COVER STORY

Brian Burkhart, Baker Hughes, USA, seeks to define 'zero leakage' of equipment and outlines how it can be achieved.

FROM ZERO TO HERO

Pressure relief devices (PRDs) are designed to ensure the protection of life, property, and equipment from the occurrence of unexpected overpressure events in refineries. However, this safety has historically come at the expense of unwanted environmental emissions and costly loss of process from leaking PRDs.

Pilot-Operated Pressure Relief Valves (POPRV) offer significant advantages over traditional PRDs including reduced emissions, improved operating efficiency, and increased profitability by allowing users to operate their system closer to set pressure while ensuring 'zero leakage' during normal operation, even at operating pressures as high as 99% of set pressure.

But how is 'zero leakage' defined by the industry and, more importantly, how can it truly be achieved?

Zero leakage? Who cares?

The US Environmental Protection Agency (EPA) was established in December 1970 by US President Richard Nixon with a stated mission to protect human and environmental health. Since the inception of the EPA and other similar agencies around the world, humans have developed a deeper understanding of the negative impact of emissions on human and environmental health, leading to a rapid expansion in EPA authority and exponential growth in environmental regulations around the world.

As it relates to equipment leaks, the EPA publishes the 'Leak Detection and Repair Compliance Assistance Guidance - A Best Practices Guide' to offer guidance on why and how to reduce or eliminate these unwanted emissions. In Section 1.0 of this guide, the EPA lays out a compelling problem statement: "In general, EPA has found significant widespread noncompliance with Leak Detection and Repair (LDAR) regulations and more specifically, noncompliance with Method 21 requirements. In 1999, EPA estimated that, as a result of this noncompliance, an additional 40 000 tons of Volatile Organic Compounds (VOCs) are emitted annually from valves at petroleum refineries alone."

Raising the bar for reducing emissions

LDAR Guidance also speaks to why equipment leaks must be identified and regulated in Section 2.0 Why Regulate Equipment Leaks?: "The Agency has estimated that approximately 70 367 tons per year of VOCs and 9357 tons per year of Hazardous Air Pollutants (HAPs) have been emitted from equipment [including valves] leaks. Emissions from equipment leaks exceed emissions from storage vessels, waste-water, transfer operations, or process vents."

Historically, the primary focus in the hydrocarbon processing industry for reducing emissions has been only on the biggest offenders, such as flare gas, with valves

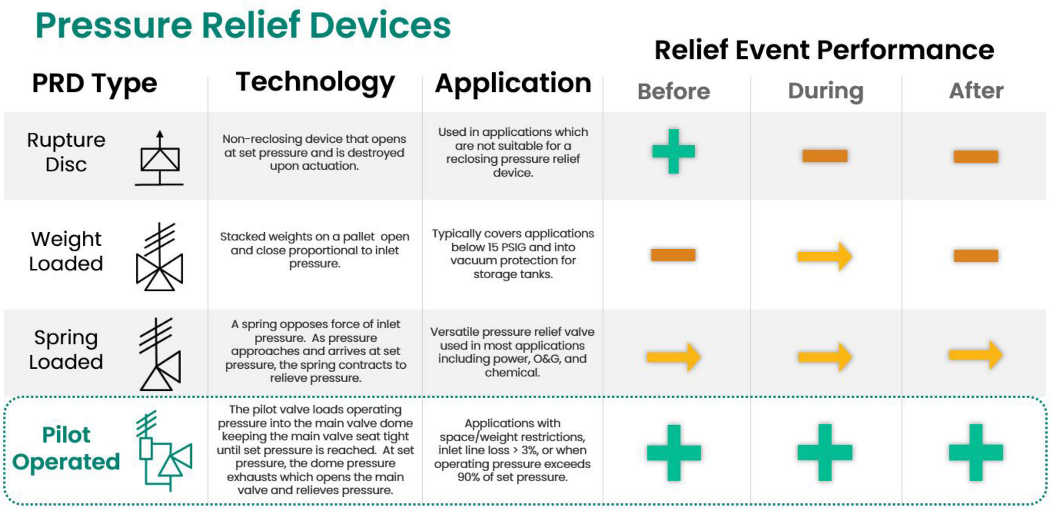

Figure 1. Types of pressure relief device (PRD).

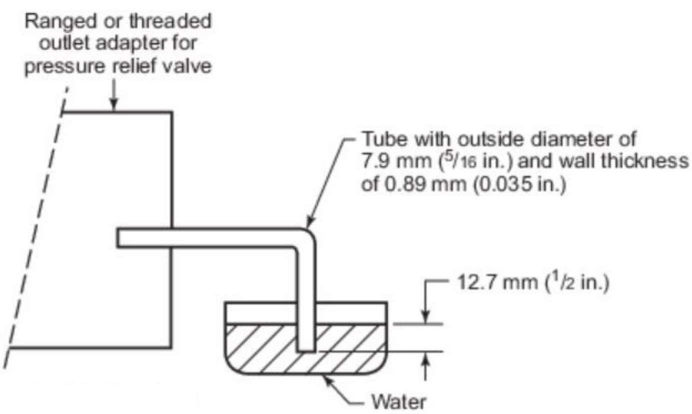

Figure 2. Apparatus to test seat tightness with air.

being a lower priority. However, the industry is quickly trending toward a more comprehensive and holistic approach to reducing emissions.

Fugitive emissions have been centred around on/off valves and pumps historically. However, the bar is being raised higher every day, and engineers and product managers are now exploring new boundaries to ensure product portfolios meet zero emissions.

With a clear and growing trend to reduce equipment leakage and emissions, what does this mean in the context of PRDs?

The 'perfect' PRD

If a perfect PRD were to exist, what would its attributes be? Broken down into the three stages of operation, the perfect PRD would look something like the following:

- Before relief event: closed with zero leakage up to 100% of set pressure.
- During relief event: opens exactly at set pressure, relieves only enough capacity to protect the system, and operates in a stable manner without chatter or flutter.
- After relief event: re-closes on its own with a minimum blowdown and returns back to its original state of zero leakage.

When compared to other PRDs such as rupture discs, weight loaded PVRVs, and direct spring PRVs, modulating action POPRV technology comes the closest to achieving 'perfect PRD' status, particularly as it relates to zero leakage before and after a relief event occurs (Figure 1).

Obviously zero leakage is a critical factor in the performance of a PRV, but what exactly does it mean? The answer begins with a deeper examination of PRV seat leakage.

PRV seat leakage defined

API 527 Fourth Edition 'Seat Tightness of Pressure Relief Valves' is the globally accepted standard for establishing the methods of determining PRV seat leakage as well as defining acceptable seat leakage rates.

Methods of determination

API 527 Section 1 prescribes a seat leakage test with air, steam, or water in accordance with the primary stamped media of the valve. For each of the test procedures on air, steam, or water, API 527 Sections 2 through 5 only require a leakage test to be performed on the seat of the main valve, making no mention of main valve dome media discharging from the pilot exhaust.

For example, API 527 Section 2.1 and 2.2.2 shows and describes the test apparatus and configuration for PRV seat leakage testing on air: "The valve shall be vertically mounted on the test stand, and the test apparatus shall be attached to the valve outlet, as shown in Figure 2. All openings-including but not limited to caps, drain holes, vents, and outlets-shall be closed."

From a scope perspective, API 527 focuses only on one aspect of PRV leakage yet fails to comprehensively address all forms of possible PRV media releases.

Acceptable leakage rates

API 527 defines acceptable leakage rates by media type for the valve outlet, but again offers no guidance on acceptable leakage or allowable media discharge from the main valve dome through the pilot exhaust.

For example, Section 2.3 Table 1 of API 527 defines an allowable leakage rate for metal-to-metal seated PRVs on air. Leakage rates as high as 100 bubbles/min. at operating pressures as low as 90% are deemed allowable according

Table 1. **Maximum seat leakage rates for metal-seated pressure relief valves**

Set pressure at 15.6°C (kPa [psig])	Orifice diameter less than or equal to 18 mm		Orifice diameter greater than 18 mm	
	Leakage rate (bubbles/min.)	Approximate leakage per 24 hr (standard m³ [ft³])	Leakage rate (bubbles/min.)	Approximate leakage per 24 hr (standard m³ [ft³])
13 to 6896 [15 to 1000]	40	0.017 [0.60]	20	0.0085 [0.30]
10 300 [1500]	60	0.026 [0.90]	30	0.013 [0.45]
13 800 [2000]	80	0.034 [1.20]	40	0.017 [0.60]
17 200 [2500]	100	0.043 [1.50]	50	0.021 [0.75]
20 700 [3000]	100	0.043 [1.50]	60	0.026 [0.90]
27 600 [4000]	100	0.043 [1.50]	80	0.034 [1.20]
34 400 [5000]	100	0.043 [1.50]	100	0.043 [1.50]
41 400 [6000]	100	0.043 [1.50]	100	0.043 [1.50]

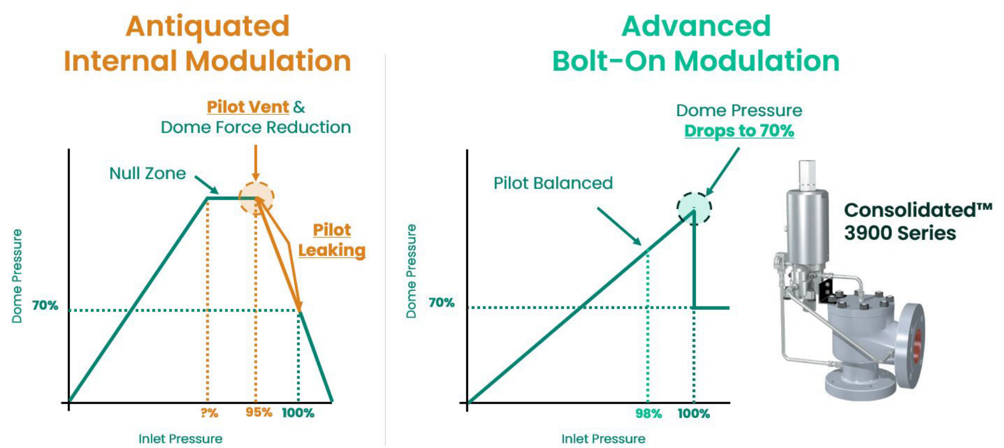

Figure 3. Antiquated internal modulation vs advanced modulation technology.

to the acceptance criteria. By contrast, soft seated valves, including POPRVs, are allowed no leakage (0 bubbles/min.).

It should also be noted that this standard and acceptance criterion only applies to the state of the valves in a controlled production and testing environment, but not in a true operating environment full of service debris, vibration, and other undesirable operating conditions. Actual operating conditions along with wear of metal components will presumably increase the actual leakage rate of a metal seated valve over time.

Are all modulating pilots created equal?

All modulating POPRVs are not created equal, particularly when it comes to zero leakage at high operating pressures.

What is causing this difference and how big is the delta? All modulating POPRV designs can be boiled down to two different technologies: internal modulation and bolt-on modulation.

Antiquated internal modulation technology pilots lock in main valve dome pressure at some unknown point before 95% operating pressure (commonly referred to as the 'null zone'). In the range of 95% to 100% of set pressure, they achieve main valve modulation by continually venting main valve dome pressure (premature leakage), inversely proportional to inlet pressure down to 70% of set pressure, creating balance in the main valve. By contrast, advanced bolt-on modulation technology enables the pilot to wait up to 100% of set pressure before venting main valve dome pressure down to 70% of set pressure. At 100% of set pressure, both main valves will then similarly modulate through the relief cycle.

Figure 3 depicts a comparison of the performance of an internal modulation pilot vs advanced bolt-on modulation technology. Here is a deeper analysis into the differing approaches to modulation of internal modulation and advanced bolt-on modulation technology.

Antiquated internal modulation

The industry standard for internal modulation pilot designs operate on a force balance described by the following formula and shown in Figure 4:

$$Fs = Pi(A1) + Pd(A2)$$

Where:

- Fs = the pilot loading spring, which allows pilot set pressure adjustment.
- Pi = system inlet pressure.
- Pd = pressure in the main valve dome chamber sensed from the pilot dome area.
- A1 = area described by the pilot main sensing piston or diaphragm.
- A2 = area described by the pilot dome area.

As the system pressure increases, the internal modulation pilot goes through four phases:

- Unbalanced: the pilot is typically in the unbalanced state during normal operating conditions, in which the pilot spring is applying a greater force (Fs) downward than the summation of forces generated by the system pressure acting on the pilot piston

(Pi x A1) and dome pressure on the pilot dome area (Pd x A2). In the unbalanced state, both the pilot and the main valve are in a zero-leakage state.

- Balanced: when the summation of forces from system pressure and dome pressure equals the force of the pilot spring, the pilot enters into a balanced state. Balance is achieved at a pressure less than the desired set pressure (typically around 95%) of the valve. In addition, due to the delicate force balance, 'stable inlet pressure' is required in order to ensure that the pilot does not leak further.
- Pilot discharge: as system pressure continues to increase beyond balanced pressure, the pilot will control the main valve dome pressure inversely proportional to the change in system pressure in order to satisfy the force balance equation. As a result, the main valve dome pressure will discharge through the pilot discharge port at a system pressure of 95% and greater. As system pressure moves up and down between 95% and 100% of set pressure, the pilot would continue to vent and supply the main valve dome as it works to maintain a balanced state.
- Modulation: when main valve dome pressure is reduced to approximately 70% of the system pressure, balance will be achieved in the main valve piston, allowing opening of the main valve and relieving system pressure.

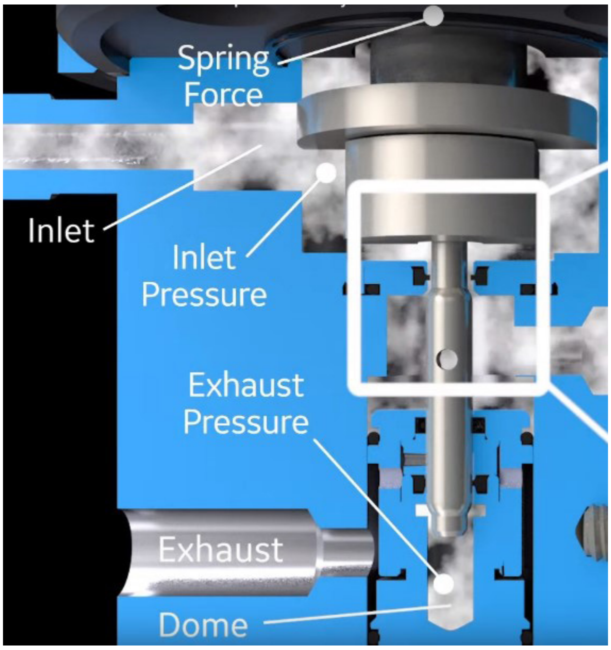

Figure 4. Internal modulation diagram.

In summary, internal modulation pilots cannot claim true zero leakage because they begin to leak at 95% of operating pressure and unrealistically require 'stable inlet pressure' during operation.

Advanced technology

Advanced bolt-on modulation technology allows the pilot valve to achieve similar main valve modulation, while completely eliminating main valve dome discharge through the pilot discharge port all the way until 100% of set pressure, thus achieving true zero leakage status. It works as follows (Figure 5):

- Below set pressure: the dome exhaust seat in the pilot remains closed all the way until 100% of set pressure.
- At set pressure: the pilot closes the inlet supply seat and opens the dome exhaust seat, thereby opening the cavity between the modulator bottom and the main valve dome. System pressure and main valve dome pressure are equal at this point. Pressure in the main valve dome will then decrease until the modulator is balanced, typically a value of 65% of set pressure.
- Above set pressure: the main valve is now balanced with a slight upward net force acting upward on the main valve piston. The main valve piston will move upward proportional to an increase in system pressure. The modulator will always be in a balanced state, thus controlling the pressure in the main valve dome chamber to 65% of inlet conditions. When pressure reduces to closing pressure of the pilot (typically 3 – 5%), the pilot will close the exhaust port and reopen the supply to pressurise the main valve dome again to system pressure.

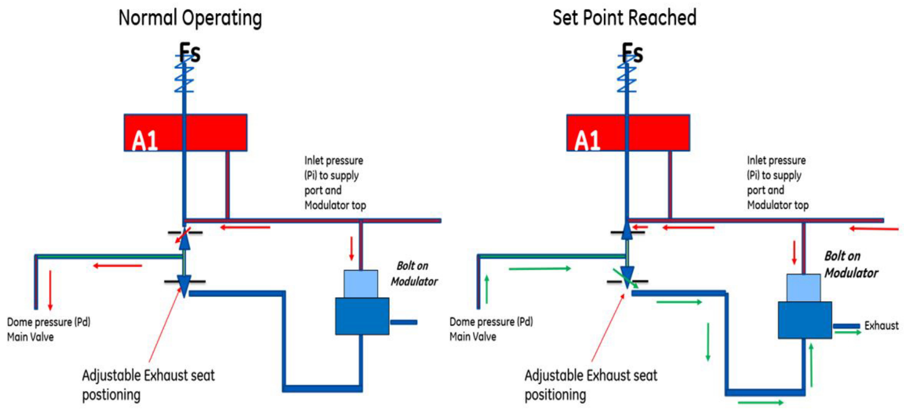

Figure 5. Bolt-on modulation diagram.

Conclusion

While antiquated internal modulation pilot valves require 'stable inlet pressure' and will begin to release dome pressure through the pilot exhaust at 95% operating pressure, advanced bolt-on modulation technology is a true zero leakage solution for the complete valve all the way up to 98 – 100% of set pressure.