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White Paper

Pressure Relief Device and Valve Monitoring:

How to Detect Releases, Leaking and Fugitive Emissions

EMERSON
Process Management

Pressure Relief Device (PRD) Monitoring with *Wireless*HART® Sensors

How to comply with environmental regulations and detect PRD malfunctions while minimizing costs and cutting operating expenses

Every country has regulations and engineering specifications to protect industrial plants and facilities against overpressure in various processes and operations. The American National Standards Institute (ANSI), the American Society of Mechanical Engineers (ASME) and the American Petroleum Institute (API) are examples of engineering specifications globally recognized to provide detailed information on best practices for overpressure protection. Insurance companies and government agencies rely on the observance of these regulations and specifications to determine if designs are correct, and if operations are being conducted correctly.

Enforcement is done by local Environmental and Occupational Safety regulatory agencies that were created to protect health and the environment by writing and enforcing regulations. New fugitive emissions regulations worldwide are growing more stringent, requiring rigorous monitoring of pressure relief devices (PRDs) and bypass valves. They also require better control of flares and air concentration monitoring at the plant fence-line.

This paper is focused on PRDs and we will discuss the various types available, and the rules and regulations covering them. This paper also describes a cost-effective and reliable PRD monitoring system to meet regulations while improving efficiency and safety, and cutting operating costs.

Pressure relief devices

The purpose of a process plant control system is to keep process variables at the desired operating point and within safety limits. However, control systems may not be able to handle all process upsets, so operator intervention, safety instrumented systems, and PRDs become the last lines of defense. One of the main safety concerns is to keep process pressure within the limits tolerated by vessels, pipes, and valves.

PRDs can be pressure relief valves (PRVs), pressure safety valves (PSVs) and/or rupture discs (RD). They activate when the pressure gets too close to the maximum allowable working pressure (MAWP) of the vessel or process component. Per regulations, all PRDs must be mechanically powered by the process itself, so they do not require external power or intervention to function.

Traditionally, PRDs have a simple mechanical design to ensure reliability under all foreseeable conditions. Excessive pressure in the pressurized system is relieved by blowing process fluid (gas or liquid) to the environment, or to a closed recovery system.

Ideally, hazardous materials being relieved by a PRD should be routed to an enclosed recovery system to be treated and properly disposed of, or neutralized through combustion in a flare system. However, this is not always the case, with many PRDs releasing process fluid directly into the environment. Regardless of whether the PRD releases to an enclosed recovery system or to the environment, or is handling hazardous area pollutants (HAP) like H_2S or more benign fluids such as steam, it is important to identify the source, time and magnitude of the release. PRDs releasing to atmosphere can create explosive and toxic emergencies.

Flare systems are the most commonly used method of neutralizing hazardous discharges, but are not perfect. Fast transients caused by sudden fluid composition and volume changes can still cause releases of unburned hazardous material. Additionally, it can be difficult to locate the source in a closed recovery system in order to take corrective action.

In addition to potential environmental and safety concerns, process upsets causing overpressures can affect production and uptime, negatively impacting profitability. A PRD is sometimes the only indicator of process upsets, so the sooner a PRD event can be detected, the sooner operators can respond to the root cause.

There are three main types of PRDs: pressure relief valves (PRVs), pressure safety valves (PSVs) and rupture discs.

The term PRV or relief valve (RV) is generically used for both PRVs and PSVs; however, these two devices have different working principles.

A short explanation on the operating principles of each follows below.

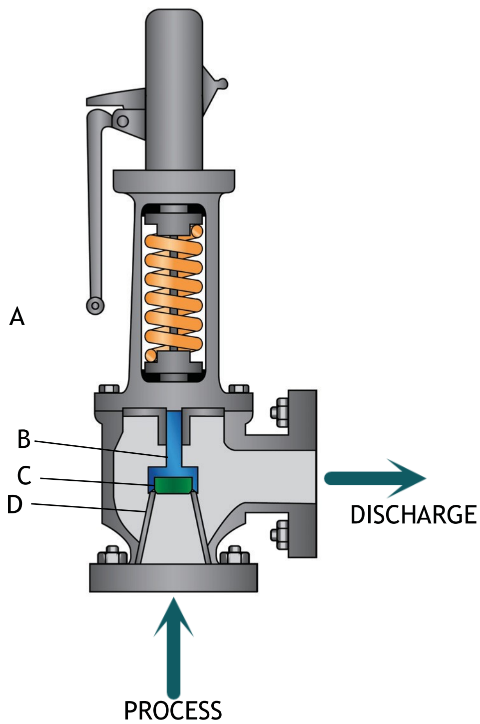
PRV basic operating principles

PRVs are safety devices protecting a vessel against overpressure. Figure 1-1 shows a typical spring loaded PRV. The disc between the process side (inlet piping) and the discharge side (discharge piping) is pushed against the seat by a compression spring. The spring force determines the PRV set-pressure and it is adjusted by the compression nut during calibration and certification.

When the spring force exceeds the force resulting from the process pressure and the pressure in the discharge side (backpressure), the disc blocks the flow from the process side to the discharge. When the process pressure exceeds the valve set pressure, the disc pushes the spring, opening the valve and forcing the process fluid to the discharge pipe. The valve will remain open until the process pressure drops approximately below 95% of set pressure. The ~5% dead-band, also known as “valve blow down,” prevents the valve from chattering when the process pressure varies close to the valve setpoint.

Unaccounted discharges also occur when the valve chatters. That happens when the vessel pressure oscillates around the PRV setpoint with an amplitude larger than the dead-band. Chattering occurs when the valve is not specified correctly and/or the piping was not designed properly.

Figure 1-1. Pressure Relief Valve



A. Spring
B. Disc/seat holder
C. Disc seat
D. Nozzle

The valve opens proportionally to the excess pressure, and returns to the closed position when the process pressure returns to normal. The discharged fluid, as explained above, can be released to the atmosphere, or routed to a treatment unit or flare system. There are more sophisticated types of PRVs, but the basic working principle is the same. In the relief valve calculation, it is necessary to take into account the pressure on the discharge side. Sometimes there is a back pressure buildup caused by relief of other PRDs in the discharge header in the enclosed recovery system.

When things don't work as expected

Many times, when the process pressure returns to normal conditions, the PRV does not close completely. There are several reasons for this:

- Pressure increase on the discharge side
- Valve seat damaged after repeated actuations
- Deposition or formation of solids between the disc and the seat
- Altered process fluid
- Corrosion
- Mechanical malfunction

Even a small leakage (0.1% from the PRV flow area) can cause losses of tens of thousands of dollars per year. Additionally, the leakage can cause significant emissions violations, resulting in expensive fines and even required shutdowns.

Table 1-1. Petrochemical Leakage Loss Costs Example

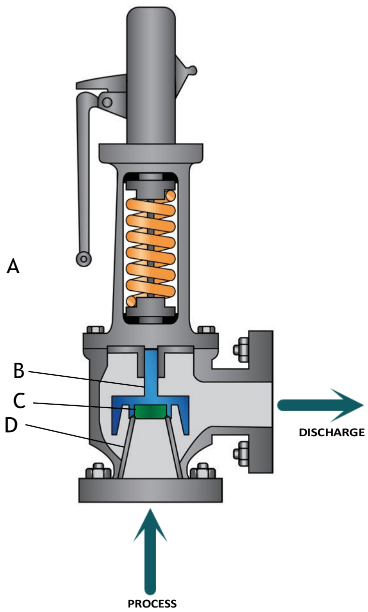
Gas type	Gas per metric ton ($)(1)	Process pressure (psig)(2)	Leakage yearly losses ($)
Ethylene	1,044	250 @ 212 °F	740,000
Ammonia	500	250 @ -28 °F	335,000
Steam	22	250 @ 400 °F	7,800

1. July, 2015 Platts Global Petrochemical Prices.
2. Relief valve set pressure - 300 psig and ASME orifice type "G".

Pressure safety valves

This device is commonly known as a "Pop Valve" because it opens completely and rapidly when the pressure exceeds the setpoint. The valve will remain open until the process pressure drops to approximately 95% of set pressure. These valves are mostly used for gas and steam.

Figure 1-2. Pressure Safety Valve



A. Spring
B. Disc/seat holder
C. Disc seat
D. Nozzle

PSVs are slightly different than PRVs. The disc blocking the nozzle has a small area and is contained in a larger diameter chamber. When the pressure exceeds the setpoint, the stem starts to lift, allowing the process fluid to flow to the chamber. As the chamber area is much larger than the one exposed by the disc, the uplifting force is much larger than the spring force and the valve opens completely.

With the discharge, the pressure reduces in the chamber and the valve closes. If the process pressure is still above the setpoint, the valve keeps popping open until the pressure returns to normal levels.

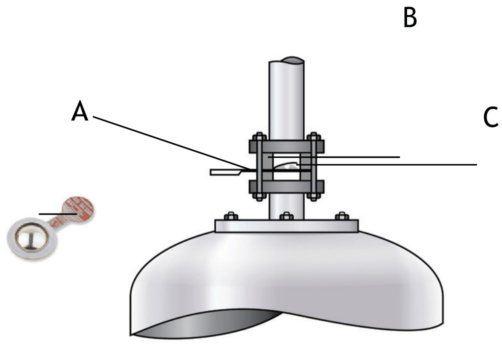
When the process pressure fluctuates around the PSV setpoint value, the blocking disc will lift to allow the chamber to fill and lift the stem. The process fluid vents to the discharge pipe, reducing the pressure, but not opening the valve completely. This process is called simmering and occurs frequently. Simmering can also cause material buildup on the disc seating and stem misalignment, which prevents the valve from closing completely. The discharge caused by simmering and its side effects are not usually detectable by conventional methods and account for a considerable emission volume and consequent economic losses, aside from fines and eventual plant shutdowns.

PSVs (Figure 1-2) are commonly equipped with a lever so an operator can initiate a manual release. This is useful to test the valve, clean possible scale or solids deposited on the seat surface, and deal with special process conditions during startup or during shutdowns.

Rupture discs

Rupture discs (Figure 1-3) are safety devices for one time use. They consist of a membrane that bursts when the differential pressure between its two sides exceeds a set value. These devices are used alone or in combination with a PRV, providing a physical isolation layer between the process and the relief valve, especially on processes containing highly corrosive fluid. Some models are equipped with a sensor that indicates when the diaphragm is broken.

Figure 1-3. Rupture Disc



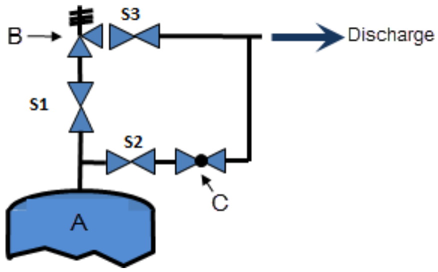
A. Rupture disc
B. Discholder
C. Diaphragm sensor

Rupture discs are very simple devices, with no moving parts. Unlike pressure relief or safety valves, the rupture disc will remain open until the ruptured diaphragm is replaced. Diaphragms are less susceptible to causing fugitive emissions, but there is always the possibility of pitting corrosion which creates pinholes, leading to undetectable leakage.

PRD bypass

Safety relief devices require shutoff valves and a bypass valve as shown in Figure 1-4. These valves are used for device maintenance and special process conditions. If a rupture disc diaphragm has to be replaced, for example, the device has to be isolated using these valves. In some cases such as during startup, shutdowns, tests or load changes, it may be necessary to bypass the PRD.

Figure 1-4. Pressure Relief Valve Bypass



S1, S2, S3. Shutoff valves
A. Protected vessel
B. Pressure relief valve
C. Bypass valve

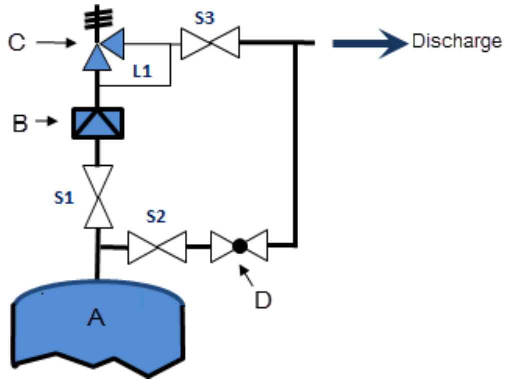
It is not uncommon for plant personnel to forget and leave these valves in the open position or not close them properly, causing process fluid losses and emissions that can go undetected for a long time. Monitoring bypass valve position enables quick response to human error or defective equipment.

RV with rupture disc

In some applications, it is necessary to use a rupture disc installed upstream from the RV (Figure 1-5). The main reasons for this are:

- The rupture disc can prevent fugitive emissions through the RV.
- The rupture disc protects the RV against corrosive process fluids. The RV may not be available with the material required for long term resistance to the process fluids, or it may be too expensive. The rupture disc diaphragm works as a shield between the process and the relief valve.
- The rupture disc protects the RV against solid particles. These particles can damage or prevent the RV from working properly, failing to open, or remaining open after a release.
- The rupture disc protects the RV against frozen vapors, material polymerization, hydrate formation, or other problems that may prevent it from working properly.

Figure 1-5. Typical Installation for an RV with Rupture Disc



S1, S2, S3. Shutoff valves
L1. Ventline
A. Protected vessel
B. Rupture disc
C. Relief valve
D. Bypass valve

It is important to note that if the rupture disc diaphragm has a pinhole leak caused by corrosion or other adverse conditions, the pressure between the rupture disc and the RV will be equal to the process pressure. Therefore, the pressure differential on the rupture disc will be always zero; i.e., it will never blow up, even if the process pressure exceeds its limit. Therefore, the leakage caused by the pinhole goes to the discharge line and can go undetected for a long period of time. Monitoring the line pressure between the PRD and PRV can detect the pressure build-up.

To avoid this problem, a vent line is often installed (L1 in Figure 1-5) to keep the pressure between the disc and the valve equal to the discharge line pressure.

Regulations

The requirements for refineries, chemical plants and other industries are similar worldwide, with the main difference being the tolerated amounts for each type of pollutant released. The more stringent rules can be generalized with three simple requirements:

1. Provide indication and location where a PRD event occurs through electronic monitoring.
2. Measure the time and duration of the PRD event for recording and reporting.
3. Notify the operator of the event so corrective action can occur.

Also, it is expected that the flare operates at all times when emissions may be vented to them, so quick identification of a PRD release is imperative.

In general, newer and more stringent rules apply not only to normal operation, but also to startup/shutdown periods, where there has historically been more leniency. These startup/shutdown periods are often when process upsets are most likely to occur, so compliance with new regulations can be very demanding.

Plants must comply with environmental regulations by law. Failing to do so can cause serious damage to the environment and personnel. It can also cause serious damage to plant equipment and explosions. In addition, lack of compliance can result in expensive fines, production disruptions, and bad publicity.

But there is another very compelling reason to monitor and curb fugitive emissions: leakages caused by PRD malfunctions can waste large amounts of valuable product, along with the energy required to produce these products.

Regulation details

Every national and international government has its own rules to control and monitor emissions of pollutants. In the U.S., the Clean Air Act (CAA) is the key federal law regulating air emissions from stationary and mobile sources. Among other things, this law authorizes the EPA to establish national ambient air quality standards to protect public health and public welfare by regulating emissions of HAPs). Many other countries' environmental agencies work together to achieve common goals, including the U.S.'s EPA, Europe's Directorate-General for Environment, China's Ministry of Environmental Protection (MEP), Brazil's Ministry of Meio Ambiente, Kuwait's Environmental Public Authority (EPA), India, and others to exchange information about best practices worldwide.

These environmental agencies periodically review emission standards for new sources of criteria air pollutants (CAP), volatile organic compounds (VOC) and other pollutants as well as set emission standards for toxic air pollutants from stationary sources reflecting the new maximum achievable control technology (MACT) based on the best performing facilities in an industry.

Several industries are subject to tight regulations, going so far as to issue detailed requirements for specific units in a plant, such as:

1. More stringent operating requirements for flare control to ensure good combustion. This is achieved, but not restricted, by:

- Measuring and monitoring the flow of waste gas going to the flare.
- Measuring and monitoring the content of the waste gas going to the flare.
- Measuring and monitoring any air or steam added into the flare.

2. Emission control requirements for storage tanks, flares and delayed coking units at petroleum refineries.

3. Pollutant monitoring around the plant fence line as a development in practices for managing emissions of toxic pollutants from fugitive sources.

4. Elimination of exemptions during periods of startup, shutdown and malfunction.

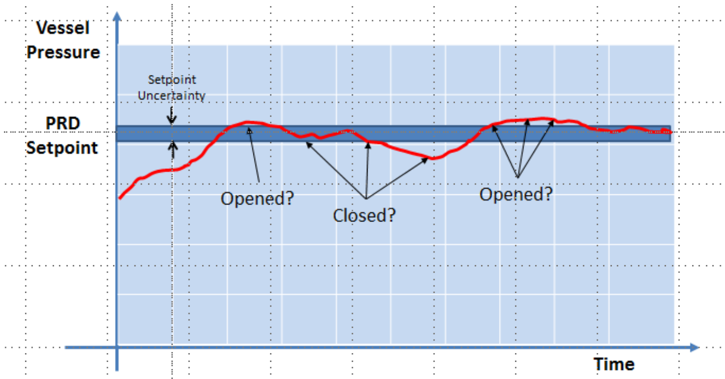
Most importantly, bypasses and discharges through PRDs are considered a violation of these laws in many countries, requiring plants to monitor discharges of individual PRDs.

Monitoring PRDs

Historically, PRDs have been difficult to monitor because they are simple mechanical devices by design. Monitoring methods typically include manual inspection of telltale signs. For example, on PRDs releasing to the atmosphere, wind socks are often used to monitor releases.

In order to monitor with this method, it is common to use process instrumentation to observe pressure peaks and valleys around the pressure limit, temperature downstream and flow in the discharge header. However, this method cannot be used in enclosed systems. Plants monitor PRDs by observing process pressure, but when the pressure is close to the operating limit, the peaks and valleys make it difficult to determine when the PRD is actually opened or closed.

Figure 1-6. Inaccurate PRD Monitoring using Process Instrumentation, Observing Pressure Variations



Unfortunately, these measurements are susceptible to false positives and inaccuracies and provide no insight into the health and status of the individual PRDs. Measuring flow in the discharge header does not show which PRD or PRDs were activated. Observing changes in the flare flame is also inaccurate and does not show which unit and which PRV caused the release.

A significant part of the difficulty when designing and installing a comprehensive monitoring system is that a typical plant will have several different PRD makes, models, sizes and operating pressures from various vendors. This can make it difficult to design a standardized monitoring system.

Another serious limitation is the introduction of pressure, flow or temperature measurements in an existing plant. Use of intrusive measuring devices disrupts plant operation and the cost of laying new cables can be very high.

As explained before, in addition to the challenges of compliance monitoring, there are other issues to contend with such as PRDs that leak, don't close and reseat after an event, or have their bypass valves in the wrong position due to human error. These issues can all cause a waste of product, and inefficient use of human resources.

In theory, PRD activation should occur only in exceptional circumstances, but in actuality, activation happens quite often. This may be an indication of other problems, such as issues with the PRDs, plant operating practices, or equipment specifications.

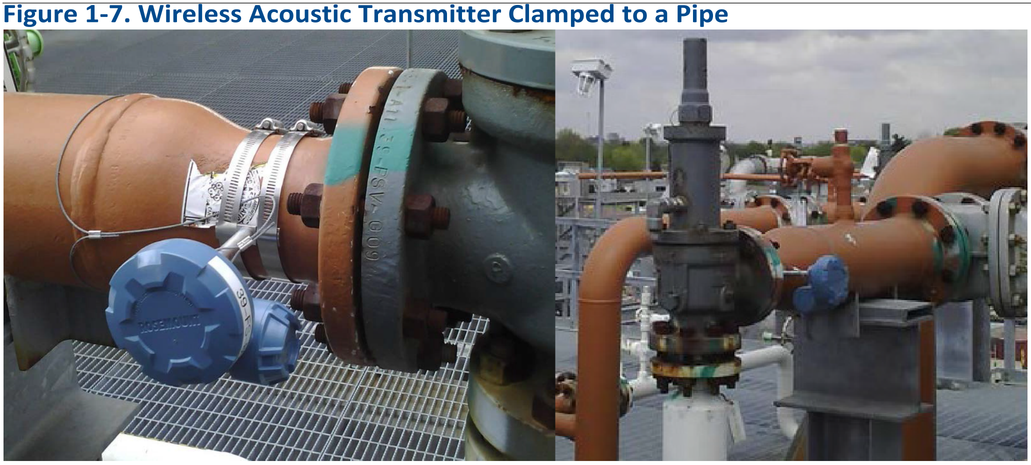
Monitoring how many times PRDs activate and how long each was releasing product helps plant personnel understand processes better, and it can also help improve combustion control. But it does not give visibility on leakages caused by PRD malfunction.

An effective way to monitor PRD activation and leakage

A very reliable, effective and economic way to monitor PRDs is to use wireless acoustic transmitters.

Process fluid flowing through valves and orifices generates acoustic waves in a wide and complex range of frequencies and magnitudes. A majority of the acoustic energy is in the ultrasound range, but some is also in the human audible range as well. Acoustic transmitters are able to detect ultrasound acoustic waves in the pipe wall as well as its temperature. These devices are wireless, small, lightweight and non-intrusive, so they do not require any change in plant installation. They can be easily clamped on the exhaust pipe, as shown in Figure 1-7.

Figure 1-7. Wireless Acoustic Transmitter Clamped to a Pipe



PRD operating condition can be determined by:

a. A noise level increase indicates that the PRD has been activated (Figure 1-8)

b. Noise level returning to the previous level indicates that the PRD is no longer discharging (Figure 1-8)

c. Noise level returning to a level above the previous level indicates leakage due to the valve not closing completely. This may be caused by deposition of particles or scale between the disc and its seat or due to a mechanical misalignment (Figure 1-9)

d. Noise level changing continuously indicates that the valve may be simmering or chattering (Figure 1-10)

e. Temperature changes may be used as an additional indication to validate a release. Figure 1-8 illustrates the flow discharge followed by a temperature change.

Figure 1-8. PRD Discharge Followed by Temperature Change

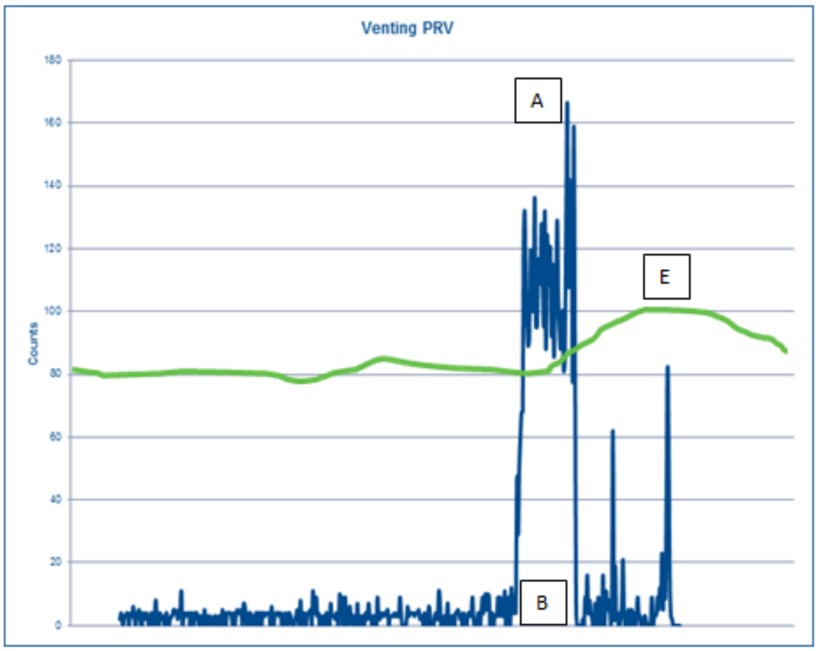


Figure 1-9. PRD Discharge Followed by Leakage

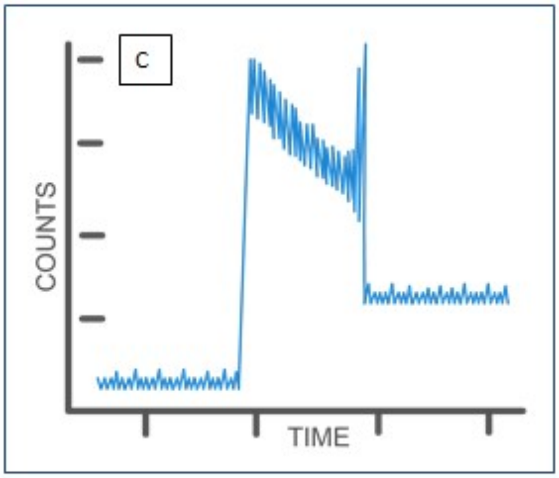
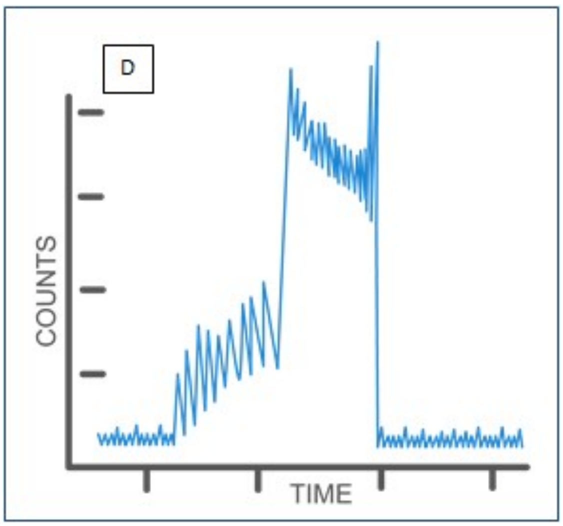


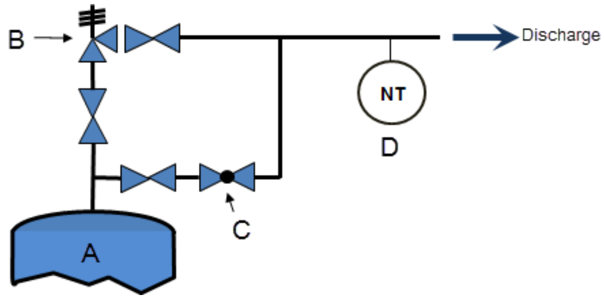
Figure 1-10. Noise Level Changing Continuously Indicates Valve may be Simmering or Chattering



Relief valve monitoring

Acoustic wireless transmitters should be installed downstream of the relief valve (RV), as close as possible to the valve. RVs are usually installed with shutoff and bypass valves for maintenance and special operating conditions. Bypass valves may be inadvertently left open or not close completely, causing unexpected flow to the recovery system. The wireless acoustic transmitter installed as indicated in Figure 1-11 monitors not only discharges or leakages of the relief valve, but can also monitor flow through the bypass valve.

Figure 1-11. Wireless Acoustic Transmitter should be Installed Downstream, Close to Valve



A. Protected vessel
B. Pressure relief valve
C. Bypass valve
D. Wireless acoustic transmitter

Sometimes the wireless acoustic transmitter can measure noise originated in other parts of the process. The signal from a PRD discharge is usually larger than the background noise signal, so it is still possible to detect a discharge. When the noise is too high, the total reading may go out of range. The transmitter attenuation function can bring the signal back to the readable range.

If the background noise varies too much, it may be difficult to determine when there is a discharge. In this case, it may be necessary to install a second acoustic transmitter downstream or upstream of the first one to measure the background noise and subtract its signal value from the signal being measured by the PRD monitoring transmitter. The calculation is done in the host system.

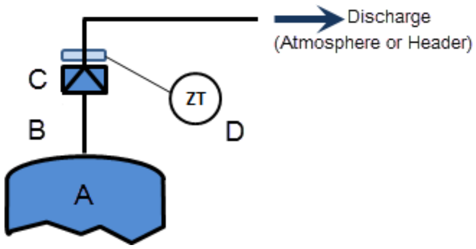
Rupture disc monitoring

Some types of rupture discs are equipped with a burst detector that generates a discrete signal indicating disc rupture. There are also devices that can be installed on the rupture disc surface that can detect when the disc ruptures and indicate the event through a discrete signal. The discrete signal is usually wired back to a supervisory system or safety system. The signal can initiate an action to minimize the release effect and cancel the overpressure root cause.

A wireless discrete transmitter can be used to transmit the discrete signal, eliminating costly and troublesome wiring, as indicated in Figure 1-12. The burst detector wires are connected to the transmitter that sends the signal wirelessly to a host system.

Rupture discs use a relatively thin membrane that may have pinholes created by pitting corrosion. Process fluid leaks through the pinholes. The burst detectors are not activated unless the disc ruptures, so the leakage can go undetected for a long time.

Figure 1-12. Rupture Disc Monitoring with Burst Detectors and Wireless Discrete Transmitter

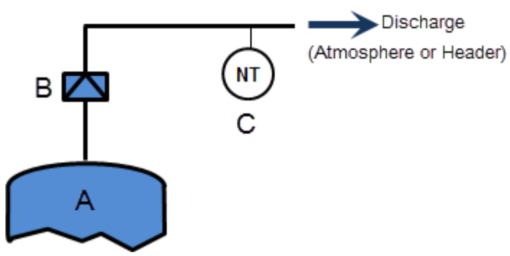


A. Protected vessel
B. Rupture disc burst detector
C. Rupture disc
D. Wireless acoustic transmitter

A more effective way to monitor rupture discs

Rupture discs can be better monitored with the use of a wireless acoustic transmitter as indicated in Figure 1-13. The transmitter can detect when the disc ruptured and the duration of the discharge, as it does for relief valves, but it may also detect even small leaks caused by pinholes.

Figure 1-13. Rupture Disc Monitoring with an Acoustic Wireless Transmitter



A. Protected vessel
B. Rupture disc
C. Wireless acoustic transmitter

Monitoring a combination of relief valves and rupture discs

As discussed before, rupture discs are one-time devices. Once they burst, they cannot close again, so the process fluid will be discharged until there is not enough pressure to make it flow. RVs are a better solution, as they close when the process pressure returns to normal conditions. However, in some applications, they must be isolated from harsh process conditions by using rupture discs. In normal operation, the relief valve is not in contact with corrosive, gumming or hot process fluids. If the vessel pressure reaches unsafe values, the rupture disc bursts, followed by the RV opening. The RV closes when the pressure returns to safe values.

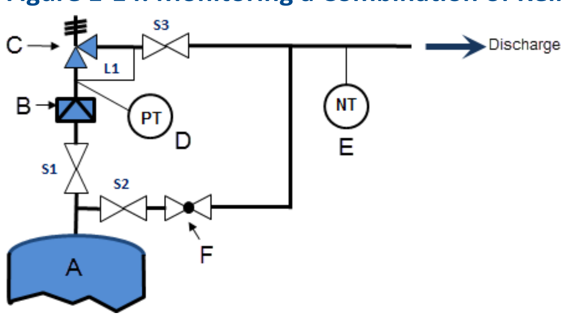
One problem with this type of installation is the possibility of rupture disc leakage caused by pinholes. The volume between the rupture disc and the relief valve can be filled with process fluid and the pressure between the two sides of the rupture disc will be the same, so the disc will not burst. Vent lines and/or excessive flow valves may be installed to release eventual leakage, but to be safe, standards and regulations ask for remote monitoring of the pressure in that space. In the U.S., ASME UG127, section VIII, Division 1 establishes this requirement.

A pressure switch can be used, but these switches do not provide a pressure measurement, which is very important to determine potential dangerous conditions. A wireless pressure transmitter can provide accurate and reliable pressure measurement; however, monitoring the pressure between the RD and an RV is not sufficient to reliably determine when the RV has opened or closed. A wireless acoustic transmitter installed downstream of the RV, as shown in Figure 1-14, provides dependable information about RV releases.

Note

The rupture disk does not need to be replaced immediately after bursting, because the wireless acoustic transmitter is still monitoring pressure releases. This allows maintenance personnel to replace or maintain the equipment at the most convenient time, without having to slow or shut down the process.

Figure 1-14. Monitoring a Combination of Relief Valves with Rupture Discs



A. Protected vessel
B. Rupture disc
C. Relief valve
D. Wireless pressure transmitter
E. Wireless acoustic transmitter
F. Bypass valve

Rupture discs can also be used downstream from the valve to protect the valve against aggressive fluids, particulates and other damaging conditions that may be present in the discharge header.

Wireless transmitters

The wireless devices mentioned in this paper utilize *Wireless*HART technology. *Wireless*HART is an open standard that provides secure, reliable and flexible wireless communication. The devices form a self-organizing, self-healing mesh network, with redundant communication paths.

Planning, installation and configuration of the wireless network is very simple and flexible. Click here for more information about *Wireless*HART.

Conclusion

Pressure Relief Device monitoring is necessary for environmental protection compliance and can avoid expensive fines, and possible process unit or plant shutdowns. Monitoring also prevents waste of costly material and energy, avoids bad publicity and helps improve plant personnel and neighboring communities' health.

Wireless acoustic, pressure, and discrete transmitters are a very effective, reliable, and economic way to have a compliant and better performing process as shown on Table 1-2.

Table 1-2. Total Cost Comparison

Total cost of implementation[1] 200 X PRDs		
	Traditional method	Pervasive Sensing™ Solution[2]
Total project cost ($K)	$3,520	$464 - $1,088
Total cost per PRD ($K)	$18	$2.3 –$5.4
Savings	N/A	69% - 87%
Field installation	Intrusive	Non-intrusive
Cabling and trenches required	Yes	No
Technology	Wired	Wireless
Total compliance and operational improvements at a fraction at fraction of the cost of traditional methods		

1. Total costs include monitoring of the wireless system, tamper-proof secure data, and engineered services.
2. Cost range dependent on application: PRV only or PRV with rupture disc monitoring.

For more information, see additional resources below.

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