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## BENEFITS AND METHODS OF AUTOMATING SURGE RELIEF VALVES

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### ABSTRACT

*When using nitrogen loaded surge relief valves it is believed that the relief valve is in control of the upper pressure limit of the pipeline. In reality, it is the nitrogen system together with the valve in a master and slave relationship that sets the upper threshold. The negative effects of changing temperature on the stability of a nitrogen loaded relief valve's set point is well known but poorly understood. There have been many attempts to minimize this effect. Burying the plenum and using the soil as an insulator has proven to be ineffective. Manual adjustments are not cost effective. Regulators offer inconsistent performance and are often misapplied. Evolving technology now allows for this process to be automated. Set points can be held with remarkable accuracy and plenums no longer need to be buried.*

### INTRODUCTION

Environmental requirements and governmental oversight of liquid pipelines has increased significantly over the past decade. Aging pipelines are operating beyond their original design capacity in an effort to accommodate shifting and growing populations. The need to improve safety and operating efficiency is driving the process of automating nitrogen loaded surge relief valves. Changes in the relief valve set point caused by daily and seasonal swings in ambient temperature can now be eliminated. It is the intent of this paper to bring the basic characteristics of nitrogen to light and how to manage the effects of temperature on the set point of a surge relief valve. We also intend to show how the surge relief valve will take on all the good or bad characteristics of the nitrogen loading system and how this combination of conditions will ultimately affect the performance and safety of a pipeline.

### SURGE RELIEF VALVES

Nitrogen loaded surge relief valves come in a variety of designs (Fig.1). All of them are known for their quick speed of response and excellent flow characteristics. Some use pistons with external plenums while others use elastomeric tubes and internal chambers. In spite of their design differences the one thing they have in common is that they rely on a charge of nitrogen to establish their set point.

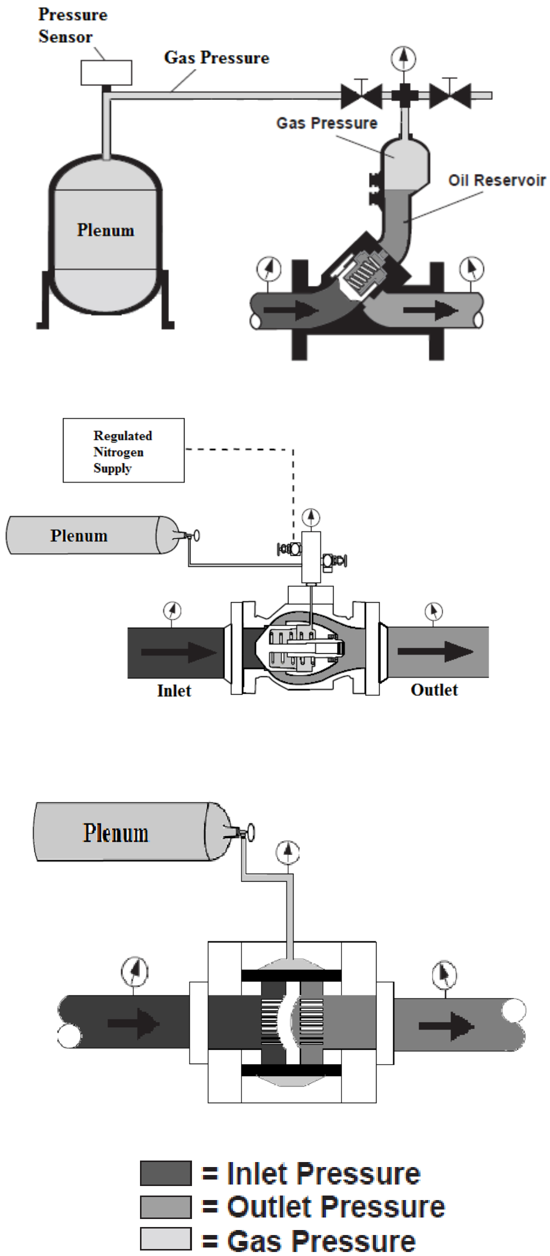


**FIGURE (1) RELIEF VALVE DESIGNS [1-3]**

## TEMPERATURE EFFECTS IN A CLOSED SYSTEM

The chart in Fig. 2 shows the typical pressure to time response of a pipeline with and without surge relief. The solid line shows how an unprotected system is overstressed while the dotted line shows how the pressure spike stays within the 10% maximum allowable over pressure of the 4,999kPa (725 PSI) set point in a pipeline with surge protection. What the chart also shows is the projected uncertainty of the set point caused by temperature fluctuations in the nitrogen system. If the starting temperature of the nitrogen is 16°C (60°F), increasing the temperature of the nitrogen by 28°C (50°F) will increase the set point by 482kPa (70 PSI) to 5,481kPa (795PSI). Conversely, if the nitrogen temperature decreases by 28°C (50°F) the set point will change to 4,516kPa (655 PSI). Seasonal temperature changes can produce even wider swings. A 56°C (100° F) rise or drop in the nitrogen temperature can drive the set point anywhere from 4,033kPa (585 PSI) to 5,985kPa (865 PSI). Nitrogen systems with higher set points can experience even larger pressure changes over a similar temperature swing.

The way operators have dealt with this in the past is by monitoring the set point and responding to high/low pressure alarms. This method requires a technician to visit the site to add or vent nitrogen from the system. That can translate to numerous visits over the course of a year depending on the number of valves in the system, the set point of the valves, ambient weather conditions, and the valve set point tolerance. In critical applications with a tight tolerance manual adjustments can be made several times per week. The frequency of making manual corrections may vary but with increasing concern for safety and the need to improve operating efficiency even periodic adjustments are considered unacceptable. In a system with 35 nitrogen loaded valves that require a single adjustment each week and an average call out cost of $500 the price of maintaining the systems set points starts to approach $1 million dollars per year.

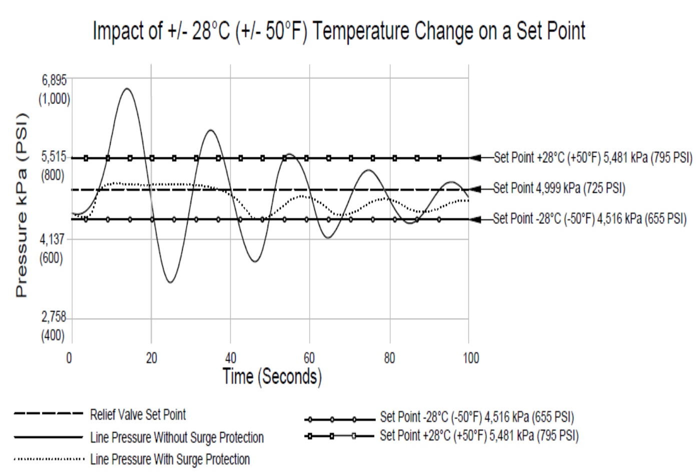


**FIGURE (2) TEMPERATURE IMPACT ON A SET POINT [4]**

## GAY - LUSSAC'S LAW

Gay-Lussac's law explains the relationship between pressure and temperature. It states that the pressure of a gas of fixed mass and fixed volume is directly proportional to the gas' absolute temperature. Simply put, if a gas' mass and volume are held constant, as the temperature changes so does the pressure. Since temperature is the measure of the average kinetic energy of the gas, as the temperature increases, its molecules collide with the container walls more rapidly causing the pressure to increase. [5] The formula for observing the impact of temperature on pressure can be written as:

$$P_2 = P_1 \times \frac{T_2}{T_1} \quad [5]$$

P1 is the starting pressure of the gas
T1 is the starting temperature of the gas in Kelvin
P2 is the ending pressure of the gas
T2 is the ending temperature of the gas in Kelvin

Gay-Lussac's law provides the information needed to understand the effects of temperature on the set point of a surge relief valve. Figure 3 shows three different set points and how they vary over a 56°C (100°F) temperature range.

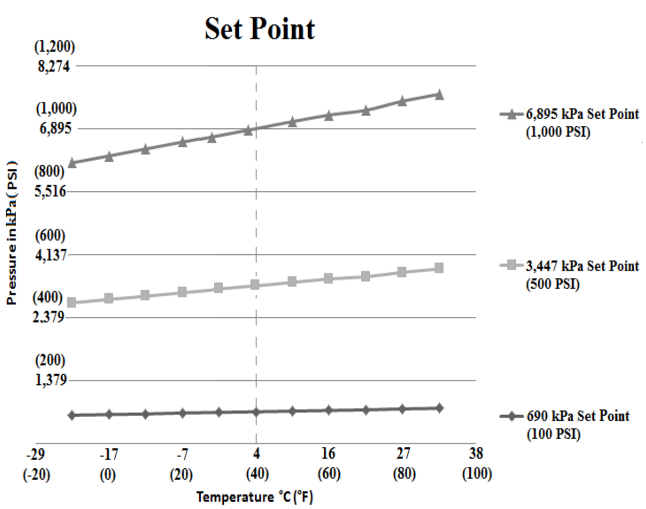


**FIGURE (3) PRESSURE AND TEMPERATURE**

It shows that a valve with a lower set point will be more stable than one with a higher set point. Since there are fewer nitrogen molecules inside a plenum at lower pressure there will be less molecular activity when the temperature changes. In practical terms, a valve having a 689kPa (100 PSI) set point with a +/- 138kPa (20 PSI) tolerance would require an adjustment after a 44°C (80°F) change in temperature. Conversely, a valve with a 3,447kPa (500 PSI) set point and a +/- 138kPa (20 PSI) tolerance would require adjustment after an 11°C (20°F) change.

## BURIED PLENUMS

One of the methods used to reduce the effect of thermal swing on a relief valve's set point has been to bury the plenum. With the increasing popularity of geothermal energy the information on the effectiveness of using the ground as an insulator is becoming better understood. Soil temperatures can vary from month to month as a function of incident solar radiation, rainfall, seasonal swings in air temperature, surface cover, soil type and depth in the earth. Figure 4 shows the relation between depth and temperature for soil in the central United States. Even in this temperate climate, a consistent temperature cannot be obtained until reaching a depth of 9.1 meters (30 feet). Figure 5 highlights the effect of seasonal temperature change in relation to depth. Since most plenums are buried from grade to 1.5 meters (5 feet) they can experience an average annual temperature change of up to 18°C (32°F). [6]

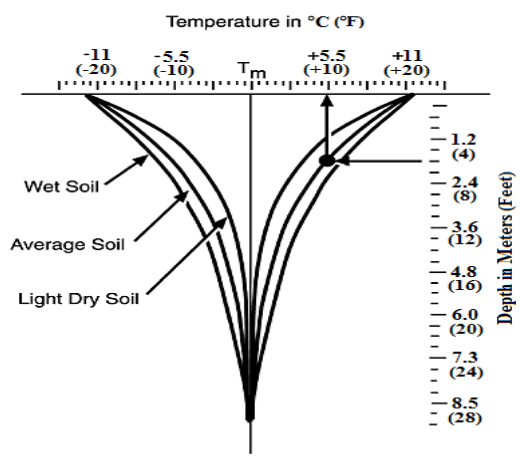


**FIGURE (4) SOIL TEMPERATURE AND DEPTH [6]**

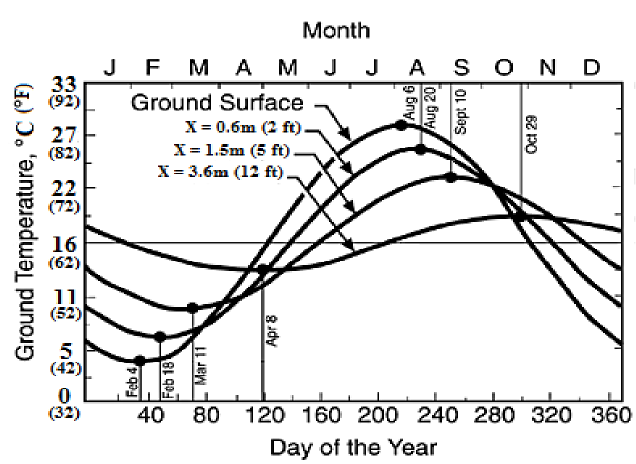


**FIGURE (5) SEASONAL SOIL TEMPERATURE [6]**

Other issues associated with burying a plenum are beginning to gain attention. Contractors are concerned about hitting undocumented product lines or electrical conduit during installation. Additionally, plenums can rise to the surface in areas with a high water table or heavy frost action. Since the plenum is often viewed as part of the pipeline it requires periodic inspection and recertification. Buried plenums are difficult to maintain and inspect.

## REGULATOR PANELS

A variety of regulator panels have been developed in an effort to automatically correct for changes in plenum pressure. When regulators are used in a closed end plenum system to correct for gradual changes in pressure the need for repeatability becomes critical. The regulator must add and vent nitrogen at the same time, every time, in order to hold a set point. Mechanical regulators have good flow characteristics over a specific range but fall short on the requirement for repeatability. The issues that affect repeatability are,

(a) The regulator spring is affected by changes in ambient temperature. As temperature begins to rise it weakens the spring causing the set point to become lower.

(b) The regulator spring can take a set if it is allowed to remain static. This generates additional spring tension that has to be overcome which causes the regulator to be late in adding nitrogen to the plenum.

(c) Since the increase in plenum pressure is gradual it has to overcome the mechanical friction of the stem and piston o-rings in the regulator. Inconsistency in overcoming this friction can affect the set point.

(d) Regulators using a captured vent can have a significant dead band.

(e) When the nitrogen supply pressure begins to decay the outlet pressure of a mechanical regulator will rise.

(f) Regulator lock up can be a significant issue when correcting for thermal expansion. Fig. 6 is a typical curve for a pressure reducing regulator. It shows several phenomenon including the ideal operating range and lock up. Lockup can be seen in the upper left of the curve. When correcting for thermal change the amount of nitrogen added or vented from the plenum can be relatively small. Using Charles's Law the volume of nitrogen needed to be moved can be calculated.

**Charles's Natural Gas Law**

$$V_2 = V_1 \times \frac{T_2}{T_1} \quad [5]$$

V1 is the starting volume of the gas
T1 is the starting temperature of the gas in Kelvin
V2 is the ending volume of the gas
T2 is the ending temperature of the gas in Kelvin

A typical plenum with a 49 liter (1.73 cubic feet) capacity at a set point of 690kPa (100PSI) contains 333 liters (11.7 cubic feet) of nitrogen. If the gas experienced a 5.5°C (10°F) change in temperature, 5.7 liters (0.2 cubic foot) of gas would need to be added or vented to maintain the same 690 kPa (100 PSI) pressure on the valve. The volume being relieved is small, and typically it will take several hours for the ambient temperature to change. If you make the same 5.7 liter correction over the course of an hour, the flow rate becomes 0.095 SLPM (0.003 SCFM). This means that the regulator must operate at the low end of the performance curve which is outside its ideal operating range (Fig. 6). The regulator is also attempting to perform an on/off function in this application which it was not designed to do.

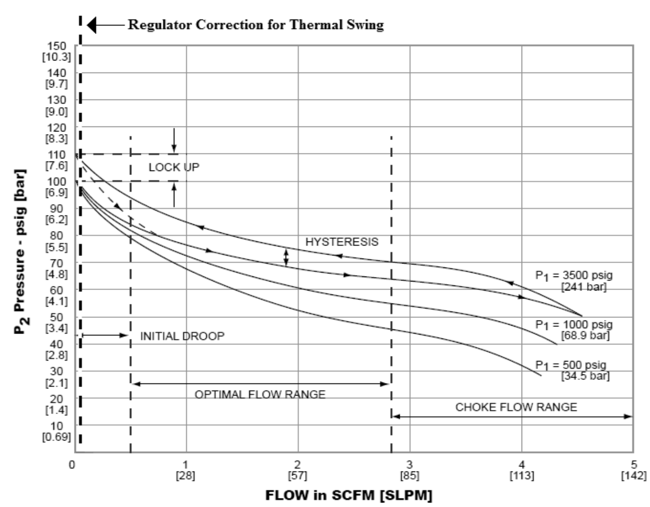


**Figure (6) Typical Flow Chart for a Gas Regulator [7]**

## AUTOMATION ARCHITECTURE

Automating a nitrogen loading system starts with a pressure transmitter that continuously monitors the plenum pressure and provides an output to the set point controller. The controller then adds or vents nitrogen from the plenum in order to maintain the set point of the valve. This is done by activating an input solenoid when plenum pressure drops due to decreasing temperature or conversely opening an exhaust solenoid when pressure increases due to rising temperature. A regulator is used to simply knock down supply bottle pressure and a pressure safety valve protects the surge relief valve from being over pressured by the nitrogen supply. Supply bottles are required to pressurize the system. The plenum provides the required volume needed to compress the nitrogen molecules without causing excessive force against the back side of the valve's piston or elastomeric tube.

## CHARGING THE SYSTEM

The most active time for a nitrogen loading system is the first two days after being charged and put into service. The plenum is typically at ambient temperature and either insulated or buried. The surge relief valve is in the line and subject to process temperatures. The nitrogen supply bottles are filled to capacity and equipped with a brass valve with a quarter inch opening. Once the nitrogen supply is opened and begins to flow, it flashes across numerous choke points in the system where it is compressed and then relieved. The system rapidly cools and ice begins to form on the tubes and gauge bezels. This sets up a scenario where there is a wide range of temperatures in the system which will take days to equalize. This is the time when the nitrogen loading system not only has to correct for ambient temperature but also unstable conditions caused by dissimilar temperatures in the system.

## AUTOMATION BENEFITS

With the evolution of automation, the negative issues associated with operating surge relief valves can be overcome. Since the surge relief valve takes on all the good or bad characteristics of the nitrogen system, any improvements made by automation can directly translate into improvement in a pipeline's performance. The advantages of automation are:

(1) The relief valve's plenum pressure is continuously monitored and adjusted to correct for changes in ambient conditions. Set point accuracy of +/- 34kPa (5 PSI) can be easily maintained. The issues associated with increasing set point pressure which can jeopardize pipeline safety, and set point decreases which can reduce pipeline efficiency are virtually eliminated.

(2) The need to bury the plenum is eliminated. With an automated panel controlling the set point, the insulation on the plenum takes on the secondary job of reducing the systems nitrogen consumption. It no longer has the primary role of trying to stabilize the set point.

(3) Automated nitrogen systems can be used to upgrade existing valves in the field. They can be installed on any nitrogen loaded valve requiring improved performance.

(4) The automation system can be remotely accessed in order to change the set point or adjust operating parameters. This can be helpful when multiple carriers are delivering to the same facility and different set points are required.

(5) Call outs and reporting for high / low nitrogen level alarms along with the need to make manual adjustments are virtually eliminated.

(6) DOT Testing and plenum inspection are greatly facilitated. Plenums can be returned to the manufacturer for inspection and recertification rather than performing this task in the field.

(7) An automated system can cover a wide range of set points from 172 to 13789 kPA (25 to 2,000 PSI). This reduces the number of panel variations required in the field.

(8) The components of an automated surge relief run can be easily assembled onto a skid.

## NITROGEN CONSUMPTION

The reason automated nitrogen loading systems can precisely maintain a set point is due to their ability to add and vent nitrogen from the plenum when necessary. When the temperature rises nitrogen from the plenum is vented to atmosphere. This part of the process does not consume nitrogen from the supply, but when the temperature starts to drop and the plenum pressure decreases the nitrogen that was previously vented from the system will need to be replaced. In a traditional mechanical system, the reason for insulating the plenum was to minimize the impact temperature had on the pressure in the closed system. In an automated system, plenum insulation is relegated to the secondary role of reducing nitrogen consumption.

Plenum size is a primary factor in nitrogen consumption. The greater the volume of the plenum the more nitrogen is required for making corrections in the pressure.

It's important to understand the nitrogen supply bottle. Any pressure in the supply bottle that is below the set point of the valve has no value. If a nitrogen supply bottle is filled to 2,300 PSI and the valves set point is 1,000 PSI there is only 1,300 PSI of available nitrogen in the supply bottle to perform a correction to the set point. Another example would be a supply bottle with 2,300 PSI being used on a system with a 200 PSI set point. In this application there would be 2,100 PSI of nitrogen available to make a correction. When determining the number of supply bottles you can quickly see that smaller valves with a lower set point will require fewer nitrogen supply bottles than large valves with a high set point

Another item to consider is the effects of ambient conditions on the supply bottle. There is no attempt to correct for thermal expansion and contraction on the supply side of the nitrogen system. It's not uncommon to see pressure swings in excess of 100 PSI on a static nitrogen bottle that was initially filled to 2,300 PSI

The remaining piece that is needed to determine nitrogen consumption is the average number of cycles you can expect form the nitrogen system in a 24 hour period. Clearly, there are numerous variables ranging from the installation's climate, changes in ambient conditions and the quality of the plenum insulation. Extensive testing and field experience has helped determine that the average cycle rate is 6 times per day. Half of these cycles are venting nitrogen and have no impact on supply consumption. The remaining 3 cycles are replacing the vented nitrogen which directly impacts the nitrogen supply.

Equipped with this information we can apply it to a specific application. A nitrogen loaded valve with a 400 PSI set point, +/- 5 PSI tolerance and a single "T" size plenum (2,990 cubic inch) would consume approximately 15 PSI of supply nitrogen each day. This is based on 3 daily cycles where nitrogen is added to the plenum. With 1,900 PSI of usable nitrogen there is approximately 126 days of run time in a single "T" size supply cylinder. Three supply bottles would be adequate for a year of normal operation. In a more demanding application with a set point of 750 PSI and a 3 bottle plenum the life expectancy of a single supply bottle would be approximately 34 days. In this case a rack of 12 supply bottles would provide 1 year of operation.

## DIFFERENCES OF A DYNAMIC SYSTEM

Automated surge relief valves have several advantages but it's important to understand that they are different from regulator style or closed plenum systems. The operator needs to take the time to understand these differences and insure the system is installed and set up correctly. Points to consider when using an automated nitrogen system are,

A. The nitrogen system should fail closed on the loss of electrical power. This causes the plenum system to become static allowing it to hold the last set point until power returns.

B. The nitrogen supply pressure should be continuously monitored to insure an adequate supply. The loss of supply pressure prevents the system from correcting for thermal contraction.

C. In the event a set point cannot be maintained an integral back up should lock down the system when it is more than 2 PSI outside of the predetermined operating range.

D. The nitrogen system must be kept free of contamination or liquids that can freeze. Anything that can adversely affect the performance of the system will ultimately affect its ability to hold the valves set point.

E. The purpose of an automated nitrogen system is to insure the valve is prepared to relieve at the required set point. It is not it's function to interfere with an event or the operating relationship between the valve and the plenum.

## PERFORMANCE CURVES

Figure 7 shows a typical 24 hour operating period for an automated nitrogen loading system. Corrections are made throughout the course of the day to add and vent nitrogen keeping the relief valve operating within the required +/- 10 PSI tolerance. Corrections to the set point usually last less than 30 seconds. The chart also has a curve for a mechanical system. It shows how the plenum pressure drifts in and out of the required operating range. Most operators continuously monitor a relief valves set point. This allows them to set limits on the nitrogen systems performance and quickly determine if a Technicians intervention is required.

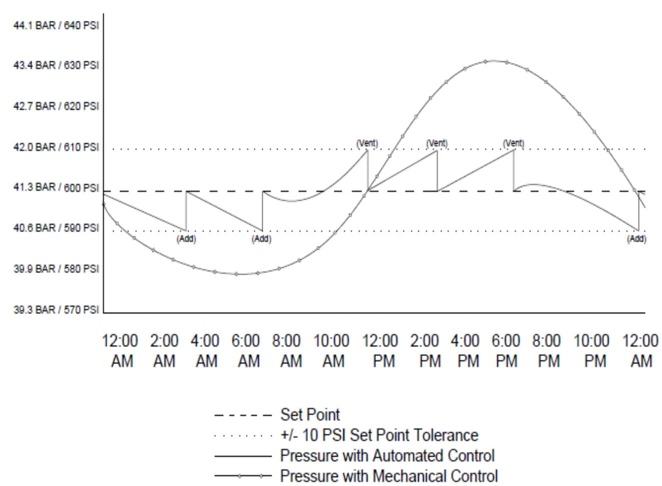


**Figure (7) Pressure Control Performance Curve: Automated vs. Mechanical**

## SURGE RELIEF RUN

Mechanically the surge relief run remains the same. It still consists of the relief valve, test ports, gauges and isolation valves. In terms of the nitrogen supply very little remains the same. Figure 8 shows a typical installation with an automated nitrogen loading system and above ground plenum. The nitrogen system is mounted on a concrete slab. The plenum is attitude insensitive making it easy to mount near the relief valve.

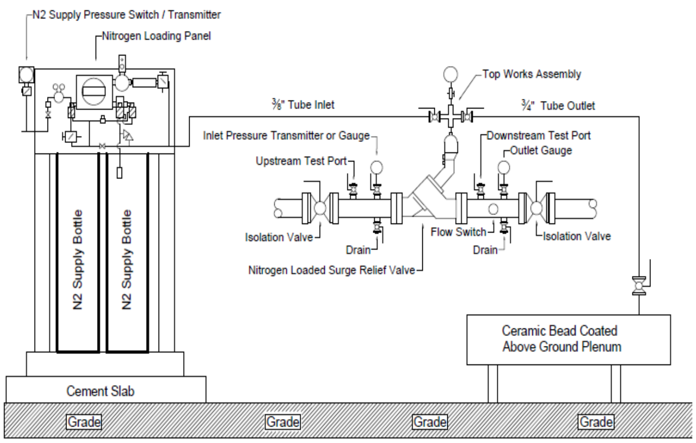


**Figure (8) Typical Surge Relief Instilation**

## ISSUES WITH INSTALLATION

With all the benefits that automation brings it cannot overcome the negative effects of a bad installation. Calculations should be performed for each application to insure the plenum has been sized properly. An undersized plenum can limit the valves speed of response and limit the stroke of the piston. Tube size from the valve to the plenum must be a minimum of 19mm (3/4 in.) to insure the relief valve can obtain the required speed of response. There can be no damage or obstructions in the nitrogen line leading from the valve to the plenum. If a DOT tank is used as the plenum, the brass valve should be removed. It has a 6mm (1/4 in.) orifice that can greatly restrict the flow of nitrogen. If the relief valve uses cover oil, care should be used in selecting one with the proper characteristics. The oil must be compatible with the relief valve's materials of construction and have a light viscosity that is stable over a wide temperature range. Using oil with a high viscosity can negatively affect the relief valve's speed of response.

## CONCLUSION

Automation has made its way into almost every aspect of today's pipeline. Tremendous advances have been made in everything from tank gauging to SCADA, yet somehow the critical function of surge relief has been overlooked. To a large extent, surge relief valves are being installed today using nitrogen loading systems that were developed decades ago. Set points continue to drift and the process of making manual corrections has gone on for so long it is considered a normal part of operating a pipeline. With a basic understanding of Gay-Lussac's Law and today's instrumentation it is possible to precisely correct for the changes in nitrogen pressure caused by thermal expansion and contraction in a plenum. Control is gained over the upper pressure limit of the pipeline allowing for improvement in both safety and efficiency. Alarms and manual adjustments are virtually eliminated along with the hidden costs of call outs that pipelines are no longer willing to pay.

## NOMENCLATURE

Plenum: A pressure vessel used to hold a nitrogen charge that is used in conjunction with a surge relief valve.

## ACKNOLEDGMENTS

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