Designing facilities that manufacture, use, and store hazardous chemicals demands a more stringent set of requirements.

W. M. Huitt
W. M. Huitt Co.

The potential for an accidental occurrence of a fire in a process facility or plant is something that is very much on the minds of folks that work in and manage these facilities as well as those of the community fire departments responsible for the protection of both personnel and property within and around such a facility. Incorporating fire safety into plant design takes on two fundamental goals: That of trying to prevent the occurrence of fire and the other to protect the initially uninvolved piping and equipment long enough for operations personnel to perform their duties and for emergency responders to get the fire under control.

Fire has proven time and again its potential to initiate and develop rapidly into a catastrophic loss of capital and ultimately the loss of life. While it is impractical to expect to build a complex process plant facility, one that is expected to handle and process hazardous chemicals, to be completely safe from the potential of an accidental fire, it *is* reasonable to assume that certain aspects of design can certainly reduce that risk. While this is a fundamental topic that should be on the minds of the designers and engineers charged with the design of these facilities, it is certainly not a job for complacent minds.

Designing facilities that manufacture, use, and store hazardous chemicals demands a more stringent set of requirements, at times beyond what can be practically written into Industry Codes and Standards. It is ultimately the responsibility of the Engineer of Record (EOR) and the Owner to fill in those blanks and to read between the lines of the adopted Codes and Standards to create a safe operating environment, one that minimizes the opportunity for fire and its uncontrolled spread and damage.

This discussion will not delve into the various trigger mechanisms of how a fire might get started in a process facility, but will instead discuss containment and control of the fuel component of a fire that resides in piping systems that contain combustible, explosive, or flammable fluids. The discussion will also touch on extenuating issues that go beyond the piping system proper.

OSHA (Occupational Safety and Health Administration), under the United States Department of Labor, defines “Hazardous Chemicals” as:

Any chemical that is a health hazard or a physical hazard.

It goes further to define both “Health Hazard” and “Physical Hazard”:

A health hazard is 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. Chemicals covered by this definition include carcinogens, toxic or highly toxic agents, reproductive toxins, irritants, corrosives, sensitizers, hepatotoxins, nephrotoxins, neurotoxins, agents that act *on the hematopoietic system, and agents that damage the lungs, skin, eyes, or mucous membranes.*

And, *a 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.*

In this discussion we will focus on physical hazards, and more precisely on combustible, explosive, and flammable fluids. Hereafter such fluids will be referred to simply as hazardous. When designing piping systems containing such fluids there are critical aspects of the overall design of these systems that need additional consideration beyond that of what might be involved in the design of piping systems containing non-hazardous fluids. For those systems considered hazardous, under the above criteria, there are two key safety aspects that need to be incorporated into the design. They are: system integrity and fire-safety.

Part of fire-safety takes into consideration the protection of process piping and equipment from accidental damage creating the potential for fire, and the protection of process piping and equipment not involved in the initial occurrence of a fire. By protecting the surrounding piping and equipment in close proximity to a fire it controls and delays the potential for the fuel contained in that piping and equipment to be added to the fire.

System Integrity

System integrity describes an expectation of engineering that is integrated into the design of a piping system in which the selected material of construction, system joint design, valve selection, examination requirements, design, and installation have all been engineered and performed in a manner that instills the proper degree of integrity into a piping system. While this approach is certainly needed for the piping design of what ASME B31.3 considers Normal Fluid Service it is absolutely critical for hazardous fluid systems.

The design of any piping system, hazardous or non-hazardous, is based, in large part, on regulations and industry accepted standards published by such organizations as the American Society of Mechanical Engineers (ASME) and the American Petroleum Institute (API). The Standards published by these organizations include tables that establish joint ratings based on Material of Construction (MOC) and temperature. Where the design consideration for hazardous fluid services departs from that of non-hazardous fluid services is in gasket and seal material specifications.

This is due to the need for sealing material to contain hazardous chemicals that are in close proximity to a fire. The effect of heat from a fire on an otherwise uninvolved piping system can only be delayed for a relatively short period of time. And the first thing to fail will be mechanical joints.

Depending on the type of fire and whether the piping is directly in the fire or in close proximity that window of opportunity, prior to joint seal failure, for an emergency response team to get the fire under control is anywhere from a few hours to less than 30 minutes. As you will see a number of factors dictate the extent of that duration in time.

A system in which the gasket material is selected on the basis of material compatibility, design pressure, and design temperature may only require a solid fluoropolymer. In a fire this non-metallic material would readily melt allowing the contents of the pipe to discharge from the joint once sealed by the gasket. Specifying a gasket that is better suited to hold up in a fire for a longer period of time, gives the emergency responders time to bring the initial fire under control, making it quite possible to avoid a major catastrophe.

Fire-Safe System

In a process plant environment in which hazardous liquids are routinely handled one of the key concerns is fire; its prevention and control. While consideration for preventing a fire from occurring is paramount in the design and ongoing maintenance of a facility, the protection of piping and equipment containing hazardous liquids from the effects of a fire, in an effort to minimize or eliminate the ability of a fire to sustain itself or to spread uncontrolled, is just as critical.

Preventing the potential for a fire goes to the piping material specification itself. Controlling and restricting the spread of fire goes beyond the piping proper. Results of the assessment reports of catastrophic events coming from the U. S. Chemical Safety and Hazard Investigation Board (CSB) have shown that many of the occurrences of catastrophic incidents have actually played out through a complex set of circumstances resulting from design flaws, instrumentation problems, pipe modifications, inadequate fire-proofing, and/or human error.

Events, such as a fire, are not necessarily then the result of a hazardous fluid simply escaping through a leaky joint then coming in contact with an ignition source. There are usually a complex set of events leading up to a fire incident. Its subsequent spread, into a possible catastrophic event, is then the result of inadequate design requirements that extend beyond the piping itself, which we will discuss later.

While this discussion touches only on piping issues know that this is only a part of the overall integration of safety into the design of a facility that handles hazardous fluids. What follows are recommended piping design considerations that are intended to substantially reduce the risk of the onset of fire and its uncontrollable spread throughout a facility. In discussing the spread of fire it will be necessary to include discussion regarding the needs of disciplines other than piping, namely fire proofing of structural steel.

In General

From a fire-safety standpoint some requirements and industry regulations are stipulated in the International Fire Code (IFC), published by the International Code Conference (ICC) under IFC 3403.2.6.6. There are also requirements by the National Fire Protection Association (NFPA) under NFPA 1 and NFPA 30. Test requirements for fire-safe valves can be found under American Petroleum Institute (API) API 607 – *Fire Test for Soft Seated Quarter Turn Valves*. Starting with the 4th edition of this API Standard it was added that, among other things, the tested valve has to be operated from fully closed to fully open after the fire test. Prior to the 4th edition a soft-seated fire-safe valve had to only remain sealed when exposed to fire without having to be operated, or rotated. Additional fire test requirements can be found as published by the BSI Group (formerly known as British Standards Institution) as BS-6755-2 *Testing of Valves. Specification for Fire Type-Testing Requirements*, and FM Global FM-7440 *Approval Standard for Firesafe Valves*.

With exception to the specific requirements covered in the valve testing Standards, the Codes and Standards referenced above provide generalized requirements that touch on such key aspects of safety as relative equipment location, mass volume vs. risk, electrical classifications, valving, etc. They cannot, and they are not intended to provide criteria and safeguards for every conceivable situation. Designing safety into a particular piping system containing a hazardous liquid goes beyond what should be expected from an industry-wide Code or Standard and falls to the responsibility of the Owner or Engineer of Record. As ASME B31.3 states in its introduction, *"The designer is cautioned that the Code is not a design handbook; it does not do away with the need for the designer or for competent engineering judgment"*.

In other words, an Industry Code or Standard, while containing, in many cases, essential design criteria, is not intended to provide all of the information needed to design all of the piping for all facilities. It is the intent of the American National Standards (ANS) Developers, those organizations given accreditation by ANSI (American National Standards Institute) to develop industry Standards, to establish the minimum requirements necessary to integrate safety into the design, fabrication, inspection, installation, and testing of piping systems for a wide range of facility types.

When designing piping systems to carry hazardous liquids the design basis of a project or an established protocol for maintenance needs to incorporate a mitigation strategy against two worse-case scenarios. Those being:

1. A leak at a pipe joint containing a hazardous liquid, and
2. The rupture or loss of containment, during a fire, of surrounding hazardous piping systems, not otherwise compromised, adding fuel to the fire.

The occurrence of those two failures, one initiating the incident and the other perpetuating and sustaining the incident, can be minimized or eliminated by creating a design basis that provides:

1. Added assurance against the potential for joint failure,
2. Added assurance of containment and control of a hazardous liquid during a fire, and
3. Safe evacuation of a hazardous liquid from the operating unit under distress.

FIRE PREVENTION THROUGH DESIGN

Piping Joints

When designing piping systems containing hazardous liquids one of the key objectives for the design engineer should be in consideration of taking the necessary steps to minimize the threat of a leak, steps beyond those typically necessary in complying with the minimum requirements of a Code. There are certainly other design issues that warrant consideration, and they will be touched on much later. However, while the pipe, valves, and instrumentation all have to meet the usual criteria of material compatibility, pressure, and temperature requirements there are added concerns and cautions that need to be addressed.

Those concerns and cautions are related to the added assurance that hazardous liquids will stay contained within their piping system during normal operation and for a period of time during a fire as expressed in such Standards as API-607, FM-7440, and BS-6755-2. Designing a system, start to finish, with the intent to minimize or eliminate altogether the potential for a hazardous chemical leak to occur will greatly help in reducing the risk of fire. If there is no fuel source there is no fire. In the design of a piping system leak prevention begins with an assessment of the piping and valves joints.

To elaborate and help clarify the previous point, let me say this: There are specified minimum requirements such as component rating, examination, inspection, and testing that are required for all fluid services. Beyond that, there is no guidance given for fire safety with regard to the piping Code other than a statement in B31.3 Para. F323.1 in which it states, in part:

> *The following are some general considerations that should be evaluated when selecting and applying materials in piping: (a) the possibility of exposure of the piping to fire and the melting point, degradation temperature, loss of strength at elevated temperature, and combustibility of the piping material under such exposure. (b) the susceptibility to brittle failure or failure from thermal shock of the piping material when exposed to fire or to fire-fighting measures, and possible hazards from fragmentation of the material in the event of failure (c) the ability of thermal insulation to protect piping against failure under fire exposure (e.g., its stability, fire resistance, and ability to remain in place during a fire).*

The Code does not go into specifics on this matter. It is the engineer's responsibility to raise the compliance level requirements to a higher level where added safety is warranted, and to define the compliance criteria in doing so.

Joints in a piping system are its weak points. All joints, except for the full penetration buttweld, will de-rate a piping system to a pre-determined or calculated value based on the type of joint. This applies to pipe longitudinal weld seams, circumferential welds, flange joints, and valve joints such as the body seal, stem packing, and bonnet seal, as well as the valve seat. For manufactured longitudinal weld seams refer to ASME B31.3 Table A-1B for quality factors (E_j) of the various types of welds used to manufacture welded pipe. The quality factor (E_j) is a reduction, as a percentage, of the strength value of the longitudinal weld in welded pipe. It is used in wall thickness calculations as in the following equations for straight pipe under internal pressure:

$$t = \frac{PD}{2(SEW+PY)}$$

or

$$t = \frac{P(d+2c)}{2[SEW-P(1-y)]}$$

Where:

c	=	sum of mechanical allowances
D	=	outside diameter of pipe
d	=	inside diameter of pipe
E	=	quality factor from Table A-1A and A-1B
P	=	internal design gage pressure
S	=	stress value for material from Table A-1
W	=	weld joint strength reduction factor
y	=	coefficient from Table 304.1.1

Also found in Para. 304 of B31.3 are wall thickness equations for curved and mitered pipe.

With regard to circumferential welds, the designer is responsible for assigning a weld joint reduction factor (*W*) for welds other than longitudinal welds. What we can do, at least for this discussion, is to provide some quality ranking for the various circumferential welds based on the stress intensification factor (SIF) assigned to them by B31.3. In doing so, the full penetration buttweld is considered to be as strong as the pipe with a SIF = 1.0. The double fillet weld at a slip-on flange has a SIF = 1.2. The socket-weld 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. With that said, and assuming an acceptable weld, the weld joint, and particularly the full penetration buttweld, is still the joint with the highest degree of integrity. In a fire the last joint type to fail will be the welded joint.

connections and then only if the instrument is not available with a flange or welded connection. If a threaded connection is used it should be assembled without thread compound then seal-welded. This may require partial dismantling of the instrument to protect it from the heat of the welding process.

It is recommended that piping systems be welded as much as possible and flanged joints be minimized as much as possible. If flanged joints are necessary for connecting to equipment nozzles, flanged valves, in-line components, or needed for break-out joints it is suggested that a spiral wound type gasket with graphite filler be specified. This type material can withstand temperatures upwards of 3000ºF. There are also gasket designs that are suitable for when a fluoropolymer material is needed for contact with the chemical, while also

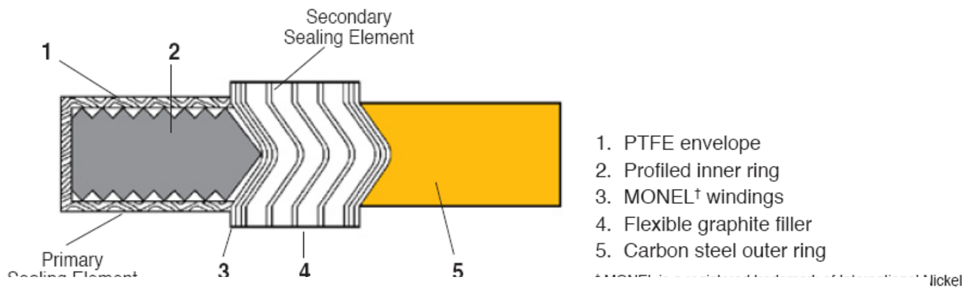

Figure 1 – Fire Safe Spiral Wound Type Gasket

The threaded joint has a SIF = 2.3 and requires a thread sealant applied to the threads, upon assembly, to maintain seal integrity. With flame temperatures in a fire of around 2700ºF to 3000ºF the thread sealant will become completely useless if not vaporized leaving bare threads with no sealant to maintain a seal at the joint.

The flange joint sealing integrity, like the threaded joint, is dependent upon a sealant, which, unlike the threaded joint, is a gasket. Flange bolts act as springs and will provide a constant applied load so long as all things remain constant. Should the gasket melt or flow, due to the heat of a fire, that initial tension that was given the bolts when the joint was assembled will be lost. Once the gasket has been compromised the joint will leak.

Knowing that the mechanical type threaded and flange joints are the weak points in a piping system, and the primary source for leaks, it is suggested that they be minimized to the greatest extent possible. Threaded joints should be limited to instrument

holding up well in a fire. These are gaskets similar in design to that shown in Fig. 1. It is still preferable to make the piping system an all welded system except for equipment and instrument connections, and that includes using welded end valves and in-line components where possible.

Valves

A fire-safe rated valve meeting the requirements of API 607 – *Fire Test for Soft Seated Quarter Turn Valves* is designed and tested to assure the prevention of fluid leakage both internally along the valve's flow path, and externally through the stem packing, bonnet seal, and body seal (where a multi-piece body is specified). Testing under API 607 subjects a valve to well defined and controlled fire conditions. It requires that after exposure to the fire-test the valve shall be in a condition that will allow it to be rotated from its closed position to its fully open position using only the manual operator fitted to the test valve.

Quarter turn describes a type of valve that goes from fully closed to fully open within the 90º rotation of its operator. It includes such valve types as ball, plug, and butterfly having a valve seat material of a fluoropolymer, elastomer, or some other soft, non-metallic material.

Standards such as FM-7440 and BS-6755-2, touched on earlier, apply to virtually any valve type that complies with their requirements. Under the FM and BS Standards valve types such as gates, globes, and piston valves with metal seats can also make excellent fire-safe valves when using a body and bonnet gasket and stem packing material similar to a graphite.

2. The flow path at the systems use point valves (VA-1) needs to remain open,
3. The flow path at drain and vent valves (VA-2) needs to remain sealed,
4. The external path through stem packing and body seals needs to remain intact during a fire,
5. The bottom outlet valve (XV-2) on a vessel containing a flammable liquid should have an integral fusible link for automatic shut-off, with its valve seat, stem packing, and body seals remaining intact during a fire,

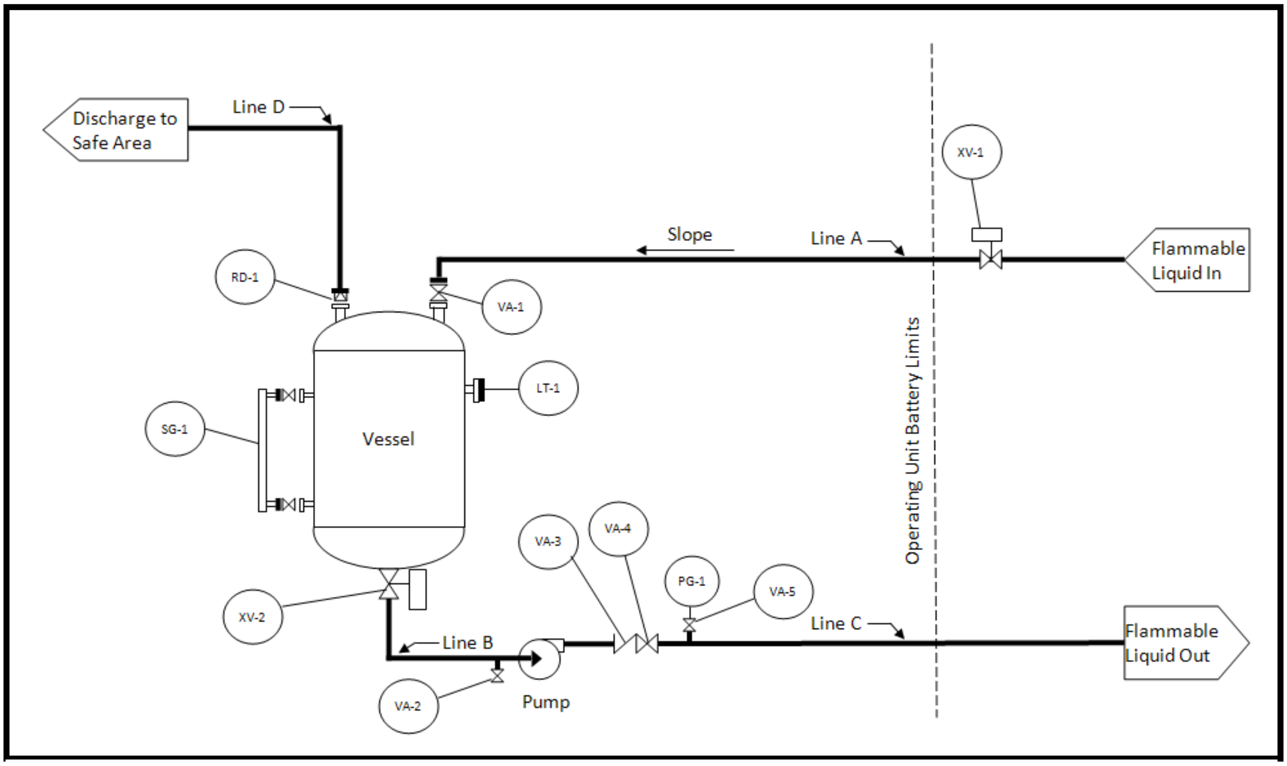

Figure 2 – Simplified P&ID

and

6. Pipeline A should be sloped to allow all liquid to drain into the vessel.
7. The liquid in the vessel should be pumped out to a safe location until the fusible link activates, closing the valve. There should be an interlock to notify the control room and to shut down the pump when the fusible link valve closes.

Process Systems

At the onset of a fire within an operating unit the initially unaffected process piping systems should not be a contributor to sustaining are spreading what is already a potentially volatile situation. There are basic design concepts that can be incorporated into the physical aspects of a process system that will, at the very least, provide precious time for operators and emergency responders to get the situation under control. In referring to the simplified flow diagram in Fig. 2 there are seven main points to consider:

1. Flow supply (Line A), coming from the fluid's source outside the operating unit, needs to be remotely shut off to the area that is experiencing a fire,

Those seven points, with the help of the flow diagram in Fig. 2, are explained as follows:

Point 1: The supply source, or any pipeline supplying the operating unit with a flammable liquid, should have an automated, fire-safe isolation valve (XV-1) located outside the building or operating unit area and linked to the unit's alarm system with remote on/off operation (From a safe location) at a minimum.

Point 2: Any point-of-use valve (VA-1) at a vessel should remain open during a fire. The area or unit isolation valve (XV-1) will stop further flow to the system, but any retained or residual fluid downstream of the automatic shut-off valve needs to drain to the vessel where the increasing overpressure will be relieved to a safe location, such as a flare stack, through RD-1. If the Valves (VA-1) are closed in a fire situation the blocked in fluid in a heated pipeline will expand and potentially rupture the pipeline; first at the mechanical joints such as seals and packing glands on valves and equipment, as well as flange joints, and then ultimately the pipe itself will rupture (catastrophic failure). During a fire expanding liquids and gases should have an unobstructed path through the pipeline to a vessel that is safely vented.

Point 3: Valves at vents and drains (VA-2) need to be fire-safe and remain closed with seals and seat intact for as long as possible during a fire.

Point 4: During a fire another source for valve leakage is by way of stem packing and body seal, as mentioned earlier. Leakage, at these seal points, can be prevented with valves that are not necessarily fire-safe rated, but contain stem packing and body seal gasket material specified as some acceptable form of graphite (flexible graphite, graphoil, etc.). This is a fire-safe material which is readily available in non-fire-safe rated valves.

Point 5: The valve on the bottom of the vessel should be fire-rated with a fusible link or a Fail Closed position. Relying on an air or electric operated valve actuator may not be practical. A fusible link is most certainly needed on a manually operated valve. The content of a vessel containing a hazardous liquid needs to get pumped to a safe location during a fire until such time as the fusible link is activated, closing the tank bottom valve. All valved gage and instrument connections (SG-1) mounted on a vessel should have a graphite type stem packing and body seal gasket material at a minimum. Flange gaskets at these gage and instrument connections should be spiral wound fire-safe type gaskets similar to those mentioned earlier. Specialty tank-bottom valves (XV-2) should be given special consideration in their design by considering a metal-to-metal seat, or a piston valve design along with fire rated seal material.

Point 6: As mentioned in Point 2, the residual fluid in Line A, after flow has been stopped, should be drained to the vessel. To help the liquid drain the pipeline should be sloped toward the vessel. The intent, as mentioned above, is to prevent sections of any pipeline, not containing a relief device, from being blocked and isolated during a fire. If the piping system for a flammable fluid service is designed properly the contents will be able to drain or expand into a vessel where over-pressurization can be relieved and safely vented.

Point 7: It will be necessary to evacuate as much of the hazardous fluid as possible from tanks and vessels in the fire area to a safe location. The pump-out should continue until there is inadequate pump suction head, or until the fusible link on XV-2 is activated. At that time the pump interlocks would shut down the pump.
With regard to tank farms, the following is a suggested minimum: Drain valves should be a fire-safe type valve. Outlet valves should be a fire-safe type valve with a fusible link. Tank nozzles used for gages or instrument connections should have, at a minimum, valves containing stem packing and seal gasket material specified as some acceptable form of graphite, as mentioned above, or some other fire rated material. Gaskets used at nozzle flange joints should be a fire-safe gasket similar to the spiral wound gaskets mentioned earlier or the gasket shown in Fig. 1.

In-line valves in piping downstream of the tank outlet valve, such as pump transfer lines and recirculation lines, do not necessarily need to be fire-rated, but should have stem packing and seal gasket material that is fire-safe as mentioned earlier.

Specific Points made above:

1. Use welded connections to the maximum extent possible, and minimize flange joints throughout the piping system for flammable fluids.
2. Where flange joints are required use a fire-safe spiral wound type gasket.
3. Threaded joints should be relegated to instrument connections, and then only

when a flanged or welded instrument is not available,

4. In making a threaded connection, do so without thread compound, then seal-weld,
5. The supply line of a flammable fluid should have an automated on/off fire-rated valve installed prior to entering the building or operating unit battery limits. The valve should have an interlock with the fire alarm system and have remote, on/off, operation from a safe location.
6. All valves in a flammable fluid service inside a building or operating unit should be either:
    a. A fire-rated valve used at the following locations:
        i. Vents and drains
        ii. Tank bottom
        iii. Any location where the valve is required to be in a closed position during a fire to maintain a blocked flow path
    b. A non-fire-safe valve with fire-safe type stem packing and body seal gasket material used at the following locations:
        i. Any location other than those listed in 2,a
7. All hazardous service valves inside a building or operating area should either have welded ends (preferred) or flanged ends with a fire-safe, spiral wound type gasket at the flange joint.
8. There may be exceptions, but generally all in-line valves (not vents, drains or source shut-off) should be in the open position during a fire with all residual fluid able to drain freely toward a vessel with a relief device that is vented to a safe location.
9. For a vessel containing a flammable liquid a fire-safe tank-bottom valve with a fusible link, when possible, should be used.
10. The liquid inside vessels and tanks, at the onset of a fire, should be pumped to a safe location until the fusible link is activated, closing the valve.
11. Valved gage and instrument connections should have valves with a fire-safe type stem packing and body seal gasket material, at a minimum.
12. Each flange joint for flanged gage and instrument connections should use a fire-safe spiral wound type gasket.
13. Outside tank farms should have a fire-safe valve connected directly to each nozzle located below normal liquid level with the exception of gage or instrument connections.
14. Each tank outlet valve (does not include drain valves) should have a fusible link.
15. Gage and instrument nozzles should have, at a minimum, valves that have stem packing and body seal material made of a fire-safe type material.
16. Fire-safe spiral wound type flange gaskets should be used at all flange nozzles, gage and instrument connections.
17. All other valves installed in tank farm piping should, at a minimum, have a fire-safe type material specified for stem packing and seal gasket material.

Situations will arise that do not fall neatly into those described above. If there is any doubt with regard to valving default to a fire-rated valve. Each piping system identified as needing to be fire-safe should be designated as such. Where individual fire-safe valves are to be strategically located in a system they should be designated on their respective P&ID's either by notation or through the assigned pipe material specification. The pipe material specification should be indicated on each pipeline of the P&ID. The specification itself should be descriptive enough for the designer to know which valve to apply at each location.

INCIDENT EXAMPLES AND LESSONS LEARNED

While this particular discussion is specific to piping leaks and joint integrity it bares touching on a few subjects that are integrally associated with piping safety: pipe rack protection, protecting piping from vehicle traffic, and designing for disaster (HAZOP).

In Incident #1 below, the onset of a fire that might otherwise have been quickly controlled becomes a catastrophic event because piping mounted on the unprotected structural steel of a pipe rack, outside the extent of the initial occurrence, becomes collateral damage adding more fuel to the fire causing it to sustain itself, increase in intensity, and continue to spread.

In Incident #2 below, an unprotected and protruding pipeline component (Y-strainer) is damaged causing a major leak that operations was unable to stop. The ensuing fire lasted for five days.

In Incident #3 below, two dimensionally identical spool pieces were designed for a system in which the two were fabricated from different material because their service conditions were very different. It can only be assumed that this was an erroneous attempt at trying to achieve duplication of pipe spools in an effort to assist the fabricator in their productivity of pipe fabrication. Instead it ultimately caused injury to one person and cost the plant Owner $30MM.

Incident #1 – Valero-McKee Refinery, Sunray, TX, February 16, 2007

Figure 3 – Valero-McKee Refinery – 90 Seconds After Ignition.

Without going into great detail as to the circumstances that led up to this incident, piping handling liquid propane in a Propane Deasphalting (PDA) unit ruptured. The location of the rupture was in a section of isolated piping that had been abandoned in place several years prior. A valve, intended to isolate the active flow of liquid propane from the abandoned-in-place piping, had been unknowing left partially open due to an obstruction inside the valve. Water had gradually seeped in past the valve seat over the years and being heavier than the liquid propane, settled at a low point control station where it eventual froze during a cold period. The expanding ice inside the pipeline subsequently cracked the pipe. When the temperature outside began to warm the ice thawed allowing liquid propane to escape from the active pipeline, through the partially closed valve, and out the now substantial crack. The resultant cloud of propane gas drifted toward a boiler house where it found an ignition source. The flame of the ignited gas cloud tracked back toward its source where the impending shockwave from the explosion ripped apart piping attached to the PDA Extractor Columns (No. 1 Extractor identified in Fig 3) causing ignited propane to erupt from one of the now opened nozzles on the column at such a velocity as to create a jet fire.

The ensuing jet fire, which is a blow torch like flame, discharged toward a main pipe rack approximately 77 feet away engulfing the pipe rack in the jet fire. As the temperature of the non-fire proofed structural steel of the pipe rack reached its plastic range and began to collapse in on itself the piping in the rack, which contained additional flammable liquids, collapsed along with it (Ref. Fig. 4).

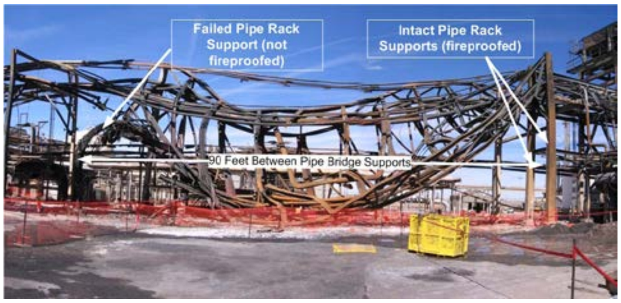

Figure 4 – Collapsed Pipe Rack as a Result of Heat from a Jet Flame.

Due to the loss of support and the effect of the heat, the pipes in the pipe rack, unable to support their own weight, began to sag. The allowable bending load eventually being exceeded from the force of their unsupported weight, the rack piping ruptured spilling their flammable contents into the already catastrophic fire. The contents of the ruptured piping, adding more fuel to the fire, caused the flames to erupt into giant fireballs and thick black smoke.

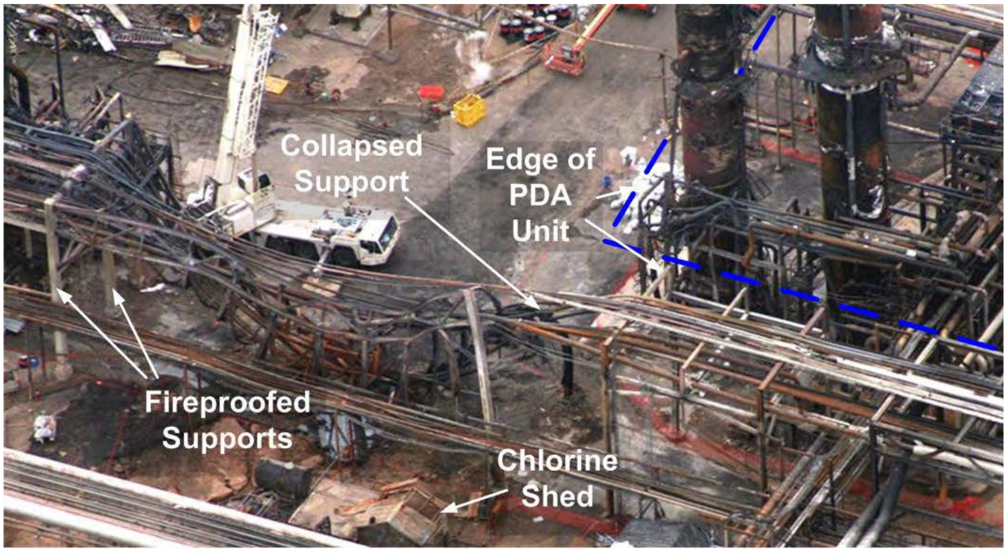

Figure 5 – Same Collapsed Pipe Rack as Fig. 4 Seen From Above

The non-fire proofed support steel, seen on the left in Fig. 4 and on the right in Fig. 5, was actually in compliance with API recommendations. Those recommendations can be found in Publication 2218 – *Fireproofing Practices in Petroleum and Petrochemical Processing Plants;* API Publications 2510 – *Design and Construction of LPG Installations*; and 2510A – *Fire-Protection Considerations for the Design and Operation of Liquefied Petroleum Gas (LPG) Storage Facilities.* In these issues of the Publications it was recommended that pipe rack support steel within 50 feet of an LPG vessel be fire proofed. The collapsed support steel was approximately 77 feet from the Extractor Columns, which is beyond the 50 foot recommended distance.

While the Engineer of Record (EOR) was in compliance of the governing Code, with regard to fire proofing, there may have been a degree of complacency in their defaulting to that minimum requirement. This goes back to a point made earlier in which it was said that industry Standards are not intended to be design manuals. They instead provide, "… *the minimum requirements necessary to integrate safety into the design, fabrication, inspection, installation, and testing of piping systems*…" Proprietary circumstances make it the imperative responsibility of the EOR or the Owner to make risk assessments based on specific design conditions and go beyond the minimum requirements of an industry Code or Standard when the assessment results and good engineering practice dictates.

Incident #2 – Formosa Plastics Corp., Point Comfort, TX, October 6, 2005

Figure 6 – Formosa Plastics, Point Comfort, TX 10/6/05

A trailer being towed by a forklift operator down a pipe rack alley in the olefins II operating unit of Formosa's Point Comfort facility attempted to back the trailer up into an open area between pipe rack support columns in an effort to turn the rig around. When the operator, in the process of pulling back into the pathway, began to pull forward the trailer struck a protruding 2" blow-down valve on a vertically mounted Y-strainer that was connected to a 4" NPS liquid propylene line subsequently ripping the valve and nipple from the strainer (Ref. Fig. 7). Liquid propylene under 216 PSIG pressure immediately began discharging into a liquid pool from the 2" opening and partially vaporizing into a flammable cloud.

Figure 7 – Impact Point Showing Damaged Y-Strainer

The flammable cloud eventually found an ignition source, ignited and exploded, in-turn igniting the pool of liquid propylene. The fire burned directly under the pipe rack and an attached elevated structure containing process equipment and piping. About 30 minutes into the event non-fire proofed steel sections of the pipe rack and the elevated structure containing process equipment collapsed. The collapse caused the rupture of equipment and additional piping containing flammable liquids, adding more fuel to an already catastrophic fire. The flare header was also crimped in the collapse and ruptured causing flow that should have gone to the flare stack to be discharged into the heart of the fire. The fire burned for 5 days.

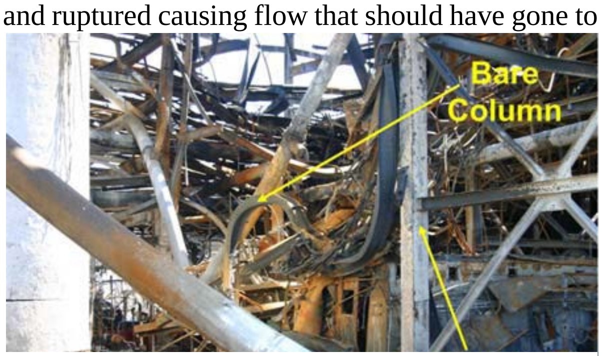

Figure 8 – Collapse of Non-Fire Proofed Structural Steel

Again, as in Incident #1, you can see in Fig. 8 the result of insufficient fire proofing of steel beams and columns in close proximity to process units. And fire protection does not apply only to vertical columns. As you can see, it is not sufficiently effective enough to have the vertical columns protected while the horizontal support steel is left unprotected and susceptible to the heat from a fire.

Another key factor in the Formosa fire was the ambiguous decision by the designer to orient the Y-strainer blow-down in such a position of vulnerability. While there is absolutely nothing wrong with installing the Y-strainer in the vertical position, as this one was, they are normally installed in a horizontal position with the blow-down at the bottom, inadvertently making it almost impossible to accidentally strike it with enough force to dislodge the valve and nipple.

However, orienting the blow-down in such a manner, about the vertical axis, should have initiated the need to evaluate the risk and make the determination to rotate the blow-down about its vertical axis to a less vulnerable location, or to provide vehicle protection around the blow-down in the form of concrete and steel stanchions. Both of these precautionary adjustments were overlooked.

The plant did perform a hazard and operability study (HAZOP) and a pre-startup safety review (PSSR) of the Olefins II operating unit. In the CSB report, with regard to process piping and equipment, it was stated that, "*During the facility siting analysis, the hazard analysis team* [Formosa] *discussed what might occur if a vehicle (e.g., fork truck, crane, man lift) impacted process piping. While the consequences of a truck impact were judged as "severe," the frequency of occurrence was judged very low (i.e., not occurring within 20 years), resulting in a low overall risk rank* [The ranking considered both the potential consequences and likely frequency of an event]. *Because of the low risk ranking, the team* *considered existing administrative safeguards adequate and did not recommend additional traffic protection."*

Incident #3 – BP Refinery, Texas City, TX, July 8, 2005

In the design layout of a duplex heat exchanger arrangement (Fig. 9) in the Resid-Hydrotreater unit of the BP Refinery in Texas City, TX, the designer duplicated the fabrication dimensions of the 90º fabricated elbow spool assemblies shown in Fig. 9 as Elbows 1, 2, and 3. While the pipe sizes and equipment nozzle sizes were the same, prompting this to be done, the service conditions were not.

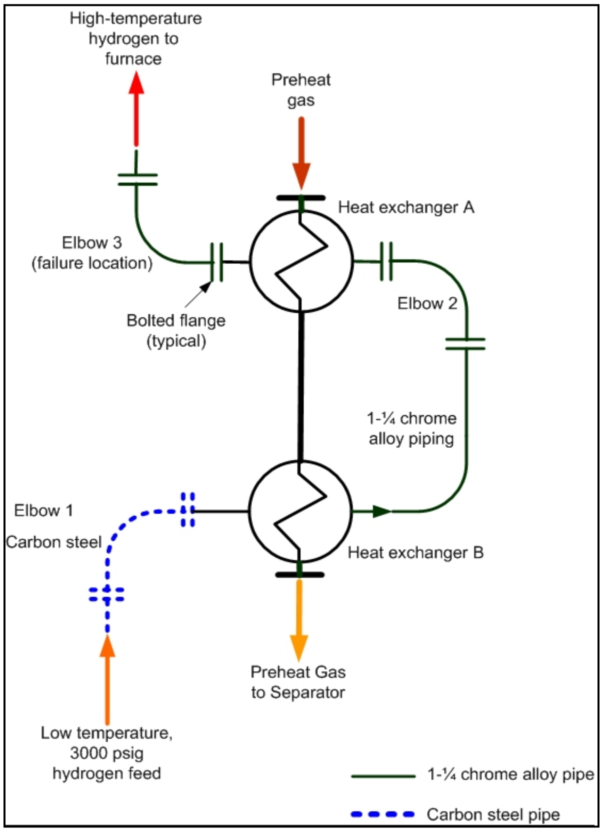

Figure 9 – Heat Exchanger Flow Diagram

The shell side conditions on the upstream side (at Elbow 1) were 3000PSIG at 400ºF. The shell side conditions on the downstream side (at Elbow #3) were 3000PSIG at 600ºF. The intermediate temperature at Elbow #2 was not documented. In the initial design the material for Elbow #1 was specified as carbon steel, Elbow #3 was specified as 1 - 1/4 chrome/moly alloy. The reason for the difference in material of construction is that carbon steel is susceptible to High Temperature Hydrogen Attack (HTHA) above ~450ºF at 3000PSIG, therefore the chrome/moly alloy was selected for the higher temperature Elbow #3.

At 3000PSIG and temperatures above 450ºF hydrogen permeates the carbon steel and reacts with dissolved carbon to form methane gas. The degradation of the steel's tensile strength and ductility due to decarburization coupled with the formation of methane gas creating localized stresses weakens the steel until it ultimately fatigues and ruptures.

In January 2005 scheduled maintenance was performed on the heat exchanger assembly. The piping connected to the heat exchangers was dismantled and stored for the next 39 days. After maintenance was completed the piping was retrieved from storage and reinstalled.

The elbows of different material were not marked as such and the maintenance contractor was not warned of the different MOC for the elbows. Elbows #1 and #3 were unknowingly installed in the wrong locations. On July 8, 2005, approximately five months after re-installing the piping around the heat exchangers, the elbow in the #3 position catastrophically failed as shown in Fig. 10.

Figure 10 – 8" NPS Hydrogen Piping Severed

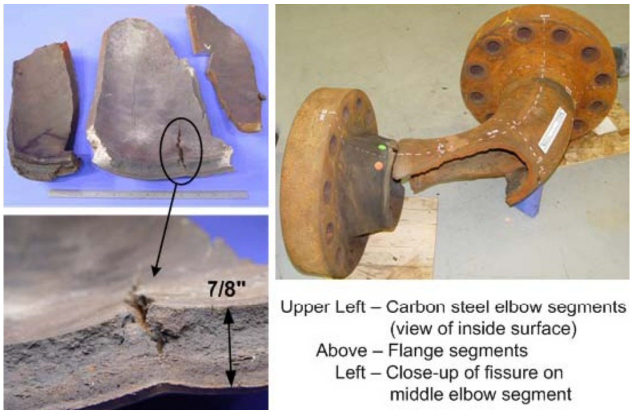

Figure 11 – Fragments of the Failed 8" NPS Carbon Steel Spool

As you can see in Fig. 11 the carbon steel, after becoming progressively weakened by HTHA, fractured on the inside of the pipe and catastrophically failed. The incident injured one person in operations responding to the emergency and cost the company $30MM.

The one thing you can take away from this incident is – Do Not Dimensionally Replicate Piping Spools or Assemblies of Different Material. The other underlying, but significant component you can also take away is this: In the initial design of a plant facility the Engineer of Record will routinely hold formal design reviews that will include all key personnel with vested interest in the project. In doing so, include, among the attendees, key operations and management plant personnel from one of the Owner's operating facilities, if available. These individuals typically bring a lot of insight and knowledge to a review. Whereas the designers may not have the wherewithal to think along the lines of issues that might pertain to a facility turnaround, the plant personnel will. These are issues that they normally think long and hard about. Make use of this resource.

TO SUMMARIZE

This article has touched on only a few isolated, but key safety issues and criteria that should be taken into consideration when designing, modifying, or maintaining a process facility. Whether it is a petroleum refinery, chemical plant, or a pharmaceutical API facility the same safety considerations apply.

The key points covered in this discussion pertaining to fire safety are:

1. Joint integrity
   a. Minimize mechanical joints
   b. Specify all welded joints accept where mechanical joints are absolutely required
   c. Specify gasket material that will extend the life of the gasket seal in a fire
2. Valving
   a. Specify and locate valves based on an engineered strategy
   b. Select bonnet seal, body seal, and stem packing material that can withstand upwards of 3000ºF
   c. Select fire-safe valves specifically when the valve needs to remain sealed in the closed position
   d. Metal seated valves with high temperature seals and packing can also be considered fire-safe
3. Process system overview
   a. A HAZOP review of P&ID's should include the analogy of the occurrence of a fire
   b. The review should identify the need for automated fire-safe shut-off valves to be controlled from a safe location outside the battery limits of the operating unit under review
   c. Sloped piping to allow liquid contents of the piping to drain to a vented vessel
   d. In accordance with ASME Boiler and Pressure Vessel Code (BPVC) pressure vessels require a relieving device. That relieving device should be vented to a safe location outside the battery limits of the operating unit
   e. Assess the need for a fusible link on tank bottom valves
   f. Vent and drain valves shall either have metal seats or be certified fire-safe
4. Strategic fire proofing of structural steel
   a. While industry Codes and Standards provide the minimum requirements for determining when structural steel should be fire proofed there are proprietary circumstances that should be analyzed, evaluated, assessed, and a pragmatic engineering decision made based on that assessment, so long as the result does not go below the minimum requirement.
5. Evaluating and assessing potential process hazards

a. Performing a HAZOP review of a plant layout is a very circumspect process. It requires the reviewers to assimilate a number of what-if propositions and to then thwart the outcome of those various scenarios by reacting with design corrections and changes. This is a process that should begin with P&ID's, progress with design by reviewing design layouts, and finally walkthroughs of the physical plant. It is a completely ongoing process throughout the life-cycle of a project.
b. At the P&ID stage the effects of the process design are considered should there be a fire, or runaway reaction, etc. At this stage the reviewers will create a scenario and determine the fail position (FC or FO) of automated valves; should the need for a valve to be car seal open (CSO) or car seal closed (CSC) be countermanded; does a tank bottom valve require a fusible link; this is also the time when there should be inter-discipline discussions between process design and structural engineering on the subject of fire proofing requirements.
c. At the design layout stage, when drawings are at the 60% to 90% completion stage, reviewers should look for, among other things, maintenance and operational accessibility; equipment, instruments, or attachments that may be vulnerable to traffic related damage; unwanted pockets in piping; unwanted dead-legs in piping; the need for valve chain wheels.
d. A physical plant review can take on various characteristics depending on how the program is set up. An informal approach can be adopted by the HAZOP team, in tandem with a formal program.
    i. The informal approach basically integrates a procedure that allows for anyone involved with the project (green field, retrofit, upgrade, or modification) to submit a written form describing a concern based on an observation made while performing their regular duties. These concerns can be originated by a contractor, an operator, validation team member, start-up team member, or others. Each issue is documented, reviewed, and responded to by the HAZOP review team. This dovetails in with the more formal HAZOP team activities.
    ii. The formal program is orchestrated and performed by the HAZOP team. This involves strict procedural guidelines establishing both a checklist of specific concerns and the flexibility to evaluate unexpected concerns. The procedure should include a formal process for reporting concerns, the review and assessment of those concerns, and the resolution to either reject or remediate each concern.
e. As with the dimensionally identical spool assemblies in the resid hydrotreater unit in Incident #3, this is the type of design issue that can be very easily overlooked. Unless you are reviewing the isometric fabrication drawings that depict the fabrication dimensions and connect the dots with future maintenance requirements a potentially hazardous circumstance such as this may not readily be identified.

IN CLOSING

Keep in mind that fire prevention is an attempt to incorporate various means and methods intended to prevent the mechanisms needed to start a fire from occurring. Fire protection, on the other hand, is a time related design element integrated into the elements of a facility that is intended to delay the effects of fire for a period of time sufficient enough to allow for personnel to evacuate the area and for emergency responders to gain control and suppression of a fire.

The events that initially spawned the creation of the American Society of Mechanical Engineers (ASME) were the many catastrophic boiler failures that had been occurring during the late 1800's. Engineering had not caught up with industrialization at that point and much of the engineering and fabrication taking place at the time was accomplished through the inconsistencies of trial and error. In response to the need for sound, safe, and repeatable engineering concepts the ASME was born. Thus the manufacture of safe operating boilers through improved design and pragmatic engineering was, over time, created, establishing a new era of safety and consistency in engineering.

Today safety remains at the heart of not only the ASME, but virtually all of the American National Standards Developers. The cost impact on a project to engineer a plant with piping systems that are inherently safer in both preventing leaks that can precipitate a fire and in containing hazardous fluids during a fire is minimal. Doing otherwise is more of a risk than most of us wish to accept. At the end of the design and construction of a CPI facility there should be a high degree of assurance that the men and women working in those facilities are safe from possible harm and are absent the concerns, not the awareness, of working in a high risk environment.

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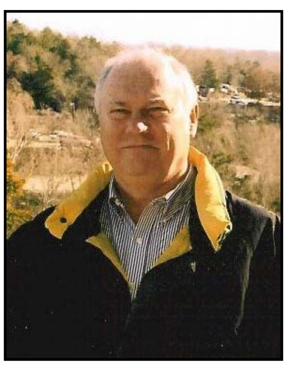
6. International Code Conference (ICC) www.iccsafe.org
7. National Fire Protection Association (NFPA) www.nfpa.org



W. M. (Bill) Huitt has been involved in industrial piping design, engineering and construction since 1965. Positions have included design engineer, piping design instructor, project engineer, project supervisor, piping department supervisor, engineering manager and president of W. M. Huitt Co. a piping consulting firm founded in 1987. His experience covers both the engineering and construction fields and crosses industrial lines to include petroleum refining, chemical, petrochemical, pharmaceutical, pulp & paper, nuclear power, biofuel, and coal gasification. He has written numerous specifications, guidelines, papers, and magazine articles on the topic of pipe design and engineering. Bill is a member of ISPE (International Society of Pharmaceutical Engineers), CSI (Construction Specifications Institute) and ASME (American Society of Mechanical Engineers). He is a member of three ASME-BPE subcommittees, several Task Groups, an API Task Group, and sets on two corporate specification review boards. He can be reached at:
W. M. Huitt Co.
P O Box 31154
St. Louis, MO 63131-0154
(314)966-8919
wmhuitt@aol.com
www.wmhuitt.com

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