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The Use of Porous Structures in Flameproof Enclosures to Reduce the Maximum Explosion Pressure

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Electrical and non-electrical equipment used in hazardous areas can be designed in the type of protection “flameproof enclosure”. Following this safety concept, potential ignition sources are enclosed by containments. If a combustible enters the enclosure and is ignited, flame transmission to the surrounding explosive atmosphere has to be definitely avoided. Additionally, the enclosure must be robust enough to withstand the emerging explosion pressure without rupturing or temporarily opening up any of the joints to a critical value. The design of these enclosures is, therefore, related to the maximum explosion pressure of an internal explosion and as a consequence, the enclosures must be constructed with an enormous material effort. To develop more efficient enclosure constructions, it is necessary to reduce the maximum explosion pressure.
This paper presents a novel approach to reducing the explosion pressure within flameproof enclosures, which offers the possibility of improving the design of flameproof enclosures, leading to lower production costs without reducing any safety aspects. This approach is based on the integration of porous structures into the enclosure walls acting as venting and flame quenching elements. Different porous structures were investigated in terms of their ability to relieve pressure and to avoid flame transmissions. It is shown that proper use of these structures can enormously decrease the maximum explosion pressure inside the enclosure while safely avoiding flame transmissions, depending on the structure specifics. Based on these results it is possible to introduce a novel approach of flameless venting, which is named, regarding its application in flameproof enclosures, “flameproof explosion pressure relief”.

1. Introduction

In chemical facilities and other industrial areas explosive atmospheres can occur. Several measures of explosion protection have to be taken in order to avoid any ignition induced by, e.g., hot exhaust gases, hot surfaces or an electrical spark, respectively. For preventing ignition due to electrical equipment it has to be specially designed and manufactured according to the types of protection given in the international standard series IEC 60079-0 and the following (IEC, 2011). The type of protection “flameproof enclosure” (IEC, 2012) encapsulates potential ignition sources in such a way that an explosion within the enclosure may take place; flame transmission to the surroundings, however, has to be safely prevented. On the one hand, the explosion has to be quenched properly within inevitable gaps, so that flames and hot exhaust gases do not ignite the outer explosive atmosphere. On the other hand, the enclosure must withstand the thermal and pressure loads of an internal explosion without any ruptures or deformations.
The risk assessment of flameproof enclosures in accordance with IEC 60079-1 (IEC, 2012) includes experimental tests regarding the ability of the enclosure to withstand explosion pressure. When igniting explosive mixtures inside the enclosure, the reference pressure is determined as the highest value of the maximum pressure in several tests. The pressure build-up mainly depends on the initial pressure and temperature, the fuel type and its concentration and burning rate. Considering ambient pressure and temperature, the slightly rich mixtures used in these tests lead to typical reference pressure values in the range of 6 to 11 bar. However, in enclosures of complex geometry precompression in a subdivision of the enclosure can occur prior to the flame arriving. Depending on the amount of compression, pressure piling occurs which results in reference pressure values up to 35 bar (Singh, 1984) or even higher. According to

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IEC 60079-1, such an enclosure has to withstand a static overpressure test of either a minimum of 1.5 times the reference pressure in routine overpressure testing or up to four times the reference pressure to avoid routine testing. Considering these requirements for flameproof enclosures, the reduction of explosion pressure is worth pursuing.

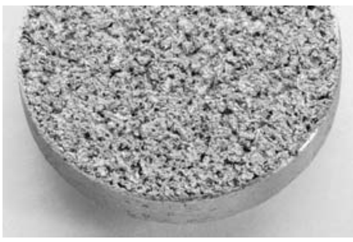
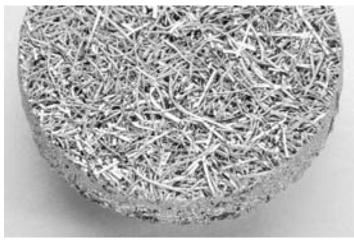
Venting is a technique commonly used to limit structural damage of equipment or buildings against accidental explosion pressures by means of pressure relief (Molkov et al., 2000). The opening of an explosion vent normally leads to a turbulent jet flame emerging from the venting device with high velocity. Considering dust explosions, flameless venting devices have been developed to release explosion pressure and concurrently extinguish the flame (see, e.g., Chao and Dorofeev, 2012). These passive devices consist of various layers of stainless steel wire mesh which act as a flame arrester and are installed over an existing explosion vent. If a dust explosion takes place inside the equipment, the expanding explosion is given relief through the explosion vent. The subsequent flame, burned and unburned dust discharge enters the flame arrester element. The dust will be retained in the device and the flame extinguishes within the wire mesh due to cooling. However, the use of these devices to extinguish flames from explosion vents also results in less efficient venting, increasing the reduced overpressure.

In this work, we present a methodology to expand the concept of flameless venting devices to the pressure relief of gas explosions inside flameproof enclosures. In this case, much smaller quenching distances and stronger loads due to faster pressure rise have to be considered (Hattwig and Steen, 2004). It is based on the integration of porous structures into the enclosure walls acting as venting and flame arresting devices. Several requirements have to be fulfilled by these structures. First, flame transmission has to be avoided safely. The porous structures, therefore, must have a large internal surface to quench the flames and sufficiently cool down the hot gas flow (Mecke et al., 2008). Second, they have to be strong enough to withstand the thermal and pressure loads due to the internal explosion (Hornig et al., 2010). Third, the flow resistance of these structures should be as low as possible, improving their capability of relieving pressure (Mecke et al., 2007). Therefore, different porous structures were tested in accordance with IEC 60079-1 to determine their pressure relief capability, using three different volumes of commercially available flameproof enclosures. The results clearly show that proper use of these structures can enormously decrease the maximum explosion pressure inside the enclosure while safely avoiding flame transmissions, depending on the structure specifics.

2. Experimental Setup

Within this analysis, three different types of porous structures were examined during various explosion tests regarding their ability to relieve explosion pressure within flameproof enclosures. These structures are a traditional flame arrester made of crimped ribbon (Braunschweiger Flammenfilter GmbH, 2012), a sintered metal which is usually used for filtration applications in the field of chemical engineering (Tridelta Siperm GmbH, 2012) and sintered fibre structures of three different porosities (Fraunhofer IFAM, 2012). The basic specifications of all test samples are given in table 1, including a photograph of each type of structure. Further detailed information on the materials is given in Hornig (2012).

Table 1: Test samples used and their basic specifications

Crimped ribbon flame arrester	Sintered metal	Sintered fibre structures
		
• width of gap 0.15 mm (IIC), thickness 10 mm	• porosity approx. 50 %, thickness 5 mm	• porosity 60 %, thickness 5 mm • porosity 70 %, thickness 5 mm • porosity 70 %, thickness 10 mm • porosity 80 %, thickness 5 mm

The scale of pressure and temperature loads depends, of course, on the volume and the internal structure of the enclosure. However, in order to compare and to classify different porous structures systematically in terms of their pressure relief capability and flame quenching ability, all experimental tests were conducted using a basic experimental setup based on the same type of commercially available flameproof enclosure. Within the scope of the investigations described, three different volumes of this type of enclosure have been prepared in such a way that it is possible, first, to integrate them into the existing testing hardware to induce internal explosions and to measure the emerging explosion pressure and, second, to insert as many test samples as possible into the enclosure walls. The enclosures are nearly cubic and the smallest one (enclosure 1) has a volume of almost 2 L and openings for at most 12 test samples. Enclosure 2 has a volume of nearly 4 L and 24 openings, and the largest enclosure (enclosure 3) has a volume of about 8 L and 48 openings. To easily integrate the porous structures to be tested into the enclosure walls and to enable fast modifications during test series, a special sample holder was developed. Figure 1 gives an impression of the experimental setup showing a cross section of the 3-dimensional model of the smallest enclosure with its openings to adapt the test samples, using the specially developed sample holder (pictured as exploded view including a test sample).

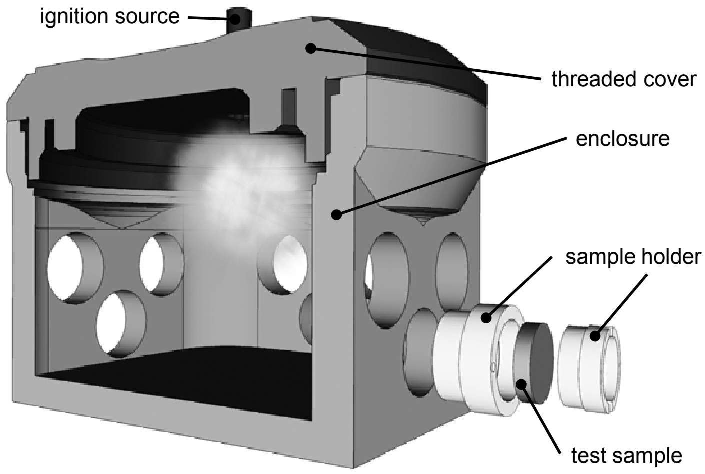


Figure 1: Experimental setup in principle showing enclosure 1 as an example, including one sample holder and a test sample

Test series determining the explosion pressure within these enclosures have been conducted to analyse the pressure relief capability of the different structures, depending on the size of the vent area, in accordance with IEC 60079-1 (IEC, 2007), using explosive gas/air mixtures of (14 ± 1) vol. % C_2H_2 (acetylene) or (31 ± 1) vol. % H_2 (hydrogen). Therefore, the number of inserted test samples, each having an active surface area acting as vent area A_V of about 315 mm^2, was gradually reduced from the maximum to the minimum while sealing the non-equipped openings.
For every configuration investigated, a test series consisted of three explosion tests for each given gas mixture. The ignition of the gas mixtures was induced by a spark plug inserted in the enclosure cover and the resulting maximum overpressure (gauge pressure) inside the enclosure was determined using a piezoelectric pressure sensor (Kistler, type 6031).

3. Results

Increasing the number of test samples increases the total size of the vent area. Considering enclosure 1, Figure 2 shows for acetylene (Figure 2a) and hydrogen (Figure 2b), for different kinds of porous structures, the respective average values of the three measured explosion overpressures as a function of vent area A_V. Because this overpressure occurs as a consequence of venting, it is called reduced overpressure Δp_{red}. As expected, it was shown that the larger the vent area the better the pressure relief. Furthermore, as can be seen in Figure 2 for both gas/air mixtures, the reduced overpressure Δp_{red} strongly depends on the type of porous structure: Elements of sintered metal provide, in all cases, the lowest pressure relief due to their low porosity. In contrast to this, the sintered fibre structures with a porosity of 80 % have only a low flow resistance leading to the strongest decrease of overpressure. The higher the porosity, the better the pressure relief is. Besides, it is remarkable that sample thickness hardly affects the pressure relief capability of porous structures as evidenced by the sintered fibre structures with a porosity of 70 %.

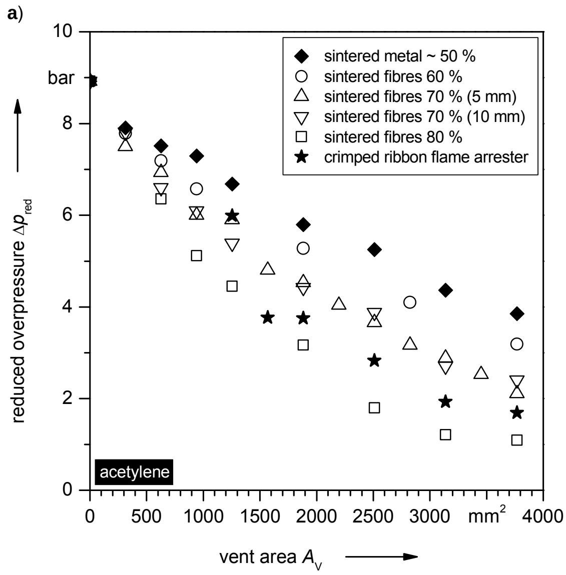


Figure 2: Reduced explosion overpressure Δp_{red} within enclosure 1 as a function of vent area A_V using different porous structures; a) (14 ± 1) vol. % acetylene/air mixture and b) (31 ± 1) vol. % hydrogen/air mixture

Comparing the results of both gas mixtures for every structure examined, the higher value of reduced overpressures Δp_{red} for the largest vent area A_V of approximate 3.800 mm^2 surprisingly always occurs when using the hydrogen/air mixture, whereas the higher value within the completely sealed enclosure (A_V = 0 mm^2) occurs when using the acetylene mixture. As the explosion pressure within sealed enclosures mainly depends on the combustion temperature, the acetylene/air mixture with its higher flame temperature compared to the hydrogen mixture generates the higher reduced overpressure in this case. Increasing the vent area by using more and more pressure relief elements, the combustion velocity of the gas mixture becomes more and more important. Immediately after initiating the explosion, unburned gas mixture escapes through the porous structures and thus is no longer available to play a part in the explosion. The maximum pressure, therefore, depends on the ratio of burned gas mixture to escaped gas mixture. Because of its comparatively higher combustion velocity, the hydrogen/air mixture always generates the higher maximum pressure beyond a certain size of vent area.

With regard to flame transmissions which have to be safely avoided, the explosion tests conducted have shown that all structures determined are principally able to quench explosion flames sufficiently. However, it is a matter of vent area size: All flame transmissions observed were caused by hot test sample surfaces heated by explosion flames and exhaust gases streaming through. Therefore, porous structures with high porosities and thus comparatively low densities need larger vent area sizes to prevent these ignitions. Whereas porous structures with lower porosities, like sintered metals, are already flameproof when only using one pressure relief element.

To appropriately compare the results of different enclosure sizes it is necessary to introduce a new variable. Therefore, instead of an absolute value like the vent area A_V, a relative value is used which takes the enclosure size into account. This variable representing the ratio of vent area A_V to inner surface of the enclosure A_I is named relative vent area A_{rel}. Figure 3 shows the reduced overpressures Δp_{red} as a function of this relative vent area A_{rel} for only one porous structure (sintered fibres with a porosity of 60 %), using the three different enclosures and the given acetylene/air mixture.

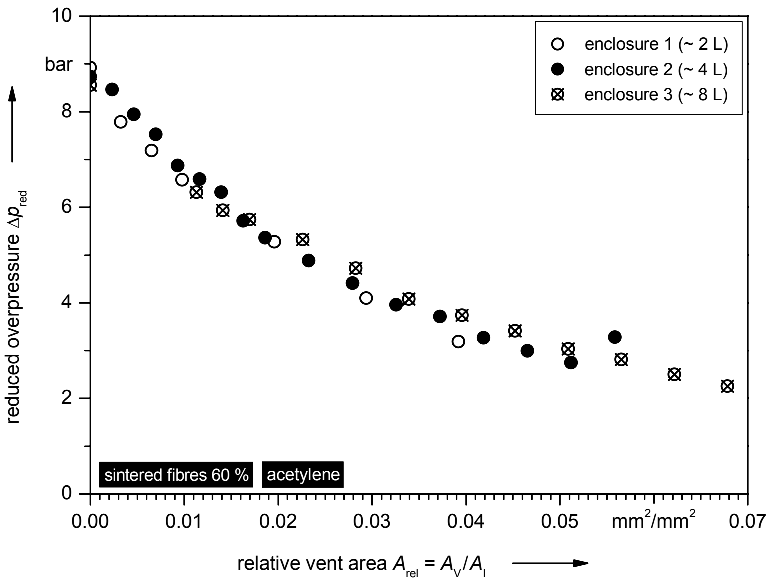


Figure 3: Reduced explosion overpressure Δp_{red} as a function of relative vent area A_{rel} within three different enclosures using sintered fibre structures with a porosity of 60 %, using a (14 ± 1) vol. % acetylene/air mixture

These results surprisingly show, considering the relative vent area, that the enclosure volume doesn't seem to affect the pressure relief capability of the porous structure. The non-illustrated results of these sintered fibres using the hydrogen/air mixture show the same behavior which indicates a volume independency of this new kind of pressure relief. Thus, based on these results we assume a characteristic functional correlation between relative vent area size A_{rel} and the resulting reduced overpressure Δp_{red} for each porous structure tested, which could be easily used to design a new generation of flameproof enclosures.

4. Conclusions and outlook

The pressure rise due to an internal explosion leads to high pressure loads on flameproof enclosures. By using porous structures as an integral part of the enclosures acting as venting and flame quenching elements it is possible to enormously reduce the explosion pressure inside these enclosures. These structures require a low flow resistance by which they are capable of relieving the explosion pressure and venting the enclosure. At the same time, flame transmission through the structure has to be avoided in any case by sufficient cooling. Sintered structures made of high-temperature resistant materials are promising components to fulfil these contradictory requirements.
Furthermore, it was shown that the enclosure size doesn't affect the pressure relief capability of porous structures. This characteristic functional correlation between relative vent area A_{rel} and resulting reduced overpressure Δp_{red} could be experimentally determined for various porous materials and, thus, be used for dimensioning a new kind of flameproof enclosure. Thereby, an aimed pressure reduction could be predicted.
In order to validate the correlation mentioned above and to develop definite design guidelines based on this correlation, further investigation of other porous structures needs to be done. Regarding its application in flameproof enclosures, this novel approach of flameless venting is named "flameproof explosion pressure relief".
Finally, this approach could also offer a possibility of avoiding or at least reducing pressure piling.

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