

WinVent



HANDBOOK

by Richard Siwek and Christoph Cesana
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Warranty, Development Team

The information contained in this **Handbook** is essentially based on the European Standards EN 14491-2012 “Dust explosion venting protective systems”, EN 14994-2007 “Gas explosion venting protective systems”, Guideline VDI-3673, Part 1-2002 “Pressure release of dust explosions” and the book of Wolfgang Bartknecht “Explosionsschutz, Grundlagen und Anwendungen (Explosion Protection, basics and application, only in German)”, 1993 and is subject to change without prior notice. Cesana AG and Fire**Ex** Consultant GmbH hereby state that they will accept no liability whatsoever for consequences arising from such changes.

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1 Preliminary Remarks

The present **Handbook** describes explosion venting as one of the possible measures to mitigate the effects of explosions. The **Handbook** aids in the selection and the design of pressure venting devices. The specified method for the selection and the design of such devices is generally applicable. Additional explosion isolation systems must be incorporated because European Standards mandate them. "Explosion pressure venting" is a protective measure for equipment in which combustible dusts, flammable gases or hybrid mixtures is processed. Special regulations apply for explosives, which are covered by an "Explosives Act".

Explosion venting should not be used if products or compounds are released which are classified as very poisonous, poisonous, corrosive, irritant, teratogenic as per "CLP/GHS" /7/.

For environmental and production related reasons it is very important to avoid ignition sources, irrespective of the applied explosion venting. Thus, the probability of the existence of one of the prerequisites for an explosion can be reduced.

The **Handbook** is meant to be a tool for the engineer who is faced with the task of venting the equipment within his plant. The information contained in this **Handbook** is based on internationally accepted standards, guidelines and literatures e.g., European Standards EN 14491-2012 "Dust explosion venting protective systems"/1/, EN 14994-2007 "Gas explosion venting protective systems"/2/, EN 14797-2006 "Explosion venting devices /3/, VDI-3673, Part 1-2002 "Pressure release of dust explosions" /4/, the book of Wolfgang Bartknecht "Explosionsschutz, Grundlagen und Anwendungen (Explosion Protection, basics and application, only in German)", 1993 /5/ and EN 14460-2018: Explosion resistant equipment /6/.

When applying WinVent a profound knowledge about explosion venting is necessary.

Due to the great variety of conditions in industry, it is impossible to cover all applications. However, the thorough treatment of the topic should allow the design engineer to arrive at a favourable solution for all cases.

*It is permissible to deviate from the vent areas given in this **Handbook** provided the same level of safety could be guaranteed and documented through actual tests.*

Equipment cannot be protected through explosion venting from the hazardous consequences of a detonation.

To get a clear and simple representation in the WinVent program and the **Handbook** the abbreviations and symbols may deviate from those given in the different European Standards. The selection of the abbreviations and symbols is such that they best conform to the international standards or are optimum for the program representations.

The following Table 1-1 shows the abbreviations and symbols used in this **Handbook**.

**Table 1-1. Comparison of the abbreviations and symbols:
European Standards / Handbook**

European Standards	Handbook
Pressure resistance (overpressure)	P_o
Design overpressure of vessel	P
Dust specific characteristic	K_{max}
Explosion overpressure	P_m
Equivalent diameter	D_e
Gas specific characteristic	K_{max}
Length of the vent pipe	L_A
Diameter of the vent pipe	L_D
Length of vent duct where velocity of sound is reached	L_{AS}
Maximum flame range	LF
Maximum rate of pressure rise	$(dP/dt)_{max}$
Maximum reduced explosion overpressure	$P_{red,max}$
Maximum peak overpressure	P_{Amax}
Peak overpressure	P_{Ar}
$P_{red,max}$ without vent pipe	P_o
$P_{red,max}$ with vent pipe	P
$P_{red,max}$ without explosion door	P_o
$P_{red,max}$ with explosion door	P
Rate of pressure rise	$(dP/dt)_m$
Recoil duration	t_d
Recoil force, maximum	FR_{max}
Specific mass of venting device	GE
Total impulse	IR

All pressure data in connection with the protective measure "explosion venting" are given in gauge pressure with the unit bar or mbar.

Examples are:

Resistance of vessel P in bar

Explosion overpressure P_{\max} in bar

Activation overpressure P_{stat} in bar

Vacuum resistance of vessel V_{Res} in mbar

External pressure max PA_{\max} in mbar

External pressure PA_r in mbar.

Exception:

*To avoid confusion with the explosion pressure data, the unit **bar abs.** was deliberately used for the Operating Pressure OP.*

Table 1-2. summarizes all check parameters that are specially marked with an *. They are listed separately, because on the one hand these parameters can influence the calculations significantly or on the other hand, they are not directly included in the calculations but require an entry to check whether the calculations are within the validity range.

Table 1-2. Check parameters:

Check Parameter	Abbreviation
* Operating pressure	OP
* Conveying speed	vF
* Air flow	Q
* Diameter (equivalent)	DF
* Amount of product discharge	MP
* Metal dust	-
* Hybrid mixture	-
* Weight of venting device	GE
* Angle between axis of vent and duct	WAr

2 Course of Explosions in Vessels, Pipelines and Vessel - Pipeline Combinations

When considering the propagation of a flame front and the rise in pressure during an explosion, one must differentiate between:

- Flame propagation in vessels $L/De = 1$,
- Flame propagation in vessels, silos, and pipelines $L/De > 1$.

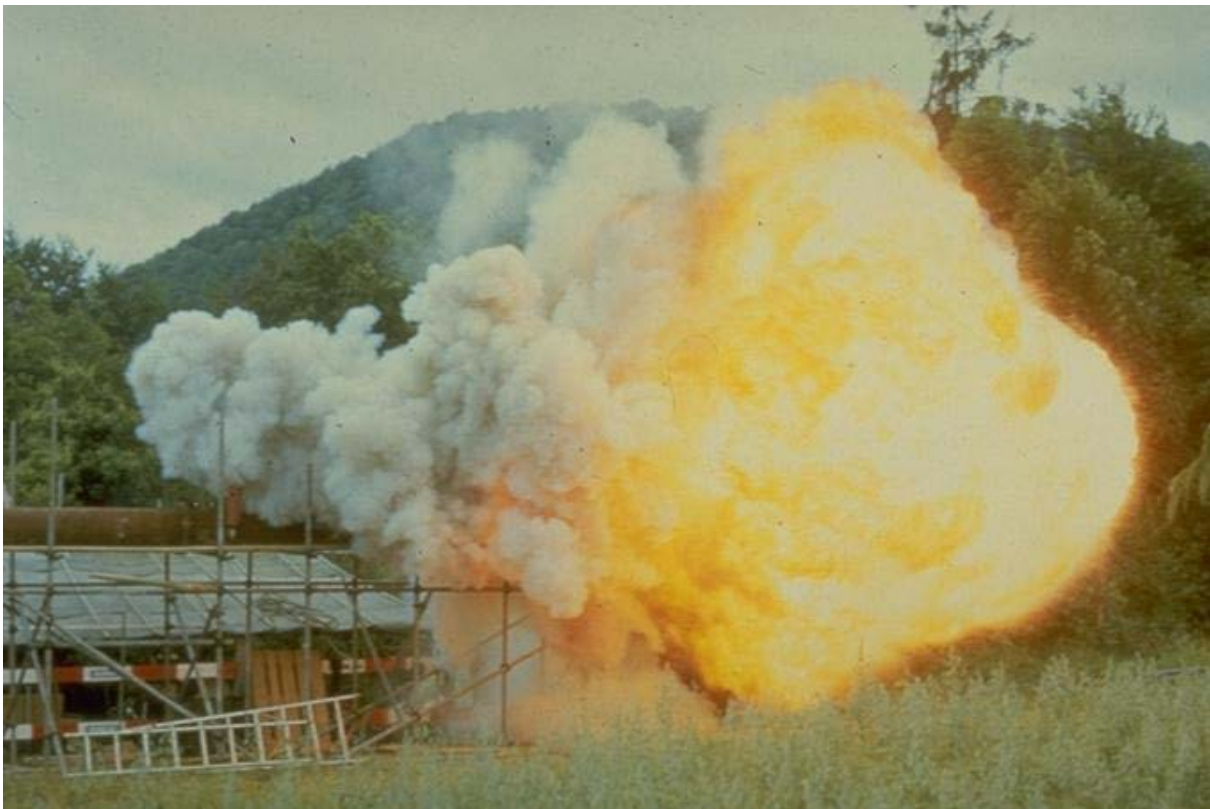
Generally, the velocity of flame propagation during explosions in vessels $L/De = 1$ remains small relative to the sonic velocity so that no local pressure differences occur in closed vessels. The maximum explosion overpressure may reach ten times the initial starting pressure. Such a value may be markedly exceeded with some dusts /1/. Obstructions may increase the violence of the explosion.

In pipelines, the flame propagation accelerates as a function of pipe length. Gases and dusts, especially the ones with medium or high gas specific or dust specific characteristics /1, 2/, may behave in a detonation-like fashion, e.g., if the explosion is transmitted out of a closed vessel and into a closed pipeline. In such a case, the flame front propagates at supersonic speed. The pressure exerted locally on the pipe wall may reach a multiple of the explosion overpressure for a short time. Even higher pressures may occur at end flanges and pipe bends due to pressure piling of the explosive mixture ahead of the flame front.

The combination vessel/pipeline predominates in practice. Examples are:

- Silos, milling and drying devices with downstream dust collectors.
- Local and general dust collection.
- Combination of storage, mixing and process vessels with pipelines.

In such a combination, where the dust explosion propagates from one vessel to another through a pipeline, the reaction may be more violent and result in a higher pressure than in a single vessel (Fig. 2-1). The propagation of an explosion can be prevented, or the effect can be limited through the measure "*explosion isolation/decoupling*" /9/.



**Figure 2-1. Propagation of a dust explosion through a pipeline into a dust filter
above: test arrangement, below: dust explosion in dust filter**

3 Explosion Venting of Equipment

The protective measure explosion venting prevents an unacceptably high-pressure build-up of a gas or dust explosion inside vessels or equipment through the timely opening of a defined area (Fig. 3-1). This means, that the maximum explosion overpressure P_{\max} , which was obtained by systematically changing the fuel concentration in a closed vessel, will be reduced to a maximum reduced explosion overpressure $P_{\text{red,max}}$.

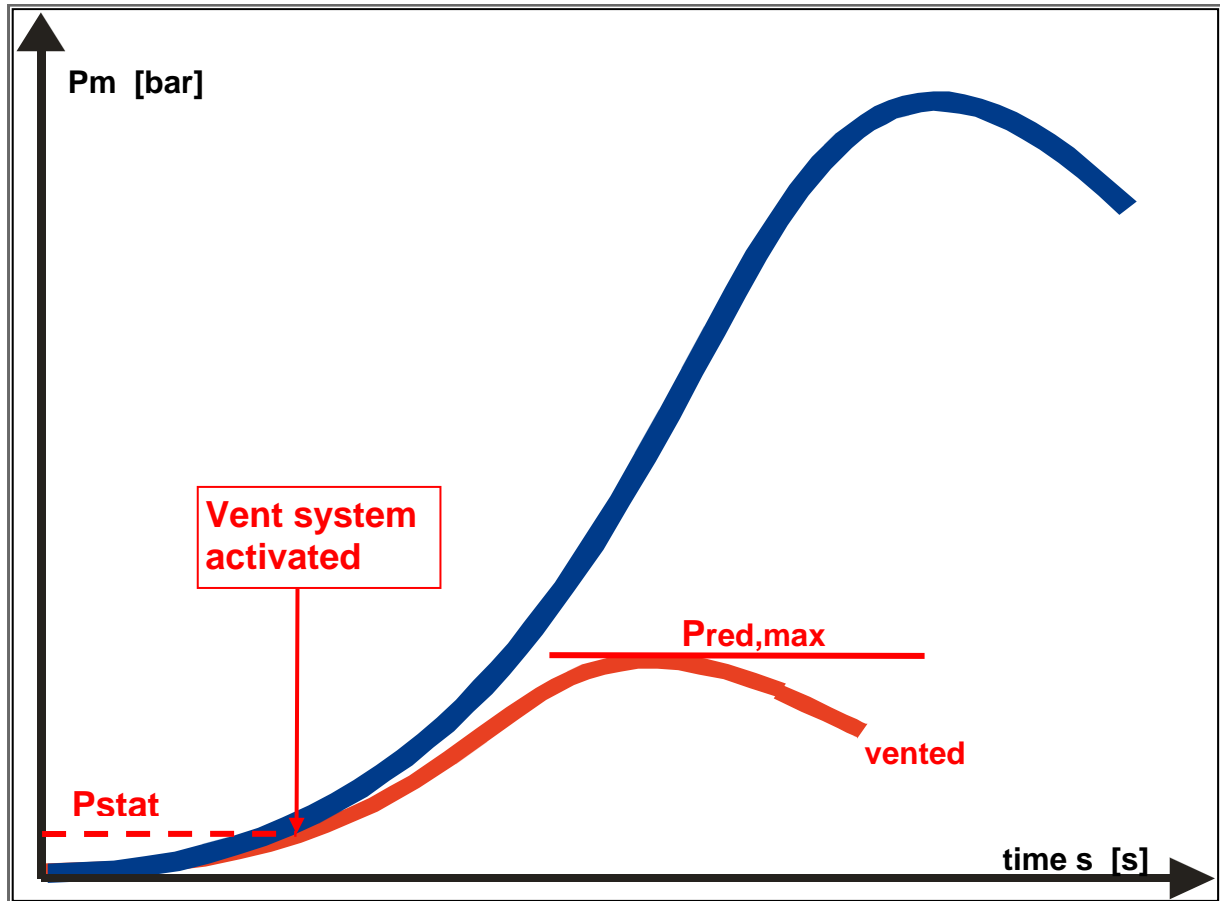


Figure 3-1. Schematic representation of the rate of pressure rise of an explosion in a closed and in a vented vessel - optimum fuel concentration -

Explosion venting devices limit the explosion overpressure by releasing unburned mixture and products of combustion (Fig. 3-2). The resulting maximum reduced explosion overpressure may not exceed the design pressure of the equipment. Applying the venting technique as such does not prevent the explosion; only the dangerous consequences are mitigated.

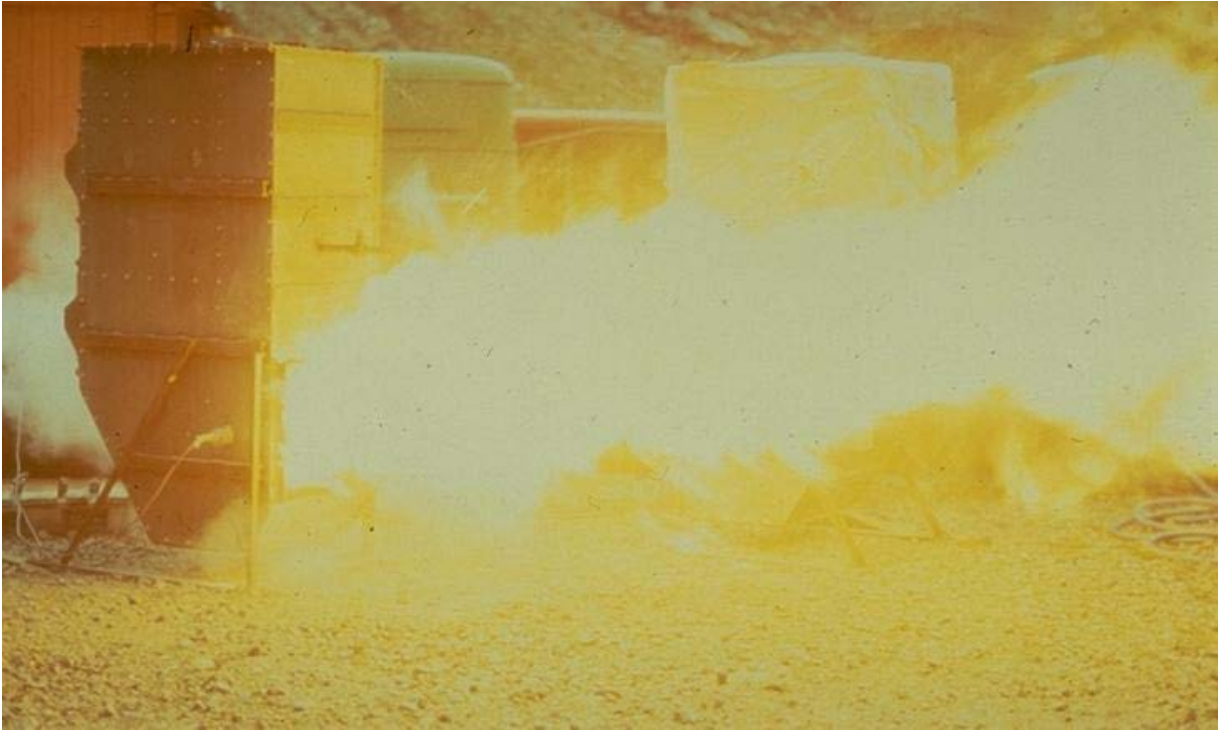


Figure 3-2. Explosion vented filter

However, outside the vented vessels, near the vent area, considerable pressure and flame spreading must be expected. The latter is very pronounced in case of combustible dusts (Fig. 3-2). Subsequent fires must be expected as well (Fig. 3-3).



Figure 3-3. Subsequent fires after a dust explosion in a vented silo

Pressure venting devices may be designed for one incident only e.g., rupture disks (explosion panels), or for multiple use e.g., explosion doors. The prerequisite for the use of pressure venting devices is the selection of the proper design pressure of the vessel or equipment. It has to withstand a certain venting pressure (maximum reduced explosion overpressure $P_{red,max}$). All parts of the equipment, which are exposed to the explosion pressure, must meet the design strength e.g., valves, sight glasses, manholes, cleaning ports as well as ducts.

In case the explosion pressure is not released directly but through a vent duct (Fig. 3-4), into the open, there will be an increase in the maximum reduced explosion overpressure $P_{red,max}$ in the vessel being protected which calls for an increase of the design strength of the vessel.

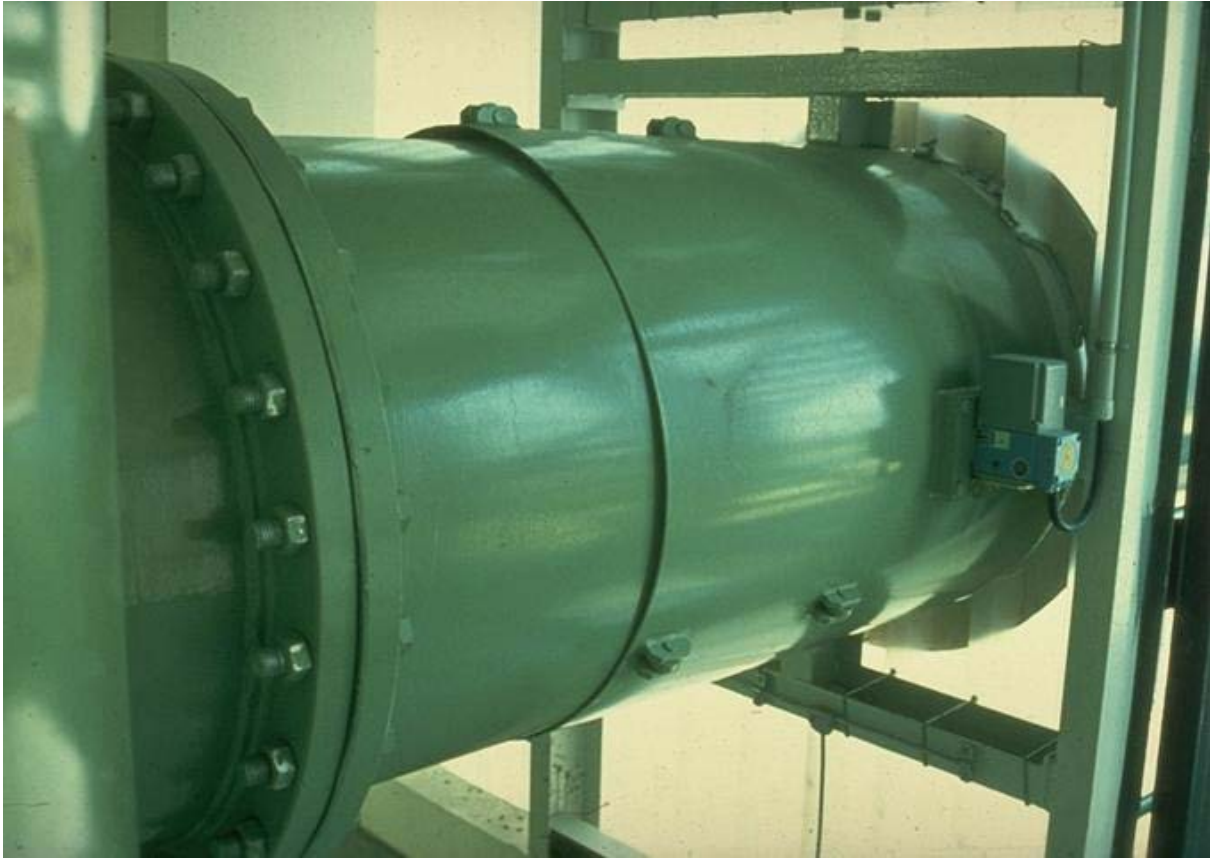


Figure 3-4. Vent duct, installed after a vent opening of a filter housing

The intensified effect of the explosion is not only dependent upon the length of the pipe but also upon whether gas or dust-air-mixtures are anticipated (see Section 9). The design of the vessels and equipment exposed to a fuel explosion has to be in accordance with applicable codes /8, 9/. Explosion venting devices must be installed in such a way that nobody will be endangered. Figure 3-5 shows a poor example where the danger area (effects of pressure and flames) is not signposting and cordoning off!



Figure 3-5. Endangerment of personnel by poorly placed vent areas

In addition, the operation of any equipment, which is important regarding safety, shall not be restricted (Fig. 3-6).

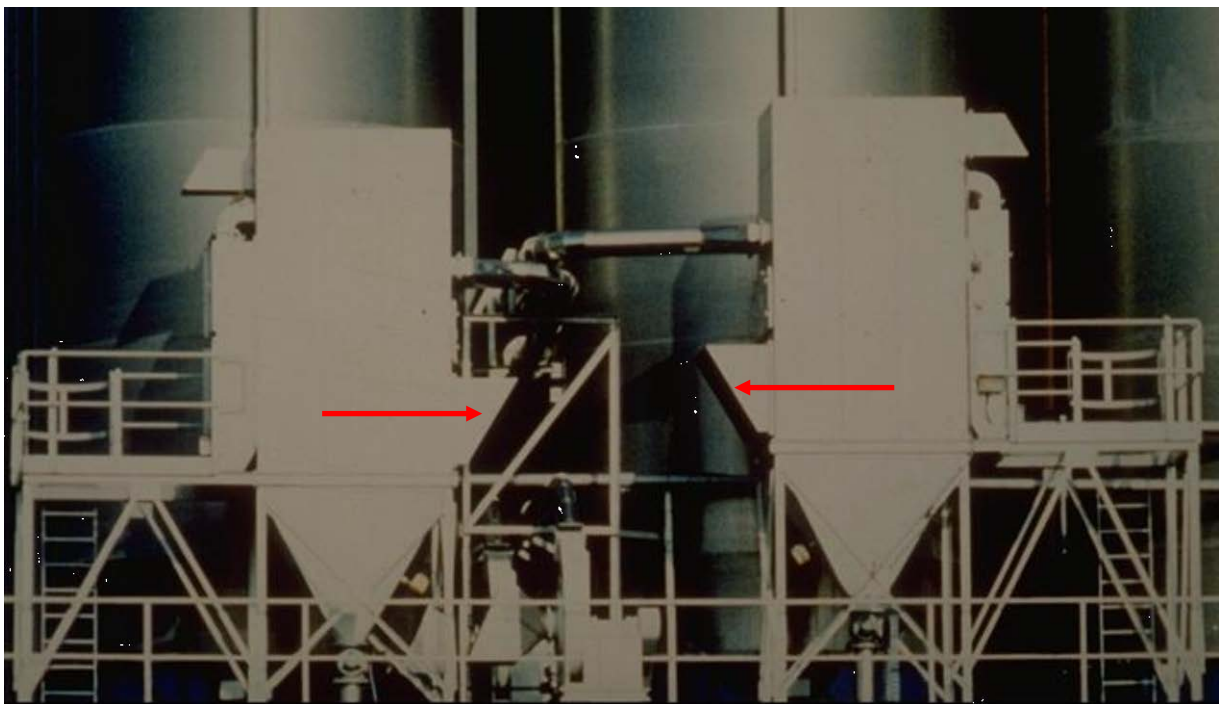
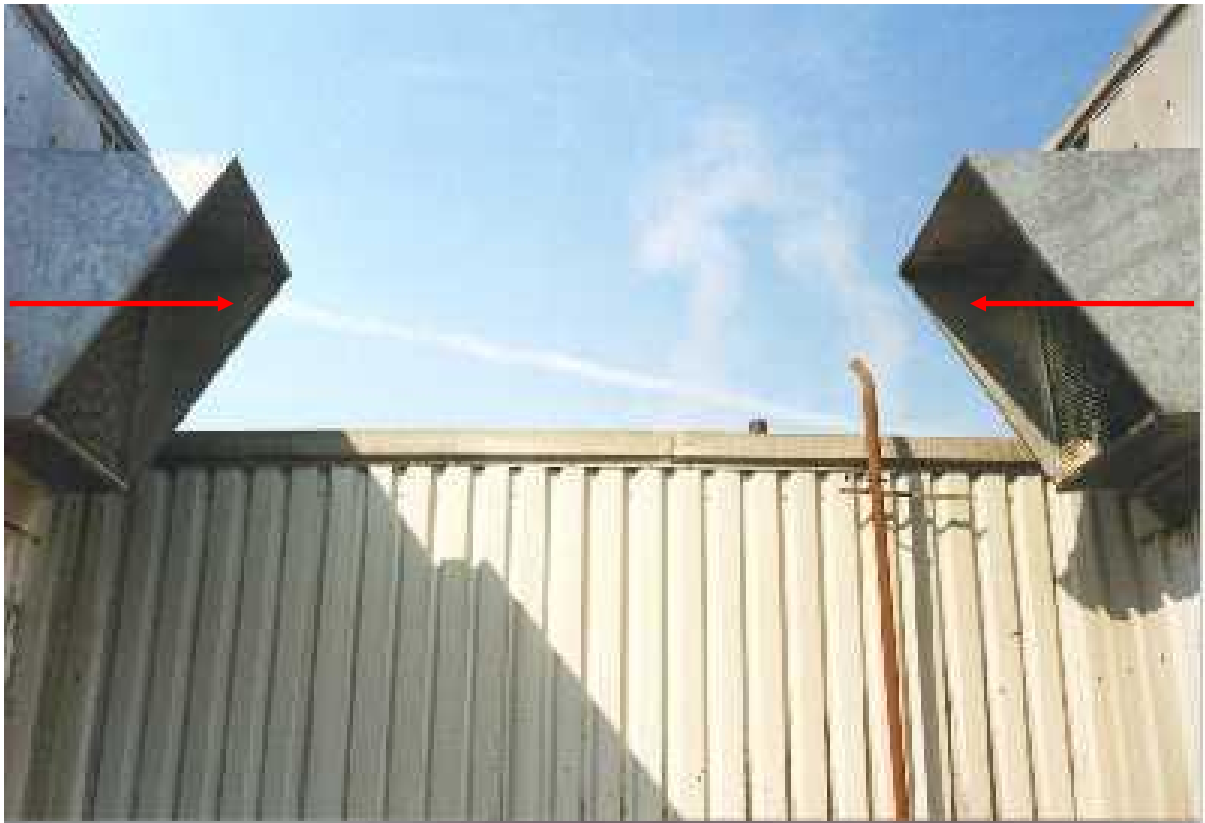


Figure 3-6. Endangerment of the filter unit and restricting the vent efficiency by poorly placed vent areas including vent pipes

4 Explosion Venting of Low Strength Enclosures

Rooms or parts of a building may also be protected by means of explosion venting, but not personnel, which stay in these areas. In this case, explosion venting serves the purpose of protecting the integrity of the building. Venting may be accomplished e.g., by using the windows, the outside walls, or the roof of the room (Fig. 4-1) to be protected.



Figure 4-1. Venting of enclosure through the roof

In case of side venting, a solid railing must be provided. This is necessary to prevent employees from falling into the lightly supported facade covering which serves as a venting device (Fig. 4-2).

An ample safety zone must be provided near the venting system outside the room so that humans are not affected by the hazards and the operation of safety and major equipment is not affected.



Figure 4-2. Facade covering of a production building after a dust explosion

Window glass (Fig. 4-3) or similar material, which tends to fragment, shall not be used as the material of construction for vent devices.



Figure 4-3. Window glass shattered by an explosion

Materials are preferred, which will not form large sharp-edged fragments. The effects of flying fragments must be considered when using e.g., safety glass (Fig. 4-4).

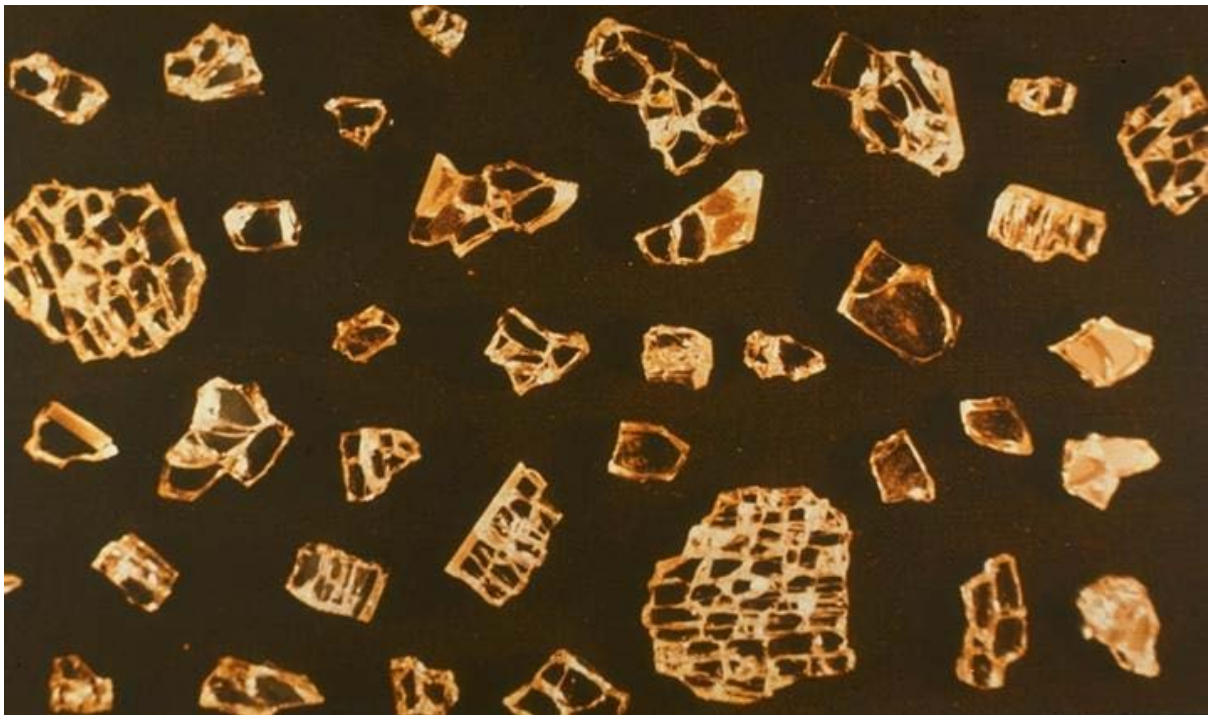


Figure 4-4. Safety glass with score points, after explosion

Sandwich type facade walls or light metal facade elements are preferred for the venting of buildings (Fig. 4-5) /4/.

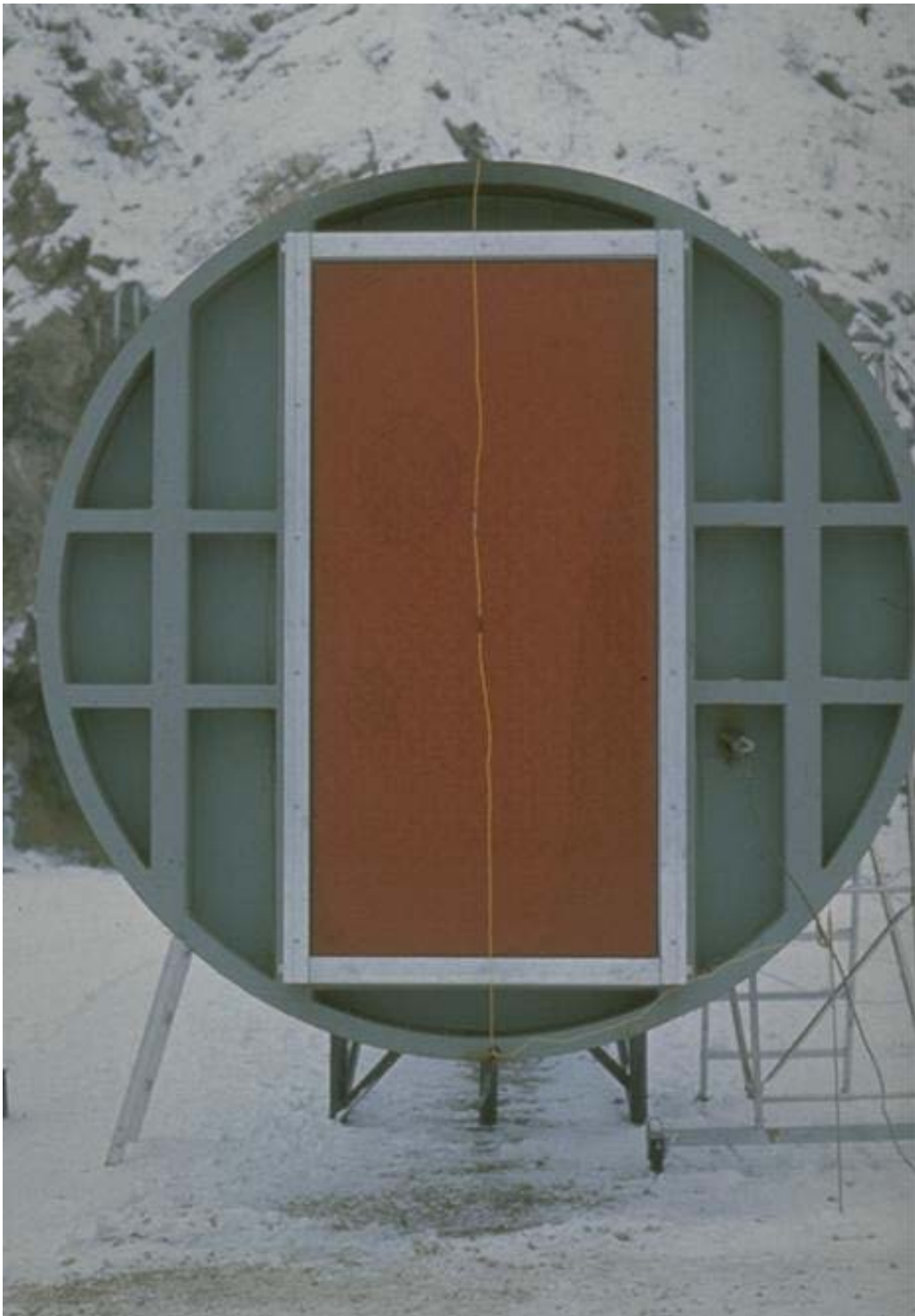


Figure 4-5. Light metal facade element

Fore venting of enclosures through the roof, a roof construction consisting of a great number of aluminium fins (Fig. 4-6) has proven to be successful /10/.

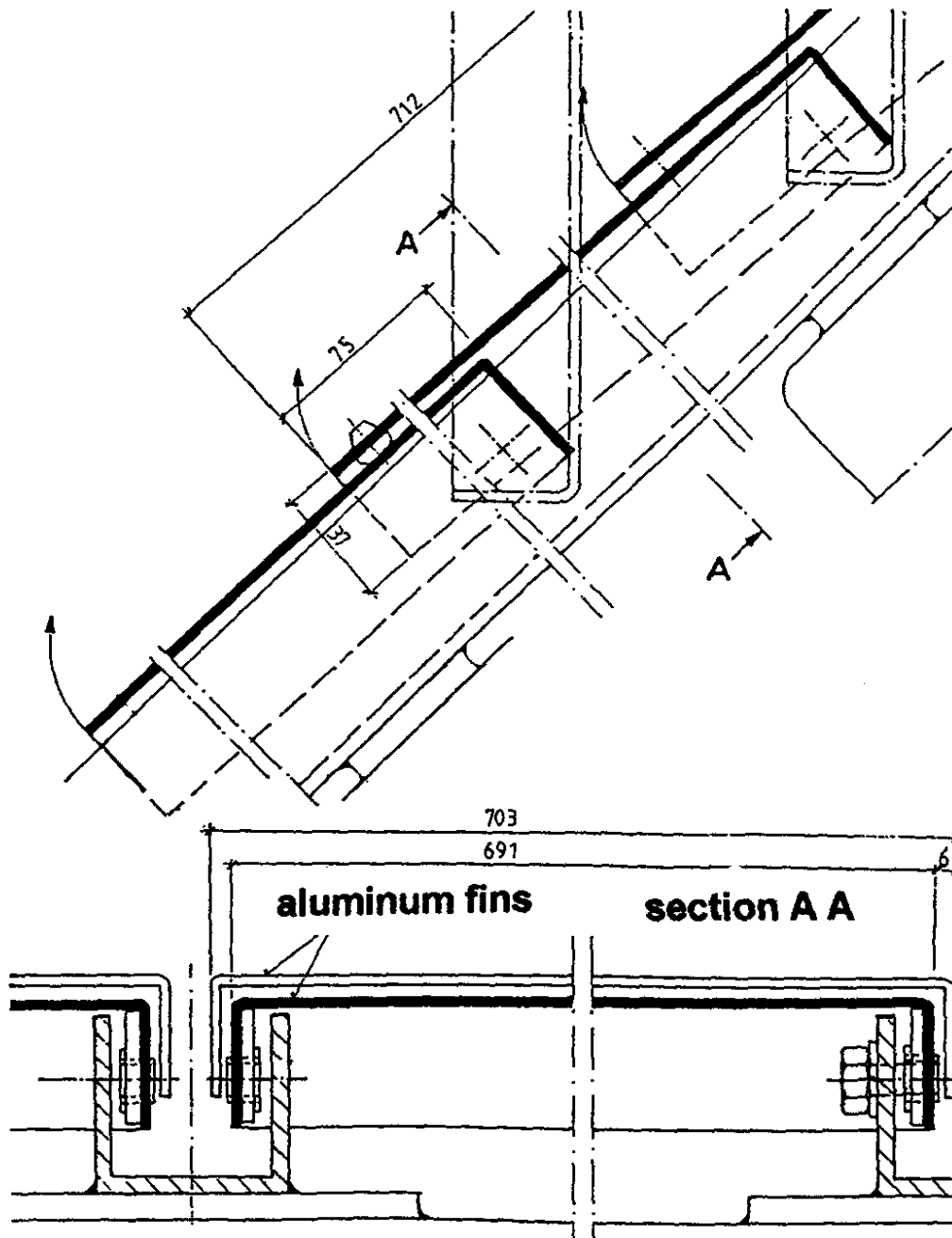


Figure 4-6. Roof venting with aluminium fins

5 Venting Devices

Rupture disks, explosion panels or explosion doors may be used as venting devices. With respect to the activation overpressure, these devices shall be the weakest part of the equipment. All basic investigations on explosion venting were carried out with nearly inertia-free rupture disks/bursting foils made of polyethylene or aluminium membranes (with a specific mass $GE \leq 0.5 \text{ kg}\cdot\text{m}^{-2}$). This corresponds to a venting efficiency of $EF = 1$. These venting devices do not obstruct venting. Explosion venting devices with an inertia greater than $0.5 \text{ kg}\cdot\text{m}^{-2}$ and smaller or equal to $10 \text{ kg}\cdot\text{m}^{-2}$ can be considered as inertia-free provided that the specific vent area $A/V^{0.753}$ is smaller than 0.07 /3/. Other sorts of venting devices containing venting elements with a specific mass greater than $10 \text{ kg}\cdot\text{m}^{-2}$ may affect venting. This effect shall be tested regarding the determination of the venting efficiency (see Section 5.3). All pressure-venting devices are protection systems according to the Directive 94/9/EC and must be subject to an EC suitability test from July 2003 on /11/. An increase in the static activation overpressure due to dirt, snow load, excessive friction, or a decrease due to corrosion or material fatigue may jeopardize the efficient performance of the venting device and affects the venting efficiency. Therefore, a sufficient preventive maintenance of the venting device is necessary.

5.1 Rupture Disks

After exceeding the activation overpressure, the low mass rupture disks will respond almost without inertia if the specific mass GE of the device is equal to or less than $0.5 \text{ kg}\cdot\text{m}^{-2}$ /1/ or venting devices with specific mass of $> 0.5 \text{ kg}\cdot\text{m}^{-2}$ to $\leq 10 \text{ kg}\cdot\text{m}^{-2}$ if the specific vent area $A/V^{0.753}$ is smaller than 0.07 /3/. This type of disks can be installed independently of location and guarantee a tight closure. In case of an explosion, they will free the whole area after their destruction (Fig. 5-1). Common materials of construction for ductile rupture disks are metal or alloys.

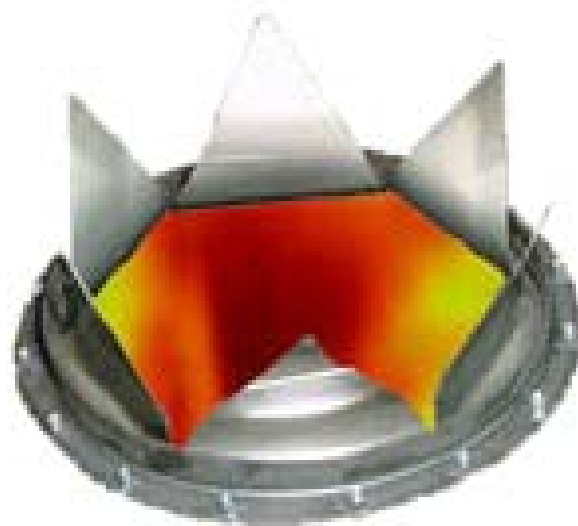


Figure 5-1. Proper opening of the vent areas

Popular are triple rupture discs (Fig. 5-2) and segmented-rupture discs (Fig. 5-3).

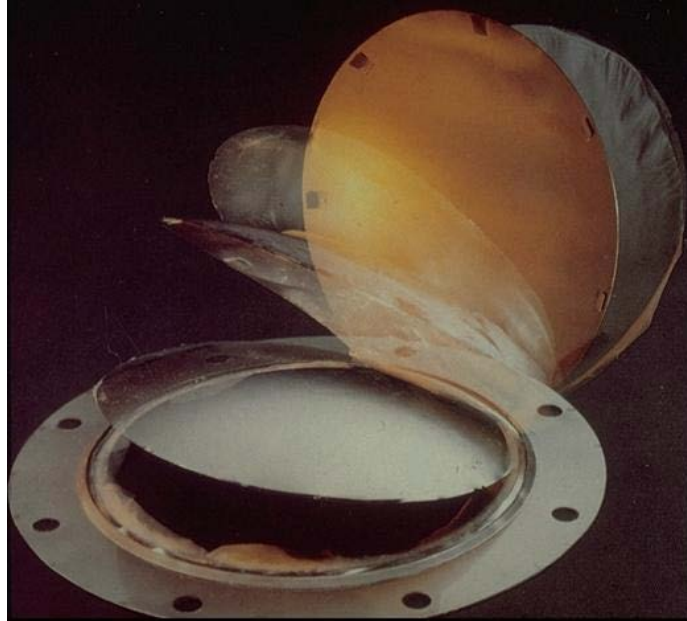


Figure 5-2. Triple rupture disk round style /12/

The rupture disk shown in Fig. 5-3 is a round domed disk of composite construction laser cut in a stitch pattern in the dome area. An FEP/PTFE liner covers the slits providing a seal. The vent burst pressure is controlled by the arrangement of the stitch pattern. This rupture disk is fitted with a vacuum support to resist high vacuum.

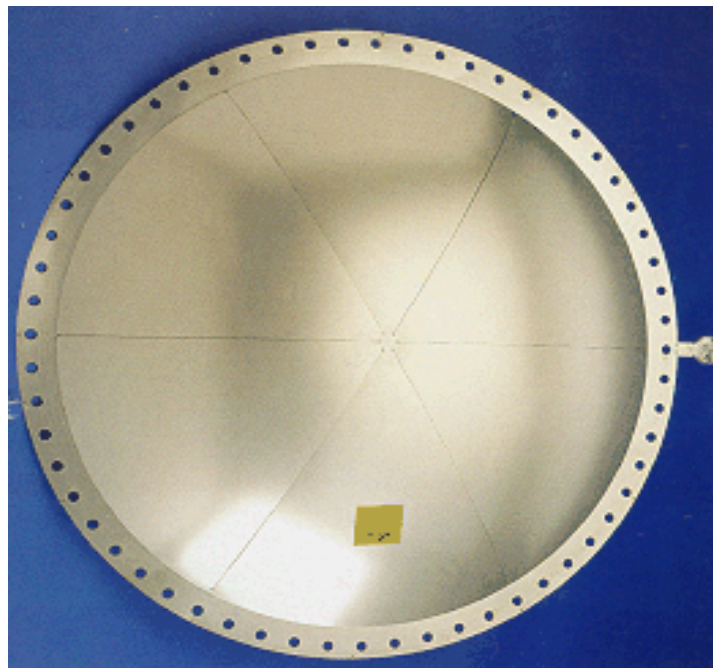


Figure 5-3. Domed and segmented metal rupture disk round style /13/

Vents with their domed constructions are designed to resist high vacuum under cycling conditions without the need for vacuum support bars attached to the inner safety Frame. The vacuum rating of a vent is dependent on the type of rupture disk. The rupture disk shown in Figure 5-3 has been tested to over 1 million pressure cycles from vacuum to light positive pressure while retaining its burst accuracy. The vent exhibits superior performance compared to conventional composite vents that fatigue after less than 40'000 pressure cycles under equivalent test conditions.

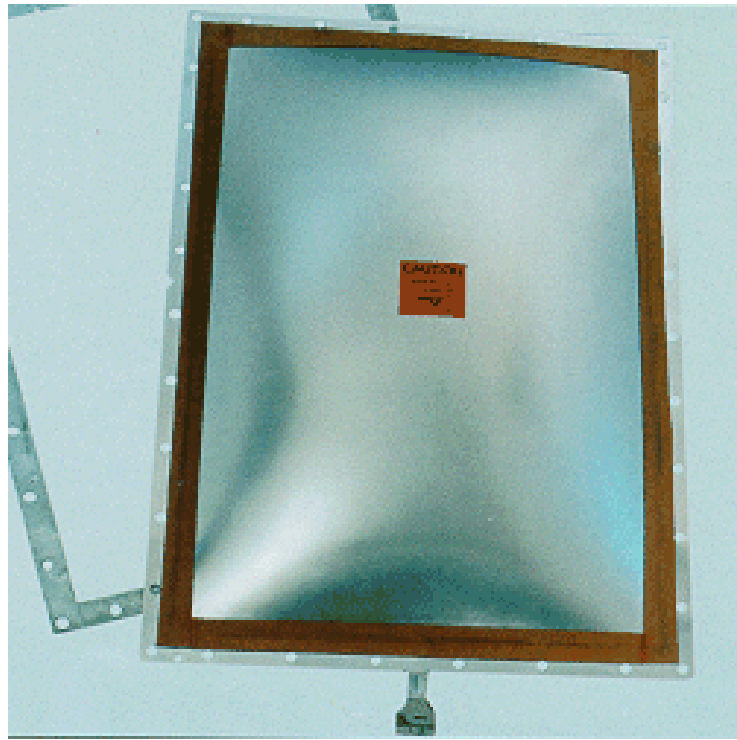


Figure 5-4. Domed single section metal explosion vent rectangular style /13/

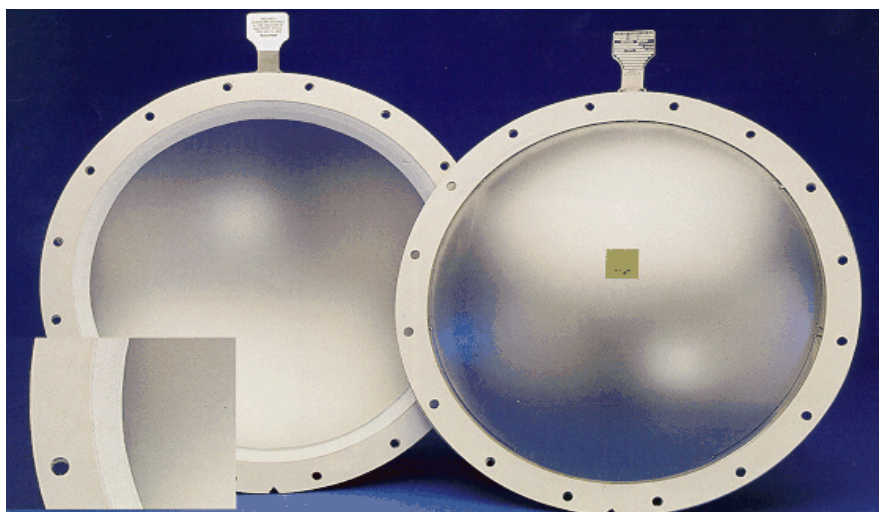


Figure 5-5. Domed single section metal rupture disk round style /13/

Rupture disks may be combined with signalling devices e.g., a wire runs across the device and a holding current flow through this wire. When the device is destroyed the current is interrupted and this signal is used to trigger an alarm (Fig. 5-6) or a magnetic burst sensor (magnetically activated sensor), which will trigger a shut down or a controlling mode and immediately warns of a ruptured or exploded disk. The magnetic burst sensor is combined with a burst disk monitor to provide continuous monitoring of rupture or explosion disk integrity (Fig.5-7).

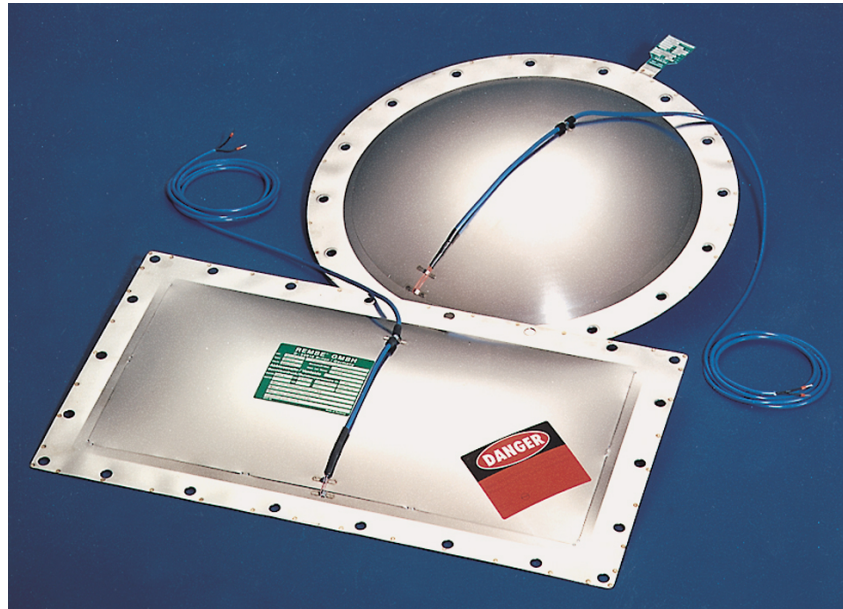


Figure 5-6. Rupture disk with signalling device in form of a magnetic burst sensor spot-welded to the rupture disk /12/

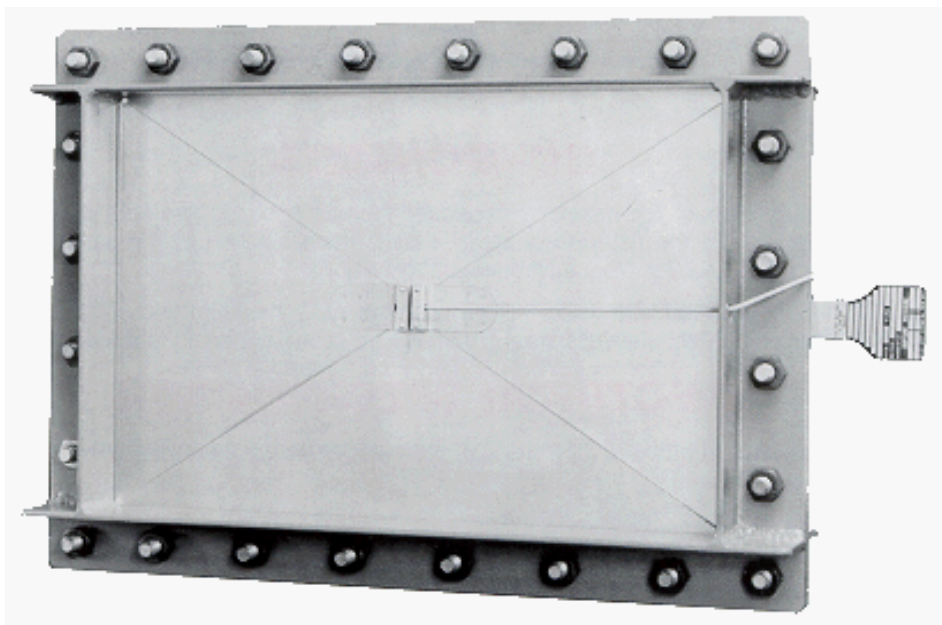


Figure 5-7. Rupture disk with signalling device in form of a magnetic burst sensor spot-welded to the rupture disk /13/

For personnel protections beware of fragments if brittle rupture disks are used. Variations in load may lead to fatigue of the material. Exposure to widely fluctuating temperatures may lead to softening or embrittlement of special materials used for rupture disks. In addition, the effects of corrosion, erosion, snow load or icing must be considered since they may change the static activation overpressure of the rupture disk. Only rupture disks are to be used which are restrained from becoming shrapnel through design measures. Special designs for multiple uses are explosion panels supported by rubber mouldings or other devices - like the windshield of a car - (Fig. 5-8 and 5-9).

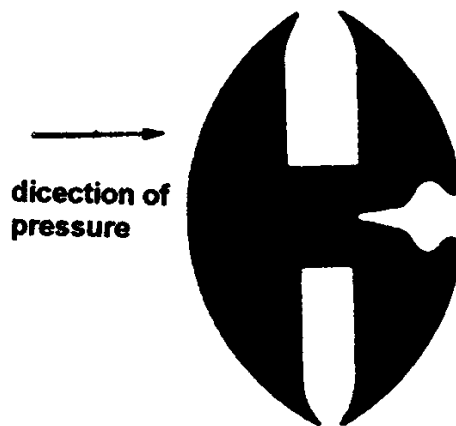


Figure 5-8. Rubber mouldings (cross section) for explosion panels



**Figure 5-9. Explosion panels supported by rubber mouldings;
panels restrained by cables from flying away /14/**

The explosion overpressure will release the explosion panel from its rubber melding. Cables or other restraining devices of appropriate strength must be preventing the panels from flying away. The venting capability of the panel and the effectiveness of the restraining device must be documented (Fig. 5-10). The explosion panel supported by rubber mouldings can be used up to an activation overpressure of 0.2 bar.



Figure 5-10. Explosion panels secured by 8 mm steel cables after explosion in filter housing

For higher activation overpressures the principle can be combined with notched pins (Fig. 5-11) /10/.

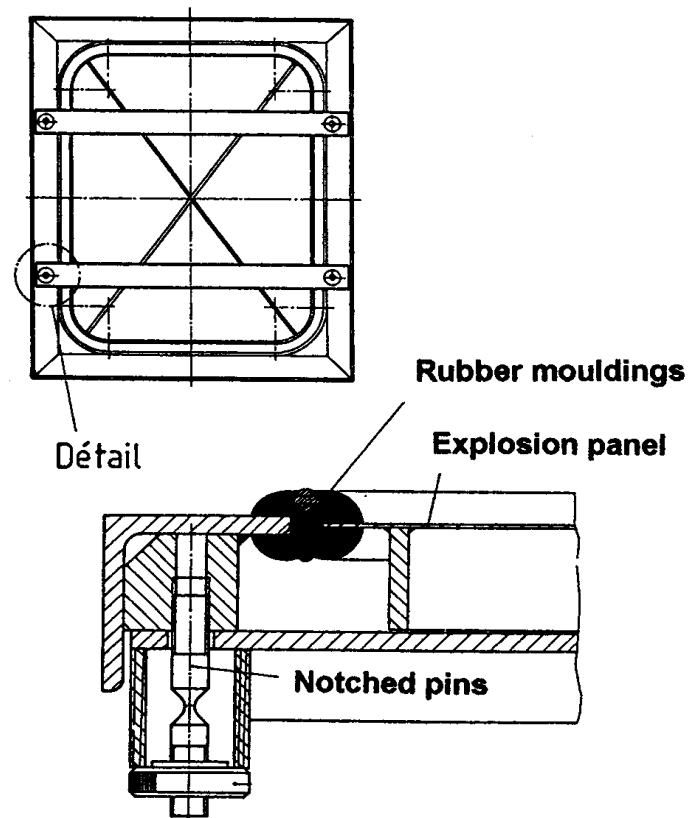


Figure 5-11. Explosion panels supported by rubber mountings combined with notched pins ($P_{stat} = 0.3$ bar)

For special applications, buckling pin devices (Fig. 5-12) are available.

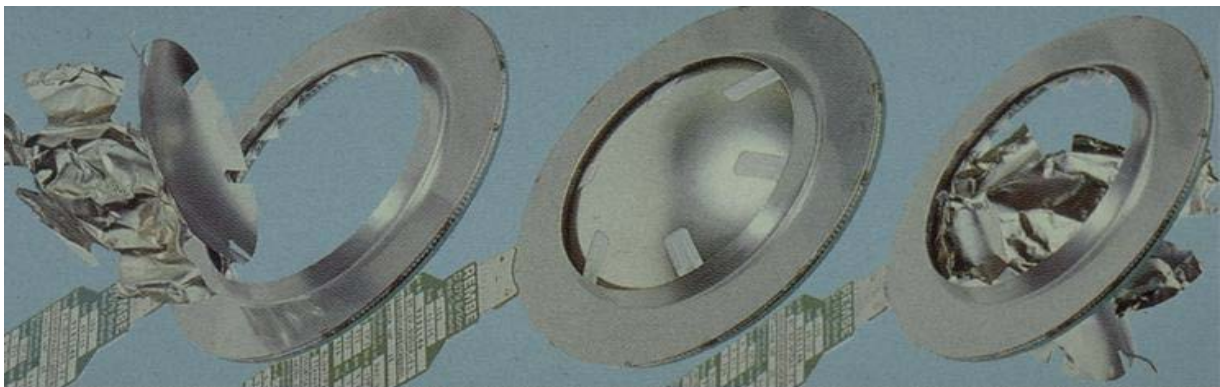


Figure 5-12. Rupture disks for negative and positive pressure with buckling pin devices /12/

5.2 Explosion Doors

Explosion doors (Fig. 5-13 and Fig. 5-14) open in case of an explosion, thereby releasing the vent area.

Explosion doors with a specific mass of up to $10 \text{ kg} \cdot \text{m}^{-2}$ will respond almost without inertia if $A/V^{0.753}$ is smaller than 0.07 /3/.

Depending upon the application explosion doors may be selected which remain either open or close automatically after releasing the explosion. In case of an explosion, they will free the vent opening. A horizontal or vertical arrangement will also affect its effectiveness.



Figure 5-13. Explosion door rectangular style /15/



Figure 5-14. Explosion door round style /15/

In addition to the venting efficiency (see Section 5.3) of an explosion door, its mechanical strength is also of utmost importance. A suitability test shall document that the device will function at the anticipated explosion conditions and that there will be no hazard from flying parts.

The forces arising due to the impact of the opening venting device must be taken into account in the design of the vented vessel (e.g., groove).

Corrosion, unprofessionally applied coats of paint on the movable parts to the explosion door as well as icing or snow load may result in an increase of the activation overpressure. The movability of such venting devices and the static activation overpressure must be checked in predetermined conditions.

Icing or snow loads can be prevented by installing e.g., an effective electrical heating system for the explosion device (Fig. 5-15).

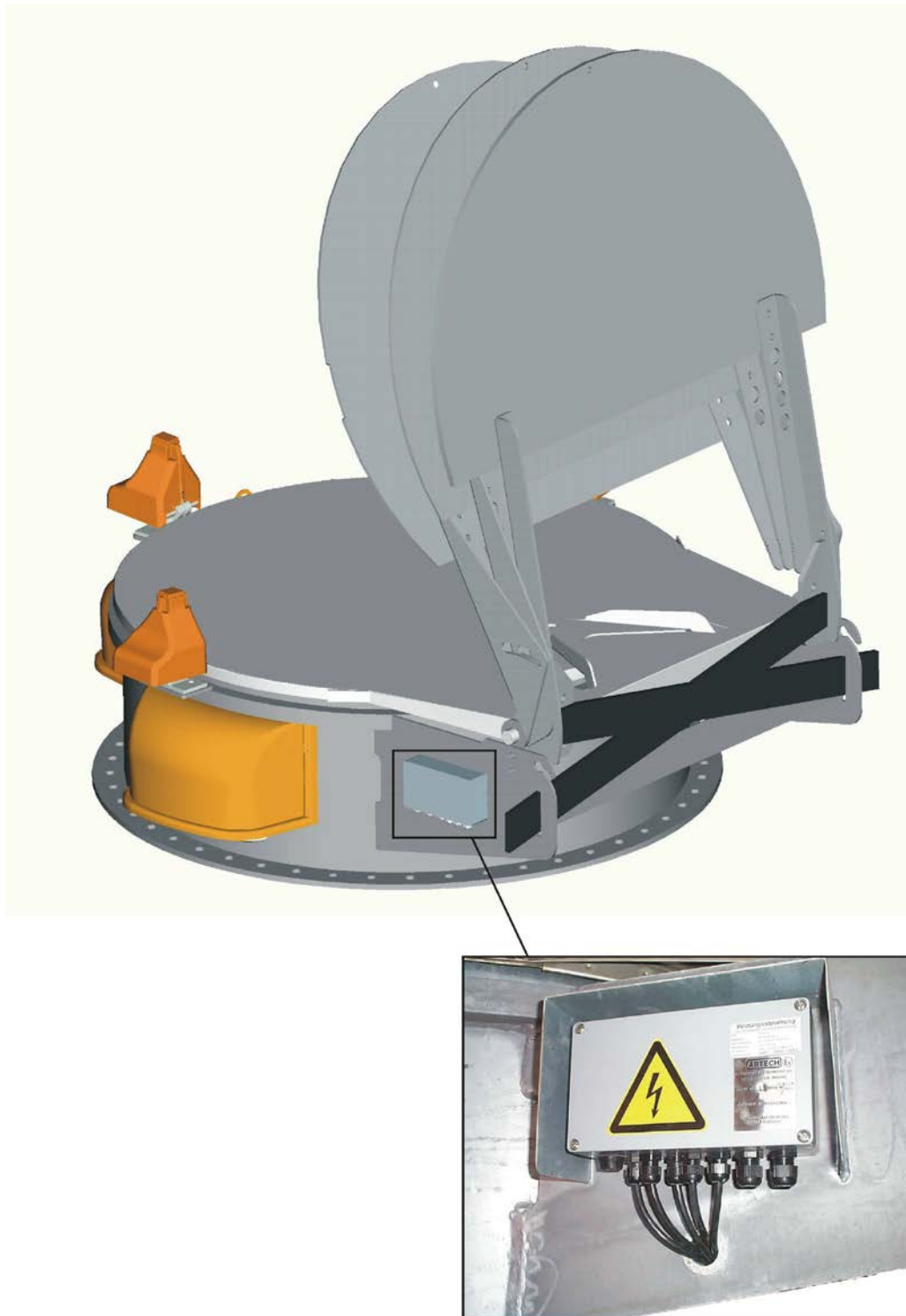


Figure 5-15: Electrically heated explosion door /15/

5.3 Venting Efficiency, EF

The inertia, the opening behaviour of a bursting disk or of the movable cover of an explosion device and its arrangement (horizontal, vertical) can affect the venting efficiency and may result in a higher maximum reduced explosion overpressure inside the protected vessel (Fig. 5-16). This venting efficiency is mainly dependent upon the specific mass of the venting device.

5.3.1 Specific Mass Smaller or Equal to 0.5 kg m^{-2}

These types of explosions venting devices have a venting efficiency of $EF = 1$ and are called inertia-free and do not impede the venting process. For such explosion venting devices venting efficiency, testing is therefore not required.

5.3.2 Specific Mass Greater than 0.5 kg m^{-2} to Smaller or Equal to 10 kg m^{-2}

Explosion venting devices with venting elements with a specific mass greater than 0.5 kg m^{-2} can influence the venting process by their opening and release behaviour. Experiments have shown that explosion venting devices with a specific mass greater than 0.5 kg m^{-2} and smaller or equal to 10 kg m^{-2} can be considered as inertia-free, that means having a venting efficiency $EF = 1$ provided for /3/:

$$A/V^{0.753} < 0.07$$

The equations are only valid for:

- vessel volumes $0.1 \text{ m}^3 \leq V \leq 10'000 \text{ m}^3$,
- static activation overpressure of venting device $P_{\text{stat}} \leq 0.1 \text{ bar}$,
- vessel strength (= $P_{\text{red,max}}$) $0.1 \text{ bar} < P \leq 2 \text{ bar}$,
- $P_{\text{red,max}} > P_{\text{stat}}$.

For all other conditions, the venting efficiency must be determined by tests (Fig. 5-16 and 5 - 17). The venting efficiency EF and therefore the effective vent area A_w of a non-inertia-free explosion device is smaller than the venting efficiency of an inertia-free vent device made of polyethylene or aluminium membranes (specific $GE < 0.5 \text{ kg m}^{-2}$) with the same vent area.

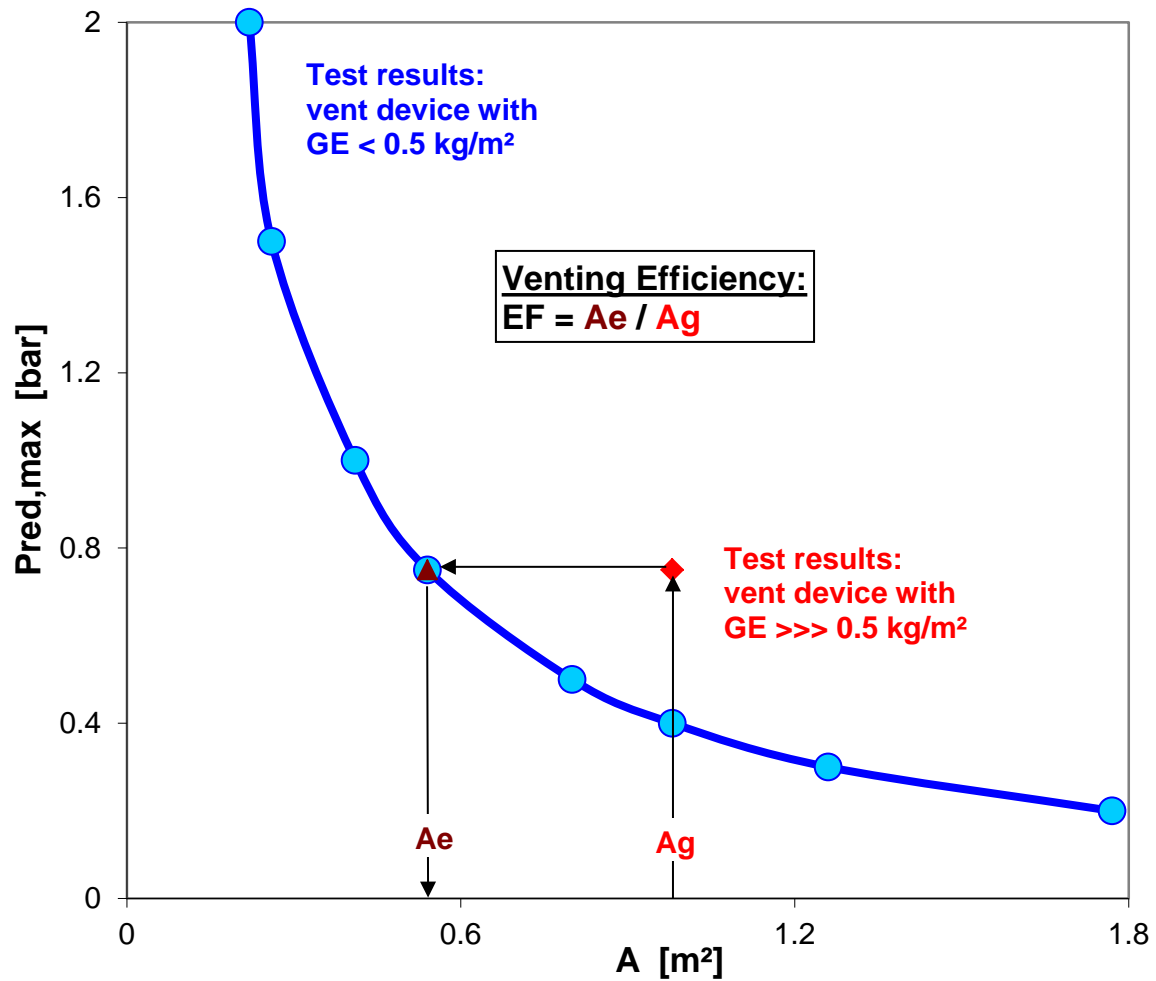


Figure 5-16. Definition of the venting efficiency EF of an explosion device in comparison with a rupture disk

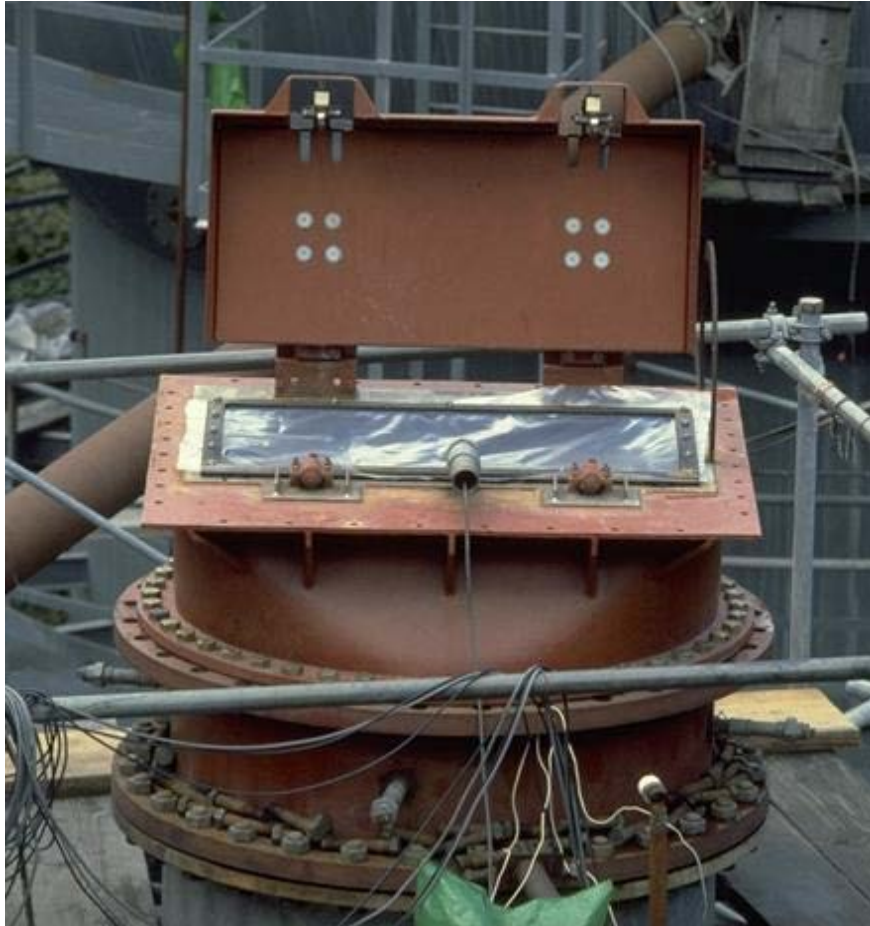


Figure 5-17. Testing of an explosion door

Investigation /17/ have shown, that the venting efficiency EF generally increases with increased maximum reduced explosion overpressure $P_{red,max}$ and decreases with increased mass of the explosion device. This shall be considered for practical use. The venting efficiency of a vent device must be known for a given application (vessel size, dust explosion class) and the restrictive venting behaviour offset either by increasing the design strength of the vessel or enlargement of the vent area. Obviously, the mechanical strength of the explosion door must be consistent with the design pressure of the vessel.

5.4 Vacuum Breakers

When using explosion doors, which close the vent area after the explosion the cooling of the hot gases of combustion may create a vacuum in the vessel, resulting in its deformation (Fig. 5-20).



Figure 5-20. Silo, which was protected with explosion doors, destroyed due to vacuum /15/

To prevent this from happening, vacuum breakers (Fig. 5-21) must be provided /1, 4/ and are either built strongly enough to withstand the $P_{red,max}$ during venting, or provided they break away like rupture diaphragms to leave a clear opening.

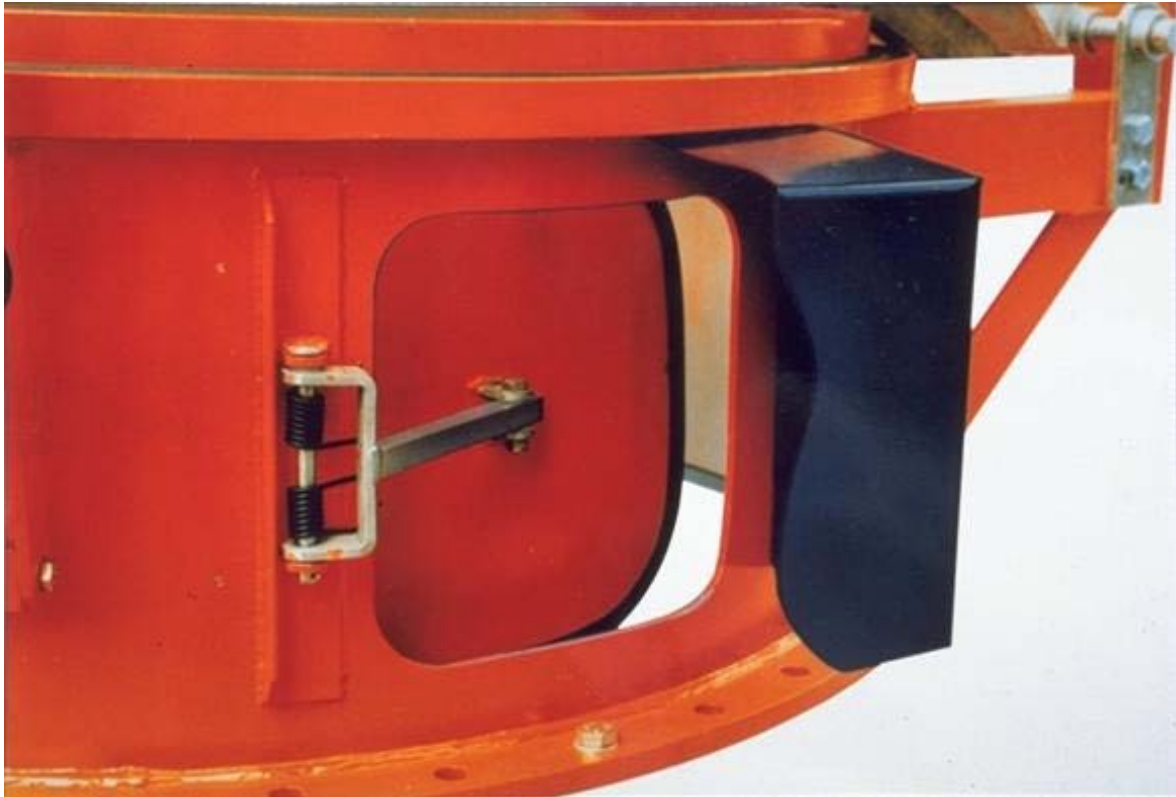


Figure 5-21. Vacuum breakers for vessels/silos /15/

Figure 5-22 shows the roof of a silo, which is correct protected with an explosion door and integrated vacuum breakers.



Figure 5-22. Silo roof: correct protected with an explosion door and integrated vacuum breakers /15/

6 Sizing of Venting Devices

6.1 General

For sizing a vent area, the following explosion parameters of a fuel are needed, which describe the course of an explosion in a closed vessel /5, 18, 19/:

- maximum explosion overpressure P_{\max} and
- fuel specific characteristic K_{St} or K_{\max} respectively.

Generally, they are independent of the vessel size and are determined in accordance with an agreed standardized method /18, 19/.

The **Handbook** does not make a distinction between K_G -values for flammable gases and K_{St} -values for combustible dusts. Generally, a maximum product specific constant K_{\max} is given without reference to the type of fuel.

The equations given below represent the optimum mathematical expression of a multitude of experimental test results obtained by varying the single parameters within the stated limited range. The combination of the single parameters within the equations is not based on their physical-chemical dependency.

The experimental investigations, which are the bases of the equations, were carried out under conditions, which reflect actual practice and, from experience, cover the unfavourable conditions, too. For deviating conditions, it must be proven that the same level of safety will be maintained (Safety analyses or experimental proof) /1, 2/.

The areas calculated from the equations, which are valid for the stated range only, can be directly incorporated into practical applications.

In the following no distinction is made between the design using the European Standards /1, 2/ and the VDI-3673, Part 1 /4/, because they are in principle identical.

6.2 Proper Design

Not following the recommendation mentioned in this handbook, which is based on the actual standards, may result in material damages.

Figure 6-1 shows the consequences of poor design. The calculated vent area was insufficient, and the installed vent device did not have a test certificate. The material of the explosion vent was a thick acrylic glass piece. The static activation overpressure of this device was not known. Furthermore, it is most probable that this isolating vent device was also the ignition source.



Figure 6-1. Consequences of poor vent design

If explosion venting is used as a protective measure in more than 50 % of the cases the isolation measures e.g., extinguishing barriers, diverters are missing, even it is mentioned in all actual standards and guidelines.

In a protected vessel, an explosion propagates from this vessel to others through pipelines and creates more damages in the pipelines and other vessel. This propagation of an explosion must also be prevented.

Figure 6-2 shows the consequences when the application of EXPLOSION ISOLATION IS NOT APPLIED. The explosion was properly controlled by the applied constructional measure in the vessel, but the pipeline carrying the product to other equipment was destroyed.

Figure 6-3 shows the consequences of the secondary equipment (bag-filter) protected by explosion venting. The dust explosion propagates from the first vessel also protected by explosion venting WITHOUT ISOLATION through a pipeline into the secondary vessel. Because the reaction is more violent and results in a higher pressure than in the first vessel, the second vessel (bag-filter) was destroyed.



Figure 6-2. Consequences of no installing isolation systems



Figure 6-3. Consequences of no installing isolation systems

6.3 Combustible Dusts

The agreed upon, standardized dust procedure /4, 5, 18, 19/ was used to simulate standard dust dispersion (Fig. 6-4) for venting tests involving vessel sizes of 1 to 250-m³. The procedure calls for a rapid release of combustible dust from air pressurized containers and the triggering of an ignition source ($E = 2 \times 5 \text{ kJ}$) after a given delay time from the start of the dust dispersion.



Figure 6-4. Standard dust dispersion by rapid release of combustible dust from storage containers

Under « standard dust dispersion » or « Standard » it is understood a dust-air-mixture where the dust concentration is independent on the location. They are generated by rapid discharge of combustible dust from pressurized storage vessels (20 barg air) via dispersion arrangements (Fig. 6-4) following the standard procedure (VDI-/ISO-Methods) /5/. The term « standard dust dispersion » is often called "homogeneous dust dispersion".



Figure 6-5. Explosion of standard dust dispersion in a vented 250-m³-vessel (left) and 20-m³-silo (right)

If, in practice, the filling of vessels or silos is carried out by pneumatic conveying with product discharge (Fig. 6-6 and 6-7), the course of the explosion is different from that of the « standard dust dispersion », because it is caused, for example, by pneumatic conveying with axial or tangential discharge into vessels and silos, or by free-fall (gravity) filling from, for example, a rotary valve or screw feeder /1, 4, 5/, i.e. the dust concentrations are different and depend on the location! The above term "pneumatic conveying of product into vessels or silos" is often referred to as "non-standard dust dispersion" or "non-homogeneous dust dispersion".



Figure 6-6. Explosion of a vented 250-m³-vessel introducing combustible dust through pneumatic transport in the form of pneumatic conveying

Within the applicable range, the vent areas obtained from the equations can be used directly in practice. The numerical values of the parameters defined in Section 16.1 are entered into the equations.



Figure 6-7. Explosion of a vented 20-m³-silo introducing combustible dust through pneumatic transport in the form of pneumatic conveying

The static activation overpressure P_{stat} of the venting device must be equal to or smaller than the strength of the vessel P (corresponding to the excepted maximum reduced explosion overpressure $P_{red,max}$).

6.3.1 Vessels / Silos

In general, for explosion venting it must distinguish between:

- area requirement for vessels having a length/diameter ratio of $L/D_e = 1$ (Fig. 6-8) and
- area requirement for elongated vessels/silos having a length/diameter ratio of $L/D_e > 1$ (Fig. 6-9 and Fig. 6-10).

Elongated vessels are characterized by their length being larger than diameter respectively equivalent diameter D_e :

$$D_e = 2 \cdot \sqrt{\frac{A^*}{\pi}}$$

D_e is the diameter of a circle which has the same area as the reference area A^* of any shape. Such geometry accelerates the flame propagation as a function of increased length. Investigations /5/ in a closed and vented vessels with different L/D_e ratios have shown that the influence of the flame acceleration effect is valid already if the ratio of length to diameter is $L/D_e > 1$.

In the European Standards or Guidelines /1, 2, 4/ the following was therefore defined:

Vessels in which the ratio of length to diameter is 1.

Other vessels (horizontal or vertical) in which the ratio of length to diameter is greater than 1.

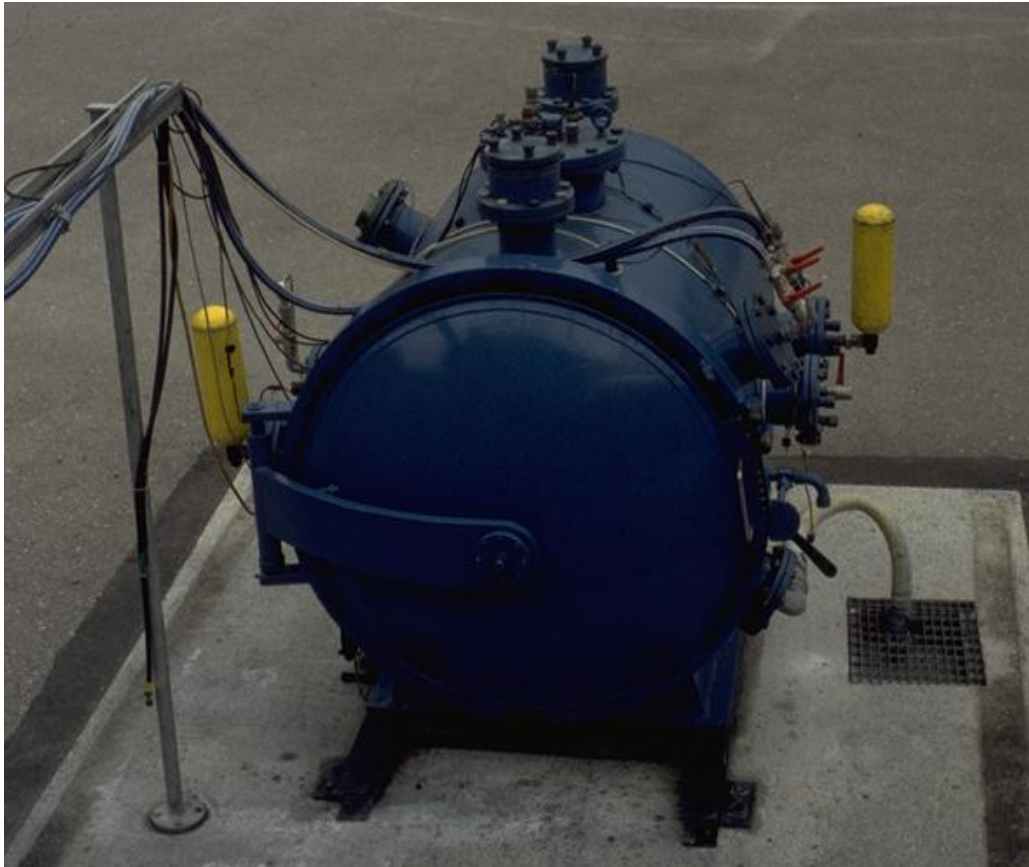


Figure 6-8. Vessel ($L/D_e = 1.55$) of 2.4-m³ content



Figure 6-9. Elongated 20-m³-vessel with a $L/D_e = 6.25$



Figure 6-10. Vertical elongated 20-m³-silo ($H/D_e = 6.25$) with explosion venting: dust explosion test

6.3.1.1 Standard design method

The following is applicable for dusts belonging to the dust explosion classes St 1 and St 2 having a maximum explosion overpressure $P_{\max} \leq 10$ bar and a dust explosion class St 3 with a maximum explosion overpressure $P_{\max} \leq 12$ bar and for operating overpressures for up to 0.2 bar. When using metal dusts of the same explosion classes, check the applicability of the following equations or consult experts.

In sizing the vent area for a vessel without obstructions, generally the completely empty volume must be considered. With obstructions present (e.g., filter bags on cages or filter elements (Fig. 6-11) the exterior volume of the filter elements can be deducted from the vessel volume. However, one must ensure that the venting process is not hindered by the obstructions /1, 5/.



Figure 6-11. Pocket filter with filter elements: Filter volume (dirty volume) = 7.5-m³; Volume of the filter elements = 2.5-m³; Free dirty volume = 5-m³

Therefore, the filter cages must not cover the vent area (Fig. 6-12). In case of doubt, a satisfactory venting capability must be documented.



Figure 6-12. Filter hoses obstructing vent area

The following empirical equation allows the calculation of the size of a vent area A (in m^2). One has to know the explosion strength P (in bar) of the vessel /1, 4/ (i.e., the anticipated maximum reduced explosion overpressure $P_{\text{red,max}}$), the static activation overpressure P_{stat} (in bar) of the venting device, the vessel volume V (in m^3), the length/diameter ratio L/D_e of the vessel to be protected, the explosion characteristics (maximum explosion overpressure P_{max} , maximum product specific constant K_{max}) and the reference area A^* (in m^2). If necessary, the calculated area may be subdivided into several single areas.

For $0.1 \text{ bar} < P_{\text{red,max}} < 1.5 \text{ bar}$

$$A = B (1 + C \cdot \log(L/D_e)) \text{ in } \text{m}^2$$

For $1.5 \text{ bar} \leq P_{\text{red,max}} \leq 2.0 \text{ bar}$

$$A = B \text{ in } \text{m}^2$$

With

$$B = [3.264 \cdot 10^{-5} \cdot P_{\max} \cdot K_{\max} \cdot P^{-0.569} + 0.27 (P_{\text{stat}} - 0.1) \cdot P^{-0.5}] \cdot V^{0.753}$$

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

The equations are valid for:

- vessel volumes $0.1 \text{ m}^3 \leq V \leq 10'000 \text{ m}^3$,
- static activation overpressure of venting device $0.1 \text{ bar} \leq P_{\text{stat}} \leq 1 \text{ bar}$,
for $P_{\text{stat}} < 0.1 \text{ bar}$ use $P_{\text{stat}} = 0.1 \text{ bar}$
- vessel strength (= $P_{\text{red,max}}$) $0.1 \text{ bar} < P \leq 2 \text{ bar}$ without vent duct,
- $P_{\text{red,max}}$ shall be at least $P_{\text{stat}} + 2$ times the tolerance range of P_{stat} ,
- maximum explosion overpressure $5 \text{ bar} \leq P_{\max} \leq 10 \text{ bar}$ for a maximum product specific constant $10 \text{ bar} \cdot \text{m} \cdot \text{s}^{-1} \leq K_{\max} \leq 300 \text{ bar} \cdot \text{m} \cdot \text{s}^{-1}$,
- maximum explosion overpressure $5 \text{ bar} \leq P_{\max} \leq 12 \text{ bar}$ for a maximum product specific constant $300 \text{ bar} \cdot \text{m} \cdot \text{s}^{-1} \leq K_{\max} \leq 800 \text{ bar} \cdot \text{m} \cdot \text{s}^{-1}$,
- $L/De \leq 20$,
- L/De is limited in the way that the maximum vent area shall not be greater than the cross area of the vessel or silo,
- venting efficiency $EF = 1$.

A is the vent area that shall be fitted to the enclosure assuming the venting efficiency factor of the venting device is $EF = 1$ and thus the effective vent area is equal to the geometric venting area (see Section 5.3.2). Some explosion venting devices have a venting efficiency less than 1, and the effective vent area is thus less than the geometric vent area. It is this effective vent area that shall be used in marking up the vent area A in practice.

If the maximum explosion overpressure, the maximum product specific constant or the static activation overpressure are smaller than the ones stated in the parameters, then the above equations may be used with the minimum value given above.

It is necessary to limit the upper maximum reduced explosion overpressure in the vessel or silos. Extensive testing has shown that the spread of results increases markedly with very small vent areas.

The required area for pressure venting increases with increased length (height) to diameter ratio, in comparison with the area requirement for $L/De = 1$ vessels (Fig. 6-13).

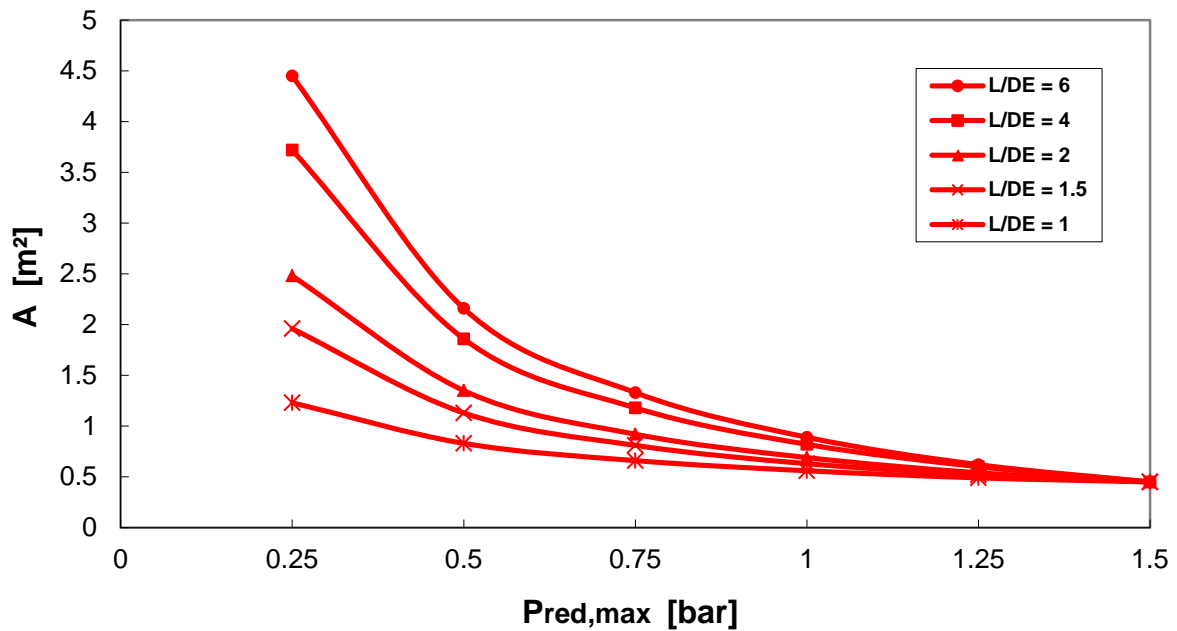


Figure 6-13. Influence of the ratio L/De on the relationship between the vent area A and maximum reduced explosion overpressure $P_{red,max}$ ($V = 20 \text{ m}^3$, $P_{stat} = 0.1 \text{ bar}$, $St 1$)

For low reduced maximum explosion overpressures, the required effective vent area will be markedly influenced by the ratio L/De . Such influence diminishes with increasing reduced explosion overpressure and ceases at $P_{red,max} = 1.5 \text{ bar}$ as per experimental results.

However, with a maximum reduced explosion overpressure $\geq 1.5 \text{ bar}$ no influence of the height / diameter ratio can be noticed.

6.3.1.2 Seizing of vent devices for special conveying systems

6.3.1.2.1 General

Vent areas, which have been sized in accordance with the following equations, can be used for practical applications provided the parameters stay within the range of validity given for the equations. This design is only valid for explosive dusts. It is **not** valid for **metal dusts** or for **hybrid mixtures**.

6.3.1.2.2 Pneumatic conveying of product with axial discharge into vessels/silos

Investigations with pneumatic conveying systems, which closely resembled practical applications, indicated that products discharged axially into vessels and silos generated a lower maximum explosion overpressure than the standard ones [19, 20]. The reason for this behaviour lies in a locally much lower dust concentration and turbulence than the ones generated with the standard method. The burning velocity of the dust-air-mixture is slower, resulting in a less explosion behaviour and a lower reduced explosion overpressure requiring a smaller venting area.

The following empirical equations may be used to calculate the required vent area A for cases using the outlined mode of filling.

With vessel height $L \leq 10$ m:

$$A = X (1 + Y \log (L/De)) \text{ in m}^2$$

With vessel height $L > 10$ m:

$$A = X (1 + Y \log (L/De)) \cdot 0.1 \cdot L \text{ in m}^2$$

With

$$X = [1/Dz (8.6 \cdot \log P - 6) - 5.5 \log P + 3.7] \cdot 0.011 \cdot K_{\max} \cdot DF$$

$$Y = 1.0715 \cdot P^{-1.27}$$

The equations independent of the load in the conveying stream are valid for:

- Axial and central discharge **from above** through **one** pipe with a diameter DF in m into a vessel/silo without obstructions (measurement devices are not considered),
- vessel volumes $10 \text{ m}^3 \leq V \leq 250 \text{ m}^3$, according to /1/ and up to $10'000 \text{ m}^3$ according to /4, 5/,
- air conveying speed of $v_F = 30 \text{ m} \cdot \text{s}^{-1}$ according to /1/ and up to $40 \text{ m} \cdot \text{s}^{-1}$ according to /4, 5/,
- air flow $Q \leq 2'500 \text{ m}^3 \cdot \text{h}^{-1}$,
- diameter of the conveying tube $DF \leq 0.3 \text{ m}$,
- static activation overpressure of venting device $P_{\text{stat}} \leq 0.1 \text{ bar}$,
- vessel strength (= Pred,max) $0.1 \text{ bar} < P \leq 2 \text{ bar}$; and Pred,max shall be at least $P_{\text{stat}} + 2$ times the tolerance range of P_{stat} ,
- maximum explosion overpressure $P_{\text{max}} \leq 9 \text{ bar}$,
- maximum product specific constant $50 \text{ bar} \cdot \text{m} \cdot \text{s}^{-1} \leq K_{\max} \leq 300 \text{ bar} \cdot \text{s}^{-1}$,
- venting efficiency $EF = 1$.

The size of the volume V which needs protection is to be equivalent to a cylinder which a length/diameter ratio = 1. The diameter Dz is calculated as follows:

$$D_z = 3 \sqrt[3]{\frac{4 \cdot V}{\pi}}$$

Note: The height of the product fall has no effect on the calculation of the required pressure vent areas, as these are based on the L/De of the vessel or silo.

A is the vent area that shall be fitted to the enclosure assuming the venting efficiency factor of the venting device is $EF = 1$ and thus the effective vent area is equal to the geometric venting area (see Section 5.3.2). Some explosion venting devices have a venting efficiency less than 1, and the effective vent area is thus less than the geometric vent area. It is this effective vent area that shall be used in marking up the vent area A in practice.

If the maximum explosion overpressure, the maximum product specific constant or the static activation overpressure are smaller than the ones stated in the parameters, then the above equations may be used with the minimum value given above.

Silos and bunkers may be placed or erected as single units (Fig. 6-14) or in clusters in open areas (Fig. 6-15) or as an integral part of a building.

As a rule, silos and bunkers are part of materials handling systems. The formation of the dust dispersion during filling depends upon the type of conveying system. When discharging the formation of the dust dispersion depends upon the product characteristic (e.g., tendency for bridging), the geometry and the condition of the wall surface (dust buildup).



Figure 6-14. Upright elongated vessels/silos

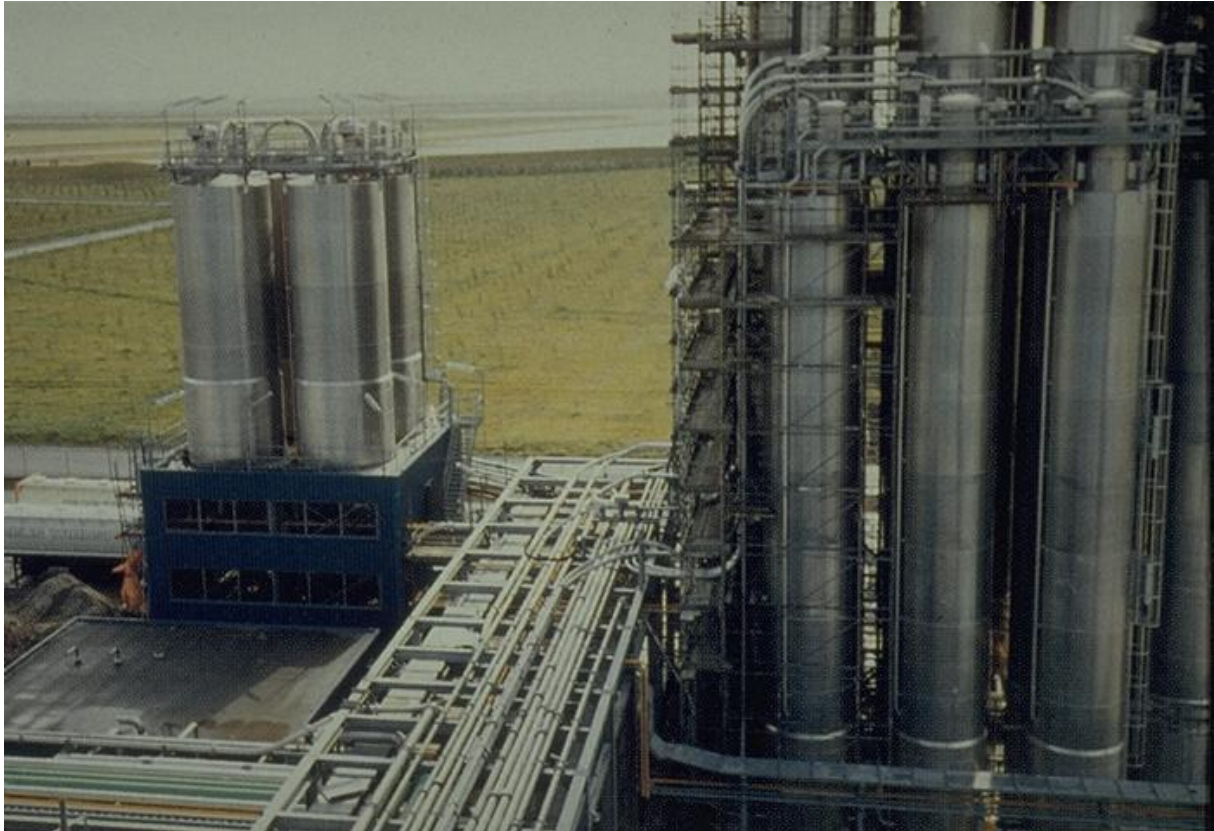


Figure 6-15. In clusters placed, upright elongated vessels/silos

Examine the building constraints that often limit explosion venting to the top of the silo. Often not even this area is available due to the space requirements of the conveying system (Fig. 6-16).



Figure 6-16. Roof of a silo, approximately 2/3 of roof used as vent area

The larger the height/diameter ratio is, the higher the required pressure resistance of the silo will be.

If silos must be vented on the side (Fig. 6-17) recoil forces must be considered according Section 11.



Figure 6-17. Silo vented on the side

In cases where silo clusters must be vented into a space, which is enclosed for weather protection (not an operating floor), e.g., silo floors (Fig. 6-18), such a space needs explosion venting (Fig. 6-19). Otherwise, the explosion must be prevented from propagating through other means (Fig. 6-20).



Figure 6-18. 20-m³-silo with a 100-m³-silo floor

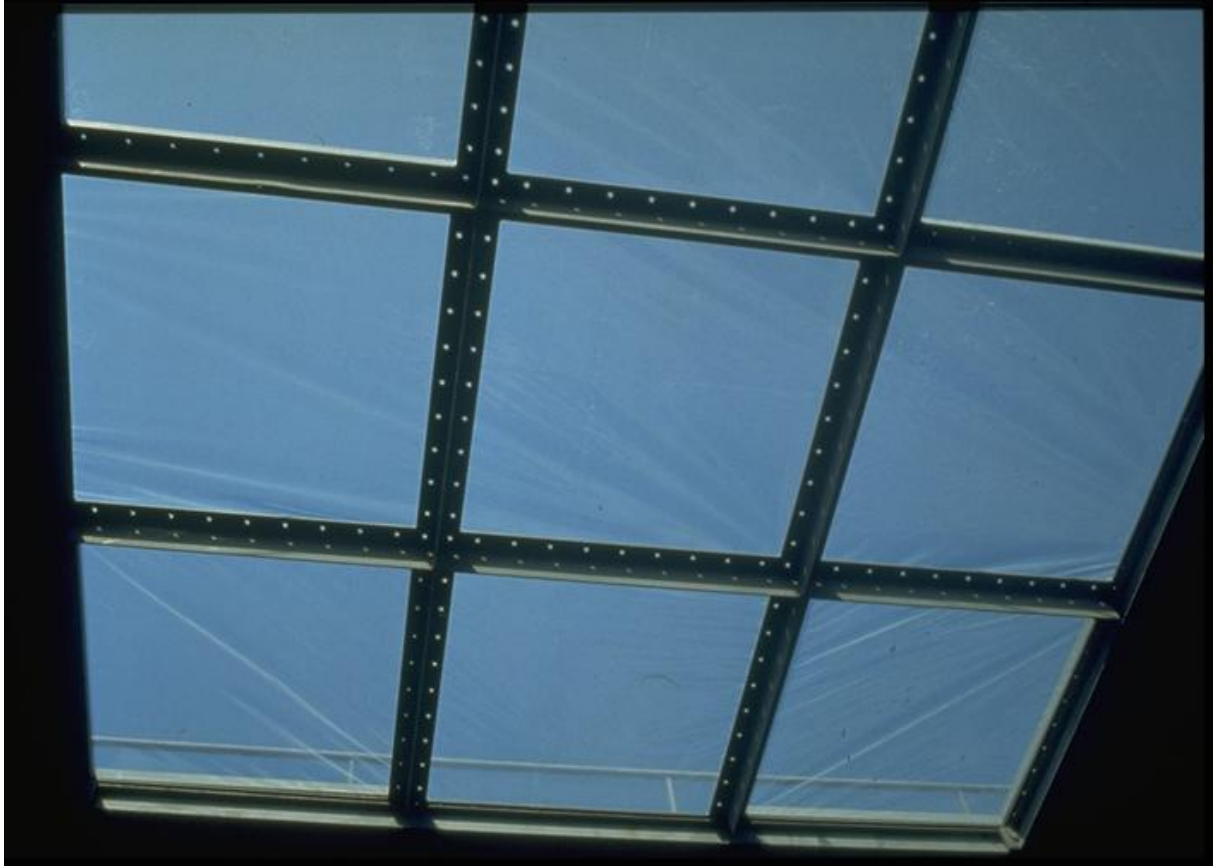


Figure 6-19. 20-m³-silo with vented silo floor



Figure 6-20. Extinguishing barrier inside the silo floor close to the vented silo top

6.3.1.2.3 Pneumatic conveying of product with tangential discharge into vessels/silos

The following empirical equations may be used to calculate the required vent area A for pneumatic filling of vessels and silos where the filling line is mounted tangential at the perimeter near the top of the vessel silo:

$$A = X (1 + Y \log (L/De)) \quad \text{in m}^2$$

with

$$X = [1/Dz (8.6/k \cdot \log P - K_{\max}/44 - 0.513) - 5.5/k \log P + K_{\max}/69 + 0.191] 0.011 \cdot K_{\max} \cdot DF$$

$$Y = 0.166 \cdot e^{K_{\max}/129} P^{-1.27/k}$$

with

$$k = 1 \text{ for } 0.1 \text{ bar} \leq P_{\text{red,max}} \leq 1 \text{ bar}$$

$$k = 2 \text{ for } 1 \text{ bar} < P_{\text{red,max}} \leq 1.7 \text{ bar}$$

The equations are valid independent from the product load of the conveying stream in case of tangential pneumatic filling for:

- **tangential** product release through **one** conveying tube with a diameter $DF \leq 0.2$ m,
- round vessels/silos without obstructions (measurement devices are not considered),
- vessel volumes $10 \text{ m}^3 \leq V \leq 120 \text{ m}^3$, according to /1/ and $6 \text{ m}^3 \leq V \leq 120 \text{ m}^3$ according to /4, 5/)
- air conveying speed of $v_F = 30 \text{ m} \cdot \text{s}^{-1}$,
- air flow $Q \leq 2'500 \text{ m}^3 \cdot \text{h}^{-1}$,
- length/diameter ratio $1 \leq L/De \leq 5$,
- static activation overpressure of venting device $P_{stat} \leq 0.1$ bar,
- vessel strength (= $P_{red,max}$) $0.1 \text{ bar} < P \leq 1.7 \text{ bar}$ and $P_{red,max}$ shall be at least $P_{stat} + 2$ times the tolerance range of P_{stat} ,
- maximum explosion overpressure $P_{max} \leq 9$ bar,
- maximum product specific constant $100 \text{ bar} \cdot \text{m} \cdot \text{s}^{-1} \leq K_{max} \leq 220 \text{ bar} \cdot \text{m} \cdot \text{s}^{-1}$,
- venting efficiency $EF = 1$.

A is the vent area that shall be fitted to the enclosure assuming the venting efficiency factor of the venting device is $EF = 1$ and thus the effective vent area is equal to the geometric venting area (see Section 5.3.2). Some explosion venting devices have a venting efficiency less than 1, and the effective vent area is thus less than the geometric vent area. It is this effective vent area that shall be used in marking up the vent area A in practice.

If the maximum explosion overpressure, the maximum product specific constant or the static activation overpressure are smaller than the ones stated in the parameters, then the above equations may be used with the minimum value given above.

6.3.1.2.4 Free fall filling (gravity)

The equations shown in Section 6.3.1.2.2 may be used to calculate the required vent area in case product enters the vessel/silo by free fall (gravity) from e.g., a rotary valve or screw feeder.

The equations independent of the load in the conveying stream are valid for:

- vessel volumes $10 \text{ m}^3 \leq V \leq 250 \text{ m}^3$, (EN) or $5 \text{ m}^3 \leq V \leq 10'000 \text{ m}^3$ (VDI),
- **axial, central** discharge **from above** through **one** feed opening in m^2 into a vessel/silo without obstructions,
- Equivalent diameter of the feed opening $DF \leq 0.3$ m,
- amount of product discharge $MP \leq 8'000 \text{ kg} \cdot \text{h}^{-1}$,
- static activation overpressure of rupture disk $P_{stat} \leq 0.1$ bar,
- $P_{red,max} > P_{stat}$,
- vessel strength (= $P_{red,max}$) $0.1 \text{ bar} \leq P \leq 2 \text{ bar}$ and $P_{red,max}$ shall be at least $P_{stat} + 2$ times the tolerance range of P_{stat} ,
- maximum explosion overpressure $P_{max} \leq 9$ bar,
- maximum product specific constant $50 \text{ bar} \cdot \text{m} \cdot \text{s}^{-1} \leq K_{max} \leq 300 \text{ bar} \cdot \text{m} \cdot \text{s}^{-1}$,
- venting efficiency $EF = 1$.

A is the vent area that shall be fitted to the enclosure assuming the venting efficiency factor of the venting device is $EF = 1$ and thus the effective vent area is equal to the geometric venting

area (see Section 5.3.2). Some explosion venting devices have a venting efficiency less than 1, and the effective vent area is thus less than the geometric vent area. It is this effective vent area that shall be used in marking up the vent area A in practice.

If the maximum explosion overpressure, the maximum product specific constant or the static activation overpressure are smaller than the ones stated in the parameters, then the above equations may be used with the minimum value given above.

6.4 Flammable Gases

The empirical equation given in /2, 3/ can be used to calculate the required vent area for flammable gas or solvent vapor explosions. The equation is valid for flammable gas-air-mixtures which have been ignited in a quiescent state (non-turbulent) with an ignition source of $E = 10 \text{ J}$.

With the known parameters such as constant maximum explosion overpressure of $P_{\max} = 6.8 - 8.9 \text{ bar}$, the maximum product specific constant K_{\max} , the vessel strength P (respectively the maximum reduced explosion overpressure $P_{\text{red,max}}$), the static activation overpressure P_{stat} of the rupture disk (explosion panel) and the vessel volume V the empirical equation will read as follows:

$$A = [(0.1265 \cdot \log K_{\max} - 0.0567) \cdot P^{-0.5817} + 0.1754 \cdot P^{-0.5722} \cdot (P_{\text{stat}} - 0.1)] V^{2/3}$$

The equation is valid for:

- vessel volumes $0.1 \text{ m}^3 \leq V \leq 1'000 \text{ m}^3$,
- length/diameter ratio $1 \leq L/D \leq 2$,
- static activation overpressure of rupture disk $0.1 \text{ bar} \leq P_{\text{stat}} \leq 0.5 \text{ bar}$,
- vessel strength (= $P_{\text{red,max}}$) $0.1 \text{ bar} \leq P \leq 2 \text{ bar}$,
- $P > P_{\text{stat}} + 0.05 \text{ bar}$,
- maximum explosion overpressure $P_{\max} \leq 9 \text{ bar}$,
- maximum product specific constant $50 \text{ bar} \cdot \text{m} \cdot \text{s}^{-1} \leq K_{\max} \leq 550 \text{ bar} \cdot \text{m} \cdot \text{s}^{-1}$,
- gas-air-mixtures ignited at zero turbulence,
- venting efficiency $EF = 1$.

A is the vent area that shall be fitted to the enclosure assuming the venting efficiency factor of the venting device is $EF = 1$ and thus the effective vent area is equal to the geometric venting area (see Section 5.3.2). Some explosion venting devices have a venting efficiency less than 1, and the effective vent area is thus less than the geometric vent area. It is this effective vent area that shall be used in marking up the vent area A in practice.

If the maximum explosion overpressure, the maximum product specific constant or the static activation overpressure are smaller than the ones stated in the parameters, then the above equations may be used with the minimum value given above.

Based on today's knowledge it is necessary to limit the upper maximum reduced explosion overpressure in the cubic vessel. Extensive testing has shown that the spread of results increases markedly with very small vent areas.

Flammable gas-air-mixtures with more or less turbulence or solvent vapor-air-mixtures exist in industrial applications. Therefore, venting tests with turbulent propane-air-mixtures were carried out in a 2-m^3 -vessel. The same test procedure was followed as with combustible dusts. The propane-air-mixture was maintained at 20 bar in a 5-ℓ-container. A detonator-activated valve released the mixture to a perforated semi-annular pipe inside the 2-m^3 -vessel. After a set delay time (t_v) an ignition source ($E = 10 \text{ J}$) was activated. The results were such that the equation for area requirements of quiescent propane-air-mixtures ($K_{\max} = 100 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$) is

also valid for light turbulent mixtures (delay time between valve opening and ignition $t_v = 0.6$ s). This is also true for high turbulence ($t_v = 0.3$ s) and large vent areas ($P_{\text{Pred,max}} = P \leq 0.5$ bar).

6.5 Venting of Building Enclosures

6.5.1 Combustible Dusts

For buildings $P (= P_{\text{Pred,max}})$ shall always exceed P_{stat} by at least 0.02 bar. The vent area shall be distributed as symmetrically and as evenly as possible over the available surface. The course of an explosion in buildings will be affected by several parameters such as the shape of the building, the presence of equipment and structural elements, the possibility of propagation from room to room and the presence of flammable dust left to lie on surfaces such as windowsills, pipe work and floors etc. The dust explosion may be limited to a small part of the total volume. Pressure development will vary according to circumstances and a wide range of dust explosion loads can be expected.

Vent areas on buildings shall be distributed uniformly over the wall and roof areas. In estimating P , ($P_{\text{Pred,max}}$) care shall be taken to ensure that the weakest structural element, as well as any equipment or other devices that can be supported by structural elements, is identified. All structural elements and supports shall be considered.

For example, floors and roofs are not usually designed to be loaded from beneath. However, a lightweight roof can be considered sacrificial, provided its movement can be tolerated and provided ice or snow does not hinder its movement.

The recommended venting equation for buildings is as follows:

$$A_e = c_v \times A_S \times P^{-0.5} \quad \text{in m}^2$$

where

A_e is the effective vent area, in m^2 ,

A_g is the geometric vent area $A_g = A_e/EF$, in m^2 ,

EF is the venting efficiency,

c_v is the venting equation constant:

$$0 < K_{\text{max}} \leq 100 : c_v = 0.018 \text{ bar}^{0.5},$$

$$100 < K_{\text{max}} \leq 200 : c_v = 0.026 \text{ bar}^{0.5},$$

$$200 < K_{\text{max}} \leq 300 : c_v = 0.030 \text{ bar}^{0.5},$$

A_S is the internal surface area of enclosure, in m^2 ,

P is the maximum explosion overpressure ($P_{\text{Pred,max}}$) developed in a vented enclosure during a vented deflagration. P in this application is not to exceed an overpressure of 0.1 bar.

Note 1:

For the calculation of the length-to-diameter ration of the room, (L/D_e) WinVent calculates the effective diameter as follows:

$$D_{\text{eff}} = D_e = 4 (A_c/L_p),$$

where

A_c is the cross-sectional area normal to the longest dimension, in square-meters (m^2);

L_p is the perimeter of cross-section, in meters (m).

Note 2:

The form of the venting formula is such that there are no dimensional constraints on the shape of the room, provided the vent area is not applied solely to one end of an elongated room. The vent area should be applied as evenly as possible over the available wall area; but if it is restricted to the end of an elongated room, the ratio of length-to-diameter of the room should not exceed 3.

For rooms with venting restricted to one end, the application of the venting formula is constrained as follows:

$$L < 12 \times A_c \times L_p^{-1} \quad \text{in m}$$

where

L is the longest dimension of the building, in meters (m);

A_c is the cross-sectional area normal to the longest dimension, in square-meters (m²);

L_p is the perimeter of cross-section, in meters (m).

6.5.2 Flammable Gases

EN 14994 has no formula for venting of building enclosures. Therefore, WinVent 4.0 uses the recommended venting formula from the NFPA 68, 2002. For buildings P (= $P_{\text{Pred,max}}$) shall always exceed P_{stat} by at least 0.02 bar. The vent area shall be distributed as symmetrically and as evenly as possible over the available surface. The course of an explosion in buildings will be affected by several parameters such as the shape of the building, the presence of equipment and structural elements and the possibility of propagation from room to room. The gas explosion may be limited to a small part of the total volume. Pressure development will vary according to circumstances and a wide range of gas explosion loads can be expected.

Vent areas on buildings shall be distributed uniformly over the wall and roof areas. In estimating P ($P_{\text{Pred,max}}$) care shall be taken to ensure that the weakest structural element, as well as any equipment or other devices that can be supported by structural elements, is identified. All structural elements and supports shall be considered.

For example, floors and roofs are not usually designed to be loaded from beneath. However, a lightweight roof can be considered sacrificial, provided its movement can be tolerated and provided ice or snow does not hinder its movement.

The recommended venting equation for buildings is as follows:

$$A_e = c \times A_S \times P^{-0.5} \quad \text{in m}^2$$

where

A_e is the effective vent area, in m²,

A_g is the geometric vent area $A_g = A_e/EF$, in m²,

EF is the venting efficiency,

c is the venting equation constant:

$$1 < K_{\text{max}} \leq 60 \quad : c = 0.037 \text{ bar}^{0.5},$$

$$60 < K_{\text{max}} \leq 130 \quad : c = 0.045 \text{ bar}^{0.5},$$

A_S is the internal surface area of enclosure, in m²,

P is the maximum explosion overpressure ($P_{\text{red,max}}$) developed in a vented enclosure during a vented deflagration. P in this application is not to exceed an overpressure of 0.1 bar, P_{stat} minimum 0.02 bar lower than P .

The internal surface area, AS , is the total area that constitutes the perimeter surfaces of the enclosure that is being protected. Non-structural internal partitions that cannot withstand the expected overpressure are not considered to be part of the enclosure surface area.

The enclosure internal surface area AS includes the roof or ceiling, walls, floor, and vent area and can be based on simple geometric figures. Surface corrugations are neglected, as well as minor deviations from the simplest shapes. Regular geometric deviations such as saw-toothed roofs can be "averaged" by adding the contributed volume to that of the major structure. The internal surface of any adjoining rooms should be included. Such rooms include adjoining rooms separated by a partition incapable of withstanding the expected overpressure.

The surface area of equipment and contained structures should be neglected.

Note: 1

For the calculation of the length-to-diameter ration of the room, WinVent calculates the effective diameter $D_{\text{eff}} = D_e$ as follows:

$$D_{\text{eff}} = D_e = 4 (A_c/L_p) \quad \text{in m}$$

where

A_c is the cross-sectional area normal to the longest dimension, in square-meters (m^2);

L_p is the perimeter of cross-section, in meters (m).

Note: 2

The form of the venting formula is such that there are no dimensional constraints on the shape of the room, provided the vent area is not applied solely to one end of an elongated room. The vent area should be applied as evenly as possible over the available wall area; but if it is restricted to the end of an elongated room, the ratio of length-to-diameter of the room should not exceed 3.

For rooms with venting restricted to one end, the application of the venting formula is constrained as follows:

$$L < 12 \times A_c \times L_p^{-1} \quad \text{in m}$$

where

L is the longest dimension of the building, in meters (m),

A_c is the cross-sectional area normal to the longest dimension, in square-meters (m^2),

L_p is the perimeter of cross-section, in meters (m).

If an enclosure contains a highly turbulent gas mixture and the vent area is restricted to one end, or

if the enclosure has any internal obstructions and the vent area is restricted to one end, then the L/D_e of the enclosure should not exceed 2, or the following formula should be used:

$$L < 8 \times Ac \times Lp^{-1} \quad \text{in m}$$

where

L is the longest dimension of the building, in meters (m),

Ac is the cross-sectional area normal to the longest dimension, in square-meters (m²),

Lp is the perimeter of cross-section, in meters (m).

6.6 Venting in combination with mechanical isolation systems

6.6.1 Introduction

WinVent calculates for single vessels like silos, mixers, filters, cyclones etc. either the required size of the venting device or the expected maximum reduced explosion overpressure in the vented vessel /21/.

This concept does not consider what types of equipment are installed upstream or downstream of the pressure-vented vessel.

It has been known for several years that closing the mechanical isolation system installed in a pipe connected to a vented vessel can result in a significant increase in the (WinVent) calculated reduced explosion overpressure $P_{red,max}$ in that vented vessel. This is due to the retroactive effects of closing the mechanical isolation system.

This task is not the responsibility of the WinVent software, as the design of the explosion isolation is not included in this software. However, it is the responsibility of the person who is in charge of designing the explosion venting system in combination with the explosion isolation system.

6.6.2 Estimation of smallest non-critical vented vessel volume

With the help of K_{max} and the diameter of the pipe D_p equipped with a mechanical isolation system MIS is possible to estimate the smallest non-critical vessel volume V_{nc} /22, 23/.

$$V_{nc} = (D_p)^2 \cdot \pi / 4 \cdot \text{EXP} ((1.2 - 252.58 \cdot (K_{max})^{-0.85}) / (-65.531 \cdot (K_{max})^{-1}))$$

If the vessel volume used in the WinVent software is equal to or smaller than the calculated smallest volume of the non-critical vessel V_{nc} , no problem will arise when a pipe equipped with a mechanical isolation system is connected to the vented vessel. This calculation of V_{nc} is only valid for K_{max} values between 70 and 230 m·bar·s⁻¹.

7 Design of Vacuum Breakers

An unacceptably high vacuum is prevented if the vacuum breaker is sized in with the following equation, which describes the correlation of the minimum required suction area with the size of the protected vessel or silo and its vacuum resistance:

$$A_{suc} = [-0.00219 \times \text{LN} (P_{vac}) + 0.014] \cdot V^{(-0.0207 \times \text{LN} (P_{vac}) + 0.8147)}$$

With

A_{suc} = effective suction area in m^2 ,

P_{vac} = vacuum resistance of vessel in mbar,

V = vessel volume in m^3 .

The equation is valid for:

- vessel volumes $5 \leq V \leq 5'000 \text{ m}^3$,
- vacuum resistance $25 \leq P_{vac} \leq 500 \text{ mbar}$.

Figure 7-1 shows an explosion door with integral vacuum breaker.



Figure 7-1. Explosion door with integral vacuum breaker to avoid an inadmissibly high vacuum /15/

Figure 7-2 shows the roof of a coal silo fitted with several explosion doors with integrated vacuum breakers.



Figure 7-2. Explosion doors with integral vacuum breakers to avoid an inadmissibly

8 Hazards due to Flame and Pressure

Explosion venting is always accompanied by flame propagation (Figs. 8-1 and 8-2) plus pressure consequences in the surrounding areas.



Figure 8-1. Dust explosion in a vented 7.5-m³-filter with standard dust dispersion

The reason for this is the unburned product, which is pushed outside once the vent system actuates. The fuel-air-mixture generated externally is then ignited by a flame jet exiting the vent area. The flame length will be larger with a lesser static activation overpressure and smaller vent area.

Dependent on the volume of the equipment it can reach up to 60 m (Fig. 8-3). Longer ranges of flame than 60 m even in case of greater volumes are not to be expected.

The venting process should not endanger personnel. In addition, the operation of any equipment, which is important regarding safety, should not be restricted. This shall be considered when designing the plant and may be accomplished by releasing the pressure upwards (Fig. 8-3).



Figure 8-2. Gas explosion in a vented 25-m³-vessel with propane-air-mixture ignited at zero turbulence



Figure 8-3. Dust explosion in a 250-m³-vessel with standard dust dispersion, venting upwards

If a pressure venting upwards is not feasible, then the vent openings should be placed as high as possible at the side of the vessel. For this, the recoil forces with respect to the overturning moment must be considered, see Section 12.

Large fireballs were observed during vented dust explosion in cases where additional dust deposits accumulated near the vent opening (Fig. 8-4). *The lower edge of the vent must be sufficiently higher than the maximum dust pile to limit the danger of dust discharge.*



Figure 8-4. Dust explosion in a filter housing with additional deposits of loose dust near the venting area by standard dust dispersion

8.1 Open Air Installations

8.1.1 Standard dust cloud conditions

With open-air installations one must ensure that escaping flames and pressure does not jeopardize the surroundings. Combustible materials (e.g., roofing material) shall not exist near the vent opening. When using metal dusts instead of organic dust check the applicability of the following equations or consult experts.

8.1.1.1 Flame propagation

The maximum external flame length LF emanating from a vessel increases as the volume of the vented vessel increases. Figure 8-5 clearly shows that the maximum external flame length LF increases as the venting vessel volume increases. Since the horizontal flame length is not expected to exceed 60 m and the vertical flame length is not expected to exceed 50 m in vessels with a volume of $V \geq 250 \text{ m}^3$, these two limits are taken as the upper limits for estimating the maximum external flame length LF.

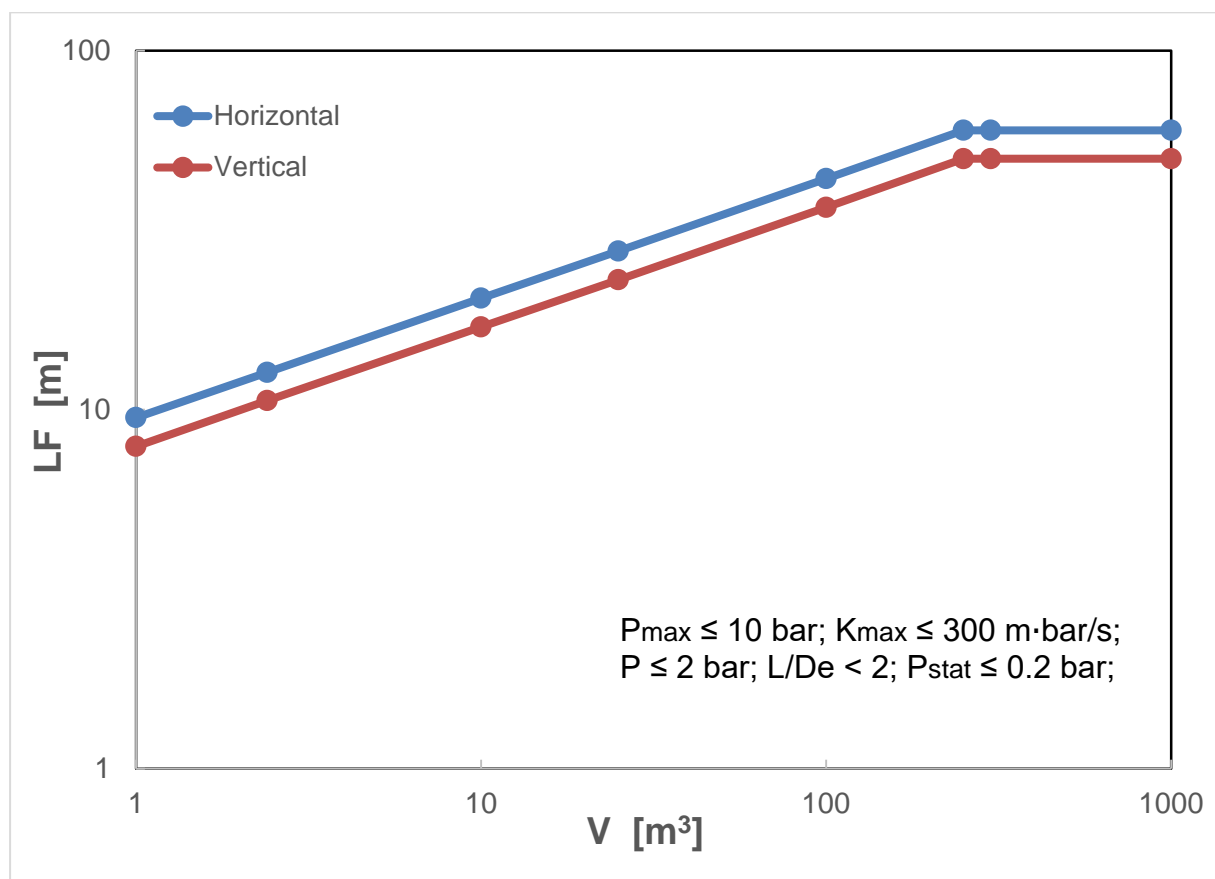


Figure 8-5. Maximum external flame length LF of standard dust cloud explosions into the outside area of vented vessels V without vent duct

The LF is determined using the following slightly modified empirical equations, considering the 60 m and 50 m limits mentioned above:

For horizontal venting:

$$LF_h = 9.5 \cdot V^{1/3} = 9.5 \cdot 250^{1/3} = 60 \text{ m}$$

For vertical venting:

$$LF_v = 7.9 \cdot V^{1/3} = 7.9 \cdot 250^{1/3} = 50 \text{ m}$$

For vessel volumes above 250 m³, LF remains constant.

Note:

Hybrid dust-propane-air-mixtures have the same range of the flame as dust-air-mixtures.

The equations are valid for:

- vessel volumes $0.1 \text{ m}^3 \leq V \leq 10'000 \text{ m}^3$,
- static activation overpressure of the rupture disk $0.1 \text{ bar} \leq P_{\text{stat}} \leq 0.2 \text{ bar}$,
- maximum vessel strength (= Pred,max) of $0.1 \text{ bar} < P \leq 2 \text{ bar}$, with $P_{\text{Pred,max}} > P_{\text{stat}}$,
- maximum explosion overpressure $5 \text{ bar} \leq P_{\text{max}} \leq 10 \text{ bar}$,
- maximum product specific constant $10 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1} \leq K_{\text{max}} \leq 300 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$,
- $L/De < 2$,
- Only valid for vessels without vent duct.

Since the LF has been limited, it also makes sense to limit the external width of the flame WF accordingly. The maximum external width of a flame WF is determined for horizontal and vertical venting according to the following slightly modified empirical equation:

$$WF = 2.7 \cdot V^{1/3} = 2.7 \cdot 250^{1/3} = 17 \text{ m}$$

For vessel volumes above 250 m³, WF remains constant.

The equation is valid for:

- vessel volumes $0.1 \text{ m}^3 \leq V \leq 10'000 \text{ m}^3$,
- static activation overpressure of the rupture disk $0.1 \text{ bar} \leq P_{\text{stat}} \leq 0.2 \text{ bar}$,
- maximum vessel strength (= Pred,max) of $0.1 \text{ bar} < P \leq 2 \text{ bar}$, with $P_{\text{Pred,max}} > P_{\text{stat}}$,
- maximum explosion overpressure $5 \text{ bar} \leq P_{\text{max}} \leq 10 \text{ bar}$,
- maximum product specific constant $10 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1} \leq K_{\text{max}} \leq 200 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$,
- $L/De < 2$,
- only valid for vessels without vent duct.

Tests have shown that if the vent area is subdivided into several single areas the maximum flame range will not be reduced.

Figure 8-6 clearly shows that with increasingly venting vessel volume the maximum external flame width WF of dust explosions increases up to remain constant above $V = 250 \text{ m}^3$.

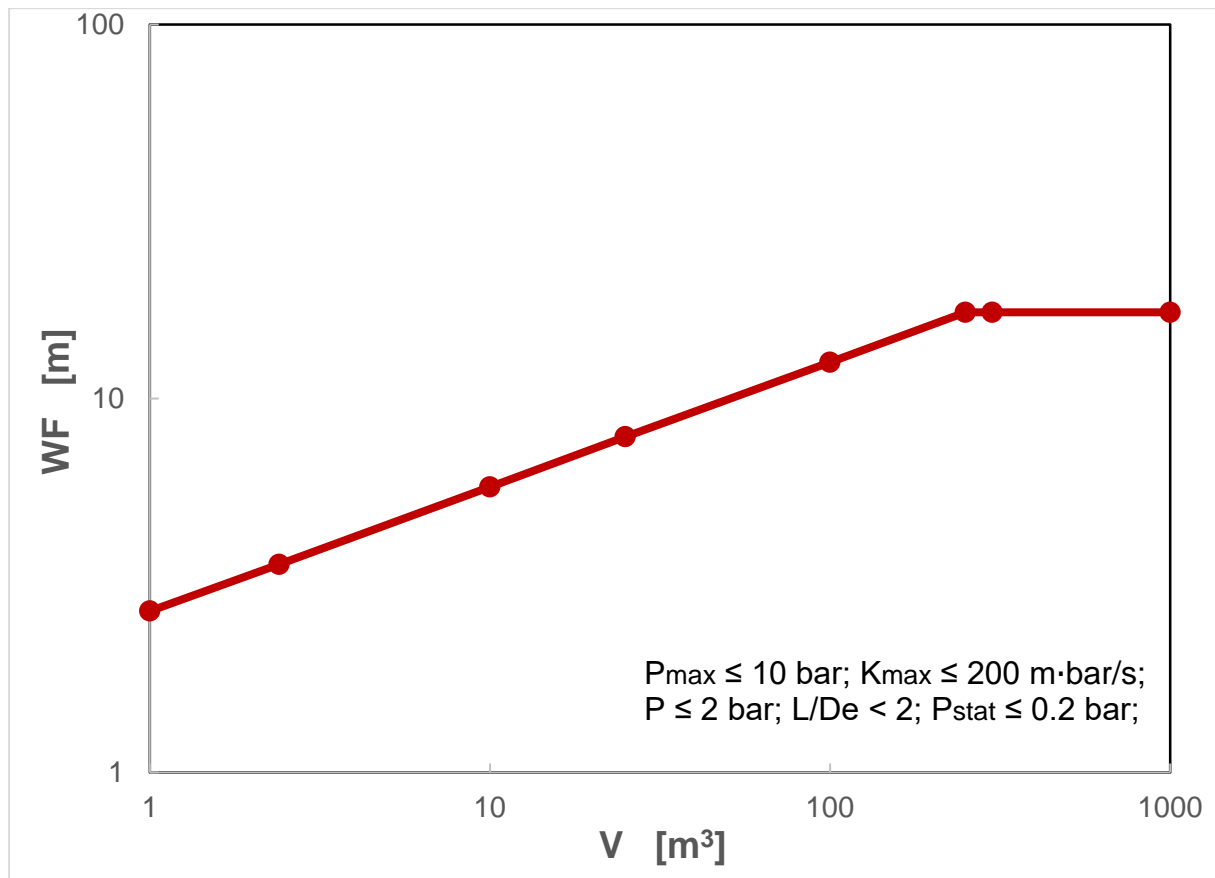


Figure 8-6. Maximum external flame width WF of standard dust cloud explosions into the outside area of vented vessels V without vent duct

No information is currently available on the maximum external flame range for elongated vessels and silos. Longer flames ranges are expected for elongated vessels with a height to diameter ratio $H/D \geq 2$.

8.1.1.2 Deflectors

The extent of the flame produced by a vented explosion external to the enclosure can be limited by deflectors. These can be designed and installed to reduce flame length. A possible design of deflector plate, and its installation, is shown in Figure 8.7.

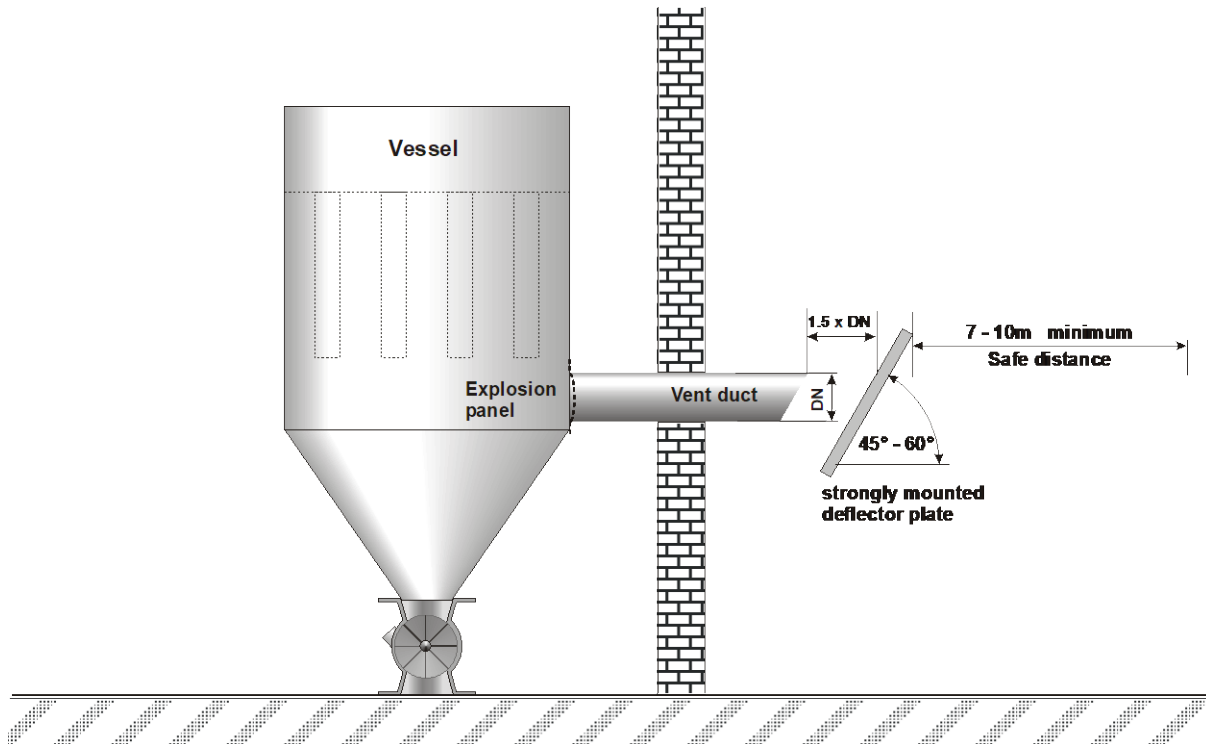


Figure 8-7. Design of a deflector plate

The area of the plate should be at least three times the area of the vent, and its dimensions should be at least 1.6 x the dimensions of the vent. The plate should be inclined at least 45° - 60° to the horizontal to deflect the ejected flame upwards. The plate should be installed at a sufficient distance from the vent to ensure that it does not act as an obstacle to the venting process and so cause an increase in the reduced explosion pressure inside the enclosure. Neither should the plate be installed at too great a distance from the vent; the distance of 1.5 DN given in Figure 8.7, where DN is the nominal diameter of the vent, has been shown to be satisfactory in explosion trials, but may need to be modified in practice, depending on circumstances. The plate should be mounted so that it can withstand the force exerted by the vented explosion, which can be calculated by multiplying the reduced explosion pressure by the area of the plate.

The length of the flame along the axis of the vent is limited by the plate. Explosion trials show that, a deflector plate positioned as in Figure 8.7 approximately halves the length of the flame compared to when the plate is absent. A safe distance beyond the deflector should be specified from which personnel are excluded while the plant is operating. The plate deflects flame sideways and the lateral extent of the safe area should be sufficient to avoid harm from this sideways deflection.

Deflectors should not be installed when the enclosure volume is greater than 40 m³ because test were only performed with vessel volumes up to 35 m³ /24/ (Fig. 8.8).



Figure 8-8. Test with a deflector plate

Note:

Such deflectors reduce flame lengths by approximately 50%.

8.1.1.3 Pressure effects

Because there are many different effects, only guiding statements are possible regarding the pressure propagation outside a cubic vessel near the vent area. Two pressure peaks characterize the pressure/time behaviour. The venting process (primary explosion) and the other cause one by the subsequent ignition of an externally created dust-air-mixture (secondary explosion). They both are influenced by the product specific constant K_{max} and the location of the ignition in the vessel.

The maximum external overpressure P_{Amax} for standard dust cloud explosions ignited in a cubic vessel vented by rupture discs arising at outside the vented enclosure can either be due to one of these two above-mentioned effects. Therefore, both shall be calculated, and the worst (highest) value shall be used. When using metal dusts instead of organic dust check the applicability of the following equations or consult experts.

8.1.1.3.1 Overpressure due to the explosion of the dust cloud in the area outside the vent (secondary explosion)

Figure 8.9 demonstrate the meaning of secondary explosion.



Figure 8-9. Explanation of the secondary explosion outside the vented vessel

The maximum external overpressure P_{Amax} can be estimated using the following formula:

$$P_{Amax} = 200 \cdot P_{red,max} \cdot A^{0.1} \cdot V^{0.18} = 200 \cdot P_o \cdot A^{0.1} \cdot V^{0.18} \text{ in mbar}$$

For vessel volumes above 250 m³, P_{Amax} remains constant.

This estimated external overpressure can be expected at a distance $R_s = 0.25 \cdot LF$ in axial discharge direction from the vent area A.

Figure 8-10 shows the measured R_s for different vented vessel volumes. The maximum value of the external overpressure P_{Amax} at a distance R_s from the venting area increases up to a volume of $V = 250 \text{ m}^3$ and then it is assumed that it does not change anymore.

As with the maximum external flame length LF and the maximum external width of a flame WF , it can be assumed that the calculated distance R_s are also limited and will not further increase above of $V = 250 \text{ m}^3$.

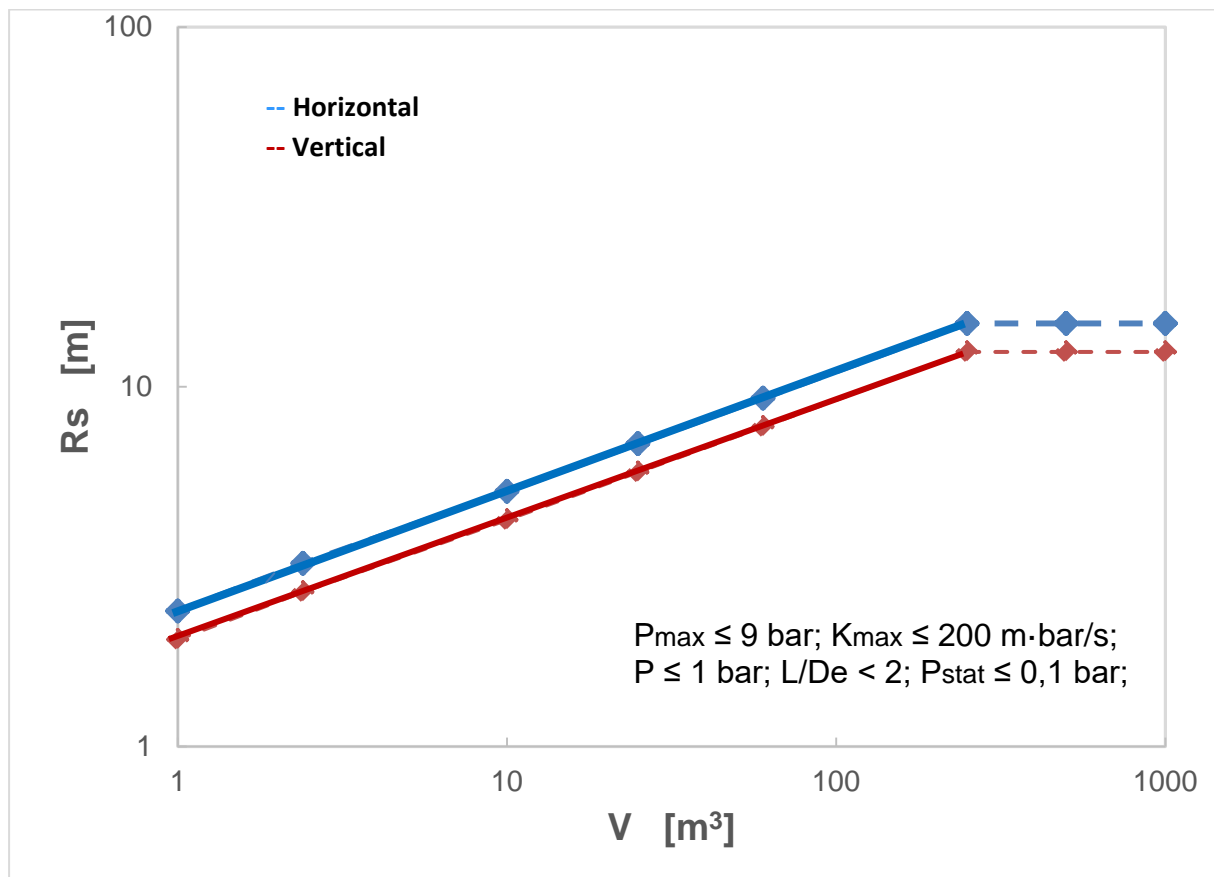


Figure 8-10. The calculated expected distance R_s as a function of different horizontally or vertically vented vessels V without vent duct

The corresponding distance R_s at with the maximum external overpressure P_{Amax} will occur, can be calculated as follows:

For horizontal venting:

$$R_s = 0.25 \cdot 9.5 \cdot V^{1/3} = \underline{2.38 \cdot V^{1/3}} = 2.38 \cdot 250^{1/3} = 15 \text{ m}$$

For vertical venting:

$$R_s = 0.25 \cdot 7.9 \cdot V^{1/3} = \underline{1.98 \cdot V^{1/3}} = 1.98 \cdot 250^{1/3} = 12.5 \text{ m}$$

For larger vessel volumes as 250 m^3 the R_s remains constant.

For larger distances, r ($r > R_s$), from the vent, the external overpressure P_{Ar} decreases as follows:

$$P_{Ar} = P_{Amax} \cdot (R_s/r)^{1.5}$$

For vessel volumes above 250 m^3 , P_{Ar} remains constant.

The equations are valid **for**:

- vessel volumes $0.1 \text{ m}^3 \leq V \leq 250 \text{ m}^3$,
- static activation overpressure of the rupture disk $P_{stat} = 0.1 \text{ bar}$,
- maximum vessel strength (= $P_{red,max}$) $0.1 \text{ bar} < P \leq 1 \text{ bar}$,
- maximum explosion overpressure $5 \text{ bar} \leq P_{max} \leq 9 \text{ bar}$,
- maximum product specific constant $10 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1} \leq K_{max} \leq 200 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$,
- $L/De < 2$,
- Only valid for vessels without vent duct.

Which effect such peak pressures may have on parts of constructions can be taken from annex 21.3.

At present no information are available on the pressure behaviour outside elongated vessels and silos near the vent area.

8.1.1.3.2 Overpressure due to the vented explosion (primary explosion)

Figure 8.10 demonstrate the meaning of primary explosion.

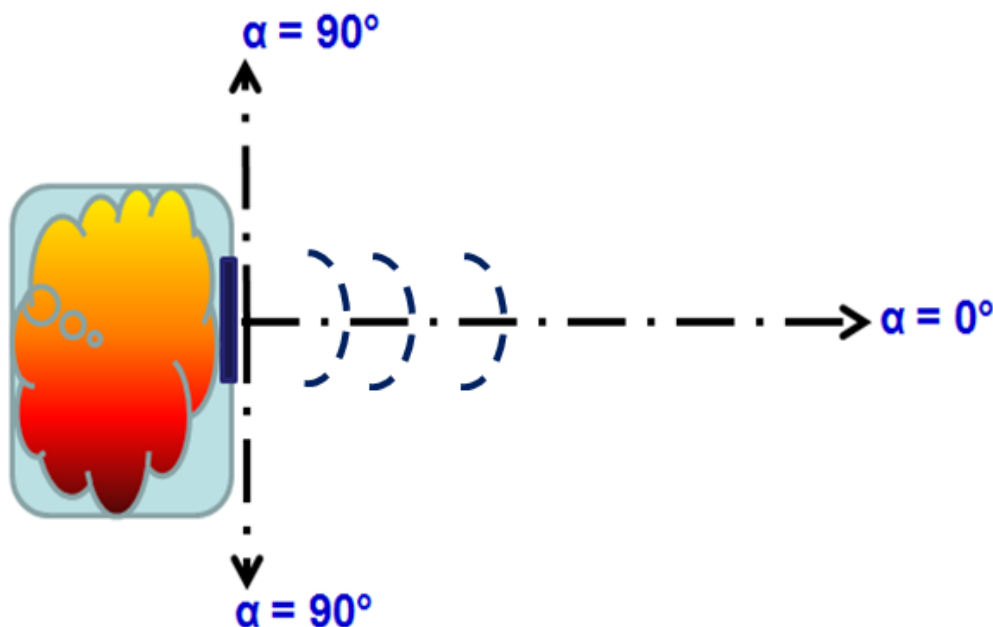


Figure 8-10. Explanation of the primary explosion – no secondary explosion outside

The maximum external overpressure P_{Ar} at a certain location can be estimated using the following formula (see also Fig 8-10):

$$P_{Ar} = 1.24 \cdot P_{red,max} \cdot (D_H/r)^{1.35} / (1+(\alpha/56)^2) \text{ in bar}$$

Where

r is the distance from the vent area, in m with $r > R_s$,

D_H is the hydraulic diameter of the vent area, in m².

$\alpha = 0^\circ$ means in front of the vent area,

$\alpha = 90^\circ$ means sideways from the vent area.

The equations are valid for:

- vessel volumes $0.1 \text{ m}^3 \leq V \leq 250 \text{ m}^3$,
- static activation overpressure of the rupture disk $P_{stat} = 0.1 \text{ bar}$,
- maximum vessel strength (= $P_{red,max}$) $0.1 \text{ bar} < P \leq 1 \text{ bar}$,
- maximum explosion overpressure $5 \text{ bar} \leq P_{max} \leq 9 \text{ bar}$,
- maximum product specific constant $10 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1} \leq K_{max} \leq 200 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$,
- $L/De < 2$,
- only valid for vessels without vent duct.

Figure 8-11 shows the definition of hydraulic diameter D_H of vent devices with different shapes.

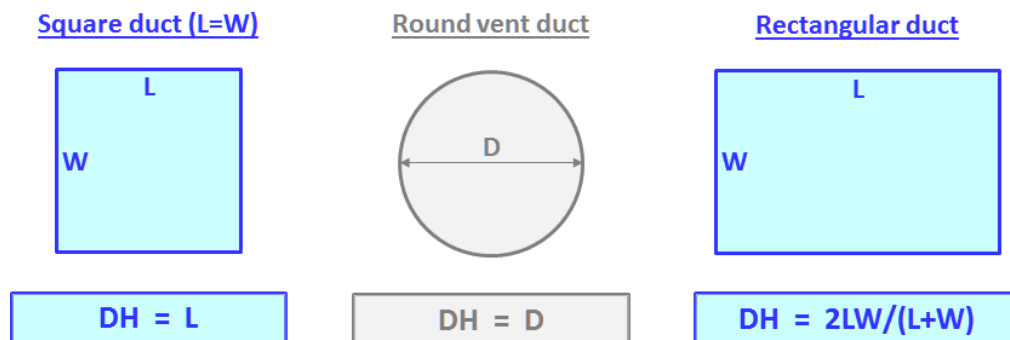


Figure 8-11. Definition of hydraulic diameter D_H of vent devices with different shapes
 $DH = 4A/P_{\text{perimeter}}$

Which effect such peak pressures may have on parts of constructions can be taken from annex 21.3.

The EN 14491 recommends that both effects of primary and secondary explosion shall be calculated and the worst (highest) value shall be used.

The following Table 8-12 compares the two calculation methods using 2 different vessel sizes and 3 different pressure resistance of the vessel.

Table 8-12. Comparison of the horizontal calculation methods for secondary and primary dust explosion in front of the vent area (without vent duct)

$V = 10 \text{ m}^3$; $L/D = 1$; $P_{\text{max}} = 9 \text{ bar}$; $K_{\text{max}} = 100 \text{ m bar/s}$; $P = 0.3 \text{ bar}$; $A = 0.33 \text{ m}^2$, $P_{\text{stat}} = 0.1 \text{ bar}$ $PA_{\text{max}} = 81 \text{ mbar}$ at $R_s = 5.1 \text{ m}$		
Equation	Secondary Explosion Cloud outside $\alpha = 0^\circ$	Primary Explosion Cloud outside $\alpha = 0^\circ$
External Pressure P_{Ar} at $r = 10.2 \text{ m}$	29 mbar	9 mbar
External Pressure P_{Ar} at $r = 20 \text{ m}$	11 mbar	4 mbar

$V = 10 \text{ m}^3$; $L/D = 1$; $P_{\text{max}} = 9 \text{ bar}$; $K_{\text{max}} = 200 \text{ m bar/s}$; $P = 0.3 \text{ bar}$; $A = 0.66 \text{ m}^2$, $P_{\text{stat}} = 0.1 \text{ bar}$ $PA_{\text{max}} = 87 \text{ mbar}$ at $R_s = 5.1 \text{ m}$		
Equation	Secondary Explosion Cloud outside $\alpha = 0^\circ$	Primary Explosion Cloud outside $\alpha = 0^\circ$
External Pressure P_{Ar} at $r = 10.2 \text{ m}$	31 mbar	14 mbar
External Pressure P_{Ar} at $r = 20 \text{ m}$	11 mbar	6 mbar

$V = 10 \text{ m}^3$; $L/D = 1$; $P_{\text{max}} = 9 \text{ bar}$; $K_{\text{max}} = 200 \text{ m bar/s}$; $P = 0.5 \text{ bar}$; $A = 0.49 \text{ m}^2$, $P_{\text{stat}} = 0.1 \text{ bar}$ $PA_{\text{max}} = 141 \text{ mbar}$ at $R_s = 5.1 \text{ m}$		
Equation	Secondary Explosion Cloud outside $\alpha = 0^\circ$	Primary Explosion Cloud outside $\alpha = 0^\circ$
External Pressure P_{Ar} at $r = 10.2 \text{ m}$	50 mbar	20 mbar
External Pressure P_{Ar} at $r = 20 \text{ m}$	18 mbar	8 mbar

$V = 10 \text{ m}^3$; $L/D = 1$; $P_{\text{max}} = 9 \text{ bar}$; $K_{\text{max}} = 200 \text{ m bar/s}$; $P = 1 \text{ bar}$; $A = 0.33 \text{ m}^2$, $P_{\text{stat}} = 0.1 \text{ bar}$ $PA_{\text{max}} = 271 \text{ mbar}$ at $R_s = 5.1 \text{ m}$		
Equation	Secondary Explosion Cloud outside $\alpha = 0^\circ$	Primary Explosion Cloud outside $\alpha = 0^\circ$
External Pressure P_{Ar} at $r = 10.2 \text{ m}$	97 mbar	30 mbar
External Pressure P_{Ar} at $r = 20 \text{ m}$	35 mbar	12 mbar

$V = 30 \text{ m}^3$; $L/D = 1$; $P_{\text{max}} = 9 \text{ bar}$; $K_{\text{max}} = 200 \text{ m bar/s}$; $P = 0.5 \text{ bar}$; $A = 1.1 \text{ m}^2$, $P_{\text{stat}} = 0.1 \text{ bar}$ $PA_{\text{max}} = 186 \text{ mbar}$ at $R_s = 7.4 \text{ m}$		
Equation	Secondary Explosion Cloud outside $\alpha = 0^\circ$	Primary Explosion Cloud outside $\alpha = 0^\circ$
External Pressure P_{Ar} at $r = 14.8 \text{ m}$	66 mbar	20 mbar
External Pressure P_{Ar} at $r = 30 \text{ m}$	23 mbar	8 mbar

$V = 30 \text{ m}^3$; $L/D = 1$; $P_{\text{max}} = 9 \text{ bar}$; $K_{\text{max}} = 200 \text{ m bar/s}$; $P = 1 \text{ bar}$; $A = 0.76 \text{ m}^2$, $P_{\text{stat}} = 0.1 \text{ bar}$ $PA_{\text{max}} = 359 \text{ mbar}$ at $R_s = 7.4 \text{ m}$		
Equation	Secondary Explosion Cloud outside $\alpha = 0^\circ$	Primary Explosion Cloud outside $\alpha = 0^\circ$
External Pressure P_{Ar} at $r = 14.8 \text{ m}$	127 mbar	32 mbar
External Pressure P_{Ar} at $r = 30 \text{ m}$	44 mbar	12+ mbar

It can clearly be seen that a secondary dust explosion in front of the venting area will always result in pressures outside the vented vessel that are approximately 2 to 4 times higher.

8.1.2 Pneumatic conveying of product into vessels and silos

With open-air installations, one must ensure that escaping flames and pressure does not jeopardize the surroundings. Combustible materials (e.g., roofing material) should not exist near the vent opening. The following is only valid for explosive dusts **without metal dusts**.

8.1.2.1 Flame propagation

The maximum external flame length LF originating from non-standard dust cloud explosions in vessels **decreases** with increased size of cubic, vented vessels V. The empirical equation is as follows:

$$LF = 30 \cdot V^{-1/3} \quad \text{in m}$$

LF calculation is not valid for metal dust.

The equation is valid for:

- vessel volumes $10 \text{ m}^3 \leq V \leq 250 \text{ m}^3$,
- static activation overpressure of the rupture disk $P_{\text{stat}} = 0.1 \text{ bar}$,
- maximum vessel strength (= $P_{\text{red,max}}$) $0.1 \text{ bar} < P \leq 1 \text{ bar}$,
- $P_{\text{red,max}} > P_{\text{stat}}$
- maximum explosion overpressure $5 \text{ bar} \leq P_{\text{max}} \leq 9 \text{ bar}$,
- maximum product specific constant $10 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1} \leq K_{\text{max}} \leq 200 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$,
- $L/De < 2$,
- only valid of vessels without vent duct.

Figure 8-13 shows that the maximum external flame length LF changes - as in the case of standard dust cloud explosions - with the third root of the vented vessel volume V. In contrast to the standard dust cloud explosions, the maximum external flame length LF for the non-standard dust cloud explosions decreases with increasing vented vessel volume V.

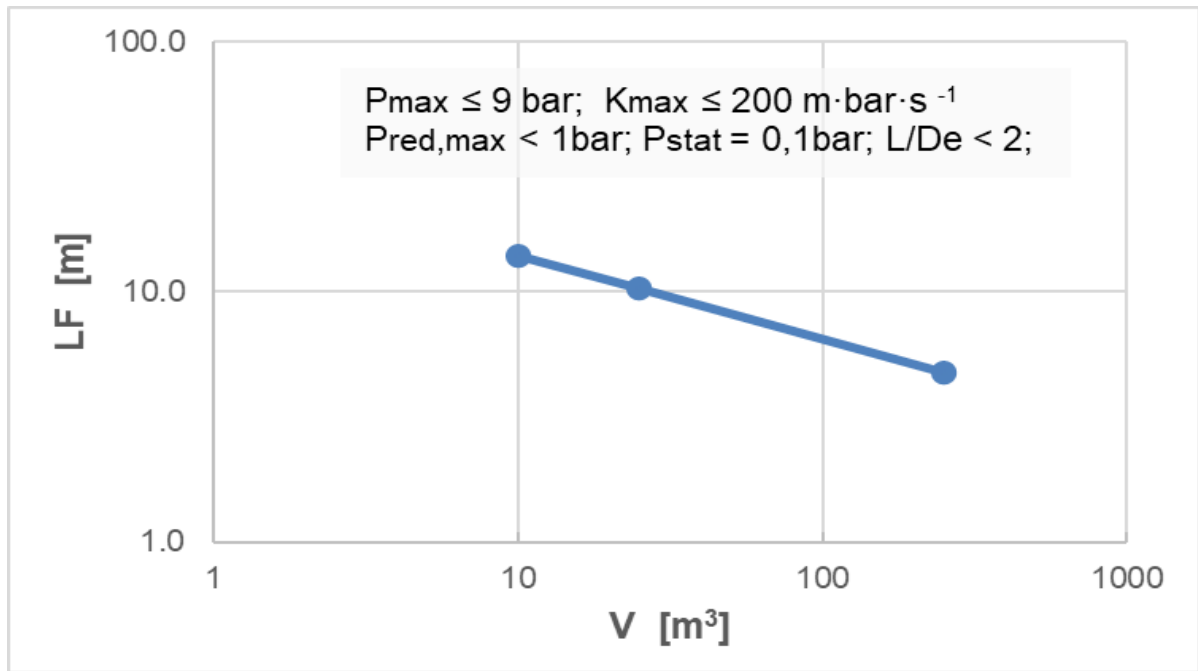


Figure 8-13. Maximum external flame length LF of pneumatic conveying systems into the outside area of vented vessels V without vent duct

Tests have shown that if the vent area is subdivided into several single areas the maximum flame range will not be reduced.

At present, no guidance can be given for flame ranges from elongated vessels and silos. It is expected that the length of the flame will be longer for elongated vessels with a height/diameter ratio $H/D \geq 2$.

8.1.2.2 Pressure effect

The maximum external overpressure P_{Amax} for non-standard dust cloud explosions in a cubic vessel vented by rupture discs arising at outside the vented enclosure can be **estimated** using the following formula:

$$P_{Amax} = 200 \cdot P_{red,max} \cdot A^{0.1} \cdot V^{0.18} = 200 \cdot P_o \cdot A^{0.1} \cdot V^{0.18} \text{ in mbar}$$

P_{Amax} calculation is not valid for metal dust.

This maximum external overpressure can be expected at an **estimated** distance R_s in axial discharge direction from the vent area A.

$$R_s = 0.25 \cdot LF = 0.25 \cdot 30 \cdot V^{1/3} \text{ in m}$$

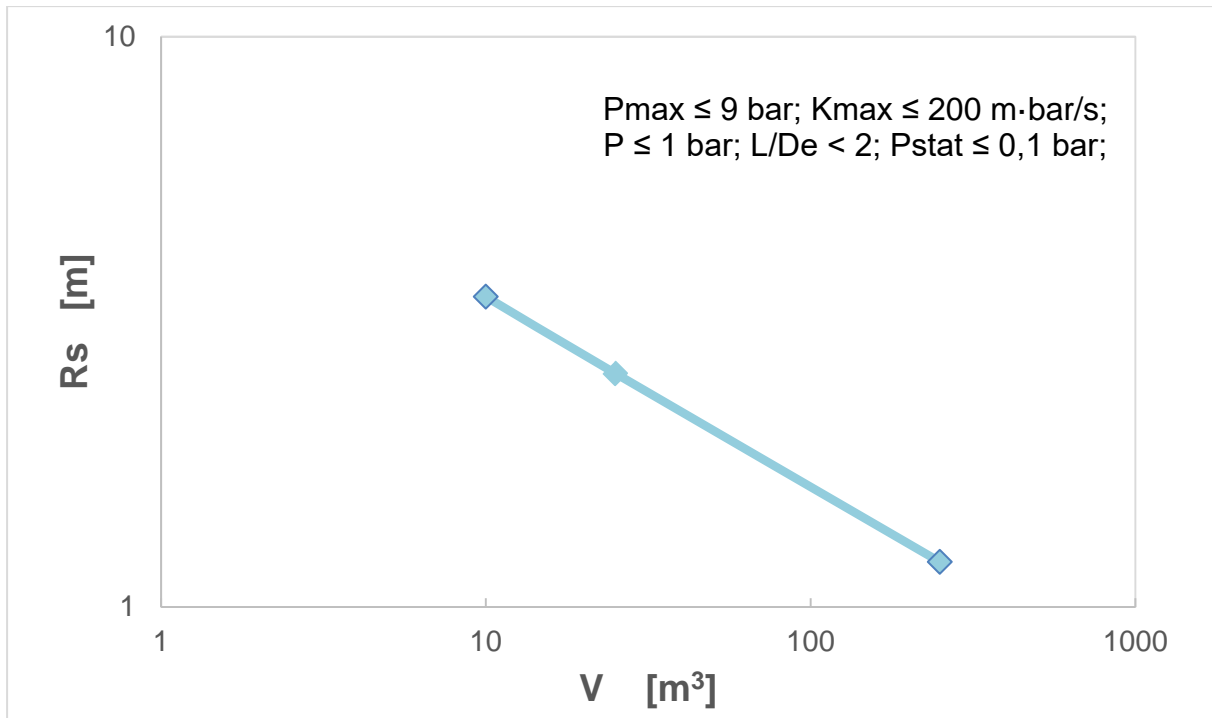


Figure 8-14. The estimated expected distance R_s as a function of vented vessels V without vent duct for pneumatic conveying systems

For larger distances, r ($r > R_s$), from the vent, the **estimated** external overpressure P_{Ar} decreases as follows:

$$P_{Ar} = P_{A\max} \cdot (R_s/r)^{1.5} \text{ in mbar}$$

P_{Ar} calculation is not valid for metal dust.

The equations are valid for:

- vessel volumes $10 \text{ m}^3 \leq V \leq 250 \text{ m}^3$,
- static activation overpressure of the rupture disk $P_{\text{stat}} = 0.1 \text{ bar}$,
- maximum vessel strength (= $P_{\text{red,max}}$) $0.1 \text{ bar} < P \leq 1 \text{ bar}$,
- maximum explosion overpressure $5 \text{ bar} \leq P_{\max} \leq 9 \text{ bar}$,
- maximum product specific constant $10 \text{ m}\cdot\text{bar}\cdot\text{s}^{-1} \leq K_{\max} \leq 200 \text{ m}\cdot\text{bar}\cdot\text{s}^{-1}$,
- $L/D_e < 2$,
- Only valid for vessels without vent duct.

At present no information are available on the pressure behaviour outside elongated vessels and silos near the vent area.

8.1.3 Zero turbulence gas cloud condition

With open-air installations, care must be taken to ensure that escaping flames and pressure does not jeopardize the surroundings. Combustible materials (e.g., roofing material) should not exist near the vent opening.

8.1.3.1 Flame propagation

The maximum outside range of a flame LF originating from explosions of propane-air-mixtures ignited at zero turbulence in a vessel **increases** with increased size of the cubic, vented vessel. The empirical equation is as follows:

$$LF = 5 \cdot V^{1/3} \text{ in m}$$

Note:

Propane-air mixtures have a flame range that is approximately 50% less than that of standard dust-air mixtures.

The equation is valid for:

- vessel volumes $0.1 \text{ m}^3 \leq V \leq 50 \text{ m}^3$, EN 14994 ;
- static activation overpressure of the rupture disk $P_{\text{stat}} = 0.1 \text{ bar}$,
- maximum vessel strength (= $P_{\text{red,max}}$) $0.1 \text{ bar} < P \leq 1 \text{ bar}$,
- $P_{\text{red,max}} > P_{\text{stat}}$
- maximum explosion overpressure $5 \text{ bar} \leq P_{\text{max}} \leq 9 \text{ bar}$,
- maximum product specific constant $10 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1} \leq K_{\text{max}} \leq 100 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$,
- propane-air-mixtures ignited at zero turbulence ($t_v = 0 \text{ s}$),
- $L/De < 2$,
- only valid of vessels without vent duct.

Figure 8-15 documents that the range of the flame from a vented propane-air-mixture ignited in its quiescent (zero turbulence) state in a cubic vessel increases with increased vessel size. With the markedly shorter flame ranges the vessel size dependency is much more pronounced than which standard dust-air-mixtures.

Exploratory tests indicate that the maximum range of the flame is not shortened in cases where the vent area is spread over multiple segments.

At present, no guidance can be given for flame ranges from elongated vessels and silos. It is expected that the length of the flame will be longer for elongated vessels with a height/diameter ratio $H/D \geq 2$.

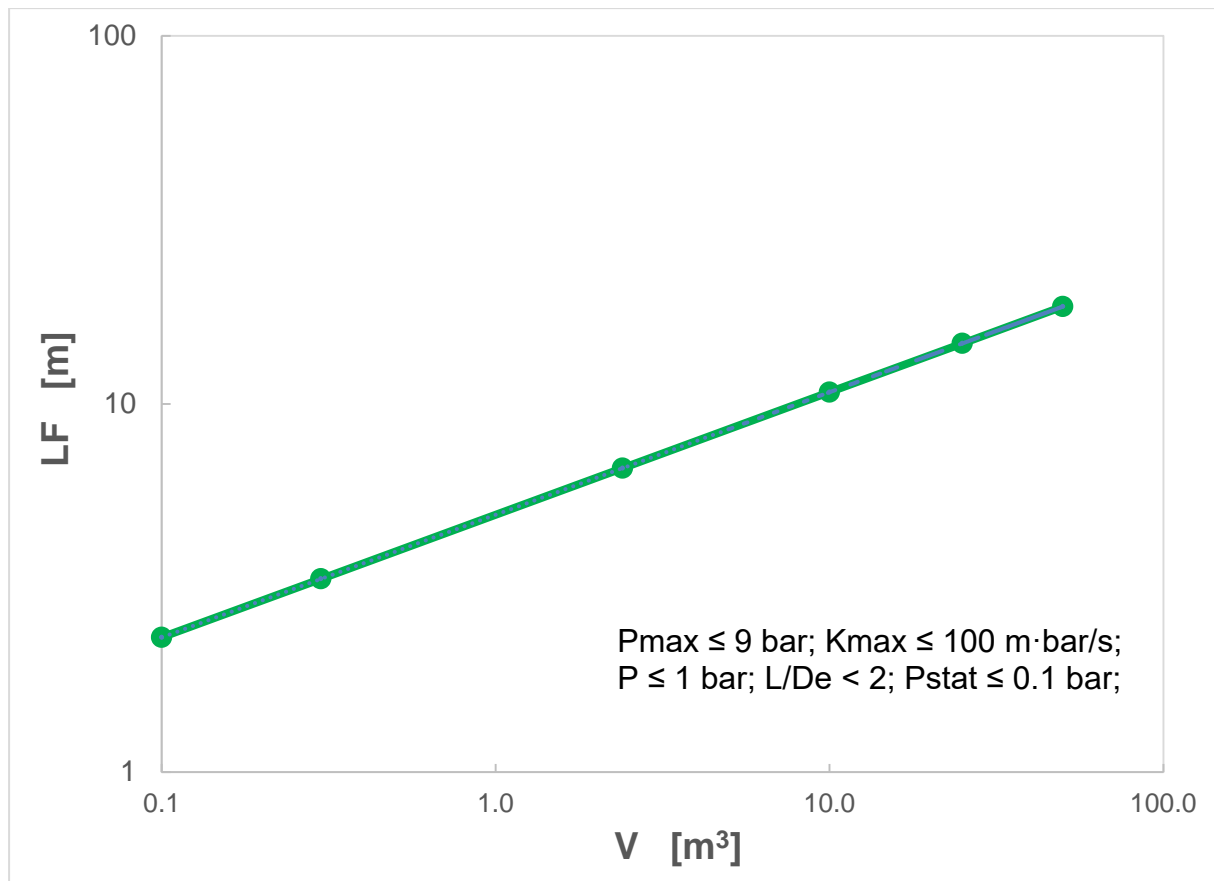


Figure 8-15. Maximum flame range LF of propane-air-mixtures ignited at zero turbulence into the outside area of vented vessels V without vent duct

8.1.3.2 Pressure effect

Pressure and blast effects external to a vent area from pressure generated by the vented explosion inside the enclosure and the explosion of an explosive gas cloud generated in the area outside the vent.

The following estimate can be made for the maximum peak pressure for gas/air mixtures ignited in a compact enclosure:

$$P_{Ar} = 1.24 \cdot P_{\text{Pred,max}} \cdot (\sqrt{A}/r)^{1.35} / (1 + (WAa/56)^2) \text{ in bar}$$

Where

r is the distance to vent opening, in m,

A is the vent area, in m^2 ,

WAa defines the direction towards the vent (see also Fig. 8-10)

with

$WAa = 0^\circ$ means in front of the vent area,

$WAa = 90^\circ$ means sideways from the vent area.

The equations are valid for:

- vessel volumes $0.1 \text{ m}^3 \leq V \leq 250 \text{ m}^3$,
- static activation overpressure of the rupture disk $P_{\text{stat}} = 0.1 \text{ bar}$,
- maximum vessel strength (= $P_{\text{red,max}}$) $0.1 \text{ bar} < P \leq 1 \text{ bar}$,
- maximum explosion overpressure $5 \text{ bar} \leq P_{\text{max}} \leq 9 \text{ bar}$,
- maximum product specific constant $10 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1} \leq K_{\text{max}} \leq 200 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$,
- $L/De < 2$
- only valid for vessels without vent duct.

Which effect such peak pressures may have on parts of constructions can be taken from annex 21.3.

8.2 Installations in Enclosed Areas

If pressure venting is applied to equipment installed in enclosed areas, then the venting must be done through a pipeline (so-called vent duct) to the outside in a safe direction (see Section 9).

Newer developments indicate that flame propagation from explosion vented equipment can be stopped, under certain conditions, by using approved diverters /4, 5/, e.g., mechanical flame barriers (flame arresters, quenching devices with dust retainers). Compare Section 10.

9 Design of Vent Duct

9.1 General

If a vent duct is attached *downstream* of the venting device, then after activation of the venting device the duct may be filled with an explosive mixture before the flames leave the protected vessel. This results in a secondary explosion in the vent duct, which will hinder the venting process. Therefore, the maximum reduced explosion overpressure inside the vessel will increase with increasing length of the vent duct. The pressure effect depends upon the expected maximum reduced explosion overpressure while using a rupture disk but without vent duct and upon type of the fuel.

Figure 9-1 demonstrates what can happen if the design of vent duct is not correct.



Figure 9-1. Consequences of a bad design of vent duct

9.2 Rupture Disks as Venting Devices

9.2.1 Combustible Dusts – standard distribution

The influence of the length of a vent duct (LA) upon the pressure increase is most pronounced when the flame propagation from the secondary explosion in the vent duct reaches the velocity of sound /1, 4/. This is valid for vent ducts of

$$LA = LAS = 4.564 \cdot P_{red,max}^{-0.37} = 4.564 \cdot P_o^{-0.37} \quad \text{in m}$$

Where

LAS is the length of vent duct where velocity of sound is reached.

Vent ducts with a length of $LA > LAS$ have no additional effect upon the pressure increase.

Therefore, the length of vent duct where velocity of sound is reached (LAS) will be the maximum length that has to be considered.

Note: *The above-mentioned formula is not valid for metal dusts!*

The presence of the vent duct has no effect on the $P_{red,max}$, if the ratio length of the vent duct (LA) to diameter of a single vent (LD) is $LA/LD \leq 0.5$: provide that the volume of the vent duct is less than the volume of the protected vessel (Fig. 9.2).

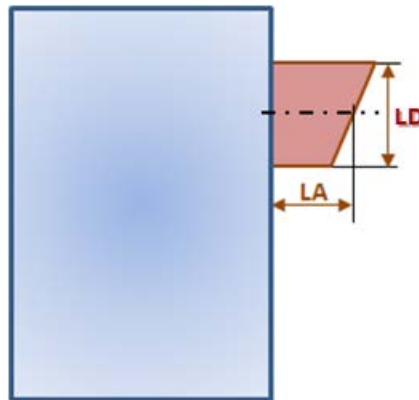


Figure 9-2. Definition of vent duct

Independent of the location of the vent duct (longitudinal or transversal arrangement Fig. 9-3), the maximum reduced explosion overpressure $P'_{red,max}$ (the design pressure P of the vessel to be protected) caused by the downstream duct can be calculated for vessels having L/D_e ration of 1 with the following equation:

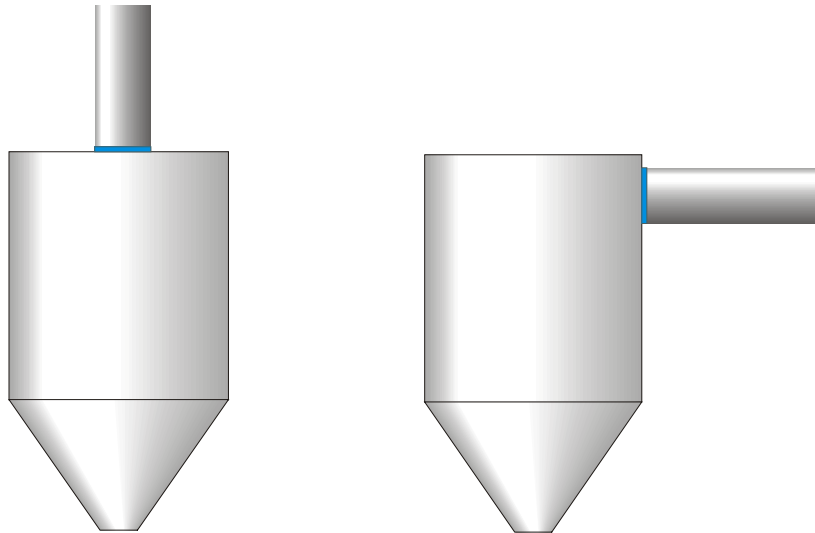


Figure 9-3. Silo with "longitudinal" (left) and "transversal" (right) arrangement of vent duct on a silo

L/De = 1 (longitudinal and transversal):

$$P'_{red,max} = P_0 \cdot (1 + 17.3 \cdot LA \cdot (A \cdot V^{-0.753})^{1.6}) \quad \text{in bar}$$

Where

$P'_{red,max}$	maximum explosion overpressure with vent duct (= P) in bar;
$P_{red,max}$	maximum explosion overpressure without vent duct (= P_0) in bar;
A	required vent area in m^2 without vent duct;
V	volume of protected vessel in m^3 ;
LA	length of vent duct in m.

The equation is valid for:

- vessel volumes $0.1 m^3 \leq V \leq 10'000 m^3$;
- LA/LD ratio of vent duct $0.5 < LA/LD \leq 20$;
- Length of vent duct $LA \leq 10m$ but if $LA > LAS$ use LAS for calculation.
- static activation overpressure of the venting device $0.1 \text{ bar} \leq P_{stat} \leq 0.2 \text{ bar}$;
- maximum vessel strength ($P'_{red,max}$) without vent duct $\leq 2 \text{ bar}$;
- maximum vessel strength (= $P_{red,max}$) of $0.1 \text{ bar} < P \leq 2 \text{ bar}$; and P shall be at least $P_{stat} + 2$ times the tolerance range of P_{stat} ;
- maximum explosion overpressure $5 \text{ bar} \leq P_{max} \leq 12 \text{ bar}$ and a maximum product specific constant $10 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1} \leq K_{max} \leq 800 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$,
- $L/De = 1$,

If the maximum explosion overpressure, the product specific constant or the static activation overpressure are smaller than the ones stated in the parameters than the above equation may be used with the minimum values given above.

Experimental studies have proven that the influence of vent duct with longitudinal arrangement - ***located on the roof*** - decreases markedly with increased length diameter ratio (Fig. 9-3, left and Fig. 9-4). The increase of the maximum explosion overpressure is at its maximum if $L/De = 1$.

For a length diameter ratio $L/De = 6$ the elevated "maximum reduced explosion overpressure" $P'_{red,max}$ (the design pressure P of the vessel to be protected) caused by the downstream pipe can be calculated from the simple equation:

$L/De = 6$ (only longitudinal):

$$P'_{red,max} = (0.0586 \cdot LA + 1.023) \cdot P_{red,max}^{(0.981 - 0.01907 \cdot LA)}$$

With a given

- maximum explosion overpressure without vent pipe of $0.1 \text{ bar} < P_{red,max} \leq 2 \text{ bar}$,
- vessel length diameter ratio $1 < L/De < 6$ and
- length of vent pipe $LA \leq L_{AS}$

the reduced maximum explosion overpressure between vessel L/De 1 and 6 with vent duct becomes for:

$1 < L/De < 6$ (only longitudinal):

$$P'_{red,max} = 0.2 (C1 - C2) (1 - L/De) + C1 \quad \text{in bar}$$

Where $C1 = P'_{red,max}$ from the equation for vessel $L/De = 1$ and $C2 = P'_{red,max}$ from the equation for vessel $L/De = 6$.

For a vessel ratio $L/De > 6$ the maximum reduced explosion overpressure will not increase anymore /4, 5/. Figure 9-4 depicts a horizontal silo with a 2 m long vent duct. As mentioned before there will be no influence of the duct upon the maximum reduced explosion overpressure because the vessel ratio L/De is larger than 6.

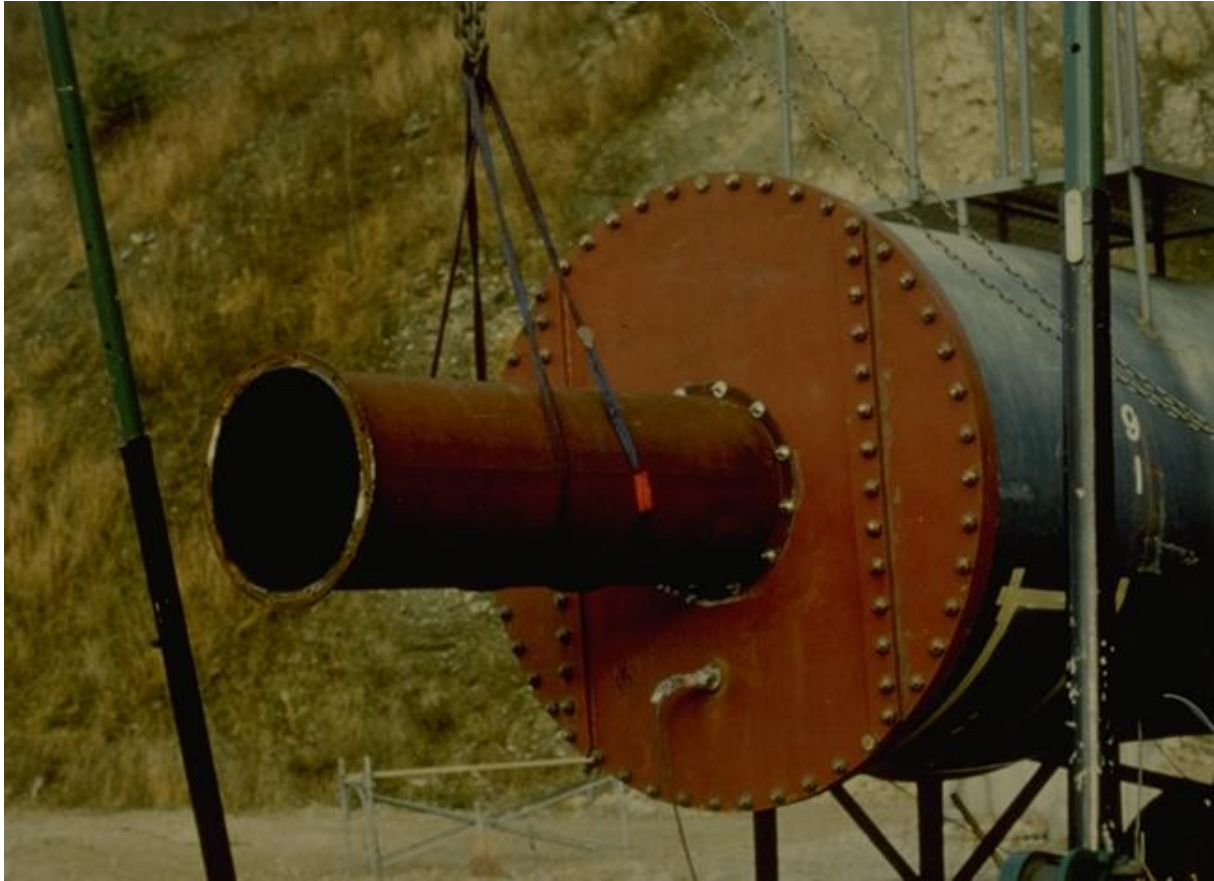


Figure 9-4. Horizontal arranged silo ($L/D_e = 6.25$), which will be vented through the roof via a 2 m long vent pipe (longitudinal arrangement)

If the location of the vent duct is installed on the side (transversal arrangement Fig. 9-3, right), the influence of the downstream vent duct on the maximum reduced explosion overpressure $P'_{red,max}$ (the design pressure P of the vessel to be protected) can only be calculated by the equation for vessels having a L/D_e ratio of 1 which is - for the transversal arrangement - also valid up to a L/D_e ratio of 20.

$1 \leq L/D_e \leq 20$ (only transversal):

$$P'_{red,max} = P_0 \cdot (1 + 17.3 \cdot LA \cdot (A \cdot V^{-0.753})^{1.6}) \quad \text{in bar}$$

The above information on vent duct design applies to all dust injection methods, including the *standard method* and *pneumatic conveying* with *axial and tangential* inlets, as well as *free-fall filling*. However, it should be noted that the calculations are particularly conservative for the latter three conditions.

9.2.2 Combustible Dusts – pneumatic conveying of product into vessels and silos

If pneumatic conveying procedures are to be expected in pressurised cubic vessels, the effect of vent pipes (LA) on increasing the $P_{red,max}$ in the vessel to be protected is much more limited than for standard mixtures. The range of influence is only from $P_{red,max}$ 0.1 bar to 2 bar. Furthermore, systematic investigations in a 25-m³ cubical vessel with two St 1 and one St 2 dust and two different vent areas have shown (see Fig. 9-5) that the amplification of the explosion process is greatest in a range for $P_{red,max} = 0.6 - 1.1$ bar and decreases significantly at lower or higher-pressure levels [16]. The design is **not valid for metal dusts!!**

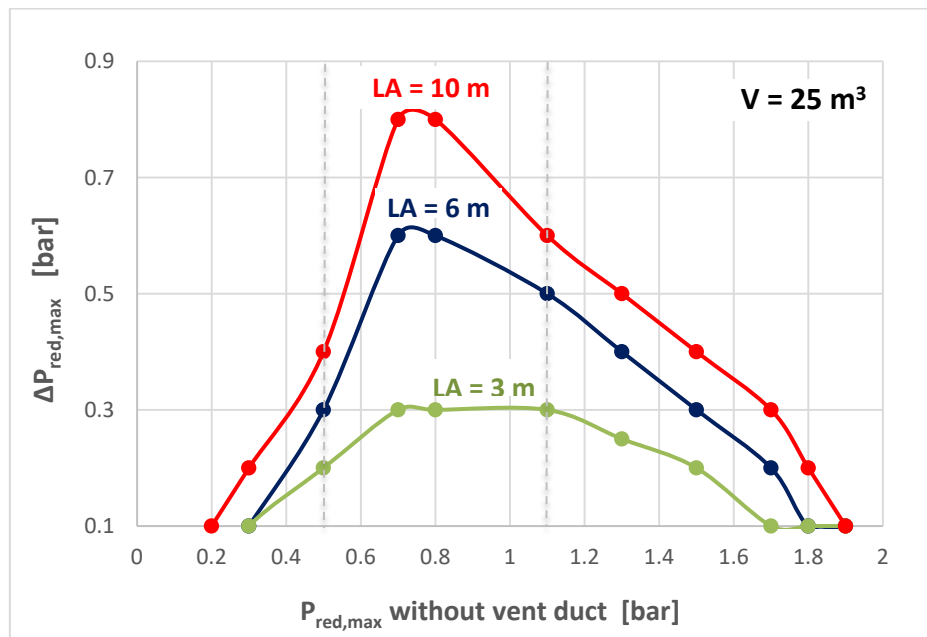


Figure 9-5. Influence of the length of the vent pipe on the amplification of the explosion process
- $Q \sim 15 \text{ m}^3/\text{min}$; optimum product loading -

It was also found that the pressure increase caused by the 10 m length vent pipe in the vented vessel also flattens out when $P_{red,max}$ without vent pipe exceeds 0.8 bar. The explosion velocity in the pipework then approaches the speed of sound. The maximum reduced explosion overpressure with vent duct P caused by the downstream vent duct can be calculated as follows:

0.1 bar $\leq P_{red,max} \leq 0.7$ bar:

$$P = 0.977 \times LA^{0.395} \times P_0^{(1.02 \times LA^{0.132})}$$

0.7 bar $< P_{red,max} \leq 2.0$ bar:

$$P = (0.321 \times \ln(LA) + 0.95) \times P_0^{(-0.318 \times \ln(LA) + 1.013)}$$

where

P = $P_{red,max}$ with vent duct in bar

LA = Vent duct length in m

P_0 = $P_{red,max}$ without vent duct in bar

9.2.3 Flammable Gases

If free venting is based on $P_o (= P_{red,max})$ of 0.1 bar to 2.0 bar then the design pressure of the protected vessel must be at least $P = 0.2$ bar to 2.3 bar when using short vent pipes ($LA \leq 3$ m) and at least $P = 0.8$ bar to 3.6 bar when using longer vent pipes ($LA > 3$ m). Vessels with a design overpressure of less than 0.2 bar (short vent pipes) or 0.8 bar (longer vent pipes) cannot be pressure vented in conjunction with vent pipes (they require too large a vent area) [6].

In accordance with the expected increase of the maximum reduced explosion overpressure $P_{red,max}$ the design pressure P of the vessel to be protected must be augmented as follows in which P correspond to the design pressure with vent pipe and P_o without vent pipe:

Length of vent pipe $0 \text{ m} < LA \leq 3 \text{ m}$:

$$P = 1.24 \cdot P_o^{0.8614} \quad \text{in bar}$$

Length of vent pipe $3 \text{ m} < LA \leq 6 \text{ m}$:

$$P = 2.48 \cdot P_o^{0.5165} \quad \text{in bar}$$

In case the design pressure is given as P then the vent area A must be increased so that the following maximum reduced explosion overpressure P_o results during free (unobstructed) venting:

Length of vent pipe $0 \text{ m} < LA \leq 3 \text{ m}$:

$$P_o = 0.7790 \cdot P^{1.161} \quad \text{in bar}$$

Length of vent pipe $3 \text{ m} < LA \leq 6 \text{ m}$:

$$P_o = 0.1723 \cdot P^{1.936} \quad \text{in bar}$$

9.3 Explosion Doors as Venting Devices

9.3.1 Combustible Dusts

Once can assume that the influence of vent ducts downstream from explosion doors with a very good venting efficiency, EF upon the pressure in the protected vessel is like the pressure increase caused by rupture disks with comparable venting efficiency (see Section 9.1.1). As per /1, 3/ this is normally the case when the specific mass of the explosion door does not exceed $GE = 0.5 \text{ kg} \cdot \text{m}^{-2}$. Explosion doors with an inertia greater than $0.5 \text{ kg} \cdot \text{m}^{-2}$ and smaller or equal to $10 \text{ kg} \cdot \text{m}^{-2}$ can be considered as inertia-free if the specific vent area $A/V^{0.753} < 0.07$ /3/. The equations for rupture disks can be used to determine the augmented pressure. It will be referenced to the $P_{\text{red,max}}$, which results from an explosion door without vent duct (Po).

Test with dust-air-mixtures and rectangular explosion doors of low efficiency have shown that in certain cases the influence of vent ducts can be reduced. This is true for explosion doors with substantial specific mass $GE > 45 \text{ kg} \cdot \text{m}^{-2}$ /17/. The following performance is related to the efficacy of rectangular explosion doors in presence of homogeneous dust-air-mixtures and vent pipes having a **special construction** (Fig. 9-6).

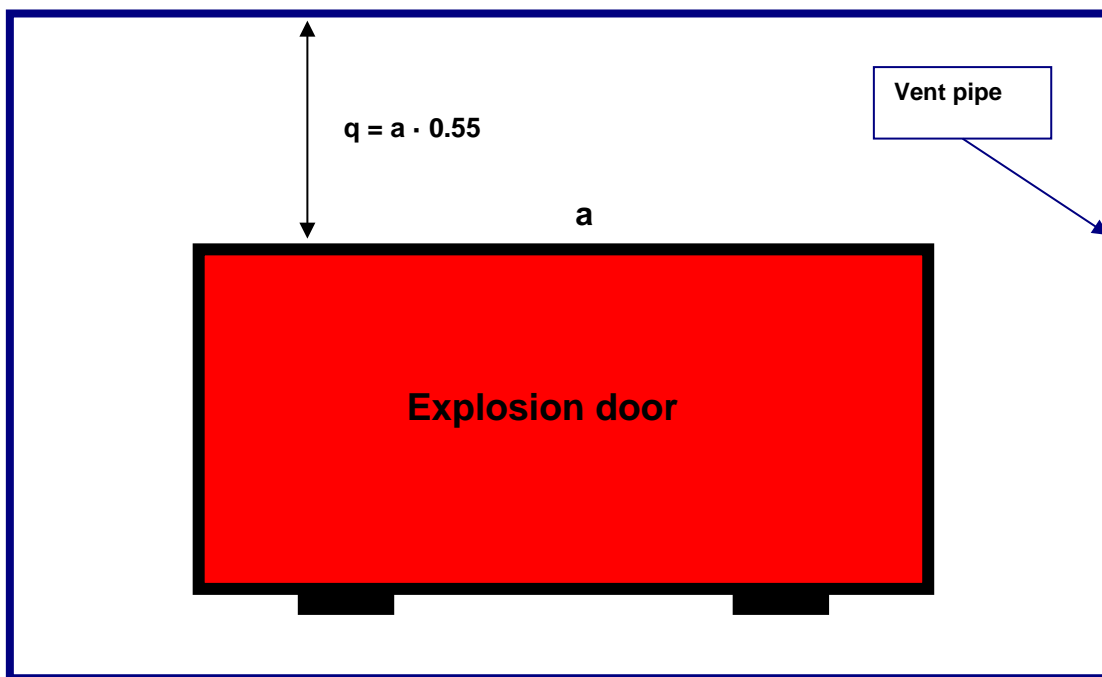


Figure 9-6. Special construction of vent pipe attached to rectangular explosion doors

Once the distance q (Fig. 9-5) is calculated as:

$$q = a \cdot 0.55 \quad \text{in m}$$

there is no augmentation of the pressure inside the vessel because of the vent duct. The reason for this is that the cross section of the vent duct is markedly larger than the effective area of

the vent door. In contrast to a rupture disk as the venting device the flow of unburned dust-air-mixture is “metered” into the duct therefore maintaining a low dust concentration. The full development of the secondary explosion in the duct is hindered provided dust deposits near the venting device are preventable. In such a case the design strength P of the protected vessel may be lower than for rupture disks or low specific mass explosion doors (generally specific $GE < 10 \text{ kg} \cdot \text{m}^{-2}$) with regular ducts.

Only longer vent ducts ($LA > 8 \text{ m}$) have a small influence upon the course of the explosion inside the protected vessel /5/.

For a heavier specific mass of the explosion door ($GE > 10 \text{ kg} \cdot \text{m}^{-2}$) and without special design of the vent duct (see Fig. 9-3 and Fig. 9-4) the equations for rupture disks can be used to determine the augmented pressure. It will be referenced to the $P_{\text{red,max}}$, which results from an explosion door without vent duct (P_0). When in doubt special tests may be needed.

9.3.2 Flammable Gases

One can assume that the vent duct has the same influence when installed behind a vent door with good venting characteristics or behind a rupture disk of comparable venting behaviour. The pressure inside the protected vessel should be augmented in a similar manner (see Section 9.1.2). This is always the case as per /2, 3/ when the specific mass of the vent door is smaller or equal to $GE = 0.5 \text{ kg}\cdot\text{m}^{-2}$. Explosion venting devices with an inertia greater than $0.5 \text{ kg}\cdot\text{m}^{-2}$ and smaller or equal to $10 \text{ kg}\cdot\text{m}^{-2}$ can be considered as inertia-free if the specific vent area $A/V^{0.753} < 0.07$ /3/. The equation for rupture disks can be used to determine the augmented pressure. It will be referenced to the $P_{\text{red,max}}$, which results from an explosion door without vent duct (P_o).

For a specific mass of the vent door more than $GE = 10 \text{ kg}\cdot\text{m}^{-2}$ the influence of the vent duct upon the augmented pressure in the protected vessel may be smaller -similarly to the behaviour with combustible dusts (see Section 9.2.1). A deviation from the usual calculation method given in Section 9.1.2 is permitted if documented with actual explosion tests.

9.4 Constructional Design of Vent Ducts

9.4.1 Maximum Length and Strength

Vent ducts should be as short and straight as possible. Its maximum length shall not exceed 10 m. Circular vent ducts should be given preference over square ducts for reasons of strength. They must have at least the strength of the vessel under protection /6/.

If an inspection hatch is in the vicinity of the venting device for servicing purposes, cover and closing device must have the same strength as the vent duct /1, 2, 4, 21/.

9.4.2 Form Design

Vent ducts should be as short as possible and installed straight (Figure 9-6, left). The angle to the axis of the vent opening must not exceed 20° (Figure 9-7, right).

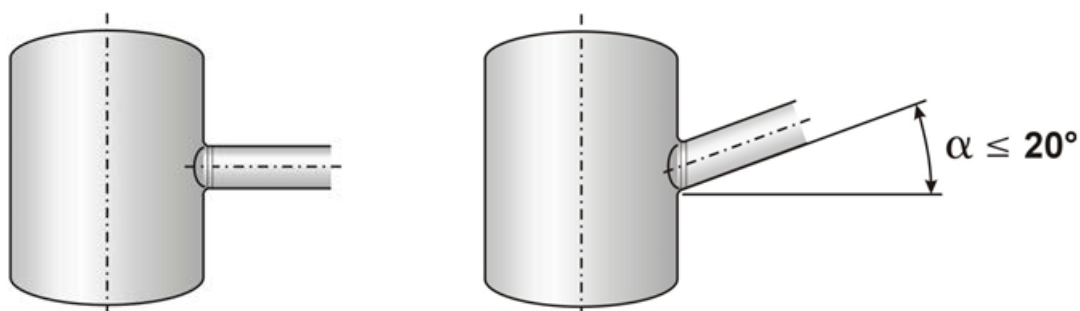


Figure 9-7. Vent duct design to which the equations shown in chapter 9.2.1 to 9.2.3 apply

Vent duct shapes with a gradual bend (Fig. 9-8) is also acceptable if the ratio of the radius r of the curvature to the duct diameter DN is greater than 2.

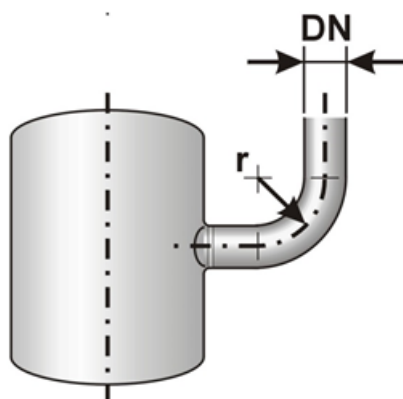


Figure 9-8. Vent duct design to which the equations shown in chapter 9.2.1 and 9.2.2 apply if $r / DN > 2$

On the other hand, if the vent duct has a bend of 90° after the area of the vent (Fig. 9-9, left), the explosion venting process shows particularly severe inhibition and the maximum reduced explosion overpressure can be raised by this arrangement up to 400%.

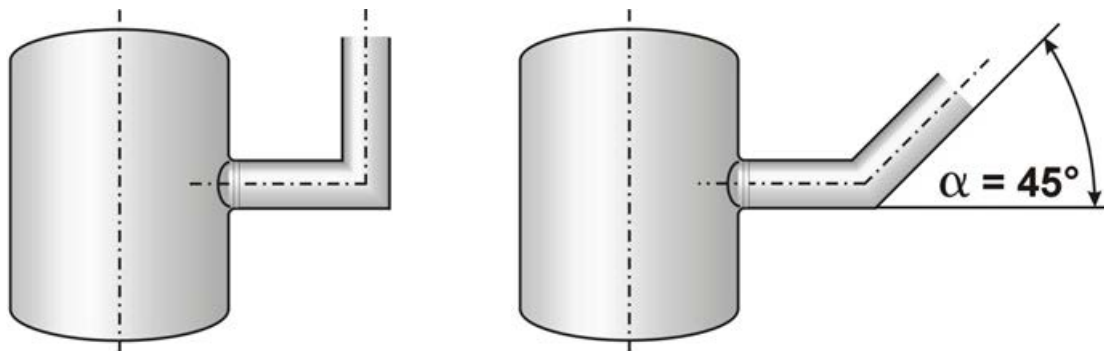


Figure 9-9. Vent duct design to which the equations shown in chapter 9.2.1 to 9.2.3 do not apply

9.4.3 Cross-Sections

The cross-section of vent ducts must be at least that of the vent opening of the vessel under protection. An increase in the vent duct cross-section compared with that of the vent area (Fig. 9-10, left) does not promote the venting process [1, 4, 21/].

Constriction of the cross-section (Fig. 9-9, right), on the other hand, can have a considerably greater effect on the increase in the maximum reduced explosion overpressure than, e.g., straight (Fig. 9-7) or slightly bent vent ducts (Fig. 9-8).

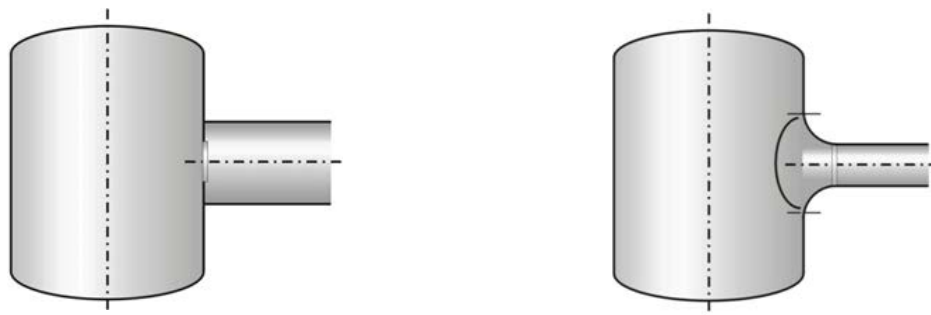


Figure 9-10. Vent duct design to which the equations shown in chapter 9.2.1 to 9.2.3 do not apply

Constriction of the cross-section (Fig. 9-10, right), on the other hand, can have a considerably greater effect on the increase in the maximum reduced explosion overpressure than, e.g., straight (Fig. 9-7) or slightly bent vent ducts (Fig. 9-8).

9.4.4 Conclusions

The vent duct design shown in Figures 9.9 and 9.10 are not forbidden; rather the equation shown in chapter 9.2.1 to 9.2.3 do not apply to them.

These and other designs can be used if the predictions of the effects of the vent duct on the maximum reduced explosion overpressure in the protected vessel are based on either published or experimental data that has been obtained from representative explosion venting trials,

9.4.5 Weather Protection

With a horizontal arrangement (Fig 9-11), the end of vent pipes should be cut away at an angle to prevent the ingress of rain and snow. In addition, a wire mesh is used as a constructional measure to prevent bursting disks flying off.

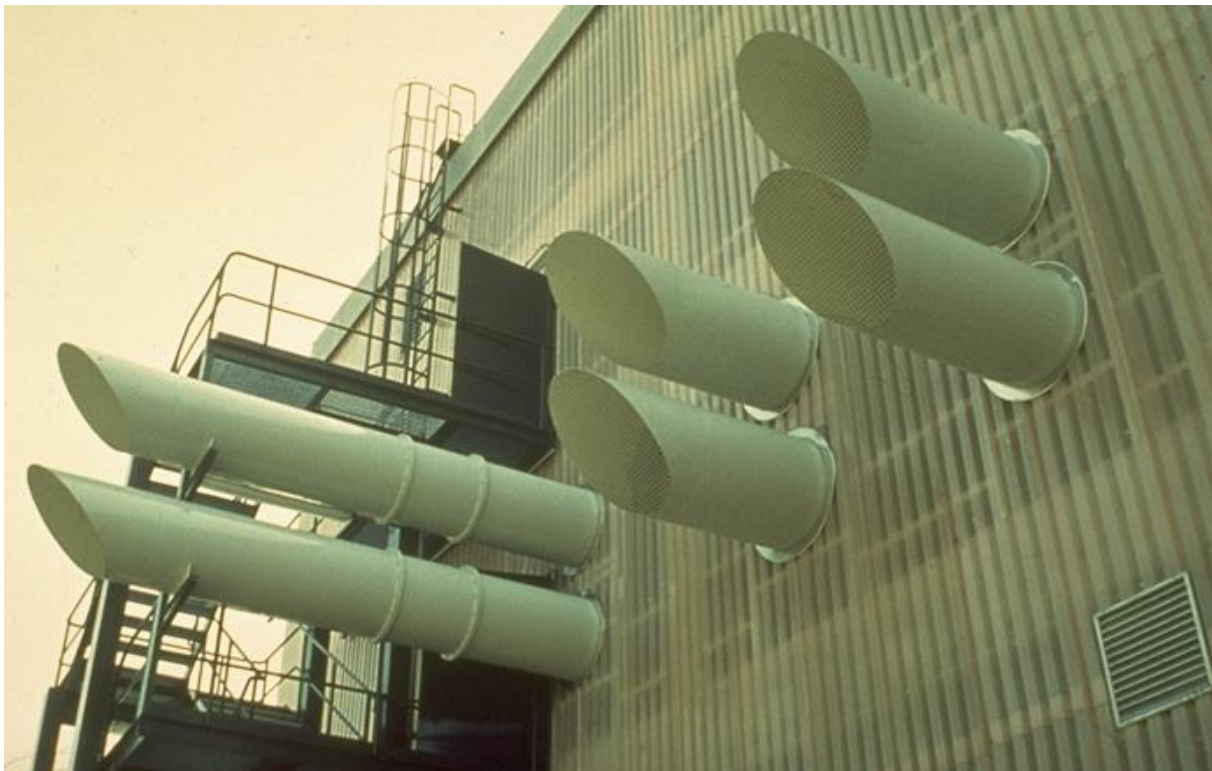


Figure 9-11. Vent pipes ends cut away at an angle with additional mesh

A vent duct angled downward slightly also prevents the ingress of rain or snow (Fig. 9-12).



Figure 9-12. Vent duct angled downward slightly with additional mesh

Regarding how the length of the vent duct with angled cutaway end should be measured, the length LA of the median axis always applies (Fig 9-13).

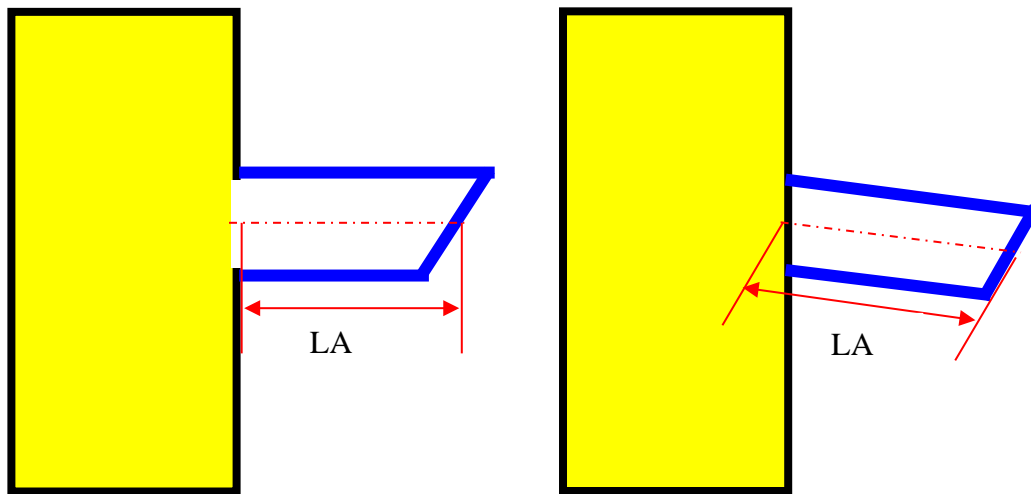


Figure 9-13. Determination of the length of the vent duct with angled cutaway end

To prevent the ingress of rain and snow into the vent ducts, light covers, e.g., foils/films or disks in clamping profiles are admissible (weight $< 0.5 \text{ kg/m}^2$) if these covers free the vent duct cross-section at very low overpressures (less than 50% of P_{stat} , to be proven by tests). The covers shall not affect the venting process or endanger people or things (Fig. 9-14).

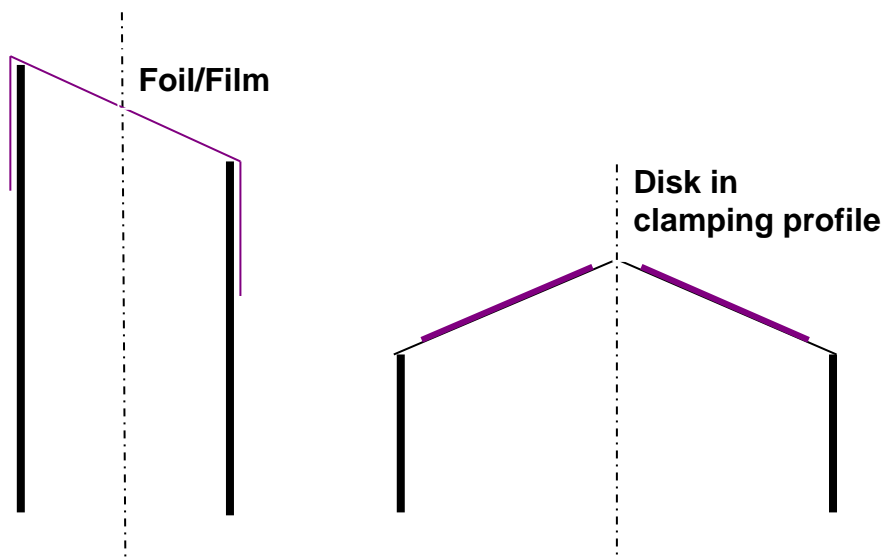


Figure 9-14. Foil/film cover (left) and cover with disks in rubber clamping profile (right)

Other vent duct covers such as those shown in Figure 9-14 can also be used if the required low activation overpressure (less than 50% of P_{stat}) has been proven by tests and flying off, e.g., of metal covers can be reliably prevented by retaining wires.



**Figure 9-15. Tested metal covers held by rubber bands
(the retaining wires for the covers are not visible)**

Figure 9-16 shows a heavy metal cover installed at the end of a vent duct. The corresponding static activation overpressure does not fulfil the requirements of very low static activation overpressures $< 50\%$ of P_{stat}) and a low weight of less than 0.5 kg/m^2 . The flying off the metal cover is not reliably prevented.

Explosion tests with a similar type of metal cover shows that this type of hinged cover was torn off and hurled away even at rather low-pressure loads. This is creating an additional hazard in the vicinity.



Figure 9-16. NOT tested heavy metal cover

The connection between the protected vessel and the vent duct frequently requires elastic rubber compensators (Fig. 9-17). They often comprise fibre-reinforced rubber with an explosion strength, which is virtually impossible to prove by calculation.

The use of such compensators is possible when explosion tests have provided proof of the required strength.

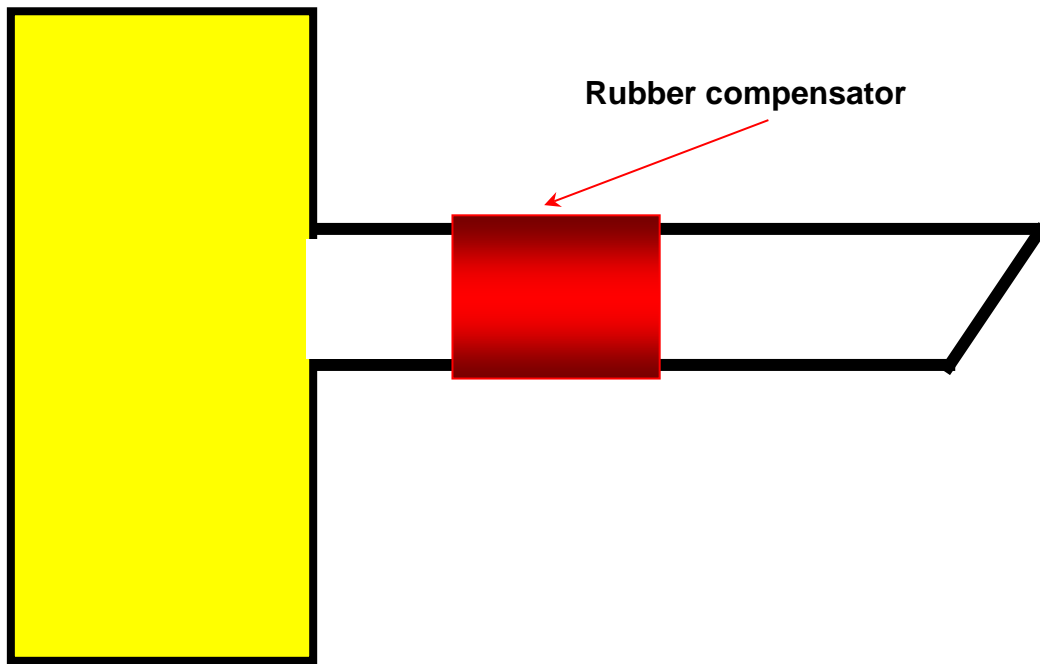


Figure 9-17. Rubber compensator for the connection between the protected vessel and the vent duct

Special care must be exercised in the installation of the rubber compensators and, if applicable, the clamping rings of sleeve connections.

Figure 9-18 shows the missing rubber compensator for the connection between the protected vessel and the vent duct. In this case, the missing rubber compensator is creating an additional hazard in the vicinity.



Figure 9-18. Missing rubber compensator for the connection between protected vessel and vent duct

10 Flameless Explosion Venting

10.1 Basics

Flameless explosion venting devices consist of an explosion-venting device and a flame-quenching element as a minimum. Flame quenching elements shall be suitable for the intended use (e.g., temperature range, mechanical strength, fuel type). Explosion venting devices shall be designed according to /3, 25/. Material used for the parts of explosion venting devices shall be selected based on their suitability about the chemical and physical conditions to which they will be subjected in service.

All parts of the flame-quenching element shall resist the expected mechanical, thermal and chemical loads of the intended use. During or after the venting process, deformations of the flameless explosion-venting device may occur. This shall not lead to gaps in the housing that could lead to flame transmission into the surrounding. The flame quenching capability of the device shall be demonstrated by tests.

10.2 Quenching-Tube-System (Q-Rohr System)

The quenching tube (Q-tube) comprises an upstream, integrated three-part bursting disk, which vents the explosion in the Q-tube. Hot gases are formed which are cooled via a special high-grade steel mesh filter cage (Fig. 10-1).

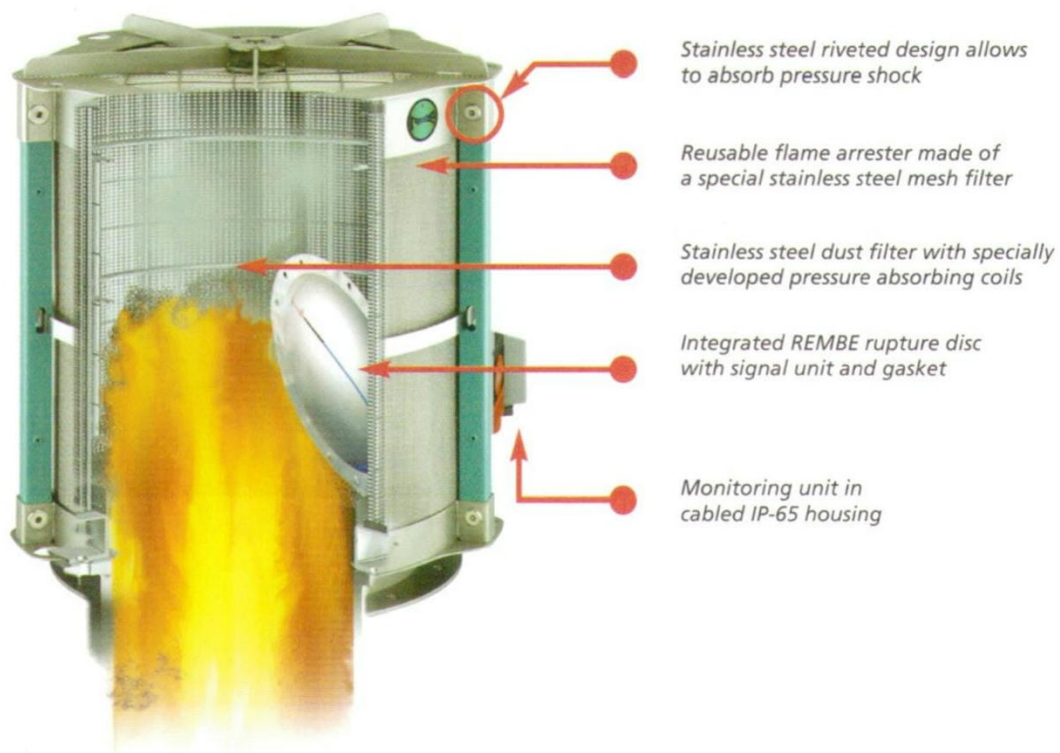
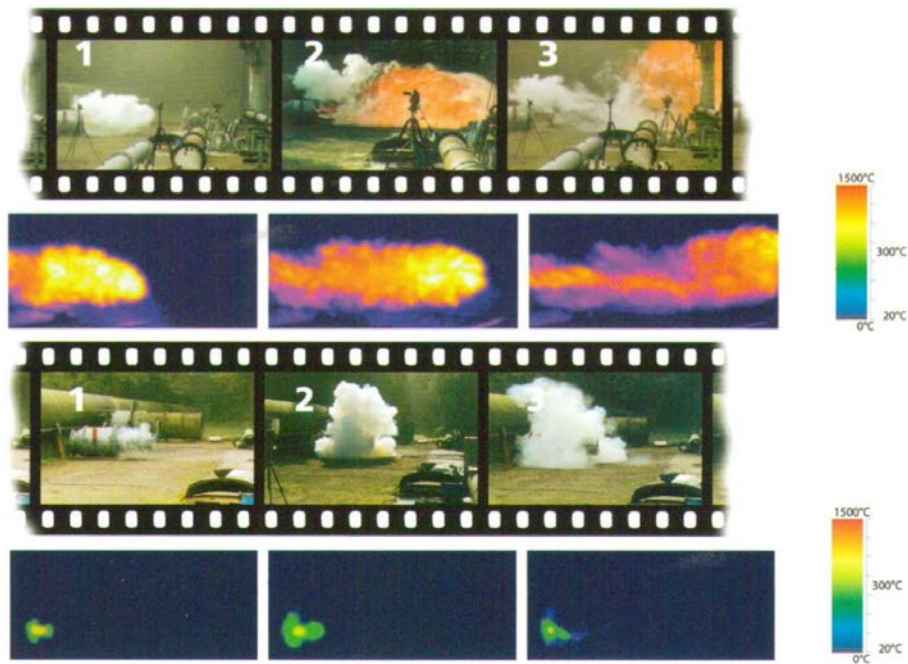


Figure 10-1. Schematic representation of a bursting disk with combined flame barrier and dust filter (Quenching-Tube System) /12/

In a thermo graphical investigation of a dust explosion, it has been recorded that when using a Q-Tube System there is a huge reduction in temperatures generated (Fig 10-2).



**Figure 10-2. Above: conventional explosion venting with a bursting disc
Below: conventional explosion venting with Q-Rohr System [12]**

Figure 10-3 shows examples of such Q-Rohr systems.



Figure 10-3. Example of Q-Rohr Systems [12/]

10.3 Quenching-Box-System (Q-Box System)

The quenching box (Q-Box) comprises an integrated bursting disk, which vents the explosion in the Q-Box. Hot gases are formed which are cooled via a special high-grade steel mesh filter cage (Fig. 10-4).

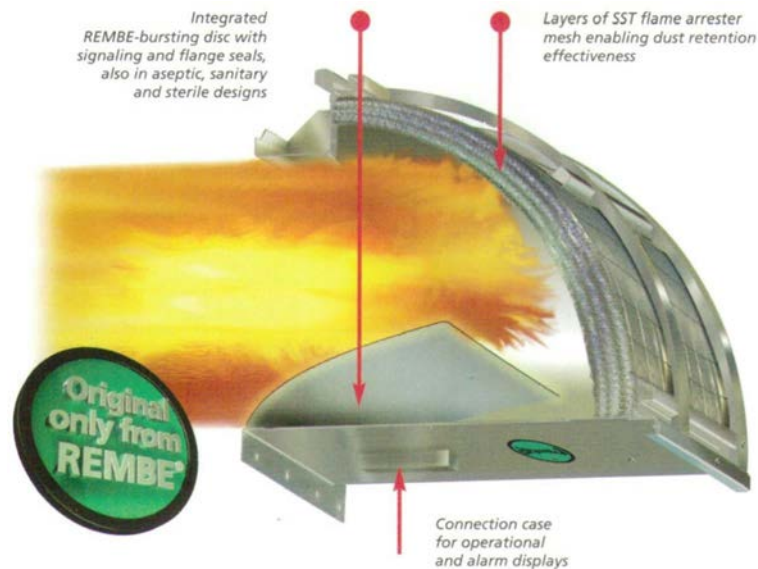


Figure 10-4. Schematic representation of a bursting disk with combined flame barrier and dust filter (Quenching-Box System) /12/

In a thermo graphical investigation of a dust explosion, it has been recorded that when using a Q-Box System there is a huge reduction in temperatures generated (Fig 10-5).

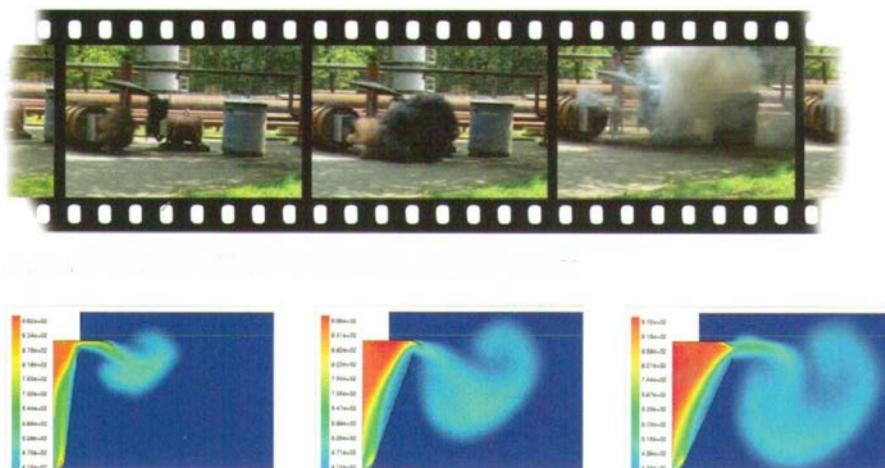


Figure 10-5. Conventional explosion venting with Q-Box System [12]

Figure 10-6 shows an example of such a Q-Box systems.



Figure 10-6. Example of a Q-Box System /12/

10.4 Explosion Relief Valve System

The explosion relief valve system consists of a low-mass valve plate opens within milliseconds and a flame arrester installed around the valve plate (Fig.10-7).



Figure 10-7. Schematic representation of an explosion relief valve system; left: closed; right: open during explosion /26/

Figure 10-8 shows an example of such an explosion relief valve system, which is normally, installed in dust extraction systems.



Figure 10-8. Example of an explosion relief valve system; EVN 2.0 /26/

10.5 Effects of Flameless Explosion Venting Devices

Even with complete retention of flame and particles, the immediate area surrounding the vent can experience overpressure and radiant energy. Venting indoors influences the building that houses the protected equipment due to increased pressurization of the surrounding volume. Expected overpressure should be compared to the building design and building venting should be considered to limit overpressures. The resulting pressure increase in an unvented building can be estimated from the following:

$$V_0 = \alpha (P_0/\Delta P) V$$

- V_0 is volume of the room/building;
- α is expansion constant, empirically derived from the volume and temperature of gases external to the protected equipment;
- P_0 is ambient pressure;
- ΔP is maximum pressure rise in the room/building;
- V is volume of the protected equipment.

The pressure effect should be determined based on estimating the exhaust gas volume and temperature.

Considering the typical design strength of standard industrial building is 0.01 bar, reinforcing or venting of the surrounding area (building/room) should be considered when this room or building is smaller than 300 times the vented volume, or a ratio which is determined by testing and/or calculation as per above.

Local overpressure shall be avoided. The flameless venting device shall not be placed close to a wall.

11 Explosion Venting of Filters

Dust filters are the most common type of dust/air separation equipment. Dust filters will typically have a dirty air volume and a clean air volume. The clean air volume includes the inner volume of filter bags, candle or cartridge filter elements, cassette filter elements, disk filters and sinter plate filter elements if the dust is separated from the air at the outer surface of the filter /27/.

In the case of filter elements which have a certain rigidity and strength, the volume of all filter elements or, under certain conditions, the entire enveloping volume of the filter elements can be subtracted from the dirty air volume.

If the distance a between the circular filter elements is $\leq 0.5 d$ of the filter elements, then the entire enveloping volume of the filter elements can be subtracted from the dirty volume. The same is valid if $a \leq w$ with w being the width of the enveloped or pocket filters (Fig. 11-1.)

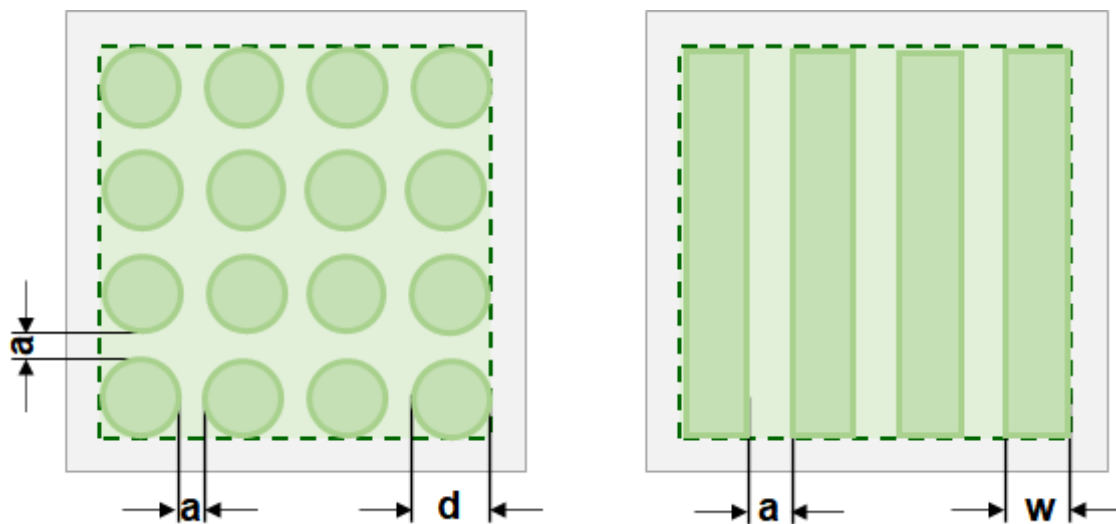


Figure 11-1. Left-hand side: bag, candle, or cartridge filter elements; right-hand side: pocket, flat bag, cassette filter elements or disk filters /EN 14491, VDI 2263 Part 6.1/

(a = distance between filter elements; w = width of flat bag or pocket filters; d = diameter of filter elements)

If no information regarding the distance a between the filter elements is given, WinVent automatically calculates only the total volume of all filter elements, i.e., **bag total** or **pocket total**.

11.1 Calculation of the entire enveloping volume of filter elements V_E

To be able to calculate the envelope volume of the filter elements, the necessary corresponding input/output window of WinVent were adapted e.g., F3 Equipment, select Filter.

After entering all necessary data specifically for the bags or pockets, WinVent checks if the necessary conditions for the calculation of the envelope volume are given.

If the conditions for the calculation of the envelope volume are fulfilled WinVent automatically calculates the envelope volume otherwise only the total volume of the bag/pocket filter elements is calculated.

Filter bags on support cages, rigid candle or cartridge filter elements

In the following “bags” represents all filter elements for which the envelope volume can be calculated. If the distance **a** between the circular filter elements is equal to or smaller than the half diameter **d** ($a \leq d/2$) of the filter elements, then the entire enveloping volume of the filter elements can be subtracted from the entire dirty air volume. The most common diameters of the circular filter elements are between 120 mm and 180 mm.

The distance **a** does not fall below a minimum distance, as otherwise too many dust particles are released onto the surrounding hoses during cleaning and will then stick to them. For jet filters, during cleaning in operation, the distance should be at least 50 mm.

Because often, apart from the distance of circular filter elements **a**, the exact arrangement of the circular filter elements is not known, WinVent calculates the entire enveloping volume of the circular filter elements as follows if the distance between to circular filter elements is between **$a \geq d/3$ up to $a \leq d/2$** .

$$V_E = [d + a]^2 \cdot l_e \cdot N_o$$

where

V_E = entire enveloping volume of the “bags” in m³,

d = diameter of circular filter elements in m,

a = distance between two circular filter elements in m,

l_e = length of circular filter elements in m

N_o = total number of circular filter elements.

The screenshot shows the WinVent software interface for calculating the volume of a cylindrical filter. The interface is divided into several sections:

- Input Fields:**
 - body diameter b_d : 5
 - clean air c_a : 0,3
 - length l_e : 2
 - bags/pockets: 444
 - diameter d : 0,12
 - space a : 0,055
 - bottom diameter: 0,4
 - vent to top v_t : 2,3
 - body b_h : 3,3
 - hopper h_o : 1
 - depth x : (empty)
 - width w : (empty)
- Diagram:** A 3D diagram of a cylindrical filter with a hopper at the bottom. Dimensions are labeled: b_d (body diameter), c_a (clean air), l_e (length), b_h (body height), v_t (vent to top), h_o (hopper height), d (diameter), a (space), x (depth), and w (width).
- Results Table:**

Cylindrical Filter		
Vent on Body		
Bags - envelope	27,2	m ³
Clean Air Plenum	5,89	m ³
Dirty Air Plenum	58,9	m ³
Hopper	7,11	m ³
Total Volume	71,9	m ³
Dirty Volume	$V = 38,8$	m ³
Linear length	$L = 1,33$	m
Diameter (eff)	$D_e = 4,58$	m
Resistance	$P = 0,8$	bar
* Operating press.	$OP = 1$	bar abs
* Check parameter		
input dimensions	meters	▼

Support body for pocket filter, cassette filter, disk filters or sinter plate filters elements

In the following “pocket” represents all filter elements for which the envelope volume can be calculated. If the distance **a** between the pocket filter elements is equal to or smaller than the width **w** ($a \leq w$) of the pocket filter elements, then the entire enveloping volume of the filter elements can be subtracted from the entire dirty air volume.

The distance **a** must does not fall below a minimum distance, as otherwise too many dust particles are released onto the surrounding hoses during cleaning and will then stick to them. For pockets, during cleaning in operation, the distance should be at least 40 mm.

The entire enveloping volume of the pocket filter elements is calculated as follows if the distance between to pockets filter elements is between $a \geq w/3$ up to $a \leq w$.

$$V_E = [N_o \cdot w + (N_o - 1) \cdot a] \cdot x \cdot l_e$$

where

- V_E = entire enveloping of the pocket filter elements in m^3 ,
- N_o = total number of pocket filter elements,
- w = width of pocket filter elements in m,
- a = distance between two pocket filter elements in m,
- x = depth of pocket filter elements in m,
- l_e = Length of pocket filter elements in m

Rectangular Filter

Vent on Body

Pockets - volume	14,4	m ³
Clean Air Plenum	6	m ³
Dirty Air Plenum	60	m ³
Hopper	7,4	m ³
Total Volume	73,4	m³
Dirty Volume	V = 53	m ³
Linear length	L = 1,33	m
Diameter (eff)	De = 4,63	m

Resistance P = 0,8 bar

* Operating press. OP = 1,0 bar abs

* Check parameter

input dimensions meters

11.2 Location of the explosion venting devices

A key assumption is that the clean air volume is essentially free of fuel. With this statement being true, the vent panel will be calculated for the dirty air volume and be installed on the dirty air section. This requires that the structural integrity of the elements that separate the

clean air volume from the dirty volume (tube sheet and filter elements) is maintained during the initial explosion event /27/.

If the clean air contains fuel, then an additional separate vent on the clean airside should be calculated based on the clean airside volume.

The preferred location of the vent is below the filter elements (Fig. 11-2). It must be ensured, however, that the built-in components neither will entirely nor partially impede the venting process. Therefore, the filter bags, for instance, must not cover the explosion vents.

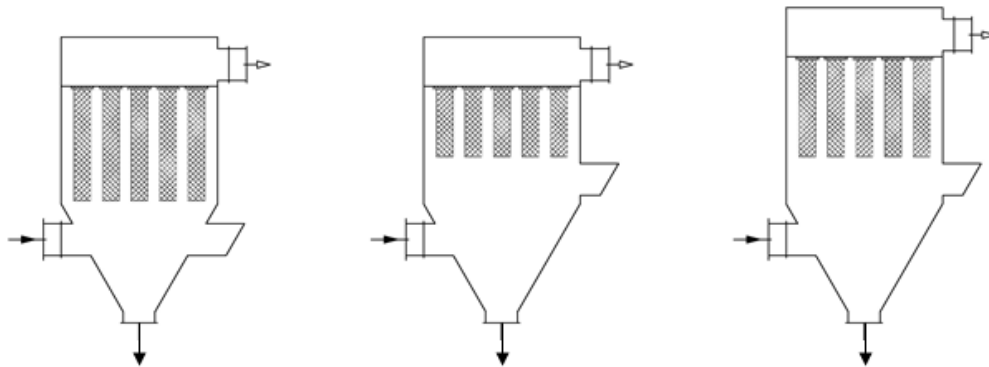


Figure 11-2. Arrangement of the vents on the dirty side of the filter
(*left: in the cone below the filter elements; centre: in the dirty air volume by shortening the filter elements; right: increasing the cylindrical part of the dirty air volume of the filter housing*)

Where the vents can only be arranged near the filter elements rather than underneath them (see Fig. 11-2), the required number of filter elements in front of the vent system shall be removed or shortened to ensure an undisturbed venting process.

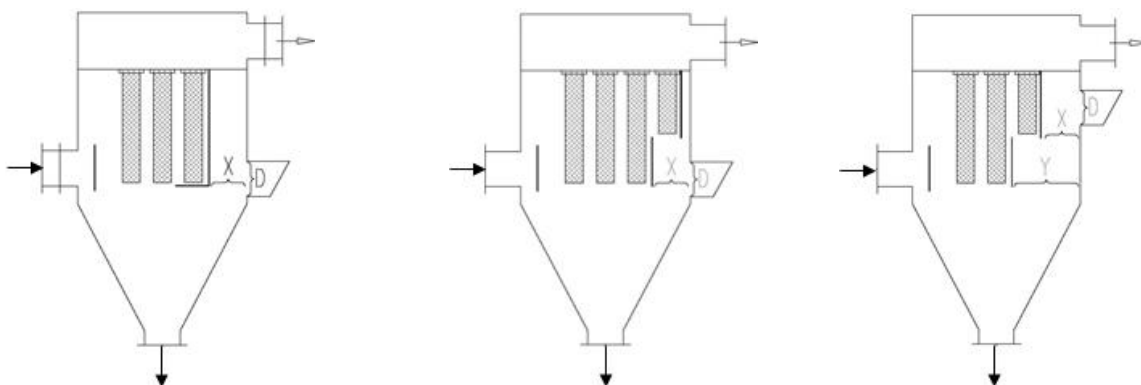


Figure 11-3. Arrangement of the vents near the filter elements
(*left/centre: near bottom section of filter elements; right: near top section of filter elements*)

The distance X between the first arrays of the filter elements and the vents (as per Fig. 11-3. Left-hand side or centre), shall be so dimensioned that the passage area directly in front of the

vent at least equals that of the vent. The resultant passage area shall be confined to the width of the explosion vent.

The right-hand side of Fig. 11-3 shows a vent arranged in front of the first array of the filter elements, which have been halved in length. To ensure favourable flow conditions for unimpeded explosion venting, the distance Y between the installation plane of the explosion vent and the array of filter elements that has not been shortened shall be determined in the same manner as the distance X ; however, the clear passage area must be at least twice that of the vent device in this case. Suitable retaining devices (no plates) shall be provided to prevent the filter elements from obstructing the vents in the event of an explosion.

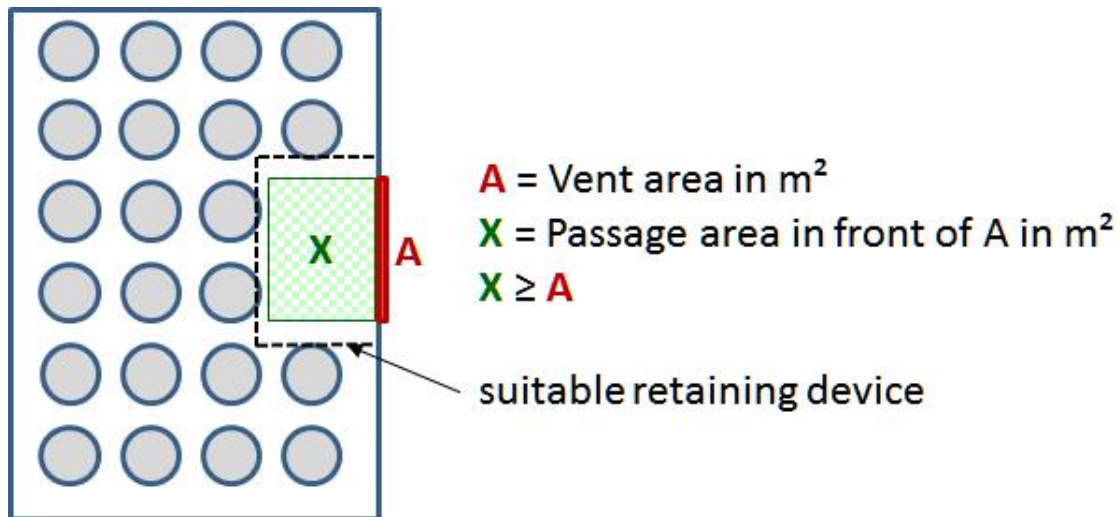


Figure 11-4. Arrangement of passage area in front of one vent near the filter elements

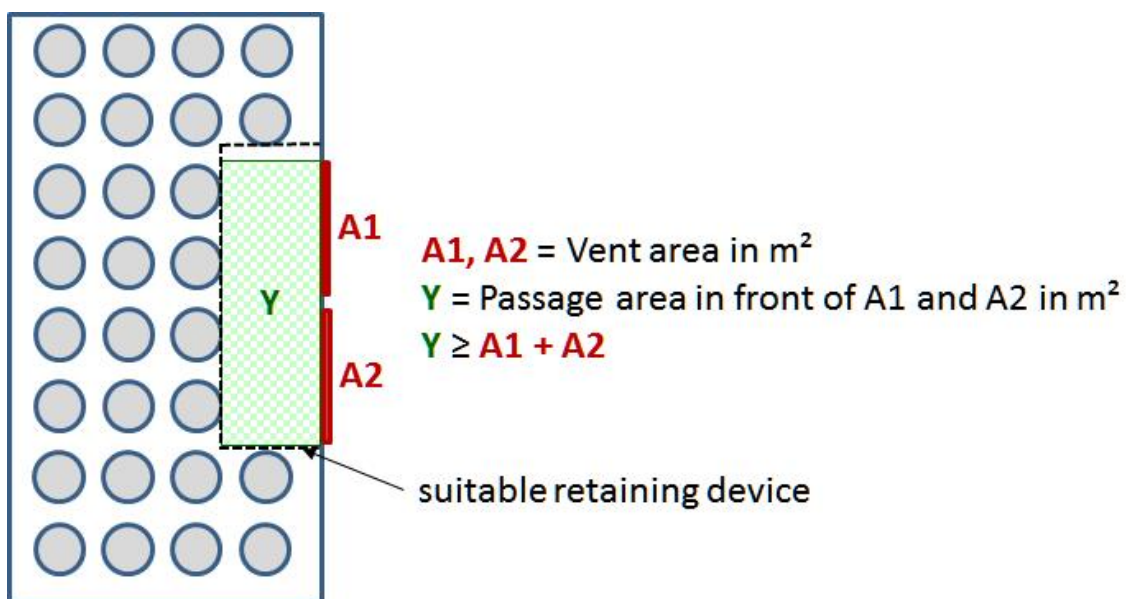


Figure 11-5. Arrangement of passage area in front of two vents near the filter elements

11.3 Examples for calculation of effective length to diameter ratio

In the following examples, the focus is only on determining the effective length to diameter ratio (L_{eff}/D_{eff}). All the other aspects related to explosion pressure venting are not discussed here. Figure 11.6 shows a rectangular vented bag filter. The vents (3) are evenly installed at both longer sides of the filter body housing /27/.

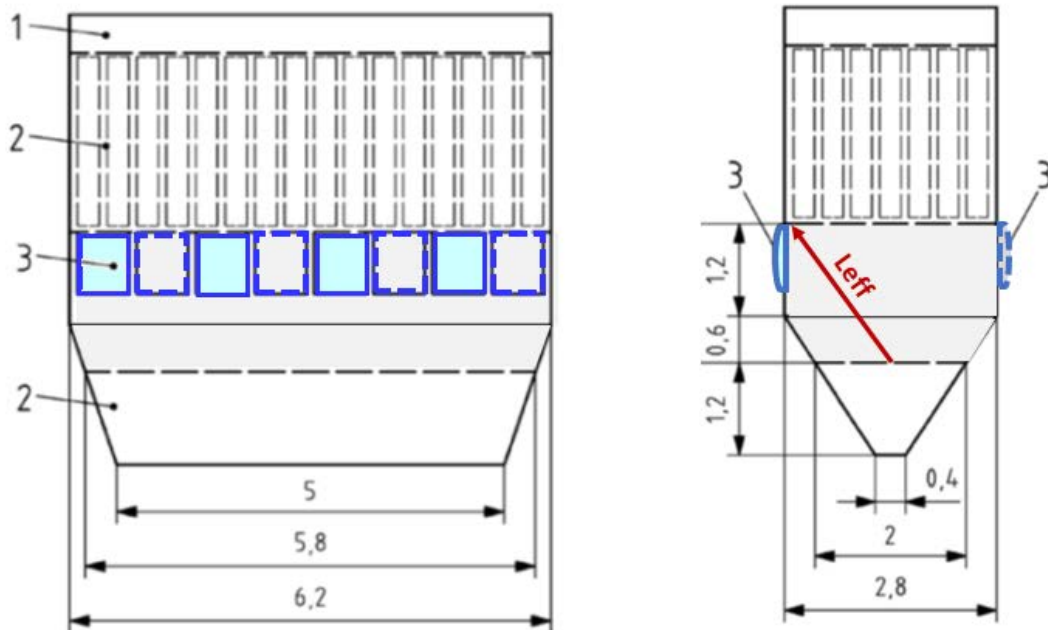


Figure 11-6. Rectangular filter evenly vented at both longer sides of the body
(1: clean air side; 2: dirty air side with rigid bag filters; 3: vent devices)

Calculation of ratio L_{eff}/D_{eff} :

Effective flame path:

$$L_{eff} = (1.8\text{m})^2 + (1.4\text{m})^2 = \sqrt{5.2\text{m}^2} = 2.28 \text{ m}$$

Effective flame volume:

$$V_{\text{body}} = 6.2\text{m} \times 1.2\text{m} \times 2.8\text{m} = 20.83 \text{ m}^3$$

$$V_{\text{hopper}} = [6.2\text{m} \times 2.8\text{m} + [(6.2\text{m}+5\text{m}) \times (2.8\text{m}+0.4\text{m})] + (5\text{m} \times 0.4\text{m})] \times 1.8\text{m}/6 = 16.56 \text{ m}^3$$

$$V_{\text{eff}} = V_{\text{body}} + V_{\text{hopper}}/3 = 20.83\text{m}^3 + 16.56\text{m}^3/3 = 26.35 \text{ m}^3$$

Effective cross-sectional area:

$$A_{\text{eff}} = V_{\text{eff}} / L_{\text{eff}} = 26.35\text{m}^3/2.28\text{m} = 11.56 \text{ m}^2$$

Effective diameter:

$$D_{\text{eff}} = (4 \times 11.56\text{m}^2/\pi)^{0.5} = 3.84 \text{ m}$$

Effective length/diameter ratio:

$$L_{\text{eff}}/D_{\text{eff}} = 2.28\text{m}/3.84\text{m} = 0.59 = 1.$$

The next Figure 11.7 shows a rectangular vented bag filter where the vents are evenly installed only at one longer side of the body of the filter housing.

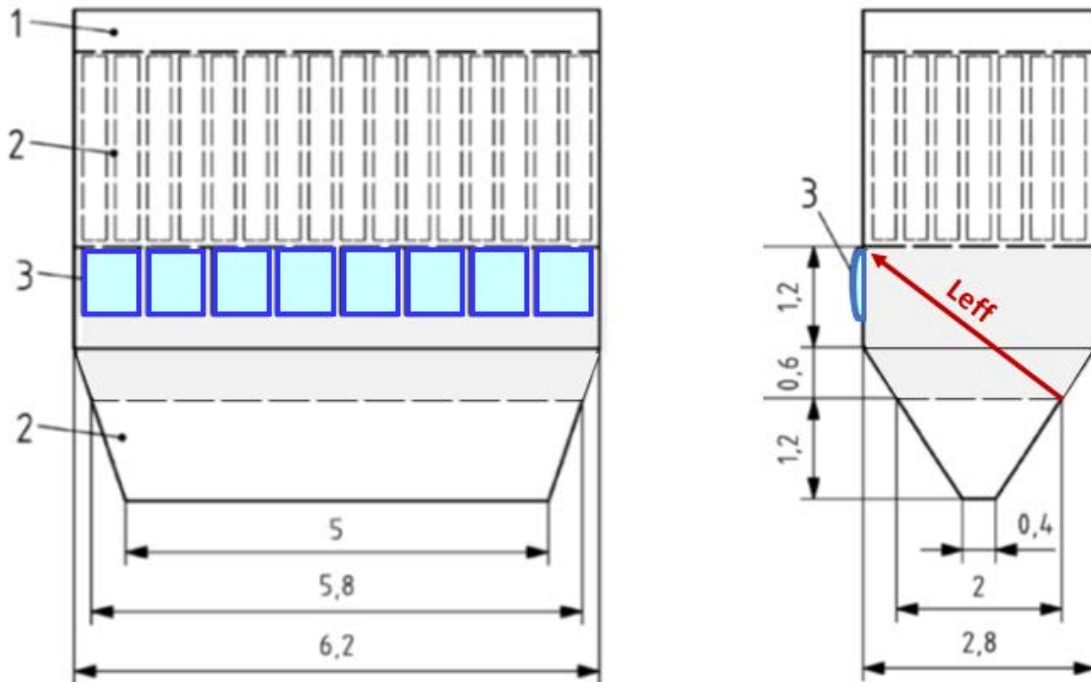


Figure 11-7. Rectangular filter evenly vented only at one longer side of the body
(1: clean air side; 2: dirty air side with rigid bag filters; 3: vent devices)

Calculation of ratio L_{eff}/D_{eff} :

Effective flame path:

$$L_{eff} = (1.8\text{m})^2 + (1.4\text{m})^2 = \sqrt{5.2\text{m}^2} = 2.28 \text{ m}$$

Effective flame volume:

$$V_{body} = 6.2\text{m} \times 1.2\text{m} \times 2.8\text{m} = 20.83 \text{ m}^3$$

$$V_{hopper} = [6.2\text{m} \times 2.8\text{m} + [(6.2\text{m} + 5\text{m}) \times (2.8\text{m} + 0.4\text{m})] + (5\text{m} \times 0.4\text{m})] \times 1.8\text{m}/6 = 16.56 \text{ m}^3$$

$$V_{eff} = V_{body} + V_{hopper}/3 = 20.83\text{m}^3 + 16.56\text{m}^3/3 = 26.35 \text{ m}^3$$

Effective cross-sectional area:

$$A_{eff} = V_{eff} / L_{eff} = 26.35\text{m}^3/3.0\text{m} = 8.78 \text{ m}^2$$

Effective diameter:

$$D_{eff} = (4 \times 8.78/\pi)^{0.5} = 3.34 \text{ m}$$

Effective length/diameter ratio:

$$L_{eff}/D_{eff} = 3.0\text{m}/3.34\text{m} = 0.90 = 1$$

Figure 11.8 shows a rectangular vented bag filter. The vents are evenly installed at both shorter sides of the body of the filter housing.

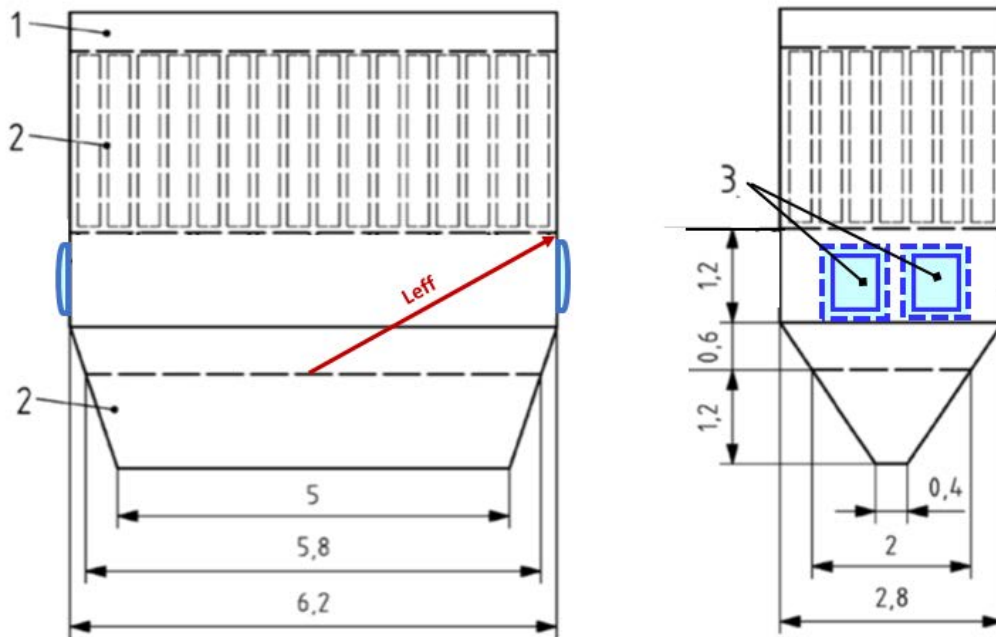


Figure 11-8. Rectangular filter evenly vented at both shorter sides of the body
(1: clean air side; 2: dirty air side with rigid bag filters; 3: vent devices)

Calculation of ratio L_{eff}/D_{eff} :

Effective flame path:

$$L_{eff} = (1.8\text{m})^2 + (1.4\text{m})^2 = \sqrt{5.2\text{m}^2} = 2.28 \text{ m}$$

Effective flame volume:

$$V_{body} = 6.2\text{m} \times 1.2\text{m} \times 2.8\text{m} = 20.83 \text{ m}^3$$

$$V_{hopper} = [6.2\text{m} \times 2.8\text{m} + [(6.2\text{m}+5\text{m}) \times (2.8\text{m}+0.4\text{m})] + (5\text{m} \times 0.4\text{m})] \times 1.8\text{m}/6 = 16.56 \text{ m}^3$$

$$V_{eff} = V_{body} + V_{hopper}/3 = 20.83\text{m}^3 + 16.56\text{m}^3/3 = 26.35 \text{ m}^3$$

Effective cross-sectional area:

$$A_{eff} = V_{eff} / L_{eff} = 26.35\text{m}^3/3.58\text{m} = 7.36 \text{ m}^2$$

Effective diameter:

$$D_{eff} = (4 \times 7.36\text{m}^2/\pi)^{0.5} = 3.06 \text{ m}$$

Effective length/diameter ratio:

$$L_{eff}/D_{eff} = 3.58\text{m}/3.06\text{m} = 1.17 = 1.2$$

The next Figure 11.9 shows a rectangular vented bag filter where the vents are evenly installed only at one shorter side of the body of the filter housing.

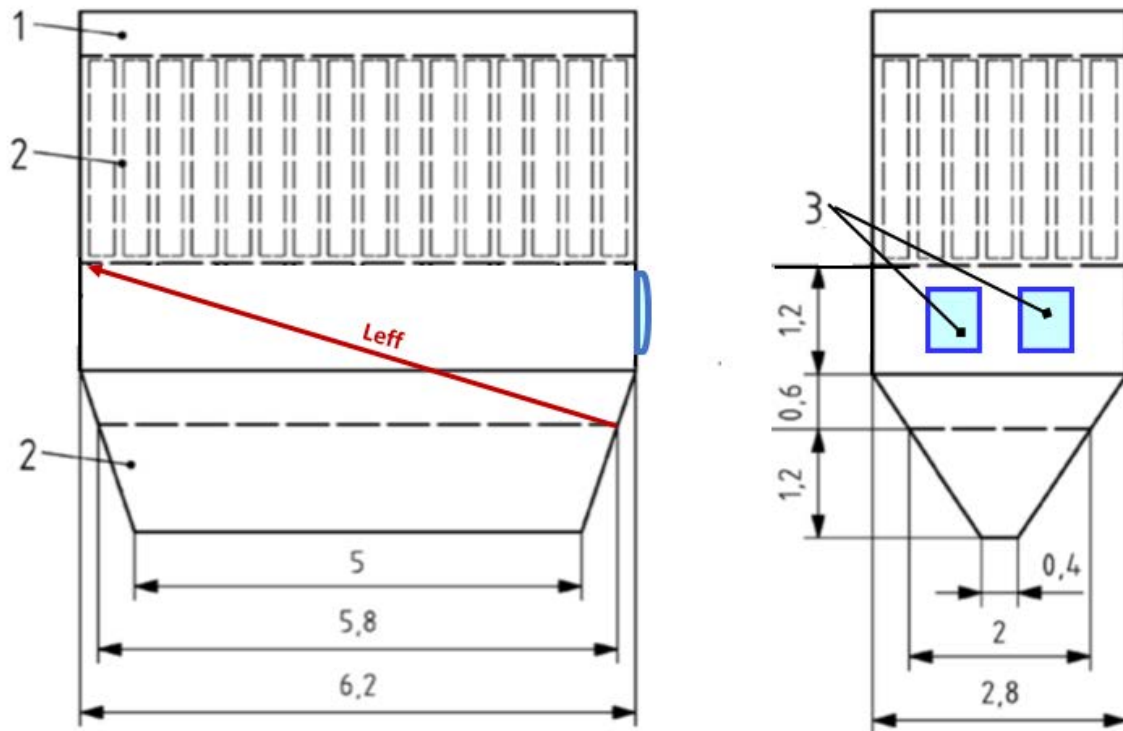


Figure 11-9. Rectangular filter evenly vented only at one shorter side of the body
(1: clean air side; 2: dirty air side with rigid bag filters; 3: vent devices)

Calculation of ratio L_{eff}/D_{eff} :

Effective flame path:

$$L_{eff} = (1.8\text{m})^2 + (1.4\text{m})^2 = \sqrt{5.2\text{m}^2} = 2.28 \text{ m}$$

Effective flame volume:

$$V_{body} = 6.2\text{m} \times 1.2\text{m} \times 2.8\text{m} = 20.83 \text{ m}^3$$

$$V_{hopper} = [6.2\text{m} \times 2.8\text{m} + [(6.2\text{m}+5\text{m}) \times (2.8\text{m}+0.4\text{m})] + (5\text{m} \times 0.4\text{m})] \times 1.8\text{m}/6 = 16.56 \text{ m}^3$$

$$V_{eff} = V_{body} + V_{hopper}/3 = 20.83\text{m}^3 + 16.56\text{m}^3/3 = 26.35 \text{ m}^3$$

Effective cross-sectional area:

$$A_{eff} = V_{eff} / L_{eff} = 26.35\text{m}^3/6.26\text{m} = 4.21 \text{ m}^2$$

Effective diameter:

$$D_{eff} = (4 \times 4.21\text{m}^2/\pi)^{0.5} = 2.32 \text{ m}$$

Effective length/diameter ratio:

$$L_{eff}/D_{eff} = 6.26\text{m}/2.32\text{m} = 2.70 = 2.7$$

12 Explosion Venting of Cyclones

For calculating the explosion-venting device of a cyclone (Fig. 12-1), consider the entire cylindrical volume, V_1 (without subtracting the air outlet pipe), the conical volume, V_2 , as well as the volume of the settling chamber, V_3 .

Typically, the explosion vent is located on top of the air pipe implying that the vent area equals the total cross-sectional area, A , of the air outlet pipe. For the venting design, the immersion pipe (air outlet pipe) should be considered as a vent duct with length, LA . Should the immersion pipe be tapered inside, use the smaller cross-sectional area X for the calculation of $P_{red,max}$ which corresponds to the cyclone strength P .

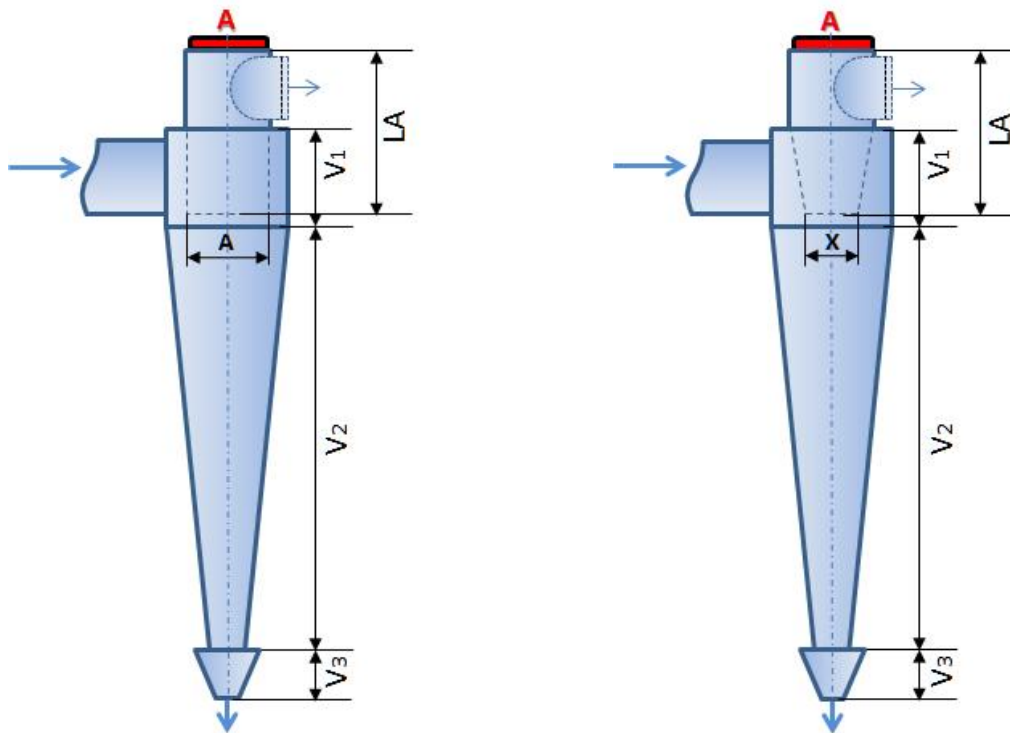


Figure 12-1. Cyclone with settling chamber, left: normal immersion pipe (A), right: tapered immersion pipe (X) /1, 27/

13 Explosion Venting of Pipelines

The following remarks apply to flammable gases, solvent vapours, and combustible dusts.

In the case of flammable gas explosions, explosion-venting perpendicular to the longitudinal axis of a pipe is not possible. After response of the bursting disk, explosion development can increase up to detonation. With ignition at the end of closed pipelines of length 30 m to DN 200-300, methane explosions have a maximum explosion overpressure of $P_{\max} = 8$ bar and a maximum explosion velocity of several $10 \text{ m}\cdot\text{s}^{-1}$. On installation of lateral venting corresponding to the pipe cross-section at some distance from the ignition site, the maximum explosion overpressure is raised to $P_{\max} = 30$ bar and the maximum explosion velocity to $1000 \text{ m}\cdot\text{s}^{-1}$ /5/.

In comparison with vessel explosions, dust explosions in pipelines can show appreciably more vehement development. With increasing pipe length, detonations with a high flame velocity up to $2000 \text{ m}\cdot\text{s}^{-1}$ and brief local pressure spots of more than 20 bar must be anticipated. The occurrence of detonations is dependent on the pipe diameter and the dust concentration and increases in probability with an increase in the K_{\max} value of the dust. At end flanges, constrictions and bends, pre-compression can lead to even higher pressures in the short term. However, pipelines constructed to PN 10 withstand the above stresses /5/.

In the case of dust explosions, due to the directional effect of the explosion, effective explosion venting of pipe systems is only possible if venting devices (bursting discs) of sufficient size are arranged radially at a short distance (1-2 m) from the pipe wall (Fig. 11-1).



**Figure 13-1. Pipeline shown with vent openings
(vent openings closed with rupture disks) /5/**

This is possible only with open-air installations owing to the escape of flame (Fig. 13-2).



Figure 13-2. Wood dust explosion in a vented pipeline /5/

If a pipeline is vented in an axial direction, pre-compression effects can be avoided at end flanges. However, this requires venting of the entire pipe cross-section. At the sealing flanges or elbows, however, pre-compression of the mixtures before the flame front can lead to pressure values, which are appreciable higher than those that appear in the usual pipe. Bursting disks or other tested venting devices must thus be used for venting in this case (Figs. 13-3 and 13-4).



Figure 13-3. Venting device at end: Counter-balanced, hinged explosion door /5/

However, it must be borne in mind that the response of such a venting device in the event of an explosion leads to an increase in the explosion velocity and hence to the explosion pressure by explosion force effects caused by release of the vent opening. The lower the static activation overpressure, the quicker this happens. A correspondingly high static activation overpressure must thus be selected - $P_{stat} = 0.5$ to 2 bar - to avoid promoting the formation of processes similar to detonations or actual detonations because of the venting process /5/.

For venting devices at the end of pipe systems, according to /5/ it is necessary to place more demands that are exacting on their mechanical strength than in the case of explosion doors of vessels.

These are as follows:

- selection of a relatively high static response pressure (corresponding to the strength of the pipeline) to avoid promoting increases in velocity and pressure,
- venting in the longitudinal direction of the pipeline over the entire cross section and
- proof of the operability by explosion or detonation tests.

The end venting devices shown in Figs. 11-3 and 11-4 also fulfil the requirement regarding a gas-tight pipe closure following an explosion.

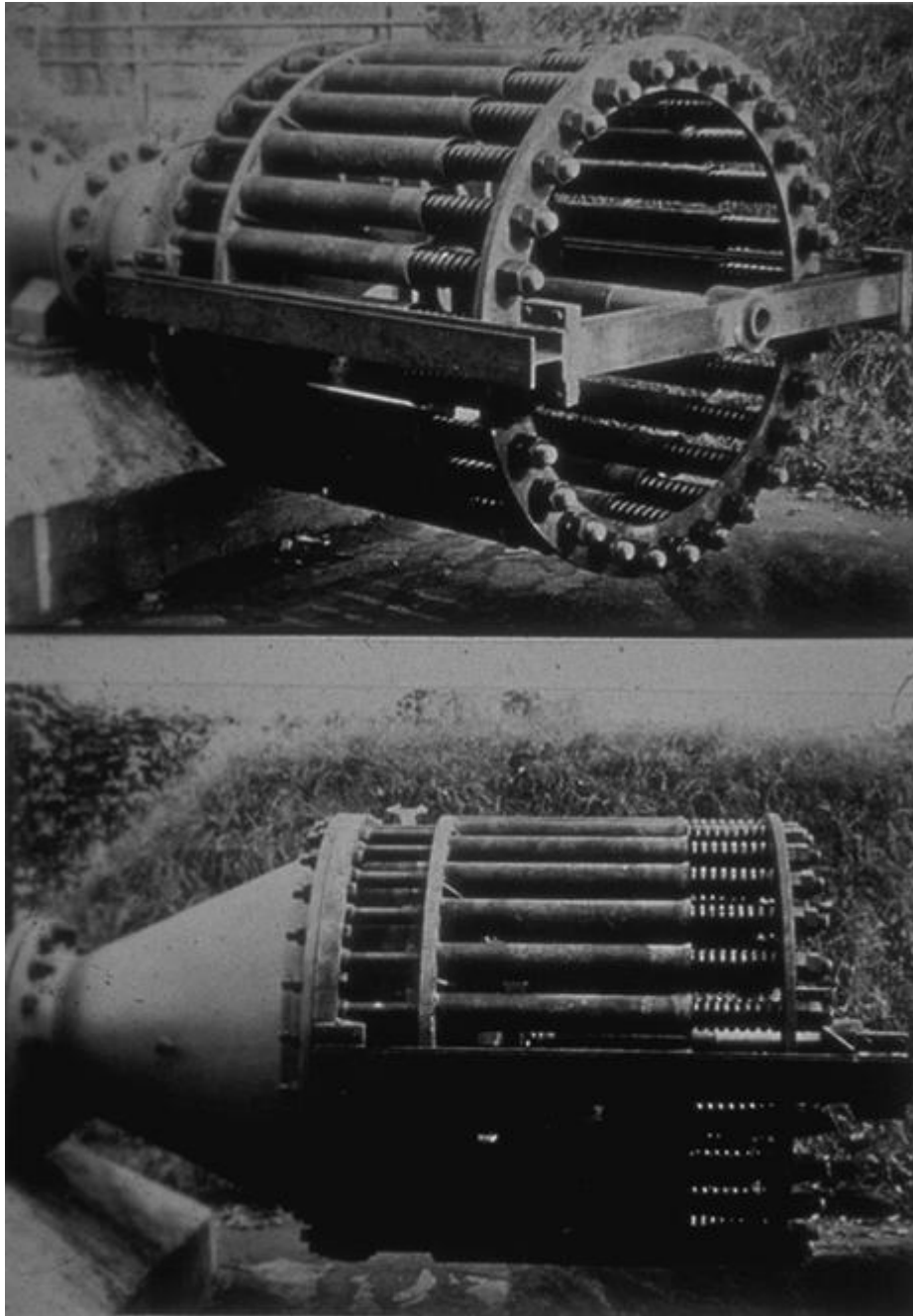


Figure 13-4. Venting device at end: Spring-loaded explosion device /5/

14 Consideration of Recoil Forces

14.1 Without Vent Pipe

During pressure venting, recoil is generated by the unburned mixtures and products of combustion flowing through the vent opening. The force bearing on the protected equipment depends upon the reduced explosion pressure and the vent area. The maximum recoil force FR_{max} can be calculated [1, 4] as a function of the maximum reduced explosion overpressure $P_{red,max}$ and the vent area A as per the following equation:

$$FR_{max} = 119 \cdot A \cdot P_{red,max} = 119 \cdot A \cdot P_o$$

Not only the calculated recoil force but also its variation over time is decisive for the practical design of the structure, which supports the explosion vented vessel.

The duration of the recoil force can be estimated with the following equation [1, 4]:

$$t_d = 10^{-4} \cdot \frac{K_{max} \cdot V}{A \cdot P_{red,max}} = 10^{-4} \cdot \frac{K_{max} \cdot V}{A \cdot P_o}$$

In order to determine the total transferred impulse, I , a rectangular load with the same area can replace the real load-time course. In practice the height of this rectangular impulse may be chosen as $0.52 \cdot FR_{max}$. This results into an impulse of

$$IR = 0.52 \cdot FR_{max} \cdot t_d$$

The effect of the recoil forces on the structure of the vented vessel needs further detailed consideration.

The influence of the recoil force can be in general compensated for by arranging vent areas of equal size opposite each other. It is always possible for one vent to open before another. Such imbalance should be considered when designing vessel or enclosure restrains for resisting thrust forces.

Figure 14-1 shows schematically the effect of the recoil forces on the vent areas installed different on the vessel during a vented explosion.

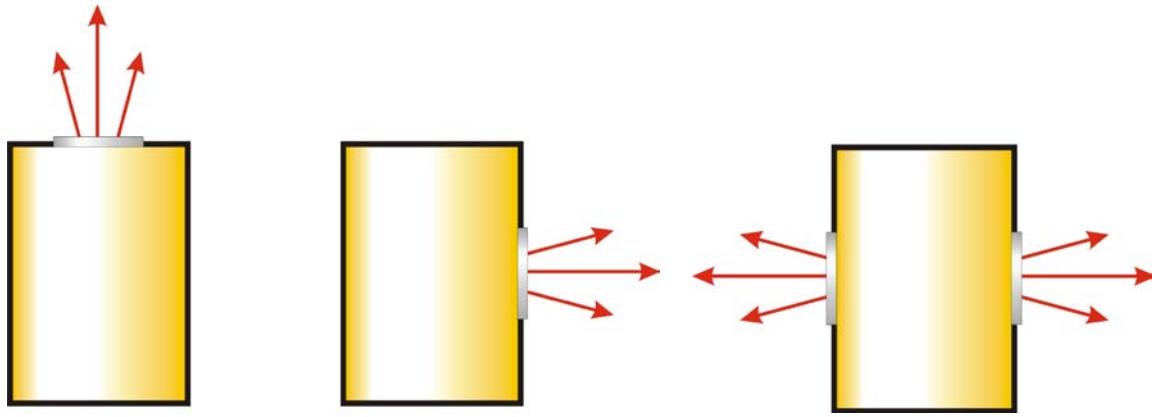


Figure 14-1. Effect of the recoil force on vent areas installed different on the vessel during a vented explosion; recoil forces effective (left), recoil forces will be compensated if both vent open simultaneously (right)

14.2 With Vent Pipe

During pressure venting through vent pipes the maximum recoil force FR_{max} can be calculated again as a function of the maximum reduced explosion overpressure $P_{red,max}$ and the vent area A as per the following equation:

$$FR_{max} = 119 \cdot A \cdot P_{red,max} = 119 \cdot A \cdot P_o$$

If a vessel is vented through a vent pipe the maximum reduced explosion overpressure $P_{red,max}$ will be increased compared to a vented vessel without vent pipe. Therefore, significant higher maximum recoil forces must be considered.

Not only the calculated recoil force but also its variation over time is decisive for the practical design of the structure, which supports the explosion vented vessel.

The duration of the recoil force can be estimated with the following equation:

$$t_d = 10^{-4} \cdot \frac{K_{max} \cdot V}{A \cdot P_{red,max}} = 10^{-4} \cdot \frac{K_{max} \cdot V}{A \cdot P_o}$$

To determine the total transferred impulse IR , a rectangular load with the same area can replace the real load-time course. In practice the height of this rectangular impulse may be chosen as $0.52 \cdot FR_{max}$. This results into an impulse of

$$IR = 0.52 \cdot FR_{max} \cdot t_d$$

The effect of the recoil forces on the structure of the vented vessel needs further detailed consideration.

The influence of the recoil force can be in general compensated for by arranging vent areas of equal size opposite each other. It is always possible for one vent to open before another. Such imbalance should be considered when designing vessel or enclosure restrains for resisting thrust forces.

Figure 14-2 shows schematically the effect of the recoil forces on the vent areas installed different on the vessel during a vented explosion.

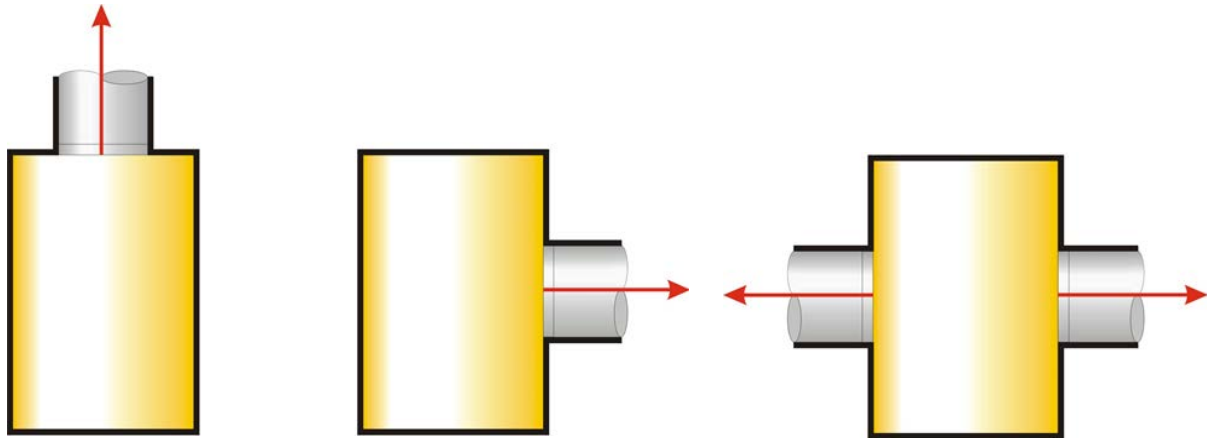


Figure 14-2. Effect of the recoil force on vent areas installed different on the vessel during a vented explosion: recoil forces effective (left), recoil forces will be compensated if both vent open simultaneously (right)

15 Pressure Venting of Vessels Interconnected with Pipelines

Vent areas determined by the equations shown in Section 6 are too small if a dust explosion propagates from one vessel into another through a pipeline. Increased turbulence, pressure piling and broad flame jet ignition may result in increased explosion violence especially with duct length > 6 m. This results in an elevated maximum reduced explosion overpressure. Measures to disengage the explosion in the connecting pipeline are therefore needed /1, 2, 4/.

In accordance with the present technology the protective measure explosion venting can be used for pipelines having a nominal diameter up to DN 300, a connecting length ≤ 6 m, for dusts with K_{max} values not exceeding $200 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$ and the venting device is to be designed for a low static activation overpressure ($P_{stat} < 0.2 \text{ bar}$), in accordance with the following criteria:

1. Vessels of the same size ($\Delta V \pm 10\%$) are to be vented as per basic equations (Fig. 15-1).

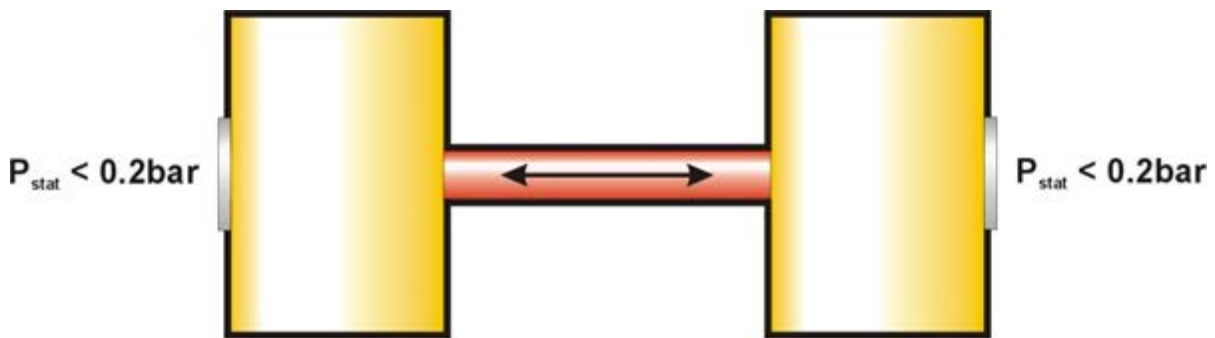


Figure 15-1. Vessels of the same size ($\Delta V \pm 10\%$) connected with a pipeline ≤ 6 m with a maximum diameter of DN = 300 ($P_{stat} < 0.2 \text{ bar}$), $K_{max} \leq 200 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$

2. The vent areas of different maximum sized vessels ($\Delta V > 10\%$) must be brought in relation to a maximum reduced explosion overpressure $P_{red,max} \leq 1.0$ bar. The design overpressure should not fall short of $P = 2$ bar (Fig. 15-2).

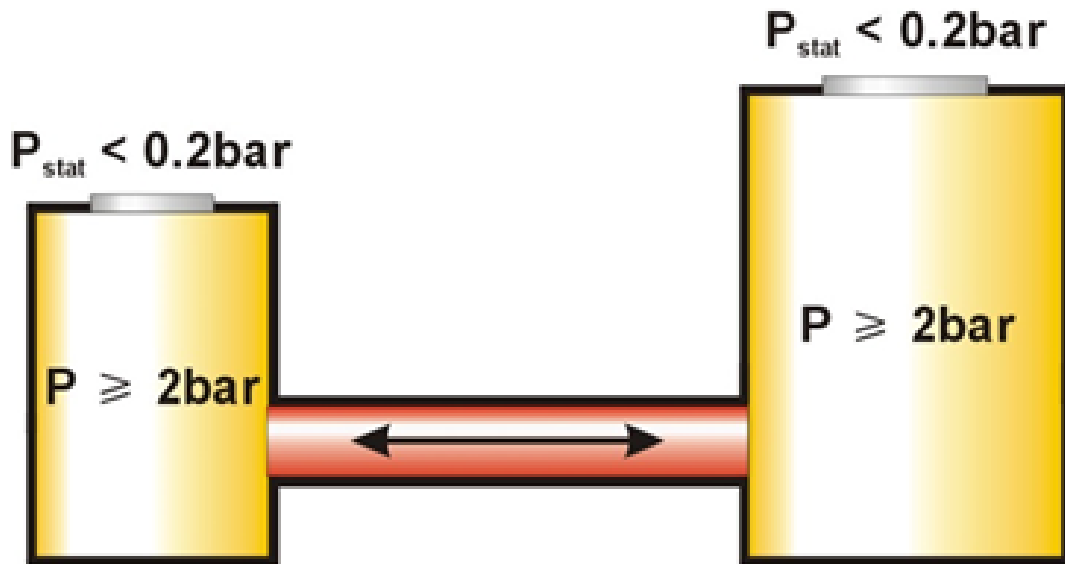


Figure 15-2. Vessels of different size ($\Delta V > 10\%$) connected with a pipeline ≤ 6 m with a maximum diameter of DN = 300 ($P_{stat} < 0.2$ bar)

3. If it is not possible to vent the smaller vessel, then this vessel must be designed for the maximum explosion overpressure (Fig. 15-3) and the vent area of the larger vessel must be doubled. Through this doubling, the maximum explosion overpressure (is equal to the vessel strength) will be reduced of about 70 %. The use of explosion venting is impossible if the larger vessel cannot be vented.

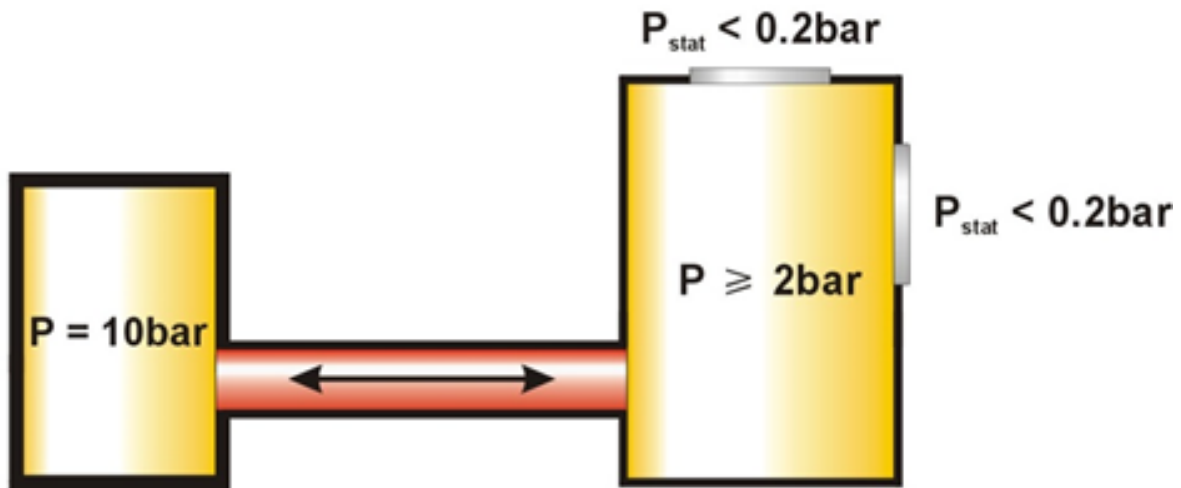


Figure 15-3. Vessels of different size ($\Delta V > 10\%$) partially vented connected with a pipeline $\leq 6\text{ m}$ with a maximum diameter of $\text{DN} = 300$ ($P_{\text{stat}} < 0.2\text{ bar}$)

Explosion venting may be used without explosion isolation for vessels $\leq 20 \text{ m}^3$ interconnected with pipes with a nominal diameter up to 500 mm, a connecting length up to 15 m and $P_{\text{stat}} \leq 0.1 \text{ bar}$, in accordance with the following criteria:

- a) For $K_{\text{max}} \leq 150 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$, dimensionless vent areas ($A/V^{2/3}$) of each vessel of greater than 0.25 will limit the maximum reduced explosion overpressure to 0.5 bar (Fig.15-4).

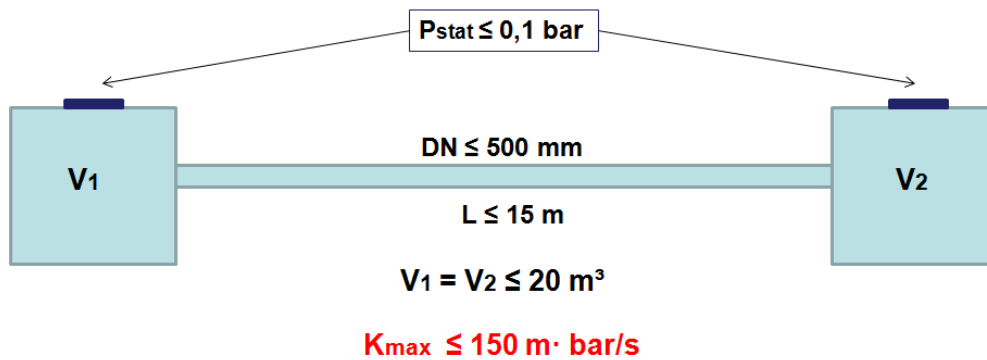


Figure 15-4. Vented vessels of $V \leq 20 \text{ m}^3$ connected with a pipeline $\leq 15 \text{ m}$ with a maximum diameter of $DN = 500$ ($P_{\text{stat}} = 0.1 \text{ bar}$) and a maximum explosion constant of $K_{\text{max}} \leq 150 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$

- b) For K_{max} values more than $150 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$ up to $250 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$, dimensionless vent areas ($A/V^{2/3}$) of each vessel greater than 0.4 will limit the maximum reduced explosion overpressure to 0.5 bar (Fig. 15-5).

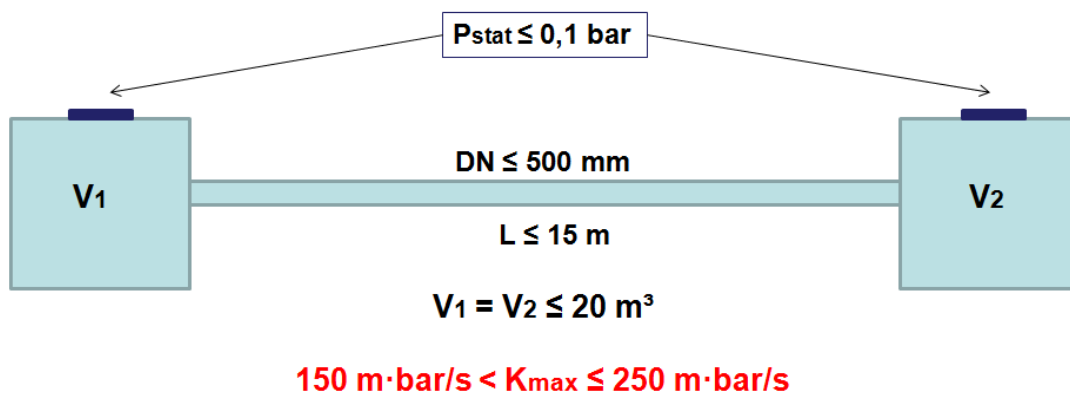


Figure 15-5. Vented vessels of $V \leq 20 \text{ m}^3$ connected with a pipeline $\leq 15 \text{ m}$ with a maximum diameter of $DN = 500$ ($P_{\text{stat}} = 0.1 \text{ bar}$) and a maximum explosion constant of $K_{\text{max}} > 150 - 250 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$

The dimensionless vent area is defined as $A/V^{2/3}$ where A is the required vent area and V is the vessel volume.

The total vent area shall be divided between the vessels so that the dimensionless vent area has the same value on each enclosure.

16 Explosion Venting of Bucket Elevators

16.1 General

Explosion venting of bucket elevators is designed to prevent internal explosion pressures exceeding the strength of the bucket elevator construction. The maximum explosion pressure allowed inside the bucket elevator is the reduced explosion pressure, $P_{red,max}$.

The following conditions are necessary for application of this part of the standard.

Explosion venting devices shall be positioned so that the effectiveness of the venting process is not impeded. Personnel and nearby plant shall not be at risk from the venting action.

Vent openings shall have an area equal to or greater than the internal cross-sectional area of the bucket elevator leg(s).

The minimum vent area for the head and the boot shall be equal to the internal cross-sectional area of the leg.

Venting devices shall comply with EN 14797 /3/. The static activation overpressure of the explosion-venting device, P_{stat} , shall not exceed 0.1 bar.

Guidance for the design of explosion venting is given for dusts with $P_{max} < 10$ bar and K_{max} up to 200 bar m s^{-1} /28, 29/.

16.2 Guidance for venting of twin leg bucket elevators

The guidance given is valid under the following conditions:

- Bucket spacing < 280 mm.
- Rectangular cross section of the bucket elevator legs.
- Free area in relation to the cross-section area (CSA) of the bucket elevator legs < 60 %
- venting area \geq cross section area (CSA) of the bucket elevator leg.
- Both bucket elevator legs are vented.
- Static activation overpressure $P_{stat} \leq 0.1$ bar
- Metal or plastic buckets (see note below on effect of plastic buckets)
- Maximum internal cross-sectional area of one leg is 0.5 m^2

These rules apply to vents positioned on one side of the bucket elevator leg. It may be necessary to position vents on two sides of the leg. The total effective area of these two vents should equal at least the area of the single vent they replace; that is, the cross-sectional area of the leg.

Where there is a requirement to put a vent on the boot and it is not possible to install it on the boot, the vent shall be put on both legs as close as possible to the boot. The distance between the lower edge of the vent and the top of the boot must not exceed 0.5 times the vent spacing

or within 3 m of the boot whichever is the smaller value. The same criterion applies to the head when it is not practical to vent the head.

Ensure that the venting process is not impeded by the belt. This can e.g., be achieved by positioning the vents in a face normal to the belt. Figure 16-1 shows the vent locations permitted in the legs relative to the belt or chain.

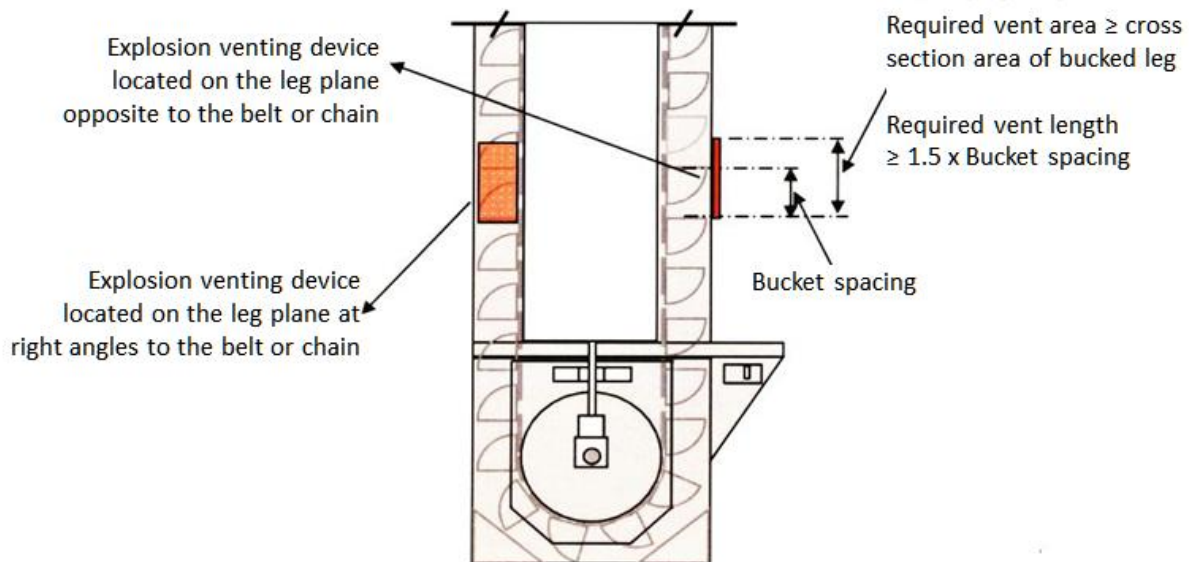


Figure 16-1. Definition of bucket spacing and vent locations on bucket elevator legs

The bucket elevator should be designed for the reduced explosion pressure, taking into account the weakening due to the vents and the reaction forces arising during the venting process. The reaction forces can be calculated using the formula in EN14491. The length of the vented flame can be calculated from the formula in EN14491 taking the volume as the volume between two subsequent vents. The external pressure effects close to the vent can be calculated from the formula in EN14491 taking the volume as the volume between two subsequent vents. On larger distances from the vent, the effects of multiple vents need to be considered. As a conservative approximation, the external overpressure from the various vents at a certain location the pressures can be added together.

Figure 16-2 shows the required pressure resistance for various K_{max} values and vent configurations /28, 29/.

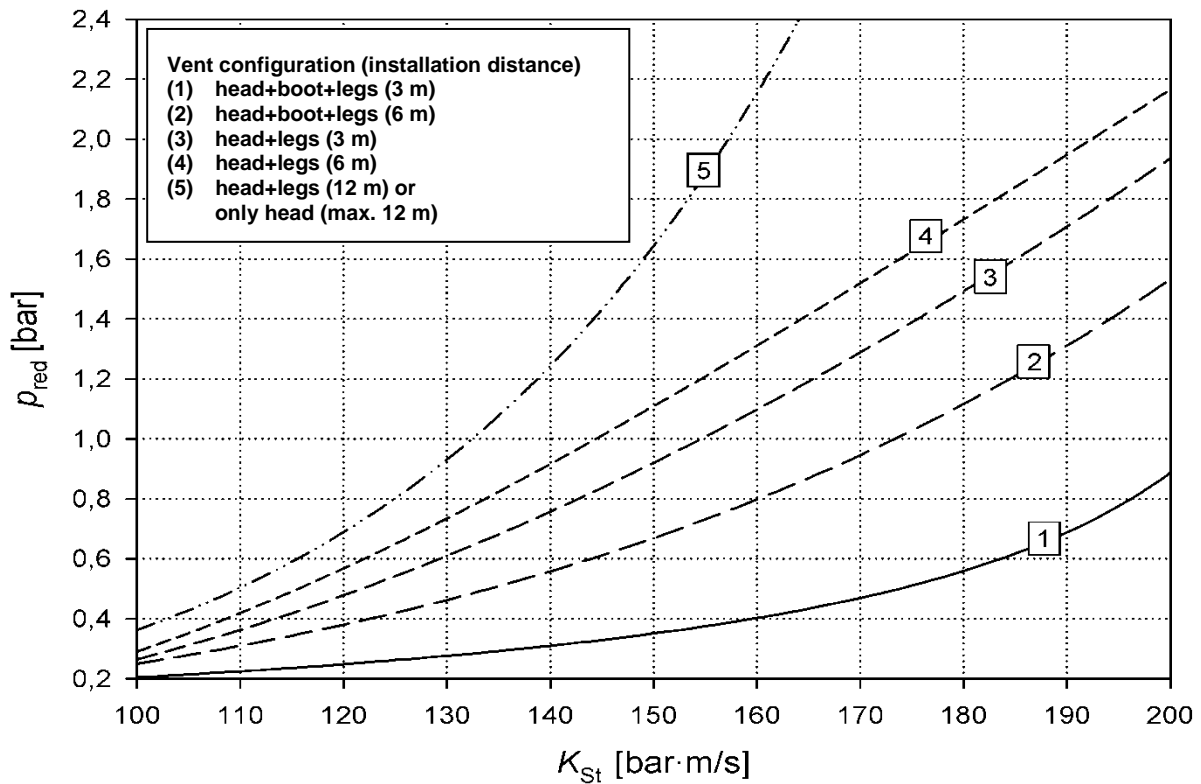


Figure 16-2. Twin leg bucket elevator vent spacing
(Pred = P and KSt = Kmax)

The curves are represented by following equation:

$$P_{red,max} = \exp(a \cdot K_{max}^c + b)$$

Vent configuration and elevator resistance with example for $K_{max} = 150 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$ for elevators with rectangular and round legs and metal buckets

Curve No.	Vent configuration (installation distance)	coefficient a	coefficient b	exponent c	rectangular legs	round legs	remark
1	head + boot + legs (3 m distance)	$3.292 \cdot 10^{-6}$	-1.957	2.5	0.4 bar	–	
2	head + boot + legs (6 m distance)	0.438	-5.761	0.5	0.7 bar	0.7 bar	
3	head + legs (3 m distance)	-67.98	5.467	-0.5	0.9 bar	–	
4	head + legs (6 m distance)	-401.6	2.78	-1	1.1 bar	1.3 bar	+15%
5	head + legs (12 m distance) or only head with length of the legs $\leq 12 \text{ m}$	0.673	-7.74	0.5	1.7 bar	–	

Figure 16.3 shows an example using a $K_{\max} = 150 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$ and metal buckets.

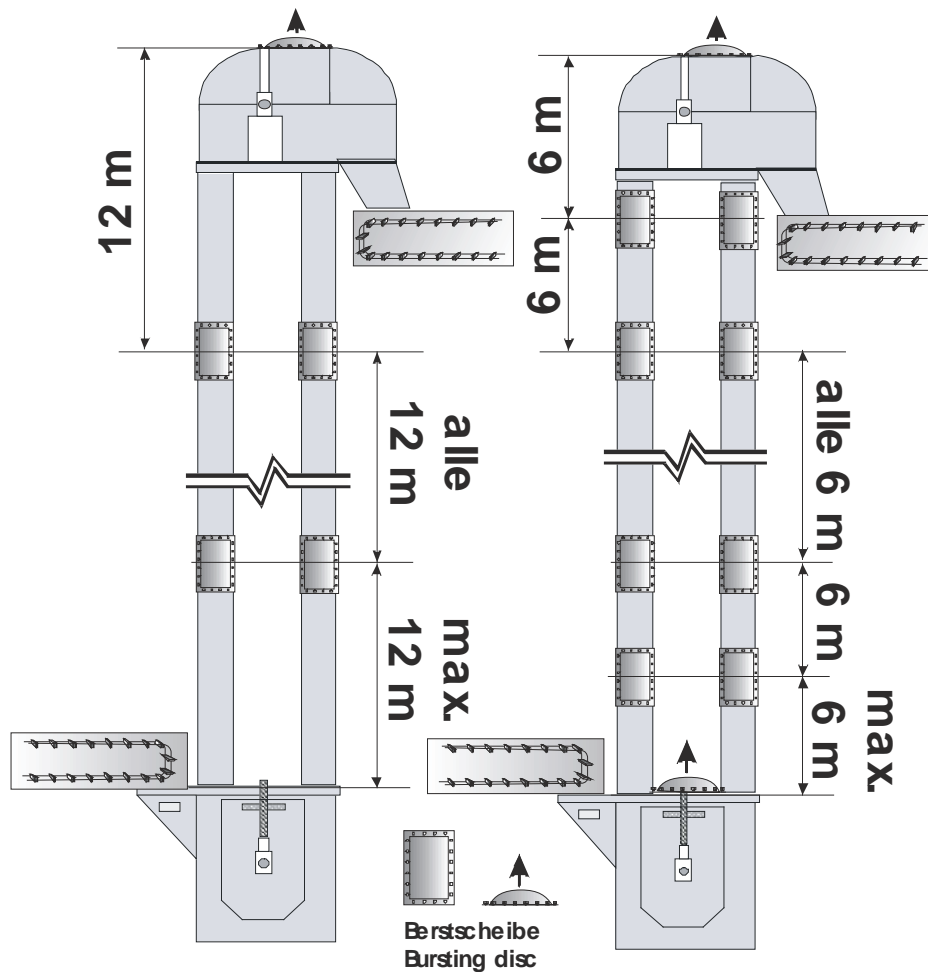


Figure 16-3. Examples of the necessary explosion protection resistance of bucket elevators, *left*: Vent spacing every 12 m, $P_{\min} = 1.7 \text{ bar}$; *right*: Vent spacing every 6 m, $P_{\min} = 0.7 \text{ bar}$

If instead of **metal** buckets **plastic buckets** are used, **then** plastic buckets will enhance explosion pressures. Increased bucket elevator strength is required to withstand the higher pressures, as given in next table.

K_{\max} [$\text{m} \cdot \text{bar} \cdot \text{s}^{-1}$]	Increase of bucket elevator strength
< 100	20 %
100 to 150	35 %
> 150 to 200	50 %

16.3 Guidance for venting of single leg bucket elevators

The guidance given is valid under the following conditions:

- Bucket spacing < 450 mm.
- Rectangular cross section of the bucket elevator leg.
- Free area in relation to the cross-section area of the bucket elevator legs < 75 %.
- Venting area \geq cross section area of the bucket elevator leg.
- Static activation overpressure $P_{stat} \leq 0.1$ bar.
- Metal or plastic buckets (see note below on effect of plastic buckets).
- Maximum internal cross-sectional area of the leg is 2.0 m^2 .

The following guidance is given:

- As a minimum requirement, vents shall be fitted to the head and the boot or as close as possible to the head and as close as possible to the boot.
- For dusts with KSt values of 100 bar m s^{-1} or less, vents installed in the head and boot of the bucket elevator, with none intervening, will limit the reduced explosion pressure to 0.5 bar.
- For dusts with a KSt value of 80 bar m s^{-1} , a vent spacing of 20 m will limit the reduced explosion pressure to 250 mbar.
- For 3 m vent spacing, use twin leg graph (Figure B.2)
- For 6 m vent spacing with vent opening pressure (P_{stat}) of 0.05 bar, use twin leg graph (Figure B.2) with P_{stat} of 0.1 bar.
- For 6 m vent spacing with vent opening pressure (P_{stat}) of 0.1 bar, use twin leg graph (Figure B.2) with P_{stat} of 0.1 bar and double the bucket elevator strength.

Increased bucket elevator strength for plastic buckets

Plastic buckets will enhance explosion pressures. Increased bucket elevator strength is required to withstand the higher pressures, as given in next table.

K_{max} [bar·m·s⁻¹]	Increase of bucket elevator strength
< 100	20 %
100 to 150	35 %
> 150 to 200	50 %

17 Hybrid Mixtures

Hybrid mixtures imply the coexistence of dispersed combustible dust with gaseous fuel (e.g., solvent vapor and flammable mist). The individual dust concentration and the individual flammable gas-air-mixtures may not be explosive but together they may form an explosive hybrid mixture /1, 4/ (Fig. 17-1).

According to Figure 17-1, a linear decrease in the lower explosion limit of the solid can be observed with increasing fuel gas content until the limit value of propane itself is reached, which with $LEL = 1.25 \text{ vol.-%}$ is lower than the value determined according to the standard method ($IE = 10 \text{ J}$) due to the influence of ignition energy ($IE = 10'000 \text{ J}$).

In hybrid mixtures with a given dust concentration, which is below the lower explosion limit LEL, the required amount of flammable gas or vapor to reach an explosive mixture becomes smaller the lower the explosion limit (Fig. 17-1).

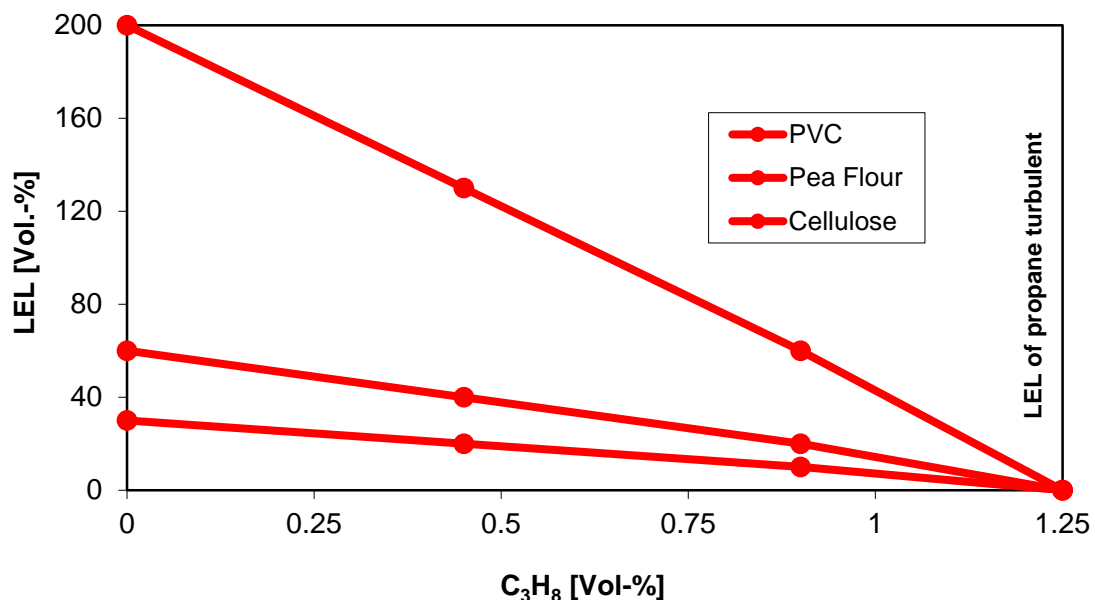


Figure 17-1. Lower explosion limit LEL of hybrid mixtures consisting of combustible dusts and propane ($V = 1 \text{ m}^3$; $IE = 10'000 \text{ J}$)

If the concentration of the vapor or gas portion remains at every location below 20 % of the lower explosion limit $LEL_{gas,vapour}$, then the safety data of the pure dust air mixture can be used to evaluate the total mixture.

If the vaporizing behaviour changes significantly due to **elevated temperatures** and/or **prolonged dwell times**, the gas or vapor concentration of the mixtures is to be **determined**.

Even where dried products contain **less than 0.5 wt.-%** of flammable solvents, this may still lead to the **formation of a potentially explosive solvent-vapor atmosphere!**

Figure 17-2 depicts for closed vessels the correlation of the explosion characteristics of combustible dusts with e.g., increasing turbulent propane content in the combustible atmosphere. The addition of gaseous fuel affects the maximum explosion overpressure P_{max} only *slightly* (Fig. 17-2 above).

The product specific constant K_{max} , however, is markedly influenced. It increases with increased content of turbulent gaseous fuel and the classification into a higher dust explosion class is possible, reaches the explosion characteristic of flammable gas for turbulent ignition and will only fall again above the stoichiometric concentration of the flammable gas or vapor (Fig. 17-2 below).

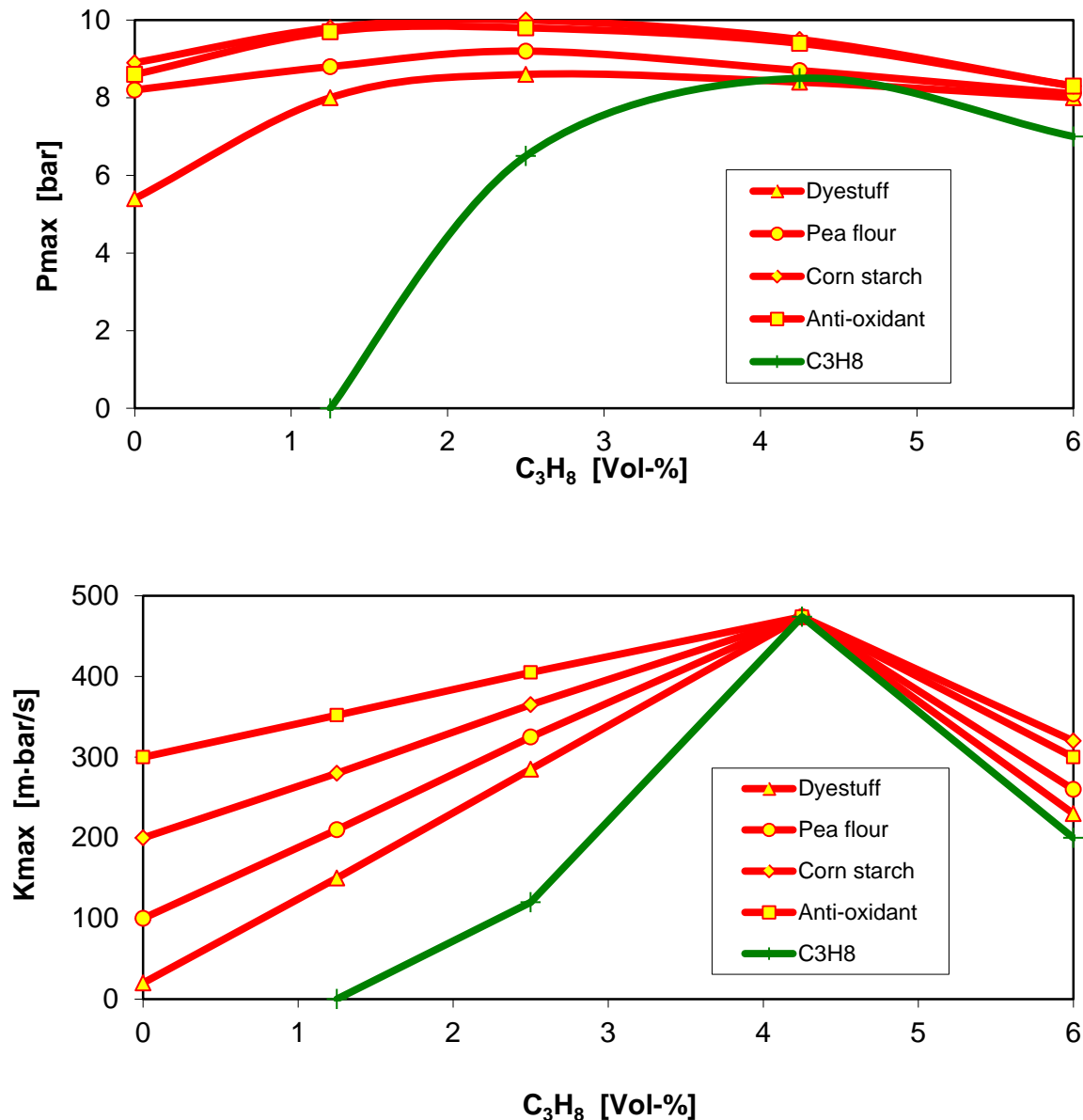


Figure 17-2. Influence of the propane (C_3H_8) concentration in the combustion air upon the explosion characteristic of combustible dusts in a closed vessel
($V = 1 \text{ m}^3$; $IE = 10'000 \text{ J}$)

Equations for **standard dust dispersion** (see Section 6.3.1.1; Fig. 6-4, 6-5) may be used for sizing the vent areas for hybrid mixtures. If the combustible dust belongs to the dust explosion class St 1 or St 2 ($P_{\max} \leq 10 \text{ bar}$, $K_{\max} \leq 300 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$) and the explosion behaviour of the flammable vapor is like that of propane ($S_u \leq 0.6 \text{ m} \cdot \text{s}^{-1}$; $K_{\max} \leq 120 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$), then the following values for P_{\max} and K_{\max} are automatically inserted by WinVent if only the answer of the question of the check parameter “*Hybrid mixture” is yes:

Check parameter:

*Metal dust	no
*Hybrid mixture	yes

WinVent insert for

- the maximum explosion overpressure	$P_{\max} = 10 \text{ bar}$,
- the maximum product specific constant	$K_{\max} = 500 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$.

Note 1:

$P_{\max} = 10 \text{ bar}$ and $K_{\max} = 500 \text{ m} \cdot \text{bar} \cdot \text{s}^{-1}$ covers the “worst hybrid case scenario” for dust explosion class St 1 and St 2. For all other cases, determine the explosion characteristics of the hybrid mixture in question or expert advice shall be obtained /1/.

Note 2:

Hybrid mixtures can only be vented if the main part of the mixture consists of explosive dusts *without metal dusts*. In the case of hybrid mixtures with metal dusts, the advice of experts should be sought.

18 Limit of Application of Venting

Explosion venting should **not** be used as a protective measure if products or compounds are released which are classified as

- very poisonous,
- poisonous,
- corrosive,
- irritant,
- carcinogenic,
- teratogenic or
- mutagenic

as per "CLP/GHS /7/ and Directive 98/24/EC" /30/.

Equipment cannot be protected from the hazardous consequences of a detonation through explosion pressure venting.

In case of difficulties in applying the contents of the explosion venting standards or guidelines, experts may be contacted for advice.

If pressure release cannot be applied e.g., where pressure and flame effects must be avoided in the vicinity of the equipment to be protected, other protective measures are required, e.g.:

- explosion suppression in combination with explosion isolation (e.g., extinguishing barriers),
- inertization,
- pressure-resistant or pressure shock-resistance design corresponding to the maximum explosion pressure in combination with explosion isolation (e.g., explosion protection valves).

19 Maintenance

Venting devices are subject to several influences, which may restrict their performance. The protective function may be completely lost, or an unintentional activation may result. Therefore, they must be adequately inspected and periodically maintained and repaired if necessary.

Rupture disks may be weakened by corrosion, pressure fluctuations, mechanical abrasion, and aging.

Explosion doors may also lose their effectiveness through corrosion and mechanical abrasion. Generally, more serious are the detrimental effects of incompetent maintenance (e.g., gumming up with paint). A regular inspection is necessary. Whenever an explosion has activated a door, it must be checked for suitability for future use.

The recommendations of manufacturers or experts listed in the preliminary remarks must be followed for the maintenance of *venting devices with different design* (e.g., buckling pin devices, plates in rubber mouldings).

The following maintenance and servicing should be carried out periodically and are considered as a minimum:

Rupture disks:

- Check on the rupture disks for perfect condition.
- Check on hold-back-devices for rupture disks.
- Electrical check on the trip circuits of signal device.

Explosion doors/ Vacuum breakers:

- Check on the explosion doors for perfect condition.
- Check on the movability of explosion doors.
- Check on hold-back-devices for explosion doors.
- Test of the static activation overpressure of the explosion door.
- Electrical check on the trip circuits of signal device.
- Check on the vacuum breakers for perfect condition.
- Check on the movability of vacuum breakers.

Explosion disks:

- Check on the explosion disks for perfect condition.
- Check on hold-back-devices for explosion disks.
- Check on the retaining-cables for perfect condition.
- Electrical check on the trip circuits of signal device.

Vent pipe:

- Check on the vent pipes for free cross-section.
- Check on the light cover for perfect condition.
- Check on hold-back-devices for light covers.
- Check on the lattice cover at the end of vent pipe.

Figure 19-1 shows that particular immediately attention should be paid to maintenance and checking of the explosion door to avoid severe consequences in case of an explosion.



Figure 19-1. This explosion door needs immediately maintenance to avoid severe consequences in case of an explosion

20 Determination of the Length/Diameter-Ratio of Vessel/Silo to be Protected when Calculating Vent Areas

20.1 General

The length to diameter ratio (L/D_e) is needed if vent areas are calculated using the equation shown in Section 6. The value of L/D_e depends on the shape of the vessel and of the position of the vent and need not necessarily equal the physical value of L/D_e evident from the design of the vessel/silo.

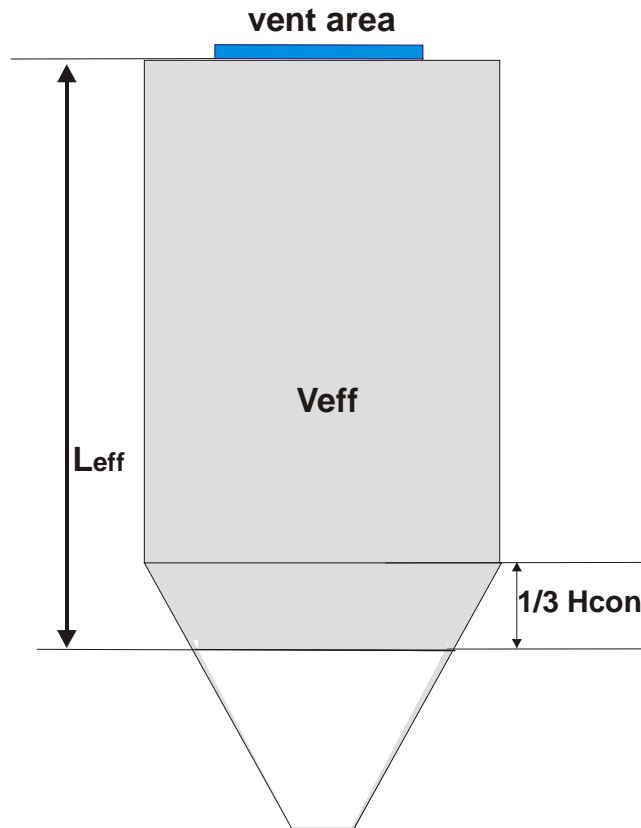
The worst-case condition, to which equations in Section 6 can be applied, is a vessel with a vent at the roof, because the flame can travel the entire length of the vessel/silo before it vents. If, in such a case, the vessel is cylindrical or rectangular, then the value of L/D_e ratio can be calculated directly from the physical dimensions (length and diameter of vessel or width and depth of vessel).

If the vessel/silo consists of a cylindrical and conical part, however, or the venting device is at the side, the appropriate value of L/D_e can only be obtained by estimating, based on the vessel/silo design, the maximum distance the flame (L_{eff}) can travel inside the vessel before venting and the volume (V_{eff}) through which the flame travels.

Note 1: The effective length of the flame travel L_{eff} is measured vertically including the pressure-venting device. In the case of lying vessels, it is measured horizontally.

Note 2: The effective volume of the flame V_{eff} , which is necessary for the calculation of the ratio (L/D_e), is not to be confused with the vessel volume V . Vessel volume V is the volume to be protected and is the base for the calculation of the vent area.

20.2 Cylindrical Vessel with Cone, Vented at the Roof



Effective flame length L_{eff}

The flame length L_{eff} of the round vessel is the vertical distance from 1/3 of the cone up to the vent area,

$L_{eff} = 1/3 \text{ cone/hopper high} + \text{cylindrical high.}$

Effective volume of the flame V_{eff}

The total free volume, which the flame travel is 1/3 of the volume of the cone part and the volume of the cylindrical part,

$V_{eff} = 1/3 \text{ cone/hopper volume} + \text{cylindrical volume (shaded region in the Figure).}$

Effective cross section area A_{eff}

$$A_{eff} = V_{eff} / L_{eff}$$

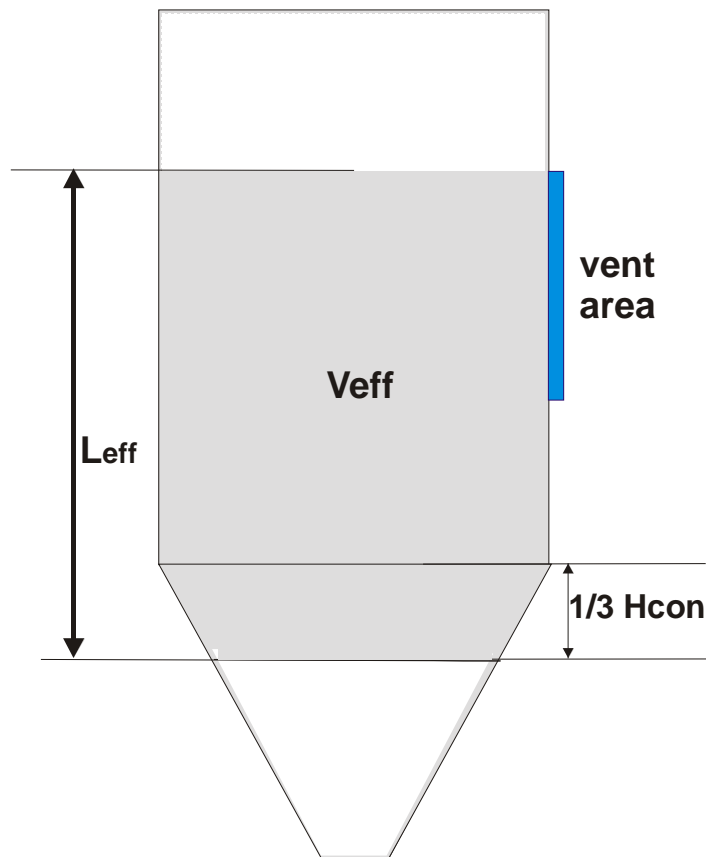
Effective diameter D_{eff}

$$D_{eff} = (4 \cdot A_{eff} / \pi)^{0.5}$$

Effective length/diameter - ratio L_{eff}/D_{eff} equals to the L/De - ratio

$$L_{eff}/D_{eff} = L/De$$

20.3 Cylindrical Vessel with Cone, Vented at the Side



Effective flame length L_{eff}

The flame length L_{eff} of the round vessel is the vertical distance from 1/3 of the cone up to the upper border of the vent area,

$L_{eff} = 1/3 \text{ cone/hopper high} + \text{cylindrical high up to the upper border of vent area.}$

Effective volume of the flame V_{eff}

The total free volume, which the flame travel is 1/3 of the volume of the cone part and the volume of the cylindrical volume up to the upper border of vent area,

$V_{eff} = 1/3 \text{ cone/hopper volume} + \text{cylindrical volume up to the upper border of vent area}$ (shaded region in the Figure).

Effective cross section area A_{eff}

$$A_{eff} = V_{eff} / L_{eff}$$

Effective diameter D_{eff}

$$D_{eff} = (4 \cdot A_{eff} / \pi)^{0.5}$$

Effective length/diameter - ratio L_{eff}/D_{eff} equals to the L/De - ratio

$$L_{eff}/D_{eff} = L/De$$

21 Annex

21.1 Definitions

Activation overpressure in bar

Static activation overpressure P_{stat} :

Pressure, which activates a pressure-venting device while the pressure rises slowly /11/.

Dynamic activation overpressure P_{dyn}

Pressure, which activates a pressure-venting device in case of an explosion. It may be higher than the static activation overpressure.

Note: The effects of the dynamic activation overpressure are already incorporated in this guideline as the formulas are based on experimental test results.

Cubic law

The correlation of the maximum rate of pressure rise $(dP/dt)_{max}$ with the vessel volume assuming complete geometrical similarity and volume independent burning velocities is:

$$V^{1/3} \cdot (dP/dt)_{max} = \text{const} = K_{max} \quad [m \cdot \text{bar} \cdot s^{-1}]$$

Explosion resistance P in bar

Characteristic of vessels or equipment built to withstand the anticipated explosion pressure resistant or explosion pressure shock resistant /5, 7, 9/.

Explosion pressure resistant, EPR

Characteristic of vessels or equipment built to withstand the anticipated explosion pressure without permanent deformation /5, 7/.

Explosion shock resistant vessels, EPSR

Characteristic of vessels or equipment built to withstand the expected explosion pressure without rupture. However, a permanent deformation is acceptable /5, 9/.

Dust explosion class St

Dusts are classified in accordance with K_{max} - values, as show in the following table.

Dust explosion class	K_{max} in $m \cdot \text{bar} \cdot s^{-1}$	P_{max} in bar
St 1	> 0 to 200	≤ 10 bar
St 2	> 200 to 300	≤ 10 bar
St 3	> 300 to 800	≤ 12 bar

Equivalent diameter D_e in m

Diameter of a circle, which has the same area as the reference area A^* of any shape:

$$D_e = 2 \cdot \sqrt{\frac{A^*}{\pi}}$$

Explosion characteristics

All explosion characteristics are determined in accordance with a standardized procedure /18, 19/ and are defined as follows:

Explosion overpressure P_m in bar

The maximum overpressure in a closed vessel after the explosion of a dust-air-mixture.

Rate of pressure rise $(dP/dt)_m$ in $\text{bar}\cdot\text{s}^{-1}$

The highest rate of pressure rise in a closed vessel after the explosion of a dust-air-mixture at any concentration.

Maximum explosion overpressure P_{max} in bar

The maximum explosion overpressure P_m obtained by systematically changing the dust concentration under defined measurement conditions /5, 18/.

Maximum rate of pressure rise $(dP/dt)_{max}$ in $\text{bar}\cdot\text{s}^{-1}$

The highest value of the rate of pressure rise $(dP/dt)_m$ obtained by systematically changing the dust concentration under defined measurement conditions /5, 19/.

K_{max} -value in $\text{m}\cdot\text{bar}\cdot\text{s}^{-1}$

Product specific characteristic (constant), which is calculated with the help of the cubic law.

Note: The numeric value of the K_{max} -value is equivalent to the maximum rate of pressure rise $(dP/dt)_{max}$ in a 1-m^3 -vessel /1, 4/.

Explosion pressure venting

Protective measure of limiting the explosion overpressure, which will prevent the vessel from exceeding its design strength (explosion resistance) by exhausting unburned mixture and products of combustion by opening a given area.

Gas-air-mixtures

Non-turbulent mixtures

Gas-air-mixtures, which are in a non-turbulent state at the time when the ignition source is activated /5/.

Turbulent mixtures

Gas-air-mixtures, which are in a turbulent state at the time when the ignition source is activated. They can be obtained in vessels (or silos) by the rapid release of air from pressurized containers through distribution devices with a standardized procedure /5/.

Hybrid mixtures

Mixtures of combustible compounds in different aggregate conditions.

Note: Mixtures of methane, coal and air or mixtures of solvent vapours and combustible dusts are example for hybrid mixtures.

Note: The mixture may be explosible even if the concentration of one or more components are below their minimum explosible concentration.

Length diameter ratios

Length diameter ratio L/D

The ratio of the longest linear dimension L (length, height) of a round vessel /silo to its geometrical diameter D .

Length diameter ratio L/D_e

The ratio of the longest linear dimension L (length, height) of an angular vessel /silo to its equivalent diameter D_e .

Effective length diameter ratio L_{eff}/D_{eff}

In case of pressure venting of vessel/silo of any shape the ratio of the effective flame traveling L_{eff} to the effective diameter D_{eff} of the effective vessel volume V_{eff} travelled by the explosion flame.

Pneumatic transport

Transport of product through ducting with a transport velocity of $vF = 15$ to $40 \text{ m}\cdot\text{s}^{-1}$.

Pressure venting devices

Devices, which closes a vent opening during normal operation and opens it in case of explosion.

Rupture disk/bursting foil

A not re-closing and not reusable pressure-venting device, which will open the vent opening by disintegration at a defined activation overpressure.

Explosion door

Pressure venting device, which will open the vent area at a defined activation overpressure and generally re-close after discharge.

Venting element

Part of a vent system, which covers the vent area and opens under explosion conditions. It may be reusable or consumable.

Reach of flame/pressure rise

Maximum reach of flame LF in m

External maximum reach of the flame during explosion pressure venting. Generally, the maximum range can be expected in the direction of the venting.

Maximum external peak overpressure PA_{max} in $mbar$

Maximum pressure value of the external peak measured during explosion pressure venting at a distance R_s from the vent opening.

External peak overpressure PA_r in $mbar$

Pressure value of the external peak measured at a distance $r \geq R_s$ from the vent opening.

Distance R_s in m

Distance from the vent opening in direction of the vent discharge, which will show the maximum peak of the external overpressure PA_{max} .

Recoil duration td in ms

Time interval between opening of the pressure-venting device and reaching ambient air pressure.

Maximum recoil force FR_{max} in kN

The maximum force developed because of explosion pressure venting acting opposite to the vent direction /1, 2, 4, 5/.

Reduced explosion characteristics

Reduced explosion overpressure P_{red} in bar

Maximum overpressure generated by an explosion of a fuel-air-mixture in an explosion pressure vented vessel.

Reduced rate of pressure rise $(dP/dt)_{red}$ in $\text{bar}\cdot\text{s}^{-1}$

The maximum rate of pressure rise in an explosion pressure vented vessel after explosion of a fuel-air-mixture.

Maximum reduced explosion overpressure $P_{red,max}$ in bar

The highest value of the reduced explosion overpressure $P_{red,max}$ obtained by systematically changing the fuel concentration under defined measurement conditions.

Maximum reduced rate of pressure rise $(dP/dt)_{red,max}$ in $\text{bar}\cdot\text{s}^{-1}$

The highest value of the reduced rate of pressure rise $(dP/dt)_{red,max}$ obtained by systematically changing the fuel concentration under defined measurement conditions.

Vent area A in m^2

Geometric vent area of an explosion pressure-venting device.

Effective vent area A_w in m^2

Area of pressure venting device, which has the same effect as a nearly inertia-free pressure-venting device with the area A .

Venting efficiency EF

Relation of the effective pressure vent area A_w and vent area A /3/.

Vent duct

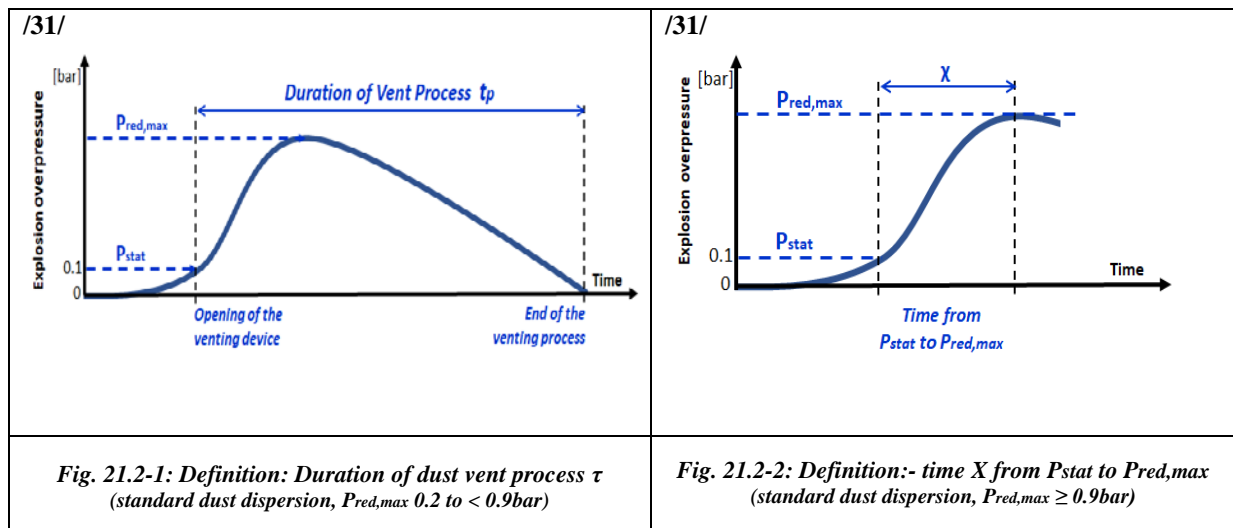
Duct work (pipeline) downstream from a venting device for the safe discharge of the pressure wave, flame, and products of combustion.

21.2 Abbreviations

A	: vent area (equivalent) für EF = 1 in m ²
A*	: reference area of any shape in m ²
AS	: internal surface area of enclosure in m ²
Ac	: cross-sectional area in m ²
Ad	: dimensionless vent area ($A/V^{2/3}$)
Ae	: vent area (effective) in m ²
Ag	: vent area (geometric) in m ²
Asp	: specific vent area ($A/V^{0.753}$)
Asuc	: effective suction area in m ²
a	: width of explosion door in m
α	: defines the direction towards the vent
Bem	: design (rated)
C	: concentration in g·m ⁻³ or Vol. %
Copt.	: optimum concentration in g·m ⁻³ or Vol. %
Cv	: vent coefficient ($V^{2/3}/A$)
c	: venting equation constant for gases
c _v	: venting equation constant for dust
D	: geometrical diameter of a round vessel/silo in m
DA	: diameter of a single vent duct in m
DE	: vent area diameter in m
De	: equivalent vessel diameter in m
Deff	: effective diameter in m
DF	: diameter of conveying tube in m
DF*	: equivalent conveying diameter in m
DH	: hydraulic diameter in m
DN	: nominal diameter in m
Dp	: diameter of pipe
(dP/dt) _m	: rate of pressure rise in bar·s ⁻¹
(dP/dt) _{max}	: maximum rate of pressure rise in bar·s ⁻¹
(dP/dt) _{red}	: reduced rate of pressure rise in bar·s ⁻¹
(dP/dt) _{red,max}	: maximum reduced rate of pressure rise in bar·s ⁻¹
dyn	: dynamic
Dz	: cylinder diameter in m
E	: energy in J
EF	: venting efficiency
FR	: recoil force in kN
FR _{max}	: recoil force, maximum in kN
GE	: specific weight of venting device in kg·m ⁻³
GL	: guideline

IE	: ignition energy in J
IR	: transferred impulse in kN·s
Kd	: discharge coefficient ($V^{2/3}$)
K _{max}	: maximum product-specific constant in m·bar·s ⁻¹
k	: kilo
kN	: kilo Newton
L	: longest linear dimension of a vessel/silo or enclosure in m
LA	: length of vent duct in m
LAS	: length of vent duct where velocity of sound is reached in m
LD	: diameter of vent duct in m
L/De	: length/diameter (eff)
LE	: vent area length in m
LF	: flame range in m
LEL	: lower explosion limit in g·m ⁻³ or Vol.%
L _{eff}	: effective flame traveling in m
LF _h	: flame range, horizontal in m
LF _v	: flame range, vertical in m
LM	: portion of solvents in Vol.% of LEL _{gas,vapour}
LO	: length of opening in m
L _p	: perimeter of cross-section area (A _c) in m
ℓ	: litre
l _s	: length of with
M	: median
MESG	: maximum experimental safe gap
MIE	: minimum ignition energy
MIS	: mechanical isolation system
MIT	: minimum ignition temperature
MP	: amount of product discharged kg·h ⁻¹
m	: meter
max	: maximum
N	: Newton
NFPA	: National Fire Protection Association
OP	: Operating pressure in bar abs.
opt.	: optimum
P	: vessel resistance (overpressure) in bar
P _{Amax}	: maximum external overpressure at distance R _s in mbar
P _{Ar}	: external overpressure at distance r in mbar
P _{Bem}	: admissible design overpressure in building in bar
P _N	: nominal pressure in bar
P _{dyn}	: dynamic activation overpressure in bar
P _m	: explosion overpressure in bar
P _{max}	: maximum explosion overpressure in bar
P _o	: vessel resistance without vent duct in bar
P _{red}	: reduced explosion overpressure in bar

$P_{\text{Pred,max}}$: maximum reduced explosion overpressure in bar
P_{stat}	: static activation overpressure in bar
P_{vac}	: vacuum resistance of vessel in mbar
Q	: air flow in $\text{m}^3 \cdot \text{h}^{-1}$
q	: distance between explosion door and vent pipe in m
R_s	: distance for maximum external overpressure in m
r	: distance for external pressure in m
red	: reduced
SA_e	: suction area of vents in m^2
SP	: solvent portion in product in wt.-%
St	: dust explosion class
s	: second
stat	: static
T	: temperature in $^{\circ}\text{C}$
T_b	: operating temperature in $^{\circ}\text{C}$
t	: time in s
t_d	: recoil duration in ms
t_p	: duration of dust vent process in ms (for $P_{\text{Pred,max}} < 0.9 \text{ bar}$)
t_v	: ignition delay time in s
V	: vessel volume in m^3
v	: speed in $\text{m} \cdot \text{s}^{-1}$
VDI	: Verein Deutscher Ingenieure
V_{eff}	: effective volume travelled by the explosion flame in m^3
v_F	: air conveying speed in $\text{m} \cdot \text{s}^{-1}$
V_{nc}	: vessel volume non-critical
V_{Res}	: vacuum resistance of vessel in mbar
W	: vessel width in m
WA_a	: 0° means in front, 90° means sideways of the vent area
WA_r	: angle between axis of vent area and duct in deg. ($^{\circ}$)
WE	: vent area width in m
WF	: maximum flame width in m
WO	: width of opening in m
w	: gap width in mm
x	: time from P_{stat} to dust $P_{\text{Pred,max}}$ in ms (for $P_{\text{Pred,max}} \geq 0.9 \text{ bar}$)
Z	: cylinder



21.3 Damage caused by Pressure Waves

The effects of fuel explosions upon buildings can be approximated from experience as a static load equivalent to the maximum explosion pressure /32/.

Overpressure [bar]	Type of Damages
0.001	Noise of low frequency (10 - 15 Hz) up to 137 dB
0.002	Breaking of large glass windows already under strain
0.003	Noise 143 dB glass breakage due to a sonic boom from a jet fighter plane
0.007	Breakage of small windows already under strain
0.01	Typical pressure for window breakage
0.02	Safe limit: 95% probability for no serious damage for pressure less than 0.02 bar. Small damage to house roofs (roof tiles and gutters) 1-10% of window glass broken
0.03	Limited minor structural damage
0.035 - 0.07	Generally large and small windows break, occasional damage to window frames
0.05	Small damage to house structure
0.06	1% structural damage, 99% of window glass shattered
0.07	Partial destruction of houses, made uninhabitable (danger of collapsing)
0.07 - 0.14	Corrugated asbestos panels shattered, failure of fasteners for corrugated steel and aluminium panels
0.09	Minor damage to steel frames of buildings (distortion)
0.10	Light structures collapse, pressure vessels intact
0.14 - 0.21	Not reinforced concrete or cinder block walls destroyed
0.16	Lower limit for serious structural damage
0.17	50% destruction of brickwork of houses
0.21	Heavy machinery (1.5 ton) within buildings suffers little damage; Steel frames of building distorted and separated from foundation; 50% structural damage
0.21 - 0.28	Light structures made out of self-supporting steel panels (without frame) demolished; Rupture of empty oil storage tanks
0.28	Cladding of light industrial buildings ruptured
0.30	Major building damage (collapse)
0.34	Wooden utility poles snapped; Minor damage to machinery (20 ton) inside buildings
0.34 - 0.41	Total destruction of houses; Reinforced walls break; 99% structural damage to buildings
0.48	Loaded freight cars overturned
0.48 - 0.55	Failure of not reinforced 20-30 cm thick brick walls due to shearing or flexure; Failure of pipe trestles (pipe rupture)
0.62	Complete destruction of loaded freight cars
0.7	Destruction of industrial buildings; Machinery (3.5 ton) within building heavily damaged due to dislodging)
0.8 - 1.5	Destruction of earthquake proof concrete and steel framed concrete buildings

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