TECHNICAL BULLETIN TB-1217-TV

TANK VENTING

A GUIDE TO VENTING OF UPSTREAM PETROLEUM STORAGE TANKS AND SOLUTIONS BY HAWKEYE INDUSTRIES

OBJECTIVE

This document aims to provide an understanding of the legislative requirements and general principals of venting atmospheric and low pressure storage tanks used in the upstream petroleum industry. Also included is an introduction to venting solutions and products manufacture by Hawkeye Industries.

1 BACKGROUND

1.1 TERMINOLOGY

Blowdown: The difference between a valve's opening pressure and closing pressure.

Design Pressure: The maximum internal pressure a tank can safely withstand by design.

Direct-Acting Valve: A valve that uses weight or springs to keep the valve closed.

MAWP: The maximum allowable working pressure (or vacuum) of a tank relative to atmosphere. Usually equal to the design pressure.

Overpressure: The amount that the actual tank to atmospheric pressure differential exceeds the valve set pressure, measured as a percent of the set pressure.

Pilot-operated Valve: A valve that relies on tank pressure to open and hold closed the valve. A pressure-sensing element controls the pressure acting on one or more diaphragms, which act to open or close the valve.

Rated Relieving Capacity: The volume flow rate of fluid that the valve relieves at the rated relieving pressure.

Rated Relieving Pressure: The pressure differential across the valve that achieves the rated relieving capacity.

Set Pressure: The pressure differential across the valve at which it is designed to begin opening.

Standard Valve: A direct-acting valve in which the internal pressure of the tank acts on a pressure bearing area and opens the valve by moving the pressure bearing area to create a relief flow path.

1.2 ALBERTA LEGISLATION

In Alberta, the storage of materials falls into the jurisdiction of three organizations: *Alberta Energy Regulator* (AER), *Alberta Municipal Affairs* (AMA) and *Alberta Environment* (AENV).

Regulation of material storage in the upstream petroleum industry is primarily the responsibility of AER, with the notable exception of oil sands mining operations.

Through the *Alberta Fire Code* (AFC), AMA regulates the storage of refined flammable or combustible materials. The task of administering relevant sections of the code falls to the *Petroleum Tank Management Association of Alberta* (PTMAA). Tanks falling under their jurisdiction must be registered and meet specific design criteria.

AENV is responsible for the regulation of a wide variety of material storage operations including many in the petroleum industry. Examples of note include oil refineries, gas processing plants, bulk petroleum storage facilities and oil sands processing plants.

1.3 DESIGN AND CONSTRUCTION STANDARDS

The AER and AMA cover the vast majority of upstream storage tanks and have specific requirements concerning the design, construction and use of liquid storage tanks and the venting required for them.

As per AER Directive 055, above ground storage tanks with a capacity equal to or greater than 5 m^3 and all underground tanks must be designed and built to a specific list of applicable *Underwriters' Laboratories of Canada* (ULC) or American *Petroleum Institute* (API) construction standards.

The AFC also requires the design of all above ground storage tanks is in accordance with applicable standards set out by either ULC or API.

The scope of these API and ULC standards are tanks with design pressures up to 15 psi, but the majority of storage tanks are limited to 2.5 psi. For design pressures beyond 15 psi, the ASME Boiler and Pressure Vessel Code (BPVC) and the CSA B51: Boiler, Pressure Vessel and Pressure Piping Code have jurisdiction under the authority of the Alberta Safety Codes Act. Therefore, the information presented herein focuses solely on tanks with design pressures of 15 psi or below and designed to API and ULC standards relevant to the upstream petroleum industry.

In the North American petroleum industry, API standards dominate the storage tank design and construction, which include:

API-12B: Bolted Tanks for Storage of Production Liquids

API-12D: Field Welded Tanks for Storage of Production Liquids

API-12F: Shop Welded Tanks for Storage of Production Liquids

API-12P: Fiberglass Reinforced Plastic Tanks

API-620: Design and Construction of Large, Welded, Low-Pressure Storage Tanks

API-650: Welded Steel Tanks for Oil Storage

API-653: Tank Inspection, Repair, Alteration, and Reconstruction

Each of these standards refers to 'API 2000: Venting Atmospheric and Low-Pressure Tanks' for the sizing and selection of venting devices. API 2000 provides a systematic approach for a tank designer or user to calculate the minimum requirements for pressure and vacuum relieving rates in both normal and emergency venting situations based on the tank size, design, intended use, location and other contextual criteria. It is important to note that under the sources of authority and standards mentioned above, determination of performance and venting capacity requirements is the responsibility of the designer or user of the tank. The standard also provides testing requirements for both flow capacity and performance of the vent device. The vent manufacturer is required to report flow capacity and performance information to the party responsible for the design or use of the tank, who in turn selects a vent and to verifies that vent's suitability in their specific application.

The International Organization for Standardization (ISO) has a similar set of tank design standards used abroad. In recent years, these standards have been coming into alignment with the API standards. In particular, the tank venting standard ISO 28300 is now intended to be identical to API 2000.

2 PURPOSE

The Alberta Government, along with other international governments, closely regulates the storage of petroleum liquids and the emission of potentially harmful vapors. Environmental protections, including tightening regulations on accidental release risk and fugitive emissions are becoming more stringent with severe punitive actions for non-conformance.

Not only will rigorous attention to venting practices and equipment improve environmental safeguards, meet regulations and avoid fines, but also help operators and tank owners reduce the risk of tank failure. Proper venting improves safety while lowering replacement, maintenance and cleanup costs. With improved sealing and set point accuracy, reduced emissions and lessening unintended loss of valuable product follows.

3 VENTING

3.1 TYPES OF VENTING

Selecting a vent requires balancing considerations to maintain the internal tank pressure within the allowable design limits while reducing product loss and emissions to satisfy environmental regulations. Different types of vents can help to meet these goals, and include **self-resetting relief vents**, **non-resetting vents** such as rupture discs, a **frangible roof-to-shell connection**, a **floating roof** or a combination of the above.

Venting standards separate venting into two categories: **normal** and **emergency**. **Normal venting** occurs during normal operation of the tank and may be caused by liquid movement in to or out of the tank, changes in atmospheric pressure, temperature changes, evaporation or condensation of tank contents and other operational and environmental influences.

Emergency venting results from unplanned or other catastrophic events affecting tank pressure, notably external fire exposure. Heat transfer through a tank wall may rapidly vaporize the contained liquid, so to avoid over pressuring the tank, emergency expulsion of these vapors is required. Often, pressure relief necessitated by fire exposure is the only consideration made in emergency venting; however, other situations such as equipment failure or rapid cooling and condensation must also be considered and may increase the required emergency venting requirements for both pressure and vacuum relief.

Due to the more frequent nature of normal venting, irreversible or non-self-resetting methods of venting, like rupture discs and frangible roof-shell connections, are not suitable for this purpose as the cost and time to manually reset, repair, or replace components after each relief is prohibitive. Even with less frequent emergency venting the expense of resetting an activated non-resetting relief device will often far exceed the cost of a self-resetting emergency relief device.

3.2 VENT VALVES

Valves are devices that control (permit, limit or stop) the flow of a fluid from a region of high-pressure to low-pressure. In the context of tank venting, the valve maintains a seal between the interior of the tank and atmosphere, and once activated (opened) allows the movement of fluid through the valve. A **vent** (or **relief vent**) is a device that contains one or more valves, as well as other mounting, shielding or ducting features to facilitate installation, operation and longevity of the valves. A valve is the active component of a vent device.

There are three traditional types of pressure regulating valves used for low-pressure and atmospheric storage tanks: **open**, **direct-acting** and **pilot-operated**. An innovative new valve, the **Unidirectional Binary Relief** (UBR) valve, from Hawkeye Industries Inc. combines the benefits of the direct-acting and pilot-operated valve to create a fourth option for pressure regulating valves.

Open vents (Figure 1 and Figure 2) have no valve to control internal tank pressure. The open vent allows free flow of air in and out of the tank through the same opening. These valves are always active and have no moving parts. Open vents provide relief and protect the tank contents from the environment, but do not act to contain the vapor in the head-space of tank.

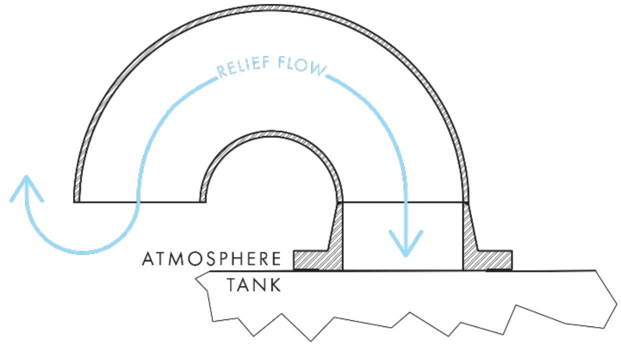

Figure 1: Gooseneck Open Vent

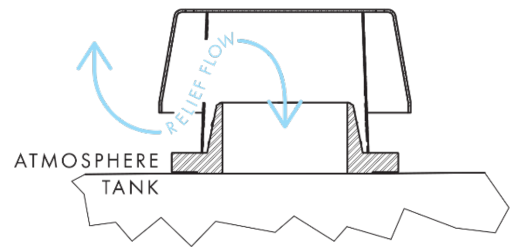

Figure 2: Mushroom Open Vent

Unlike open vents, direct-acting and pilot-operated valves maintain a seal between the tank interior and atmosphere via an impermeable pallet. The pallet, held closed against forces resulting from differential pressure between tank and atmosphere, maintains a prescribed internal tank pressure range. When the force resulting from pressure differential across pallet exceeds the force holding the valve closed, the valve begins to open allowing relief flow. The pressure differential across the valve where it will begin to open is the **set pressure**. Figure 3 shows the operation of generic pallet-type valve, indicating flow out of the tank exemplifying pressure relief. When the pressure differential relieves to the closing pressure, the closing force on the pallet reengages the seal and resets the valve.

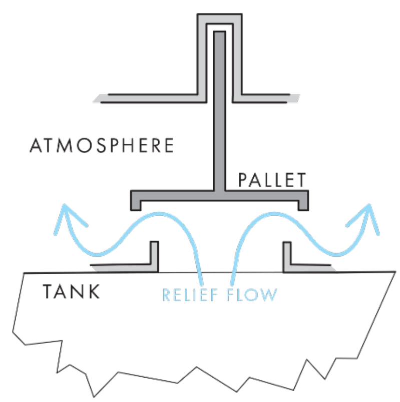

Figure 3: Generic Pallet Valve

The difference between a direct-acting valve and a pilot-operated valve is the nature of force keeping the valve closed. A direct-acting valve relies on an external force, typically a dead-weight or spring, applied to the pallet to maintain a seal up to the set pressure. Direct-acting valves are accurate, reliable and relatively inexpensive which finds them on the vast majority of storage tanks. Weight-loaded valves (Figure 4) have the advantage of being simple, allowing very accurate set pressures and the closing force is constant as the valve opens. The primary disadvantage is that set pressures beyond 2 psi require an excessive amount of weight and, in many cases, the vent would become too large and heavy to be practical, however, most low-pressure or atmospheric tanks do not require a set pressure above 2 psi.

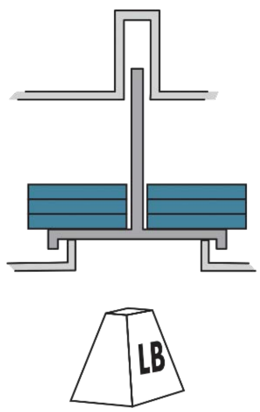

Figure 4: Weight-loaded direct-acting valve

A spring-loaded valve (Figure 5), conversely, can achieve set pressures beyond 2 psi with little added weight or size, but are less accurate and have a variable closing force. The spring closing force increases linearly as the valve opens which resists further opening, reducing the available flow area and therefore limiting the flow capacity of the valve at a given overpressure in comparison to a similar dead-weight valve. The drawback to direct-acting valves is the overpressure required to reach full venting capacity, often 100% of the set pressure. This limits the operating range of the tank and increases total emissions.

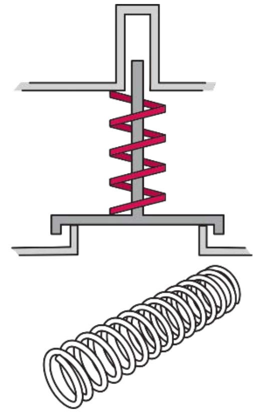

Figure 5: Spring-loaded direct-acting valve

A pilot-operated valve (Figure 6) relies on internal tank pressure to provide the force required to maintain a seal as well as open the valve at the set pressure. This is accomplished with a system of control valves and actuators that direct pressure where required to achieve the desired valve action. Due to the complexity of pilot-operated valves, they are typically more expensive and have more avenues for failure; however, pilot-operated valves exhibit greater seal tightness especially near the set pressure and offer quick, full opening action (**snap action**). This provides higher relative venting capacity as compared to direct-acting valves at small increments above the set pressure, and allows greater operating pressure ranges while reducing emissions.

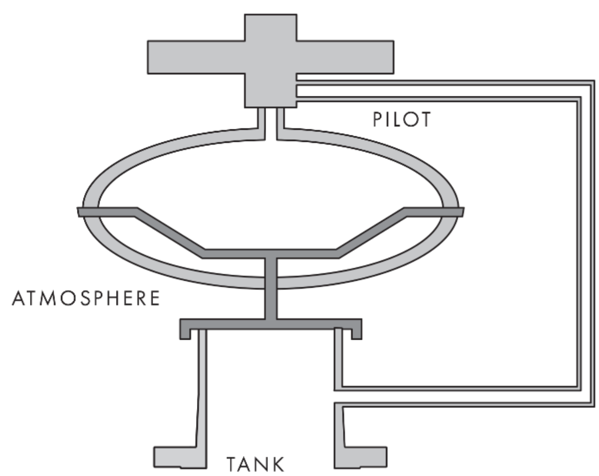

Figure 6: Pilot Operated Valve

Hawkeye's **UBR valve** (Figure 7) is an innovative patent-pending valve design combining the benefits of both direct-acting and pilot-operated valves. Sealing force is generated both by a direct-acting member with assistance from tank pressure on a secondary pallet. With only one moving part, the UBR design is simple, inexpensive, and accurate, with the same snap action opening providing higher relative venting capacity than a standard direct-acting valve. This allows the set pressure to be closer to the MAWP of the tank, resulting in a greater allowable operating pressure range and emissions reduction.

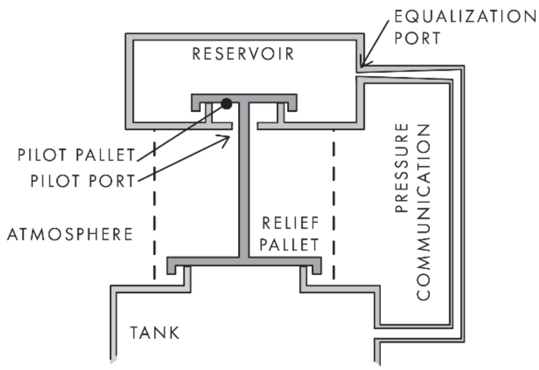

Figure 7: Unidirectional Binary Relief (UBR) valve

3.3 TYPES OF VENTS

A variety of devices can satisfy the venting requirements of a tank assembly or process. Due to their convenience, relatively low initial and maintenance cost and ability to maintain a safe environment even in emergency situations, self-resetting vents are preferred to meet most venting requirements. Through the years, devices have taken specific forms to meet industry demands and adopted industry specific names and acronyms. The most predominant of these devices include **venting gauge hatches** (VGH), **pressure and vacuum relief vents** (PVRV) and **emergency pressure relief vents** (EPRV).

Figure 8: Hawkeye TVTH 200 / 300

Almost every storage tank sports a connection for a thief, dip, or gauge hatch to allow access to measure or monitor the contents of the tank. Combining relief functionality into this device can reduce the number of roof openings required on the tank and provide primary or secondary venting. Often on small tanks, a **VGH** completely satisfies normal venting requirements, noting the well-defined, but restrictive, standards governing the construction and design of these tanks. In larger and more varied-purpose tanks, VGHs fill the role of secondary or back-up vent to assist with venting or as a backup in the event that a system component or primary vent fails.

Hawkeye Industries offers two venting gauge hatches, the **TVTH 200/300** (Figure 8) (sweet and sour service respectively) and the **Marsh Hawk TRV** (Figure 9 and Figure 10). The TVTH is an economical top-mounted venting hatch with superior sealing performance over similar budget hatches. In contrast to the top mount TVTH, The Marsh Hawk TRV sports an innovative design that recesses the sealing surfaces into the heat envelope of the tank to reduce the risk of freezing. This combined with class-leading bubble-tight sealing performance sets the Marsh Hawk TRV apart compared to other premium venting hatches.

Figure 9: Hawkeye Marsh Hawk Tank Relief Vent

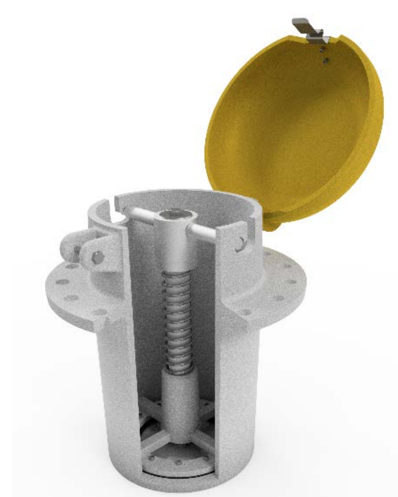

Figure 10: Hawkeye Marsh Hawk TRV (Cutaway)

In contrast to the combination venting and tank access a VGH provides, a Pressure and Vacuum Relief Vent (PVRV) is a dedicated venting-only device. As a dedicated relief vent, PVRVs have superior performance as compared to a VGH. This includes higher flow capacity, high-accuracy set pressure, superior sealing performance, and rigorous manufacturer-provided performance testing. Depending on application, a suitably sized PVRV may also satisfy emergency venting requirements.

Hawkeye's Series 6000 line of PVRVs (Figure 11), available in 4 sizes and 14 configurations, is designed to meet a wide variety of venting applications. As the name suggests, the Series 6000 PVRV provides both pressure- and vacuum-relief in the same device, but is also configurable as a pressure-only or vacuum-only relief device. Additionally, the Series 6000 is configurable as an end-of-line vent relieving to atmosphere, or an in-line vent, piping away pressure-relieved vapor to another location or process. The composite soft seal gasket design provides superior seal tightness and reliability.

The Series 6000 PVRV is also available with the patent pending UBR valve on any combination of the pressure- and vacuum relief valves.

Figure 11: Hawkeye Series 6000 PVRV

Finally, high-volume sporadic pressure relief is the primary role of the EPRV. All sizes of tanks require means to provide high volume pressure relief during emergency situations, notably external tank fires. However, other abnormal situations such as blanketing system failure, internal rupture of heating systems, chemical reactions and other unforeseen circumstances can necessitate the use of an EPRV to meet emergency venting requirements.

The Hawkeye Series 5000 EPRV (Figure 12) with compound lever design and composite soft seal gasket provide a light weight, compact vent, even at high set pressures, while maintaining a bubble tight seal up to 90% of the set pressure.

Figure 12: Hawkeye Series 5000 EPRV

4 UBR VALVE

Hawkeye's patent-pending Unidirectional Binary Relief UBR) valve combines the simplicity, reliability and cost-effectiveness of a dead-weight direct acting valve, with the set-point accuracy, bubble-tight sealing and snap action opening of a pilot-operated valve.

4.1 DESIGN

The UBR valve achieves its unique operation by utilizing a smaller, secondary pallet and seat that combined form a pilot port, in addition to the standard pallet and seat forming the relief port as shown in Figure 7. The pilot port feeds a reservoir connected to the tank through an equalization port that controls the rate of pressure equalization between the tank and pilot reservoir. The pilot pallet and relief pallet have a mechanical connection forming a pallet assembly and constitute the only moving part in the valve. The design results in the combination of the simple, reliable mechanism of the direct-acting valve with the desirable snap-action of a pilot-operated valve.

4.2 OPERATION

In the pressure-relieving configuration, tank pressure acts directly on the primary UBR relief valve pallet, that left unopposed, would open the valve as tank pressure rises. However, the weight of the pallet assembly, in conjunction with tank pressure acting on the secondary UBR pilot pallet via a restricted, tank-connected reservoir, work to counteract the opening force imparted by tank pressure on the relief pallet (Figure 13(A)). The pilot pallet, operating like the actuator in a pilot-operated valve, maintains a tight seal on the relief pallet, keeping the valve closed until tank pressure reaches the set pressure. When tank pressure matches set pressure (B), the valve begins to open and reservoir pressure drains to atmosphere via the now-revealed pilot port (C). Although the reservoir remains connected to tank pressure, pressurizing flow from the tank is restricted by the narrow equalization port and cannot counteract the flow out of the reservoir through the pilot port. The reservoir rapidly depressurizes, eliminating the pressure differential across the pilot pallet (D). With the removal of the force on the pilot pallet holding the valve closed, the valve snaps open, allowing pressure relief from the tank. Now actively relieving, tank pressure stops rising slightly above the set pressure and begin to drop (E). When internal tank pressure drops to approximately 70% of the set pressure, where the valve will reseat, reseal and reset (F). The tank pressure must rise again to 100% of the set pressure to reactivate.

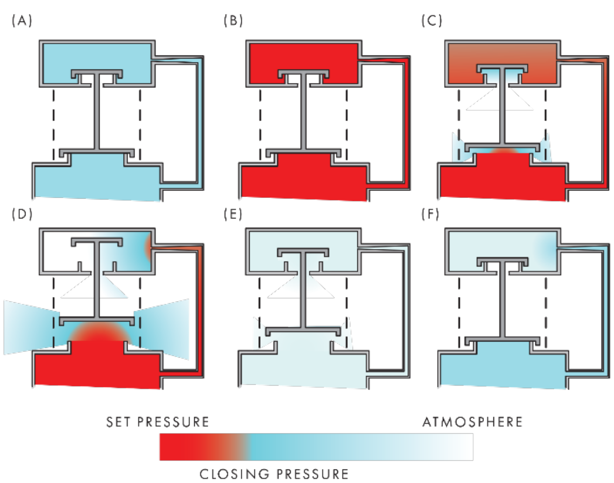

Figure 13: UBR Valve operating principles

4.3 UBR VALVE COMPARED TO STANDARD VALVE

The relieving action of the UBR valve is opposite to a standard relief valve. Where standard valves just start to open at or slightly above the set pressure and meet rated relieving capacity at substantial overpressure, the snap action of the UBR valve allows it to achieve significant relieving capacity at overpressure only marginally higher than set pressure. This allows sizing an UBR valve to achieve the required relieving flow rate at, or slightly above, the set pressure instead of two-times set pressure, typical with a standard direct-acting valve.

Figure 14 exemplifies the difference in opening and closing operation. Both the standard and UBR valves in this figure meet the required relieving flow rate at tank MAWP, optimizing the operating range of each valve by maximizing the range where the valve is not leaking or relieving. The UBR valve has a clear advantage by remaining closed up to its set pressure at MAWP, then relieving downward to the closing pressure of 70% of the set pressure. The standard valve, however, begins to relieve at its set pressure of 50% of MAWP, requires significant overpressure to reach the required relieving flow rate, and must return to 50% of the MAWP to reseat and close.

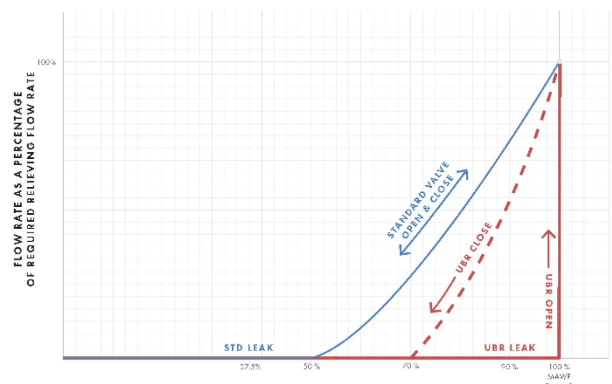

Figure 14: UBR Valve and Standard Valve Operation with respect to pressure (See Appendix A for full-size)

When the internal pressure shall not exceed the MAWP pressure of the tank, as with tanks constructed to API 650, Hawkeye reccomends a 5% safety margin between the set pressure of the valve and the MAWP. Figure 15 illustrates valve operation, taking this safety margin into account. The UBR valve behavior remains similar to that of Figure 14, just with a slightly lower set pressure.

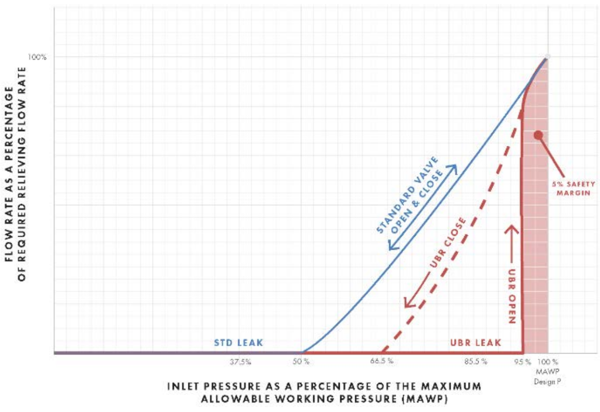

Figure 15: UBR Valve and Standard Valve Operation with Respect to Pressure with Safety Margin (see Appendix A for full-size)

For tanks built to the API 620 standard, the design calculations already include a safety margin, permitting internal pressure to exceed the MAWP of the tank during venting, allowing set pressures per Figure 14.

The primary advantage of raising the set pressure up to 95% of the MAWP is the ability to increase the operating range of the entire system or process. Figure 16 quantifies the possible increase in operating pressure (green column) over a conventional direct-acting valve as described in API 2000 by a Hawkeye direct-acting valve with soft-seal design and a Hawkeye UBR valve.

Conventional valves may begin to leak at 75% of the set pressure. Due to the typical 100% overpressure required for full relief, the allowable operating pressure is limited to only 37.5% of the MAWP of the tank to stay within the tanks operational limits.

The superior sealing performance of Hawkeye's standard valve maintains a bubble tight seal up to 90% of the set pressure, increasing the allowable operating range to 45% of the MAWP.

Finally, the UBR valve, with the same soft-seal technology and increased set pressure range increases the operating pressure range to 66.5% of the MAWP. This limitation to operating pressure is a result of the intrinsic blowdown of the UBR valve to ensure the valve can reseat and reset.

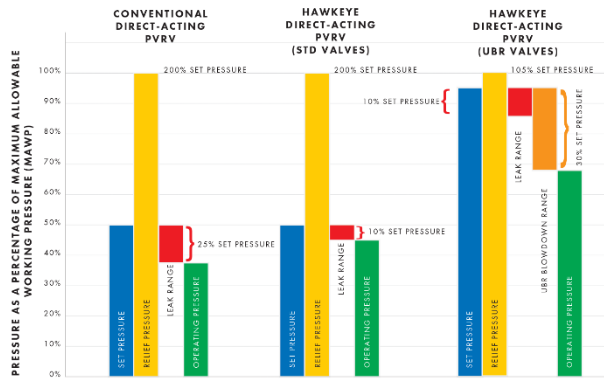

Figure 16: Operational Pressure Comparison of UBR Valve and Standard Valves (see Appendix A for full-size)

The intrinsic blowdown of the UBR valve not only has performance advantages, but also serves to improve reliability and longevity. By increasing the gap between opening and closing pressures, the valve opens less frequently reducing component wear and lessening the risk of frost closure (see Figure 17 for an example). When a vent relieves frequently, continuously or leaks slowly in a cold atmosphere, water vapor in the relieved gas can condense and freeze on the outlet of the vent. Two modes of failure can result: the valve seal can freeze to the seat preventing the valve from opening, or the frost can build up in the throat of the valve where it chokes off the flow path and can eventually block it entirely. The UBR valve relieves less frequently, as such eliminates simmering, fluttering, and reduces leakage. The result is a drastic reduction to the risk of frost closure as compared to a standard valve.

Figure 17: Frost Closure of a Tank Vent (VGH)

The unique operating behavior of the UBR valve can expand the capability of a tank system or process while reducing environmental impacts and increasing safety and reliability.

The graphs and charts provided are ideal models of each valve. In practice, each valve design will experience variations in behavior and performance. For example, every direct-acting valve exhibits some amount of blowdown due to the shape of the pallet and seal and the difference in the static pressure bearing area while closed and the stagnation pressure bearing area while venting. To take these factors into account during valve selection, the use of official manufacturer data is required.

5 VENT SELECTION

5.1 VENT TYPE

Available tank connections or secondary requirements may be the deciding factor when selecting a vent, but performance requirements imposed by tank design and venting standards, as explored below, must be considered and may limit or dictate vent selection.

5.2 RELIEVING PRESSURE

Often overlooked, determination of the relieving pressure is the first step in vent selection. The relieving pressure is the internal tank pressure at which the vent is relieving at a rate sufficient to meet minimum venting requirements. This pressure will always be above the set pressure of the valve and below the maximum relieving pressure of the tank. When selecting a relieving pressure be sure to consider interactions with other venting devices. For example, the relieving pressure of a PVRV should be lower than the set pressure of an EPRV to prevent accidental activation of the EPRV.

Every vent tested in accordance with API 2000 will have a rated relieving pressure and corresponding rated relieving capacity. This provides the relieving flow rate at a specific pressure (typically two times the set pressure, or 100% overpressure) used to size a vent provided the set pressure and relief pressure are suitable for the application. If an alternate relieving pressure is required, for example 10% overpressure, use flow curves specific to the vent to determine the relieving capacity of the vent at the alternate relieving pressure.

The maximum allowable relieving pressure will depend on the tank design, operation and construction standard. The internal tank pressure during venting of a tank designed to API 650 shall not exceed the design pressure of the tank, but must also be limited to prevent lifting of the tank roof. API 620, however, allows the relief pressure for normal venting to exceed the MAWP of the tank by 10% and the relief pressure for emergency venting to exceed the MAWP by 20%. Consult the applicable tank design standard for details.

As can be seen above, the trend in selecting a relieving pressure is be as near the MAWP as practical. Selecting and setting a relieving pressure first narrows the available options, as it is independent of valve type, operation and size.

5.3 RELIEVING CAPACITY

The required relieving capacity is a value calculated by the per the applicable tank venting standard, and is the minimum relief flow rate provided to a particular tank or process by relief devices. Determination of relieving capacity requires consideration of both normal venting and emergency venting requirements.

Normal venting originates from exhausting or replacing the vapor space volume while filling or discharging the contents of a tank, environmental pressure and temperature changes and other factors encountered during the normal operation of the tank.

Emergency venting occurs when an unplanned event causes a rapid increase or decrease in tank pressure. The primary consideration for emergency venting is external fire; however, chemical reactions, equipment failures and other abnormal catastrophic events merit consideration.

Refer to the appropriate venting standard(s) for required data and methods of calculating the required relieving capacity for each venting condition.

5.4 SET PRESSURE

The set pressure of a valve is the internal tank pressure at which the valve will begin to open and requires consideration of many factors. The set pressure must be set far enough above the operating pressure of the tank to avoid undesired relieving, leakage and the blowdown range of the vent to prevent fugitive emissions. It must be set far enough away from the set pressure of other relief devices to prevent unintended activation – most important for emergency and non-resetting relief devices. Finally, the set pressure must be far enough below the relieving pressure to allow sufficient overpressure to reach the required relieving capacity. This will often dictate the type and size of vent.

5.5 TYING IT ALL TOGETHER

Once these values have been determined, a vent type, valve type and size can be selected using manufacturer supplied data, flow curves or sizing program. Due to the vast number of variables and considerations required to determine these three values, the manufacture is unable to authoritatively size or recommend a relief device. Only the user or tank designer have the authority, and responsibility to size and select appropriate relief devices for their application based on their own data.

Available connections on the tank may dictate size as long as the size is equal to or larger than the required vent size. Using multiple vents and summing their individual relieving capacity is permitted to meet a relieving requirement larger than a single vent can provide.

6 CONCLUSIONS

Tank venting is a critical part of the upstream petroleum industry. It allows for the safe storage of the core industry product, oil, as well as a vast array of byproducts and supporting fluids used to aid in production. Proper venting reduces environmental and financial risk while improving health and safety, efficiency and profitability.

The line of venting devices from Hawkeye Industries incorporates the latest technology to provide superior venting performance, leak-free sealing and unmatched reliability. The UBR valve sets a new standard for PVRV venting performance. The snap-open operation increases the allowable operating range, reduces fugitive emissions and allows for the use of a smaller vent. This feature combined with the freeze resistance, reliability and affordability set the Hawkeye Series 6000 PVRV apart from all other venting solutions.

Vent sizing and selection involves detailed calculation and an intimate understanding of the tank system as well as the surrounding equipment and environment. The hope is that the information provided in this guide will make this process clearer and aid in creating a more sustainable, profitable and safer upstream petroleum storage industry.

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9 APPENDIX

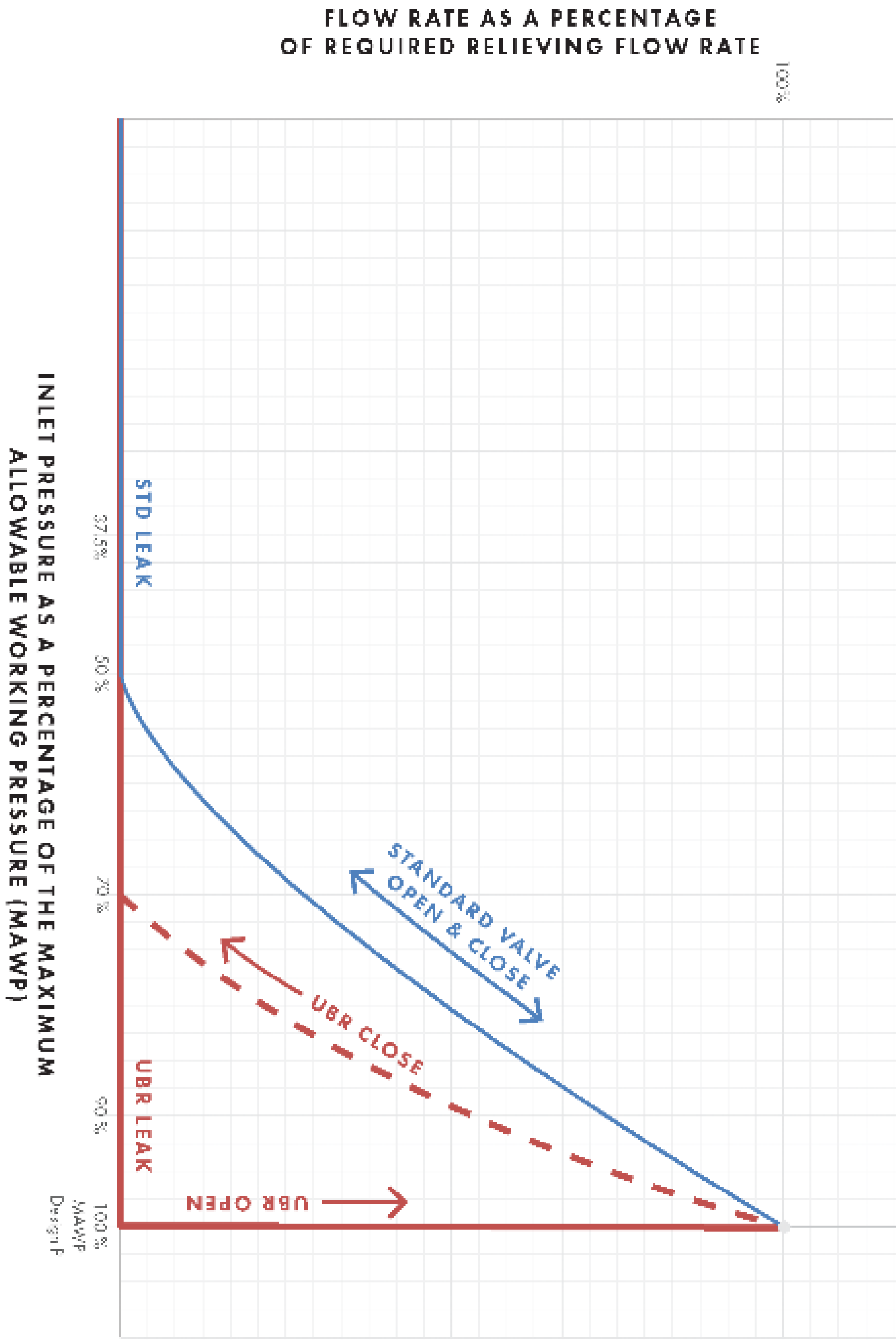

Figure 14A: UBR Valve and Standard Valve Operation with Respect to Pressure

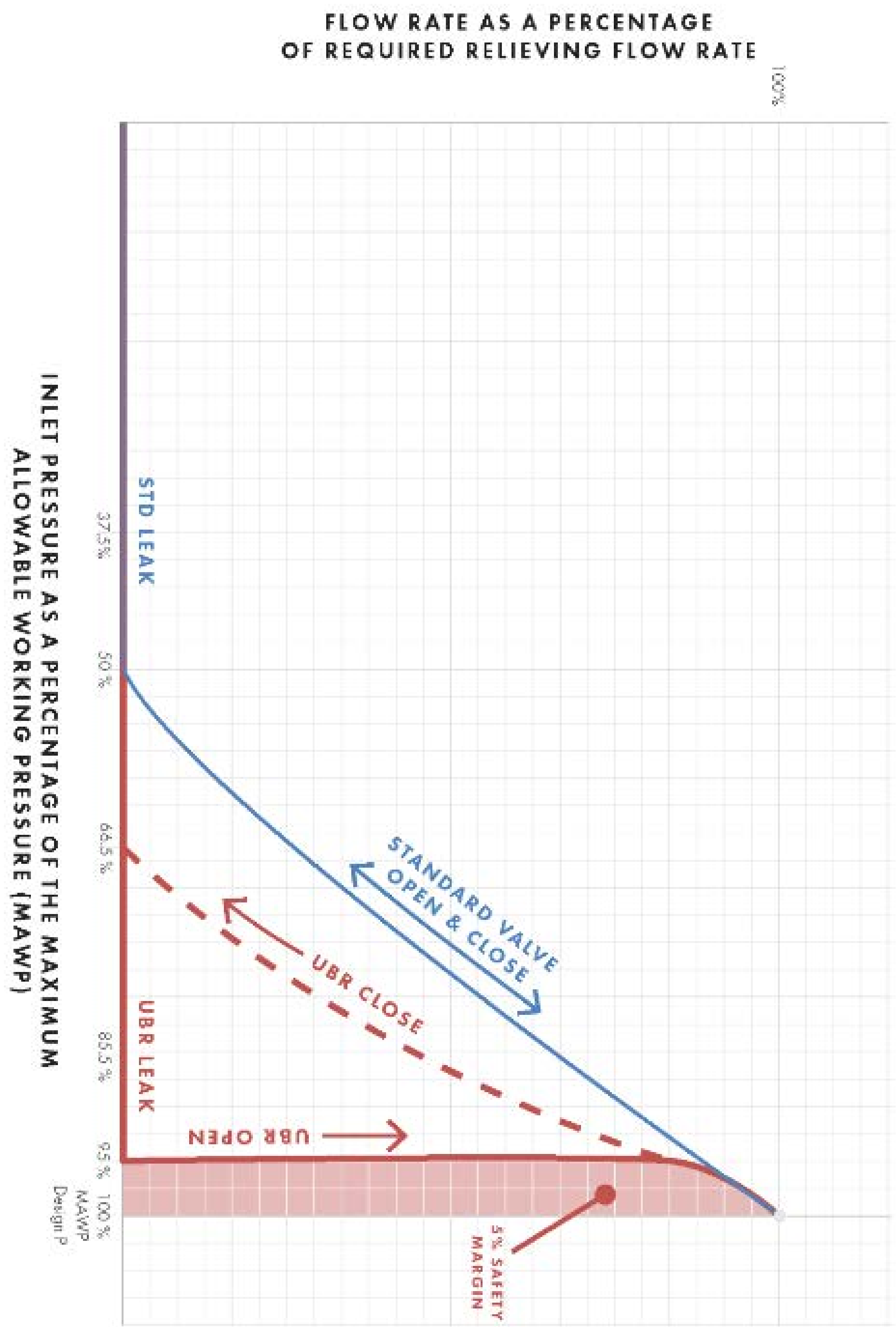

Figure 15A: UBR Valve and Standard Valve Operation with Respect to Pressure with Safety Margin

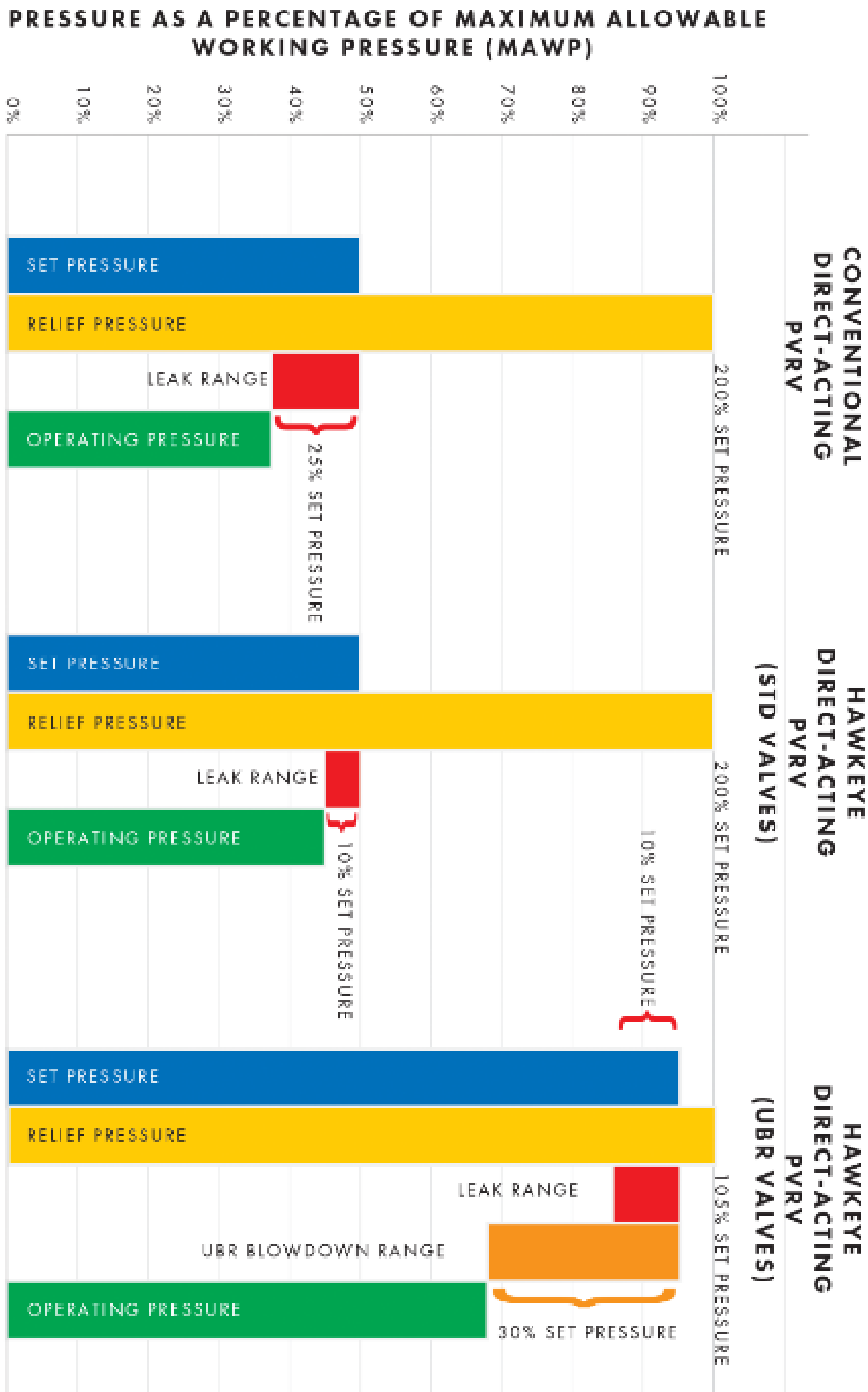

Figure 16A: Operational Pressure Comparison of UBR Valve and Standard Valves