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RELIEF VALVES 101

In this issue of the **COLD FRONT**, we present a basic overview of pressure relief valves – their purpose, theory of operation, and key selection criteria with an emphasis on industrial refrigeration applications. For those of you looking for a challenge, test your IQ by taking our safety relief systems test.

INTRODUCTION

Pressure relief devices are an engineering control designed to self-actuate and permit flow as a means of protecting system components during operating excursions that create overpressure. By permitting fluid to flow out of the protected component through a relief device, the pressure in the protected component is reduced; thereby, preventing its catastrophic failure. In order for pressure

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relief devices to be effective at achieving their intended purpose of protecting components and providing that protection in a safe manner, a properly engineered safety relief system is essential. A safety relief system is comprised of the necessary pressure relief devices, valves, fittings, piping, and treatment sub-systems arranged to direct the refrigerant vapor causing the overpressure to a safe terminal location.

Theory of Operation

The most widely used type of pressure relief valves in industrial refrigeration systems are the conventional relief valves as shown in Figure 1. The basic theory of operation for a conventional pressure relief valve is relatively simple; however, designing a pressure relief device to achieve a targeted set of performance criteria can be considerably more complicated. In this newsletter article, we will provide you with a basic understanding of how a conventional pressure relief valve functions with changes of state during both relieving and subsequent re-seating.

Relief Valve Opening

Figure 2 shows a simplified illustration of a conventional pressure relief valve in a static (non-relieving) state with the forces acting on the sealing disk just prior to lifting. A check of the forces acting on the disk reveals a spring force, F_{spring}, and two opposing pressure-related forces on the disk. The downward force on the disk, $F_{down,disk}$, arises due to pressure that exists at the outlet of the relief device (superimposed pressure, if present). The upward force on the disk, $F_{up,disk}$, is attributed to static pressure at the inlet of the valve created by the component being protected (in this case, a vessel). Note, the areas upon which the pressure upstream and

Upcoming Ammonia Courses

Engineering Safety Relief Systems
May 8-12, 2006 (2-4 pm CDT) **Anywhere**

Engineering Calculations for PSM & RMP
May 17-19, 2006 Madison, WI

Introduction to Ammonia Refrigeration
June 5-7, 2006 **Las Vegas, NV**

Ammonia Refrigeration System Safety
April 7-9, 2006 **Las Vegas, NV**

Design of NH_3 Refrigeration Systems for Peak Performance and Efficiency
September 11-15, 2006 Madison, WI

PHA for Ammonia Refrigeration Systems
September 27-29, 2006 Madison, WI

Introduction to Ammonia Refrigeration
October 4-6, 2006 Madison, WI

Intermediate Ammonia Refrigeration
December 6-8, 2006 Madison, WI

Process Safety Management Audits
January 10-12, 2007 Madison, WI

Ammonia Refrigeration: Uncovering Opportunities for Energy Efficiency Improvements
February 14-16, 2007 Madison, WI

Introduction to Ammonia Refrigeration
March 7-9, 2007 Madison, WI

See www.irc.wisc.edu/education/ for more information.

Noteworthy

- Are you interested in an analysis tool for headered safety relief vents? If you are, enroll today in the IRC's Engineering Safety Relief Systems web course scheduled for May 8-12, 2006. Those participants successfully completing the course will be granted access to the IRC's Safety Relief Vent Tool.
- Send items of note for next newsletter to Todd Jekel, tbjekel@wisc.edu.

Figure 1 Dual conventional pressure relief valves.

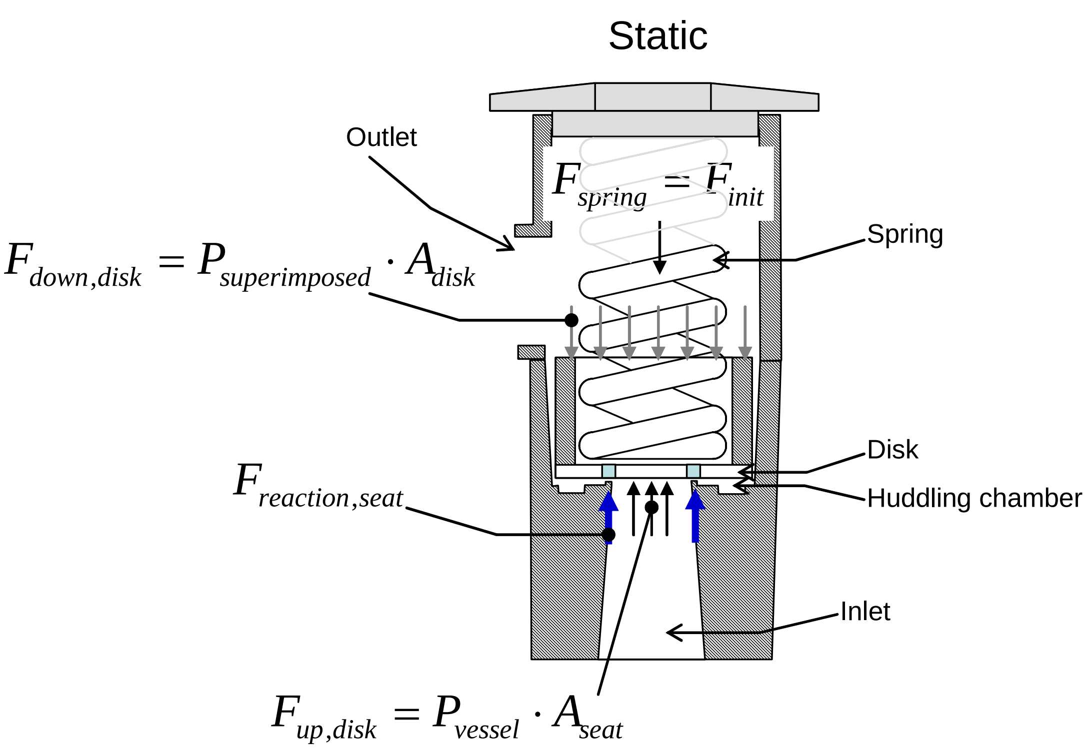


Figure 2 Conventional pressure relief valve in a **static** state.

downstream act when the disk is seated are different. The area of the seat, A_{seat}, is smaller than the disk area, A_{disk}.

$$P_{vessel} = \frac{P_{superimposed} \cdot A_{disk}}{A_{seat}} + \frac{F_{init}}{A_{seat}} + F_{reaction,seat}$$

As the upstream pressure increases and approaches that required to overcome the sum of the spring and downstream pressure forces, the reaction force at the valve seat decreases to zero; thereby, permitting gas from the upstream side of the relief device to leak across the seat. This condition is commonly referred to as "simmer" or "start to leak." The pressure at this condition corresponds to the valve's *set pressure*. With increasing upstream pressure, the opening force imposed on the bottom side of the seat will exceed the opposing closing forces and move the disk upward initiating a highly dynamic process. As the disk is lifted off the seat, gas flows into the "huddling chamber" where the upstream pressure now has a much greater area to act upon (essentially the entire cross-sectional area of the disk). The upward force that accompanies the change in area rapidly increases causing the valve to fully open; thereby, creating an audible "pop" action.

As the disk moves up off its seat allowing gas to flow through the valve, the downward forces dynamically change as well. First, the spring force will increase with the deflection in proportion to the spring constant. Second, the downstream pressure will begin to increase as the flow established through the valve and into the downstream vent line builds pressure in what is referred to as "*built-up backpressure*."

The dynamic forces that are acting on the disk are shown below in FIGURE 3. The upstream pressure will increase (possibly) to the maximum relieving pressure, P'_{vessel}. The increase in pressure from the relief valve set pressure (or start-to-leak pressure) to the upstream pressure required to achieve rated flow through the valve is defined as "*overpressure*." In order to fully lift the disk off its seat and achieve rated flow through the valve, some amount of *overpressure* is both permitted (by code) and required. *Overpressure* is generally expressed in pressure units directly or as a percentage of set pressure. *Overpressure* is the same as *accumulation* only

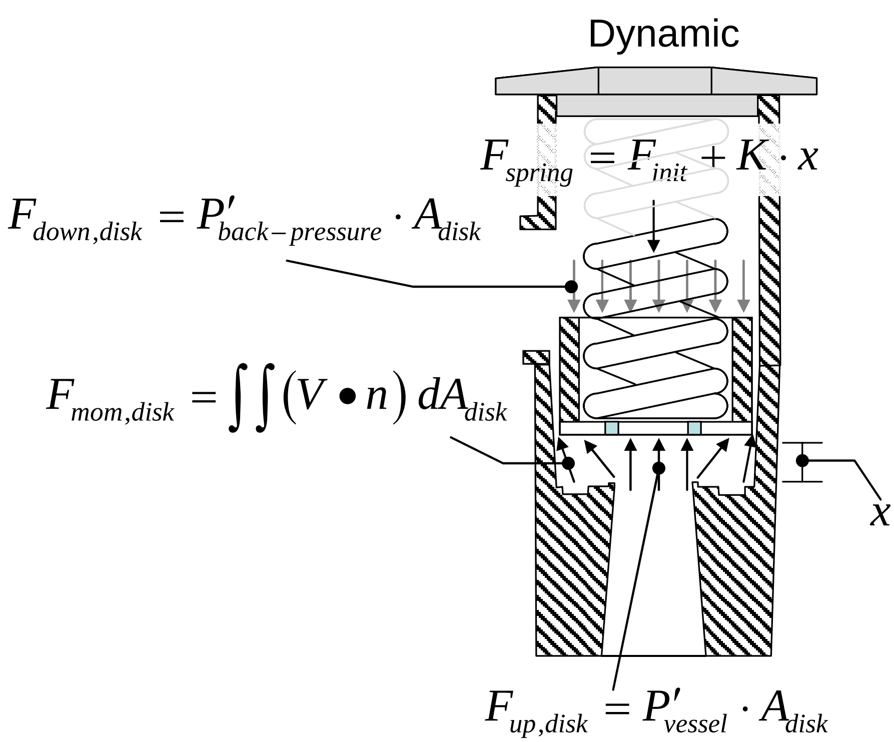


FIGURE 3 Conventional pressure relief valve in a **dynamic** state.

when the relieving device is set to open at the Maximum Allowable Working Pressure (MAWP) of the component being protected.

In its fully opened state, the upward force on the disk is the new upstream pressure multiplied by the cross-sectional area of the disk. In addition, the momentum created by the now flowing gas creates an additional reaction force by virtue of this flow, $F_{mom,disk}$. The downward forces include the built-up back pressure in the outlet multiplied by the disk area as well as the increased spring force as it moves through its deflection, x.

Relief Valve Closing

The relief valve will close when the forces on the downstream side of the disk exceed the forces on the upstream side of the disk. The two dominant and dynamic variables that change to allow the valve to close are decreasing upstream pressure, P'_{vessel}, and increasing back pressure, $P'_{backpressure}$. It is interesting to note that for the valve to close, the upstream pressure (vessel) must drop below the pressure needed to establish the initial movement of the disk in the upward direction (i.e. set pressure). This behavior arises due to a combination of the greater area available for the larger upstream pressure to act on the disk when moved off of its seat as well as the momentum force created by the gas flowing through the relief valve's orifice. As the upstream (vessel) pressure decreases, the flow through the valve decreases which causes the upward momentum force imposed on the disk generated by the gas flow to decrease. The difference in opening pressure (or *set pressure*) and closing pressure is defined as the valve's *blowdown*. Oftentimes, *blowdown* is expressed as a percentage of the valve's set pressure.

There are multiple factors that contribute to a drop in upstream pressure leading to valve closure. First, a decrease in the upstream pressure can result from a reduction in the vapor generation rate within the component being protected. Upstream pressure can also decrease as a result of excessive inlet pressure losses to the valve due to flow through inlet piping, 3-way valve, and fittings. Excessive inlet pressure loss is undesirable and can lead to valve chatter with the potential for subsequent catastrophic valve failure along with a compromised ability to protect the component it is connected to.

Another factor that will cause the relief valve to close is an increased level of built-up back pressure on the outlet side of the pressure relief valve. If the relief device vent line is inadequately sized, the pressure difference needed to expel the valve's flowing capacity will be high. This leads to an increasing pressure at the outlet of the relief device. If the pressure at the outlet of the relief valve is sufficiently high, the closing force due to back pressure, coupled with the closing force from the spring, causes the disk to fall and re-seat. Undersized relief vent lines allow conditions that enable such rapid opening and closing cycles leading to valve chatter.

In a normal relief scenario, the valve will begin to open when the inlet pressure is within 5% of its set pressure. The valve will be fully open and achieve rated flow at its *overpressure* (normally 10% of set pressure). When the conditions that created the increased pressure in the protected component are brought under control, the inlet pressure to the valve will decrease and the disk will close.

Pressure Relief Devices – Key Selection Criteria

Pressure relief valves selected for industrial refrigeration applications must be designed and constructed in accordance with the ASME Boiler and Pressure Vessel (B&PV) Code Section VIII Division 1 (UG-131). The capacities of the pressure relief devices are then certified by the National Board of Boiler and Pressure Vessel Inspectors. All pressure relief devices that meet the requirements of the National Board's *Pressure Relief Device Certificate Program* will carry the "NB" stamp as shown in Figure 4(a) below. All pressure relief valves that meet the ASME B&PV Code Section VIII Division 1 (UG-131) will carry the "UV" stamp as shown in Figure 4(b). Rupture disks meeting the requirements in Section VIII Division 1 (UG-131) will carry the "UD" stamp as shown in Figure 4(c). When rupture disks are used in series with pressure relief valves ("combination relief valve"), the assembly must meet the requirements prescribed in the ASME B&PV Code Section VIII Division 1 (UG-132). Additional requirements for safety relief valves, including methods of inspection and test, are published by ASME (Performance Test Code 25-2001), API, and AIChE (American Institute of Chemical Engineers).

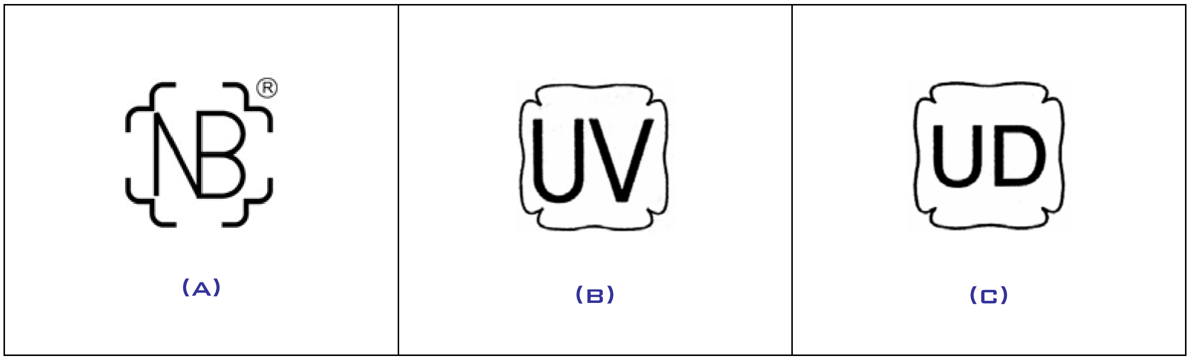


Figure 4: (A) National Board symbol stamped on pressure relief devices designed and manufactured in accordance with National Board-recognized practices.
(B) Official symbol stamp to denote compliance with the ASME B&PV Code for pressure relief valves.
(C) Official symbol for stamp to denote compliance with the ASME B&PV Code for rupture disks.

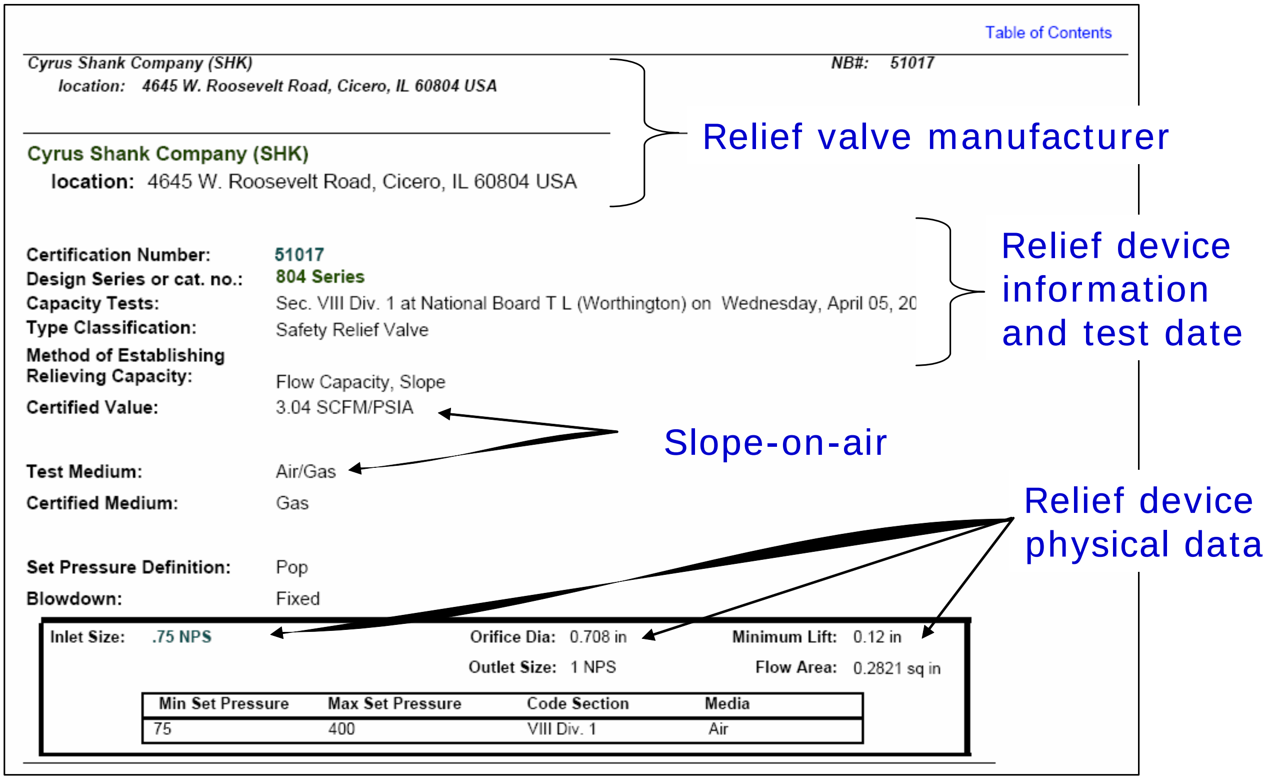
All of the relief devices receiving National Board approval are listed in publication NB-18 "National Board Pressure Relief Device Certifications" (National Board 2006). **Figure 5** is an excerpt from NB-18 showing the type of information available:

- *Relief valve manufacturer*
- *Relief device model number and classification*
- *Certified capacity* (expressed as a slope)
- *Test medium* (air)
- *Set pressure* – the value of increasing static pressure at which the pressure relief device displays one of the following operational characteristics: start-to-leak, pop, burst, or break (ASME PTC 25-2001)
- *Blowdown* – the difference between the actual popping pressure of the relief device and the actual reseating pressure expressed as a percentage of set pressure or in pressure units (ASME PTC 25-2001)
- *Relief device physical data* (inlet and outlet connection sizes, orifice diameter, flow area, and lift)
- *Pressure range*

Join the IRC!

It has been awhile since we have had a segment in our newsletter that encourages organizations to join the IRC. Over the past five years we have grown slowly and steadily. Our most recent new members are Tyson Foods & Jones Dairy Farm who joined us last year. **What can we do to make your company a new member this year?**

If you have questions on the benefits of IRC membership, please give us a call toll-free **(866) 635-4721** and we will be happy to assist you.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Cyrus Shank Company (SHK) NB#: 51017
location: 4645 W. Roosevelt Road, Cicero, IL 60804 USA

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Certification Number:	51017
Design Series or cat. no.:	804 Series
Capacity Tests:	Sec. VIII Div. 1 at National Board T L (Worthington) on Wednesday, April 05, 20
Type Classification:	Safety Relief Valve
Method of Establishing Relieving Capacity:	Flow Capacity, Slope
Certified Value:	3.04 SCFM/PSIA
Test Medium:	Air/Gas
Certified Medium:	Gas
Set Pressure Definition:	Pop
Blowdown:	Fixed

Inlet Size: .75 NPS Orifice Dia: 0.708 in Minimum Lift: 0.12 in
Outlet Size: 1 NPS Flow Area: 0.2821 sq in

Min Set Pressure	Max Set Pressure	Code Section	Media
75	400	VIII Div. 1	Air

FIGURE 5: Excerpt from National Board publication NB-18 illustrating the information provided on a typical pressure relief valve [National Board, 2006].

This particular valve has a ¾" inlet connection size and a 1" outlet connection size. It is available certified for a range of set pressures from 75 psig to 400 psig (usually, relief valve manufacturers provide them in 25 psig increments) with a rated capacity of 3.04 standard CFM per psia of pressure difference, i.e. the valve's *slope*. The valve's *slope* on air can be used to determine the relief capacity at any set pressure according to the following:

$$SCFM = slope_{\dot{V}} \cdot \left(P_{set} \cdot 1.1 + 14.7\ psia\right)$$

where

P_{set}	=	relief device set pressure, psig
$SCFM$	=	relief device capacity expressed in cubic feet of standard air per minute
$slope_{\dot{V}}$	=	slope on air expressed as SCFM of air per psia

The factor "1.1" accounts for the 10% overpressure allowed to achieve full flow through the valve.

Example:
Determine the capacity [in SCFM and lb_m/min of air] of a Cyrus Shank 804 series relief valve with a set pressure of 250 psig.

Solution:
Using the slope equation,

$$SCFM = 3.04 \frac{SCFM}{psia} \cdot (250 \cdot 1.1 + 14.7\ psia) = 880.6\ SCFM$$

Using the density for standard air at 60°F is 0.07633 lbm/ft^3, the capacity of the 804 valve becomes,

$$C = SCFM \cdot \rho_{air,60F} = 880.6 \frac{ft^3}{min} \cdot 0.07633 \frac{lb_m}{ft^3} = 67.2 \frac{lb_m}{min}$$

Both these calculated capacity values match the Cyrus Shank published capacity values. The National Board's NB-18 provides a wealth of information to not only confirm relief device certification but to provide needed information that facilitate the appropriate selection for a given application.

Conclusion

If you have any questions or comments on the information in this article, please contact Doug Reindl or Todd Jekel at the IRC (866) 635-4721.

References

ASME, Boiler and Pressure Vessel Code, Section VIII, Division I, 2004.

ASME, Pressure Relief Devices, Performance Test Code (PTC) 25-2001.

IRC, *Engineering Safety Relief Systems*, 2006. Available for purchase by clicking here.

National Board of Boiler and Pressure Vessel Inspectors, "Pressure Relief Device Certifications", www.nationalboard.org, April 3, 2006.

Test your Safety Relief System IQ

How would you rate your knowledge on safety relief systems? Do you understand the basic requirements for properly engineering a code-compliant relief vent system?

Test your knowledge of safety relief systems and compliance issues by evaluating the following example problem. Can you find any areas of this relief vent system not compliant with ASHRAE 15-2004? What about IIAR 2-1999?

Problem Statement

Four (4) components in the machinery room of an industrial refrigeration system using anhydrous ammonia are protected and piped into a common header: 1) a high-stage rotary screw compressor, 2) a high pressure receiver, 3) a pumped recirculator package, and 4) its oil pot. No combustible materials are present within 20 ft of any of the protected components. While Schedule 40 is allowed, the client requested the use of Schedule 80 piping for diameters less than 2" NPS.

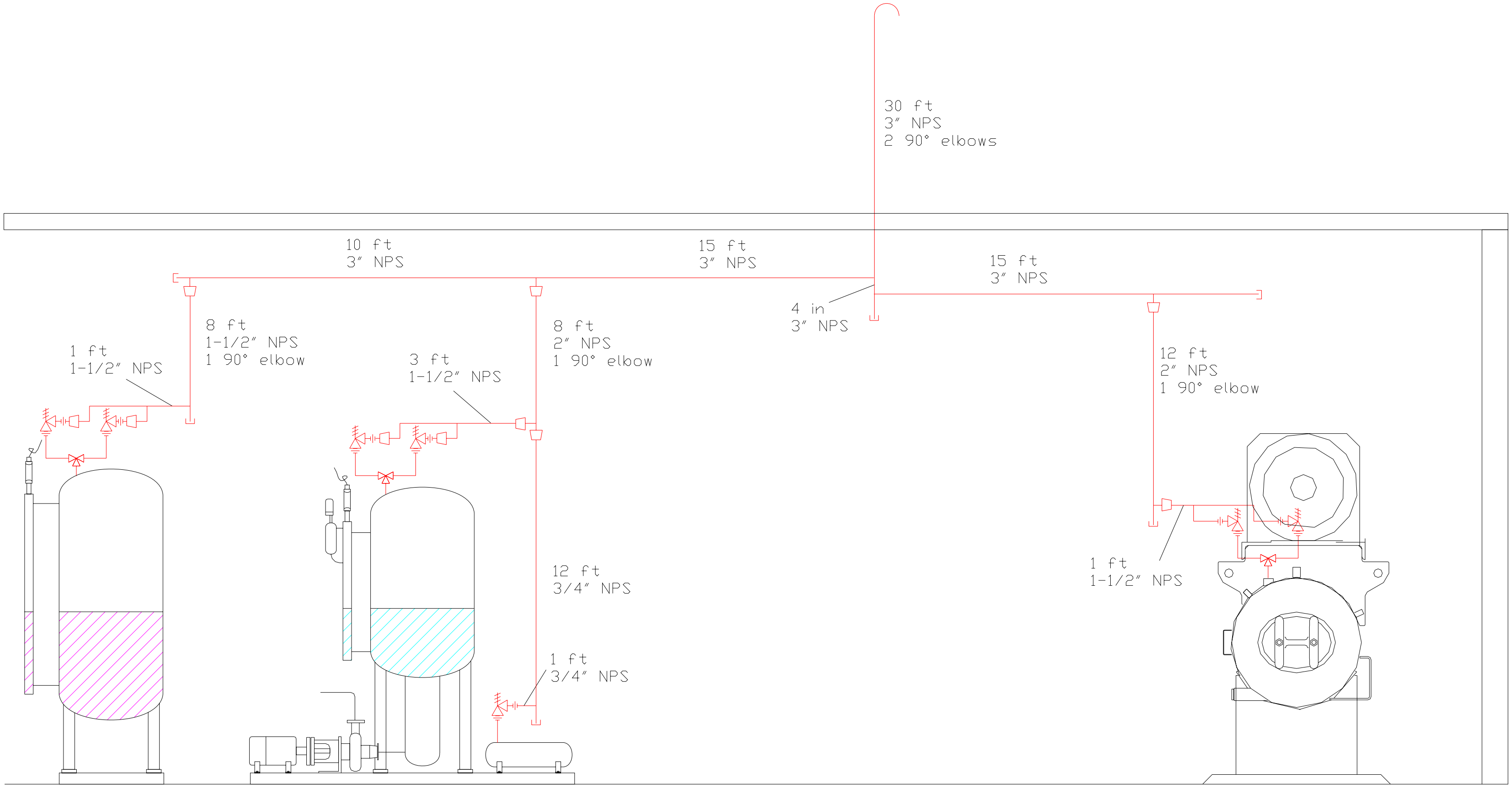
The following table shows the specifics of the protected components:

	HPR	LPR	LPR Oil Pot	RC-1
Component Type	Vessel	Vessel	Vessel	Rotary Screw Compressor
MAWP	300	150	300	300
D	72 in	72 in	6-⅝ in	36 in
L	151 in	185 in	36 in	14 ft 4 in
Relief Connection Size	1" NPS	1" NPS	½" NPS	1" NPS
Displacement Rate				3,380 cfm
Duty				High-stage

The pressure relief valves chosen to protect the components are shown in the following table:

	HPR	LPR	LPR Oil Pot	RC-1
Pressure Relief Valve Type	Conventional	Conventional	Conventional	Conventional
Assembly	Dual	Dual	Single	Dual
Manufacturer	Hansen Technologies	R/S	Cyrus Shank	Hansen Technologies
Model	H5633R	SRH3	800	H5604
Set Pressure	250	250	300	300
Inlet Connection	1" NPS	¾" NPS	½" NPS	1-¼" NPS
Outlet Connection	1-¼" NPS	1" NPS	¾" NPS	1-½" NPS

The header piping schematic is shown in the figure (not to scale) on the following page.



Is this system compliant with ASHRAE 15-2004 & IIAR 2-1999? If not, why not.

We will be covering questions and answers to situations like this in our upcoming course titled, **Engineering Safety Relief Systems**. You don't need to travel to participate because we will deliver it via the web during the week of **May 8-12** meeting daily from **2:00-4:00 pm Central**. A brochure for the course is available on or website, or by clicking here. **Enroll Today!**