Rethink your overpressure systems

Consider multiple relief valve designs

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Installing a single relief valve to handle the relieving rate of particular equipment during emergency conditions is a normal practice in the hydrocarbon processing industry. Relief valves are primarily sized using equations presented in API-520 sections 3.6 through 3.10[1] as appropriate for vapor, gases, liquid, steam or two-phase fluids. API-526[2] is used to select a standard orifice size, orifice designation, inlet and outlet flange sizes, material, pressure/temperature limits and other specifications. This preliminary relief valve sizing and selection is verified by manufacturers, using the valve's effective coefficient of discharge, back pressure correction factor and other parameters.

Installing multiple relief valves for a very large relief rate is also a well-known situation for all process designers. Some cases in which considering a multiple safety device is helpful or sometimes essential are introduced below. However, using multiple safety devices when it is not mandatory by code is usually approved by the project's owner.

Multiple-device installation may be considered when:

1. The calculated orifice area is greater than the maximum available standard orifice size. The magnitudes of some large releases may be greater than the largest single relief valve capacity that is commercially available, necessitating the use of two or more valves. The standard orifice size is illustrated in Table 1.

2. The particular orifice designation cannot be used due to its limitation on the inlet flange rating. Table 2, extracted from API-526, shows the limitation of each orifice designation on the inlet flange rating.

For example, if the calculated area for the particular spring-loaded relief valve is 10.1 in.^{2}, the selected orifice will be a Q designation with the effective area of 11.05 in.^{2}, (Table 1). If the required inlet flange rating, with respect to inlet pressure and temperature, is 900#, this additional requirement will conduct the valve selection to multiple smaller orifices. In this case, two orifices with a P designation (with the total area of 12.76 in.^{2}) may be appropriate.

The pressure temperature ranges for piping classes in Table 2 depend on orifice designation, nozzle size, body, bonnet and spring materials. An example, for spring loaded relief valves with an R or T designation, the maximum inlet flange ratings are 600# and 300#, respectively. If valve body, bonnet, and spring selected materials is carbon steel, the relief valve maximum pressure (set pressure) in relieving temperature range of –20°F to 450°F will be limited to 300 psig. This pressure is much lower than what is known as a piping class pressure limit for 600# or 300# ratings. For a pilot-operated valve with the same orifice designation, material and temperature range; the pressure limit is about 900 psig. For other orifice designations, materials and temperature ranges, the standard or vendor catalogue should be returned.

3. There is a significant difference between relieving rates of various applicable contingencies, to avoid a pressure relief device chattering at a lower relieving rate. The chattering likelihood is higher when the fluid quantity discharged is less than 25% maximum capacity of the relief valve. If relief loads of two emergency cases are 1,000 lb/hr and 10,000 lb/hr, it is advised to use two pressure relief valves: one with 1,000 lb/hr capacity and the other at 9,000 lb/hr minimum capacity. The lower capacity valve is usually

TABLE 1. Standard effective orifice areas[2]

Orifice designation	API standard orifice (cm^2)	(in.^{2})
D	0.710	0.110
E	1.265	0.196
F	1.981	0.307
G	3.245	0.503
H	5.065	0.785
J	8.303	1.287
K	11.854	1.838
L	18.406	2.853
M	23.226	3.60
N	28.000	4.34
P	41.161	6.38
Q	71.290	11.05
R	103.226	16.0
T	167.742	26.0

TABLE 2. Relief valve inlet flange rating limitations

Orifice designation	ANSI inlet flange rating: Spring-loaded relief valve	Pilot-operated relief valve
D	150,300,600,900,1500,2500	150,300,600,900,1500,2500
E	150,300,600,900,1500,2500	150,300,600,900,1500,2500
F	150,300,600,900,1500,2500	150,300,600,900,1500,2500
G	150,300,600,900,1500,2500	150,300,600,900,1500,2500
H	150,300,600,900,1500	150,300,600,900,1500,2500
J	150,300,600,900,1500	150,300,600,900,1500,2500*
K	150,300,600,900,1500	150,300,600,900,1500
L	150,300,600,900,1500	150,300,600,900,1500
M	150,300,600,900	150,300,600,900,1500
N	150,300,600,900	150,300,600,900,1500
P	150,300,600,900	150,300,600,900,1500
Q	150,300,600	150,300,600
R	150,300,600	150,300,600
T	150,300	150,300,600

*2,500# rating is only available for a 2 in. inlet flange size (2 J 3) not for 3 J 4.

set at a lower set pressure than a larger one. Another alternative is to use a single modulating-action pilot-operated relief valve.

4. API-520 section 3.5.3.4 calls for a supplemental device to provide relieving capacity for an additional hazard created by exposure to fire or other unexpected external heat sources. In fact, a supplemental device is used in addition to devices sized for non-fire (operating) contingencies.

When a fire contingency is the largest contingency and the next contingency is less than 1% of the fire relieving rate, multiple (supplemental) relief valves with staggered settings should always be used. However, when the fire contingency has a smaller load, it is generally ignored. This is because fire is a remote event, hence, there is no significant concern of chattering under the conditions.[3]

5. Multiple installations decrease the area overdesign of a pressure safety device in comparison with single installations. The relief valve orifice size is selected among standard sizes; hence, the selected orifice size is sometimes more than 70% larger than the required area. Accordingly, the rated (actual) relief valve flowrate is also 70% higher than the required flowrate. This unavoidable flowrate overdesign may not be acceptable, especially if:

- This flowrate is the design flow of flare network. Limiting overdesign will cause reduction in the flare system components size and cost
- Loss of valuable, toxic or noxious materials is a major issue
- Environmental aspect is not tolerated
- Process operation upset or equipment destruction occurs.

For example, installing an over-sized safety device on a tower may lead to top tray blow off, packing lifting and crushing, tower flooding or excessive liquid carry-over.

If the required orifice area is much smaller than the smallest available standard orifice, an alternative design to reduce the overdesign would be a nonstandard orifice. Another option is to use a rupture disc, especially when downtime for changing a rupture disc is tolerable. For instance, the required relief rate is often very low in pilot plants, but, if the calculated area is 0.02 in.^{2}, selecting the D designation will provide huge overdesign on the area. Considering this matter that production is not the major purpose of pilot plants, using a rupture disc is the ultimate solution. Rupture discs are usually available in nominal sizes of ½-in. or larger with some manufacturers supplying a ¼-in. as a nominal size.

The main focus of other techniques is to reduce the required orifice area to match it with the lower standard size so that the equipment safety is not compromised. A list of these techniques which are mainly applicable to fractionation columns is as follows:

- Increase the mechanical design pressure which makes the required relief area smaller (refer to relief valve sizing formulas) and also lowers the required relief rate in some cases when a temperature pinch happens.[4]
- Install a restricting orifice on a heat medium line to a column reboiler which restricts the hot stream flowrate in case the control valve is fully opened.
- Use fire-proof insulation, and elevate the vessel above fire height, place it below grade or earth covered. Providing adequate drainage and firefighting facilities are also effective ways for reducing the relief load and relief valve size in case of an external fire.
- Provide a turbine-driven spare for cooling water, reflux or feed pumps which is automatically put into service in case of an electric power failure.
- Use three or more (redundant) cutoff pressure switches with a voting system to remove the source of overpressure, for example, a heat input to the column.

TABLE 3. Relief valve sizing parameters for unfired pressure vessels

Installation type	Maximum set pressure, MAWP %	Maximum accumulated pressure (MAWP %) (Note 1)	
First valve	100	Non-fire cases:	116
Additional valve(s)	105 (Note 2)	Fire cases:	121
Supplemental valve	110		

Notes: (1) The maximum accumulated pressure is not more than 4 psi (28 kPa) when the MAWP is between 15 psig to 30 psig (103 kPa to 207 kPa).
(2) For set pressures below 150 psig, staggering the set pressure becomes impracticable because the difference between the set pressure tolerance of 3% and the value of 5% of the MAWP becomes too small.

TABLE 4. Relief valve sizing parameters for fired pressure vessel

Installation type	Maximum set pressure (MAWP %)	Maximum accumulated pressure (MAWP %)
First valve	100	106
Additional valve(s)	103	

6. The relative cost of a multiple valve installation is lower than a single installation. Above a certain size (typically a 12-in. discharge size), structural and piping engineering considerations, such as space-limitation and pipe-supporting difficulties associated with the large piping and valves, may result in a lower installed cost for two smaller relief valves. Refer to the standard, sections 4.3 and 4.4, to study the different types of forces and stresses transmitted to relief valves and the associated piping and minimum standard requirements for relief valve inlet and outlet pipe support.[5]

Another concern with large discharge pipes is fatigue failures resulting from acoustically induced vibration. This occurs in piping systems when upstream valves and/or restriction orifices have high gas flowrates and large pressure drops. The relief valves with downstream piping 10 in. or larger are potentially susceptible to mechanical failure due to this phenomenon. If the sound power level calculated from Eq. 1 for these relief valves exceeds 155 dB, the detailed screening of the piping downstream of the safety device is carried out to highlight any welded connections likely to be an acoustic fatigue failure risk. Based on the results of this analysis, some remedial actions, including changes in piping and support reinforcement, piping layout modifications and changing piping schedule as well as using more relief valves with smaller capacities are recommended.

$$L_w = 10 \log \left[W^2 \left(\frac{\Delta P}{P_1} \right)^{3.6} \left(\frac{T}{MW} \right)^{1.2} \right] + 55 \quad (1)$$

7. When the revamping of an existing plant is a design concern, the installation of a new relief valve next to the existing one may be the most cost-effective way. In this way, reviewing the existing system's configuration and problems accompanied with dismantling of existing facilities and new relief valve installation is removed. Moreover, it is possible to connect the new relief valve to the atmosphere (where acceptable) or a new closed disposal system instead of an existing disposal system. If it is decided to connect the new relief

valve to an existing disposal system, the ability of the existing system to handle the additional flowrate shall be thoroughly checked.

8. When the bare-tube water-heating surface of a boiler is more than 500 ft^2 (47 m^2) or when electric boiler input power is more than 1,100 kW, the boiler should be equipped with two or more relief valves. For a boiler with combined bare tube and an extended water-heating surface exceeding 500 ft^2 (47 m^2), two or more relief valves are required only if the boiler's design steam generation exceeds 4,000 lb/hr (1,800 kg/hr). The minimum required relieving capacity of each relief valve for all types of boilers shall not be less than the maximum designed steaming capacity, as determined by the manufacturer, and shall be based on the capacity of all fuel-burning equipment as limited by other boiler functions.[6]

Installation rules. The following criteria should be followed when dealing with designing a multiple safety device.

From a relief valve sizing point, according to ASME VIII Div. 1, relief valves installed on an unfired pressure vessel in multiple arrangements should have a staggered set pressure. This is so that the set pressure of the first device is equal to the maximum allowable working pressure (MAWP) of the vessel, and the set pressure of additional device(s) is 105% of the vessel's MAWP. If the supplemental device installation is justified, its set pressure shall not exceed 110% of the MAWP. Tables 3 and 4 summarize multiple device sizing rules for vessels designed according to ASME code for unfired and fired pressure vessel design.

From an installation point, the inlet piping to multiple relief valves in a common section for all relief valves must have a flow area that is at least equal to the combined inlet areas of the multiple relief valves connected to it. This is likely to cause a common header size too large than is really practicable. It is preferred to install all safety devices directly on or near the overpressure source. Like single installations, the total non-recoverable pressure loss between protected equipment and the relief valves, using the rated valve relief capacity, should not exceed 3% of the set pressure of the valve except for pilot-operated types.

Example. The example given in API-520, section 3.6.2.2, with higher flowrate is used with the following specifications:

- Required hydrocarbon vapor flow caused by an operational upset is 391,800 lb/hr
- The hydrocarbon mixture molecular weight, compressibility factor and C_p/C_v of 65.0, 0.84 and 1.09, respectively
- Relieving temperature of 627R
- Relief valve set at 75 psig, which is the equipment's design pressure
- Total back pressure of 14.7 psia.

Substituting the above data into equation 3.2 of API-520, gives 36.10 $in.^2$ as required orifice area, which is larger than the maximum available standard size in Table 1. Accordingly, several relief valves should be installed. Since the relief valve inlet nozzle flange rating is 150#, three reasonable options are envisaged for this case:

1. Two T-type orifices with a total area of 52.0 (26 + 26).
2. One T-type and one R-type orifice with a total area of 42.0 (26 + 16).
3. One R-type and two Q-type orifices with a total area of 38.10 (16 + 11.05 + 11.05).

The author prefers the second choice due to relatively lower overdesign on the orifice area as well as a minimum number of safety devices. Keep in mind, that better fitting may be possible with numerous smaller orifices, but is not practical. It is better to set the smaller valve at MAWP and the larger one at 105% of MAWP. **HP**

LITERATURE CITED

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NOMENCLATURE

L_w	Sound power level, dB
MW	Gas molecular weight
W	Relief rate, kg/hr
P_1	Upstream pressure, bara
ΔP	Pressure drop, bar
T	Gas temperature, K

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