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Reliability Estimation for Double Containment Piping

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RELIABILITY ESTIMATION FOR DOUBLE CONTAINMENT PIPING

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Double walled or double containment piping is considered for use in the ITER international project and other next-generation fusion device designs to provide an extra barrier for tritium gas and other radioactive materials. The extra barrier improves confinement of these materials and enhances safety of the facility. This paper describes some of the design challenges in designing double containment piping systems. There is also a brief review of a few operating experiences of double walled piping used with hazardous chemicals in different industries. The authors recommend approaches for the reliability analyst to use to quantify leakage from a double containment piping system in conceptual and more advanced designs. The paper also cites quantitative data that can be used to support such reliability analyses.

I. INTRODUCTION

Placing a process pipe, also called a carrier pipe, within a larger, or outer, pipe to serve as an additional containment barrier, has been successfully used in several industries. The elements of a double containment piping system are shown in Figure 1.

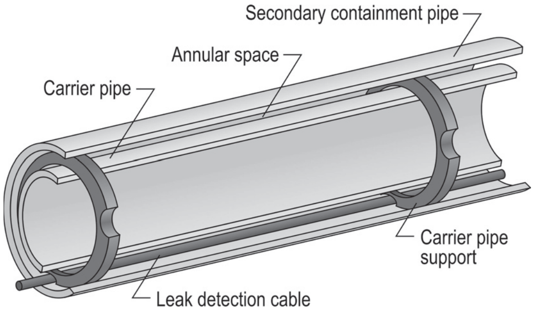

Fig. 1. Features of double containment piping.

The double pipe design approach has been referred to as pipe-in-pipe (PiP), double-walled piping, double containment piping, jacketed piping, enclosed piping, and other names.

In the US, this two pipe approach is usually referred to as secondary containment and is given as a design option to confine hazardous liquid chemicals for both underground and above ground tanks and piping.[1,2] There can be three configurations to operate the outer piping: pressurized, vacuum, and purge.[3] In the former, the outer pipe is sealed at both ends and the annular space is pressurized to greater than the pressure of the process fluid in the carrier pipe. If the carrier pipe experiences a leak, there will be a net flow of the pressurization gas (often nitrogen, sometimes argon or helium) into the carrier pipe. A pressure transducer in the annular space is set up to signal this condition. The loss of annular gas pressure may be due to a leak of the outer pipe; this possibility must be taken into account.

In the vacuum mode, the outer pipe is again sealed but this time contains some fluid (air or another gas) at subatmospheric pressure. This configuration can be advantageous when the carrier pipe must be thermally insulated. A pressure transducer is set up to signal if pressure increases because of carrier pipe leakage. This operating mode also shares the issue that if the outer pipe leaks, the incoming air will cause a pressure alarm rather than the process fluid causing an alarm.

The third configuration is purge operation. Purging is usually performed with a pressurized carrier pipe. The annular space between the pipes is continually swept with a low, but above atmospheric pressure gas, and the purge gas is monitored for fluid leakage from the carrier pipe. In the gas purging method, the monitor could be a specific chemical monitor to sense carrier pipe fluid leakage.

This paper investigates the means available to the analyst to estimate the reliability of double containment piping against leakage and makes recommendations on the best approaches to use to quantify reliability of such piping designs.

II. DOUBLE CONTAINMENT PIPING DESIGN

There are several design guides available to the system designer who chooses to employ double containment piping.[4-7] Given that this confinement design approach is typically a modest cost relative to other approaches (e.g., concrete lined trench enclosure, designated enclosure rooms), there are a fairly high number of such systems in operation. Typical industrial systems follow governmental regulations and use centering rings or spacers in the annulus, leak detection cables in the annulus, and assume that the secondary pipe can adequately confine a process fluid leak for up to 30 days without leakage to the environment. Fusion facilities also use double containment.[8] Double containment improves safety against leaks but also presents tradeoffs. If carrier pipe maintenance or inspection is required, there will generally be greater maintenance time with double containment piping—this reduces system availability. If the piping is in a radiation field, then there is also higher occupational radiation exposure from the longer maintenance time.

The US federal rule on double containment piping specifies that the inner space or annulus must be monitored for leakage.[2] Detectors in the annulus must be able to detect liquid leaks of ≥0.19 L/min (3 gal/hr) or a pressure change of 68,948 Pa (10 psi) within one hour of leak inception in the annulus between pipes; the detectors must be tested annually. Many applications use either a conductive or resistance-based leak detection cable, or else use a periodic sampling procedure from a low point drain in the piping to achieve this requirement. Some users dislike the manpower-intensive periodic sampling and prefer the cables. Cable systems are stated to have an accuracy of ±1% of the total cable length.[9] Some users have reported that condensation from humid air has formed in the annulus and created false alarms from the detection cables.

The American Society of Mechanical Engineers' piping inspection code for fission power plants states that pipe welds are exempt from examination if they are encapsulated by guard pipe.[10] In some safety significant applications, however, the regulator may insist that piping welds be inspected periodically despite the code exemption. In one nuclear fission power plant with a guard pipe around the 1-m diameter steam generator outlet pipe, access was needed to perform radiographic inspection of the welds. Personnel placed blank flanges in the guard pipe to allow personnel access to the carrier pipe.[11] If carrier pipe inspection is necessary, this would appear to be a feasible means to accomplish weld radiography or ultrasonic inspection as well as a very limited visual inspection of the carrier pipe exterior. A second option is a commercial off-the-shelf technology called 'ultrasonic guided wave technology' for inspecting the carrier pipe. Liu discusses the advantages of this method where a transducer can be left in place on the carrier pipe to facilitate periodic inspections.[12] Another possibility is robotic inspection of the carrier pipe by inserting the inspection robot so that it traverses carrier pipe interior. This would mean draining and opening the pipe for robot entry and exit, which may not be desirable for a quick return to operation. Generally, the annulus between pipes has too many obstructions (pipe centering supports or spacers, instrumentation taps, perhaps a leak detection cable, etc.) to allow robotic inspection of the exterior of the carrier pipe from the annulus.

Ziu described another challenge for secondary containment piping design.[13] Ziu states that thermal expansion, if not compensated for properly in piping design, can cause a double-containment piping system to have a shorter service life than a properly designed single wall pipe, at least for plastic piping. Given the coefficients of thermal expansion of metals, there is certainly concern about this issue for metal pipes as well. Differential expansion of inner and outer piping can cause reaction loads at interconnecting components. Figure 2 gives an illustration of thermal expansion induced component contact.

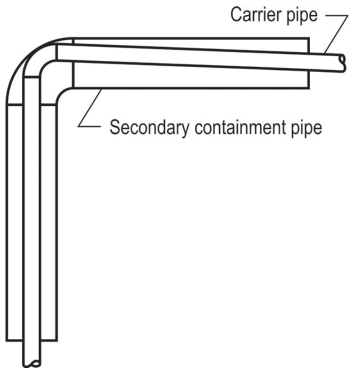

Fig. 2. Carrier pipe thermal expansion resulting in contact with the secondary pipe (Ref. 5).

The loads at these contacts can produce tensile stresses that approach the yield strength of the pipe materials and induce stress cracking at the interconnection points. These loads can lead to inner and outer pipe failure.

Ziu discusses that thermal expansion of the two pipes, the carrier and the containment pipes, will differ for two primary reasons.[4] The first reason is if the carrier pipe holds a hot fluid, its temperature will always be higher than the outer pipe. With temperature mismatch, the linear thermal expansion will be greater for the carrier pipe, so the carrier pipe will expand more than the containment pipe. Great care is needed in the design of these systems despite the fact that any facility will place constraints on space given to route the larger diameter outer pipe. When in underground applications, the outer pipe could be in contact with the earth, and the pipe could be held at a reasonably constant low temperature of perhaps 10°C depending on the depth and the thermal conductivity of the soil at the location.

The second reason for differing thermal expansion between pipes is that the two pipes may be constructed of different materials. The idea behind materials selection is that the outer pipe may be neither challenged to contain leaks very often nor required to contain the leaking fluid for very long times (e.g., the governmental requirement of 30 days), so the outer pipe could be constructed more inexpensively if it were made of a less strong material, such as plastic. Indeed, many hazardous chemical systems use fiberglass or plastic pipe as the outer pipe. The outer pipe does have to meet basic chemical compatibility and fluid pressure requirements. If the two materials used in carrier and outer piping vary greatly, then the mismatch of their thermal expansion may be large, which poses design concerns.

Another concern with double containment piping is vibration, usually flow-induced vibration in the carrier pipe. The vibration is transferred by centering rings or restraints to the outer pipe or when the carrier pipe is slip-lined into the outer pipe. The carrier pipe typically cannot be seen or easily inspected, so it can experience premature failure from vibration. For plastic pipes, Ziu states that vibration has been a failure cause leading to premature failure within the first year of operations.[13] Futukawa studied vibration in a gas-cooled fission reactor double walled pipe.[14] He concluded that vibration characteristics varied considerably with the locations of the spacers used to keep the pipe walls apart. The damping ratio of the coaxial double pipe increased with the number of supporting points and was larger than that of a single pipe.

An additional concern with double piping is corrosion because the carrier pipe is difficult to inspect for issues such as erosion-corrosion wall thinning or even surface corrosion. There are design provisions, such as cathodic protection, available to address corrosion concerns. Depending on the pipe material, keeping the annulus gas free of moisture can also be an important part of corrosion protection.

III. RELIABILITY APPROACHES FOR DOUBLE CONTAINMENT PIPING

Ostensibly, adding a second, independent pipe wall should mean that the chance of leakage (either outward or inward) should be treated as two independent confinement barriers. Therefore, two-pipe leakage failure rates on the order of ≈ 1E−08/hr-m or lower are combined by an AND gate to give a result that is a vanishingly small rate of leakage to the environment given the constraints of pipe length and mission time. The fusion Blanket Comparison and Selection Study approached double wall coolant tubing (a tube sleeved on another tube) in this manner, giving double wall reliability, R, as R = 1 − (number of failed tubes/total number of coolant tubes) (Ref. 15). That is, the reliability equation assumed that the tube wall failures were independent and no common mode failures were assumed to occur. That is perhaps the most important assumption in regard to assessing the reliability of double containment piping. This assumption has been found in a wide variety of studies (for example, Refs 16, 17).

Some analysts have modeled the outer pipe as an unchallenged standby component until a leak of the carrier pipe has occurred. This is because the outer pipe must operate for only a short duration of challenge until the system is shut down, repairs are made to the carrier pipe, and the outer pipe is flushed and cleaned. The short duration could be on the order of 1 hour for a sensor to give an alarm and then the plant proceeds to an orderly shutdown that could perhaps require up to another 24 hours (or 30 days can be used). If the environmental factors of the standby pipe component (vibration effects, corrosion effects, etc.) are properly accounted for in a standby component model, then this is a sound approach to estimating the reliability of a double-walled piping system.

Literature searches were performed to identify operating experiences that would indicate failure rates of double containment piping. Despite the fact that double containment systems have been widely used in the chemical industry since the 1990s, very little information was found in the literature. There is some qualitative information that industrial systems overall have performed very well.[18-20] Two additional cases are described below. No data sets were found that could serve as a basis for a failure rate calculation. Therefore, either modeling or analyst judgment is needed to determine the reliability. Analyst judgment approaches vary in the risk literature from assuming independent piping to a conservative common-cause type approach of a 0.5 multiplier on the failure rate of single walled piping to account for the secondary containment pipe.[21]

Kumagai gives an important case history.[22] He stated that for double containment piping used in the semiconductor industry, the reactant gas is contained in the carrier pipe while the outer pipe provides mechanical protection as well as acts as a containment for reactant leakage from the inner pipe.[22] The pipes under discussion were stainless steel, the carrier pipe was 6.35 mm diameter, and the outer pipe was 12.7 mm diameter. The room temperature carrier gas flowed at ≈ 25 L/min in the carrier pipe, or about 13 m/s flow velocity, at 0.16 MPa (20 psig). In the semiconductor industry, the annulus is sealed and pressurized with nitrogen to 0.79 MPa (100 psig). Continuous pressure monitoring alerted operators to a loss of nitrogen pressure, either a nitrogen leak into the carrier pipe or out to the room. Kumagai stated that in practice, leakage failures of the carrier gas to the room were practically nonexistent in properly assembled installations. Kumagai also said that the annulus could be evacuated rather than pressurized, but the nitrogen pressurized annulus was regarded to be simpler than a vacuum annulus and was adequate to detect leaks in either tube while not compromising safety of operating personnel.[22] These semiconductor gas manifolds operated at room temperature; the process gas and the nitrogen annulus gas were also at room temperature. The operating environment was low corrosion and the gas flow rates did not cause vibration. This system had no thermal expansion, corrosion, or flow-induced vibration concerns, making this one of the few instances that the double-walled piping could reasonably be modeled as two independent pipes.

Another interesting case is the Experimental Breeder Reactor-II reactor vessel. Since the reactor was cooled by sodium, a prudent design measure of a double walled reactor vessel (a primary vessel and a guard vessel) was used. The primary vessel was basically lowered into a ‘well’ formed by the guard vessel. The annulus was 12.5 cm between the two vessels. The primary vessel was given a failure rate of 1E−08/year for catastrophic failure (rupture). The vessel operated at about 370°C. The argon cover gas in the annulus did not flow quickly enough to remove heat, so the guard vessel reached close to the same temperature. In the event of a primary vessel rupture to the annulus (e.g., due to inclusions or other metallurgical flaws), the analysts assumed that a guard vessel rupture would be very improbable.[23] The term ‘very improbable’ is difficult to interpret but they likely meant below 1E−06/demand. One common cause failure mechanism for both inner and outer vessel failure was uncontrolled overpressure of the argon cover gas in the annulus. The Argon Gas System having an overpressure event was calculated to be a frequency of 2.9E−08/year (Ref. 23).

In other, more typical, situations where the carrier and outer pipes operate at different temperatures, the situation is not as straightforward and assuming pipe independence is too optimistic. A good approach to quantify the reliability of double containment piping where there can be temperature, vibration, or other effects, is to apply a Beta factor to account for the outer, non-independent pipe. The carrier pipe is given a multiplier of 0.01 to its leakage failure rate to account for the second, proximate-location pipe of the same material. Therefore, the external leak failure rate of the double containment pipe would be the carrier pipe leak failure rate multiplied by 0.01. If the outer pipe is a different, less strong material, then a Beta factor of 0.1 is recommended. This Beta approach was put forward early in the ITER international project and remains a valid approach today.[24,25] Certainly some can argue that this approach is also conservative, that the outer pipe could function better than the Beta factor suggests, especially in view of the opportunity for constant monitoring of the pipe annulus. For early reliability studies on conceptual designs, this Beta factor approach is recommended for its simplicity and speed to address the double-walled piping issue.

For designs advanced past the conceptual design level, there will be enough design information to support a detailed analysis. The two pipes can either be modeled as a primary and standby component, as mentioned above, or an engineering assessment can be performed. A rigorous finite element analysis can be performed to determine if any common modes (pipe walls touching and transferring forces, vibration through spacers or centering rings) are affecting both pipes. A corrosion assessment can be performed for both pipes to determine if there is a high likelihood of corrosion pitting or breaches in either pipe. The reliability analyst can use these analysis results to estimate the “leak tightness” of the double containment system.

IV. SOURCES OF PIPING FAILURE RATE DATA

There are some failure rate data available in the literature that can support reliability assessments of double containment systems. Single walled carbon steel pipe data can be found in Eide.[26] Fleming has some stainless steel pipe data as well as carbon steel pipe data.[27] Plastic pipe failure rate data were scarce in the literature. A data point was calculated from Petro.[28] The Petro data show that for polyethylene piping used in natural gas distribution systems, the failure rates are close to the failure rates of carbon steel piping used for the same purpose, giving an average failure rate on the order of 2E−08/hr-m for gas leakage. Some data accumulated from polyvinyl chloride piping used in water distribution systems gave a point estimate leakage failure rate of 3.8E−09/hr-m (Ref. 29).

Basta discusses that detection cables used in the annulus of double piping may give false alarms; the conductivity type cables were more susceptible to false signals than the resistance cables.[30] False signals were often attributed to condensed moisture from air trapped when the piping for these industrial systems was installed; the conductivity cable responded to the accumulated condensation water rather than to a process liquid. Thus, the detection cable did properly detect liquid; the signal was only ‘false’ in that there was no leak of process liquid. Condensed water within the outer pipe can create other issues due to the deleterious effects of standing water on some pipe materials (e.g., rust). Suggestions to avoid this issue were to sweep the annulus with dry nitrogen gas, or draw a vacuum on the annulus so that the initially trapped moist air is removed from the system.

V. CONCLUSIONS

There are some fusion facility needs for confinement that are well addressed by double containment piping. Several design guides exist to support the designer in the double pipe design, which must be performed carefully to gain all the advantages of double containment without the liabilities of premature failure. This paper presents the Beta factor method for the reliability analyst to use to quantify the leakage failure rate of a double piping system in conceptual design. A Beta factor of 0.01 can be applied to two pipes of the same material, and a Beta factor of 0.1 is recommended if the outer pipe is not as robust as the carrier pipe. For more detailed work on advanced designs, more rigorous pipe modeling can be used.

ACKNOWLEDGMENTS

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DOUBLE WALLED PIPING SYSTEMS

The design and construction of a double wall pipe is more complex than a single wall pipe because of the additional pipe, associated welds and tie in procedures. There are numerous design, operating and monitoring difficulties associated with spacers and bulkheads or shear rings. There is no compelling reason to use them when the primary function of the outer pipe is secondary containment.

Double wall pipeline configurations offer moderate-to-significant operating and maintenance advantages relative to single wall pipelines because of the ability for secondary containment of hydrocarbon in the event of an inner pipe failure.

The main operating and maintenance disadvantages of a double wall pipeline relative to single wall pipelines are the limited capability to inspect and monitor the condition of the outer pipe.

Double wall and single wall pipeline configurations have similar operating and maintenance requirements on the product (inner) pipe for operational condition monitoring, leak detection, chemical inhibition application, pipe cleaning, defect monitoring and evaluation, and cathodic protection testing, monitoring and maintenance .

When evaluating single walled pipe vs. double walled pipe systems, one must consider two important types of failures: 'functional failure' and 'containment failure'. A functional failure is defined as pipeline system damage without loss of product containment integrity to the environment. A containment failure is defined as pipeline system damage with loss of product containment integrity, that is product loss to the external environment. Hence a breach of either the inner or outer wall of a double wall pipe is considered as a functional failure, provided the other pipe retains its integrity or containment. Loss of containment through only one of the two pipes comprising the double wall system is not considered to be a containment failure of the system. Any failure to a single walled pipe system would constitute a containment failure.

The most compelling reason for a double wall pipe, instead of a robust single wall pipeline, is the containment of a product leak. The annulus (headspace between the inner and outer pipes) can also be monitored for evidence of a leak (or even pipe degradation). In these respects it has advantages over a single wall pipe. However, a leak in a robust single wall pipe has a very low probability. The thicker wall than normally used provides greater strength to resist environmental loads and greater resistance to erosion and corrosion.

The major advantages of a single wall pipe are simpler construction, lower construction costs, lower life cycle costs and greater inspection reliability. The major disadvantage is that any size of leak will release product into the environment. The major advantage of the double wall pipe is that the probability of a failure or leak in both pipes at the same time is very low. It has a lower risk of product release to the environment than a single wall pipe. The disadvantages of the double wall pipe include its relative complexity and potential difficulties with integrity monitoring of the outer pipe.

Corrosion

The double wall pipe and single wall pipeline configurations have similar corrosion related design considerations.

The potential corrosion of the inside of the inner pipe of the double wall pipe is the same as the inside of the single pipe. The outside of the inner pipe and the inside of the outer pipe have low potential corrosion because of the nitrogen gas that will be used to fill the annulus. The outside of the outer pipe will have a slightly lower corrosion potential than the single wall pipe because of the somewhat lower skin temperature. It is assumed that the robust single wall pipe and the double wall pipe will have similar coating and cathodic protection.

Constructability

Construction of a double wall pipe is more complex than construction of a single wall pipe. The additional construction activities consist of inserting one pipe within the other, with the associated outer pipe tie-in welds, pressure testing the outer pipe and drying and charging the annulus following construction.

The amount of pipe and the number of girth welds is double for the double wall system.

Construction Quality

All welds of the double wall pipe can be inspected by radiography methods as for the single wall pipe with the exception of tie-in welds on the outer pipe. These tie-in welds can be adequately non-destructively examined by ultrasonic inspection.

Split sleeves may be required for final tie-in welds on the outer pipe of the double wall pipe. Manual ultrasonic inspection of the associated longitudinal welds should be adequate.

Operations and Maintenance

The double wall system has several maintenance disadvantages, relative to single wall pipelines. These include reduced outer pipe defect monitoring capability and more complicated commissioning requirements. Repair procedures would be more complicated and the increased complexity of the double wall system would increase the repair frequency.

Double wall pipe configurations have a potentially lower lifecycle cost for “containment failure”, relative to single wall pipelines, due to the secondary containment capability offered by the outer pipe. Containment failure cost includes lost product, service interruption / lost production, cost of repair and recommissioning, environmental restoration and intangible costs.

Double wall configurations have a potentially higher lifecycle cost for functional failure, relative to single wall pipelines, due to the inability to readily inspect, evaluate, monitor and control outer pipe defects. Functional failure cost includes service interruption / lost production, and cost of repair and recommissioning.

Double wall and single wall pipeline configurations have similar operating and maintenance costs, for operations (operational monitoring, leak detection, application of corrosion and chemical inhibition) and for maintenance (corrosion control, inspection, defect evaluation and defect control).

Comparative Risk Assessment

The configuration of a double wall pipeline is more complex than a single wall pipeline; it has more material and more welds and it is more difficult to monitor. Hence it has a greater risk than a single wall pipeline for operational problems. However, a leak in a single wall pipe results in loss of product to the environment. It is unlikely that simultaneous failure of inner and outer pipe would occur with the double wall system. The risk of loss of product to the environment is lower for double wall system.

Pipe-in-pipe (PIP) configurations have been adopted for many different industrial applications. These applications include thermal insulation, leak containment and protection of flowlines. The PIP configurations may involve single or multiple inner pipes. For example, multiple flowlines and other service lines are often bundled together inside one outer pipe in a pipe bundle for ease of installation.

Thermal insulation is currently the most common application of single or multiple (pipe bundle) PIP systems. Hot water and chilled water, heat transfer fluids, hot oils, liquefied gases (cryogenic service) and molten sulfur are typical service types common to industrial and commercial construction.

Chemical Industry Application

Chemical process facilities handle a variety of chemical substances and compounds at various temperatures and pressures. The piping system for transporting the fluids must be compatible with the intended service conditions. The selection of piping materials of construction depends on the specific application. Petroleum refinery piping is generally characterized as large-diameter metallic piping, operated at elevated temperature and pressure. Chemical plant piping is typically characterized by relatively small diameter pipes (2 in or smaller), with lower operating pressure and temperature, and corrosive fluids. The use of exotic alloy materials, thermoplastics, and thermoset resin materials is common for the pipe construction. Many chemical plant pipes transport flammable and toxic substances.

Pipe-in-pipe (or more commonly jacketed pipe) systems are used in petrochemical industries mainly for containment and thermal insulation. Jacketed pipelines are commonly used to carry certain fluids in process facilities. Process fluids that require temperature control (i.e., molten sulfur) are good candidates for the applications of jacketed pipes. For molten materials (i.e., polymers) where high temperature is required, jacketed pipelines can also be used. Some advantages of jacketed pipelines are:

1) uniformity of heat input around circumference of process pipe;
2) tighter temperature control over entire pipeline length; and
3) elimination of cold spots that may cause degradation or localized freezing of process fluids.

Pipe bundles comprising several inner pipes in a single containment casing are also used for economic advantage.

In jacketed pipe systems, various heating media (liquid phase and vapor phase fluids) can be used for temperature control of process fluids. Jacketed piping systems where the annular space is evacuated are often used to convey cryogenic temperature process fluids. The vacuum minimizes heat gain from the atmosphere to the cryogenic fluids. The annulus of the system can also be used for passive thermal insulation by the addition of insulation materials.

The heat from the flowing fluids makes the outer pipes expand. Measures are available for reducing the thermal stresses in the jacketed pipes.

Regulatory Requirements

The US Environmental Protection Agency (EPA) regulations now require secondary containment for piping and storing hazardous fluids. The Health & Safety at Work Act has also imposed exacting standards for transporting dangerous chemicals through piping to prevent spillage or leak. A common solution is to use a jacketed pipe with the inner pipe within a containment casing equipped with leak detection. The inner pipe is normally within a size from 0.5 to 18 in. The outer pipe is approximately two nominal sizes larger than the inner pipe.

Double Walled Piping Design Considerations

The primary objective for considering a double wall pipe system is based on reducing the potential for accidentally releasing product from the pipeline into the environment.

Structural integrity issues are concerned with pipeline response and performance due to the imposed operational and environmental loads. General considerations for issues on pipeline structural response are summarized in the table below.

Structural Integrity Issues for Pipeline Design

Parameter		**Structural Integrity Issues**
Working Stress	MAOP	Maximum allowable internal operating pressure (MAOP)
	Temperature	Thermal stress load
	Stress	Membrane (i.e. in-plane) stress due to internal and external pressure
Strain Limit State	Rupture	Membrane tensile strain limit due to primary and secondary loads
	Combined Strain	Membrane strain due to combined differential displacements and/or rotations
Stress Limit State	Burst (Yield)	Maximum internal pressure limit
	Combined Stress	Membrane stress due to differential loads, pressure distributions or moment couples
Stability	Buckling	Loss of global or local structural stability due to bending moment, internal or external pressure, excess temperature differential
	Ovalization	Local sectional collapse due to effects such as overburden pressure, or interaction between carrier and outer pipe
Integrity	Weld CTOD	Interaction of weld defects with tensile strain and accumulated plastic strain

Acceptable stress or strain limits are established as a function of a number of parameters including operating pressure and temperature, pipeline diameter, wall thickness, material grade.

Double walled pipelines are generally expected to utilize a series of bulkheads or shear rings and/or spacers to transfer loads between the inner and outer pipes and centralize the inner pipe within the outer pipe.

Bulkheads are pressure containing, load transferring structural attachments between the inner and outer pipes. Shear rings are essentially bulkheads that contain ports that allow communication (fluid flow) between adjacent annular segments. Bulkheads and shear rings would be custom manufactured from low alloy steel very similar to the steel used in the line pipe. Spacers are generally non-metallic bands manufactured as half cylinders and fixed to the outside of the inner pipe. Each spacer has a series of longitudinal ribs that fit snugly inside the outer pipe. They serve to position the inside pipe within the outer pipe, allow more even annular space and allow less restricted movement of the inner pipe. Spacers are commercially available manufactured items. If specific dimensions are required, spacers can be customized. Typical spacer spacing is about thirteen feet. This amounts to three spacers per forty foot long joint of pipe.

Bulkheads isolate the annulus into a series of annular segments. Bulkheads have the potential advantage over shear rings of isolating a leak from the inside pipe from defective segments of outside pipe. There is no known inspection method for monitoring the overall condition of the outer pipe, however. Consequently, bulkheads are not considered to afford adequate advantage to compensate for the lost opportunity of utilizing the annulus to continuously monitor the pressure containing integrity of both the inner and outer pipes. As such, in principle, Venture Engineering favors spacers or shear rings over bulkheads.

For normal product pipeline operating temperatures when the only functional requirement of the outer pipe is containment, there does not appear to be any design imperative for the use of bulkheads, shear rings or spacers for double walled pipelines. This would reduce the fabrication and constructability issues of double walled pipelines significantly. The only caveat on this statement is that the overall condition of the outer pipe can only be monitored on a pass/fail basis with respect to its ability to contain a leak. This would be done by means of maintaining the annulus at a pressure above or below the ambient pressure and monitoring this pressure.

The double walled concept preferred by Venture Engineering is simply one pipe inserted within the next larger standard pipe size (simple double wall system). The inner and outer pipes would be suitably attached at each end by means of a bulkhead like device. Side outlets suitable for filling and purging the annulus and instrument connections would be installed on the outer pipe at each end to provide operating and maintenance access to the annulus.

The following design rationalizations were made with the decision to eliminate the bulkheads or shear rings and spacers for double walled pipe:

1. There seems to be no significant structural advantage to the use of a centered inner pipe.
2. There does not seem to be a requirement to avoid contact between the inner and outer pipes to control corrosion, as is the case with cased crossings where the annulus is vented to atmosphere.
3. To practically eliminate corrosion in the annulus, it is suggested that following construction, the pipeline be placed in service and allowed to warm up. The annular space can then be vacuum dried. Once dried, the annulus could be evacuated or filled with nitrogen. To provide an extra measure of insurance against corrosion in the annulus in case the drying is incomplete, a volatile amine vapor phase oilfield corrosion inhibitor could be injected into the annulus with the nitrogen to elevate the pH anywhere moisture is present.

Based on the following reasons, the simple double wall system should be at lower risk from corrosion than a single walled pipeline. Internal corrosion would be the same for both systems. There should be virtually no corrosion in the annulus. Pipe corrosion barrier coating and cathodic protection would be as effective in protecting the outside of a double walled pipeline as they are for a single walled pipeline. The outer pipe of a double walled pipeline operates at lower temperature than a comparable single walled pipeline by virtue of the heat transfer resistance provided by a vacuum or inert gas-filled annulus. It would therefore experience a lower rate of external corrosion in the event that external corrosion is not effectively mitigated. As a general rule, corrosion rate doubles for every 20F increase in system temperature. For example, the maximum temperature of the outer pipe is estimated to be 80F for a design product temperature of 110F. Such a temperature reduction would result in a reduction in the corrosion rate on the outer pipe compared to that of the single walled pipeline.

Dave Moniot has over 19 years experience Mr. Moniot has over 19 years of experience in the management, coordination, and execution of chemical, energy (including cogen and CHP), petrochemical, refinery, pharmaceutical, healthcare and research and development projects, and metals. He holds a Bachelor chemical engineering degree from the University of Pittsburgh. He can be reached at (412) 231-5890 x301, or at dmoniot@ventureengr.com.