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SELECTING A VALVE FOR COLD SERVICE

INTRODUCTION

Since the first quarter of the 19th century, countless scientists and natural philosophers have taken on the study of "cold." Commercializing on the mastery of these discoveries, life on this planet has never been the same. For example, in the early 1800s, a temperature of -110° C (-166° F) was not proven to exists. The vocabulary, never mind the means to attain it, did not exist. Through many years of experimentation and the rough road of trying to commercialize on scientific breakthroughs in the marketplace, we enjoy the advancements to human life and the comfort it brings.

It has been generally accepted, at least commercially, that the cryogenic temperature range starts at -150° C (-238° F). Certain gases are considered "cryogenic" because it takes more than just an increase in pressure to compress a volume of gas – as stipulated by Robert Boyle. Little did he know at the time (1665) that the relationship between volume and pressure would become much later the cutting edge for cold research.[1]

Today, anything warmer than cryogenic temperatures is considered "refrigeration," at least in relation to valve selection in cold service. Refrigeration, at one time, was the temperature range required for the preservation of food from 3° C to 5° C (37° F to 41° F). Later, the range went as low as -43° C (-45° F) upon the invention of fast freezing food for commercial purposes. Later still, the temperature range decreased to -110° C (-166° F) with the invention of non-cryogen liquefaction. This then set the stage for the descent toward the liquefying of cryogens and absolute zero.

THE VALVE INDUSTRY

Now we get down to the matter of understanding cold as it pertains to the "mundane" matter of valve selection. There are a number of things we need to understand about cold temperatures when considering how we go about selecting a valve that will work over the long term. What do we have to take into consideration in terms of the physical properties of cryogens themselves and materials that will handle them?

The valve industry is conservative. A general rule is that continuous temperatures less than -73° C (-100° F) is considered cold service and warrants valve preparation for cryogenic temperatures. There are always exceptions to this rule, as many readers can probably attest, but for the sake of this discussion, that will be the general rule.

PROBLEMS ASSOCIATED WITH THE TRANSPORT OF CRYOGENS

The question of how to handle media that is not naturally liquid at atmospheric pressure needs to be approached from a thermodynamic view point. Leakage of cryogens is not only dangerous, but also very expensive, taking into consideration the cost to make a gas a cryogen in the first place. In relation to the valves controlling this media, thermal swings have been called the *Achilles heel* for any valve in cold service. The contraction and expansion of the various valve components (e.g., body, bonnet, stem, seats,

[1] *Absolute Zero and the Conquest of Cold*, Tom Shachtman, 1999, Houghton Mifflin Company

etc.) can cause premature failure of the valve, potentially exposing personnel and the environment to highly-pressurized, freezing gas. Defining what is “intermittent” or “steady state” service further complicates valve selection.

Take, for example, the seat leakage potential for a quarter-turn ball valve at the ball/seat interface between two common materials selected for cold service. When cryogenic temperatures are involved, the thermal expansion difference between a PTFE[2]-based seat and a 316 stainless (316 SS) ball is greatly enhanced. PTFE expands approximately five times the rate of 316 SS. This expansion difference necessitates particular attention to design considerations. What tests well on the bench is no guarantee of seal tightness in the deep cold where seat geometry and surface finish play a big role.

The linear and radial growth of the valve stem in relation to the body often can be underestimated as well. Properly designed stems (and stem seals) need to bridge this thermal rate of expansion difference as they are tasked to dynamically seal on the stem OD and packing chamber ID at all times.

Heat gains from the environment also pose challenges for valves in cold service, such as the buildup of pressure and the subsequent vapor formation. Valves and piping need to be insulated to help navigate this. In gas processing, the physical properties of the gases (such as liquefied natural gas [“LNG” which is mostly methane – CH_4], nitrogen, oxygen, argon, and helium) make them resist becoming liquids at atmospheric pressure and, if allowed, can violently transform back to a gas in a heartbeat (approximately a 700:1 expansion factor).

VALVE CONFIGURATIONS USED IN CRYOGENIC SERVICE

VALVE TYPE

There is no hard-and-fast rule for which valve type to use for cryogenic service (which is typically clean media). The industry does seem to prefer quarter-turn valves for their tight shutoff, however, and this generally means a ball valve or high-performance/triple offset (TOV) butterfly valve. For larger valve size requirements, gate valves are often utilized. Above 250 mm (10”) sizes, TOVs are generally selected because the mass of a ball valve often makes it cost prohibitive. This is not a strict rule, however, and largely depends on how much the user wants to pay “up front” versus “later on” in terms of valve performance and life cycle maintenance.

The piping connections selected for cryogenic service are usually flanged or welded configurations. Either of these connection types can handle a wide pressure range; the majority of applications being ASME Classes 150-600 (and some applications up to Classes 1500 and 2500).

Typical Cryogenic Service Valve Selection by Size Range[3]	
Size Range	***Valve Type***
15 mm – 400 mm (1/2” – 16”)[4]	Ball Valve
250 mm – 800 mm (10” – 32”)	High-Performance or Triple-Offset Butterfly Valve
600 mm – 1400 mm (24” – 56”)	Gate Valve

[2] Polytetrafluoroethylene
[3] This chart outlines the general trends, but is not set in stone.
[4] The majority of valves selected up through 200 mm (8”) are ball valves.

BODY CONFIGURATIONS

There are various body configurations for ball valves. For flanged valves, an end-entry (some refer to this as side-entry), uni-body design is available; where there are no breaks in the valve body that could be potential leak paths to the environment. To access the internals, there is a threaded end plug that inserts into one of the flanges.

A second option is a split-body arrangement, where the endplate (sometimes called a tail piece) is bolted to the body. To access the internals, the two components are unbolted.

There also are three-piece body arrangements, which include a body center section and two endplates (sometimes called pipe ends) that are bolted to the body. This design is popular because the center section can swing out while the valve is in-line, making the valve in-line repairable after it is isolated. As with end-entry, flanged valves for cryogenic service, a welded extension is fabricated to the body.

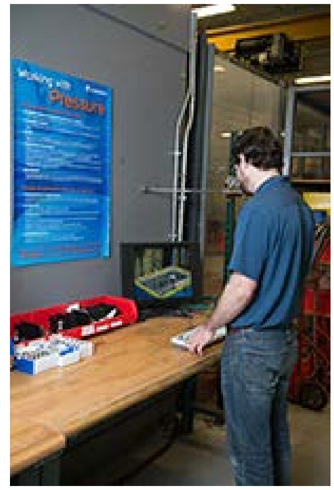
There is often a desire to eliminate potential leak paths when installing valves for large LNG projects, particularly for smaller valves (50 mm [2"] and below and there are usually a lot of them). As a consequence, some piping engineers have moved from a three-piece body design (two possible leak paths) toward a top-entry (only one possible leak path) design. This single potential leak path on a top-entry ball valve is between the bonnet-to-body flange connection, which is required to access the internals of the valve. It is generally assumed that maintenance is easier on a top-entry valve, because it is in-line repairable. However, testing the seal integrity in-line after maintenance may be difficult. For larger valves especially, scaffolding is often required to access the valve and take it apart. After the time and expense to do this, operators generally feel compelled to take the valve out of line so that it can be tested for sealing integrity. There are always two sides to any claim, so each designer (ultimately the buyer) must decide what the best philosophy for their plant is.

WELDING

If a three-piece valve is to be welded in-line, without first undertaking the recommended disassembly and replacement of soft parts, heat damage to the body seals and seats from the welding process or the post weld heat treatment (PWHT) must be considered. Body seals are the "soft" components that create a seal between the body and the two endplates that comprise a three-piece valve. The seats may be reusable after welding, but they too should be checked for damage. Depending on the skill of the welder, it is possible to weld a valve in-line without doing any heat damage to soft seal components. It is strongly recommended, however, that the valve be disassembled after welding and seats and seals replaced. This is often ignored, causing problems later on.

Most people are risk averse and will not take that chance of welding in-line, especially with projects where large numbers of small valve installations are involved. As a result, designers often specify pup extensions to remove the concerns of heat damage to the body seal components during the welding process. Keeping track of body seal replacement parts (which come with the valve) specifically for the post-weld replacement can be difficult, as they are frequently discarded inadvertently. Pup extensions take the welding process away from the end connections of the valve, so that the possibility of heat damage is greatly reduced and body seal component replacement is not necessary.

Basic Valve Design Objectives



Design Standards for Cold Service[5]

- ASME B31.3 Boiler and Pressure Code (all valve types)
- ANSI B16.34 (all valve types)
- API 600, 602, 603 (gate valves)
- API 602 (gate, globe, and check valves)
- API 608 (ball valves)
- API 609 (butterfly valves)

As it pertains to large projects in particular, European and International Standards also prevail. Often there are many material specifications involving the choice of castings or forgings and the subsequent quality, verification, and non-destructive testing of each.

MATERIAL SELECTION

For cryogenic valves, one area of concern for material selection is the ability to maintain ductility at low temperatures. Brass can be used and is often specified, but the material most commonly specified for cold service is 316 SS, in its forged or cast form, for body and internal components. Valve specifications can go into great detail about non-destructive testing requirements, radiography, material impact testing, and positive material identification (PMI).

For ball valves especially, there is general consensus that fluoropolymer materials (generally classified as thermoplastics) seal very well in extremely cold temperatures. There are numerous melt processable and powder forms of fluoropolymers, such as PTFE, PCTFE[6] (known by the brand name Kel-F®[7]), FEP[8], PFA[9], and ECTFE[10]. Some are stronger than others, but all exhibit non-stick and friction reducing properties. These materials are universally impervious to most media and lend themselves particularly well to cryogenic applications. Fluoropolymers are used for both the seat and stem seal components. If fire safety is a requirement and the melting of fluoropolymers is a concern, graphite stem seals can be used.

BONNET CONSTRUCTION

Isolation of the stem seals from cryogenic temperatures will require an extended bonnet. Over time, as the cryogen leaks and absorbs heat as it vaporizes to the atmosphere, ice will form. This can take the form of an "ice ball" on top of the bonnet extension. The handle (or actuator/coupling area), will be impeded and the valve will not operate. An extended bonnet helps to capture a column of this vapor between the diametrical clearance of the stem and the bonnet. This vapor exerts pressure on the cryogenic liquid and prevents its contact with the stem seals. Because fluoropolymers shrink approximately five times faster than the surrounding metal in the valve, contact of the stem seals with the cryogen will cause the valve to malfunction.

The preferred method to attach the extended bonnet to the body is a full penetration weld, which helps ensure weld integrity (this can most easily be achieved via a butt-weld type connection). In addition, seamless tubing for the bonnet extension should be used. There is no recognized standard in the valve industry that addresses bonnet height. There are some end user specifications (Shell MESC SPE 77, for

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[5] These are the same standards utilized in the manufacturing of process valves.
[6] *Polychlorotrifluoroethylene*
[7] Kel-F is a registered brand of 3M Company
[8] *Fluorinated ethylene propylene*
[9] *Perfluoroalkoxy polymer resin*
[10] *Ethylene chlorotrifluoroethylene*

example), which specify minimum bonnet extension heights (called thermal lagging) for all types of valves, but many valve companies have calculated and incorporated designs that work for their products.

BLOWOUT-RESISTANT STEM

As previously noted, the 700:1 liquid-to-gas expansion ratio makes it necessary to have a stem design that is blowout resistant. If this design feature is not in place, the stem could physically jettison itself from the valve if the operator (e.g., actuator, gearbox, handle, etc.) were removed. Not putting the retention ring screw back in place during normal maintenance has caused major incidences when the valve was later disassembled, which resulted in significant loss of media, evacuation, and personnel harm. All it takes is a momentary lapse in judgment. It is worth emphasizing that during valve repair precautions are necessary; the retention ring screw must be properly put back in place before the valve is in service again.

CAVITY PRESSURE RELIEF

In addition to the blowout-proof stem, there must be a way for cavity pressure relief (CPR) within the valve to remedy a liquid-to-gas transition. Cavity pressure buildup can destroy the sealing components of a valve. It can also distort the ball or cause the valve to leak externally past the body seal(s), if it is a split-body or three-piece design. The worst case scenario is a catastrophic failure to the whole piping system itself. For a ball valve, the most dependable way to relieve pressure buildup is through a hole in the high pressure side of the ball. However, this modification makes the valve unidirectional. When a valve is unidirectional by design, it must be indicated which side is the high pressure end. This information is covered in the installation instructions that come with the valve, but for whatever reason, they are often not read. As a result, valves can be installed backwards with the relief side pointing towards the low pressure side, which results in the valve experiencing seat leakage in the closed position. If cavity pressure relief was not a design concern, there would be no need for a vented ball. Consequently, the valve would be bi-directional and the preferred-pressure side marking would not be required.

For larger-sized quarter-turn valves where both bi-directionality and cavity pressure relief is required, another method of CPR is available. A CPR device can be externally mounted to the outside of the valve that enables relief to the upstream side while maintaining bi-directionality of that valve[11].

INSTALLATION

It is recommended that cryogenic valves with PTFE stem seals not be installed more than 45 degrees from the vertical. This is a precautionary measure to keep the cryogen away from the stem seals. Valve installers often take exception to this as there are space constraints and pipe interference issues that frequently need to be contended with. Beyond the 45-degree position, the probability of the cryogen making contact with the stem seals goes up, increasing the odds of stem seal failure. If the stem seals are made from graphite, concerns of orientation are not usually a factor as the graphite does not have a rate of thermal contraction like fluoropolymers when exposed to cold temperatures. The surface finish is critical on the sealing components of a valve for cryogenic service. The slightest imperfection – a slight scratch, the smallest of indentations, a hair – can all lead to unacceptable “through” leakage during cryogenic testing and service. Any buildup on the ball, such as lubricant or shop dirt, can cause leakage or make the valve difficult to operate. This is why clean room capability, stringent cleaning procedures, and component inspection are followed during the assembly of cryogenic valves. The fact that a PTFE-based seat material acts very much like metal at cryogenic temperatures only exacerbates these issues. It is not the forgiving and resilient substance we know at ambient conditions.

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[11] Note: While the valve is bi-directional, the CPR device is not. Bi-directional valves with CPR systems must be installed in the line as a unidirectional valve would be, or the CPR will relieve downstream.

THROTTLING SERVICE

In cold service, care must be taken when throttling with PTFE-based soft seat materials. During throttling, when the valve is in travel (between opening and closing, or vice versa), the seats are unsupported by the ball surface and can shrink faster than the metal ball. If seat contraction does occur, and if the ball rotates back across the seat, the seat may fracture as it now interferes with the ball's rotation. If the valve is allowed time to fully cool, then this theoretically should not be a problem. The question is how much time is enough to constitute a "steady state" condition?

To allay these concerns, a buyer may specify round-port metal seats which will shrink at the same rate as the ball when subjected to cold conditions. Round-port metal seats can be used for crude control[12]. If a more precise flow characteristic is desired, a characterized control seat (which is always metallic) suited for the flow conditions can be designed, as with many control application.

Valve Design Considerations

At what point does valve specification become overkill, though? How robust do valve design requirements really need to be? How sensitive is the environment in which the valves will be used? What is at risk? Most users are likely to use the "standard" offering from valve manufacturers, such as PTFE stem seals (if fire-testing is not a concern; graphite seals when it is). Things get more complicated when there are low fugitive emissions (FE) requirements, and even more complicated when fire safety is required at the same time. Under these circumstances, some designers go further by requesting that graphite not be used as the primary seal for a valve that needs to meet both low FE requirements and be fire-safe – a request that is not easy to achieve.[13]

BONNETS

An extended bonnet is not required for every cryogenic application. However, not using extended bonnets where they should be used is not good practice. To make the final determination, one has to understand what is going on with the process itself and what is expected of the valve. Generally, extended bonnets are not specified if the service is perceived to be intermittent, or if there are physical constraints prohibiting their use. Most valve companies offer valves for cryogenic service with body and seat materials suitable for cold temperatures, but without an extended bonnet. If valves in a cold "area" are considered utilitarian in scope – like a drain or vent application – people may opt to not use an extended bonnet.

What is the better bonnet construction for cryogenic service – bolted or welded? If one is comfortable with welding techniques, a welded joint can certainly eliminate a potential leak path. A bolted bonnet design provides for potential leak paths, especially if actuators are involved. If the valve/actuator units are installed off the vertical position, the overhanging mass can put strain on the bonnet bolts. Thermal cycling also can create havoc, as it would for any bolted design. Added safety can be gained by specifying some form of non-destructive testing for welded connections – either dye penetrate inspection or radiography, which is an added cost. Generally, the decision between bolted or welded construction is determined by the specific application and what has worked over time.

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[12] "Crude" meaning that a small change in valve position (e.g., opening a valve from 30% to 40%) results in a large, undesirable change in flow. This is a characteristic of round-ported seats and is allowable in some instances. Most of the time, finer control is required because preciseness is needed to avoid this large flow change. This can be accomplished with characterized seats.

[13] This configuration would include PTFE-based primary seals, and graphite seals as the secondary seals, which would need to be independently loaded to work effectively during and after a fire.

CLEAN ROOM ASSEMBLY

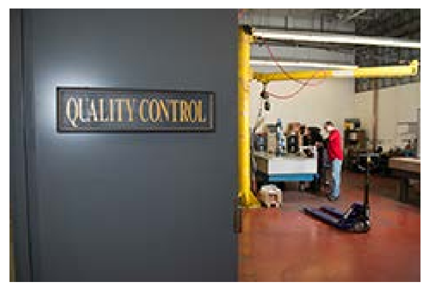
Valves intended for cryogenic service should be assembled in a clean room, be lubricant free, or utilize lubricants compatible with cold service. The valves should not have machine oils, grease, dirt, or any foreign material in the valve for the clean service for which it is intended. Any extraneous matter can inhibit the performance of sealing at cryogenic temperatures. Anything that can get in between the ball and seat can cause sealing problems. The buyer should insist to see documented procedures for cleaning, and should verify they are actually being followed during the assembly process.

WITNESSED TESTING

Passing the rigors of witnessed testing for cryogenic service is not easy. Valves that work at ambient conditions often do not work at cryogenic temperatures. Similarly, valves that work at cold temperatures may not work well when subjected to warm temperatures again. Torque values may be inconsistent in the cold, which is why most cryogenic testing requires testing over a range up to the maximum-rated pressure of the valve. Testing for use in cryogenic conditions also requires the valves to be warmed to ambient conditions to make sure they still sealed.

QUALITY COMMITMENT

Most importantly, a buyer needs to know that a valve manufacturer uses the right materials and has standards of workmanship that lend to valves that consistently work in cold conditions. The valves that are shipped must have the proper material and quality certification documentations, along with the pertinent production testing results that shows the rigors of the manufacturing process.



CONCLUSION

In closing, when selecting valves for cold service, the user should not assume that a valve designed for “middle of the road” process conditions, coupled with an extended bonnet and seats compatible for cold service, constitutes a valve for cryogenic service. These applications should not be taken lightly; especially when cold temperature requirements are coupled with fire safety, low fugitive emissions, and tight shutoff. Users want a valve manufacturer that has experience – with testing and in real applications, and who has high-quality standards. The rigorous preparation of valve components for clean room assembly and the precautions required to avoid contamination are difficult for any valve manufacturer to meet, so it is important to verify that a manufacturer says what they say they do on a daily basis. While it can be more expensive up front, it is important to be supported after installation. The decision to go with an experienced supplier for cold service will pay off down the road.

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Nathaniel Paxton is currently the Product Manager of Cameron's TBV™ ball valves, which are manufactured in Millbury, Mass. Nate earned his Bachelor of Science in Mechanical Engineering from The State University of New York (a.k.a. SUNY) in Buffalo and his MBA from the University of Massachusetts. Nate has a varied background of work experience with job challenges ranging from Research and Development, Design, Manufacturing, Business Development, and Product Management with a diverse range of companies including Dresser Clark, A.W. Chesterton, Varian, Worcester Controls, and Cameron. Nate has spent a majority of his 30 years of experience as a product champion for his lines in a managerial role involving all facets of the business focusing on product development and sales. Nathaniel.Paxton@c-a-m.com

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