Piping Design for Potentially Lethal Chemicals

Integrity and reliability are critical for piping and equipment that handle chemicals with extreme health hazards

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SETTING THE TONE

It is one thing to sit in an office designing and engineering a CPI (Chemical Process Industry) facility, but an altogether different thing to work in and operate such a facility day in and day out. Working in close proximity to the high pressures and temperatures often used in processing is cause enough for concern over a person's well being; working in close proximity to chemicals that are considered toxic, hazardous, or reactive escalates that concern to a very high degree indeed. This is why integrity and reliability in equipment and piping systems should be of paramount consideration in the design of such facilities.

Integrity, of such things as a piping system, is a relative term. In all practicality you would not expect the same level of integrity to be designed into a Cooling Tower Water piping system as that of a piping system containing 30% sulfuric acid. Nor would you expect the same level of integrity to be designed into a system containing 30% sulfuric acid as that of a piping system containing cyanogen bromide.

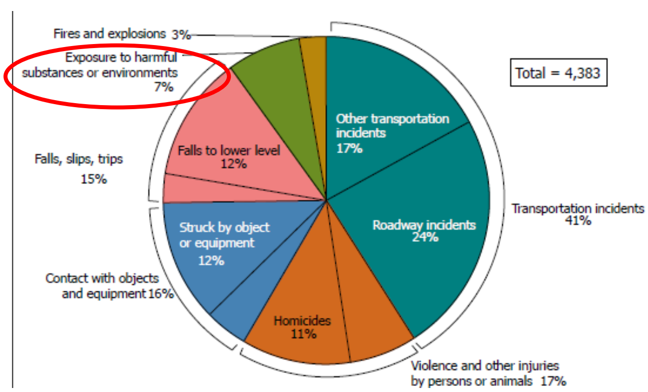

Figure 1 – Fatal Occupational Injuries by Major Event (Bureau of Labor Statistics 2012)

The degree of integrity assigned to the design elements and components of a piping system is therefore related, not only to the design coincident of pressure/temperature, but also to the degree of potential hazard (read volatility or toxicity) that can be attributed to the fluid itself.

This discussion will focus on piping systems that contain potentially lethal fluids. It will guide the designer/engineer through the process of making the determination for when a fluid should be considered potentially lethal and what attributes need to be considered in the design of such systems.

As Fig. 1 shows, of the 4383 work related deaths overall for 2012, 9% were attributed to exposure to harmful substances in the workplace.

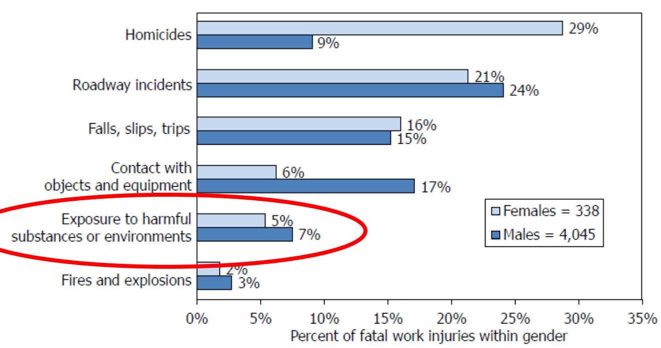

Figure 2 – Distribution of Fatal Injury Events by Gender (Bureau of Labor Statistics 2012)

As Fig. 2 shows, statistics do not disparage between genders. For those exposed to harmful substances there is only a 2% differential between men and women.

Figure 3 points out the fact that even though the fatality count for the manufacturing sector at 314 is moderate the per capita rate, at 2.2/100,000 is a relatively low ratio. But that, by no means, negates the fact that even one fatality is one too many.

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What can skew such data are incidents that draw the attention of the public and lawmakers. Incidents such as the 1984 Bhopal, India, incident resulting in a number of deaths ranging from 2259 to 16,000 and injuries in excess of 500,000; October 1989 Phillips Petroleum Company, Pasadena, TX, incident resulting in 23 deaths and 132 injuries; the May 1991 IMC, Sterlington, LA, incident resulting in 8 deaths and 128 injuries; the September 2005 explosion at the Texas City, TX BP refinery where 15 were killed and 180 injured; and the February 2010 explosion at the Kleen Energy Power Plant in Middletown, CT that killed six and injured more than fifty personnel.

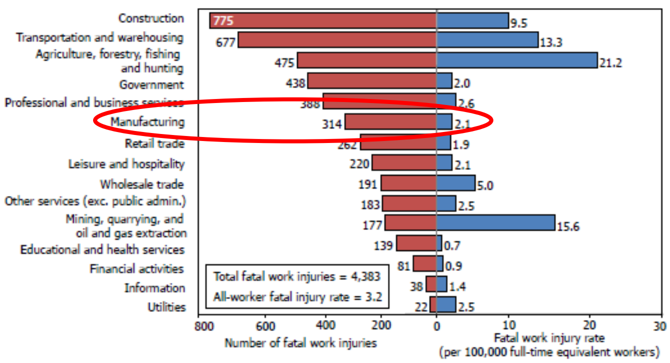

Figure 3 – Number and Rate of Fatal Occupational Injuries by Industry Sector (Bureau of Labor Statistics 2012)

Not only do such incidents capture the attention of the public and lawmakers alike they also capture the attention of organizations such as the NFPA (National Fire Protection Association) and the ASME (American Society of Mechanical Engineers). These and other organizations will quite often modify or introduce content into their codes and standards in response to the causal effects of such incidents.

The other relevant metrics required for a safe operating facility, beyond that of the piping, and equipment itself, is a well thought out preventative maintenance program and operating procedure. But our focus here is on the piping, so let us dig a little deeper into what we mean when discussing lethal chemicals.

GETTING INTO THE WEEDS OF CHEMICAL LETHALITY

To put our discussion into context we can turn to such resources as the Department of Transportation (DOT) (49CFR), National Fire Protection Association (NFPA), Occupational Safety and Health Organization (OSHA) (29CFR), the Environmental Protection Agency (EPA) (40CFR), and REACH, a European Union Regulation. OSHA currently addresses 400 substances within their regulations; Their Chemical Sampling Information database contains data on approximately 1500 chemical substances; The EPA's TSCA (Toxic Substance Control Act), which by the way is currently under review on Capitol Hill, Chemical Substance Inventory contains over 62,000 chemical substances; and in general there are currently in excess of 100,000 MSDS (Material Safety Data Sheets) on file. Having said that, this discussion will be more acutely focused on the 140 chemicals found in OSHA's "List of Highly Hazardous Chemicals, Toxics, and Reactives (Mandatory)" found under 29CFR1926.64 Appendix A.

In drilling down even further we will look at only those chemicals that are considered lethal, from a toxic standpoint; Chemicals that could be considered within the criteria to be declared candidates for ASME B31.3 Category M Fluid Service.

The 2012 edition of ASME B31.3 Process Piping code defines Category M fluid service as:

> *a fluid service in which the potential for personnel exposure is judged to be significant and in which a single exposure to a very small quantity of a toxic fluid, caused by leakage, can produce serious irreversible harm to persons on breathing or bodily contact, even when prompt restorative measures are taken.*

OSHA, under The OSHA Hazard Communication Standard, Subpart Z, Toxic and Hazardous Substances 29CFR1910.1200, defines Hazardous Chemicals as:

> "*Any chemical which is a physical hazard or a health hazard*."

It goes on to define physical hazard as

> "*a chemical for which there is scientifically valid evidence that it is a combustible liquid, a compressed gas, explosive, flammable, an organic peroxide, an oxidizer, pyrophoric, unstable (reactive) or water-reactive*."

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It also defines Health hazard as

> "*a chemical for which there is statistically significant evidence based on at least one study conducted in accordance with established scientific principles that acute or chronic health effects may occur in exposed employees. The term "health hazard" includes chemicals which are carcinogens, toxic or highly toxic agents, reproductive toxins, irritants, corrosives, sensitizers, hepatotoxins, nephrotoxins, neurotoxins, agents which act on the hematopoietic system, and agents which damage the lungs, skin, eyes, or mucous membranes*."

Appendix A under 29CFR1910.1200 defines the term "toxic" in three forms of human interaction:

- **By ingestion** – A chemical that has a median lethal dose (LD_{50}) of more than 50 milligrams per kilogram but not more than 500 milligrams per kilogram of body weight when administered orally to albino rats weighing between 200 and 300 grams each.
- **By contact** – A chemical that has a median lethal dose (LD_{50}) of more than 200 milligrams per kilogram but not more than 1,000 milligrams per kilogram of body weight when administered by continuous contact for 24 hours (or less if death occurs within 24 hours) with the bare skin of albino rabbits weighing between two and three kilograms each.
- **By inhalation** – A chemical that has a median lethal concentration (LC_{50}) in air of more than 200 parts per million but not more than 2,000 parts per million by volume of gas or vapor, or more than two milligrams per liter but not more than 20 milligrams per liter of mist, fume, or dust, when administered by continuous inhalation for one hour (or less if death occurs within one hour) to albino rats weighing between 200 and 300 grams each.

That same Appendix A also defines the term "highly toxic" in three forms of human interaction as well:

- **By ingestion** – A chemical that has a median lethal dose (LD_{50}) of 50 milligrams or less per kilogram of body weight when administered orally to albino rats weighing between 200 and 300 grams each.
- **By contact** – A chemical that has a median lethal dose (LD_{50}) of 200 milligrams or less per kilogram of body weight when administered by continuous contact for 24 hours (or less if death occurs within 24 hours) with the bare skin of albino rabbits weighing between two and three kilograms each.
- **By inhalation** – A chemical that has a median lethal concentration (LC_{50}) in air of 200 parts per million by volume or less of gas or vapor, or 2 milligrams per liter or less of mist, fume, or dust, when administered by continuous inhalation for one hour (or less if death occurs within one hour) to albino rats weighing between 200 and 300 grams each.

FOOTNOTE: LD_{50} , in which LD stands for "Lethal Dose", is the amount of a material, given all at once, which causes the death of 50% (one half) of a group of test animals. The LD_{50} is one way to measure the short-term poisoning potential (acute toxicity) of a material.
LC_{50}, in which LC stands for "Lethal Concentration", is, in inhalation experiments, the concentration of an airborne chemical that kills 50% of the test animals in a given time (usually four hours). In environmental studies LC values can also mean the concentration of a chemical in water.

Also found in this discussion is the term "*highly hazardous chemicals*". OSHA defines this as "…*a substance possessing toxic, reactive, flammable, or explosive properties* …" While this definition reaches beyond the scope of this discussion it nevertheless captures the essence of and remains within the realm of potentially lethal chemicals.

Selecting Category M Fluid Service Candidates

If your CPI facility resides in California, Oregon, Michigan, Kentucky, or any of the Canadian provinces then you are required by code to comply with the ASME B31.3 Process Piping code; or if your facility or project has adopted B31.3 as a compliance code through self stipulation and contractual obligation then all of the fluid services used for processing are required to be Categorized in accordance with B31.3.

One such Category to be considered will be the aforementioned Category M fluid service. The definition, as stated above, suggests that such fluids can be lethal or at the very least debilitating to humans upon exposure. While ASME does not extend their definition to a list of possible Category M chemical candidates other resources do, although in a different manner.

Other resources consider these types of chemicals as hazardous or poisonous to personnel. OSHA, the DOT, the EPA, and the NFPA each provide their own listing of what they consider hazardous or poisonous chemicals based on their own set of criteria.

By adopting the consensus of one or more of these resources for determining whether a chemical is hazardous or poisonous, and therefore under consideration as a Category M Fluid, an owner can use such lists as a resource in the process of determining which chemicals within their own facility may be considered Category M Fluid service candidates.

OSHA

Under 29CFR OSHA provides a listing of Highly Hazardous Chemicals, Toxics, and Reactives. However, their list is broad in its interpretation and provides a Threshold Quantity (TQ) for each chemical, which requires further consideration on the part of the owner. This is a good resource, but not without the need for additional analysis.

EPA

The EPA under 40CFR provides a listing of Hazardous Substances as defined by the EPA under the TSCA's Chemical Substance Inventory list (http://www.epa.gov/oppt/existingchemicals/pubs/tscainventory/howto.html).

This is justifiably a broad interpretation of hazardous chemicals that does not define or categorize the various chemicals to the extent that it would assist the owner in making a Category M determination.

DOT

The Hazardous Material Table in 49CFR (DOT) has 23 Class and Division Numbers that categorize chemicals according to their degree of hazard, or non-hazard, for the purpose of transportation. Of those 23 Classes and Divisions, 3 would be considered Category M Fluids:

1. (no Class No.) Forbidden Materials,
2. (2.3) Poisonous Gas,
3. (6.1) Poisonous Materials.

49CFR Definitions for the above:

Forbidden Materials – *(The definition is too elaborate and lengthy for this venue. Refer to 49CFR 173.21 for clarification)*

Division 2.3 – A gas *poisonous by inhalation,* means a material which is a gas at 68°F in accordance with ASTM E681, Standard Test Method for Concentration Limits of Flammability of Chemicals or other equivalent method approved by the Associate Administrator for Hazardous Materials Safety. The flammability of aerosols is determined by the tests specified in 49CFR 173.306(i) of this part.

Division 6.1 – A material, other than a gas, which is known to be so toxic to humans as to afford a hazard to health during transportation, or which, in the absence of adequate data on human toxicity:

1. Is presumed to be toxic to humans because it falls within any one of the following categories when tested on laboratory animals (whenever possible, animal test data that has been reported in the chemical literature should be used):
   - (i) *Oral Toxicity*. A liquid with an LD_{50} for acute oral toxicity of not more than 500mg/kg or a solid with an LD_{50} for acute oral toxicity of not more than 200 mg/kg.
   - (ii) *Dermal Toxicity*. A material with an LD_{50} for acute dermal toxicity of not more than 1000 mg/kg.
   - (iii) *Inhalation Toxicity*.
     - (A) A dust or mist with an LC_{50} for acute toxicity on inhalation of not more than 10 mg/L; or

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(B) A material with a saturated vapor concentration in air at 68°F greater than or equal to one-fifth of the LC_{50} for acute toxicity on inhalation of vapors and with an LC_{50} for acute toxicity on inhalation of vapors of not more than 5000 ml/mm^3; or

2. Is an irritating material, with properties similar to tear gas, which causes extreme irritation, especially in confined spaces.

NFPA

The NFPA's Chemical Hazardous Rating System places chemicals into three groups: Health, Flammability, and Reactivity. Within those groups are twelve Classes. The only group identifying potential Category M Fluids is the Health group. Within the Health group are four Classifications. The Classification identifying possible Category M Fluids is #4 – Danger: May be fatal on short exposure. Specialized protective equipment required.

DOT and NFPA

Using both the Hazardous Material Table in 49CFR and NFPA's Table of Chemical Ratings a determination of possible Category M Fluids can readily be made. Any chemical flowing through pipe or tubing listed as either a "4" in the Health column of NFPA's Table of Chemical Ratings, or as a "Forbidden", "2.3", or "6.1" in the "Hazard Class or Division" column of the Hazardous Materials Table in 49CFR could be considered a Category M Fluid.

While these two resources provide essentially the same information, they do so with two different objectives, and therefore do not always agree. As an example NFPA considers Bromine a Class 3 – Warning: Corrosive or toxic, avoid skin contact or inhalation. While the DOT, under 49CFR, considers Bromine a Class 6.1 – Poisonous Materials. NFPA considers Chloroform a Class 2 – Warning: May be harmful if inhaled or absorbed. While the DOT considers Chloroform a Class 6.1.

Regardless of whether or not they agree on the hazard level of a chemical, if a chemical is indicated as a 4 by NFPA, or "Forbidden", 2.3, or 6.1 by the DOT it could be considered a potential Category M Fluid.

Declaring a fluid service to be classified as Category M places added requirements on the design, fabrication, construction, and examination of the piping. These additional requirements are identified in ASME B31.3 Chapter VIII – Piping for Category M Fluid Service. The added requirements themselves are not significant; however B31.3 Chapter VIII, like the rest of the code, does not go into the details required for piping layout requirements and other detail design considerations.

There are various aspects of piping design that go beyond the scope and dictates of a code. And therein lies the point at which good design and engineering practice supplements the sound basis of code requirements and blends with the owner's particular needs and a facilities proprietary dictates.

The B31 series of Codes address the requirements necessary to assure system safety and integrity by specifying material limits, stipulating fabrication requirements, providing minimal examination requirements, etc., and they do include some essential design guidelines when needed to achieve that assurance. They cannot specify routing requirements, when to use double containment piping systems, determine accessibility, or whether this type of piping can or cannot run underground, etc. This type of detail is owner or site specific. Even within a large, multi facility corporation these requirements may vary from plant to plant.

Whenever a chemical, designated as a Category M Fluid, is made part of a project there should be a well-defined basis of design established by the owner or engineer in order to convey to the designer a predetermined set of design parameters.

CODE REQUIREMENTS FOR LETHAL FLUID SERVICE

As stated in the Introduction to the ASME-B31.3 piping code, "*The designer is cautioned that the Code is not a design handbook*…" In stating this ASME is explaining to the reader in very few words that this code will not provide pointers on the best way to route a piping system, how to support piping, or the amount of slope a pipeline might require. It will instead provide such criteria, methods, and formulae for such things as how to determine maximum loads on piping and ways to test installed piping for leak integrity. Just as the piping code provides the criteria for welding, but does not explain how to weld, it also provides the minimum requirements necessary for a safe piping system, but does not tell you how to design it.

The 2012 ASME B31.3 piping code is composed mainly of ten Chapters and nineteen appendices. The first six Chapters are considered the base code. Supplementary to the base code are four additional Chapters that pertain to the specific needs of piping systems with conditional requirements that vary from the content of the base code.

The supplemental chapters, VII through X, uses the same paragraph numbers as the base code with a prefix that identifies the particular chapter it is associated with.

In the case of Chapter VIII, for Category M Fluid Service, the paragraph prefix is 'M'. As an example, the base code paragraph 302.2.4 would be M302.2.4 in Chapter VIII. If there are no additional requirements in a paragraph beyond that of the base code there is a statement that clarifies that. As an example, there are no additional requirements in paragraph M302.4 beyond what is required in the base code. The statement under M302.4 in Chapter VIII is therefore "*Paragraph 302.4 applies in its entirety.*" meaning that the requirements stated in paragraph 302.4 (of the base code) are sufficient for the supplemental requirements in Chapter VIII.

With that said, we will take a look at just a few of the variances required by ASME B31.3 for piping systems containing a fluid service that may be considered lethal if personnel come in contact with it. This is to provide examples of the types of variances that are required for Category M type fluid services beyond what is stated in the base code.

> *Before taking another step further allow me to provide something of a disclaimer at this interval. Even though I hold membership on various ASME committees, subcommittees, and subgroups, including that of B31.3, any clarification I make of statements contained within B31.3, or any design concepts I put forth in the writing of this article are mine and not those of ASME. The process and procedures by which ASME publishes clarifications and responses to inquiries are based on a thorough, multi-tiered consensus process established and audited by ANSI (American Nations Standards Institute). That process encompasses the thinking of many respected individuals who are expert in their field and giving of their time and expertise in both maintaining the code and responding officially to inquiries about the code.*

M306.1 Pipe Fittings
M306.1.3 The following shall not be used:
***(a)* fittings conforming to MSS SP-43 and MSS SP-119**
***(b)*proprietary "Type C" lap-joint stub-end buttwelding fittings**

Under M306.1.3*(a)* above, fittings manufactured to MSS SP-43 - *Wrought and Fabricated Butt-Welding Fittings for Low Pressure, Corrosion Resistant Applications*, do not qualify for use in Category M Fluid Service due to the low integrity design of the fittings. Mentioned too, under paragraph M306.1.3*(a)*, are fittings manufactured under MSS SP-119 - *Factory-Made Wrought Belled End Socket-Welding Fittings* (Fig. 4). These fittings also do not comply due to the low integrity design of the bell & socket joint.

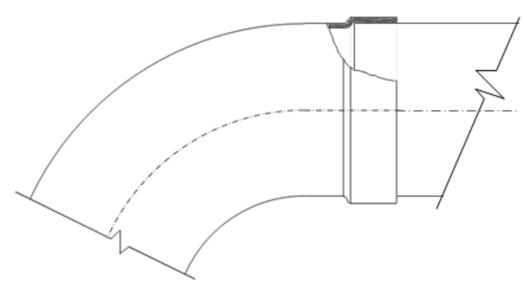

Figure 4 – Bell End Socket-Welding Elbow with Pipe

With regard to paragraph "**M307 Metallic Valves and Specialty Components**, paragraph **307.1 applies, subject to the requirements in paragraph M307.2.**"
Paragraph "**M307.2 Specific Requirements**", states in subparagraph *(a)* that: "***Valves having threaded bonnet joints (other than union joints) shall not be used.***" Threaded joints, in accordance with

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paragraph 314, are to be used for normal fluid service and Category D fluid conditions only, but can be used in severe cyclic fluid service conditions only when not subjected to external moment loading such as with thermowells.

M307.2*(b)* states that: ***"Only metallic valves conforming to the following requirements may be used*:**
(1) Special consideration shall be given to valve design to prevent stem leakage to the environment."

What is implied here is the suggested use of a bellows sealed valve to prevent leakage of vapor or liquid to the atmosphere by way of the valve stem gland packing.

"(2) Bonnet or cover plate closures shall be: flanged, secured by at least four bolts with gasketing conforming to para. 308.4; or proprietary, attached by bolts, lugs, or other substantial means, and having a gasket design that increases gasket compression as fluid pressure increases; or secured with a full penetration weld made in accordance with para. M311; or secured by a straight thread sufficient for mechanical strength, a metal-to-metal seat, and a seal weld made in accordance with para. M311, all acting in series*"*.

The underlined statement above refers to a pressure seal bonnet design (Fig. 5). Such a design, which will vary between valve manufacturers, uses the internal operating pressure of the fluid as a sealing force; as the internal pressure increases the sealing load on the pressure seal gasket increases. This provides an increase in the sealing integrity of the bonnet joints.

The above are just a few examples of the added requirements stipulated for Category M Fluid Service piping. There are many other instances in which the requirements for the construction of potentially lethal piping systems go beyond that of the base code. And one more example of that lies in the examination requirements.

Under M341.4 Extent of Required Examination,
Paragraph 341.4.1 applies with the following exceptions:

"(a) Visual Examination
(1) All fabrication shall be examined. (Instead of 5%)
(2) All threaded, bolted, and other mechanical joints shall be examined. (Instead of random)
(b) Other Examination
(1) The random radiography/ultrasonic examination requirements of para. 341.4.1(b)(1) apply except that at least 20% of circumferential butt and miter welds and of fabricated lap and branch connection welds comparable to those shown in Figs. 328.5.4E and 328.5.5 sketches (d) and (e) shall be examined. (Instead of 5%)
(2) The in-process examination alternative permitted in para. 341.4.1(b)(1) may be specified on a weld-for-weld basis in the engineering design or by the Inspector. It shall be supplemented by appropriate nondestructive examination."

This sheds light on the fact that these types of piping systems demand a much higher level of scrutiny when being evaluated and are examined to a much higher degree than required for normal fluid services.

DESIGNING FOR CATEGORY M PIPING SYSTEMS
The need to integrate and instill personnel safety and well-being into the operation and maintenance of a CPI facility is a basic essential. Such a core philosophy extends from the conceptual design of a facility to its ultimate operation. But this too is applied in degrees. The design and material specifications for a chilled water system certainly would not apply to a system containing a hazardous or potentially lethal chemical. The added cost necessary to attain the integrity required for the more hazardous chemical service would be money poorly spent on a chilled water system.

In designing a piping system that contains a highly hazardous chemical the engineer needs to give added consideration to the following key design elements that will be touched on as follows:

- Component joint type
- Valve design attributes
- System drainability
- Emergency valve shut-off, isolation, and shutdown
- Protruding instruments and valves

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- Isolated and controlled access room

Component joint type
One of the key aspects of piping system integrity is based on the type of component joint type used in constructing the system. Giving serious consideration to the selection of the type of joints used in the design of a system should include, in order of priority:

- Buttweld joint
- Socketweld joint
- Flanged joint

The buttweld, or circumferential weld joint is fully rated to the strength of the pipe. This should be of primary consideration. As stated in my June 2010 article in CE magazine titled Piping Design for Hazardous Fluid Service, "*…the full penetration buttweld is considered to be as strong as the pipe with an SIF [Stress Intensification Factor]= 1.0*." It goes on to state that, "*The socketweld joint has a SIF = 2.1. Any value in excess of 1.0 will de-rate the strength of the joint below that of the pipe*."

Where flanges are specified for equipment connections and break-out joints, the weak point in the flange joint assembly is the gasket. Should a fire occur in which temperatures could reach into the 2,700 to 3,000°F range the gasket material would be compromised causing the joint to lose its seal and leak deadly toxins into the atmosphere.

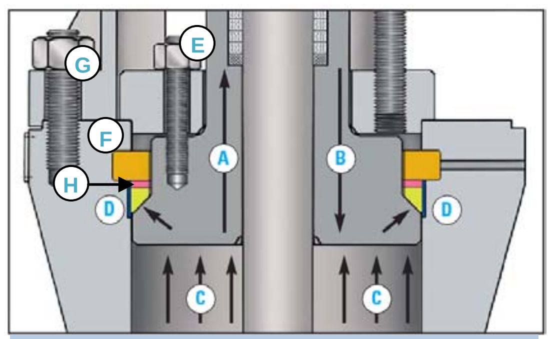
Valve design attributes
In identifying the requirements of a valve intended for a highly hazardous fluid service the short list would include:

- No quarter-turn on/off operation
- Buttweld end connections
- Pressure seal
- Bellows seal

Quarter-turn valves, such as ball, plug, and butterfly valves are great for ease of operation and quick on/off requirements. Those attributes are not necessarily what is needed for highly hazardous fluids. What is needed, particularly for manually operated valves, are valve types that offer control over response time. Multi-turn valves such as gate and globe valves are a safer valve option from the standpoint of control. A valve handle that extends out away from the valve body has the risk of being inadvertently bumped and unknowingly opened to flow.

It is suggested that the valve have buttweld (preferred) or socketweld ends. If there is a need to remove the valve periodically then a valve with flanged ends is a consideration, but any type of mechanical joint should be used sparingly and with due consideration.

The valve bonnet is a mechanical joint and is therefore a potential leak point. Two bonnet designs help alleviate this: the welded bonnet and the pressure seal bonnet. If access to the valve's internals is not a concern then the welded bonnet would be a consideration. If access to the valve internals is needed then the pressure seal bonnet would be an option.



A/B Bonnet's tendency to move up & down.
C System pressure
D Internal sealing forces against the spacer ring
E Bonnet take-up bolts
F Segmental thrust ring
G Outer row of body studs
H Gasket

Figure 5 – Pressure Seal Bonnet Design (Courtesy Velan)

Referring to Fig. 5, the pressure seal bonnet is designed to utilize internal pressure to increase its sealing capability in direct response to an increase in internal pressure. As internal pressure increases so too does the load on the gasket 'H' creating a seal that exceeds that of the initial gasket pre-load. The bonnet take-up bolts 'E' establish the initial load on the bonnet gasket. The segmental thrust ring 'F' provides the sealing surface against which the gasket load is applied. This design provides a high degree of sealing integrity.

The part of a valve that is the most prone to leak is at the interface of the valve stem and the packing used to prevent leakage. The addition of the bellows seal design prevents fluids or vapors from escaping to the atmosphere should a leak occur in the stem packing.

The bellows creates a hermetically sealed barrier between the service fluid and the stem. This significantly alleviates the possibility of stem leakage.

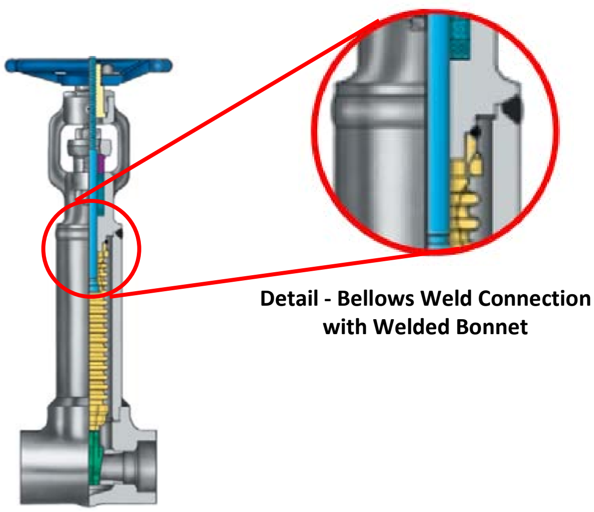


Figure 6 – Bellows Seal Design (Courtesy Velan)

System drainability

An essential to designing a piping system handling a highly hazardous fluid is the ability to safely and completely drain the system. Piping should be sloped at a degree that will allow free draining of all liquids to a point where it can be captured for containment and removal. The design and layout should be done in such a way as to provide for:

- No entrapment of fluids
- Sufficient room and reasonable access to:
  - valving,
  - drains,
  - vents,
  - hose connections
- Appropriately located pressure gages
- All piping should be drainable to a pressure vessel for pump-out to a safe location

Note:
"*Reasonable access*", as mentioned in the second bullet point, should give consideration to not having to climb a ladder or the use of other means of gaining access to a valve or hose connection. Consideration should also be given to the fact that workers will most likely be wearing hazmat suits while working on such highly hazardous fluid piping.
"*Appropriately located*", as mentioned in the third bullet point, implies that all local read-out gages should be located in such a manner as to allow for good line of sight viewing of the gage's dial face without the need for visual enhancements (magnification) or a temporary means of access, such as a ladder.

Emergency valve shut-off

At the onset of a fire, explosion, or a major rupture and leak in a processing unit any highly hazardous fluid or any fluid that can be considered flammable should have a means of isolating and halting its flow at a point outside the battery limits of the facility in distress. If there are fluid supply lines in which flow cannot be halted there should be a means of diverting the fluid to a safe secondary location, away from the location of the emergency.

The shutting down of these pipelines should be done with automated valving from a remote location. Manual valve isolation, while sufficient for isolating systems for maintenance work and planned turnovers is not practical when an event calls for the evacuation of all non-essential personnel.

In the event of an emergency the plan should be to give the first responders the best opportunity to get the situation under control. This means stopping the flow of all flammable and otherwise hazardous fluids from entering the area where the event has occurred. And, as mentioned under "System drainability", design the system so that once all of the fluids are stopped from entering the area any residuals in the area are drained to a pressure vessel so they can then be pumped out of the area to a secondary location such as a flare stack or secondary containment. Stopping flow and removing all of the hazardous fluids from the area is a key element in preventing escalation and perpetuation of an already bad situation.

Protruding instruments and valves

It is a necessity to have instruments, gages, and valves extending at various angles from piping. But while there is a need for such things as pressure and temperature gages, drain and vent valves, Y-strainer drains, and hose connections, added consideration needs to be given to the branch design of these types of protruding components.

These types of components protruding from a pipeline should be kept in a vertical plane. Extending these branches horizontally from the pipeline adds the risk that such an extension opens the opportunity for the gage or valve to be struck by a maintenance cart (refer to Incident 2 in the June 2010 Chemical Engineering article "Piping Design for Hazardous Fluid Service") or by some other means with enough force to rupture the piping causing a catastrophic rupture.

Isolated and controlled access room

Another major holistic type approach in the handling of highly hazardous fluids is the possibility of placing all related piping and equipment for a highly hazardous fluid service in a controlled environment. This would be a room under negative pressure in relation to any surrounding rooms in a facility. The room would require controlled access by only those employees trained to handle the highly hazardous fluids contained in the room.

Unless these highly hazardous chemicals are used throughout a plant site injection of these fluids into a process stream would be accomplished inside the room. This would be done by routing the process piping into and out of the controlled access room where the addition of these fluids into the process stream would take place. This keeps the raw hazardous chemicals contained and better controlled.

Alarmed and redundant atmosphere sampling and leak detection devices would be put in place to notify the control room, first responders, and all plant personnel that leakage has been detected followed by a scripted announcement regarding any action to be taken.

IN CLOSING

Designing a facility to accommodate the storage and handling of highly hazardous chemicals does not end with proper design and construction. It is an ongoing effort of developing procedures and a training program such as that described in OSHA's "Process Safety Management Guidelines for Compliance." https://www.osha.gov/Publications/osha3133.html

Developing procedures and a training program for those that have to work on or around piping and equipment that contain highly hazardous chemicals is an essential. And in so doing the process helps identify possible areas that could be improved upon, either from a security standpoint or from the standpoint of making improvements to the design of the piping system itself.

Proportionally there are few catastrophic events that occur in chemical processing facilities. The majority of incidents originate from small leaks that were discovered in time to evacuate personnel, shut down the system, and rectify the situation. And most catastrophic events stem from a series of indicators that were largely ignored until the unthinkable finally happened.

It happened in Bhopal, India, again in Pasadena, TX, again in Sterlington, LA, again in Texas City, TX, and again in Middletown, CT. In each case protocol was pushed aside, specific concerns were ignored, and in some cases the cost to risk evaluation was tilted to the side of cost over risk. Meaning that even though the risk was high the cost of remediation was more than the company wished to incur.

From a regulatory standpoint OSHA's "Process safety management of highly hazardous chemicals" under 29CFR1910.119 sets forth requirements that each chemical processing facility must adhere to in the manufacture, handling, or storage of chemicals within the guidelines of the regulation. It also provides guidance for the required "Process Hazard Analysis" procedure.

From a piping engineering standpoint the ASME B31.3 Process Piping code Chapter VIII Piping for Category M Fluid Service stipulates requirements in the design, fabrication, inspection, examination, testing, and installation of piping used to handle potentially lethal fluids.

The people that work in such CPI (Chemical Process Industry) facilities have the right to fully expect that they can go off to work with the expectation of returning home safely upon completion of their shift. It is the job and responsibility of every designer and engineer of CPI facilities to make certain that such an expectation is made valid in the design and construction of CPI facilities in general.

References

American Society of Mechanical Engineers (ASME) B31.3 "Process Piping" (2012)
Occupational Safety and Health Organization (OSHA) 29CFR1910.119 "Process safety management of highly hazardous chemicals"
OSHA 29CFR1926.64 Appendix A "List of Highly Hazardous Chemicals, Toxics, and Reactives (Mandatory)" found under 29CFR1926.64
Department of Transportation (DOT) (49CFR)
National Fire Protection Association (NFPA)
Environmental Protection Agency (EPA) (40CFR)
REACH (**R**egistration, **E**valuation, **A**uthorisation and Restriction of **Ch**emical substances) The European Community Regulation on chemicals and their safe use.
Bureau of Labor Statistics
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Author

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