



SHAPA TECHNICAL PAPER 10 (Revised)

SIZING OF EXPLOSION RELIEF VENTS

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This article is written such that it creates a better understanding on the how explosion vent relief sizing should be carried out; it will explain the formula used and show some examples. *It is not intended to be a document that can be used for sizing as it is not possible to cover all applications and limitations and as such some limitations have been omitted.* It is advised that the reader seeks specialist advice or uses certified software for the sizing process.

Introduction:

This article is written such that it creates a better understanding on the how explosion vent relief sizing should be carried out; it will explain the formula used and show some examples. *It is not intended to be a document that can be used for sizing as it is not possible to cover all applications and limitations and as such some limitations have been omitted.* It is advised that the reader seeks specialist advice or uses certified software for the sizing, which also incorporates specific details of venting efficiencies which should not be overlooked as these can greatly influence the relief vent area required as will be demonstrated later.

An explosion results from the oxidisation of a substance which release its energy in the form of heat when the chemical bonds break. The heat when enclosed in a sealed vessel creates pressure (ideal gas law e.g. $P.V = n.R.T$) and if the pressure exceeds the strength of the enclosure the stored energy (pressure) is released – this is what is *seen externally* as a direct consequence of a dust explosion. The sudden release of pressure can, if present disturb surrounding dust deposits within the building which in turn lead to catastrophic secondary explosions.

The amount of fuel and oxidant defines the amount and rate of heat generated. This information is important for people designing process protection as it is assumed that the explosion occurs under the worst case conditions. It should be noted that there are very few occasions where this basic assumption can be altered but this is discussed under “Special Dust Cloud Conditions”

Background:

Explosion venting of process equipment is one of the most frequently used methods to mitigate explosion risks in industry. The principle has been used for many years and, if applied correctly, works very well. This paper will look at the recent history of explosion venting and approach why some of the standards differ from one another along with guidance for designers and engineers on how to use and implement the standards.

The author is often asked the question; *when I ask two people to size a vent to the latest standard why do I end up with two different answers and what is correct?* The reason for this is will hopefully become clear during the article; if not then please contact me.

The foundations of the most widely used vent sizing methods can be traced back to “The Nomograph Method” which was created by Verein Deutscher Ingenieure (VDI) in 1979 and then adopted in the USA 1988 by the National Fire Protection Association (NFPA). This method is derived from large scale testing by Donat (1971) and Bartknecht (1978) along with some theoretical work by Heinrich (1974). This involved the product characterisation for rate of pressure rise and maximum pressure in a 1m^3 test vessel. This product characterisation is known as K_{st} (K = constant and “ST” is from the German for dust, Staub) for the rate of pressure rise and P_{max} for the *maximum* pressure generated. A third reference was also introduced then and this was P_{stat} the *static* opening pressure of the relief vent.

Over the years various modifications to the nomographs were made mainly by extending the range of applicability and eventually formula where produced in VDI 3673. It is the same basic formula that was used in VDI 3673, NFPA 68 and EN14491 up until 2007 when NFPA 68 decided to use a total different method. However the formula used the EN14491: 2012 is the same basic formula that VDI 3673 uses. It should also be noted that in circa 1989 the Institute of Chemical Engineers (ICHEM^F) published nomographs and these are still available to be used in the UK where it can be proven it

provides a higher level of safety or there is a case that "state of the Art" can be demonstrated in preference to using EN14491:2012.

The main "advances" have really been in understanding how to apply the formula to a specific application and this is where recently the standards specifically detail certain elements like;

- What volume to use
 - *What volume is explosible and what is non-explosible. The larger the volume the more vent area will be required or the higher the resultant explosion pressure (P_{Pred}) will be.*
- How to take into account the vessel geometry e.g. length to diameter ratio (L/D)
 - *As the fireball grows it expands in three dimensions and the pressure generated is distributed/equalized throughout the volume. If the fireball cannot expand in three dimensions (due to vessel geometry) then it will expand the easiest way it can, however because this will result in a greater surface area of flame (spherical flame is the optimum surface area to volume ratio) more heat is generated at a given point in time, this in turn increases the pressure rise. Hence the reason for vessel geometry being an important factor.*
- The influence of vent location.
 - *This is also associated with the vessel L/D and sometimes referred to as flame length. If the fireball does not have far to travel before it reaches the vent then it has less time to generate heat inside the vessel. Conversely the greater the distance the flame has to travel to reach the vent the larger the fireball will grow (increase in surface area of flame) and the more influential the L/D becomes. Locating vents at strategic locations can often reduce the L/D and effective flame length and reduce the vent area requirements.*

It is often these elements that create the difference in the vent sizing from one person to another, hence the standards detailing precisely how to calculate them.

The use of computers for Explosion Vent Sizing:

As noted above, the European Standard and the German (VDI) standard use the same formula however there are a number of computer programs available that will size an explosion relief vent and they will (should) result in the same answer *providing* the same criteria (elements) are used. One of the major problems found is that the incorrect criteria are used e.g. incorrect volume, incorrect L/D ratio, incorrect vent location etc. To ensure that this is controlled it is vital that the sizing tool is validated by a third party, preferably a Notified Body, as this will ensure that for a given application the correct volume, L/D, vent location etc. are used for the calculation.

What is the Formula & how does it work?

$$\text{Vent Area (m}^2\text{), } A = B (1 + C \times \log L/D)$$

Where,

$$B = [3.264 \times 10^{-5} \times P_{max} \times K_{St} \times P_{red,max}^{0.569} + 0.27 \times (P_{stat} - 0.1) \times P_{red,max}^{0.5}] \times V^{0.753}$$

$$C = (-4.305 \times \log P_{red,max} + 0.758)$$

The above equations are only valid for;

Enclosure volume (V): $0.1 \text{ m}^3 < V < 10,000 \text{ m}^3$

Static Activation Pressure (P_{stat}): $0.1 \text{ bar.g} < P_{\text{stat}} < 1 \text{ bar.g}$ (for $P_{\text{stat}} < 0.1 \text{ bar.g}$ use 0.1 bar.g).

Maximum Reduced Explosion Pressure ($P_{\text{red,max}}$): $0.1 \text{ Bar.g} < P_{\text{red,max}} < 2.0 \text{ bar.g}$

$P_{\text{red,max}}$ shall be at least equal to $P_{\text{stat}} + 2 \times$ vent burst pressure tolerance

K_{st} & max explosion pressure (P_{max}):

$5 \text{ bar} < P_{\text{max}} < 10 \text{ bar}$ for a parameter of $10 \text{ bar.m.s}^{-1} < K_{\text{st}} < 300 \text{ bar.m.s}^{-1}$

$5 \text{ bar} < P_{\text{max}} < 12 \text{ bar}$ for a parameter of $300 \text{ bar.m.s}^{-1} < K_{\text{st}} < 800 \text{ bar.m.s}^{-1}$

Initial Process Conditions at the point of Ignition:

- Absolute pressure : $< 110 \text{ kPa}$
- Oxygen concentration: $< 21\%$
- Temperature between: -20°C and $+60^\circ\text{C}$ (can be used outside these limits if correction factors are applied).
- Length/Diameter ratio (L/D): $1 < L/D < 20$

The above equations can only be used where appropriate measures (explosion isolation) have been taken to prevent flame propagation between interconnected enclosures to prevent pressure piling and flame jet ignition; these have dramatic influence to explosion characteristics such that they can be magnitudes more severe.

For values outside the above criteria venting may still be possible; seek professional advice.

From the above formula you will note the reference to the volume (V) and L/D. These are fundamental in the calculation and therefore the standards control these in the following ways:

The volume is based on the volume that contains the hazardous atmosphere with the longest flame path and is referred to the effective Volume (V_{eff}).

The L/D is calculated based on firstly the geometric shape of the vessel combined with the vent location, such that the diameter is based on the effective diameter using the flame path height and V_{eff} ; so for instance two examples below will give different vent area requirements based on the different location of the vent simply because the L/D ratio is different.

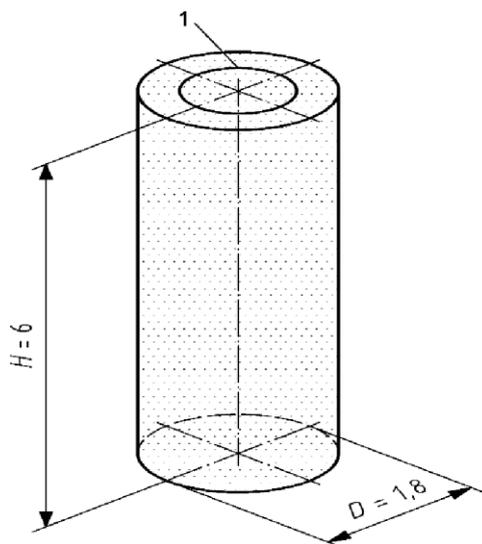


Figure 1 – Cylindrical Enclosure – Top Vent

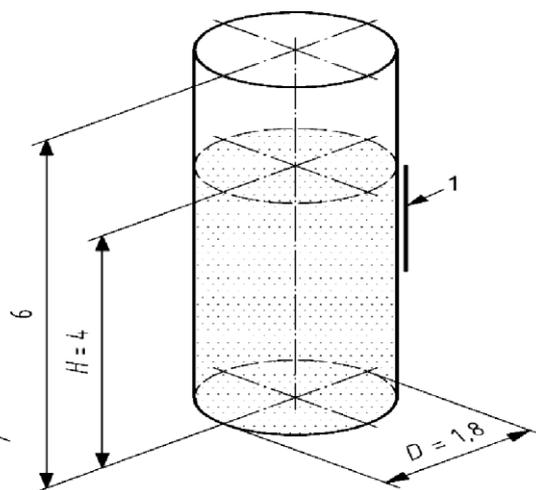


Figure 2 – Cylindrical Enclosure – side

$$V_{\text{eff}} = H \cdot 7C \cdot r^2 = 15.27\text{m}^3$$

$$A_{\text{eff}} = \frac{V_{\text{eff}}}{H} = 2.545\text{m}^2$$

$$D_{\text{eff}} = 2 \cdot \sqrt{(A_{\text{eff}} / 7C)} = 1.8\text{mts}$$

$$L/D = H/D_{\text{eff}} = 3.33$$

Vent Area based (Volume = 15.27 m³, P_{red, max} = 0.5barg, K_{st} 150, P_{max} 8.0barg is:

$$A = 0.94\text{m}^2$$

$$V_{\text{eff}} = H \cdot 7C \cdot r^2 = 10.17\text{m}^3$$

$$A_{\text{eff}} = \frac{V_{\text{eff}}}{H} = 2.545\text{m}^2$$

$$D_{\text{eff}} = 2 \cdot \sqrt{(A_{\text{eff}} / 7C)} = 1.8\text{mts}$$

$$L/D = H/D_{\text{eff}} = 2.22$$

It is important to note that the L/D may be higher in the horizontal plane e.g. it is not always vertical and in such instances it is advisable to seek further advice from a suitably qualified person with the relevant experience

Venting Efficiency

The formulae are based on experimental test data that did not use proprietary explosion vents, typically they used kitchen foil or lightweight plastic sheeting. Even though proprietary explosion vents are considered to be lightweight they still have a mass. This mass dramatically affects the vent performance and this characteristic must be used when calculating the vent area. Explosion vents must be certified using EN 14797 – Explosion Venting Devices.

EN 14797 describes how the specific mass affects the venting efficiency as follows:

- 1) For devices <0.5kg/m² then the efficiency can be assumed to be 100%.
- 2) For devices 0.5kg/m² to 10kg/m² the efficiency is 100%, provided:
 - a. $A/v^{0.753} < 0.07$ (refer to EN14494). If >0.07 then the efficiency MUST be determined by testing – the efficiency will vary depending on the $A/v^{0.753}$. More often than not it will be the case that the venting efficiency must be taken into account.
- 3) For Devices >10kg/m² the device must be tested against a device of <0.5kg/m² to determine its efficiency.

Therefore it is not possible to say that an explosion vent panel is 100% effective in all cases.

The calculated *Required Area* (A) is based on an assumed 100% venting efficiency and therefore if the vent efficiency after calculation/testing is less than the assumed 100% efficiency the actual efficiency needs to be applied to the *Required Area* (A) to give the *Geometric Vent* (A_v).

Using the example above (A) =0.94m² using a vent of **90% efficiency** will require a vent area (A_v) 0.94m²/0.9 = 1.045m²

The difference in the *Required Area* (A) and the *Geometric Area* (A_v) may not appear to be significant however the influence it can have on the Reduce Explosion Pressure (P_{red}) often is significant.

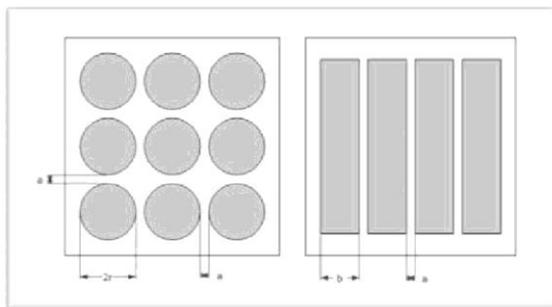
Application to different Type of Vessels

As discussed at the start, the volume and L/D dramatically influence the vent area requirements. From actual tests conducted on certain types of process vessels it is clear that credit can be taken for volumes in which no dust (explosible atmosphere) is expected. This is particularly useful when considering filters.

The protected volume of filters is therefore carefully controlled within EN 14994 in a similar way to NFPA 68:2007 such that the filter bag volumes (clean) space between the filter bags etc. can be removed from the protected volume as follows:

The size and spacing of the bags will determine how much volume you can deduct. If the space between the bags is greater than their radius, only the internal bag volumes can be deducted. However if the spacing between the bags is smaller, the total volume enveloped by the bags can be deducted. (i.e. bag volume + the volume in the spacing between the bags.). See the following table.

	Remove filter bags Only	Remove total volume above bottom of Filter bags
$a > r$ OR $a > b$	YES	
$a \leq b$ OR $a \leq r$		YES

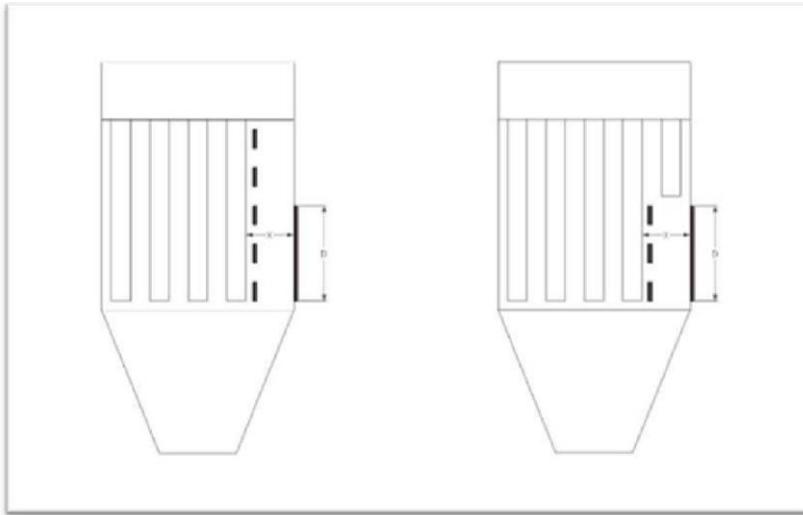


Internal obstructions of the vent area:

During an explosion event the pressure generated will be relieved through the explosion vent. This may result in any free-hanging filter elements being dragged with the pressure wave into the vent opening which will have a negative effect on the efficacy of the venting process. Where possible the vent should be located below the filter elements. When this is not possible the elements in front of the vents must be removed or retained (see diagram), to ensure an undisturbed venting process.

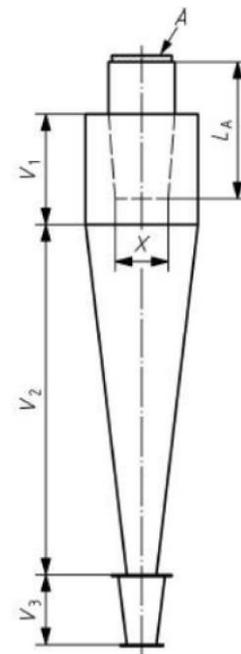
It should be noted that in addition to the direct effect the filter elements have on impeding the venting process, general obstructions inside the vessel in can disrupt the flame front thus creating

higher level of flame surface area thus more heat leading to increase in pressure, than would otherwise be expected. Therefore in vessels which have separate compartments/divisions or large obstructions it is advisable to seek advice from a suitably qualified person.



Cyclones

Cyclones require some special attention due to the difficulty of locating the explosion vent. This is due to internal wall surfaces being critical to the efficient operation of the cyclone. If a panel was simply installed on the wall the cyclone may fail to create the required cyclonic air flow. Therefore the vents are typically installed on the top of the immersion pipe (the hat). This generates its own issues as this pipe is effectively an internal vent duct, which has a negative effect on the explosion venting. Therefore the dimensions of the immersion pipe (shown in the diagram) need to be accounted for and treated as a vent duct - details of this calculation are in section 4.0. Any taper in the bottom of the pipe must also be accounted for.



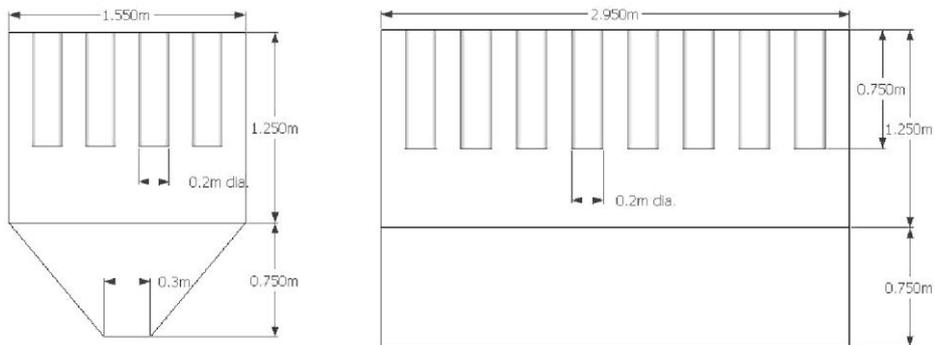
Special Dust Cloud Conditions

Silos, due to their large volume and method of filling etc. do not always have a homogenous explosible mixture throughout the complete volume. It is therefore possible to take this into account and EN14994:2012 provides a method of applying this when the silos are fed by gravity or pneumatically filled. Before implementing and using this as a basis of safety it must be first confirmed that all parameters are met and that inherent dust deposits cannot participate in the explosion – generally this should be undertaken under specialist advice.

Worked Example:

Dust Filter

$P_{red} = 0.35$, $K_{st} = 170$, $P_{max} = 8.5 \text{ barg}$, $P_{stat} = 100 \text{ mbar.g}$.



Solution

1. Calculate the total volume:

$$\begin{aligned}\text{Top Section} &= 1.55 \times 2.95 \times 1.25 = 5.72\text{m}^3 \\ \text{Bottom section} &= (2 \times (0.5 \times (0.625 \times 0.75)) + (0.3 \times 0.75)) \times 2.95 = 2.05\text{m}^3 \\ \text{Total volume} &= 2.05 + 5.72 = \mathbf{7.77\text{m}^3}\end{aligned}$$

2. Deduct the bag volume:

As the distance between the bags is greater than the bag radius ($a > r$), we can only deduct the bag volume from the total:

$$\begin{aligned}\text{Bag Volume} &= 32 \times ((\pi \times 0.1^2) \times 0.75) = 0.75\text{m}^3 \\ \text{Total Dirty Volume} &= 7.77 - 0.75 = \mathbf{7.02\text{m}^3}\end{aligned}$$

3. Calculate the L/D factor

$$\begin{aligned}\text{Calculate H} &= 0.75 \text{ (assuming vents will be installed underneath the lower bag level along the 2.95mt length)} \\ \text{Flame Volume } \mathbf{V_{eff}} &= 2.95 \times 1.55 \times 0.5 + 1/3(\text{hopper volume}) = 2.97\text{m}^3 \\ \text{Flame Area } \mathbf{A_{eff}} &= \mathbf{V_{eff}} / \mathbf{H} = 2.97/0.75 = 3.96 \text{ m}^2 \\ \text{Eff. Diameter } \mathbf{D_{eff}} &= 2 \times \sqrt{(A_{eff} / \pi)} = 2.24 \\ \text{Calculate L/D} &= \mathbf{H} / \mathbf{D_{eff}} = 0.75 / 2.24 = 0.33 \text{ (L/D} < 1 \text{ so use } \mathbf{L/D = 1})\end{aligned}$$

4. Calculate the vent area

$$\text{Vent Area, } \mathbf{A} = B (1 + C \times \log L/D) :$$

$$B = [3.264 \times 10^{-5} \times P_{max} \times K_{St} \times P_{red,max}^{0.569} + 0.27 \times (P_{stat} - 0.1) \times P_{red,max}^{0.5}] \times V^{0.753} \\ B = [3.264 \times 10^{-5} \times 8.5 \times 170 \times 0.35^{0.569} + 0.27 \times (0.1 - 0.1) \times 0.35^{0.5}] \times 7.020.753$$

$$\mathbf{B = 0.3718}$$

$$C = (-4.305 \times \log P_{red,max} + 0.758)$$

$$C = (-4.305 \times \log 0.35 + 0.758)$$

$$\mathbf{C = 2.7208}$$

$$\mathbf{A} = B (1 + C \times \log L/D)$$

$$\mathbf{A} = 0.3718 (1 + 2.7208 \times \log 1)$$

$$\mathbf{A = 0.3718\text{m}^2}$$

With a venting efficiency of 85% this gives an actual *Geometric Area* ($\mathbf{A_v}$) = 0.44m².

However if the vents are located on the end panel (1.55mts x 1.25mts) the area would be calculated as follows:

3b. Calculate the L/D factor

$$\begin{aligned}\text{Calculate H} &= 2.95 \\ \text{Flame Volume } \mathbf{V_{eff}} &= 2.95 \times 1.55 \times 0.5 + 1/3(\text{hopper volume}) = 2.97\text{m}^3 \\ \text{Flame Area } \mathbf{A_{eff}} &= \mathbf{V_{eff}} / \mathbf{H} = 2.97/0.75 = 3.96 \text{ m}^2 \\ \text{Eff. Diameter } \mathbf{D_{eff}} &= 2 \times \sqrt{(A_{eff} / \pi)} = 2.24 \\ \text{Calculate L/D} &= \mathbf{H} / \mathbf{D_{eff}} = 0.75 / 2.24 = 0.33 \text{ (L/D} < 1 \text{ so use } \mathbf{L/D = 1})\end{aligned}$$

Influence of explosion vent ducts.

Explosion vent ducts influence the $P_{red,max}$ in two ways. Firstly they offer a restriction to the flow of hot gases and unburnt fuel released through the vent – in the same way a pipe will restrict flow of water if the bore is reduced. However the second reason they influence the $P_{red,max}$ prevents the use of oversizing the duct to compensate for the former effect. The unburnt fuel which is forced into the duct when the explosion vent opens ignites when the flame catches up with this fuel and creates a secondary explosion (high pressure/back pressure) inside the duct, which in turns slows the explosion venting process down in the main, protected vessel – increasing the duct diameter will enhance this effect and thus is not advised. The increase in pressure created by the acceptable duct design given in the standards can be calculated from the following equation.

$$P'_{red,max} = P_{red,max} \times (1 + 1.73 \times (A \times V^{-0.753})^{1.6} \times l)$$

Where;

l = the vent duct length in meters (m)

V = Vessel volume in cubic meters (m^3)

A = Required vent area without the vent duct in square meters (m^2)

$P'_{red,max}$ = the maximum reduced pressure in the vessel with the vent duct in bar.g

The vent duct should be designed so that it is not larger than the explosion vent and it must be straight or have a minimum curvature to radius >2 and angle no more than 20° from the horizontal.

Important note:

The data used for developing the effect of explosion vent ducts is limited to small test vessels. Although EN14491:2012 specifies a maximum volume limit of $10,000m^3$ great care should be taken when designing explosion vents ducts for the protection of volume greater than $100m^3$. For this reason British Standards Institute (BSI) have added a forward to BSI EN 14491:2012.

External Effects

The relief of pressure from a process vessel into the atmosphere will firstly create a local increase in pressure external to the vent and a fireball. Both of these can be characterised using formula within the EN standard.

There are a number of restrictions to these predictions and as such it is recommended that specialist advice be sought.