Pressure relief valves (PRVs) are used to prevent over-pressurisation of equipment and piping. A PRV is a self-automated valve that opens to relieve process fluid when the inlet pressure reaches the PRV’s set pressure. The set pressure is selected to ensure that equipment and piping are protected against damage due to over-pressure. Typical PRVs include conventional, balanced bellows, and pilot type valves. API 520 provides a good overview of the differences between each of these types of valves.  

This article discusses the selection of bellows for balanced bellows pressure relief valves and some of the different design options available from vendors. It also describes how misspecification on the bellows rating is possible. Both new design and debottlenecking examples are considered.

**Backpressure**

Backpressure is the pressure at the outlet of a PRV and is a critical design parameter for the sizing and performance of the PRV. It is determined by the sum of both the superimposed backpressure (constant or variable pressure at the PRV outlet before the valve starts to lift) and built-up backpressure (pressure resulting from the opening of the given PRV).
Both conventional and balanced bellows PRVs use a spring to keep the disc closed against the seating surface. The initial opening of the PRV is governed by the force balance on the disc assembly. For uncompensated conventional valves, high superimposed backpressures increase the opening pressure and can lead to overpressure of the protected equipment. High built-up backpressures tend to reclose conventional valves once they open, and can lead to valve instability and damage. Conventional PRVs can have their opening pressures adjusted to compensate for constant superimposed backpressures, but their use is not recommended in cases with high variable backpressures or in cases with built-up backpressures exceeding the allowable code over-pressure.

**Balanced bellows PRVs**

Balanced bellows valves can be used to compensate the backpressure limitations faced by conventional valves. This is achieved through the use of a bellows that isolates a portion on the top of the disc holder from the flare backpressure (Figure 1). The bellows forms a leak tight seal, the interior of which is connected to the bonnet chamber via ports. For balanced bellows PRVs, it is critical that the bonnet vent is left open to the atmosphere. By balancing the top and bottom areas of the exposed portion of the disc and keeping the portion of the disc inside the bellows exposed to atmospheric pressure, the influence of backpressure opening is greatly reduced compared to a conventional PRV. Maintaining atmospheric pressure in the bonnet chamber requires that the bonnet vent must not be plugged.

Balanced PRVs can be used with total backpressures of up to 50% of the set pressure, and possibly higher if the vendor is consulted. Backpressure correction factors may be required to compensate for reduced lift at high backpressures (refer to API 520 for additional details).

**General considerations**

A balanced bellows PRV is considered when the backpressure does not allow the use of conventional valves. While backpressure compensation is one of the most notable features of this type of PRV, there are additional considerations. Damage to the bellows can prevent the PRV from operating properly through either mechanical interference or, in the case of bellows leakage, by allowing the flare backpressure to be applied to the portion of the disc that is usually exposed to atmospheric pressure. This will result in the bellows PRV opening at a higher than expected pressure, and potentially damaging the equipment that it is protecting. The impact on the performance of the balanced bellows PRV is related to the size of the leak in the bellows relative to the bonnet chamber vent. A bellows leak that is small in relation to the bonnet vent has a smaller effect on the balancing of the PRV.

Bellows leakage can also result in the atmospheric release of flare fluids via the bonnet vent. Use of bellows in highly toxic or dangerous services should be carefully considered. In some instances, the bellows vent is directed via tubing to a safe location to mitigate against bellows leakage. An auxiliary balanced piston is sometimes used as an additional mitigation against the failure of the bellows. If the bellows leaks, the balanced piston will still allow the PRV to open at the expected set pressure, and the piston can reduce leakage through the bonnet vent after a bellows failure. Regular valve inspection, and gas sniffing at the outlet of the bonnet vent should be used to allow early identification of a bellows leak. Due to the manufacturing tolerances of the bellows, it is impossible to perfectly balance the disc. Therefore, the balancing is purposefully designed such that the disc will lift at, or below, the set pressure. API 520 notes that this slight imbalance is typically acceptable, but advises to consult the vendor if there is a concern.

A bellows may also be used as a means of protecting the spring and other ‘top works’ from corrosive materials in the flare system. It is important to distinguish between an unbalanced and balanced bellows – the unbalanced bellows is selected for corrosion protection, but does not provide backpressure compensation. A bellows is sometimes used to protect the clearance between the disc holder and guide from fluids that could interfere, for example viscous fluids, with the movement of the disc holder through the guide.

Since the bonnet vent is open to the atmosphere, there is a possibility of ambient moisture freezing inside the bonnet and obstructing the valve’s operation. This can be of concern in cold ambient climates or in cryogenic services. Operator experience and the vendor should be consulted to confirm if valve insulation and tracing are acceptable mitigations.

Since the bellows acts as additional resistance against the process pressure lifting the disc there can be restrictions on the minimum set pressure of the PRV. Generally, PRVs with smaller orifices can require a minimum set pressure to allow the process pressure to lift the disc against the combined spring and bellows resistance. These minimum set pressures are typically in the range of 10 – 50 psig.

**Bellows construction and materials**

The bellows is constructed of thin metal to provide flexibility, and requires replacement if damaged or compromised. In one method of construction the bellows can be made from a single sheet of rolled metal that is formed into a cylinder and seam welded before being fluted using a hydraulic machine. A bellows flange is welded to the top of the bellows and is held in place by pinching the flange between the guide and valve body – effectively, the compression resulting from tightening
Bellows pressure and temperature ratings

API 526 is a specification for flanged steel PRVs that includes the PRV outlet flange rating and the bellows rating. The API 526 pressure ratings of the bellows are reported at 100°F (37.8°C). Depending on the bellows metallurgy, the pressure limit is derated for temperatures above 100°F. Generally speaking, the larger the orifice that the PRVs have, the lower the allowable bellows pressure rating. For orifices larger than ‘K’, Area = 1.838 in², there is a marked reduction in bellows pressure ratings.

Outlet flange ratings generally follow ASME B16.34 ratings, but, in some cases that are noted in API 526, the PRV outlet flanges may be rated lower. It is important to note the bellows ratings can be lower than the outlet flange rating. This difference between outlet flange rating and bellows design depends on the PRV body/bonnet material, flange rating, and orifice.

Bellows misspecification

Poor balanced bellows PRV design has been described in previous literature. It can lead to excessive backpressure due to evaluating built-up backpressure at the required flow rate instead of the valve rated capacity, oversized PRVs or undersized inlets leading to chatter, and valve flutter due to operating too close to the set pressure.

Example one

Bellows type PRVs are frequently used in flare network systems due to the highly variable backpressures (Figure 2). Assume that PRV-2 and PRV-3 in Figure 2 both relieve as part of a power failure upset, while PRV-1 only relieves a small load due to a blocked flow (single contingency case). It is not uncommon for the power failure to result in the largest flare header backpressure since multiple PRVs can relieve simultaneously. However, if the designer is not careful and only designs PRV-1 for the blocked-flow backpressure, then the PRV-1 bellows may become damaged in the case of a power failure when it is exposed to a higher backpressure.

Often, the bellows PRV data sheets do not have a specific area for the bellows design temperature/pressure. If this is the case, the designer should consider adding a note to the data sheet that specifies the maximum backpressure and temperature that the bellows can be exposed to, even if the PRV does not participate in the relief event that generates the governing design conditions.

Example two

When units are debottlenecked, the unit relief loads will typically increase. This results in higher flare backpressures. During a debottlenecking study, the owner may only evaluate the flare header backpressure for the governing upsets (such as power failure). As such, they may choose only to evaluate PRV-2 and PRV-3 as part of that check-rate since these PRVs contribute to the power failure flare load. PRV-1 may not be evaluated at all, and there is a chance that a new higher backpressure could damage the bellows, post-debottleneck.

Conclusion

It is recommended that data sheets for bellows type PRVs specify the highest backpressure/temperature combination that the bellows can be exposed to in the flare. This requires consideration of relieving events in which the PRV may not directly participate. In debottlenecking studies, it is important to ensure that the bellows ratings for all bellows PRVs that are tied into the flare are checked.

References