Fundamentals of Pressure Relief Valves

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Introduction

Overpressure protective devices are of vital concern to the gas industry. Safety codes and current laws require their installation each time a pressure reducing station is installed that supplies gas from any system to another system with a lower maximum allowable operating pressure.

The purpose of this article is to provide a review of various types of pressure relief valves, understand how they operate and how to size and select these devices so that overpressure protection is provided.

Overpressure Protection

Overpressure protection is a primary consideration in the design of any piping system. The objective of overpressure protection is to maintain the pressure downstream of a regulator at a safe maximum value.

Main Regulator

Pressure reducing regulators have different pressure ratings which refer to the inlet, outlet, and internal components. The lowest of these should be used when determining the maximum allowable pressure.

Piping

Piping is limited in its ability to contain pressure. In addition to any physical limitations, some applications must also conform to one or more applicable pressure rating codes or regulations.

Relief Valves

Relief involves maintaining the pressure downstream of a regulator at a safe maximum pressure using any device that vents gas to the atmosphere. Relief valve exhaust must be directed or piped to a safe location. Relief valves perform this function. They are considered to be one of the most reliable types of overpressure protection available and are available in a number of different types. Fisher® relief valves are not ASME safety relief valves.

Maximum Pressure Considerations

Overpressure occurs when the pressure of a system is above the setpoint of the device controlling its pressure. It is evidence of some failure in the system (often the upstream regulator), and it can cause the entire system to fail if it’s not limited. To implement overpressure protection, the weakest part in the pressure system is identified and measures are taken to limit overpressure to that component’s maximum pressure rating. The most vulnerable components are identified by examining the maximum pressure ratings of the:

- Downstream equipment
- Low-pressure side of the main regulator
- Piping

The lowest maximum pressure rating of the three is the maximum allowable pressure.

Downstream Equipment

The downstream component (appliance, burner, boiler, etc.) with the lowest maximum pressure rating sets the highest pressure that all the downstream equipment can be subjected to.
Relief Valve Popularity

Relief valves are popular for several reasons. They do not block the normal flow through a line. They do not decrease the capacities of the regulators they protect. And, they have the added advantage of being an alarm if they vent to atmosphere.

Relief Valve Types

Relief valves are available in four general types. These include: pop type, direct-operated, pilot-operated, and internal relief valves.

Selection Criteria

Pressure Build-up

A relief valve has a setpoint at which it begins to open. For the valve to fully open and pass the maximum flow, pressure must build up to some level above the setpoint of the relief valve. This is known as pressure build-up over setpoint, or simply build-up.

Periodic Maintenance

A relief valve installed in a system that normally performs within design limits is very seldom exercised. The relief valve sits and waits for a failure. If it sits for long periods it may not perform as expected. Disks may stick in seats, setpoints can shift over time, and small passages can become clogged with pipeline debris. Therefore, periodic maintenance and inspection is recommended.

Cost Versus Performance

Given several types of relief valves to choose from, selecting one type is generally based on the ability of the valve to provide adequate protection at the most economical cost. Reduced pressure build-up and increased capacity generally come at an increased price.

Installation and Maintenance Considerations

Initial costs are only a part of the overall cost of ownership. Maintenance and installation costs must also be considered over the life of the relief valve. For example, internal relief might be initially more economical than an external relief valve. However, maintaining a regulator with internal relief requires that the system be shut down and the regulator isolated. This may involve additional time and the installation of parallel regulators and relief valves if flow is to be maintained to the downstream system during maintenance operations.

Pop Type Relief Valve

The most simple type of relief valve is the pop type. They are used wherever economy is the primary concern and some setpoint drift is acceptable.

Operation

Pop type relief valves are essentially on-off devices. They operate in either the closed or wide-open position. Pop type designs register pressure directly on a spring-opposed poppet. The poppet assembly includes a soft disk for tight shutoff against the seat ring. When the inlet pressure increases above setpoint, the poppet assembly is pushed away from the seat. As the poppet rises, pressure registers against a greater surface area of the poppet. This dramatically increases the force on the poppet. Therefore, the poppet tends to travel to the fully open position reducing pressure build-up.
**Build-up Over Setpoint**

Recall that pressure build-up relates capacity to pressure; increasing capacity requires some increase in pressure. In throttling relief valves, pressure build-up is related to accuracy. In pop type relief valves, build-up over setpoint results largely because the device is a restriction to flow rather than the spring rate of the valve’s loading spring.

**Fixed Setpoint**

The setpoint of a pop type valve cannot be adjusted by the user. The spring is initially loaded by the manufacturer. A pinned spring retainer keeps the spring in position. This is a safety measure that prevents tampering with the relief valve setpoint.

**Typical Applications**

This type of relief valve may be used where venting to the atmosphere is acceptable, and when relief pressure variations are allowable. They are often used as inexpensive token relief. For example, they may be used simply to provide an audible signal of an overpressure condition.

These relief valves may be used to protect against overpressure stemming from a regulator with a minimal amount of seat leakage. Unchecked, this seat leakage could allow downstream pressure to build to full $P_1$ over time. The use of a small pop type valve can be installed to protect against this situation.

These relief valves are also commonly installed with a regulator in a natural gas system farm tap, in pneumatic lines used to operate air drills, jackhammers, and other pneumatic equipment, and in many other applications.

**Advantages**

Pop type relief valves use few parts. Their small size allows installation where space is limited. Also, low initial cost, easy installation, and high capacity per dollar invested can result in economical system relief.

**Disadvantages**

The setpoint of a pop type relief valve may change over time. The soft disk may stick to the seat ring and cause the pop pressure to increase.

As an on-off device, this style of relief valve does not throttle flow over a pressure range. Because of its on-off nature, this type of relief valve may create pressure surges in the downstream system.

![Direct-Operated Relief Valve Schematic](image)

**Direct-Operated Relief Valves**

Compared to pop type relief valves, direct-operated relief valves provide throttling action and may require less pressure build-up to open the relief valve.

**Operation**

A schematic of a direct-operated relief valve is shown in Figure 5. It looks like an ordinary direct-operated regulator except that it senses upstream pressure rather than downstream pressure. And, it uses a spring-close rather than a spring-open action. It contains the same essential elements as a direct-operated regulator:

- A diaphragm that measures system pressure
- A spring that provides the initial load to the diaphragm and is used to establish the relief setpoint
- A valve that throttles the relief flow

If the relief valve capacity is significantly larger than the failed regulator’s capacity, the relief valve may over-compensate each time it opens and closes. This can cause the downstream pressure system to become unstable and cycle. Cycling can damage the relief valve and downstream equipment.
Opening the Valve

As the inlet pressure rises above the setpoint of the relief valve, the diaphragm is pushed upward moving the valve plug away from the seat. This allows gas to escape.

Pressure Build-up Over Setpoint

As system pressure increases, the relief valve opens wider. This allows more gas to escape and protects the system. The increase in pressure above the relief setpoint that is required to produce more flow through the relief valve is referred to as pressure build-up. The spring rate and orifice size influence the amount of pressure build-up that is required to fully stroke the valve.

Selection Criteria

Pressure Build-up

Some direct-operated relief valves require significant pressure build-up to achieve maximum capacity. Others, such as those using pitot tubes, often pass high flow rates with minimal pressure build-up. Direct-operated relief valves can provide good accuracy within their design capacities.

Product Example

Pitot Tube

The relief valve shown in Figure 6 includes a pitot tube to reduce pressure build-up. When the valve is opening, high gas velocity through the seat ring creates an area of relatively low pressure. Low pressure near the end of the pitot tube draws gas out of the volume above the relief valve diaphragm and creates a partial vacuum which helps to open the valve. The partial vacuum above the diaphragm increases the relief valve capacity with less pressure build-up over setpoint.

Typical Applications

Direct-operated relief valves are commonly used in natural gas systems supplying commercial enterprises such as restaurants and laundries, and in industry to protect industrial furnaces and other equipment.
Cost Versus Performance

The purchase price of a direct-operated relief valve is typically lower than that of a pilot-operated design of the same size. However, pilot-operated designs may cost less per unit of capacity at very high flow rates.

Pilot-Operated Relief Valves

Pilot-operated relief valves utilize a pair of direct-operated relief valves; a pilot and a main relief valve. The pilot increases the effect of changes in inlet pressure on the main relief valve.

Operation

The operation of a pilot-operated relief valve is quite similar to the operation of a pilot-operated pressure reducing regulator. In normal operation, when system pressure is below setpoint of the relief valve, the pilot remains closed. This allows loading pressure to register on top of the main relief valve diaphragm. Loading pressure on top of the diaphragm is opposed by an equal pressure (inlet pressure) on the bottom side of the diaphragm. With little or no pressure differential across the diaphragm, the spring keeps the valve seated. Notice that a light-rate spring may be used because it does not oppose a large pressure differential across the diaphragm. The light-rate spring enables the main valve to travel to the wide-open position with little pressure build-up.

Increasing Inlet Pressure

When the inlet pressure rises above the relief setpoint, the pilot spring is compressed and the pilot valve opens. The open pilot bleeds fluid out of the main valve spring case, decreasing pressure above the main relief valve diaphragm. If loading pressure escapes faster than it can be replaced through the restriction, the loading pressure above the main relief valve diaphragm is reduced and the relief valve opens. System overpressure exhausts through the vent.

Decreasing Inlet Pressure

If inlet pressure drops back to the relief valve setpoint, the pilot loading spring pushes the pilot valve plug back against the pilot valve seat. Inlet pressure again loads the main relief valve diaphragm and closes the main valve.

Control Line

The control line connects the pilot with the pressure that is to be limited. When overpressure control accuracy is a high priority, the control line tap is installed where protection is most critical.

Product Example

Physical Description

This relief valve is a direct-operated relief valve with a pilot attached (Figure 8). The pilot is a modified direct-operated relief valve, the inlet pressure loads the diaphragm and flows through a restriction to supply loading pressure to the main relief valve diaphragm.

Operation

During normal operation, the pilot is closed allowing loading pressure to register above the main relief valve’s diaphragm. This pressure is opposed by inlet pressure acting on the bottom of the diaphragm.

If inlet pressure rises above setpoint, the pilot valve opens, exhausting the loading pressure. If loading pressure is reduced above the main relief valve diaphragm faster than it is replaced through the pilot fixed restriction, loading pressure is reduced and inlet pressure below the diaphragm will cause the main regulator to open.
Principles of Relief Valves

If inlet pressure falls below the relief set pressure, the pilot spring will again close the pilot exhaust, increasing loading pressure above the main relief valve diaphragm. This increasing loading pressure causes the main valve to travel towards the closed position.

**Performance**

Pilot-operated relief valves are able to pass large flow rates with a minimum pressure build-up.

**Typical Applications**

Pilot-operated relief valves are used in applications requiring high capacity and low pressure build-up.

**Selection Criteria**

**Minimal Build-up**

The use of a pilot to load and unload the main diaphragm and the light-rate spring enables the main valve to travel wide-open with little pressure build-up over setpoint.

**Throttling Action**

The sensitive pilot produces smooth throttling action when inlet pressure rises above setpoint. This helps to maintain a steady

**Internal Relief**

Regulators that include internal relief valves may eliminate the requirement for external overpressure protection.

**Operation**

The regulator shown in Figure 9 includes an internal relief valve. The relief valve has a measuring element (the main regulator diaphragm), a loading element (a light spring), and a restricting element (a valve seat and disk). The relief valve assembly is located in the center of the regulator diaphragm.

**Build-up Over Setpoint**

Like other spring-loaded designs, internal relief valves will only open wider if the inlet pressure increases. The magnitude of pressure build-up is determined by the spring rates of the loading spring plus the main spring. Both springs are considered because they act together to resist diaphragm movement when pressure exceeds the relief valve setpoint.

**Product Example**

A typical internal relief regulator construction is shown in Figure 9. The illustration on the left shows the regulator with

**Figure 9. Internal Relief Design**

Regulators that include internal relief valves often eliminate the requirement for external overpressure protection. The illustration on the left shows the regulator with both the relief valve and the regulator valve in the closed position. The illustration on the right shows the same unit after P2 has increased above the relief valve setpoint. The diaphragm has moved off the relief valve seat allowing flow (excess pressure) to exhaust through the screened vent.
both the relief valve and regulator valve in the closed position. The illustration on the right shows the same unit after the inlet pressure has increased above the relief valve setpoint. The diaphragm has moved off the relief valve seat allowing the excess pressure to exhaust through the vent.

Performance and Typical Applications

This design is available in configurations that can protect many pressure ranges and flow rates. Internal relief is often used in applications such as farm taps, industrial applications where atmospheric exhaust is acceptable, and house service regulators.

Selection Criteria

Pressure Build-up

Relief setpoint is determined by a combination of the relief valve and regulator springs; this design generally requires significant pressure build-up to reach its maximum relief flow rate. For the same reason, internal relief valves have limited relief capacities. They may provide full relief capacity, but should be carefully sized for each application.

Space

Internal relief has a distinct advantage when there is not enough space for an external relief valve.

Cost versus Performance

Because a limited number of parts are simply added to the regulator, this type of overpressure protection is relatively inexpensive compared to external relief valves of comparable capacity.

Maintenance

Because the relief valve is an integral part of the regulator’s diaphragm, the regulator must be taken out of service when maintenance is performed. Therefore, the application should be able to tolerate either the inconvenience of intermittent supply or the expense of parallel regulators and relief valves.

Selection and Sizing Criteria

There are a number of common steps in the relief valve selection and sizing process. For every application, the maximum pressure conditions and the wide-open regulator flow capacity should be determined. Finally, this information is used to select an appropriate relief valve for the application.

Maximum Allowable Pressure

Downstream equipment includes all the components of the system that contain pressure; household appliances, outlet rating of the upstream regulators, or other equipment. The component with the lowest maximum pressure rating establishes the maximum allowable system pressure.

Regulator Ratings

Pressure reducing regulators upstream of the relief valve have ratings for their inlet, outlet, and internal components. The lowest rating should be used when determining maximum allowable pressure.

Piping

Piping pressure limitations imposed by governmental agencies, industry standards, manufacturers, or company standards should be verified before defining the maximum overpressure level.

Maximum Allowable System Pressure

The smallest of the pressure ratings mentioned above should be used as the maximum allowable pressure. This pressure level should not be confused with the relief valve setpoint which must be set below the maximum allowable system pressure.

Determining Required Relief Valve Flow

A relief valve must be selected to exhaust enough flow to prevent the pressure from exceeding the maximum allowable system pressure. To determine this flow, review all upstream components for the maximum possible flow that will cause overpressure. If overpressure is caused by a pressure reducing regulator, use the regulator’s wide-open flow coefficient to calculate the required flow of the relief valve. This regulator’s wide-open flow is larger than the regulating flow used to select the pressure reducing regulator.

Sizing equations have been developed to standardize valve sizing. Refer to the manufacturer’s literature section to find these equations and explanations on how they are used.
Determine Constant Demand

In some applications, the required relief capacity can be reduced by subtracting any load that is always on the system. This procedure should be approached with caution because it may be difficult to predict the worst-case scenario for downstream equipment failures. It may also be important to compare the chances of making a mistake in predicting the level of continuous flow consumption with the potential negative aspects of an error. Because of the hazards involved, relief valves are often sized assuming no continuous flow to downstream equipment.

Selecting Relief Valves

Required Information

We have already reviewed the variables required to calculate the regulator’s wide-open flow rate. In addition, we need to know the maximum allowable pressure of the system, and the size of the piping. Finally, if a vent stack will be required, any additional build-up due to vent stack resistance should be considered.

Regulator Lockup Pressure

A relief valve setpoint is adjusted to a level higher than the regulator’s lockup pressure. If the relief valve setpoint overlaps lockup pressure of the regulator, the relief valve may open while the regulator is still attempting to control the system pressure.

Identify Appropriate Relief Valves

Once the size, relief pressure, and flow capacity are determined, we can identify a number of potentially suitable relief valves. Final selection is usually a matter of compromise. Relief capacities, build-up levels, sensitivity, throttling capabilities, cost of installation and maintenance, space requirements, initial purchase price, and other attributes are all considered when choosing any relief valve.

Applicable Regulations

The relief valves installed in some applications must meet governmental, industry, or company criteria.

Sizing and Selection Exercise

To gain a better understanding of the selection and sizing process, it may be helpful to step through a typical relief valve sizing exercise.

Initial Parameters

We’ll assume that we need to specify an appropriate relief valve for a regulator serving a small farm. There is sufficient space to install the relief valve without adding a vent stack.

Upstream Regulator

The regulator used is 1-inch in size with a 3/8-inch orifice. The initial system parameters of pressure and flow were determined when the regulator was sized for this application.

Pressure Limits

The gas engineer has determined that the relief valve should begin to open at 50 psig, and downstream pressure should not rise above 60 psig maximum allowable system pressure.

Relief Valve Flow Capacity

The wide-open regulator flow is calculated to be 38,880 SCFH.

Relief Valve Selection

Product Bulletin

If we look at the product bulletin for the potential relief valves, we find that a 1-inch Type 289H provides the required capacity within the limits of pressure build-up specified in our initial parameters.

Checking Capacity

Capacity curves for the 1-inch Type 289H with this spring are shown in Figure 10. By following the curve for the 50 psig setpoint to the point where it intersects with the 60 psig division, we find that our relief valve can handle more than the 38,880 SCFH required.
Summary

The gas design engineer has many choices of pressure relief valves to implement his overpressure protection plan. The selection process starts with a clear understanding of the system requirements and then a thorough understanding of the performance features of these devices. With proper selection, installation, and maintenance, pressure relief valves can provide a reliable means of overpressure protection for most gas system applications.