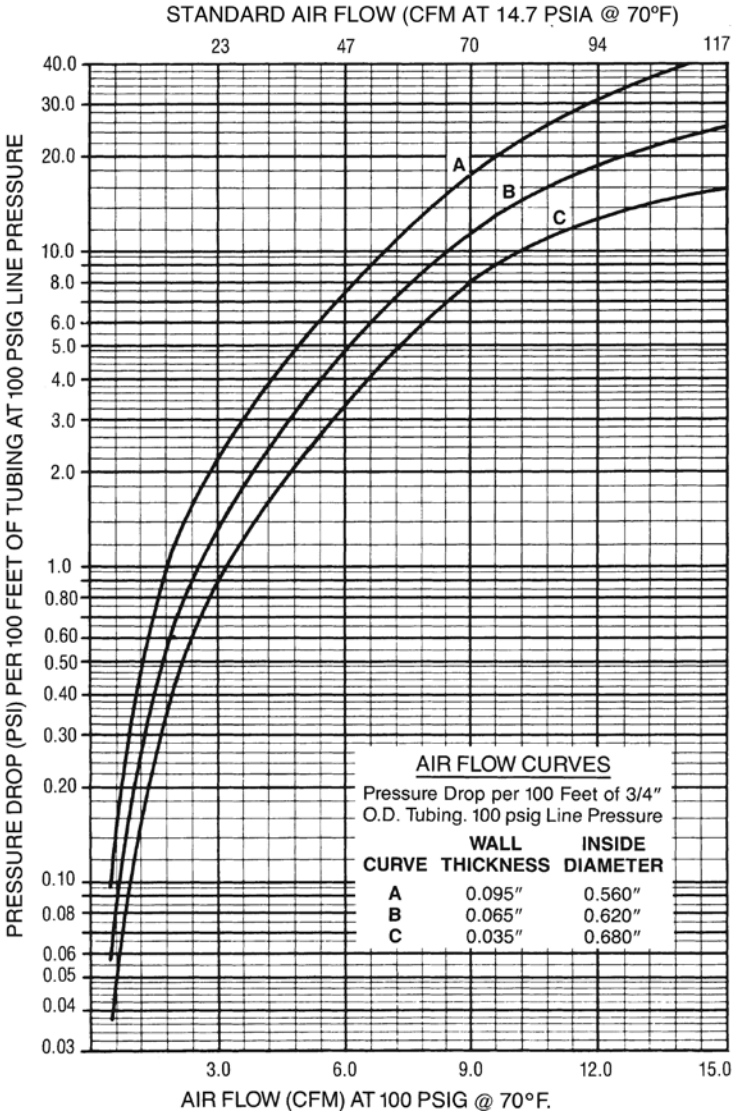


Chart 16: 1 in. OD Tubing

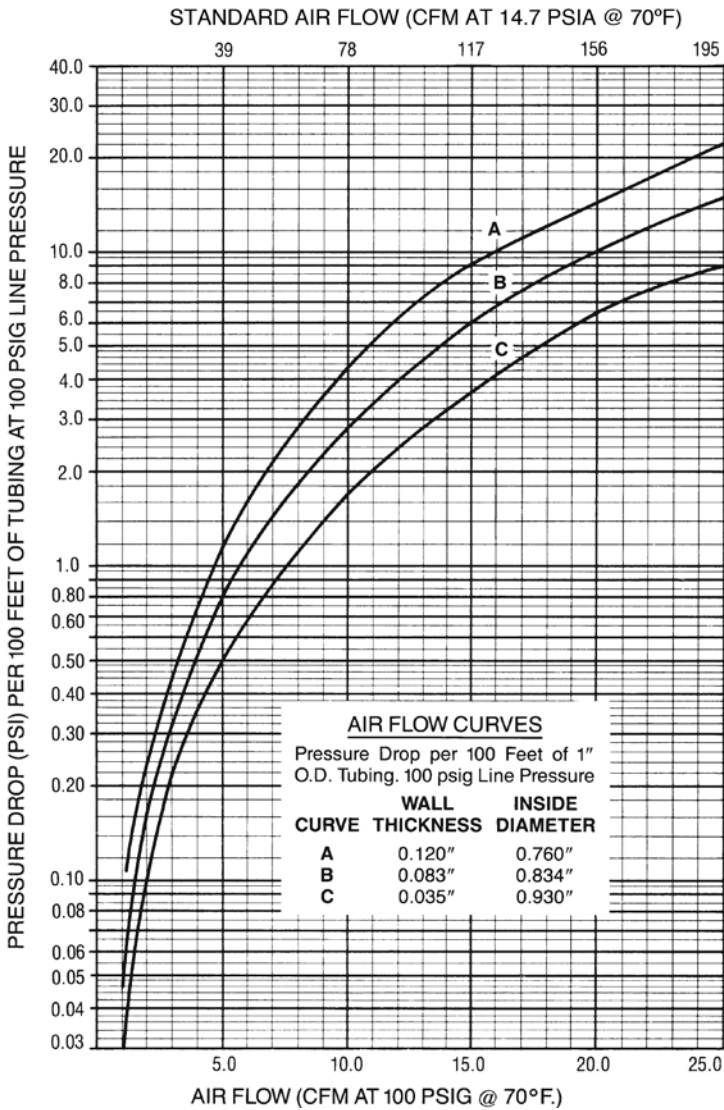


Chart 17: 1 1/4 in. OD Tubing

STANDARD AIR FLOW (CFM AT 14.7 PSIA @ 70°F)

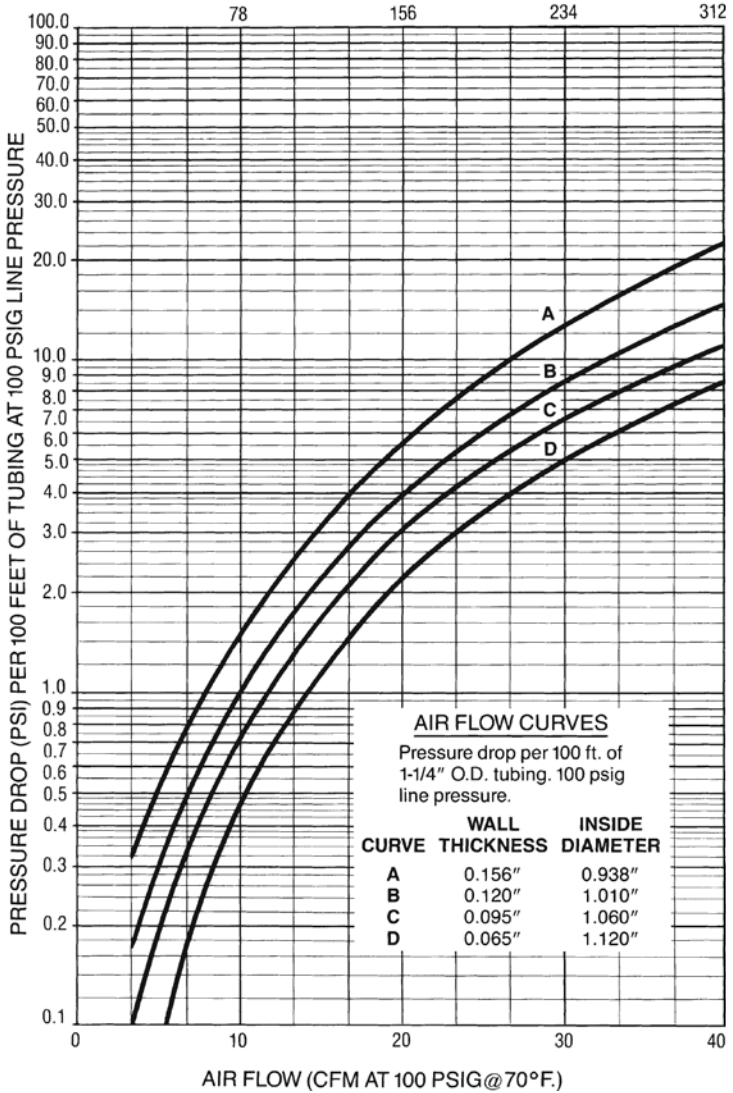


Chart 18: 1 1/2 in. OD Tubing

STANDARD AIR FLOW (CFM AT 14.7 PSIA @ 70°F)

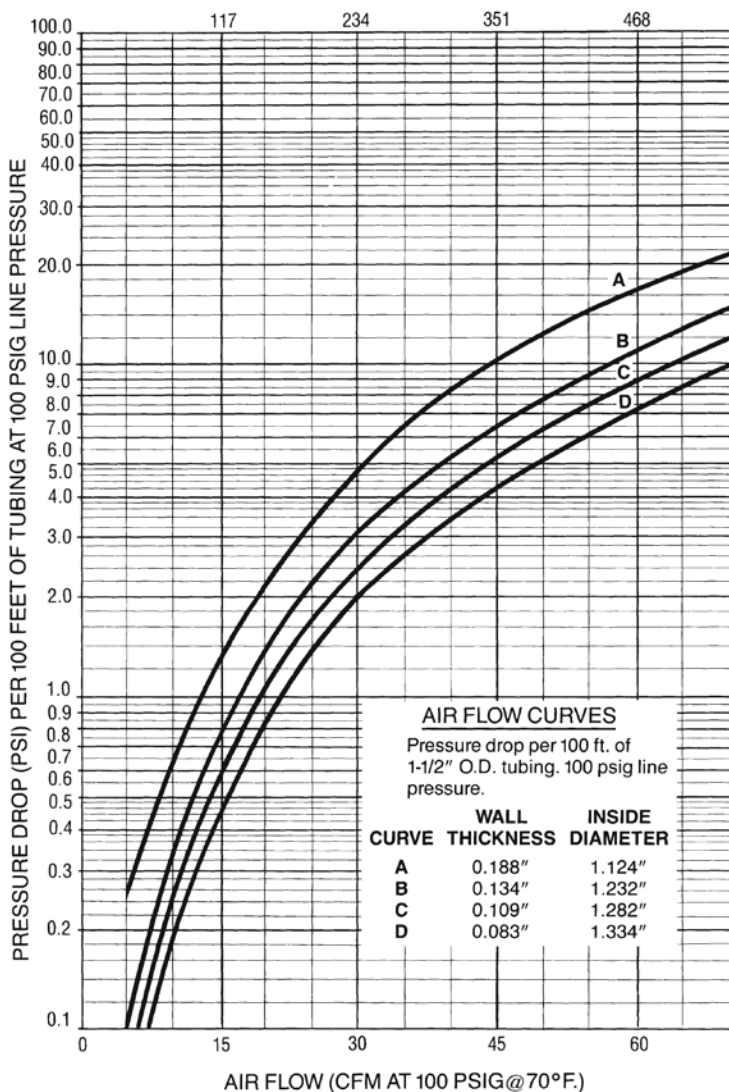


Chart 19: 2 in. OD Tubing

STANDARD AIR FLOW (CFM AT 14.7 PSIA @ 70°F)

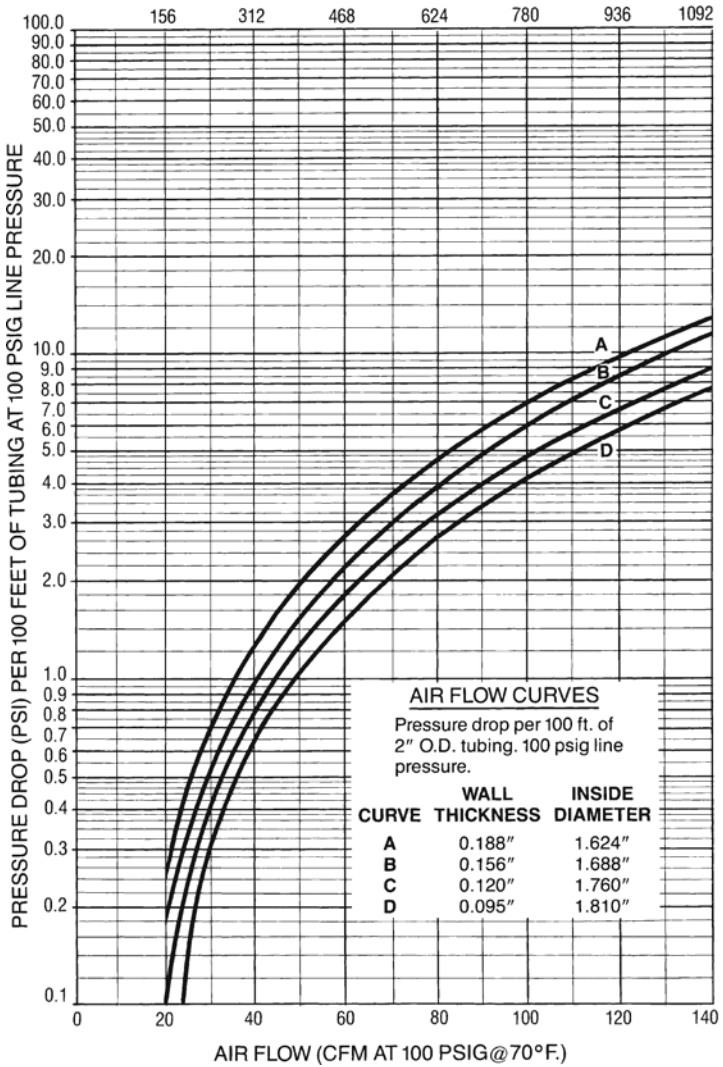
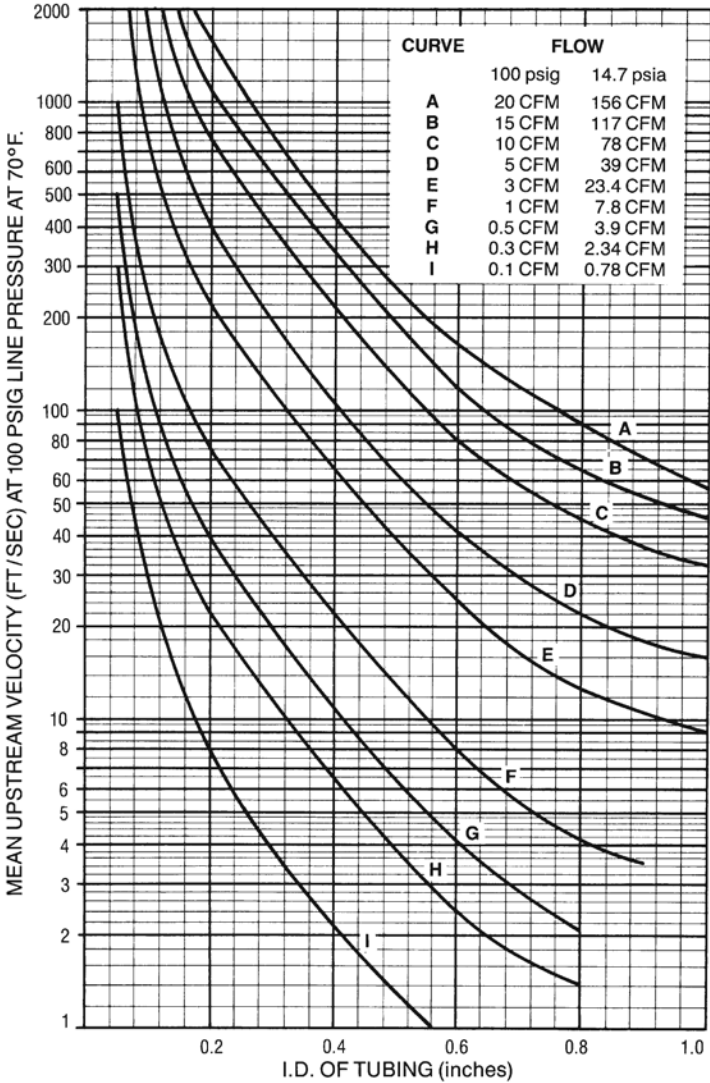


Chart 20:

Mean Air Velocity versus Tubing ID for 100 PSIG Air and 14.7 PSIA Air



HEADS AND EQUIVALENT PRESSURE CONVERSIONS

To Convert	Into	Multiply By
atmospheres	pounds per sq in.	14.70
atmospheres	pounds per sq ft.	2116.22
atmospheres	in. of water at 60°F	407.17
atmospheres	ft. of water at 60°F	33.931
atmospheres	in. of mercury at 32°F	29.921
atmospheres	mm of mercury at 32°F	760
ft. of water at 60°F	pounds per sq in.	0.4335
ft. of water at 60°F	pounds per sq ft.	62.43
ft. of water at 60°F	in. of water at 60°F	12
ft. of water at 60°F	in. of mercury at 32°F	0.8826
ft. of water at 60°F	mm of mercury at 32°F	22.418
ft. of water at 60°F	atmospheres	0.029481
in. of water at 60°F	pounds per sq in.	0.03613
in. of water at 60°F	pounds per sq ft.	5.204
in. of water at 60°F	ft. of water at 60°F	0.08333
in. of water at 60°F	in. of mercury at 32°F	0.073483
in. of water at 60°F	mm of mercury at 32°F	1.8665
in. of water at 60°F	atmospheres	2.458×10^{-3}
in. of mercury at 32°F	pounds per sq in.	0.49116
in. of mercury at 32°F	pounds per sq ft.	70.7266
in. of mercury at 32°F	in. of water at 60°F	13.608
in. of mercury at 32°F	ft. of water at 60°F	1.1340
in. of mercury at 32°F	mm of mercury at 32°F	25.40005
in. of mercury at 32°F	atmospheres	0.033421
mm of mercury at 32°F	pounds per sq in.	0.019337
mm of mercury at 32°F	pounds per sq ft.	2.78450
mm of mercury at 32°F	in. of water at 60°F	0.53576
mm of mercury at 32°F	ft. of water at 60°F	0.04461
mm of mercury at 32°F	in. of mercury at 32°F	0.03937
mm of mercury at 32°F	atmospheres	1.3158×10^{-3}
pounds per sq ft.	pounds per sq in.	6.9445×10^{-3}
pounds per sq ft.	in. of water at 60°F	0.19224
pounds per sq ft.	ft. of water at 60°F	0.01603
pounds per sq ft.	in. of mercury at 32°F	0.01414
pounds per sq ft.	mm of mercury at 32°F	0.35916
pounds per sq ft.	atmospheres	4.725×10^{-4}
pounds per sq in.	pounds per sq ft.	144.0
pounds per sq in.	in. of water at 60°F	27.684
pounds per sq in.	ft. of water at 60°F	2.307
pounds per sq in.	in. of mercury at 32°F	2.03601
pounds per sq in.	mm of mercury at 32°F	51.7148
pounds per sq in.	atmospheres	0.06804

PRESSURE CONVERSIONS

To From	mmHg	in. Hg	in. H ₂ O	ft. H ₂ O	atm	lb/in. ²	kg/cm ²	kPa	bar
mmHg	1	0.03937	0.5353	0.04461	0.00132	0.01934	0.00136	0.1333	0.0013
in. Hg	25.40	1	13.60	1.133	0.03342	0.4912	0.03453	30.387	0.0339
in. H ₂ O	1.868	0.07355	1	0.08333	0.00246	0.03612	0.00254	0.2490	0.0025
ft. H ₂ O	22.42	0.8826	12	1	0.02950	0.4334	0.03048	2.988	0.0299
atm	760	29.92	406.8	33.90	1	14.70	1.033	101.3	1.013
lb/in. ²	51.71	2.036	27.69	2.307	0.06805	1	0.07031	6.894	0.0689
kg/ cm ²	735.6	28.96	393.7	32.81	0.9678	14.22	1	98.05	0.981
kPa	7.500	0.2953	4.016	0.3347	0.00987	0.1451	0.0102	1	0.01
bar	750	29.53	401.6	33.47	0.987	14.51	1.02	100	1

FLOW RATE CONVERSIONS

To From	L/s	gal/min	ft. ³ /s	ft. ³ /min	bbl/hr	bbl/day
L/s	1	15.85	0.03532	2.119	22.66	543.8
gal/ min	0.06309	1	0.00223	0.1337	1.429	34.30
ft. ³ /s	28.32	448.8	1	60	641.1	1.54×10^4
ft. ³ /min	0.4719	7.481	0.01667	1	10.69	256.5
bbl/hr	0.04415	0.6997	0.00156	0.09359	1	24
bbl/ day	0.00184	0.02917	6.50×10^5	0.00390	0.04167	1

Appendix B

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Birmingham Wire Gauge Table

BWG	Wall Thickness Decimal Equivalent (in.)	Wall Thickness Decimal Equivalent (mm)
30	0.012	0.30
29	0.013	0.33
28	0.014	0.36
27	0.016	0.41
26	0.018	0.46
25	0.020	0.51
24	0.022	0.56
23	0.025	0.64
22	0.028	0.71
21	0.032	0.81
20	0.035	0.89
19	0.042	1.07
18	0.049	1.24
17	0.058	1.47
16	0.065	1.65
15	0.072	1.83
14	0.083	2.11
13	0.095	2.41
12	0.109	2.77
11	0.120	3.05
10	0.134	3.40
9	0.148	3.76
8	0.165	4.19
7	0.180	4.57
6	0.203	5.16
5	0.220	5.59
4	0.238	6.05
3	0.259	6.58
2	0.284	7.21
1	0.300	7.62

O-Ring Dimensional Table

Uniform Size Number	Actual Dimensions		
	ID (in.)	Cross-Section (in.)	OD (in.)
006	0.114	0.070	0.254
007	0.145	0.070	0.285
008	0.176	0.070	0.316
009	0.208	0.070	0.348
010	0.239	0.070	0.379
011	0.301	0.070	0.441
012	0.364	0.070	0.504
013	0.426	0.070	0.566
014	0.489	0.070	0.629
111	0.424	0.103	0.630
112	0.487	0.103	0.693
113	0.549	0.103	0.755
114	0.612	0.103	0.818
115	0.674	0.103	0.880
116	0.737	0.103	0.943
117	0.799	0.103	1.005
118	0.862	0.103	1.068
119	0.924	0.103	1.130
120	0.987	0.103	1.193
121	1.049	0.103	1.255
122	1.112	0.103	1.318
123	1.174	0.103	1.380
125	1.299	0.103	1.505
126	1.362	0.103	1.568
128	1.487	0.103	1.693
130	1.612	0.103	1.818
132	1.737	0.103	1.943
133	1.799	0.103	2.005
134	1.862	0.103	2.068
136	1.987	0.103	2.193
212	0.859	0.139	1.137
215	1.046	0.139	1.324
219	1.296	0.139	1.574
223	1.609	0.139	1.887
902	0.239	0.064	0.367
903	0.301	0.064	0.429
904	0.351	0.072	0.495
905	0.414	0.072	0.558
906	0.468	0.078	0.624
908	0.644	0.087	0.818
910	0.755	0.097	0.949
912	0.924	0.116	1.156
916	1.171	0.116	1.403
920	1.475	0.118	1.711
924	1.720	0.118	1.956
932	2.337	0.118	2.573

Properties of Saturated Steam

Abs press. (psia)	Temp. (°F)	Abs press. (psia)	Temp. (°F)	Abs press. (psia)	Temp. (°F)	Abs press. (psia)	Temp. (°F)	Abs press. (psia)	Temp. (°F)
1.0	101.74	38	264.16	84	315.42	160	363.53	520	471.07
1.2	107.92	39	265.72	85	316.25	162	364.53	540	475.01
1.4	113.26	40	267.25	86	317.07	164	365.51	560	478.85
1.6	117.99	41	268.74	87	317.88	166	366.48	580	482.58
1.8	122.23	42	270.21	88	318.68	168	367.45	600	486.21
2.0	126.08	43	271.64	89	319.48	170	368.41	620	489.75
2.2	129.62	44	273.05	90	320.27	172	369.35	640	493.21
2.4	132.89	45	274.44	91	321.06	174	370.29	660	496.58
2.6	135.94	46	275.80	92	321.83	176	371.22	680	499.88
2.8	138.79	47	277.13	93	322.60	178	372.14	700	503.10
3.0	141.48	48	278.45	94	323.36	180	373.06	720	506.25
4.0	152.97	49	279.74	95	324.12	182	373.96	740	509.34
5.0	162.24	50	281.01	96	324.87	184	374.86	760	512.36
6.0	170.06	51	282.26	97	325.61	186	375.75	780	515.33
7.0	176.85	52	283.49	98	326.25	188	376.64	800	518.23
8.0	182.86	53	284.70	99	327.08	190	377.51	820	521.08
9.0	188.28	54	285.90	100	327.81	192	378.38	840	523.88
10	193.21	55	287.07	102	329.25	194	379.24	860	526.63
11	197.75	56	288.23	104	330.66	196	380.10	880	529.33
12	201.96	57	289.37	106	332.05	198	380.95	900	531.98
13	205.88	58	290.50	108	333.42	200	381.79	920	534.59

14	209.56	59	291.61	110	334.77	205	383.86	940	537.16
14.70	212.00	60	292.71	112	336.11	210	385.90	960	539.68
15	213.03	61	293.79	114	337.42	215	387.89	980	542.17
16	216.32	62	294.85	116	338.72	220	389.86	1,000	544.61
17	219.44	63	295.90	118	339.99	225	391.79	1,050	550.57
18	222.41	64	296.94	120	341.25	230	393.68	1,100	556.31
19	225.24	65	297.97	122	342.50	235	395.54	1,150	561.86
20	227.96	66	298.99	124	343.72	240	397.37	1,200	567.22
21	230.57	67	299.99	126	344.94	245	399.18	1,250	572.42
22	233.07	68	300.98	128	346.13	250	400.95	1,300	577.46
23	235.49	69	301.96	130	347.32	260	404.42	1,350	582.35
24	237.82	70	302.92	132	348.48	270	407.78	1,400	587.10
25	240.07	71	303.88	134	349.64	280	411.05	1,450	591.71
26	242.25	72	304.83	136	350.78	290	414.23	1,500	596.23
27	244.36	73	305.76	138	351.91	300	417.33	1,600	604.90
28	246.41	74	306.68	140	353.02	320	423.29	1,700	613.15
29	248.40	75	307.60	142	354.12	340	428.97	1,800	621.03
30	250.33	76	308.50	144	355.21	360	434.40	1,900	628.58
31	252.22	77	309.40	146	356.29	380	439.60	2,000	635.82
32	254.05	78	310.29	148	357.36	400	444.59	2,200	649.46
33	255.84	79	311.16	150	358.42	420	449.39	2,400	662.12
34	257.08	80	312.03	152	359.46	440	454.02	2,600	673.94
35	259.29	81	312.89	154	360.49	460	458.50	2,800	684.99
36	260.95	82	313.74	156	361.52	480	462.82	3,000	695.36
37	262.57	83	314.59	158	362.03	500	467.01	3,200	705.11

Note: To convert psia into psig, subtract 14.7 (approx.)

Specific Gravity of Water versus Temperature

Water Temperature (°F)	Specific Gravity
32	1.0013
40	1.0013
50	1.0006
60	1.0000
70	0.9989
80	0.9976
90	0.9963
100	0.9945
110	0.9920
120	0.9902
130	0.9872
140	0.9848
150	0.9817
160	0.9787
170	0.9751
180	0.9716
190	0.9681
200	0.9645
210	0.9605
212	0.9594
220	0.9565
240	0.9480
260	0.9386
280	0.9294
300	0.9193
350	0.8917
400	0.8606
450	0.8269
500	0.7863
550	0.7358
600	0.6797

Specific Gravity of Liquids

Liquid	Specific Gravity Relative to Water at 60°F
Acetone	0.792
Alcohol, Ethyl (100 %)	0.789
Alcohol, Methyl (100 %)	0.796
Acid, Muriatic (40 %)	1.20
Acid, Nitric (91 %)	1.50
Acid, Sulfuric (87 %)	1.80
Bunkers C Fuel Max.	1.014
Distillate	0.850
Fuel 3 Max.	0.898
Fuel 5 Min.	0.966
Fuel 5 Max.	0.993
Fuel 6 Min.	0.993
Gasoline	0.751
Gasoline, Natural	0.680
Hydrochloric Acid	1.256
Kerosene	0.815
M. C. Residuuum	0.935
Mercury	13.570
Olive Oil	0.919
Pentane	0.624
SAE 10 Lube*	0.876
SAE 30 Lube*	0.898
SAE 70 Lube*	0.916
Salt Creek Crude	0.843
Seawater	1.025
32.6° API Crude	0.862
35.6° API Crude	0.847
40° API Crude	0.825
48° API Crude	0.788
Water	1.000

*100 viscosity index.

Specific Gravity of Gases Relative to Air @ 68°F (20°C) at 1 atm

Name of Gas	Chemical Formula	Specific Gravity Relative to Air
Acetylene	C_2H_2	0.90
Air	—	1.000
Ammonia	NH_3	0.59
Anthracite Producer Gas	—	0.85
Argon	Ar	1.377
Benzene	C_6H_6	2.696
Bituminous Producer Gas	—	0.86
Blast Furnace Gas	—	1.000
Blue Water Gas	—	0.53
Butane	C_4H_{10}	2.0061
Butylene	C_4H_8	1.94
Carbon Dioxide	CO_2	1.5189
Carbon Monoxide	CO	0.9672
Carbureted Water Gas	—	0.63
Chlorine	Cl_2	2.486
Coke Oven Gas	—	0.44
Ethane	C_2H_6	1.0378
Ethyl Chloride	C_2H_5Cl	2.23
Ethylene	C_2H_4	0.968
Freon (F-12)	CCl_2F_2	4.520
Helium	He	0.138
Hydrogen	H_2	0.06959
Hydrogen Chloride	HCl	1.261
Hydrogen Sulfide	H_2S	1.176
Methane	CH_4	0.5537
Methyl Chloride	CH_3Cl	1.738
Natural Gas*	—	0.667
Neon	Ne	0.696
Nitrogen	N_2	0.9718
Nitric Oxide	NO	1.037
Nitrous Oxide	N_2O	1.530
Oxygen	O_2	1.1044
Pentane	C_5H_{12}	2.4872
Propane	C_3H_8	1.5219
Propylene	C_3H_6	1.4504
Sulfur Dioxide	SO_2	2.264
Toluene	C_7H_8	3.1082
Xylene	C_8H_{10}	3.6618

*Representative value.

Table of Elements

Name	Symbol	Atomic number	Atomic weight	Name	Symbol	Atomic number	Atomic weight
Actinium	Ac	89	227	Copernicium	Cn	112	285
Aluminum	Al	13	26.982	Copper	Cu	29	63.54
Americium	Am	95	243	Curium	Cm	96	247
Antimony	Sb	51	121.76	Darmstadtium	Ds	110	281
Argon	Ar	18	39.948	Dubnium	Db	105	262
Arsenic	As	33	74.922	Dysprosium	Dy	66	162.50
Astatine	At	85	210	Einsteinium	Es	99	254
Barium	Ba	56	137.33	Erbium	Er	68	167.26
Berkelium	Bk	97	247	Europium	Eu	63	151.96
Beryllium	Be	4	9.0122	Fermium	Fm	100	253
Bismuth	Bi	83	208.98	Flerovium	Fl	114	289
Boron	B	5	10.811	Fluorine	F	9	18.9984
Bromine	Br	35	79.907	Francium	Fr	87	223
Cadmium	Cd	48	112.41	Gadolinium	Gd	64	157.25
Calcium	Ca	20	40.078	Gallium	Ga	31	69.723
Californium	Cf	98	249	Germanium	Ge	32	72.630
Carbon	C	6	12.012	Gold	Au	79	196.97
Cerium	Ce	58	140.12	Hafnium	Hf	72	178.49
Cesium	Cs	55	132.91	Helium	He	2	4.0026
Chlorine	Cl	17	35.453	Holmium	Ho	67	164.93
Chromium	Cr	24	51.996	Hydrogen	H	1	1.00797
Cobalt	Co	27	58.933	Indium	In	49	114.82
Iodine	I	53	126.90	Rhenium	Re	75	186.2

continued

Table of Elements (Continued)

Name	Symbol	Atomic number	Atomic weight	Name	Symbol	Atomic number	Atomic weight
Iridium	Ir	77	192.22	Rhodium	Rh	45	102.905
Iron	Fe	26	55.845	Roentgenium	Rg	111	272
Krypton	Kr	36	83.798	Rubidium	Rb	37	85.47
Lanthanum	La	57	138.91	Ruthenium	Ru	44	101.07
Lawrencium	Lr	103	262	Rutherfordium	Rf	104	261
Lead	Pb	82	207.2	Samarium	Sm	62	150.36
Lithium	Li	3	6.939	Scandium	Sc	21	44.956
Lutetium	Lu	71	174.97	Seaborgium	Sg	106	266
Magnesium	Mg	12	24.307	Selenium	Se	34	78.971
Manganese	Mn	25	54.938	Silicon	Si	14	28.086
Meitnerium	Mt	109	268	Silver	Ag	47	107.87
Mendelevium	Md	101	256	Sodium	Na	11	22.990
Mercury	Hg	80	200.59	Strontium	Sr	38	87.62
Molybdenum	Mo	42	95.95	Sulfur	S	16	32.064
Neodymium	Nd	60	144.24	Tantalum	Ta	73	180.95
Neon	Ne	10	20.180	Technetium	Tc	43	99
Neptunium	Np	93	237	Tellurium	Te	52	127.60
Nickel	Ni	28	58.693	Terbium	Tb	65	158.93

Niobium	Nb	41	92.906	Thallium	Tl	81	204.38
Nitrogen	N	7	14.0067	Thorium	Th	90	232.04
Nobelium	No	102	254	Thulium	Tm	69	168.93
Osmium	Os	76	190.23	Tin	Sn	50	118.71
Oxygen	O	8	15.999	Titanium	Ti	22	47.867
Palladium	Pd	46	106.42	Tungsten	W	74	183.85
Phosphorous	P	15	30.974	Ununoctium	Uuo	118	294
Platinum	Pt	78	195.08	Ununpentium	Uup	115	288
Plutonium	Pu	94	242	Ununseptium	Uus	117	294
Polonium	Po	84	210	Ununtrium	Uut	113	286
Potassium	K	19	39.098	Uranium	U	92	238.03
Praseodymium	Pr	59	140.91	Vanadium	V	23	50.942
Promethium	Pm	61	147	Xenon	Xe	54	131.29
Protactinium	Pa	91	231.04	Ytterbium	Yb	70	173.05
Radium	Ra	88	226	Yttrium	Y	38	88.906
Radon	Rn	86	222	Zinc	Zn	30	65.38
				Zirconium	Zr	40	91.224

Volume Conversions

To Convert	Into	Multiply By
Cubic feet	Cubic centimeters	2.83×10^4
Cubic feet	Cubic meters	0.02832
Cubic feet	Cubic yards	0.03704
Cubic feet	Cubic in.	1728
Cubic feet	Gallons (Br.)	6.229
Cubic feet	Liters	28.32
Cubic feet	BBL (oil)	0.1781
Cubic feet	BBL (liq.)	0.2375
Gallons	Cubic centimeters	3785
Gallons	Cubic millimeters	0.00379
Gallons	Cubic feet	0.1337
Gallons	Cubic in.	231
Gallons	Gallons (Br.)	0.8327
Gallons	Liters	3.785
Gallons	Pounds of water	8.35
Gallons	BBL (oil)	0.02381
Gallons	BBL (liq.)	0.03175
Liters	Cubic centimeters	1000
Liters	Cubic millimeters	0.001
Liters	Cubic yards	0.00131
Liters	Cubic feet	0.0353
Liters	Cubic in.	61.02
Liters	Gallons (Br.)	0.2200
Liters	Gallons	0.2642
Liters	BBL (oil)	0.00629
Liters	BBL (liq.)	0.00839
Cubic centimeters	Cubic meters	1×10^{-6}
Cubic centimeters	Cubic feet	3.531×10^{-5}
Cubic centimeters	Cubic in.	0.06102
Cubic centimeters	Gallons (Br.)	2.20×10^{-4}
Cubic centimeters	Gallons	2.642×10^{-4}
Cubic centimeters	Liters	0.001
Cubic centimeters	BBL (oil)	6.29×10^{-6}
Cubic centimeters	BBL (liq.)	8.39×10^{-6}
Cubic in.	Cubic centimeters	16.387

Area Conversions

From \ To	cm ²	m ²	km ²	in. ²	ft. ²	mile ²
cm ²	1	0.0001	1×10^{10}	0.1550	0.00108	3.86×10^{11}
m ²	1×10^4	1	1×10^6	1550	10.76	3.86×10^7
km ²	1×10^{10}	1×10^6	1	1.55×10^9	1.08×10^7	0.3861
in. ²	6.452	6.45×10^4	6.45×10^{10}	1	0.00694	2.49×10^{10}
ft. ²	929.0	0.09290	9.29×10^8	144	1	3.59×10^8
mile ²	2.59×10^{10}	2.59×10^6	2.590	4.01×10^9	2.79×10^7	1

Decimal Equivalents

8ths	32nds	64ths	
1/8 = 0.125	1/32 = 0.03125	1/64 = 0.015625	33/64 = 0.515625
1/4 = 0.250	3/32 = 0.09375	3/64 = 0.046875	35/64 = 0.546875
3/8 = 0.375	5/32 = 0.15625	5/64 = 0.078125	37/64 = 0.578125
1/2 = 0.500	7/32 = 0.21875	7/64 = 0.109375	39/64 = 0.609375
5/8 = 0.625	9/32 = 0.28125	9/64 = 0.140625	41/64 = 0.640625
3/4 = 0.750	11/32 = 0.34375	11/64 = 0.171875	43/64 = 0.671875
7/8 = 0.875	13/32 = 0.40625	13/64 = 0.203125	45/64 = 0.703125
16ths	15/32 = 0.46875	15/64 = 0.234375	47/64 = 0.734375
1/16 = 0.0625	17/32 = 0.53125	17/64 = 0.265625	49/64 = 0.765625
3/16 = 0.1875	19/32 = 0.59375	19/64 = 0.296875	51/64 = 0.796875
5/16 = 0.3125	21/32 = 0.65625	21/64 = 0.328125	53/64 = 0.828125
7/16 = 0.4375	23/32 = 0.71875	23/64 = 0.359375	55/64 = 0.859375
9/16 = 0.5625	25/32 = 0.78125	25/64 = 0.390625	57/64 = 0.890625
11/16 = 0.6875	27/32 = 0.84375	27/64 = 0.421875	59/64 = 0.921875
13/16 = 0.8125	29/32 = 0.90625	29/64 = 0.453125	61/64 = 0.953125
15/16 = 0.9375	31/32 = 0.96875	31/64 = 0.484375	63/64 = 0.984375

Inches to Millimeters	Millimeters to Inch Equivalent	
1/16 in. = 1.59 mm	1 mm = 0.039 in.	15 mm = 0.590 in.
1/8 in. = 3.17 mm	2 mm = 0.079 in.	16 mm = 0.630 in.
3/16 in. = 4.76 mm	3 mm = 0.118 in.	17 mm = 0.669 in.
1/4 in. = 6.35 mm	4 mm = 0.157 in.	18 mm = 0.709 in.
5/16 in. = 7.94 mm	5 mm = 0.197 in.	19 mm = 0.748 in.
3/8 in. = 9.52 mm	6 mm = 0.236 in.	20 mm = 0.787 in.
7/16 in. = 11.11 mm	7 mm = 0.276 in.	21 mm = 0.827 in.
1/2 in. = 12.70 mm	8 mm = 0.315 in.	22 mm = 0.866 in.
9/16 in. = 14.29 mm	9 mm = 0.354 in.	23 mm = 0.905 in.
5/8 in. = 15.87 mm	10 mm = 0.394 in.	24 mm = 0.944 in.
11/16 in. = 17.46 mm	11 mm = 0.433 in.	25 mm = 0.984 in.
3/4 in. = 19.05 mm	12 mm = 0.472 in.	25.4 mm = 1 in.
13/16 in. = 20.64 mm	13 mm = 0.512 in.	
7/8 in. = 22.22 mm	14 mm = 0.551 in.	
15/16 in. = 23.81 mm		
1 in. = 25.40 mm		
1 1/4 in. = 31.75 mm		
1 1/2 in. = 38.10 mm		
2 in. = 50.80 mm		

Temperature Conversion Formulas

Degrees Fahrenheit (°F)	Degrees Celsius (Centigrade) (°C)	Absolute Degrees Rankine (°R) Degrees Kelvin (°K)
$^{\circ}\text{F} = 1.8(^{\circ}\text{C}) + 32$	$^{\circ}\text{C} = \frac{^{\circ}\text{F} - 32}{1.8}$	$0^{\circ}\text{R} = 0^{\circ}\text{K}$
		$^{\circ}\text{R} = ^{\circ}\text{F} + 459.69$
$^{\circ}\text{F} = ^{\circ}\text{R} - 459.69$	$^{\circ}\text{C} = ^{\circ}\text{K} - 273.16$	$^{\circ}\text{K} = ^{\circ}\text{C} + 273.16$

Celsius (°C) Fahrenheit (°F) Temperature Conversion Table

°C	°F	°C	°F	°C	°F	°C	°F
-200	-328	65	149	410	770	790	1454
-180	-292	70	158	420	788	800	1472
-160	-256	75	167	430	806	810	1490
-140	-220	80	176	440	824	820	1508
-120	-184	85	185	450	842	830	1526
-100	-148	90	194	460	860	850	1562
-95	-139	95	203	470	878	900	1652
-90	-130	100	212	480	896	950	1742
-85	-121	110	230	490	914	1000	1832
-80	-112	120	248	500	932	1050	1922
-75	-103	130	266	510	950	1100	2012
-70	-94	140	284	520	968	1150	2102
-65	-85	150	302	530	986	1200	2192
-60	-76	160	320	540	1004	1250	2282
-55	-67	170	338	550	1022	1300	2372
-50	-58	180	356	560	1040	1350	2462
-45	-49	190	374	570	1058	1400	2552
-40	-40	200	392	580	1076	1450	2642
-35	-31	210	410	590	1094	1500	2732
-30	-22	220	428	600	1112	1550	2822
-25	-13	230	446	610	1130	1600	2912
-20	-4	240	464	620	1148	1650	3002
-15	5	250	482	630	1166	1700	3092
-10	14	260	500	640	1184	1750	3182
-5	23	270	518	650	1202	1800	3272
0	32	280	536	660	1220	1850	3362
5	41	290	554	670	1238	1900	3452
10	50	300	572	680	1256	1950	3542
15	59	310	590	690	1274	2000	3632
20	68	320	608	700	1292	2050	3722
25	77	330	626	710	1310	2100	3812
30	86	340	644	720	1328	2150	3902
35	95	350	662	730	1346	2200	3992
40	104	360	680	740	1364	2250	4082
45	113	370	698	750	1382	2300	4172
50	122	380	716	760	1400	2350	4262
55	131	390	734	770	1418	2400	4352
60	140	400	752	780	1436	2450	4442

Pipe Wall Thickness

Nominal Size	OD	Wall Thickness			Inside Diameter		
		Sch 10	Sch 40	Sch 80	Sch 10	Sch 40	Sch 80
1/8	0.405	0.049	0.068	0.095	0.307	0.269	0.215
1/4	0.540	0.065	0.088	0.119	0.410	0.364	0.302
3/8	0.675	0.065	0.091	0.126	0.545	0.493	0.381
1/2	0.840	0.083	0.109	0.147	0.674	0.622	0.546
3/4	1.050	0.083	0.113	0.154	0.884	0.824	0.742
1	1.315	0.109	0.133	0.179	1.097	1.049	0.957
1 1/4	1.660	0.109	0.140	0.191	1.442	1.380	1.278
1 1/2	1.900	0.109	0.145	0.200	1.682	1.610	1.500
2	2.375	0.109	0.154	0.218	2.157	2.067	1.939

All dimensions in inches.

Fractional Tubing OD, Wall, ID Cross-Sectional Area

Tube (in.)	OD (in.)	Wall Thickness (in.)	Tube ID (in.)	ID Cross-Sectional Area (in. ²)
1/16	0.062	0.010	0.042	0.0014
		0.015	0.032	0.0008
		0.020	0.022	0.0004
1/8	0.125	0.028	0.069	0.0037
		0.035	0.055	0.0024
3/16	0.187	0.028	0.131	0.0135
		0.035	0.117	0.0108
		0.049	0.089	0.0062
1/4	0.250	0.028	0.194	0.030
		0.035	0.180	0.025
		0.049	0.152	0.018
		0.065	0.120	0.011
5/16	0.312	0.035	0.242	0.046
		0.049	0.214	0.036
		0.065	0.182	0.026
3/8	0.375	0.035	0.305	0.073
		0.049	0.277	0.060
		0.065	0.245	0.047
1/2	0.500	0.035	0.430	0.145
		0.049	0.402	0.127
		0.065	0.370	0.108
		0.083	0.334	0.088

Fractional Tubing OD, Wall, ID Cross-Sectional Area (Continued)

Tube (in.)	OD (in.)	Wall Thickness (in.)	Tube ID (in.)	ID Cross-Sectional Area (in. ²)
5/8	0.625	0.049	0.527	0.218
		0.065	0.495	0.192
		0.083	0.459	0.166
		0.095	0.435	0.149
3/4	0.750	0.049	0.652	0.334
		0.065	0.620	0.302
		0.083	0.584	0.268
		0.095	0.560	0.246
7/8	0.875	0.109	0.532	0.222
		0.049	0.777	0.474
		0.065	0.745	0.436
		0.083	0.709	0.395
1	1.000	0.095	0.685	0.369
		0.109	0.657	0.339
		0.049	0.870	0.595
		0.065	0.834	0.546
1 1/4	1.250	0.083	0.810	0.515
		0.095	0.782	0.480
		0.109	0.760	0.454
		0.120	0.760	0.454
1 1/2	1.500	0.083	1.084	0.923
		0.095	1.060	0.883
		0.109	1.032	0.837
		0.120	1.010	0.801
2	2.000	0.134	0.982	0.757
		0.156	0.938	0.691
		0.095	1.310	1.348
		0.109	1.282	1.291
2	2.000	0.120	1.260	1.247
		0.134	1.232	1.192
		0.156	1.188	1.109
		0.188	1.124	0.992
2	2.000	0.109	1.782	2.494
		0.120	1.760	2.433
		0.134	1.732	2.356
		0.156	1.688	2.238
2	2.000	0.188	1.624	2.071

Metric Tubing OD, Wall, ID Cross-Sectional Area

Tube OD (mm)	Wall Thickness (mm)	Tube ID (mm)	ID Cross-Sectional Area (mm ²)
1	0.2	0.6	0.2827
	0.3	0.4	0.1257
	0.4	0.2	0.0031
3	0.5	2.0	3.14
	0.6	1.8	2.54
	0.8	1.4	1.54
6	0.6	4.8	18.10
	0.8	4.4	15.21
	1.0	4.0	12.57
	1.25	3.5	9.62
	1.5	3.0	7.07
8	1.6	2.8	6.16
	0.8	6.4	32.17
	1.0	6.0	28.27
	1.25	5.5	23.76
10	1.5	5.0	19.64
	1.6	4.8	18.10
	0.8	8.4	55.42
	1.0	8.0	50.27
12	1.25	7.5	44.18
	1.5	7.0	38.48
	1.6	6.8	36.32
	1.0	10.0	78.54
14	1.25	9.5	70.88
	1.5	9.0	63.62
	1.6	8.8	60.82
	2.0	8.0	50.27
	1.0	12.0	113.10
15	1.2	11.6	105.68
	1.5	11.0	95.03
	1.8	10.4	84.95
	2.0	10.0	78.54
	2.2	9.6	72.38
15	1.2	12.6	124.69
	1.5	12.0	113.10
	1.6	11.8	109.36
	2.0	11.0	95.03
	2.3	10.4	84.95

Metric Tubing OD, Wall, ID Cross-Sectional Area (Continued)

Tube OD (mm)	Wall Thickness (mm)	Tube ID (mm)	ID Cross-Sectional Area (mm ²)
16	1.2	13.6	145.27
	1.5	13.0	132.73
	1.6	12.8	128.68
	2.0	12.0	113.10
	2.3	11.4	102.07
18	1.2	15.6	191.13
	1.5	15.0	176.72
	1.6	14.8	172.03
	2.0	14.0	153.94
	2.3	13.4	141.03
	2.5	13.0	132.73
20	2.6	12.8	128.68
	1.5	17.0	226.98
	1.6	16.8	221.67
	2.0	16.0	201.06
	2.3	15.4	186.27
	2.5	15.0	176.71
22	2.6	14.8	172.03
	1.5	19.0	283.53
	1.6	18.8	277.59
	2.0	18.0	254.47
	2.3	17.4	237.79
	2.5	17.0	226.98
25	2.6	16.8	221.67
	1.5	22.0	380.13
	1.6	21.8	373.25
	2.0	21.0	346.36
	2.3	20.4	326.85
	2.5	20.0	314.16
	2.6	19.8	307.91
28	3.0	19.0	283.53
	2.0	24.0	452.38
	2.2	23.6	437.43
	2.5	23.0	415.47
	2.8	22.4	394.08
	3.0	22.0	380.13
	3.5	21.0	346.36

continued

Metric Tubing OD, Wall, ID Cross-Sectional Area (Continued)

Tube OD (mm)	Wall Thickness (mm)	Tube ID (mm)	ID Cross-Sectional Area (mm ²)
30	2.0	26.0	530.92
	2.2	25.6	514.71
	2.5	25.0	490.87
	2.8	24.4	467.59
	3.0	24.0	452.38
	3.5	23.0	415.47
32	2.0	28.0	615.75
	2.2	27.6	598.28
	2.5	27.0	572.55
	2.8	26.4	547.39
	3.0	26.0	530.92
	3.5	25.0	490.87
38	4.0	24.0	452.38
	2.2	33.6	886.68
	2.5	33.0	855.29
	2.8	32.4	824.47
	3.0	32.0	804.24
	3.5	31.0	754.76
	4.0	30.0	706.85
4.5	29.0	660.51	

Appendix C

Corrosion Charts

The data presented is believed reliable, but a chart of this sort cannot cover all conditions of concentration, temperature, impurities, and aeration. It is suggested that this chart be used only to select possible materials for use and then a more extensive investigation be made of published corrosion results under the specific conditions expected. Where such information cannot be found, corrosion testing should be conducted under actual usage conditions to determine which materials can be utilized.

	1. Excellent.	2. Good, most conditions.	3. Fair, limited life, and restricted conditions.	4. Unsatisfactory.	Aluminum	Brass	Steel	Alloy 400	316 SS	PTFE/PFA	Polyethylene	Buna-N (Nitrile)	FKM	Neoprene	Delrin®	Alloy 600	Alloy C276	Titanium
Acetaldehyde					1	1	3	2	1	1		4	3	4	2	2	1	
Acetic Acid					2	4	4	3	1	1	3	3	4	3	4	2	1	1
Acetic Anhydride					1	4	4	1	2	4		3	4	3	4	1		
Acetone					2	1	2	1	1	1	3	4	4	3	1			1
Acetylene					1	2	1	1	1	1		1	1	1	1	1		1
Acrylonitrile					2	1	1	1	1	1		4	3	4	4	1	1	1
Alcohols					2	2	2	1	1	1		1	1	1	1	1		1
Aluminum Chloride					4	4	4	2	4	1	2	2	1	2	1	4	1	
Aluminum Fluoride					1	4	4	2	3	1	2							2
Aluminum Hydroxide					2	2	2	2	2	1								2
Aluminum Sulfate					3	4	4	2	3	1	2	1	1	1	1	4	1	1
Amines					2	2	2	1	1	1			4	4	1	2	1	1
Ammonia, Anhydrous					2	4	1	1	1	1	2	2	3	2		1	1	
Ammonium Bicarbonate					2	4	2	4	2	1	1	2	1	1	1	4		1
Ammonium Carbonate					2	3	2	2	2	1		2	2	1	1	2	2	
Ammonium Chloride					4	4	3	2	2	1	2	2	1	1	1	2	1	1
Ammonium Hydroxide					2	4	2	4	1	1	2	3	1	1	1	1	1	1
Amm. Monophosphate					2	4	4	2	2	1	1	1	1	1	2			
Ammonium Nitrate					2	4	1	3	1	1	2	1	1	1	1			2
Ammonium Phosphate					1		1	1	1	1		1	1	1	1			
Ammonium Sulfate					4	4	3	2	2	1		1	1	1	1	2	2	1

(continued)

Ammonium Sulfite	4	4	4	3	2	1						4	2	1	4	1	1
Amyl Acetate	1	2	1	1	1	1											1
Aniline	2	4	1	2	1	1						4	3	1	2	2	1
Apple Juice	2	3	4		2	1						1	1	1	1		
Arsenic Acid	4	4	4	2	2	1						1	1	1	1	2	
Asphalt	1	2	1	1	1	1						3	1	3	1		
Barium Carbonate	4	1	2	2	2	1				1		1	1	1		2	1
Barium Chloride	2	2	2	2	2	1				2		1	1	1	1	2	2
Barium Hydroxide	4	4	2	2	1	1				2		1	1	1	2	2	1
Barium Nitrate	2	4	2	3	2	1				2					2		
Barium Sulfate		2	2	2	2	1				2		1	1	1	2	2	
Barium Sulfide	4	4	1	4	1	1				2		1	1	1	1		1
Beer	1	2	3	1	1	1				1		1	1	1			
Beet Sugar Liquor	1	3	2	1	1	1				1		1	1	1			
Benzene	2	2	2	1	2	1						4	2	4	1	2	1
Borax	3	3	2	1	1	1				2		1	1	1	1		
Blk. Sulfate Liquor	4	2	1		1	1						2		1			
Boric Acid	2	2	4	2	2	1						1	1	1	2	1	1
Brine			3	1	2	1						1	1	1	1	1	1
Bromine—Dry	2	4	4	3	4	1				2		4	2	4		4	4
Bromine—Wet	4	4	4	2	4	1				4		4	2	4		4	4
Bunker Oil	1	2	2		1	1						1	1	2	1		
Buttermilk	1	4	4	1	1	1				1		1	1	1	1		
Butyric Acid	2	4	4	2	2	1				2		2	3	3	1	3	1
Calcium Bisulfite	4	4	4	4	1	1									4	1	1
Calcium Carbonate	3	2	1	2	1	1				1		1	1	1	2	2	1
Calcium Chloride	2	2	2	1	2	1						1	1	1	1	1	1
Calcium Hydroxide	3	4	2	2	2	1						1	1	1	1	2	1

	Aluminum	Brass	Steel	Alloy 400	316 SS	PTFE/PFA	Polyethylene	Buna-N (Nitrile)	FKM	Neoprene	Delrin®	Alloy 600	Alloy C276	Titanium
1. Excellent.														
2. Good, most conditions.														
3. Fair, limited life, and restricted conditions.														
4. Unsatisfactory.														
Calcium Hypochlorite	4	4	3	3	3	1		2	1	2	1	4	2	1
Calcium Sulfate	2	2	2	2	1	1		1	1	1	1	4		1
Carbolic Acid	2	3	3	2	1	1		4	2	4	4	2	1	1
Carbon Bisulfide	1	3	2	2	2	1		4	1	4	1			1
Carbon Dioxide	1	1	1	1	1	1	2	3	1	2		1	1	1
Carbonic Acid	1	1	4	1	1	1	2	1	1	1	1	1		1
Carbon Tet—Wet	4	2	4	1	1	1	3	4	2	4	1	1	1	1
Carbon Tet—Dry	1	3	4	1	2	1		4	2	4	1	1	1	1
Carbonated Water	1	2	2		1	1		1	1	1	1	1		1
Castor Oil	1	1	2		1	1		1	1	2	1			
Chlorinated Solvent	1	1	1	1	1	1		4	3	4	1	1	1	1
Chloric Acid	4	4	4	3	3	1							1	1
Chlorinated Water	4	4	4	1	3	1							1	1
Chlorine Gas—Dry	4	4	2	1	2	1	3	3	2	3	1	4	1	4
Chlorine Gas—Wet	4	4	4	2	3	1	3	4		4		2	4	1
Chloroform—Dry	1	1	1	1	1	1	4	4	2	4	1	1	2	1
Chlorosulfonic—Dry	1	4	1	3	2	1		4		4		3	1	4
Chlorosulfonic—Wet	4	4	4	4	4	1		4		4		3	1	
Chrome Alum	3	3	2		1	1		2		2				
Chromic Acid	4	4	2	4	4	1	2	4	3	4	4	2	2	1
Citric Acid	2	4	4	2	3	1	4	1	1	1	1	1		

(continued)

Coconut Oil	1	3	3	2	1	1	1	1	2	1	1	1	1	1	1
Coke Oven Gas	1	3	2		1	1		2	2	3		1			
Copper Acetate	4	4	3	1	2	1						1	2	1	
Copper Chloride	4	4	4	2	4	1		1	1	1	1				
Copper Nitrate	4	4	4	4	2	1	2	1	1	1	1	4	2	1	
Copper Sulfate	4	2	4	2	2	1						2	1	2	
Corn Oil	4	4	4	4	1	1	2	1	1	1	2				
Cottonseed Oil	2	2	3	2	1	1	4	1	1	2	1				
Creosote	2	2	2	1	2	1	4	1	4	4	1	2			
Crude Oil, Sweet	1	2	2		1	1		1	1	2					
Diesel Fuel	1	1	1		1	1		1	1	3	1	1	1	1	1
Diethylamine	2	4	1	2	1	1		2		3		1	1	1	1
Dowtherm	1	1	2		1	1		4	1	4	1				
Drying Oil	3	3	3		2	1		1		2	1				
Epsom Salt	1	2	3		2	1		1	1	1	1	1	1	1	1
Ethane	1	1	1	1	1	1		1	1	2	1	1	1	1	1
Ethers	1	2	1		1	1		3	3	3	3				
Ethyl Acetate	1	2	1	1	1	1		4	4	4	1	1	1	1	1
Ethyl Alcohol	2	1	1	1	2	1		1	1	1	1	1	1	1	1
Ethyl Chloride—Dry	2	2	1	2	1	1	4	3		3	1	1	2	1	
Ethyl Chloride—Wet	2	2	4	2	1	1		3		3	1	1	2	1	
Ethylene Glycol	1	2	1	1	1	1	2	1	2	1	3	1	1	1	1
Ethylene Oxide	4	4	2	2	2	1	3	4	4	4		2	1	1	1
Fatty Acid	1	3	2	2	1	1		2	1	2	1	1	1	1	1
Ferric Chloride	4	4	4	4	4	1	2	1	1	1	1	4	2	1	
Ferric Nitrate	4	4	4	4	2	1	2	1	1	1	1	4	2		
Ferric Sulfate	4	4	4	4	2	1	2	1	1	1	1	1	1	1	1

	Aluminum	Brass	Steel	Alloy 400	316 SS	PTFE/PFA	Polyethylene	Buna-N (Nitrile)	FKM	Neoprene	Delrin®	Alloy 600	Alloy C276	Titanium
1. Excellent.														
2. Good, most conditions.														
3. Fair, limited life, and restricted conditions.														
4. Unsatisfactory.														
Ferrous Chloride	4	4	4	4	4	1		1	1	1	1	4	2	1
Ferrous Sulfate	3	4	4	2	2	1	2	1	1	1	1	2	2	1
Fish Oils	2	2	2		1	1		1	1	2	1			
Fluorine—Dry	2	3	1	1	2	1	2					1	2	4
Fluorine—Wet	4	4	4	1	4	1	2			3		1	2	4
Fluoroboric Acid	4		1	1	1							1		4
Fluorosilicic Acid	4	1	4	1	1	1				3		1	2	4
Formaldehyde—Cold	1	1	1	1	1	1		2		2	1	2	2	1
Formaldehyde—Hot	2	2	4	2	2	1		2		2	1	2	2	1
Formic Acid—Cold	1	2	4	3	2	1		4	1	1	4	3	1	4
Formic Acid—Hot	4	2	4	4	2	1		4	1	1	4	4	2	4
Freon	2	2	3	1	3	1	2	3	3	3		2	2	3
Fuel Oil	1	1	1	1	1	1		1	1	2	1			
Furfural	2	2	2	2	2	1	4	4	1	3	1	2	2	2
Gasoline	1	1	1	1	1	1	4	3	1	4	1	1	1	1
Gas, Manufactured	2	2	2	2	2	1		1	1	1	1	1	1	1
Gas, Natural	1	1	1	1	1	1		1		1	1	1	1	1
Gas Odorizers	1	1	2		2	1		1	1	1	1			
Gelatin	1	1	4		1	1		1	1	1	1	1		
Glucose	1	1	2		1	1		1	1	1	1	1	1	1
Glue	1	2	1		2	1		1	1	1	1	1	1	1

(continued)

Glycerine	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1
Glycols	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1
Grease	1	1	1	1	1	1	1	1	1	1	2		1	1	1	1
Heptane	1	1	1	1	1	1	1	1	1	1	2		1	1	1	1
Hexane	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1
Hydraulic Oil	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1
Hydrobromic Acid	4	4	4	4	4	1	3				3					1
Hydrochloric Acid	4	4	4	2	4	1	2	2			3	4	4			4
Hydrocyanic Acid	1	4	1	2	1	1					2	4	1	2	1	1
Hydrofluoric Acid	4	4	4	2	4	1	3				3	4	4	2	2	3
Hydrogen Gas—Cold	1	1	1	1	1	1					2		1	1	1	1
Hydrogen Cl—Dry	4	3	2	1	2	1	2						1	1	1	1
Hydrogen Cl—Wet	4	4	4	3	4	1							4			
Hydrogen Perox—Dil	1	4	4	2	2	1	2	1	1	1	1		2	1	1	1
Hydrogen Perox—Con	1	4	4	4	1	1	4				4		1	1	1	1
Hydrogen Sulfide—Dry	2	2	2	1	1	1	2	3	4	4	4	4	2	2	1	1
Hydrogen Sulfide—Wet	2	4	3	1	1	1	2	3	4	4	4	4	2	2	1	1
Hydrofluosilicic	4	4	4	1	3	1	2	1			1					
Illuminating Gas	1	1	1	1	1	1	1	1	1	1	2		1	1	1	1
Ink	3	3	4	1	1	1	1	1	1	1	1	1	1			
Iodine	4	4	4	2	2	1	3	2	1	2	1	2	1	4	2	4
Iodoform	1	1	1	2	1	1					1		1	2	2	1
Isooctane	1	1	1	1	1	1	1	1	1	1	3	1				1
Isopropyl Alcohol	2	2	1	1	1	1					3	1	3	1	1	1
Isopropyl Ether	1	1	1								3					1
JP-4 Fuel	1	1	1	1	1	1	1	1	1	1	3	1				1
JP-5 Fuel	1	1	1	1	1	1	1	1	1	1	3	1				1
JP-6 Fuel	1	1	1	1	1	1	1	1	1	1	3	1				1

	1. Excellent.	2. Good, most conditions.	3. Fair, limited life, and restricted conditions.	4. Unsatisfactory.	Aluminum	Brass	Steel	Alloy 400	316 SS	PTFE/PFA	Polyethylene	Buna-N (Nitrile)	FKM	Neoprene	Delrin®	Alloy 600	Alloy C276	Titanium
					1	1	1	1	1	1	2	1	1	3	1			1
					1	1	1	1	1	1		1	1	1	1			1
					1	1	1	1	1	1		4	4	4	1			1
					1	4	4	2	2	1	2	3	3		4	1	2	1
					1	1	3	2	2	1		1	1	2	1			
					2	2	3	2	1									
					2	2	2	1	2	1	2	1	1	1	1	1	1	1
					4	2	2	1	1	1	2	1	1	1	1			
					4	4	2	1	1	1		2	1	1	1			
					1	1	1	1	1	1	2	1	1	1	1	1	1	1
					2	3	2	2	2			1	1	1	1	2	2	1
					2	2	4	2	1	1		1	1	1	1	1	1	1
					4	4	4		1	1		1	1	1	1			
					2				2	1								
					4	4	2		2	1						2	1	1
					4	4	2	2	1	1	2	1	1	1	1	1	1	4
					1	1	1	1	1	1		1	1	2	1	1	1	1
					2	2	2	1	1	1		4	4	4		1	1	1
					2	1	1	1	1	1		4	4	4		1	1	1
					2	2	2	1	2	1		1	4	1	1	1	1	1
					4	1	1	2	1	1	2	3		3	1	2		

(continued)

Methylamine	2	4	2	3	2	1	2	3	1	1	2	2
Methyl Ethyl Ketone	1	1	1	1	1	1	4	4	1	2	2	1
Methylene Chloride	1	2	2	2	1	3	4	3	4	1	2	1
Milk	1	4	4	2	1	1	3	1	1	1	1	
Mineral Oil	1	1	1	1	1	1	1	1	2	1		
Molasses	1	1	1	1	1	1	2	1	1	1	1	
Mustard	2	1	2		1	1	1	1	1	1		
Naphtha	1	1	1	1	1	1	3	1	4	1	1	1
Naphthalene	2	1	2	1	1		3	1	4	1	2	1
Nickel Chloride	4	4	4	2	2	1	2	1	1	1	4	1
Nickel Nitrate	3	4	2	2	2	1	1	1	1	2	2	1
Nickel Sulfate	4	3	4	1	2	1	2	1	1	1	2	2
Nitric Acid — 10 %	4	4	4	4	1	1		3	1	2	4	1
Nitric Acid — 30 %	4	4	4	4	1	1		3	1	3	4	1
Nitric Acid — 80 %	4	4	4	4	1	1		4	2	4	4	2
Nitric Acid — 100 %	4	4	4	4	1	1		4	2	4	4	2
Nitric Acid — Anhyd.	4	4	1	4	1	1			4	4	1	2
Nitrobenzene	1	1	1	1	1	1		4	3	4	1	1
Nitrogen	1	1	1	1	1	1	1	1	1	1	1	1
Nitrous Acid — 10 %	4	4	4	4	2	1		3	1	1		
Nitrous Oxide	3	2	2	4	2	1		2	2	1	4	2
Oils, Animal	1	1	1	1	1	1		1	2			
Oleic Acid	2	2	3	1	2	1		1	3	1	1	1
Oleum	2	2	2		2	1		3	3	4	2	2
Olive Oil	1	2	2		1	1		1	2	1		
Oxalic Acid	3	2	4	2	2	1		3	1	1	3	2
Oxygen	1	1	2	1	1	1		1	1	1	1	1
Ozone — Dry	1	4	1	1	1	1				1	1	1

	Aluminum	Brass	Steel	Alloy 400	316 SS	PTFE/PFA	Polyethylene	Buna-N (Nitrile)	FKM	Neoprene	Delrin®	Alloy 600	Alloy C276	Titanium
1. Excellent.														
2. Good, most conditions.														
3. Fair, limited life, and restricted conditions.														
4. Unsatisfactory.														
Ozone—Wet	1	4	3		1	1						1		
Palmitic Acid	2	2	2		1	1		2	1	2	1	1		
Paraffin	1	1	2		1	1		1	1	2	1			
Parafomaldehyde	2	1	3	1	1	1		2	1	2	2	1	1	2
Pentane	1	2	2	2	2	1		1	1	2	1	2		1
Parez 607			4		4	1								
Phenol	2	1	1	2	2	1		4	2	4	4	2	1	1
Phosphoric, 10 %—Cold	1	2	4	1	2	1		2	1	1	4	1		1
Phosphoric, 10 %—Hot	1	2	4	1	4	1		2	1	1	4	4		4
Phosphoric, 50 %—Cold	4	2	4	1	2	1		2	1	2	4	1		4
Phosphoric, 50 %—Hot	4	2	4	1	4	1		2	1	2	4	4		4
Phosphoric, 85 %—Cold	4	2	2	1	1	1		3		2	4	1		4
Phosphoric, 85 %—Hot	4	2	3	1	1	1		3		2	4	4		4
Phthalic Acid	2	2	3	2	1	1		3	1	3	1	2	2	1
Phthalic Anhydride	1	2	1	1	1	1		3	1	3	1	1	1	
Picric Acid	3	4	4	4	2	1		3		1			2	
Pine Oil	1	2	2		1	1		1	1	3	1			
Pineapple Juice	1	3	3		1	1		1	1	1	1			
Potassium Bisulfite	2	2	4	4	2	1		1	1	1	1	4	3	
Potassium Bromide	4	2	4	2	2	1		1	1	1	1	2	2	1
Potassium Carbonate	4	3	2	2	2	1	2	1	1	1	1	2	1	1

(continued)

Potassium Chlorate	4	2	3	3	1	1	2	1	1	1	1	1	3	2	1
Potassium Chloride	4	3	3	2	1	1	2	1	1	1	1	1	2	2	1
Potassium Cyanide	4	4	2	1	2	1	2	1	1	1	1	1	2	2	1
Potassium Dichromate	1	2	2	2	1	1	1	1	1	1	1	1	2	2	1
Potassium Diphosphate	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1
Potassium Ferricyanide	2	2	3	2	2	1	2	1	1	1	1	1	2	2	1
Potassium Ferrocyanide	1	2	1	2	2	1	2	1	1	1	1	1	2	2	1
Potassium Hydroxide	4	4	3	1	1	1	2	1	1	1	1	1	1	2	4
Pot. Hypochlorite	4	4	3	4	2	1	1	1	1	1	1	1	4	2	1
Pot. Permanganate	1	2	2	2	2	1	2	1	1	1	1	1	2	2	1
Potassium Sulfate	1	3	2	1	1	1	2	1	1	1	1	1	2	1	1
Potassium Sulfide	4	4	4	4	2	1	2	1	1	1	1	1	2	2	1
Propane	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1
Propyl Alcohol	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Pyrogalllic Acid	2	2	3	2	2	1	1	1	1	1	1	1	2	2	1
Salad Oil	4	4	4	2	1	1	1	1	1	1	1	1	1	1	1
Salicylic Acid	2	2	4	1	2	1	1	1	1	1	1	1	2	2	1
Salt	1	2	3	1	3	1	2	1	1	1	1	1	1	1	1
Seawater	2	2	3	1	1	1	2	1	1	1	1	1	1	1	1
Silver Bromide	4	4	4	2	4	1	1	1	1	1	1	1	1	1	1
Silver Chloride	4	4	4	2	4	1	1	1	1	1	1	1	2	1	1
Silver Nitrate	4	4	4	4	1	1	2	3	1	3	1	3	1	2	1
Sodium Acetate	1	1	1	1	2	1	2	2	1	2	1	2	1	1	1
Sodium Aluminate	4	2	1	1	1	1	1	1	1	1	1	1	1	2	1
Sodium Bicarbonate	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1
Sodium Bisulfate	2	3	4	2	2	1	1	1	1	1	1	1	2	2	1
Sodium Bisulfite	4	4	2	2	1	1	2	1	1	1	1	1	2	2	2
Sodium Borate							1	1	1	1	1	1	1	2	2

	Aluminum	Brass	Steel	Alloy 400	316 SS	PTFE/PFA	Polyethylene	Buna-N (Nitrile)	FKM	Neoprene	Delrin®	Alloy 600	Alloy C276	Titanium
1. Excellent.														
2. Good, most conditions.														
3. Fair, limited life, and restricted conditions.														
4. Unsatisfactory.														
Sodium Bromide	4	3	2	2	2	1	2	1	1	1	1	2	2	
Sodium Carbonate	4	4	1	1	1	1	1	1	1	1	1	1	1	1
Sodium Chlorate	2	2	2	2	1	1		1	1	1	1	1	2	1
Sodium Chloride	1	2	3	1	3	1	2	1	1	1	1	1	1	1
Sodium Chromate	1	1	1	1	1	1		1	1	1	1	1	1	1
Sodium Cyanide	4	4	1	4	1	1	2	1	1	1	1	1	1	1
Sodium Fluoride	2	4	4	1	2	1	2	1	1	1	1		2	2
Sodium Hydroxide	4	4	2	1	1	1	2	2	3	2		1		2
Sodium Nitrate	1	3	1	1	1	1	2	3	1	1	1	1	1	1
Sodium Perborate	4	4	2	2	1	1		3	1	1	1	2	2	
Sodium Peroxide	4	4	1	2	2	1		3	1	1	1	2	2	
Sodium Phosphate	4	1	4	1	2	1		2	1	2	1	1	1	1
Sodium Silicate	1	1	1	1	1	1		1	1	1	1	1	2	1
Sodium Sulfate	2	2	2	2	1	1	2	1	1	1	1	2	2	2
Sodium Sulfide	1	3	3	2	2	1	2	1	1	1	1	2	2	
Sodium Sulfite	1	4	4	2	1	1	2					2	2	1
Sodium Thiosulfate	2	4	4	1	1	1		1	1	1	1	2	2	
Soybean Oil	2	2	3	1	1	1		1	1	2	1			
Stannic Chloride	4	4	4	3	4	1		1	1	1	1	4	2	2
Starch	1	2	3	2	1	1		1	1	1	1			
Steam—212°F	2	1	1	1	1	1		4	3	4	4	1	1	1

(continued)

Stearic Acid	4	3	3	1	1	1	1	1	3	1	2	2	2	2
Styrene	1	1	1	1	1	1	4		4		2	1	1	1
Sulfate—Blk. Liq.	1	4	2	2	1				3	1	1			
Sulfate—Grn. Liq.	4	4	2	2	1				3	3	1	2	2	
Sulfate—Whi. Liq.	2	3	3		2	1			3	3	1			
Sulfur	1	4	2	1	1	1	4				4	2	1	
Sulfur Chloride	4	4	4	3	3	1					1	1		
Sulfur Dioxide—Dry	1	3	2	2	1	1			3	1	3	1	2	4
Sulfur Dioxide—Wet	4	4	4	4	1	1						2	1	
Sulfur—Molten	1	4	2	1	1	1	4		3		4	1		
Sulfur Trioxide	2	2	2	2	2	1						2	2	
Sulfuric Acid—0-7 %	1	3	4	1	2	1			2	1	1	3	2	2
Sulfuric Acid—20 %	4	3	4	1	4	1			3	1	2	1	4	3
Sulfuric Acid—50 %	4	3	4	4	4	1			3	1	3	4	4	4
Sulfuric Acid—100 %	4	3	2	4	1	1			4	2	4	4	4	4
Sulfurous Acid	2	4	4	4	2	1			3	1	3	3	4	2
Tannic Acid	1	1	1	1	1	1	2		1	1	2	1	1	2
Tartaric Acid	1	4	4	1	1	1	4		3	1	1	1	1	2
Tetraethyl Lead	2	2	3		2	1						1		
Toluene	1	1	1	1	1	1	4		4	4	2	4	1	1
Tomato Juice	1	3	3		1	1			1	1	1	1		
Transformer Oil	1	2	1		1	1			1	1	2	1		
Tributyl Phosphate	1	1	1	1	1	1			3		3			
Trichloroethylene	1	3	1	1	2	1	4		4	2	4	1	1	2
Turpentine	2	1	1	1	1	1			3	1	4	1	1	1
Urea	2	2	3	2	2	1						1	2	
Varnish	1	1	3		1	1			3		1	1		
Vegetable Oil	1	4	2	2	1	1			1	1	2	1	1	

1. Excellent.	Aluminum	Brass	Steel	Alloy 400	316 SS	PTFE/PFA	Polyethylene	Buna-N (Nitrile)	FKM	Neoprene	Delrin®	Alloy 600	Alloy C276	Titanium
2. Good, most conditions.	3	4	4	1	1	1	2	4	4	4	2		1	
3. Fair, limited life, and restricted conditions.	3	3	2	1	1	1								
4. Unsatisfactory.	1	1	3	1	1	1		1	1	1	1			
Vinegar	3	4	4	1	1	1	2	4	4	4	2		1	
Water, Boiler Feed	3	3	2	1	1	1								
Water, Fresh	1	1	3	1	1	1		1	1	1	1			
Water, Salt	3	3	4	1	2	1	2							
Whiskey	3	3	4	3	1	1	2	1	1	1	1			
Wine	3	2	4	2	1	1	2	1	1	1	1			
Xylene—Dry	1	1	2	1	2	1		4	2	4	1			
Zinc Chloride	4	4	4	2	4	1	2	2	1	1	1	2	1	1
Zinc Hydrosulfite			1	2	1	1		1	1	1	1	2		
Zinc Sulfate	3	4	4	2	2	1	2	1	1	1	1	2	2	1

NOTE: USE THIS CORROSION CHART WITH CAUTION! See p. 283.

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