Best Practices for Pilot-Plant Piping

Richard Palluzi, P.E.
ExxonMobil
Research & Engineering Co.

Pilot-plant piping is subject to more-frequent modification than typical process plant piping, and must be able to accommodate a range of media, temperatures, and pressures during its lifetime. Use this guide to determine which piping, tubing, and fittings are optimal for your pilot plant application.

Pilot-plant piping and process-plant piping differ in numerous ways. Pilot plants are smaller, have a more-compact footprint (Figure 1), are modified more frequently, and are often subject to more-frequent cleaning and inspection. Their piping is also likely to handle a wider range of materials, often with unknown or incompletely known properties, which may lead to unexpected clogging, corrosion, higher pressure drops, and numerous similar problems.

Leakage — or, more accurately, the resistance to leakage — is a critical concern in most pilot-plant piping systems. Pilot plants are more susceptible to leakage than process plants. Because they continually undergo modification, they need to be flexible and accommodate accessibility and change. As a result, pilot-plant piping systems contain an inordinately large number of fittings and joints, all of which are potential leak points.

▲ **Figure 1.** Pilot plants come in a variety of sizes, but are typically smaller than process plants. This pilot plant, used for petrochemical research, is about average size.

The ideal piping for a pilot plant is leak resistant, easily modified, able to accommodate varying requirements, easy to install, low cost, offered in many different materials of construction, available in all sizes, and has fittings available in numerous configurations — a challenging list under the best of circumstances! Unfortunately, this ideal piping does not exist, and tradeoffs are inevitable.

The most common types of piping, tubing, and fittings used in pilot plants are:

- pipe with threaded fittings
- welded and flanged pipe
- tubing with compression fittings
- tubing with vacuum fittings
- grooved pipe with grooved fittings
- tubing or pipe with sanitary fittings.

This article describes best practices for choosing, designing, and installing pilot-plant piping, and guides selection among the most popular types of piping, tubing, and fittings.

Standard threaded piping

Standard threaded piping and fittings (Figure 2) have the advantages of being low cost, readily available, and easy to install. However, they are prone to leakage, which is aggravated by their lack of resistance to vibration and even small temperature swings. Their use in gas service is not recommended, particularly in sizes above 1 in. nominal pipe size (NPS). Most pilot plants should limit the use of standard threaded pipe and fittings (Figure 3) to low-pressure utility systems.

It is good practice to ensure that the die the facility uses to cut threads into its pipes is sharp and in good condition; otherwise, the threads are likely to be rounded and more prone to leakage. The die should also be suitable for the materials of construction. Stainless steel piping, for example, requires a specific high-strength steel die; using a carbon steel die will lead to a very short pipe life or — more commonly — poor threads. And, it is important to make sure the threading is the right length, as longer or shorter lengths are more prone to leakage.

Specify high-quality fittings. Low-grade fittings, even if they meet all applicable national standards, are more prone to leakage because they are subject to less-rigorous quality control during their manufacture.

Unions (*i.e.,* the pipe fittings that join sections of pipe together), in particular, should always be of the highest possible quality. The difference between the performance of a high-end (and more expensive) union and a low-end (and cheaper) one is significant after the first few uses. Avoid threaded connections in cyclic service, whether the temperature or the pressure cycles, as the interference fit that creates the threads' seal does not hold up when cycled.

▲ **Figure 2.** Standard threaded fittings come in a variety of styles and sizes, and are readily available from many manufacturers.

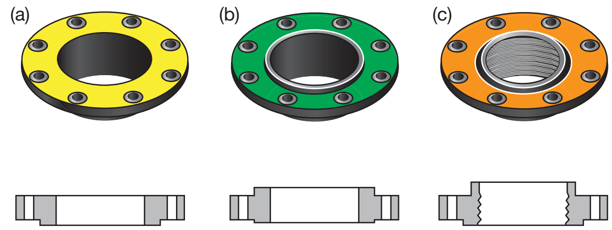
▲ **Figure 3.** Standard threaded piping and fittings are used on this pilot plant vessel.

Welded piping

Welded piping with flanged joints (Figure 4) — the most common process-plant piping — is more rare in pilot-plant service because it is difficult to modify and hard to find in small sizes. Finding flanges for piping smaller than 1 in. iron pipe size (IPS) is difficult, and almost impossible for sizes below 0.5 in. IPS. Tubing is almost always a better choice, as discussed later.

Large pilot plants that can utilize welding (*e.g.,* those that have large piping and are not likely to require major renovations) should use raised-face flanges whenever possible, as they require less force to seal, have a longer service life, and are more resistant to leakage than flat-faced flanges (Figure 5). Avoid the use of threaded flanges, as these add another potential leak point and often make bolt alignment difficult if the flange must be retightened.

▲ **Figure 4.** Flanged joints are typically only available in large pipe sizes, and nearly impossible to find below 0.5 in. IPS. Photo courtesy of Zeton, Inc.



▲ **Figure 5.** When choosing a flange for welded piping, raised-face flanges (b) should be used whenever possible, as they are more resistant to leakage than flat-faced flanges (a). Threaded flanges (c) should be avoided.

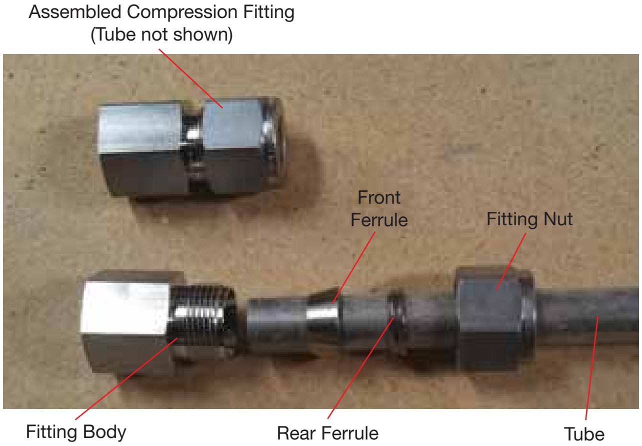
Tubing with compression fittings

Tubing with compression fittings is usually a best practice for pilot-plant piping. Tubing and compression fittings range in size from 1/16 in. to 1.5 in., though the most common sizes are 1/8 in. to 1 in. They can be constructed of materials such as stainless steels, Hastelloy, Inconel, Monel, and numerous plastics.

Tubing is easy to install and, since it can be bent, elbows — with their potential for leakage — are eliminated (Figure 6). Bending also allows for intricate shapes and specialized construction, such as heating/cooling coils and tube-in-tube heat exchangers. It is easier to install tubing than piping in cramped locations.

The connections on each compression fitting can be opened for cleaning, draining, flushing, or modification at every joint without having to unscrew long lengths of piping, as required with threaded fittings. (Some clearance is needed to spring the fittings, but this is usually available.) Although more expensive than threaded fittings, compression fittings are easier to install — even by less-skilled personnel — and require fewer specialized tools. The labor savings generally make tubing with compression fittings less expensive overall than any other type of piping.

▲ **Figure 6.** Tubing and compression fittings are frequently used in pilot plants. Tubing is easy to install and can be bent, which allows for intricate shapes and specialized construction. Photo courtesy of Zeton, Inc.



▲ **Figure 7.** A compression fitting consists of a fitting nut, rear ferrule, front ferrule, and fitting body. The ferrule assembly swages to the tube when the fitting nut is tightened.

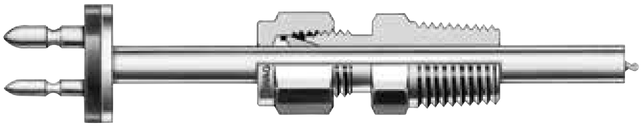
Compression fittings are also more leak resistant than threaded fittings (although not as leak resistant as welded piping). They produce a more-leakfree pilot plant, which has significant long-term operational advantages, such as reduced maintenance, improved safety, and better material balances.

Compression fittings have a significantly longer lifespan than threaded fittings. They can typically be opened and closed numerous times before they need to be replaced. Many types of specialty fittings are available, including reducers, thermocouple-insertion fittings, and tees with different port sizes. More importantly, many small valves with compression-fitting ends are available. Use of these valves and specialty fittings helps to save space in a pilot plant, reduce potential leak points, and provide for easier cleaning and modification.

The use of compression fittings imposes limitations on tubing hardness — therefore, it is critical to specify tubing within the fittings' range. The compression-fitting ferrule (*i.e.,* the metal piece that digs into the front of the tubing to create a seal) will not swage (or compress) properly onto tubing that is too hard (Figure 7). Compression fittings larger than 3/4 in. require considerable force to properly swage the ferrule. Hydraulic swagers (devices that use hydraulic power to create the fitting) are available and should be considered, particularly for units with numerous larger fittings.

Compression fittings also have minimum and maximum wall-thickness limits. If the wall is too thin, the tubing may crumple or collapse without swaging; if it is too thick, the large force required to swage the fitting might be difficult to achieve without the use of a hydraulic unit.

Compression fittings can be drilled through to allow insertion of thermocouples or dip tubes (Figure 8). However, this modification significantly reduces the pressure rating of the fittings, often by 25–70%, depending on the vendor and the size of the fitting (Table 1).



▲ **Figure 8.** Compression fittings can be drilled through to allow tubing to be used as a dip leg.

Table 1. The pressure rating of a drilled-through compression fitting is reduced, or derated.

Tubing Outer Dia., in.	Typical Pressure Derating
1/2 and less	25%
5/8 – 3/4	50%
7/8 – 1	75%

Article continues on next page

Standard compression fittings can typically withstand pressures to about 6,000 psig. Longer ferrule designs are available that can withstand up to 15,000 psig, albeit at a higher cost. Valves are also readily available for these designs, although the selection is more limited and their costs are higher. For pressures above 15,000 psig, cone-and-collar style fittings are more appropriate.

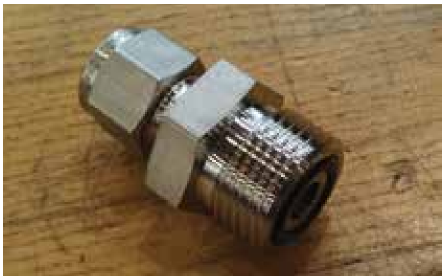
In general, heavy-wall tubing is coned (tapered at the end) and has a captured ferrule threaded onto the tubing. These cone-and-collar style fittings are suitable up to 60,000 psig, and they can sometimes be used at even higher pressures. However, there are few vendors who offer these fittings, and there are even fewer types of valves available. These components have significantly higher costs than standard fittings, and they require a higher skill level and more time for installation. The performance, leakage, and lifespan of these higher-pressure designs is equivalent to that of standard compression fittings.

Vacuum fittings

Tubing can also employ vacuum fittings (Figure 9). Typically sold by the same vendors that offer compression fittings, vacuum fittings have significant advantages over compression fittings. They have a gasket between the pieces of the fitting, and simply replacing the gasket can help extend their lifespan (Figure 10). They have significantly better leak resistance than compression fittings, particularly when exposed to temperature differentials.

However, they are more expensive than compression fittings, and the costs of gasket replacement add to their operating costs. Vacuum fittings are also larger than corresponding compression fittings, which can create issues for very tight assemblies, but their zero-clearance feature (*i.e.,* fittings that require no clearance for removal) usually compensates for this slight increase in size. Many vacuum fittings can be welded to the tubing; although this further reduces leakage, it also increases the costs to install the fittings, as well as the skill level required for the installation. But, this extra cost is often justified. Although the sealing surface can be damaged, if the installer is aware of this potential, simple care can avoid damage.

Gaskets are available in metal and elastomeric materials, but each type requires totally different fittings. Temperature is normally the deciding factor, with metal gaskets suitable for use at much higher temperatures. Corrosion, and less frequently pressure rating, may also dictate the final choice.



▲ **Figure 9.** Vacuum fittings have a gasket between the pieces of the fitting, which helps provide leak resistance and longer life. This example of a vacuum fitting has a black elastomeric (O-ring) gasket.

▲ **Figure 10.** This vacuum fitting has a metallic gasket. It is shown open (or disassembled) in the top photo, and closed (assembled) in the bottom photo.

Grooved piping and fittings

Grooved piping and fittings (Figure 11) are not commonly used in pilot plants. They allow easy disassembly, but require specialty tools and skills to make the grooves in the piping. Large sizes are readily available, but smaller sizes, less than 1 in., are rare. Typically available in stainless steel and carbon steel, their use in pilot plants is generally limited to larger process piping (2 in. and above) for which easy assembly/disassembly is important.

Sanitary fittings

Sanitary fittings are gasketed fittings designed to be welded to heavy-walled tubing or light-walled piping. They are available in only Type 304 or Type 316 stainless steel, and are generally restricted to applications with pressures of 250 psig or less; a very limited selection is available for use at pressures up to 1,000 psig. Sanitary fittings are very expensive and come in sizes of 1/2–1 in. and larger. They

▲ **Figure 11.** Grooved piping and fittings are available in larger sizes, but these sizes are often too large for most pilot plants. Photo courtesy of Zeton, Inc.

are designed to be easily cleaned or sterilized, which makes them of interest to the food and pharmaceutical industries. However, their higher costs, lower pressure ratings, limited materials of construction, and need for welding typically limit their use to specialized units (Figure 12).

Best practices

Given these numerous choices, here are some best practices to consider when choosing pilot-plant piping.

Use vacuum fittings where frequent removal or cleaning is required, as their zero-clearance design makes layout and changeout easier. The ability to replace their gaskets maximizes service life.

Consider welded joints for connections that will not need to be opened or are on systems subject to routine or frequent temperature swings, as well as for connections that are in difficult-to-reach locations or under insulation. These connections have the lowest potential for leakage.

Compression fittings require bending at one or more joints for removal. The stress placed on the adjacent connections (which are not being directly made or broken) during bending often creates additional leakage. Even if both ends of the bent section are removed, bending shortens a fitting's service life.

Tubing, while much more flexible and less prone to leakage than piping, is inherently weaker. Therefore, to avoid leakage, mount the valves, not the tubing, wherever possible (Figure 13). The very act of turning a valve can, over time, create stresses that cause additional leakage at the valve connections. Similarly, avoid unsupported elements (*e.g.,* regulators, filters, etc.), long spans (those over 24–36 in.), heavier components (Figure 14), and flimsy supports. All lead to increased leakage in the long term.

▲ **Figure 12.** Two sanitary fittings and a piece of piping are used to create a vessel.

Whether tubing or piping is used, plan the installation and mounting with bends to allow for thermal expansion whenever possible. Bends allow the tubing to expand and contract and limit the forces on fittings, which results in fewer leaks over time. Even small temperature swings (5–10°F), over time, can cause leaks.

Use specialty fittings to minimize the number of joints and potential for leaks. The large number of specialty tubing fittings available can help make this easier. Although more expensive initially, the long-term savings outweigh the initial costs. Some specialized fittings have longer delivery times, so this may require some planning and/or stocking.

When laying out the pilot plant and determining how to mount components, remember that almost everything eventually needs maintenance. Make sure the mounting and layout allow easy removal of instruments, rotating equipment, filters and strainers, reactors, regulators, relief devices, control valves, and similar equipment (Figure 15).

The single best practice in pilot plant layout is to spend time planning where everything will go and leave considerable extra room — beyond what you believe is necessary. Even the most detailed and carefully planned layout typically fails to take into account all the supports, protrusions, viewing angles, adjustment requirements, insulation, utilities, wiring, piping runs, and numerous other small items

▲ **Figure 13.** Mounting the valves, instead of the tubing, can lower stress on tubing and prevent leaks.

▲ **Figure 14.** Heavy equipment requires specialized mounting to minimize stress on the tubing.

that add up and require large amounts of extra space. No matter how good the designer, no matter how detailed the layout drawing (2D or 3D), and no matter how careful the planners are to include everything in the design, the actual installation in the field almost always requires more space than expected.

Similarly, trying to ensure an operable and ergonomic pilot plant layout almost always ends up using more space than the best layout drawing suggests. The realization that a component is just a little too high, a hair too low, a bit too far to the left, or would be much easier to operate if it were a tad to the right ends up costing inches that rapidly add up to feet. We allot contingency — an allowance for unknown but historically predictable items — on timed project schedules without hesitation. We must do the same for space on a pilot plant layout.

Another reason for allocating additional excess space is that pilot plants are continually being modified. These modifications can be made faster and easier, and produce a more operable pilot plant, when there is adequate space nearby. Conversely, cramped units can require substantial rework during modification, which is both time consuming and costly. Such modified layouts are neither ergonomic nor easy to operate. The initial costs of the extra space are usually minimal compared to the long-term savings it produces.

▲ **Figure 15.** This pilot plant has adequate room for maintenance and modifications.

▲ **Figure 16.** Use a holdback (black wrench) whenever tightening or loosening a fitting on threaded piping to avoid excess stress on adjacent fittings.

A good rule of thumb is that a pilot plant almost always ends up requiring 50% more space than any but the most detailed layouts suggest. An additional 50% excess space is a prudent investment for inevitable future modifications. At best, an excellent detailed layout drawing by an experienced pilot plant designer might reduce this to 25%. Building a pilot plant in a space that is too small adds to construction costs, makes future changes difficult or impossible, and greatly increases maintenance costs.

Operators and process engineers should be trained in these best practices to keep their pilot-plant piping leakfree for long-term service. For example, it is important to use a holdback whenever making or breaking any fitting to avoid excess stress on adjacent fittings (Figure 16).

Buying higher-quality pipe, tubing, and fittings almost always has lower long-term costs. Higher-quality gaskets and sealants similarly produce better seals and permit less leakage. Polytetrafluoroethylene (PTFE, *e.g.,* Teflon) tape and pastes generally work better than simple pipe dopes (*i.e.,* low-cost sealants). However, both pastes and dopes require a minimum time for hardening before use. Proper sealing must be used on all piping. Silver-plated vacuum gaskets seal better than plain stainless gaskets and cost only slightly more. Spiral reinforced gaskets generally seal easier and last longer than flat gaskets. Paying more for a good-quality seal is always more cost effective.

In summary, most of the best practices for pilot-plant piping rely on understanding the strengths and weaknesses of the systems, mounting components properly, and providing adequate space to lay the unit out efficiently. CEP

RICHARD PALLUZI, P.E., CSP, is a Distinguished Engineering Associate at ExxonMobil Research and Engineering Co. (1545 Route 22 East, Annandale, NJ 08801; Phone: (908) 730-2323; Email: Richard.p.palluzi@exxonmobil.com), where he is responsible for the design, construction, and support of pilot plants and laboratories at ExxonMobil's research site in Clinton, NJ. He chaired the Clinton site's Safe Operations Team, which is responsible for reviewing and approving all pilot plant and laboratory installations and operations, and chaired ExxonMobil's Pilot Plant and Laboratory Safety Standards Committee, which is responsible for the development and dissemination of more than 100 internal company standards on pilot plant design and construction. He has a BE and an ME in chemical engineering from Stevens Institute of Technology, and is a registered professional engineer in New Jersey and a Certified Safety Professional (CSP). He is the author of two books, 50 articles, and 40 presentations on all phases of pilot plant and laboratory safety and operations. He is a member of AIChE and past chair of the Process Development Division's Area 12b, Pilot Plants; a member of the National Fire Protection Association's committees on NFPA 45 Fire Protection for Laboratories using Chemicals and NFPA 55 Medical and Industrial Gases; and a member of the American Society of Safety Engineers.