

Piping Design Part 3: Installation, Cleaning, Testing & Verification

Efficiency, quality and safety are the imperatives that are factored in when considering field fabrication, but don't forget cost.

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As the title implies this article will discuss the Installation, Cleaning, Testing and, to a lesser degree, Validation of piping systems. I say to a lesser degree with Validation because Validation is a very complex, often proprietary and exceedingly difficult-to-define topic. Rather than delve into it in great detail as part of a multi-topic article I will attempt to simply provide some understanding as to its function and need.

PIPE INSTALLATION

But first things first, the installation of pipe follows its fabrication and is very frequently a part of it. The installation of pipe can be accomplished in the following four primary ways, or combinations thereof:

1. Field fabricate and install,
2. Shop fabricate and field erected,
3. Skid fabrication, assembly & installation, and
4. Modular construction

I would like to assure you that I am not going to diverge off into fabrication again since we discussed it, although somewhat briefly, in Article II. I am including fabrication in this article simply because fabrication is such an integral part of pipe installation.

FIELD FABRICATE AND INSTALL

Field fabrication and installation is just what it implies. The pipe is fabricated on site either in place or in segments

at an on-site field fabrication area and then erected. A number of factors will dictate whether or not it is feasible to field fabricate: The size and type of the project, pipe size and material, the facility itself, weather conditions, availability of qualified personnel, existing building operations, cleanliness requirements, time available to do the work, etc.

Efficiency, quality and safety are the imperatives that are factored in when considering field fabrication. And before you think I missed it, cost is the fallout of those factors. Logistically speaking, if all pipe could be fabricated on-site in a safe and efficient manner, maintaining quality while doing so, it would make sense to do it in that manner. However, before making that final decision, let's look at some of the pros and cons of field fabrication:

Pros:

1. Only raw material (pipe, fittings, valves, etc.) need to be shipped to the site location. This is much easier to handle and store than multi-plane configurations of pre-fabricated pipe.
2. No time-consuming need to carefully crib, tie-down and chock pre-fabricated *spool pieces for transport to the job site.
3. Reduced risk of damage to spool pieces.
4. More efficient opportunity to fab around unexpected obstacles (structural steel, duct, cable tray, etc.)
5. Fabricate-as-you-install reduces the rework risk assumed when pre-fabricating spools, or the cost

related to field verification prior to shop fabrication.

6. The field routing installation of pipe through an array of insufficiently documented locations of existing pipe and equipment, on a retrofit project, is quite frequently more effective than attempting to pre-fabricate pipe based on dimensional assumptions.

**Spool pieces are the pre-fabricated sections of pipe that are fabricated and numbered in the fab shop then shipped to the job site for installation.*

Cons:

1. Weather is arguably the biggest deterrent. If the facility under construction is not enclosed then protection from the elements will have to be provided.
2. When welding has to be done in conditions that are not environmentally controlled then pre-heating will be required if the ambient temperature (not the metal surface temperature) is 0° F or below.
3. In a new facility, as opposed to having to route piping through an array of poorly located existing pipe and equipment, field fabrication of butt welded pipe is not as efficient and cost effective as shop fabrication.
4. Concerns about safety and efficiency when working in a facility while it is in operation in advance of a turnaround or to begin advance work on a plant expansion.

Generally speaking, threaded, socketweld, grooved, and other proprietary type joints that do not require butt welding are field fabricated and installed. Butt welding of small, 1 1/2" NPS and less, are very often field fabricated and installed because of the added risk of damage during transport, in pre-fabricated form, from the shop to the site.

SHOP FABRICATE AND INSTALL

Shop fabrication is, generally speaking, any pipe, fittings and components that are assembled by welding into spool assemblies at the fabricator's facility. The spools are then labeled with an identifier and transported to the job site for installation.

Each spool piece needs its own identifier marked on the piece itself in some fashion that will make it easy to know where its destination is in the facility and/or where it belongs in a multi-spool system of pipe. This will allow the installer to efficiently stage the piece and ready it for installation.

As part of the process of developing spool sections field-welded joints need to be designated. These are welded joints that connect the pre-fabricated spools. In doing this the designer or fabricator will identify two different types of field-welded joints.

One is a Field Weld (FW) and the other is a Field Closure Weld (FCW). The FW indicates a joint in which the end of a pipe segment is prepared for the installer to set in place and weld to its connecting joint without additional modification in the field. This means that the length of pipe that is joined to another in the field is cut precisely to length and the end prepared in the shop for welding.

The FCW provides the installer with an additional length of pipe, usually 4" to 6" longer than what is indicated on the design drawings, to allow for field adjustment.

What has to be considered, and what prompts the need for a FCW, is the actual, as-installed, location of both the fixed equipment that the pipe assemblies may connect to and the actual installed location of the pipe assembly itself. Odds are that all equipment and piping will not be installed exactly where indicated on design drawings.

The dimensional location of the equipment items given on design drawings is not a finite location, they are merely intended locations, as are drawings for building steel, pipe supports and others. What factors into the installation of shop fabricated pipe is the actual location of the equipment nozzle it will be connecting to in relation to the pipe's installed location.

In connecting to equipment there is a build-up, or stack-up, of tolerances that will effectively place the actual, or final, location of the nozzle at some point in the xyz geometry of three-dimensional space, other than where the design drawing indicates. The tolerance stack-up comes from the following:

1. Manufacturing tolerances in material forming, nozzle location, and vessel support location.
2. The actual set-in-place location of the vessel.
3. Load cell installation (when applicable).
4. The actual set-in-place pipe run-up location.

In order to allow for these inevitable deviations between the drawing dimensions used to fabricate the vessel, set the vessel, and install the pipe assembly, and the actual installed location of the connecting points, a field closure piece, or two, will be required for that final adjustment.

The field closure piece is a designated section of the pipe assembly in which a field weld has been indicated. The section with the field closure weld would be the length required to agree with that indicated on the design drawing, plus an additional 4" to 6" (more or less depending on fabricator's comfort level with the equipment locations). What this does is allow the field to make the final determination in the adjustments when connecting to fixed equipment.

SKID (SUPER SKID) FABRICATION

A skid is a pre-packaged assembly that may contain all or some of the following that make up an operating system: vessels, rotating equipment, piping, automation components, operator interfaces, instrumentation, gages, electrical panels, wiring and connectors, framework, supports, in-line piping components, and insulation. A single process or utility system may fit onto one skid or, depending on size restraints, may comprise multiple skids.

After fabrication of a skid is complete it will typically go through Factory Acceptance Testing (FAT) at the fabricator's facility. The skid is then shipped to the job site where it is installed in its final location. After installation it would typically go through a follow-up Site Acceptance Test (SAT), including additional hydro-testing. This is basically a system shake-down to determine that everything is intact, and that those things that did not remain intact during transport are discovered and repaired.

Logistics and the necessary skill-set required for the installation, connection and start-up of a particular skid package will dictate to what extent the skid fabricator will be involved after it is shipped to the job site.

MODULAR CONSTRUCTION

The term module or modular construction is quite often, in this context, interchanged with the term skid fabrication. A module can refer to pre-fabricated units that actually form the structure of a facility as each is installed. Or, the units may be smaller sub-assemblies that, when combined, make up a complete process or utility system.

Modules too consist of all or some of the following: vessels, rotating equipment, piping, automation components, HVAC, instrumentation, electrical wiring and connectors, framework, walls, architectural components, lighting, supports, in-line piping components, and insulation. This, as an example, allows a complete locker room module to be placed and connected to a complete water treatment module.

The smaller sub-assembly modules, in many cases, are interchanged with the term skid. It saves on misperception when a company defines these terms, both for internal discussion and for the purpose of making it clear to outside contractors, as to what is meant when using the term module.

INSTALL APPROACH

Now that we have a general idea of the four primary approaches to piping installations how do we decide which is the best method, or combination of methods, to use for a particular project? But there is one major caveat I would like to address before launching into this subject.

Each project is individualized with its own particular set of decision drivers with regard to a selected execution

approach. There are no hard and fast rules for determining a best approach at job execution. It requires experienced personnel assigning values to the various aspects of project execution, overlaying a timeline, and then assessing logistics. Sounds simple, but in actuality can be a very complex process.

What I am attempting to say here is, that the following is a guideline and not hard and fast rules. There are simply too many project variables and complexities to allow it.

In approaching this decision keep in mind that the method of installation needs to be weighed against a contractor's preferred methodology. In saying that I am not implying that the contractor's preferred methodology should drive your decision on how to execute a job. On the contrary, once you determine how the job needs to be executed you then look to only those contractors whose preferred methodology agrees with your project execution plans.

Some contractors prefer to do most, if not all fabrication in the shop, others prefer to set up at the job-site, while others are flexible enough to utilize the best of both methods.

The three main criteria, efficiency, quality and safety indicated earlier under "Field Fabricate and Install", would apply here as well. Using those three elements as a basis for making our determination let us look at some common variables:

1. Environment
 - a. Controlled environment
 - b. Open to the elements
2. Industry
 - a. Pharmaceutical
 - b. Biopharmaceutical
 - c. Semiconductor
 - d. Food & Dairy
 - e. Petroleum refining
 - f. Bulk chemical
 - g. Pulp & paper
 - h. Off-Shore
 - i. Pipeline
 - j. Power generation
3. Type of project
 - a. Retrofit
 - b. Fast track approach
 - c. New (Grassroots/Greenfield) project
 - d. Clean-build
 - e. Single level
 - f. Multi-level
 - g. Room repetition
4. Range of pipe material and sizes
 - a. Small percentage of alloy pipe
 - b. Large percentage of alloy pipe
 - c. Large % of large pipe sizes

- d. Large % of small pipe sizes
- e. Mix of small and large pipe sizes
- 5. Location
 - a. Close to metropolitan area
 - b. Remote location
 - c. Country with limited resources

Environment

The environment is only a factor when work has to be done in an open-air structure or other outdoor installation (tank farm, pipeline, pipe rack or yard piping, etc.). Working in an open air structure will require protection from the elements (rain, snow, wind, cold, etc.). There may additionally be a requirement to work in elevated areas on scaffolding and otherwise. All of this can have a potential impact on safety and efficiency.

Pipe rack installation consists mainly of straight runs of pipe, and will not necessarily have a requirement or need for pre-fabrication. That is, unless it is pre-fabricated as modular skid units. Depending on the project it could be cost effective on an overall strategic basis to modularize the pipe rack, steel and all.

The big advantage to shop fabrication is the controlled environment in which it's done. This includes the Quality Control aspect, better equipment (generally speaking), a routine methodology of how a piece of work progresses through the shop, and better control, through a developed routine, of required documentation.

Industry

I know this is generalizing, but we can group the various industries into clean/indoor build and non-clean/outdoor build. There are exceptions to this, but under clean/indoor build we can list the following;

Clean/Indoor build

- a. Pharmaceutical
- b. Biopharmaceutical
- c. Semiconductor
- d. Food & Dairy

Under non-clean/outdoor build we can list the following;

Non-Clean/Outdoor Build

- a. Petroleum refining
- b. Bulk chemical
- c. Pulp & paper
- d. Off-Shore
- e. Pipeline
- f. Power generation

The clean build philosophy comes from the need to construct certain facilities with a more stringent control on construction debris. Those industries listed above under Clean/Indoor Build often require a facility, at least a portion

of a facility, to be microbial and particulate free, as stipulated by the design.

There can be no debris, organic or inorganic, remaining after construction in accessible or inaccessible spaces of the facility. Of particular concern with the pharmaceutical, biopharm and food & dairy is food waste and hidden moisture. Food waste can entice and support rodents and insects, and hidden moisture can propagate mold, which can eventually become airborne. If not discovered until the facility is in operation the impact, upon discovery, can potentially be devastating to production.

Such contamination can be discovered in one of two ways. Discovery at the source, possibly behind a wall or some other out-of-the-way place, means that not only does current production have to cease, but product will have to be analyzed for possible contamination. Once found it then has to be remediated.

The other method of discovery comes from the continuous testing and validation of the product stream. If a contaminant is discovered in the product the production line is stopped and the problem then becomes an investigation in to finding the source of the contamination.

The clean-build philosophy therefore dictates more stringent and strict requirements for controlling and inspecting for debris on an ongoing basis throughout construction and start-up.

It will be necessary, on a clean-build site, to follow some rather simple rules:

1. Smoking or smokeless tobacco products of any kind are not allowed on the site property,
2. Off site break and lunch areas, no food or drink, other than water, allowed on the site premises,
3. Do not begin installing pipe, duct or equipment until, at the very least, a roof is installed,
4. After roof and walls are installed ensure that there is no standing water remaining in the facility,
5. Prior to and during the construction of hollow walls, such as those framed and dry-walled, ensure on a daily basis that there is no moisture or debris in the wall cavity,
6. Duct work delivered to the job site shall have the ends covered with a plastic sheet material, which shall remain on the ends until connected in place,
7. Fabricated pipe delivered to the job site shall have the ends covered in a suitable fashion with suitable material, and shall remain on the ends until connected in place,
8. During and after flushing and testing of pipelines all water spills shall be controlled to the extent possible and shall be cleaned up after flushing and testing or at the end of the work day,

Type of Project

While the type of project is not the main influence in determining how you approach the execution of a project it does play a key role. It will help drive the decision as to how the piping should be fabricated and installed.

As an example, if the project is a retrofit it will require much of the pipe, regardless of size and joint connection, to be field fabricated and installed. This is due simply to the fact that the effort and cost necessary to verify the location of all existing pipe, equipment, walls, columns, duct, etc. in a somewhat precise manner, would not be very practical. You would be better served by field verifying the approximate location of the above items with existing drawings, for planning and logistic purposes, then shop or field fabricate, verify and install as you go.

A fast track project, one that has a compressed schedule, will require parallel activities where possible. Whereas shop and skid fabrication would be utilized as much as possible simply to expend more man-hours over a shorter time period while attempting to maintain efficiency. Even though there may be added cost to this approach. This approach is time driven and not budgetary driven.

A new grassroots facility still requires routing verification as you go, but certainly not the much more involved need to locate previously installed obstructions as needs to be done when working with an existing facility.

If the project is a clean-build project (typical for the pharmaceutical, biopharmaceutical, semiconductor and food & dairy industries) inside an environmentally controlled area it will be more practical to shop fabricate or utilize skid or modular fabrication for most, if not all of the piping. This will reduce the number of personnel and the amount of fabrication debris in the facility, and provide better control for keeping it out of the pipe itself. With personnel you could have food wrappers, drink cans and bottles, food waste, and clothing items. Fabrication debris could include metal filings, cutting oil, pieces of pipe, weld rod and weld wire remnants, etc.

If the project is not a clean-build, but is still inside an environmentally controlled facility the same logic does not necessarily apply. The decision to shop fab and install or to field fab and install becomes one based on efficiency rather than how best to maintain a clean area. And that's not to say that if it doesn't qualify as a clean-build project then the construction debris can just be allowed to pile up.

There is still safety and efficiency to be concerned with on any project and a clean job site is a major part of that. Maintaining a clean job site is an integral component of good project execution.

Keeping personnel and equipment to a minimum at the job site is not an absolute, but is one of the key considerations to the efficiency of pipe installation. Following that logic most of the butt welded pipe should be shop fabricated. A couple of things to consider, when determining which butt welded pipe to shop fabricate, is size and material.

Range of Pipe Material and Sizes

Shop fabricated spools need to be transported to the job site. This requires handling. Handling and transporting small diameter pipe and/or thin-wall tubing spools creates the potential for damage to those spools.

If you are shop fabricating everything and the distance from shop to site is simply across town the risk to damaging small diameter pipe spools is a great deal less than if they have to be shipped half way across the US, Europe or Asia. Or even across an ocean.

In transporting spools over long distances, unless there is a great deal of thought and care given to cribbing the load of spools, it may not be beneficial to transport butt welded pipe spools NPS 1 1/2" and less. It may be more practical to fabricate these sizes on site, unless you are fabricating hygienic or semi-conductor piping. These types of systems require a great deal more control and a cleaner fabrication. Meaning that pipe fabrication will require a clean shop area on-site, or the pipe will need to be fabricated at an off-site, better controlled shop facility.

A practical rule of thumb in determining what to shop fab and what to field fab follows in Table 3-1:

Table 3-1 Shop and Field Fabrication			
Size (in)	Material	Joint	Shop/Field
≤ 1 1/2	Pipe	1, 2, 3, 6	Field
≤ 1 1/2	Pipe	4 & 5	Shop
≥ 2	Pipe	3 & 6	Field
≥ 2	Pipe	4 & 5	Shop
≤ 1	Tubing	5	Field
≤ 1	Tubing	5	Shop (a, b)
≥ 1 1/2	Tubing	5	Shop

Joint Type:

1 = Socketweld

2 = Threaded

3 = Grooved – Fully (Grooved fittings and pipe ends.)

4 = Grooved – Partially (Shop-welded spools with grooved ends.)

5 = Butt weld

6 = Flanged – Lined or unlined Pipe

Notes:

a. Hygienic tubing

b. Special cribbing and support for transport

The above Table 3-1 is a general methodology. Dictates of the project and a contractors SOP will determine how best to define what gets shop fabricated and what gets field fabricated.

Petroleum refining and bulk chemical projects are generally open air projects in which field fabrication and installation of pipe is exposed to the elements. While a clean build is not a requirement on these types of projects efficiency and, above all, safety is, as it is on any type project. Because of this, it would make sense to utilize shop fabrication as much as possible.

Fabricating pipe spools under better controlled shop conditions will provide improved efficiency and safer per hour working conditions over what you will generally find in the field. This translates into fewer accidents.

Referring back to Table 3-1, with respect to the potential for damage during transport, pipe sizes NPS 2" to 3" and larger ship much better than smaller pipe sizes. Particularly when working with thin-wall tubing. This is a consideration when determining what to shop fab and what to field fab.

Location

Job site location is one of the key markers in determining shop or field fabrication. In many cases building a facility in a remote location will be a driver for utilizing a disproportionate amount of skid or module fabrication. Disproportionate in the sense that project management may look at modularizing the entire job, rather than mobilize the staffing and facilities needed to fab and install on or near the job site. This would constitute a larger amount of modularization over what might normally be expected for the same type project in a more metropolitan region, or an area with reasonable access to needed resources.

To expand on that thought; it was pointed out to me by Earl Lamson, Senior Project Manager with Eli Lilly and Company, an observation I fully agree with, that project resources, even in metropolitan areas, are quite frequently siloed around a specific industry. In certain regions of the US for example, you may discover that there are an abundance of craftsman available when building a refinery, but that same region may have difficulty, from a trained and experienced personnel perspective, in supporting the construction of a semiconductor facility.

Consequently when building a pharmaceutical facility in another region you may find a sufficient population of trained and experienced craftsman for that industry, but may not find that resource adequate when building a chemical plant.

Building a project in a remote location requires the project team to rethink the job-as-usual methodology. From a logistics standpoint mobilization of personnel and material become a major factor in determining the overall execution of such a project. Project planning is a big component in project execution, but is more so when attempting to build in

remote areas. And this doesn't even touch on the security aspect.

Nowadays, when constructing in any number of remote areas, security is a real concern that requires real consideration and real resolution. Reduced on-site staffing is a good counter-measure in reducing risk to personnel when building in remote or even non-remote third-world areas.

PIPE SYSTEM CLEANING

While there are requirements in ASME for leak testing cleaning requirements do not exist. In ASTM A 380 & 967 you will find Standards on cleaning, descaling and passivation, but nothing in ASTM on simply flushing and general cleaning. Defining the requirements for the internal cleaning of piping systems falls within the responsibilities of the Owner.

The term "cleaning", in this context, is a catch-all term that also includes flushing, chemical cleaning, and passivation. So before we go further let me provide some definition for these terms as they apply in this context. I say, "as they apply in this context", because these terms are somewhat flexible in their meaning, depending on source and context, and could be used to describe activities other than what is intended in this dialog.

Definitions

Cleaning: A process by which water, solvents, acids or proprietary cleaning solutions are flushed through a piping system to remove contaminants such as cutting oils, metal filings, weld spatter, dirt, and other unwanted debris.

Flushing: A process by which water, air or an inert gas is forced through a piping system either in preparation for chemical cleaning or as the *only* cleaning process. Flushing can be accomplished by using dynamic pressure head or released static pressure head, as in a fill-and-dump procedure. Blow-down can be considered as flushing with a gas.

Passivation: A process by which a chemical solution, usually with a base of nitric, phosphoric, citric acid or other mild oxidant, is used to promote or accelerate the formation of a thin (25 to 50 Angstroms) protective oxide layer (a passive layer) on the internal surface of pipe, fittings and equipment. In stainless steels, the most commonly used alloy at present, it removes any free iron from the pipe surface to form a chromium-rich oxide layer to protect the metal surface from aggressive liquids such as high purity waters.

Note: Cleaning and Flushing can be interchanged when the process only requires water, air or an inert gas to meet the required level of cleanliness. When the term "cleaning" is used in this context it may infer what is defined as flushing.

Cleaning and Testing

With regard to cleaning and leak testing, and which to do first, there are drivers for both and different schools of thought on the overall process. Each contractor will have their preference. It is in the Owner's best interest to determine their preference or be at risk in just leaving it to the contractor. In either case you should have a line of thought on the process, if for no other reason than to be able to understand what it is the contractor is proposing to do.

At the very least, in advance of leak testing, perform either a basic flush of a *test circuit, or perform an internal visual examination as the pipe is installed. A walk-down of the test circuit should be done just prior to filling the system with any liquid. The last thing you want to happen is to discover too late that a joint wasn't fully connected or an in-line component was taken out of the pipeline. In a facility that is not a clean-build it can simply be a mess that has to be cleaned up. In a clean-build facility an incident such as this can potentially be costly and time-consuming to remediate.

Note: *refer to the following section on "Leak Testing"

Before getting into further specifics of this discussion we need to define some general cleaning and testing procedures and assign them some easy to use indicators. In this way it will be much easier to discuss the various processes. We can then work through some general scenarios and see which sequencing works best.

Following is a list of cleaning requirements:

Table 3-2 – General Cleaning Scenarios	
Category	Description
C-1	Flush only (water, air or inert gas)
C-2	Flush, clean with cleaning solution, flush
C-3	Clean with cleaning solution, flush
C-4	Flush, clean, passivate, flush

Following is a list of leak testing requirements:

Table 3-3 – General Leak Testing Scenarios	
Category	Description
T-1	Initial service leak test
T-2	Hydrostatic leak test
T-3	Pneumatic leak test
T-4	Sensitive leak test
T-5	Alternative leak test

While the cleaning descriptions are self explanatory the leak testing descriptions may not be. Please refer to the following section on "Leak Testing" to find clarification of the terms used in Table 3-3.

One other thing I would like to mention before we go on. Since we are discussing new pipe installation we will not include steam-out cleaning or pipeline pigging. These are cleaning procedures that are used on in-service piping to clean the fluid service residue build-up from interior pipe walls after a period of use.

Before subjecting the system to an internal test pressure the piping should first be walked down to make certain, as mentioned earlier, that there are no missing or loose components. The system is then flushed with water or air to make sure that there are no obstacles in the piping. Over the years we have discovered in installed piping systems everything from soda cans to shop towels, work gloves, nuts & bolts, weld rod, Styrofoam cups, candy wrappers, and other miscellaneous debris including dirt and rocks.

After this initial flush, which could also be the only flush and cleaning required, the system is ready for chemical cleaning or to leak test. In large systems it may be beneficial to leak test smaller test circuits and then perform a final cleaning once the entire system is installed and tested. This would include a final completed system leak test that would test all of the joints that connect the test circuits. That is, unless these joints were tested as the assembly progressed.

If it is decided, on large systems, to leak test smaller segments, or test circuits as they are installed, prior to flushing the entire system, the piping needs to be examined internally as it is installed. This is to prevent any large debris items, as listed above, from remaining in the piping during the test.

Now that we have touched on those generalities let's take a look at each of the cleaning Categories listed in Table 3-2 and see how to apply them.

Cleaning Category C-1 is simply a flush with water, air or inert gas. The one non-manual assist that water requires in order for it to clean the inside of a piping system is velocity. But what velocity is necessary?

The main concept behind flushing a pipeline is to dislodge and remove suspected debris. In order to dislodge, suspend and remove this unwanted material in the piping system it is necessary that water or air be forced through the piping system at a velocity sufficient to suspend the heaviest suspected particles and move them along the pipeline.

The velocity required to suspend the particles and move them along the pipeline for removal is dependent upon their size and weight, and the flush medium. Metal filings, arguably the heaviest particles normally found in newly fabricated pipe, will have a terminal mid-range settling velocity, in water, of approximately 10 feet per second. Therefore, a flushing velocity of approximately 10 feet per second should be achieved during the flush. (This does not apply to acid cleaning.)

The following Table 3-4 indicates the rate of flow required to achieve approximately 10 feet per second of velocity through various sizes and schedules of pipe.

Table 3-4 – Rate of Flushing Liquid Needed to Maintain Approximately 10 FPS Velocity (GPM)							
Pipe Sch.	Pipe Sizes (inches)						
	½	¾	1	1 ½	2	3	4
5s	12	20	34	77	123	272	460
40	10	16	27	64	105	230	397
80	7	13	22	55	92	—	—

Purging a piping system clear of debris with air requires a velocity of approximately 25 feet per second. The following Table 3-5 indicates the rate of air flow required to achieve approximately 25 feet per second of velocity through various sizes and schedules of pipe.

Table 3-5 – Rate of Air Flow to Maintain Approx 25 FPS Velocity (SCFS)								
	Pipe Sch.	Pipe Sizes (inches)						
		½	¾	1	1 ½	2	3	4
Press 15 psig	5s	0.14	0.23	0.39	0.86	1.39	3.06	5.17
	40	0.11	0.19	0.30	0.71	1.18	2.59	4.47
	80	0.08	0.15	0.25	0.62	1.04	2.32	4.03
Press 50 psig	5s	0.30	0.51	0.84	1.88	3.02	6.67	11.3
	40	0.23	0.41	0.66	1.56	2.56	5.65	9.73
	80	0.18	0.33	0.55	1.35	2.26	5.05	8.79

One thing you might notice is that the size range only extends to 4” NPS for both the liquid flush and for the air or gas blow-down. The reason for that is the volume of liquid or gas required to achieve the necessary velocity through the larger pipe sizes is quite significant.

As an example a 6” NPS pipeline would require approximately 900 to 1000 GPM, depending on wall thickness of the pipe, to achieve a velocity of 10 FPS. This gets a little cumbersome and costly. That is unless you have pumps or compressors in place that can achieve the necessary flow rate.

The alternative for liquid flushing the larger pipe sizes other than using source line pressure or a pump is to perform a fill-and-dump. In this process the pipe system is completely filled with liquid and then drained through a full line size, quick opening valve.

In doing this there has to be enough static head to generate sufficient force and velocity to achieve essentially the same result as the pumped or line pressure liquid.

Cleaning Category C-2 is a three-step process by which the piping system is initially flushed out with a liquid to remove most of the loose debris. This is followed by the

circulation of a cleaning solution, which is then followed by a final flush of water.

Cleaning solutions are, in many cases, proprietary detergent or acid-based solutions each blended for specific uses. Detergent-based solutions are generally used for removing dirt, cutting oils and grease. Acid-based solutions are used to remove the same contaminants as the detergent-base plus weld discoloration and residue. The acid based solution also passivates the pipe wall.

As defined earlier, passivation provides a protective oxide barrier against corrosion. The acids used in some cleaning solutions for ferrous and copper materials leave behind a passivated interior pipe surface as a result of the cleaning process. In utility water services such as tower water, chilled water, etc., this barrier against corrosion is maintained with corrosion inhibitors that are injected into the fluid stream on an ongoing basis.

And keep in mind that when I talk about passivated surfaces this is a natural occurrence with metals in an oxygen environment. The acid merely initiates and speeds up the process.

When using stainless alloys, usually 316L, in hygienic water services such as Water For Injection (WFI), Purified Water, Deionized (DI) Water and in some cases Soft Water, passivation is a final intended step in the preparation for service of these pipelines.

Passivation is also a periodic ongoing preventative maintenance procedure. To explain: High purity water is very corrosive and attacks any free iron found on the surface of stainless pipe. Free iron has a tendency to come out of solution when material is cold worked, as in bending or forming pipe without the benefit of heat. It also occurs with the threading of alloy bolts, which are solution annealed (heat treated) after threading. Passivation removes this free iron while also accelerating, in the presence of O₂, the oxidation rate of the stainless steel providing a chromium rich oxide corrosion barrier as defined above.

Over time (and this is one hypothetical thought on the subject), this very thin corrosion barrier tends to get depleted or worn off, particularly at high impingement areas of the piping system (elbows, tees, pump casings, etc.). Once the passive layer wears through any free iron exposed to the high purity water will oxidize, or rust. This will show up as surface rouge.

Rouging is an unwanted surface discoloration which is periodically removed by means of a derouging process. This is an operational, as-needed chemical cleaning process that will remove all or most of the rouge and also re-passivate the internal pipe surface.

Discussions and research on the topic of rouging continues. This is a subject that has more questions than answers at the present time. Currently the ASME-BPE is looking into this issue. One of the questions to be answered is whether or not rouge is actually detrimental to product streams.

Cleaning Category C-3 is a two-step cleaning process that uses a detergent or acid based solution to clean the pipe interior of any unwanted residue or debris. This is then followed by a final flush of water.

Cleaning Category C-4 is a three or four-step process generally used in hygienic service piping. In most cases, simply due to the clean fabrication approach used in hygienic pipe fabrication, only a water flush with Deionized (DI) quality water or better would be necessary for cleaning followed by passivation of the piping system, then a final flush of water.

There are variations to each of these primary cleaning functions and it would be in an Owner's best interest to define these requirements, by fluid service, in advance of the work to be done.

LEAK TESTING

Pressure testing is a misnomer that is quite often used when referring to leak testing of piping systems. And as long as all parties understand what is meant by that, then that's fine. However, in a true sense a pressure test is a test you perform on a relief valve to test its set point pressure. The intent, when pressure testing a relief valve, is not to check for leaks, but to test the pressure set point of the valve by gradually adding pressure to the relief valve until it lifts the valve off of the seat.

A leak test, on the other hand, is performed to check the sealing integrity of a piping system by applying internal pressure to a pre-determined limit, based on design conditions, then checking joints and component seals for leaks. It is not intended that the MAWP of a piping system be verified or validated.

Before discussing the various types of leak tests and leak test procedures I would like to briefly talk about controlling and tracking this activity.

Cleaning and testing, like many aspects of a project, should be a controlled process. Meaning, there should be a formal method of documenting and tracking this activity as the Contractor proceeds through the leak testing process..

In documenting the leak testing activity there are certain forms that will be needed. They consist of the following:

1. A dedicated set of P&ID's to identify the limits and number the test circuits;

2. A form to record components that were either installed or removed prior to testing;
3. A checklist form for field supervision to ensure that each step of the test process is accomplished; and
4. Leak test data forms

The two sets of documents, from those listed above, that need to be retained are the P&ID's (#1) and the Leak Test Data Forms (#4). The other two sets of forms are procedural checklists.

The Leak Test Data forms should contain key data such as:

1. Test circuit number
2. P&ID number(s)
3. Date of test
4. Project name and/or number
5. Location within facility
6. Line number(s)
7. Design pressure
8. Test pressure
9. Test fluid
10. Test fluid temperature
11. Time (military) recorded test begins
12. Pressure at start of test
13. Time (military) recorded test ends
14. Pressure at end of test
15. Total elapsed time of test
16. Total pressure differential (plus or minus) from beginning to end of test period
17. Comment section (indicate if leaks were found and system was repaired and retested or if system passed)
18. Signatures & dates

Also make certain that the testing contractor has current calibration logs of their test instruments, such as pressure gages.

To continue with the leak testing, ASME B31.3 defines five primary leak tests as follows:

Initial Service Leak Test: This applies only to those fluid services meeting the criteria as defined under ASME B31.3 Category D fluid service. This includes fluids in which the following apply:

- (1) the fluid handled is nonflammable, nontoxic, and not damaging to human tissue;
- (2) the design gage pressure does not exceed 1035 kPa (150 psi); and
- (3) the design temperature is from -29°C (-20°F) through 186°C (366°F).

The Initial Service leak test is a process by which the test fluid is the fluid that is to be used in the intended piping system at operating pressure and temperature. It is accomplished by connecting to the fluid source with a

valved connection and then gradually opening the source valve and filling the system. In liquid systems air is purged during the fill cycle through high point vents. A rolling examination of all joints is continually performed during the fill cycle and for a period of time after the system is completely filled and is under line pressure.

In a situation in which the distribution of the pipeline that is being tested has distribution on multiple floors of a facility there will be pressure differentials between the floors due to static head differences. This will occur in operation and is acceptable under initial service test conditions.

The test pressure achieved for initial service testing pressure is what it is. Meaning that what you achieve in the test is what it will be in operation. The only difference is that the flowing fluid during operation will incur an amount of pressure drop that will not be present during the static test.

Hydrostatic leak test: This is the most commonly used leak test and is performed by using a liquid, normally water, and in some cases with additives to prevent freezing, under a calculated pressure.

$$P_T = \frac{1.5PS_T}{S} \quad (\text{eq. 1})$$

Where:

P_T = Test Pressure, psi

P = Internal design gage pressure, psig

S_T = Stress value at test temperature, psi (see B31.3 Table A-1)

S = Stress value at design temperature, psi (see B31.3 Table A-1)

Eq. 1 represents the equation for that calculated pressure. However, as long as the metal temperature of S_T remains below the temperature at which the allowable stress value for S_T begins to diminish and the allowable stress value of S and S_T are equal then S_T and S cancel each other leaving the simpler eq. 2:

$$P_T = 1.5P \quad (\text{eq. 2})$$

Unlike initial service testing, pressure variations due to static head differences in elevation have to be accommodated in hydrostatic testing. What I mean by that is the calculated test pressure is the minimum pressure required for the system. When hydrostatically testing a multi-floor system the minimum calculated test pressure shall be realized at the highest point. This is not stated, but is inferred in B31.3.

Pneumatic leak test: This test is performed using air or a preferred inert gas. This is a relatively easy test to perform simply from a preparation and cleanup standpoint. However, this test has a hazardous potential because of the stored

energy in the pressurized gas. And for that reason alone it should be used very selectively.

When pneumatic testing is performed it must be done under a strictly controlled procedure with on-site supervision in addition to coordination with all other crafts and personnel in the test area.

$$P_T = 1.1P \quad (\text{eq. 3})$$

$$P_T = 1.4P \quad (\text{eq. 4})$$

$$P_T = 1.2P \text{ to } 1.5P \quad (\text{eq. 5})$$

The test pressure for pneumatic leak testing under B31.3 is calculated using eq. 3, for B31.9 it is calculated using eq. 4, and for B31.1 it is calculated using eq. 5.

One misconception I need to address here with pneumatic leak testing is in its procedure, as described in B1.3. There is a misconception that the test pressure should be maintained while the joints are examined. This is not correct. As B31.3 explains, pressure is increased gradually until the test pressure is reached. At that point the test pressure is held until piping strains equalize throughout the system. (eq. 1.1)

After allowing a sufficient amount of time for piping strains to equalize the pressure is then reduced to the design pressure (refer to article II for design pressure). While holding design pressure all joints are examined for leaks. It is not required that the examination take place while holding test pressure.

There is more to the entire procedure that I did not include here. Please refer to B31.3 or B31.1 for full details on pneumatic leak testing.

Sensitive leak test: This leak test is performed when there is a higher than normal potential for fluid leakage, such as for hydrogen. I also recommend its use when a fluid is classified as a Category M fluid service. B31.1 refers to this test as *Mass-Spectrometer and Halide Testing*.

In B31.3 the process for sensitive leak testing is as follows:

The test shall be in accordance with the gas and bubble test method specified in the BPV Code, Section V, Article 10, or by another method demonstrated to have equal sensitivity. Sensitivity of the test shall be not less than 10^{-3} atm-ml/sec under test conditions.

(a) The test pressure shall be at least the lesser of 105kPa (15 psi) gage, or 25% [of] the design pressure.

(b) The pressure shall be gradually increased until a gage pressure the lesser of one-half the test pressure or 170 kPa (25 psi) gage is attained, at which time a preliminary check shall be made. Then the pressure shall be gradually increased in steps until the test pressure is reached, the pressure being held long enough at each step to equalize piping strains.

In testing fluid services that are extremely difficult to seal against, or fluid services classified as a Category M fluid service I would suggest the following in preparation for the process described under B31.3: prior to performing the sensitive leak test perform a low pressure (15 psig) test with air or an inert gas using the bubble test method. Check every mechanical joint for leakage.

After completing the preliminary low pressure pneumatic test, purge all of the gas from the system using helium. Once the system is thoroughly purged, and contains no less than 98% helium, continue using helium to perform the sensitive leak test with a helium mass spectrometer.

Helium is the trace gas used in this process and has a molecule that is close to the size of the hydrogen molecule making it nearly as difficult to seal against as hydrogen without the volatility. Test each mechanical joint using the mass-spectrometer to determine leak rate, if any.

Alternative leak test: In lieu of performing an actual leak test, in which internal pressure is used, the alternative leak test takes the examination and flexibility analysis approach.

This test is conducted only when it is determined that hydrostatic or pneumatic testing would be detrimental to the piping system and/or the fluid intended for the piping system, an inherent risk to personnel, or impractical to achieve.

As an alternative to testing with internal pressure it is acceptable to qualify a system through examination and flexibility analysis. The process calls for the examination of all groove welds, and includes longitudinal welds used in the manufacture of pipe and fittings that have not been previously tested hydrostatically or pneumatically. It requires a 100% radiograph or ultrasonic examination of those welds. Where applicable, the sensitive leak test shall be used on any untested mechanical joints. This Alternative leak test also requires a flexibility analysis as applicable.

Very briefly, a flexibility analysis verifies, on a theoretical basis, that an installed piping system is within the allowable stress range of the material and components under design conditions if a system: (a) duplicates or replaces without significant change, a system operating with a successful service record; (b) can be judged adequate by comparison with previously analyzed systems; and (c) is of uniform size, has no more than two points of fixation, no

intermediate restraints, and falls within the limitations of empirical equation (eq. 6).

$$\frac{Dy}{(L-U)^2} \leq K_1 \quad (\text{eq. 6})$$

Where:

D = outside diameter of pipe, in. (mm)

y = resultant of total displacement strains to be absorbed by piping system, in. (mm)

L = developed length of piping between anchors, in. (mm)

U = anchor distance, straight line between anchors, ft. (m)

$K_1 = 208,000 S_A/E_a \text{ (mm/m)}^2$
 $= 30 S_A/E_a \text{ (in./ft.)}^2$

S_A = allowable displacement stress range per equation (1a) of ASME B31.3, ksi (MPa)

E_a = reference modulus of elasticity at 70°F (21°C), ksi (MPa)

One example in which an alternative leak test might be used is in making a branch tie-in to an existing, in-service line using a saddle with an o-let branch fitting with a weld neck flange welded to that and a valve mounted to the flange. Within temperature limitations, the fillet weld used to weld the saddle to the existing pipe can be examined using the dye penetrant or magnetic particle method. The circumferential butt or groove weld used in welding the weld neck and the o-let fitting together should be radiographically or ultrasonically examined. And the flange joint connecting the valve should have the torque of each bolt checked after visually ensuring correct type and placement of the gasket.

There are circumstances, regarding the tie-in scenario we just discussed for alternative leak testing, in which a hydrostatic or pneumatic test can be used. It depends on what the fluid service is in the existing pipeline. If it is a fluid service that can be considered a Category D fluid service then it is quite possible that a hydrostatic or pneumatic leak test can be performed on the described tie-in.

By capping the valve with a blind flange modified to include a test rig of valves, nipples and hose connectors, you can perform a leak test rather than an alternative leak test. As mentioned this does depend on the existing service fluid. If the existing fluid service is steam or a cryogenic fluid then you might want to consider the alternative leak test.

Cleaning and Leak Testing Procedures

As you can see by equations eq. 1 through eq. 5 above, the leak test pressure, except for initial service testing, is based on design pressure and design temperature. In Article 2 we described design pressure and temperature. What we will do here is apply that understanding and describe a few general procedures for cleaning and testing.

As in all other project functions control and documentation is a key element in the cleaning and testing of piping systems. It does, however, need to be handled in a manner that is dictated by the type of project. Meaning that you don't want to bury yourself in unwarranted paperwork and place an unneeded burden on the contractor when it isn't necessary.

Building a commercial or institutional type facility will not require the same level of documentation and stringent controls that an industrial type facility would require. But even within the industrial sector there are varying degrees of required testing and documentation.

To begin with, documentation requirements in industry standards are simplistic and somewhat generalized, as is apparent in ASME B31.3, which states in Para. 345.2.7:

Records shall be made of each piping system during the testing, including:

- (a) date of test*
- (b) identification of piping system tested*
- (c) test fluid*
- (d) test pressure*
- (e) certification of results by examiner*

These records need not be retained after completion of the test if a certification by the inspector that the piping has satisfactorily passed pressure testing as required by this Code is retained.

ASME B31.3 goes on to state, in Para. 346.3:

Unless otherwise specified by the engineering design, the following records shall be retained for at least 5 years after the record is generated for the project:

- (a) examination procedures; and*
- (b) examination personnel qualifications.*

Standards, that cover such a broad array of industrial manufacturing, do not, as a rule, attempt to get too specific in some of their requirements. Beyond the essential requirements, such as those indicated above, the Owner, engineer or contractor has to assume responsibility and know-how for providing more specific and proprietary requirements for a particular project specific to the particular needs of the Owner. The following will help, to some extent, fill that gap.

Cleaning Procedures

This section will describe some fundamental cleaning procedures as they might appear in a specification or guideline, and this includes the leak test procedures that follow. This will give you some idea as to what you might consider developing for your own set of specifications. Assuming that if your company repeatedly executes projects you will have cleaning and testing guidelines, in some form,

prepared for your contractor. If not you may not get what you expect. It's better to give some forethought to these activities rather than be surprised at the results.

Once a menu of these cleaning and testing procedures are developed, using pre-assigned symbols, much as those given in the following, they can then be specified in the line list with the respective fluid services as you require. In this manner there is no second guessing during construction. Each piping circuit is assigned a specific clean and test protocol in advance.

Many pre-developed procedures I have seen over the years, those developed by Owners in particular, have been very simplistic, and typically out of date. This is an indicator to most contractors that the Owners Rep will most likely not attempt to enforce them. The contractor, in making that assumption, may simply ignore them and perform their own procedures.

What your procedural guidelines should do is be explicit enough and current to the point where the contractors know that someone has given some thought as to how they want that work accomplished. Making it far more likely they (the contractors) will execute your procedure instead of their's.

It is certainly acceptable to accommodate suggestions to a procedure from a contractor when it doesn't compromise the intent of the Owner's requirements and improves the efficiency of the contractor. If a submitted alternate procedure does not compromise the intent of the Owner it is recommended that they be accepted. This will allow the Owner to see if that efficiency is really there. With that in mind let's create a couple of general cleaning procedures.

A general practice in the flushing and cleaning process, also indicated in leak testing, is the evacuation of air when using liquids. Always provide high point vents for evacuating air during the fill cycle and low point drains for clearing out all of the liquid when the process is complete.

Using the same symbology indicated in Table 3-2 these cleaning procedures will be categorized as follows:

Category C-1: Flush or Blow Down only (water, air or inert gas)

C-1.1 These systems shall be flushed with the fluid that the system is intended for. There shall be no hydrostatic or pneumatic leak test. An Initial Service leak test will be performed. Refer to test Category T-1.

- a. Connect system to its permanent supply line. Include a permanent block valve at the supply line connection. All outlets shall have temporary hoses run to drain. Do not flush through coils, plates, strainer or filter elements.

- b. Using supply line pressure, flush system through all outlets until water is clear and free of any debris at all outlet points. Flush a quantity of fluid through each branch not less than three times that contained in the system. Use Table 3-6 to estimate volume of liquid in the system.
- c. These systems are required only to undergo an Initial Service leak test. During the flushing procedure, and as the system is placed into service, all joints shall be checked for leaks.
- d. Any leaks discovered during the flushing process, or during the process of placing the system into service, will require the system to be drained and repaired. After which the process will start over with step 2.

If no debris is found the system is ready for leak testing.

Category C2: Flush then clean with cleaning solution, followed by a neutralization rinse. Because of the thoroughness of the flush, clean and rinse process there should be no need to check for transient debris, only for neutralization. However, if circumstances dictate otherwise then a final check for debris may be warranted.

C-2.1 These systems shall be pre-flushed with potable water, cleaned with (indicate cleaning agent) then a rinse/neutralization followed by leak testing with potable water. If it is determined that the system will be installed and tested progressively in segments, the sequence of cleaning and testing can be altered to follow the segmented installation. Thereby leak

Table 3-6 – Volume of Water Per Lineal Foot of Pipe (gal.)																
	Pipe Sizes (inches)															
Sch.	1/2	3/4	1	1 1/2	2	3	4	6	8	10	12	14	16	18	20	24
5s	.021	.035	.058	.129	.207	.455	.771	1.68	—	—	—	—	—	—	—	—
20	—	—	—	—	—	—	—	—	2.71	4.31	6.16	7.34	9.70	12.4	15.2	22.2
40	.016	.028	.045	.106	.176	.386	.664	1.51	2.61	4.11	5.84	9.22	9.22	14.5	14.5	—
80	.012	.023	.037	.093	.154	.345	.60	1.36	—	—	—	—	—	—	—	—

C-1.2 These systems shall be flushed clean with Potable Water.

- a. Connect a flush/test manifold at a designated inlet to the system, and a temporary hose or pipe on the designated outlet(s) of the system.
- b. Route temporary hose or pipe from potable water supply, approved by Owner, and connect to flush/test manifold. Route outlet hose or pipe to sewer, or as directed by Owner rep. Secure end of outlet.
- c. Using a Once through procedure (not a re-circulation), and the rate of flow in Table 3-4, perform an initial flush through the system with a quantity of potable water not less than three times that contained in the system. Use Table 3-6 to estimate volume of liquid in the system. Discharge to sewer, or as directed by Owner rep.
- d. After the initial flush, insert a conical strainer into a spool piece located between the discharge of the piping system and the outlet hose. Perform a second flush with a volume of potable water not less than that contained in the system.
- e. After the second flush (step 4), pull the strainer and check for debris; if debris is found repeat step 3.

testing segments of a piping system as they are installed without cleaning. The entire system would then be cleaned once installed and tested.

- a. Hook up flush/test manifold at a designated temporary inlet to the system between the circulating pump discharge and the system inlet. Install a temporary hose or pipe on the designated outlet(s) of the system.
- b. Route temporary hose or pipe from potable water supply, approved by Owner, and connect to flush/test manifold. Route outlet hose or pipe to sewer, or as directed by Owner's Rep.
- c. Close valve between the circulating pump (if no valve included in the system design insert a line-blind or install a blind flange with a drain valve) discharge and flush/test rig. Open valve between flush/test manifold and piping system.
- d. Using the once through procedure (meaning the cleaning fluid is not re-circulated), and the rate of flow in Table 3-4, perform an initial flush through the system, by-passing the circulation pump, with a quantity of potable water equal to not less than three times that contained in the system. Use Table 3-6 to estimate volume of liquid in the system.
(Note: During the water flush check the system for leaks. Verify no leaks prior to introducing chemical cleaning solution to the piping system.)

e. Discharge to sewer, or as directed by Owner's Rep.

f. After completing the initial flush, drain remaining water in the system. Or, retain water if cleaning chemicals will be added to the circulating water.

g. Configure valves and hoses to circulate through pump. Connect head tank, or other source containing cleaning agent, to connection provided on circulation loop.

h. Fill the system with the pre-measured (*indicate preferred cleaning agent and mixing ratio or % by volume*) and circulate through the system for 48 hours. To minimize corrosion, if anticipated, circulate cleaning agent at a low velocity rate prescribed by the cleaning agent manufacturer.

i. Drain cleaning agent to sewer or containment, as directed by Owner.

j. Reconnect as in step #1 for the once through flush/neutralization, and flush system with potable water using a quantity not less than three times that of the system volume. Since the (*name cleaning agent*) solution has a neutral pH the rinse water will have to be visually examined for clarity. Rinse until clear. The rinse must be started in as short as quickly after the cleaning cycle as possible. If cleaning residue is allowed to dry on the interior pipe wall, it will be more difficult to remove by simply flushing. The final rinse and neutralization must be accomplished before any possible residue has time to dry.

k. Test pH for neutralization. Once neutralization is achieved proceed to step #12.

l. Remove pump and temporary circulation loop then configure the system for leak testing. This may include removal of some components, insertion of line-blinds, installation of temporary spools pieces, etc.

Those three examples should provide an idea as to the kind of dialog that needs to be created in providing guidance and direction to the contractor responsible for the work. And, as I stated earlier, these procedures, for the most part, are flexible enough to accommodate suggested modifications from the contractor.

Leak Test Procedures

As in the cleaning procedures we will keep this general, but provide enough specifics for you to develop leak testing

procedures that will suit your company's own particular needs.

In Article 1 I stated the B31.3 definition for Category D fluid services. I then indicated that while Category D fluid services qualified for initial service leak testing there are caveats that should be considered.

Again, this is a situation in which ASME provides some flexibility in testing by lowering the bar on requirements where there is reduced risk in failure. Provided, that if failure should occur the results would not cause catastrophic damage to property or irreparable harm to personnel.

The Owner's responsibility, for any fluid service selected for initial service leak testing lies in determining what fluid services to place into each of the fluid service Categories. Those Categories being: Normal, Category D, Category M, and High Pressure.

Acids, caustics, volatile chemicals and petroleum products are usually easy to identify as those not qualifying as a Category D fluid service. Cooling tower water, chilled water, air, and nitrogen are all easy to identify as qualifiers for Category D fluid services. The fluid services that fall within the acceptable Category D guidelines, but still have the potential for being hazardous to personnel are not so straight forward.

Using water as an example, at ambient conditions water will simply make you wet if you get dripped or sprayed on. Once the temperature of water exceeds 140°F (60°C), by OSHA standards, it starts to become detrimental to personnel upon contact. At this point the range of human tolerance becomes a factor. However, as the temperature continues to elevate it eventually moves into a range that increasing becomes scalding upon human contact and human tolerance is no longer a factor because it is now hazardous and the decision is made for you.

Before continuing I need to be clear on the above subject matter. The 140°F temperature mentioned above is with respect to simply coming in contact with an object at that temperature. Brief contact at that temperature would not be detrimental. In various litigation related to scalding it has been determined that an approximate one-second exposure to 160°F water will result in third degree burns. An approximate half-minute exposure to 130°F water will result in third degree burns. And an approximate ten minute exposure to 120°F water can result in third degree burns.

With the maximum temperature limit of 366°F (185.5°C) for Category D fluid services what the Owner needs to consider here are three factors: within that range of 140°F (60°C), the temperature at which discomfort begins to set in, to 366°F (185.5°C), the upper limit of Category D fluids, what do we consider hazardous; what is the level of

opportunity for risk to personnel; and what is the level of assured integrity of the installation.

What I mean by assured integrity is this: if there are procedures and protocols in place that require, validate and document third-party inspection of all pipe fabrication, installation and testing, then there is a high degree of assured integrity in the system. If some or all of these requirements are not in place then there is no assured integrity.

All three of these factors: temperature, risk of contact, and assured integrity, have to be considered together to arrive at a reasonable determination for borderline Category D fluid services. If, for instance, a fluid service is hot enough to be considered hazardous, but is in an area of a facility that sees very little personnel activity then the fluid service could still be considered as a Category D fluid service.

One factor I have not included here is the degree of relative importance of a fluid service, or in other words, if a system failed how big of a disruption would it cause in plant operation, and how does that factor into this process.

As an example, if a safety shower water system has to be shut down for leak repair the down-time to make the repairs has little impact on plant operations. This system would therefore be of relative low importance and not a factor in this evaluation process.

If on the other hand a chilled water system has to be shut down for leak repair to a main header, this could have a significant impact to operations and production. This could translate into lost production and could be considered a high degree of importance.

You could also extend this logic a bit further by assigning normal fluid service status to the primary headers of a chilled water system and assigning Category D status to the secondary distribution branches then leak test accordingly. You need to be cautious in considering this. By applying different Category significance to the same piping system it could cause more confusion than it is worth. In other words it may be more value added to simply default to the more conservative Category of Normal.

Continuing; if we can consider that there is a high assured integrity value for these piping systems there are two remaining factors to be considered. The first would be: within the above indicated temperature range at what temperature should a fluid be considered hazardous; and secondly, how probable is it that personnel could be in the vicinity of a leak, should one occur.

For our purpose here let us determine that any fluid 160°F (71°C) and above is hazardous upon contact with human skin. If the fluid you are considering is within this temperature range then it has the potential of being

considered a normal fluid, as defined in B31.3, pending its location as listed in Table 3-7.

Table 3-7 – Areas Under Consideration For Cat. D			
Group	Description	Yes	No
1	Personnel Occupied Space		√
2	Corridor Frequented by Personnel		√
3	Sensitive Equipment (MCC, Control Room, etc.)		√
4	Corridor Infrequently Used by Personnel	√	
5	Maintenance & Operations Personnel Only Access	√	

As an example, if you have a fluid that is operating at 195°F (90.6°C) it would be considered hazardous in this evaluation. But, if the system is located in a Group 5 area (ref. Table 3-7) it could still qualify as a Category D fluid service.

After the above exercise in evaluating a fluid service we can now continue with a few examples of leak test procedures. Using the same symbology indicated in Table 3-3 these leak test procedures will be categorized as follows:

Category T-1: Initial Service Leak Test

T-1.1 This Category covers liquid piping systems categorized by ASME B31.3 as Category D Fluid service and will require Initial Service Leak Testing only.

1. If the system is not placed into service or tested immediately after flushing and cleaning, and has set idle for an unspecified period of time it shall require a preliminary pneumatic test at the discretion of the Owner. In doing so, air shall be supplied to the system to a pressure of 10 psig and held there for 15 minutes to ensure that joints and components have not been tampered with, and that the system is still intact. After this preliminary pressure check proceed.
2. After completion of the flushing and cleaning process, connect the system, if not already connected, to its permanent supply source and to all of its terminal points. Open the block valve at the supply line and gradually feed the liquid into the system.
3. Start and stop the fill process to allow proper high point venting to be accomplished. Hold pressure to its minimum until the system is completely filled and vented.
4. Once it is determined that the system has been filled and vented properly, gradually increase pressure

until 50% of operating pressure is reached. Hold that pressure for approximately 2 minutes to allow piping strains to equalize. Continue to supply the system gradually until full operating pressure is achieved.

5. During the process of filling the system, check all joints for leaks. Should leaks be found at any time during this process drain the system, repair leak(s) and begin again with step 1. (*Caveat: Should the leak be no more than a drip every minute or two on average at a flange joint, it could require simply checking the torque on the bolts without draining the entire system. If someone forgot to fully tighten the bolts then do so now. If it happens to be a threaded joint you may still need to drain the system, disassemble the joint, clean the threads, add new sealant and reconnect the joint before continuing.*)

6. Record test results and fill in all required fields on the leak test form.

T-1.2. This Category covers pneumatic piping systems categorized by ASME B31.3 as Category D Fluid service and will require Initial Service Leak Testing.

1. After completion of the blow-down process, the system shall be connected to its permanent supply source, if not already done so, and to all of its terminal points. Open the block-valve at the supply line and gradually feed the gas into the system.

2. Increase the pressure to a point equal to the lesser of one-half the operating pressure or 25 psig. Make a preliminary check of all joints by sound or bubble test. If leaks are found release pressure, repair leak(s) and begin again with step 1. If no leaks are identified continue to step 3.

3. Continue to increase pressure in 25 psi increments, holding that pressure momentarily (approximately 2 minutes) after each increase to allow piping strains to equalize, until the operating pressure is reached.

4. Check for leaks by sound and/or bubble test. If leaks are found release pressure, repair leak(s) and begin again with step 2. If no leaks are found the system is ready for service.

5. Record test results and fill in all required fields on the leak test form.

Category T-3.1: Hydrostatic Leak Test

T-3.1. This Category covers liquid piping systems categorized by ASME B31.3 as Normal Fluid service.

1. If the system is not placed into service or tested immediately after flushing and cleaning, and has set idle for an unspecified period of time it shall require a preliminary pneumatic test at the discretion of the Owner. In doing so, air shall be supplied to the system to a pressure of 10 psig and held there for 15 minutes to ensure that joints and components have not been tampered with, and that the system is still intact. After this preliminary pressure check proceed.

2. After completion of the flushing and cleaning process, with the flush/test manifold still in place and the temporary potable water supply still connected (reconnect if necessary), open the block valve at the supply line and complete filling the system with potable water.

3. Start and stop the fill process to allow proper high point venting to be accomplished. Hold pressure to its minimum until the system is completely filled and vented.

4. Once it is determined that the system has been filled and vented properly, gradually increase pressure until 50% of the test pressure is reached. Hold that pressure for approximately 2 minutes to allow piping strains to equalize. Continue to supply the system gradually until test pressure is achieved.

5. During the process of filling the system, and increasing pressure to 50% of the test pressure, check all joints for leaks. Should any leaks be found drain system, repair leak(s) and begin again with step 1.

6. Once the test pressure has been achieved, hold it for a minimum of 30 minutes or until all joints have been checked for leaks. This includes valve and equipment seals and packing.

7. If leaks are found evacuate system as required, repair and repeat from step 2. If no leaks are found, evacuate system and replace all items temporarily removed.

8. Record all data and activities on leak test forms.

Those three examples should provide an idea as to the kind of guideline that needs to be created in providing direction to the contractor responsible for the work.

For leak testing to be successful on your project, careful preparation is key. This preparation starts with gathering information on test pressures, test fluids, and the types of tests that will be required. The most convenient place for this information to reside is the piping line list or piping system list.

A piping line list and piping system list achieve the same purpose only to different degrees of detail. On some projects it may be more practical to compile the information by entire service fluid systems. Other projects may require a more detailed approach by listing each to and from line along with the particular data for each line.

The line list itself is an excellent control document that might include the following for each line item:

1. Line size
2. Fluid
3. Nominal material of construction
4. Pipe Spec
5. Insulation spec
6. P&ID
7. Line sequence number
8. from and to information
9. Pipe code
10. Fluid Service Category
11. Heat Tracing
12. Operating Pressure
13. Design Pressure
14. Operating Temperature
15. Design Temperature
16. Type of Cleaning
17. Test Pressure
18. Test Fluid
19. Type of Test

Developing this type of information on a single form provides everyone involved with the basic information needed for each line. Having access to this line-by-line information in such a concise well organized manner reduces guess-work and errors during testing.

Test results, documented on the test data forms, will be maintained under separate cover. Together the line list provides the required information on each line or system and the test data forms provide signed verification of the actual test data of the test circuits that make up each line or system.

VALIDATION

The process of Validation has been around for longer than the 40 plus years I have been in this business. You may know it by its less formal namesakes walk-down and checkout. Compared to validation, walk-down and checkout procedures are not nearly as complex, stringent, or all inclusive.

Validation is actually a subset activity under the umbrella of Commissioning and Qualification (C&Q). It is derived from the need to authenticate and document specifically defined requirements for a project and stems indirectly from, and in response to, the Code of Federal Regulation 29CFR Titles 210 and 211 current Good

Manufacturing Practice (cGMP) and FDA requirements. These CFR Titles and FDA requirements drove the need to demonstrate or prove compliance.

These requirements can cover everything from verification of examination and inspection, documentation of materials used, software functionality and repeatability to welder qualification, welding machine qualification, etc.

The cGMP requirements under 29CFR Titles 210 & 211 are a vague predecessor of what validation has become, and continues to become. From these basic governmental outlines companies, and the pharmaceutical industry as a whole, have increasingly provided improved interpretation of these guidelines to meet many industry imposed, as well as self-imposed requirements.

To a lesser extent, industrial projects outside the pharmaceutical, food & drug, and semi-conductor industries, industries not prone to require such in-depth scrutiny, could benefit from adopting some of the essential elements of validation. Elements such as: material verification, leak test records, welder and welding operator qualification records, etc.

At face value this exercise would provide an assurance that the fabricating/installing contractor is fulfilling their contractual obligation. The added benefit is that in knowing that this degree of scrutiny will take place the contractor will themselves take extra pain to minimize the possibility of any rejects.

And I am not inferring that all contractors are out to get by with as little as they can. Just the opposite is actually true. Most contractors qualified to perform at this level of work are in it to perform well and to meet their obligations. Most will already have their own verification procedure in place.

The bottom line is that the Owner is still responsible for the end result. No one wants to head for the litigation table at the end of a project. And the best way to avoid that is for the Owner to be proactive in developing their requirements prior to initiating a project. This allows the spec writers and reviewers the benefit of having time to consider just what those requirements are and how they should be defined without the time pressures imposed when this activity is project driven.

Performing this kind of activity while in the heat of a project schedule tends to force quick agreement to specifications and requirements written by parties other than those with the Owner's best interest at heart.

Validating a piping system to ensure compliance and acceptability is always beneficial and money well spent.

Wrapping Up

Before closing out this last of three articles there are just a couple of things I would like to touch on. We had discussed industry Standards earlier and how they are selected and applied on a project. What I didn't cover is the fact that most projects will actually have a need to comply with multiple industry Standards.

In a large grass-roots pharmaceutical project you may need to include industry compliance Standards for much of the underground utility piping, ASME B31.1 for boiler external piping (if not included with packaged boilers), ASME B31.3 for chemical and utility piping throughout the facility, and ASME-BPE for any hygienic piping requirements.

These and other Standards, thanks in large part to the cooperation of the standards developers and ANSI, work hand-in-hand with one another by referencing each other where necessary. These Standards committees have enough work to do within their defined scope of work without inadvertently duplicating work done by other Standards organizations.

An integrated set of American National Standards is the reason that, when used appropriately, these Standards can be used as needed on a project without fear of conflict between those Standards.

One thing that should be understood with industry Standards is the fact that they will always be in a state of flux; always changing. And this is a good thing. These are changes that reflect updating to a new understanding, expanded clarification on the various sections that make up a Standard, staying abreast of technology, and simply building the knowledge base of the Standard.

As an example, two new Parts are being added to the seven Parts currently existing in ASME-BPE. There will be a Metallic Materials of Construction Part MMOC, and a Certification Part CR. This is all part of the ever-evolving understanding of the needs of the industrial community and improved clarification, through discussion and debate on content.

Writing these articles was a form of informational triage for me. There were definite piping topics I wanted to include and others I would have preferred to include, but could leave out without too much of an impact. And then there were the extended discussions on some topics that ultimately had to be sacrificed. This is why some topics were briefer than I would have liked.

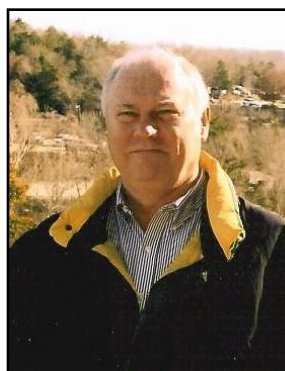
My attempt at covering such a wide range of discussion on industrial piping was to provide a basic broad understanding of some key points on this topic, not, as I said earlier, to go into great detail on any specific topic.

I hope that in writing these articles I piqued enough interest that some of you will dig deeper into this subject matter to discover and learn some of the more finite points of what we discussed here. I also hope these articles provided enough basic knowledge of piping for you to recognize when there is more to a piping issue than what you are being told.

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My deep appreciation again goes to Earl Lamson, senior Project Manager with Eli Lilly and Company, for taking the time to review each of these three articles. His comments help make this article, and the others, better documents than they otherwise would have been. He obliged me by applying the same skill, intelligence and insight he brings to everything he does. His comments kept me concise and on target.

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