Pipe, fittings and related equipment are fundamental to the operation of chemical process plants. The series of articles beginning with this one spells out the details.

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This is the first in a series of articles that will cover a wide range of piping topics. The topics will cross process-industry lines, pertaining to, for example, the chemical, petroleum-refining, pulp-and-paper and pharmaceutical and other industries. The main intent of these articles to address questions and misunderstandings as they relate to use of piping on a general basis.

Typical of the topics that will be covered in this series are the following:

- With respect to ASME flange ratings — Is the correct terminology 150- and 300-pound flange, or is it Class 150 and Class 300 flange? And do the 150 and 300 actually mean anything, or are they simply identifiers? Similarly, with respect to forged fittings, is the terminology 2,000-pound and 3,000-pound, or is it Class 2000 and Class 3000?
- How do you determine which Class of forged fitting to select for your specification?

- How do you determine and then assign corrosion allowance for piping?
- How do you select the proper bolts and gaskets for a service?
- How is pipe wall thickness established?
- What is MAWP?
- What is operating and design pressure, and how do they differ? Similarly, what are operating and design temperature? How do design pressure and temperature relate to a PSV set point and leak testing?
- For a given process application, under what Code should the design be carried out?
- What kind of problems might be expected with sanitary clamp fittings, and how can they be avoided or alleviated?
- What is ASME-BPE? And how do ASME B31.3 and ASME-BPE work in concert with one another? What is ASME BPE doing to bring accreditation to the pharmaceutical industry?
- The catch-all terminology for pipe and tubing is “tubular products.” This term includes pipe, tube and their respective fittings. The term, “piping,” itself refers to a system of pipe, fittings, flanges, valves, bolts, gaskets and other inline components that make up an entire system used to convey a fluid. As for the simple distinction between pipe and tubing, it is that tubing is thin-walled pipe with a diameter different from that of nominally comparable pipe.

**Piping and Tubing**

Piping and tubing can basically be grouped into three broad classifications: pipe, pressure tube and mechanical tube. Based on user requirements, these classifications come in various types, such as standard pipe, pressure pipe, line pipe, water well pipe, oil-country tubular goods, conduit, piles, nipple pipe and sprinkler pipe.

The two types of main relevance to the chemical process industries are standard and pressure pipe. Distinguishable only from the standpoint of use, standard pipe is intended for low-pressure, non-volatile use, whereas pressure pipe is intended for use in higher-integrity services, namely, services in which the pipe is required to convey high-pressure, volatile or non-volatile liquids and gases, particularly at sub-zero or elevated temperatures.

Pipe (standard or pressure) is manufactured to a nominal pipe size (NPS) in which the outside diameter (OD) of...
Pipe is pipe. This is a euphemism quite often used among piping designers and engineers. Taken at face value, this is a true statement — pipe is certainly pipe. However, taken in context, the statement means that no matter which process industry you work in when designing piping systems, the issues are all the same. And in that context, it could not be further from the truth.

Consider in particular the pharmaceutical industry. Although not new per se, it is a relative newcomer to the idea of dedicated design, engineering and construction principles, when compared to other process industries, such as petroleum refining, bulk chemicals, and pulp and paper industries; indeed, even in comparison with nuclear power, and with semiconductor manufacture. Here is a frame of reference, in terms of relevant standard-setting organizations: the American Society of Mechanical Engineers (ASME) was established in 1880; the American Petroleum Institute (API) was established in 1919; 3-A Standards (for the food and dairy industry) were first developed in the 1920's; the ASME committee for BFV (Boiler Pressure Vessel Code) Section III for nuclear power was proposed in 1963; the Semiconductor Equipment and Materials Institute (SEMI) was established in 1973; the International Society for Pharmaceutical Engineers (ISPE) was established in 1980; and ASME Bioprocessing Equipment (BPE) issued its first standard in 1997. Prior to ASME-BPE, the aforementioned 3-A piping standards were the common recourse for facilitating the design of pharmaceutical facilities.

While some of the above standards organizations, and their resulting codes and standards, are specific to a particular industry, others are more generalized in their use and are utilized across the various industries. For example, the design and construction of a large pharmaceutical facility depends not only upon pharmaceutical-based standards, codes, guidelines and industry practices such as those generated by ISPE and ASME-BPE; it also avails itself of standards created for other industries. In other words, when designing and constructing a bulk pharmaceutical finishing facility, or a bulk Active Pharmaceutical Ingredient (API) facility, the engineers and constructors will be working under some of the same standards and guidelines as they would when designing and building in other industries such as a petroleum refinery or bulk chemical facility.

The point is not that the pharmaceutical industry itself is young; as already stated, it is not. The point is that the standards and accepted practices appropriate for state-of-the-art design, engineering and manufacture are. As recently as the past fifteen or so years, industry practice, including dimensional standards for high purity fitting, were left to the resources of the pharmaceutical company owner or their engineering firm (engineer of record). The same point applied to construction methods and procedures, including materials of construction. These requirements were basically established for each project and were very dependent upon what the owner's personnel and the engineering firm brought to the table. Industry standards did not exist.

With regard to materials of construction, the ongoing evolution of technology (science and engineering alike) has raised expectations throughout industry. For instance, out of the research and development that went into the Hubble Space Telescope came new methodology and technology to better measure and define the limits of surface roughness required in material used in hygienic-fluid service piping. This capability is of particular interest to the pharmaceutical and biopharmaceutical industries (as well as the semiconductor industry), where cross-contamination at the molecular level cannot be tolerated in many cases. This requires surfaces to be very cleanable. Surface roughness to be expressed as polish numbers (i.e., #4 or #7) then grit numbers such as 150, 180 or 240. The problem with either of these two methods lay in their subjectivity and their generality. These indicators were not specific enough and the accept/reject result relied too much on a subjective visual verification. There will be more on surface finish requirements in a subsequent installment.

With acute awareness of the ongoing problems currently faced in the pharmaceutical industry and, for altogether different reasons, the semiconductor industry, various standards organizations have taken steps to alleviate the consistent problems that have plagued the industry in the past with, for instance, high purity welding issues, standardization of fittings, and guidelines for industry practice. This series of articles will discuss some of the finer points of these issues, and, in some cases, what the standards organizations, are doing to promote and consolidate some of the better thinking in this industry and in this field.

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Welded steel pipe is manufactured by furnace welding or by fusion welding. Furnace welding is achieved by heating strip steel, also referred to as skelp, to welding temperature then forming it into pipe. The continuous weld, or buttweld, is forged at the time the strip is formed into pipe. This is a process generally used to manufacture low-cost pipe 3 ½ in. OD and below.

Fusion Welded pipe is formed from skelp that is cold rolled into pipe and the edges welded together by resistance welding, induction welding or arc welding. Electric resistance welding (ERW) can be accomplished by flash welding, high-frequency or low-frequency resistance welding. A scarfing tool is used to remove upset material along the seam of flash-welded pipe.

Flash welding produces a high-strength steel pipe in NPS 4 in. through 36 in. Low-frequency resistance welding can be used to manufacture pipe through NPS 12 in. High-frequency resistance welding can be used to manufacture pipe through NPS 42 in.

High-frequency induction welding can be used for high-rate production of small-NPS (6 in. and less) pipe. This is a cleaner form of welding in which scarfing, or the cleaning of upset material along the seam, is normally not required.

Arc welding the longitudinal seam of production pipe is accomplished with submerged arc welding (SAW), inert gas tungsten arc welding (GTAW) also called tungsten inert gas welding (TIG), or gas shielded consumable metal arc welding (MIC).

As will be discussed later in this series, the type of weld seam used in the manufacture of pipe is a factor when calculating the Pressure Design Thickness (t) of the pipe wall. Some types of longitudinal seam pipe welding are not as strong as others, reducing the overall integrity of the pipe wall by a percentage factor given in ASME B31.3 based on the type of longitudinal seam weld.

Seamless Steel Pipe and Tubing: Statements in the following also pertain to tubing.

Seamless steel pipe, made using various extrusion and mandrel mill methods, is manufactured by first creating a tube hollow from a steel billet, which is a solid steel round. The billet is heated to its hot metal forming temperature, then pierced by a rotary piercer or by a press piercer to create the tube hollow, which will have a larger diameter and thicker wall than its final pipe form. The tube hollow is then hot-worked by the mandrel mill process, the Mannesmann plug-mill process, or the Urine Sejournent extrusion process.

Upon completion of these processes, the pipe is referred to as hot-finished. If further work is required to achieve more accuracy in the diameter or wall thickness or improve its finish, the pipe can be cold-finished, or cold-worked. If the pipe is cold-finished, it will then require heat treating to remove pipe-wall stress created during the working in its cold state.

There are also two forging processes used in the manufacture of large diameter (10 to 30 inch) pipe with heavy wall thickness (1.5 to 4 inch). The two forging methods are called forged and bored, and hollow forged.

PIPE FITTINGS
Pipe fittings are manufactured by the following processes: cast, forged and wrought.

Cast fittings
Cast fittings are available in cast iron, malleable iron, ordinary steel, stainless steel, brass, bronze, and other alloy material as follows:

Cast Iron: Cast iron threaded fittings, covered by ASME B16.4, are available in Class 125 and Class 250 for sizes NPS 1/4 in. through 12 in. Cast iron flanged fittings, under ASME B16.1, are available in Class 25, 125 and 250 in sizes NPS 1 in. through 48 in.

Malleable Iron: Malleable iron fittings, under ASME B16.3, are available in Class 150 and Class 300 in sizes NPS 1/8 in. through 6 in. for Class 150, and ¾ in. through 3 in. for Class 300.

Be aware that Classifications such as 150 and 300 are not universal throughout the ASME Standards. They are instead specific to the Standard with which they are associated. One thus cannot, for instance, automatically transfer the pressure/temperature limits of a flange joint in ASME B16.5 to that of a fitting in B16.3.

Cast Steel: Cast steel, stainless steel and alloy steel flanged fittings, under ASME B16.5, are available in Class 150, 300, 400, 600, 900, 1500 & 2500 in sizes ½ in. through 24 in.

Cast Brass: Cast brass, as well as bronze, threaded fittings, under ASME B16.15, are available in Class 125 and 250, in sizes NPS 1/8 in. through 4 in. for Class 125, and 1/4” through 4 in. for Class 250.

Cast Copper: Cast copper solder joints, under ASME B16.18, are available in sizes ¼ in. through 6 in.

Forged fittings
Before discussion of forged fittings, it is illuminating to consider the difference between forged and wrought fittings. The term, forging, actually dates from the times when metal was worked by hand. A bar of steel would be placed into a forge and heated until it reached its plastic state, at which time the metal would be pulled out of the forge and hammered into some desired shape. Today, forging metal basically means working the metal by means of hydraulic hammers to achieve the desired shape.

Wrought iron is corrosion resistant, has excellent tensile strength and welds easily, and in its plastic range is said to be like working taffy candy. What gives wrought iron these attributes is the iron silicate fibers, or slag added to the molten iron with a small percentage of carbon, whereas cast iron, having a high carbon content, is more brittle and not as easily worked.

The smelters, where the iron ore was melted to produce wrought iron, were called bloomeries. In a bloomery, the process did not completely melt the iron ore; rather the semi-finished
product was a spongy molten mass called a bloom, a term derived from the red glow of the molten metal, which is likewise how the process gets its name. The slag and impurities were then mechanically removed from the molten mass by twisting and hammering, which is where the term wrought originates.

Today forged and wrought are almost synonymous. ASTM A234, “Standard Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and High Temperature Service” states in Para 4.1 and in Para 5.1 that wrought fittings made under A234 are actually manufactured or fabricated from material pre-formed by one of the methods listed previously, which includes forging. In ASTM A961, “Standard Specification for Common Requirements for Steel Flanges, Forged Fittings, Valves and Parts for Piping Applications,” the definition for the term Forged is, “the product of a substantially compressive hot or cold plastic working operation that consolidates the material and produces the required shape. The plastic working must be performed by a forging machine, such as a hammer, press, or ring rolling machine, and must deform the material to produce a wrought structure throughout the material cross section.”

The difference, therefore, between forged and wrought fittings is that forged fittings, simply put, are manufactured from bar, while which in its plastic state is formed into a fitting with the use of a hammer, press, or rolling machine. Wrought fittings, on the other hand, are manufactured from killed steel, forgings, bars, plates and seamless or fusion welded tubular products that are shaped by hammering, pressing, piercing, extruding, upsetting, rolling, bending, fusion welding, machining, or by a combination of two or more of these operations. In simpler terms wrought signifies “worked”. There are exceptions in the manufacture of both, but that is the general difference.*

* A point concerning the ASTM specifications is worth noting. In referring to ASTM A961 above, I am referring from what I call a General Requirement Specification. Such a specification is one that covers requirements typical for multiple individual Product Specifications. In this case, the individual Product Specifications covered by A961 are A105, A181, A183, A184, A403, A404, A405, A537 and A586.

The reason I point this out is that many designers and engineers are not aware that when reviewing an A105 or any of the other ASTM individual Product Specifications you may need to include the associated General Requirement Specification in that review. Reference to a General Requirement Specification can be found in the respective Product Specification.
HYGIENIC PIPING

Major characteristics of piping for the pharmaceutical and semiconductor industries are the requirements for high-purity, or hygienic, fluid services. These requirements, as dictated by current Good Manufacturing Practices (GMP) and defined and quantified by the International Soc. of Pharmaceutical Engineers (ISPE) and by ASME Bio Processing Equipment (ASME-BPE), are stringent with regard to the manufacture, documentation, fabrication, installation, qualification, validation and quality control of hygienic piping systems and components.

The hours that the engineer or designer requires in generating, maintaining and controlling the added documentation required for hygienic fabrication and installation adds up to 30% to 40% of the overall cost of fabrication and installation. A subsequent installment in this series will cover in more detail the specific requirements of hygienic fabrication, and, accordingly, where that added cost comes from.

Hygienic is a term defined in ASME-BPE as: "of or pertaining to equipment and piping systems that by design, materials of construction, and operation provide for the maintenance of cleanliness so that products produced by these systems will not adversely affect animal or human health."

While system components such as tube, fittings, valves, as well as the hygienic aspects of the design itself, can apply to the semiconductor industry, the term "hygienic" itself does not; it instead pertains strictly to the health aspects of a clean and cleanable system for pharmaceuticals manufacture. The semiconductor industry requires a high, or in some cases higher, degree of cleanliness and cleanliness than do the hygienic systems in the pharmaceutical industry, for altogether different reasons. A term that can more appropriately be interchanged between these two industries is "high-purity," this implies a high degree of cleanliness and cleanliness without being implicitly connected with one industry or the other.

For what is referred to as product contact material, the absence of surface roughness, minimal dead-legs and an easily cleanable system are all imperative. Therefore, the pharmaceutical industry had to make a departure from the 3A standards (created for the food and dairy industries) of which it had availed itself early on, in order to develop a set of guidelines and standards that better suit its industry. Enter ASME-BPE, which has taken on the task of providing a forum for engineers, pharmaceutical manufacturers, component and equipment manufacturers, and inspectors in an effort to develop consensus standards for the industry where none existed before.

Hygienic piping was, up until just recently, referred to as sanitary piping. Because this term has been so closely associated with the plumbing industry and with sanitary drain piping, it is felt by the pharmaceutical industry that the change in terminology to hygienic is more appropriate.

In both the pharmaceutical and semiconductor industries, the need for crevice-free, drainable systems is a necessity. This translates into weld joint quality, mechanical joint design requirements, interior pipe surface roughness limits, system drainability and dead-leg limitations.

There are two basic types of fitting joints in hygienic piping: welded and clamp. The welded fittings, unlike standard butt-weld pipe fittings, have an added tangent length to accommodate the orbital welding machine. The orbital welding machine allows the welding operator to make consistent high-quality autogenous welds (welds made without filler metal). Fusion is made between the welds (welds made without filler metal). Fusion is made between the pipe and clamp. The welded fittings, unlike standard butt-weld pipe fittings under ASME B16.28 (short-radius 1D elbows), are available in sizes ½ in. through 24 in.

There is no pressure/temperature rating classification for these fittings. In lieu of fitting pressure classifications, both B16.9 and B16.28 require that the fitting material be the same as or comparable to the pipe material specification and wall thickness. Under ASME B16.9, given the same material composition, the fittings will have the same allowable pressure/temperature as the pipe. ASME requires that the fittings under B16.28, short radius elbows, be strength-rated at 80% of the value calculated for straight seamless pipe of the same material and wall thickness.

These fittings can be manufactured from seamless or welded pipe or tubing, plate or forgings. Laterals, because of the elongated opening cut from the run pipe section are strength-rated at 40% of the strength calculated for

Forged steel and alloy steel socketweld (Figure 1) and threaded fittings, under ASME B16.11, are available in sizes NPS 1/8 in. through 4 in. Forged socketweld fittings are available in pressure rating Classes 3000, 6000 and 9000. Forged threaded fittings are available in pressure rating Classes 3000, 6000 and 9000.

Misapplication of the pressure rating in these forged socketweld and threaded fittings is not infrequent; the person specifying components on many cases does not fully understand the relationship between the pressure Class of these fittings and the pipe they are to be used with.

In ASME B16.11 is a table that associates, as a recommendation, fitting pressure Class with pipe wall thickness, as follows:

<table>
<thead>
<tr>
<th>Pipe wall thickness</th>
<th>Threaded Socket-weld</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 or XS</td>
<td>2000</td>
</tr>
<tr>
<td>160</td>
<td>3000</td>
</tr>
<tr>
<td>XXS</td>
<td>6000</td>
</tr>
</tbody>
</table>

The ASME recommendation is based on matching the I.D. of the barrel of the fitting with the I.D. of the pipe. The shoulder of the fitting (the area of the fitting against which the end of the pipe butts), whether socketweld, as shown in Fig. 1, or threaded, is approximately the same width as the specified mating pipe wall thickness, with allowance for fabrication tolerances. As an example, referring to Table 1. You had a specified pipe wall thickness of Sch. 160. The matching threaded forged fitting would be a Class 3000, for socketweld it would be a Class 6000. The fitting pressure class is selected based on the pipe wall thickness. Referring to Fig. 1, one can readily see that by not matching the fitting class to the pipe wall thickness it will create either a recessed area or a protruding area the length of the barrel of the fitting, depending on which side you error on. For forged reinforced branch fittings refer to MSS Standard SP-97 - "Integrally Reinforced Forged Branch Outlet Fittings - Socket Welding, Threaded and Butt Welding Ends."
the parent metals of the two components being welded by means of tungsten inert gas welding. Pipe welding will be covered in more detail in an upcoming installment.

The photograph shows an example of an orbital, or automatic, welding machine mounted on its workpiece. In this example, the piece happens to be a 90-deg elbow being welded to a cross. One can see in this example why the additional straight tangent section of automatic weld fittings is needed — that extra length provides a mounting surface for attaching the automatic welding machine.

As for the clamp connection, it is a mechanical connection whose design originated in the food and dairy industry, but whose standardization has been under development by ASME-BPE. Due to a lack of definitive standardization, most companies that use this type connection require in their specifications that both the ferrule (the component upon which the clamp fits) and the clamp itself come from the same manufacturer. This precaution is to ensure a competent fit.

There are no specific dimensions and tolerances for the clamp assembly, except for those being developed by ASME-BPE. Currently, it is possible to take a set of ferrules from one manufacturer, mate them together with a gasket, attach a clamp from a different manufacturer and tighten up on the clamp nut. In some cases, one can literally rotate the clamp by hand about the ferrules, with no significant force being applied on the joint seal.

The clamp joint is the clamp that applies the force that holds the ferrules together. The fact that this can occur begs the need for standardization to a greater degree than what currently exists. Another issue that currently exists with the clamp joint is gasket intrusion into the pipe inside wall, due to inadequate compression control of the gasket.

Gasket intrusion is a problem in pharmaceutical service for two reasons:

- Depending on the hygienic fluid service and the gasket material, the gasket protruding into the fluid stream can break down and slough off into the fluid flow, contaminating the hygienic fluid
- The intrusion of the gasket into pipe on a horizontal line can also cause fluid holdup. This can result in the loss of residual product, cause potential cross-contamination of product, and promote microbial growth.

Some manufacturers are attempting to overcome these issues by improving on the concept of the clamp joint. One company has developed ferrules whose design provides compression control of the gasket while also controlling the creep tendency that is inherent in, arguably, the most prevalent gasket material used in high purity piping, namely, Teflon.

Another firm manufactures a clamp joint (also provided as a bolted connection) that does not require a gasket. This type of joint is currently in use in Europe. While this connection alleviates the issues that are present with a gasketed joint, added care would need to be applied in its handling. Any scratch or ding to the faced part of the sealing surface could compromise its sealing integrity. Nevertheless this is a connection design worth consideration.

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I wish to thank Earl Lamson, senior Project Manager with Eli Lilly and Co., for taking time out of a busy schedule to read through the draft of this article. He obliged me by reviewing this article with the same skill, intelligence and insight he brings to everything he does. His comments kept me concise and on target.

Edited by Nicholas P. Chopey

Recommended Reading


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His experience covers both the engineering and construction fields and crosses industrial lines to include petroleum refining, chemical, petro-chemicals, pharmaceuticals, pulp & paper, nuclear power, and coal gasification. He has written numerous specifications including engineering and construction guidelines to ensure that design and construction comply with code requirements. Owner expectations and specifications.

Bill is a member of ISPE (International Society of Pharmaceutical Engineers), CSI (Construction Specifications Institute) and ASME (American Society of Mechanical Engineers). He is a contributor to ASME-BPE and sits on two corporate specification review boards. He can be reached at W. M. Huitt Co., P.O. Box 31154, St. Louis, MO 63131-0154, (314) 966-8919