Cover Story

A greener future with cryogenic testing

Vincent Chicola and Tucker Chan, Baker Hughes Valves, outline how valves can be used within the LNG industry to help companies reach their net zero goals.

The rising need for affordable and convenient energy has seen growth in demand for LNG. This has fuelled the growth of a diverse sector, which can be seen in the increase in LNG plants, terminals, and conversions of cargo ships to LNG tankers to FSO or FSRUs, gas storage farms, or underground storages, just to name a few. LNG is cleaner to burn compared to other fossil fuels, safer to transport, more eco-friendly and economical, and easier to store; especially since when liquefied to below -162˚C at atmospheric pressure, its volume reduces to 1/600.

Originating from the wells, there are a few key processes natural gas will go through from cleansing, separation to compression, and liquefaction for transport; subsequently regasification before distribution to the end users. Complex processes are supported by a few key instruments, and the focus in this article is on control valves and safety valves.

Different types of valves

Control valves are flow technologies, responsible for manipulating precise system pressure, flow rates, fluid levels, temperatures, not to mention protecting critical equipment, whilst dissipating large amounts of energy, plus keeping in check noise pollution, vibrations, as well as fluid related difficulties such as cavitation damage and materials erosion.

Pressure relief valves are intended as the last line of protection for a system. Given the consequences of failure, pressure relief valves are highly regulated devices which must meet very stringent material and design criteria. In the pressure relief valve industry, there are many international codes and standards which govern and regulate the requirements for pressure relief devices. The most common global code which provides requirements for pressure relief devices is ASME Section XIII. In the cryogenic industry, the primary standards which has provided guidance to the pressure relief device industry is BS-EN 13648 and ISO 21013.

Regulations for valves

These standards cover a variety of topics ranging from sizing and selection to design and qualification. Achieving qualification to these standards is done through completing type testing which is broken down into two categories, A and B. The difference between the two categories is the number of times the valve must cycle prior to completing a leak test where leakage rate may not exceed $3x10^{-3}$ Std cc/s x DN at 90% of the set pressure. Category A requires 1000 cycles while Category B requires 20 cycles. Given the operational nature of pressure relief valves, Category B type testing is sufficient for the majority of applications. In addition to outlining type testing requirements, these standards also outline cryogenic testing and the necessary test stand setup required to complete. Baker Hughes has recently installed a cryogenic test stand in compliance with both BS-EN 13468 and ISO 21013 requirements which provides that ability to complete both pop

Figure 1. A cryogenic test rig for relief valves.

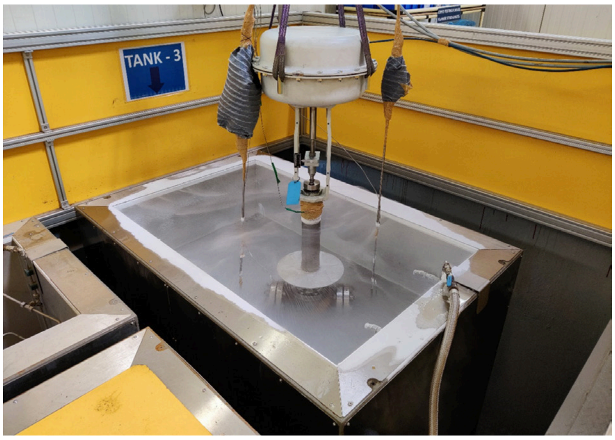

Figure 2. Control valve undergoing a cryogenic test.

Figure 3. Large inlet gas globe control valves, Masoneilan 41005 series.

and leak tests utilising cryogenic test media. This test stand utilises liquid nitrogen which is able to reach a temperature of 80 K. To meet these test standards, it is required that the temperature of cryogenic fluid relieved by the valve not exceed the equilibrium temperature of the vessel by more than 30˚C.

Control valves are also regulated devices but not to the degree that pressure relief valves are controlled. One primary aspect is judging on their ability to minimise the leakage it experiences. Leakage test normal criteria is Class IV and V tested at ambient with water, air, or nitrogen. Cryogenics, however, requires helium gas, but the lighter gas causes higher leakage; therefore, different allowable leakage rates are required. In the past, no global standard existed for control valves, so users often request references to the BS-6364 or ISO-28291-1 which are written for on-off or isolation valves and has a stringent passing rate, ultimately causing unnecessary increases in actuator and stem size, affecting the weight. Other variations of practices include enormous safety factors as much as 1.5 times required thrust to close, or even shut-off pressure itself, sometimes even larger than its design pressure.

Fortunately, IEC has recently included helium within the control valve allowable leakage for Class V at a variable cryogenic test temperature, found in *IEC 60534-4 Edition 4.0 December 2021.* The cryogenic test is an important aspect of qualifying control valves and proving the materials are still able to achieve tightness when needed, even at temperatures as low as -196˚C. Manufacturers must be able to test or have facility of a deep nitrogen pool with lifting capability for valves as large as 30 in. or more, which Baker Hughes has in-house at its manufacturing facilities in the US, France, India, and Japan.

Technical challenges

Within gas treatment or processing plants, gas separates into mainly methane, ethane, propane, butane, and condensates. Water, hydrogen sulfide (H_2S), carbon dioxide (CO_2), mercury, and nitrogen must also be eliminated.

Sour elements of H_2S and CO_2 are absorbed when contacted with chemicals such as amine liquids, alkaline salts, or benfield solutions. This absorption process is also possible through solid adsorption with molecular sieve such as iron sponges, zinc oxide, or fluor solvent; eventually producing sweet gas which passes to the dehydrating glycol contactors, essentially producing treated natural gas.

Earlier LNG plants are approximately 3 million tpy capacity, while newer plants have grown tremendously, led by the likes of Qatargas and Rasgas with 15.6 million tpy each, Gorgon – 10.4 million tpy, Freeport, the US – 10 million tpy, and Ichthys – 9 million tpy, to name a few. The increasing capacity demands larger pipes and valves, pointing to the first valve needed: gas feed or inlet gas control valve with high capacity, corrosion resistant NACE MR0175 and/or ISO 15156 materials, noise attenuation capability, wide rangeability to cater high and low incoming feed while maintaining high reliability, as it will be the valve that controls the gas entering the plant. Typically, this will be a globe type valve as large as 30 in. and above.

Next, crude enters for separation where impurities and liquids will be separated and flow out through bottom high-pressure, dirty liquid level control valves. The separator pressure relief valve and a gas vent-to-flare valve take care of excess during surge or upset. The vent valve must be tight shut-off (TSO) preventing commodity lost, maintaining plant efficiency. It handles high noise from high pressure drop, with corrosion resistant materials and consideration for potential dirt and erosion from venting at high velocity.

During sweetening, the aim is to reduce H_2S below 4 ppmv as not only is it corrosive but it is very hazardous. Exposure to even 10 ppmv causes eyes, nose, and throat irritation. If above 50 ppmv, there may be risk of severe cases of coma and even death. CO_2 kept below 50 ppmv prevents carbonic acid formation and increases quality by improving its heating value.

The sweetening process happens in the contactor, typically with 'lean amine', and the challenge starts at the chemical solution's pump re-circulation valve that sees high pressure drop with TSO for efficiency. It protects the pump during start-up, shutdown, and any upsets. Valves handle cavitation, erosion, tight seat leakage, and flashing. Popular trims are drilled holes, cages, or multi-staged.

Used 'rich amine' returns from the contactor's bottom through the amine let-down valve. Corrosive fluids containing H_2S and CO_2 that demands Duplex or Inconel materials, at high pressure drop are flashed to the flash tank. Noise and vibrations are expected during off-gassing as gas expands. Heavy-duty design and materials prevent erosion and withstand vibrations, helping to avoid wear and trim breakages.

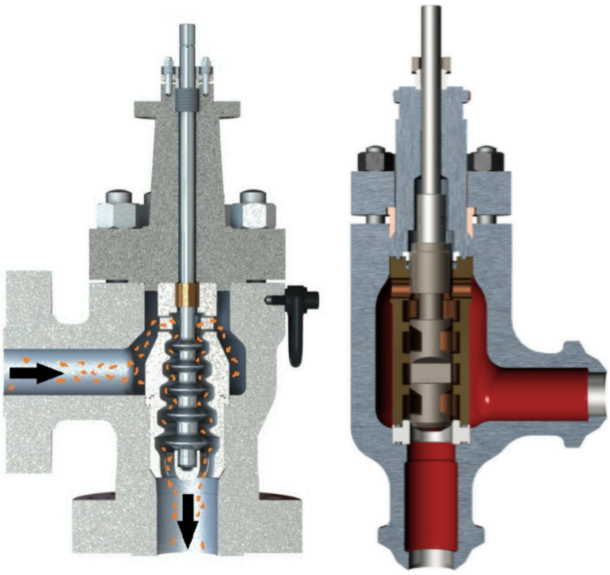

Figure 4. Heavy-duty valves with multi-stage trims, Masoneilan 77k and 78k.

Figure 5. Globes with elongated and re-inforced bonnets, and bellows ring for cold box.

At the top, sweet gas rises where a vent-to-flare valve protects from over-pressure. In the next step, the dehydration process, water and hydrates are removed to prevent issues later in the cooling and cryogenic stages. Hydrates cause erosion, clogging, and reduces the heating value of the gas. Setup here is similar to the amine contactor discussed, including pump re-circulation and let-down valves.

Treated gas will then goes through fractionation by cooling to separate off heavier hydrocarbons of propane and butane with the remaining ethane and methane as majority content. While multiple licensed methods are there, the challenges are similar for the valves. When evaluating potential leakage paths in industrial equipment, a key point to consider is the normal operational position of the valve. For a control valve, the primary position is commonly open. This is different for pressure relief valves where the normal position is closed, and the primary leak path is the valve's seating surfaces which is the disc to nozzle interface. Given the lack of available elastomers at cryogenic temperatures, the seating type for LNG applications is generally metal. This eliminates the concern around elastomer compatibility, but it generally can result in increased likelihood of leak, especially after a relief scenario.

Most PRV leakage in cryogenic applications is a result of thermal deflection and stresses due to the differential of the process fluid and ambient temperature at the seating components, which can rapidly lead to process waste and fugitive emissions. Baker Hughes has developed a disc design to address these concerns, the Cryodisc. Patented Cryodisc technology offers enhanced seat tightness before and after a relief event. The low temperature media creates thermal deflection and stresses in the material that the patented disc thermolip takes advantage of by deflecting downward to create a uniform contact pressure on the nozzle seat, resulting in enhanced seat tightness. Titanium nitride coating, an extremely hard ceramic material, applied to the bearing surface prevents galling-induced wear under extreme cryogenic conditions.

Valves for LNG applications

Several styles of valve have been developed to address the challenging applications in LNG processing. The Joule-Thomson, aka JT valve, traditionally often used as a cooling expansion valve, even nowadays is often required alongside turbo expanders (TBX). It allows great pressure drop and gas expansion, causing rapid cooling of the refrigerant, or used when the TBX is not in-service during upsets and start-ups. This JT valve must be versatile with high rangeability and able to manage noise and vibrations well. When not in use, it maintains TSO, ensuring TBX efficiency.

Next, the compressor anti-surge valve (ASV), or compressor recycle valve, protects the compressor from very costly and severe damage by opening immediately, allowing diversion of gas when surge happens or during start-up when pressure is building. Some system designs request a parallel backup valve known as a compressor bypass valve which has the same capacity as the ASV in case of ASV failures. ASV demands large capacity, big size with expanded outlet, large actuators, intermittent high noise and vibrations, requires specialised noise abatement trims, fast response to open with accurate positioning calibration of positioner, solenoid volume boosters; minimising overshoot, oscillation, and reduced dead time. Close collaboration between compressor and ASV vendor is imperative for successful system setup as all vital behaviours and needs of the machinery will be well-known and cared for by the valve supplier.

Box cryogenic valves are required in some heat exchanger designs that require the actuator sub assembly to protrude outside of the cold box. Actuators are slanted steeply with unusual long bonnet length north of 1 m. Consideration is needed to reduce actuator weight, stronger bonnet and stem/shaft materials preventing bending or galling. Regular checks should be performed on the natural frequency of the valve to prevent mechanical damage, and some mechanical support for the weight either by hanging or ground support may be required.

Cryogenic control valves may have some distinct features identifiable as follows.

- Extension bonnet: Allows a distance separating flowing liquid stream from the packing, preventing it from freezing so it maintains its recommended working temperature. The valve manufacturer decides on the required bonnet lengths.

- Drip plate: Optional thick steel plate, either welded or clamped on the extension bonnet, to prevent any water condensate dripping down to the lower bonnet area where exposed insulation materials may absorb the moisture that may expand when frozen damaging insulations.

Finally, as valves become well known as a plant's main contributor to fugitive emission caused by the nature of its reciprocating stem movement, many are looking in this direction to reduce greenhouse gases, in this case such as CO_2 and methane to near 100% efficiency compared to traditional stem packing ways. ISO being one of the leading standards, with their ISO 15848, may require manufacturers to apply live-loaded packing system, vigorously tested over thousands of cycles with different elevated or reduced temperatures while maintaining strict allowable stem leak rates with minimal operator adjustments; plus, ISO dictates a check on leak rate through gaskets (body-bonnet) in order to be certified. Baker Hughes currently has all the qualified packings on different valve types tested for such low temperatures. For production valves, detailed under ISO-15848-2, FE test can be done together during the cryogenic seat leakage test.

Conclusion

To conclude, one of the primary focuses of all industries is the reduction of overall carbon footprint tied to many net zero goals for many companies. While there are many strategies and avenues companies may use to help reduce it, one key way is to address the emissions from their equipment. In the valve world, this is most typically seen in both seat and stem leakages. In the cryogenic industry, these leakage rates are even more impactful due to the inability to find suitable elastomers for the intended service temperatures. This drives equipment manufacturers, such as Baker Hughes, to develop innovative solutions which are aligned with its four main visions: optimise service, improve reliability, increase efficiency, and reduce emissions within the company's portfolios. LNG