System Description

The system described is similar to that depicted in Figure 1 Relief Valve Layout. A header feeds three relief valves in parallel. One lifts at 150 psig and flows 20,000 PPH, and the other two lift at 158 psig and flow 75,000 PPH apiece. Each relief valve is shown to exhaust into a vertical header that, in turn, discharges into a common 400 foot, 20 inch header that discharges into a 3 psig blowdown drum and flare.

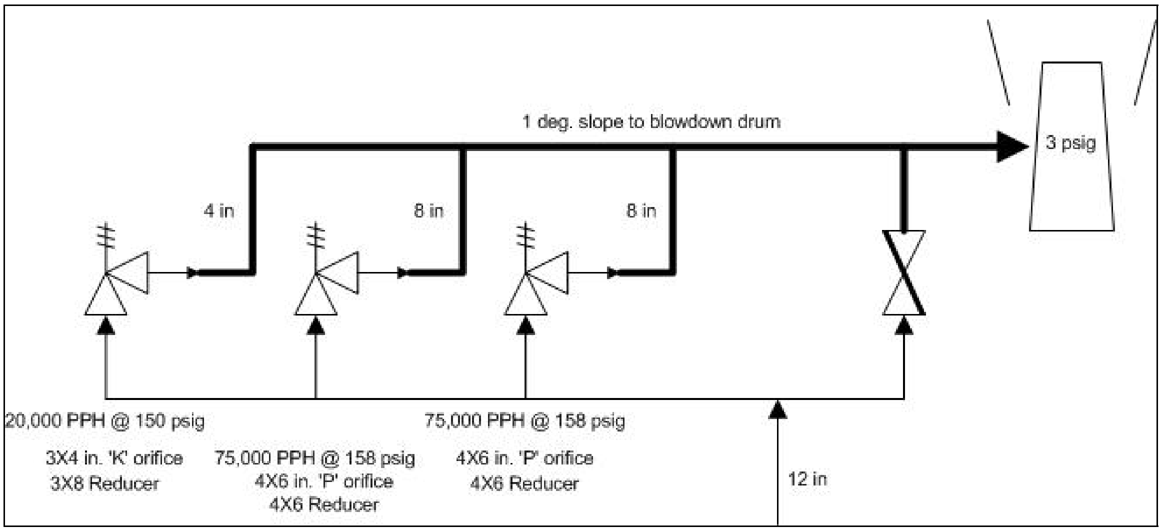

Figure 1 Relief Valve Layout

Relief Valve Construction

Generally, relief valves are designed similar to Figure 2 Relief Valve Cutaway and Forces. The plug is seated against opening pressure by 1) its weight, 2) a spring, and 3) backpressure. Relief valve internal pressure acts on a relatively small internal area. Preload on the spring plus the plug weight forces the plug against the seat. Generally, the spring preload is set with the outside pressure at one atmosphere, or 0 psig. A relatively large spring is required to get the necessary preload. This forces the plug to be manufactured with a comparatively large outside area to fit that spring.

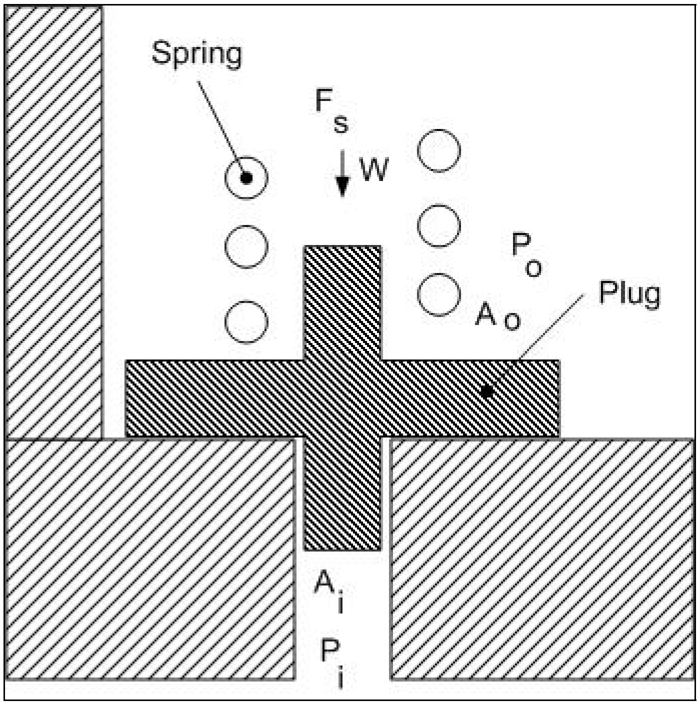

Figure 2 Relief Valve Cutaway and Forces

Forces Acting on the Plug

Figure 3 Plug Free Body Diagram shows the forces acting on the plug in a typical relief valve. The large area on the plug's outside (discharge) surface causes the relief valve to have a greater closing force if it is exposed to backpressure.

Each relief valve, as shown in Figure 1, discharges upwards against an unknown liquid head into a 3 psig header. The blowdown drum and flare backpressure of 3 psig will be on each relief valve discharge side because, using an electrical analogy, all relief valves are on the same pressure 'node' on a stagnant line. However, the condensed vapor will be at random levels in each relief valve discharge pipe. This backpressure and pressure head combination will require an internal pressure much greater than the bench set relief pressure to lift the plug.

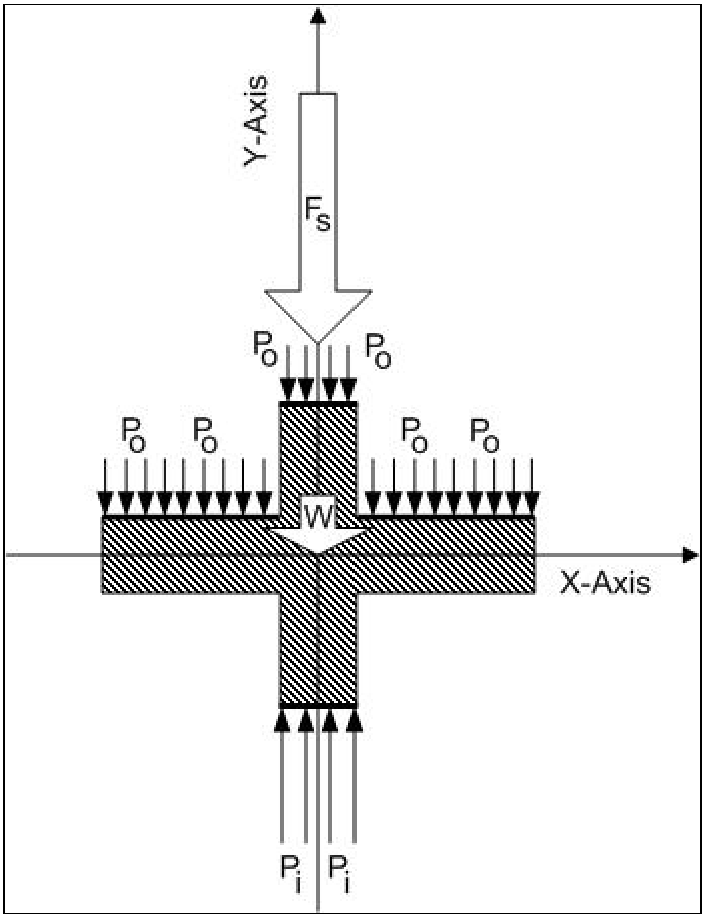

Figure 3 Plug Free Body Diagram

<u>Plug Lifting Force Analysis</u>

The pressure force acting on the outside surface of the plug is the outside pressure integrated over the effective plug outside area normal to the Y-Axis:

$$F_o = P_o \cdot A_o$$

The pressure force acting on the inside surface of the plug is the inside pressure integrated over the effective plug inside area normal to the Y-Axis:

$$F_i = P_i \cdot A_i$$

The sum of the forces acting on the plug are the inside plug pressure force minus the weight of the plug, minus the spring preload force, minus the outside plug pressure force:

$$\sum F = F_i - W - F_s - F_o$$

At lift, the inside pressure force on the plug is slightly greater than the forces on the outside of the plug plus the plug weight:

$$\sum F = 0+$$

Therefore:

$$F_i \geq W + F_s + F_o$$

Substituting pressures and areas for forces:

$$P_1 \cdot A_i \geq W + F_s + P_o \cdot A_o$$

The spring force, F_s, is generally set with the outside pressure, P_o, at 0 psig.

However, Figure 1 shows that each relief valve discharges into a vertical pipe that can contain varying depths of condensate pressure head. Additionally, the blowdown drum and flare provide a 3 psig backpressure on the plug outside area. Therefore:

$$P_o = h_D + P$$

Substituting this outside pressure on the plug, the force balance is:

$$P_1 \cdot A_i \geq W + F_s + \left(h_D + P\right) \cdot A_o$$

This analysis shows that outside pressure head and backpressure acting on the larger plug outside area can raise the operating lift pressure of a relief valve significantly.

<u>Conclusion</u>

The smaller relief valve lifts at a slightly lower internal pressure and discharges at a significantly lower flow than the larger relief valve. The 150 psig lift pressure of the smaller valve is a few pounds less than the 158 psig lift pressure of the larger valve. From an order of magnitude standpoint, the small and large size valves have substantially the same inside pressure when they lift. Because the smaller valve flows only about 27% of the flow of the larger valve at virtually the same lift pressure, the smaller valve inside plug area must be about 27% the larger valve inside plug area. Therefore, the smaller valve spring force will be roughly 27% of larger relief valve because the larger and smaller valves have virtually the same set pressure with the smaller valve having approximately 27% of the inside area of the larger valve.

Scenario A, Large and Small Relief Valves Use Identical Preload Springs:

This assumption is that the manufacturer purchases identical springs for both size valves and, therefore, both large and small relief valves have identical plug outside areas. The inside pressure is set by the spring preload on the smaller valve being about 27% of the larger valve.

Therefore the smaller valve has an outside plug area equal to the larger relief valve outside plug area so that the spring has sufficient area to seat and push against. This means that the outside plug area to inside plug area ratio is likely much larger for the smaller relief valve than the larger relief valve. The outside pressure head and backpressure will have a much greater effect to keep the smaller relief valve closed than the larger relief valve.

I suspect that the larger relief valves are opening before the smaller relief valve, but at a greater pressure than their bench settings, and possibly tossing some of their discharge heads of liquid into the discharge line of the smaller relief valve. The effect is to reduce the column pressure. Additionally reduced is the likelihood that the smaller relief valve will be able to lift against the discharge head and backpressure. Therefore, I suspect that the two larger valves are lifting, each creating 75,000+ PPH flow, and the 20,000 PPH of the smaller valve is not realized.

The larger relief valves flow into a backpressure that they were likely not designed to work against. That will reduce the larger relief valve flow rates. However, that same backpressure will act against the plug outside area and cause the lifts to be delayed until the column reaches a higher inside pressure. That higher inside pressure may increase the at-pressure relief valve flow rate above the published flow of 75,000 PPH at 158 psig.

Scenario B, The Large and Small Relief Valves Use Proportional Preload Springs:

This assumption is that the manufacturer purchases springs properly scaled for each size of valve. Therefore the outside to inside plug area ratios will be identical for the larger and smaller valves.

With equal outside to inside plug area ratios, the effect of backpressure and pressure head on the plug outside area is the same for the large and small relief valves. Therefore, the valve that would open first would be the one with the smallest discharge head pressure acting upon the plug outside area. Recall that the backpressure is the same on all valves because all relief valves are enjoying the same pressure node from the blowdown drum and flare unit.

When the first relief valve opens, it will tend to reduce pressure in the column and toss any discharge pressure head condensate out of its discharge header. This may splash into another relief valve vertical discharge pipe and increase that valve discharge pressure head, effectively raising the inside pressure required to lift that valve plug. In this scenario, it is unlikely that more than one relief valve would open. The valve coefficient for the open relief valve, coupled with the higher pressure required to open that relief valve against the backpressure and discharge head, may effectively increase the flow rate through the valve such that, by itself, it can sufficiently reduce the column pressure. However, this single valve flow rate may fall far short of the required three-valve flow rate. Should the open relief valve flow insufficiently to control pressure in the column, eventually the inside pressure for another relief valve would overcome the closing forces on its plug, and that valve would open. Hopefully that happens before reaching the failure pressure for the column.

Recommended Corrective Actions

Redesign the relief valve exhaust piping such that it drains any condensate, thereby removing the variable standing head acting on the outside plug area. This could be accomplished by having the relief valve discharge lines flow downward, and not form any traps, to an appropriate collection and disposal/flare unit. This could also be accomplished by installing a drain system to each relief valve discharge elbow that performs the same function. However, the drain piping and collection unit must be designed to accommodate the requisite relief pressure and flow should the relief valves actuate.

Remove the backpressure off of the outside plug area. Installing a separate, dedicated line to another collection unit, such as a blowdown drum and flare, or redirecting the relief valve discharge piping to a blowdown drum and flare without inherent pressure could remove this backpressure off of the outside plug area.

Perform the above two actions on the Liquid Reflux Tank relief valve. It appears to have similar design issues.

Installing relief valves with pilot valves or balanced bellows may also be options, depending on their design features, failure modes, and plant maintenance practices.

<u>Symbols</u>

A_i	Inside plug effective area
A_o	Outside plug effective area
F	The resultant sum of all forces acting on the plug
F_i	Inside plug area integrated pressure force
F_o	Outside plug area integrated pressure force
F_s	Spring force
h_D	Condensate head pressure acting on outside plug area
P	Process backpressure acting on outside plug area
P_i	Inside pressure
P_o	Outside pressure
W	Plug weight

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