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EXPLOSION PROTECTION USING FLAMELESS VENTING - A REVIEW

HSL/2006/105

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Science Group: **FIRE & EXPLOSION**

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ACKNOWLEDGEMENTS

The assistance of the following companies is gratefully acknowledged.

ATEX Explosion Hazards Limited, Warrington Lane, Lymm, Warrington WA13 0SW, England.

Brilex GmbH, Hinterm Gallberg 15-17, D- 59929 Brilon, Germany.

Fike, 35 Earl Street, Maidstone, Kent ME14 1PF, England.

Hoerbiger Ventilwerke GmbH & Co KG, Braunhubergasse 23, A-1110 Wien, Austria.

REMBE GmbH, Safety and Control, Gallbergweg 21, D-59929 Brilon, Germany.

Stuvex Safety Systems Limited, Systems House, 48 Church Street, Weybridge, Surrey KT13 8DP, England.

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EXECUTIVE SUMMARY

Objectives

The aim of this review was to determine, on the basis of existing knowledge, the following aspects surrounding flameless venting devices:

(a) Who manufactures or imports the devices into the UK.
(b) How many devices have been supplied for use in the UK. Examples of devices currently installed will be given.
(c) What certification accompanies the devices, if any, and what they are certified for.
(d) What type of testing of the devices has been done and do the results of such tests identify any limitations of the devices.
(e) What is the track record of the devices in operation i.e. (a) have any been called into use due to a deflagration and did they operate satisfactorily or were there problems, (b) have any been found to be unserviceable during maintenance/checks etc (potential for unrevealed fault), and (c) the type of equipment on which they are installed and the experience of the user.
(f) If problems are identified then what has been learnt from analysis of those problems.
(g) Recommendations will be made based on the information obtained.

Main Findings

(a) Four manufacturers of explosion venting devices have been identified. Additionally, two agents import and sell devices in the UK.
(b) The number of devices sold into the UK is in the order of 400. However, this could be greater since units have been sold to manufacturers outside the UK for installation on dust-handling equipment that may have been sold into the UK as as part of a larger installation.
(c) An EC-Type Examination Certificate would normally be provided with a device.
(d) Manufacturers have quoted testing in accordance with the following: ATEX Directive, VDI 3673, prEN14797, EN 1127-1, and NFPA 68.
(e) Information on devices in use with a sewage sludge drying plant, bucket elevator, coal mill, and storage bins have been obtained.
(f) A potential problem relates to the blockage of a device. A severe blockage could lead to the rupture of the protected equipment. The effect of potential blockages needs to be carefully considered both at the design stage and during maintenance.

Recommendation

Detailed information of device performance is limited. Manufactures have commissioned testing for the purpose of certification but reports are not generally available. Consequently the performance, efficiency and the limitations of the devices is based on information released by manufacturers. It is recommended that research is carried out to identify limiting worst-case operating conditions and assess the effects of dust characteristics, blast and noise.

1 INTRODUCTION

The Dangerous Substances and Explosive Atmosphere Regulations (DSEAR) require industry to critically review the explosion prevention/protection methods used with all equipment handling dangerous substances.

It is not uncommon for powder manufacturers/processors, particularly in the traditional industries, to find that their level/type of explosion protection does not satisfy the requirements of DSEAR. The manufacturer has to provide improved or new safety measures to adequately protect personnel and plant.

Traditional explosion protection measures, that can be readily fitted to new plant, present difficulties when applied to existing plant e.g.

(a) Containment – requires plant to be strengthened to 8-10 bar g. This can be expensive and often impractical.

(b) Explosion suppression – suitable for retrofit but expensive in capital and maintenance costs.

(c) Explosion relief – practically difficult to apply to equipment remote from external walls and the provision of a long discharge duct dramatically reduces venting efficiency.

A new option – flameless venting – has recently been developed by a number of companies and is being actively marketed as a solution to the retrofit problem.

There are several manufacturers of flameless venting devices. Typically they are passive devices that consist essentially of a cylinder closed at one end and open at the other. The surfaces are fabricated from various layers of high temperature stainless steel mesh or parallel plates. The device is bolted to the clean side of the explosion vent on the vessel with its open end overlapping the vent aperture.

In the event of a dust explosion inside the process vessel the explosion vent opens. As the explosion expands, flame, burnt and un-burnt dust will discharge through the open vent into the flameless vent cylinder (flame arrestor). It is claimed that the dust will be retained in the cylinder and, because of heat absorption, the flame from the explosion will be extinguished as it travels through the flame arrestor section. The device is claimed to only allow the safe discharge of post-combustion gases from the explosion. Advantages of flameless venting are claimed to be flame extinguishment, dust retention, eliminates need for explosion vent ducts and minimises vent relief area requirements for indoor venting.

In designing and fabricating traditional vent systems it is recognised that the products of an explosion in a plant vessel – burnt and un-burnt dust, flame and developing pressure – must have unimpeded access to a safe discharge area.

The inertia of vent panels must be below 10kg/m^2 to prevent the venting efficiency being significantly reduced.

The use of vent ducts to direct the explosion products to a safe area outside the building can also markedly increase the reduced explosion pressure. For example, a dust having a K_{St} of 200 bar m/s and a vent duct with a L/D of 10, the reduced explosion pressure could be increased by a factor of 3. Ducts containing bends can increase the reduced explosion pressures further.

It is reasonable to expect that the surface of the flameless vent device, the apertures in which are sufficiently small to quench flame, would impede the expanding explosion and increase the reduced explosion pressure. It may be possible for a flameless vent device to fail, for example due to powders that melt and block the surface apertures.

Reduced efficiency of the venting device is a critical issue. Any reduction will result in an increase in the explosion pressure generated within the protected equipment. Should this exceed the design pressure of the vessel or equipment a rupture or mechanical failure is possible with the subsequent discharge of burning product and blast. This could lead to serious injury or death of people within the immediate vicinity.

The aim of this review was to determine, on the basis of existing knowledge, issues surrounding flameless venting devices and in particular the following is addressed:

(a) Who manufactures or imports the devices into the UK.
(b) How many devices have been supplied for use in the UK. Examples of devices currently installed will be given. The types, design and size of devices available will be identified.
(c) What certification accompanies the devices, if any, and what they are certified for.
(d) What type of testing of the devices has been done and do the results of such tests identify any limitations of the devices.
(e) What is the track record of the devices in operation i.e. (a) have any been called into use due to a deflagration and did they operate satisfactorily or were there problems, have any been found to be unserviceable during maintenance/checks etc (potential for unrevealed fault). The type of equipment on which they are installed and the experience of the user will be identified.
(f) If problems are identified then what has been learnt from analysis of those problems.
(g) Recommendations will be made based on the information obtained.

2 MANUFACTURERS AND SUPPLIERS

Flameless venting devices are manufactured are sold within the UK either directly by the manufacturer, by an agent or installed and sold as part of an item of dust handling equipment.

REMBE GmbH Safety + Control, manufacture the Q-Rohr and Q-Box, flameless venting devices designed for indoor explosion venting.

The contact details are:

Address: P.O. box 1540, D-59918 Brilon, Germany

Telephone: +49(0)2961 7405-0

Fax: +49 (0)2961 50714

Web address: www.rembe.de

REMBE products are sold in the UK by ATEX Explosion Hazards Limited.

The contact details are:

Address: Gate 2 Lymm Marina, Warrington Lane, Lymm, Warrington WA13 0SW.

Telephone: +44(0)1925 755153

Fax: +44 (0)1925 755892

Web address: www.explosionhazards.com

Fike United Kingdom manufacture and market a flameless venting device - FlamQuench II.

The contact details are:

Address: 35 Earl Street, Maidstone, Kent ME14 1PF

Telephone: +44(1622) 677081

Fax: +44(1644) 685737

Web address: www.fike.co.uk

Brilex GmbH manufacture and market flameless a venting device – BRILEX IndoorVents

The contact details are:

Address: BRILEX Gesellschaft für Explosionsschutz mbH, Hinterm Gallberg 15-17, D-59929 Brilon, Germany

Tel: +49 (0) 2961/966290

Fax: +49 (0) 2961/9662999

Web address: www.brilex.de

Hoerbiger manufacture and market flameless venting devices (also termed explosion relief valves).

Contact details:

Hoerbiger Ventilwerke GmbH & Co KG, Braunhubergasse 23, A-1110 Wien, Austria

Tel: +43-1-74 004-433/233

Fax: +43-1-74004-395

Web address: http://www.hoerbiger-compression.com

Brilex and Hoerbiger product are sold in the UK by StuvEx Safety Systems Ltd.

Contact details:

Address: Systems House, 48 Church Street, GB Weybridge, Surrey, KT13 8DP

Tel: +44 (0)1932 849602

Fax: +44 (0)1932 852171

Web address: www.stuvex.co.uk

3 DESIGN AND CONSTRUCTION

Flameless venting devices typically comprise a vent panel, flanged housing, and a flame arrestor element. The general principle is that during the early stages of an explosion the explosion vent cover opens, the burned dust, unburned dust and flame enter the flame arrestor element. Flame propagation beyond device is prevented by energy dissipation in the element, reducing the burning fuel below its ignition temperature (Barton, 2002). The dust is retained within the arrestor element and gases from the explosion are vented through the device into the external atmosphere around the device.

3.1 REMBE DEVICE

Rembe GmbH manufacture a device that they market as the Q-Rohr-3 (previously ECO-Q-Rohr) venting device and is described as a flameless venting device for indoor venting. An example of an installation is shown in Figure 1 and the main features are shown in Figure 2. A bursting disc and a stainless steel mesh filter are integrated within a self-supporting chamber. The bursting disc is spot-welded to the device such that the mesh filter is not removable without special tools. When an explosion occurs the bursting disc ruptures and directs the vented explosion into the Q-Rohr chamber where the flame is arrested, gases are cooled as they pass through the stainless steel mesh and dust is retained within the mesh. It is designed to only allow burnt gases to be vented through the chamber. After an explosion the flame arrestor element can be cleaned in place or replaced with a clean element.

The device is instrumented with a status and alarm signal circuit. When the explosion panel is activated it breaks the circuit so that a signal can be used to warn of activation and shut down the plant.

It is manufactured in a number of sizes within the range DN 200 to DN 800. Rembe give the effective vent area of the DN200 as 220 cm^2 and the DN800 as 4100 cm^2. This implies that the venting efficiencies are within the range 71% to 81%.

Rembe indicate that the Q-Rohr:

a) will cool gas temperatures of 1500°C to below 100°C;

b) is suitable for use with organic dusts having K_{St} values up to 250 bar m/s, minimum ignition energy of > 3 mJ;

c) is suitable for reduced explosion pressures (P_{red}) of 0.1 to 1.3 bar g;

d) requires no maintenance or cleaning – the bursting disc separates the process from the filter element;

e) an integrated electronic control panel keeps plant personnel informed of the status of the device.

Rembe also produce a Q-Box, a flameless venting device for indoor and outdoor applications (Figure 3). This device operates on the same principle of the Q-Rohr and is manufactured in two sizes: 305 mm x 610 mm and 586 mm x 920 mm. The rectangular design makes this device more compatible with the mounting flanges associated with rectangular bursting panels and items such as rectangular section bucket elevator casings. Rembe advise that the Q-BOX device is suitable for K_{St} values up to 150 bar m/s and for P_{red} up to 0.5 bar g.

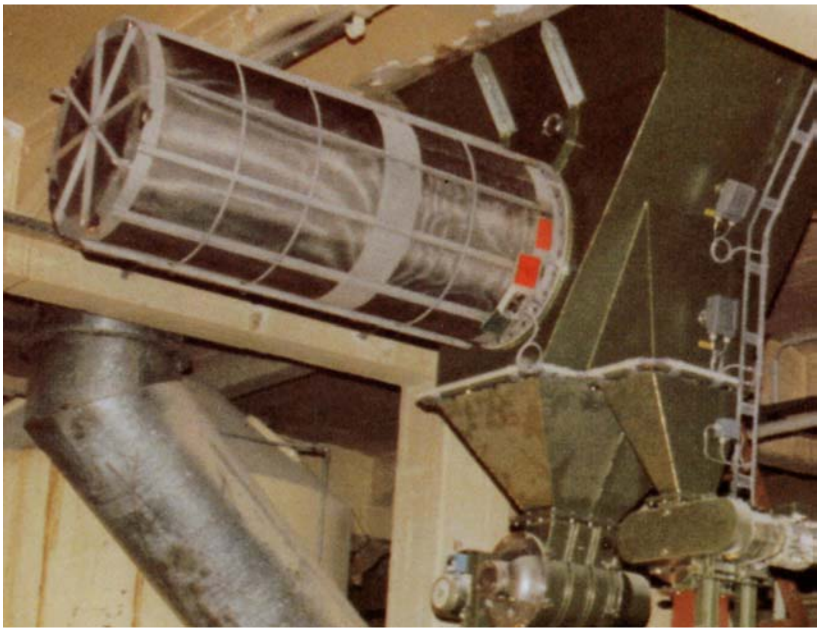

Figure 1: Q-Rohr device installed on a vessel in a brewery
(Used with permission from Rembe GmbH)

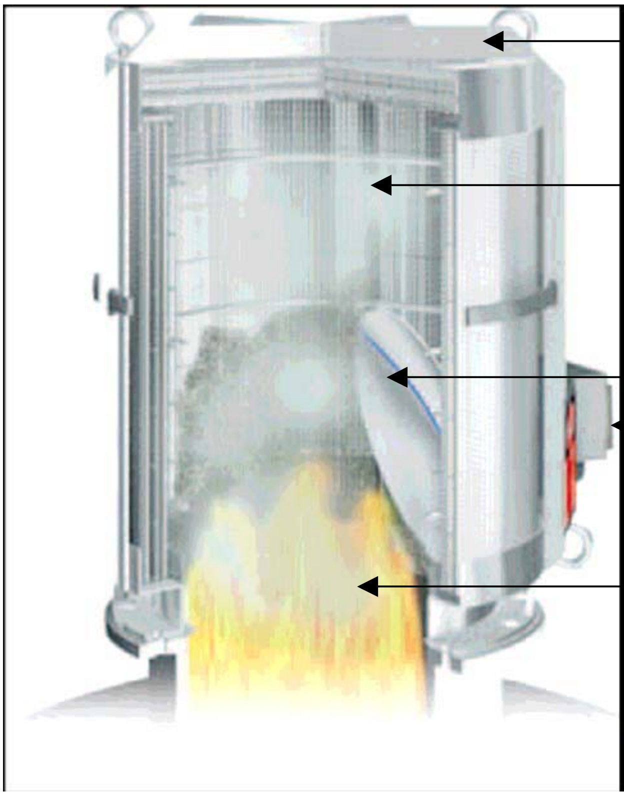

Figure 2: Q-Rohr device
(Used with permission from Rembe GmbH)

Figure 3: Q-Box device
(Used with permission from Rembe GmbH)

3.2 BRILEX

Brilex manufacture an indoor flameless venting device (Figure 4) that incorporates a Brilex bursting disc and a filter within a rectangular casing. The filter comprise five rigid porous ceramic filter cartridges. In the event of an explosion the bursting disc opens at the specified opening pressure, the explosion products enter the filter casing that retains the dust and cools the hot gas. After an explosion the used ceramic cartridges must be removed from the frame and replaced by new cartridges.

Brilex market the flameless venting device as an indoor vent within the size range DN200 to DN800. The manufacturer's technical data gives effective vent areas; the smallest device has an effective vent area of 240 cm^2 and the largest an effective vent area of 4200 cm^2. Assuming that the Brilex bursting disc is installed with the unit the venting efficiency can be calculated. Brilex specify the DN200 bursting disc has a vent area of 300 cm^2 and the DN800 bursting disc has a vent area of 4800 cm^2. This implies that the venting efficiency of the smallest and largest flameless venting device is therefore 80% and 87% respectively.

The company state that the device is suitable with:

a) dusts with K_{St} values up to 250 bar m/s;

b) reduced explosion pressures (P_{red}) of 0.2 to 1.5 bar g.

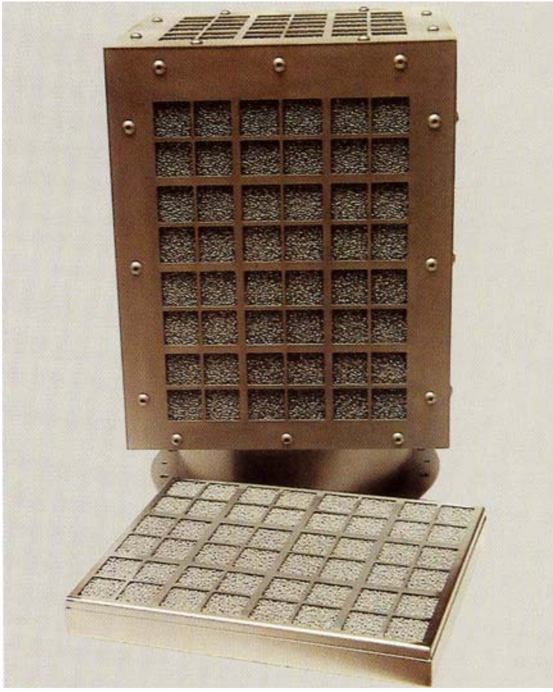

Figure 4: Brilex device
(Used with permission from Brilex GmbH)

3.3 FIKE

Fike Corporation manufacture a FlamQuench II device. An example of a vented explosion test with and without the device is shown in Figure 5. Manufactured from stainless steel, the main features of the device are shown in Figure 6 and comprise a certified bursting disc and a stainless steel mesh flame arrestor element. The FlamQuench II is cylindrical and uses circular bursting panels in conjunction with the device.

The Fike data sheet gives sizes within the range DN200 (200 mm) to DN1000 (1000 mm). The smallest has an outside diameter of 270 mm and a length of 597 mm; the largest has an outside diameter of 1124 mm and a length of 2241 mm.

Fike quote venting efficiencies above 80% (Chatrathi K. and Going J., 2003).

The company state that the device is suitable with:

a) Non-metalic organic dusts and K_{St} of 300 bar m/s.

b) Ambient pressures and temperatures (-40 to 140° F). Non-metallic organic dusts with flame temperatures of $\leq$ 1500°C and $K_{St} \leq 300$ bar m/s or less.

c) The reduced explosion pressure (P_{red}) $\leq$ 1 bar.

d) Maximum process temperature 500°F.

e) Safe distance for personnel 2.5 m.

f) Safe distance for equipment 1 m.

A square flanged flameless device is produced by Fike “Flamquench II Square” (Figure 7) and is intended for use with square and rectangular vents. An “Ele-Quench” device (Figure 8) and is intended to be used in conjunction with rectangular flange connection for use on equipment such as bucket elevators.

Figure 5: Vented explosion test with and without the FlamQuench II device
(Used with permission from Fike)

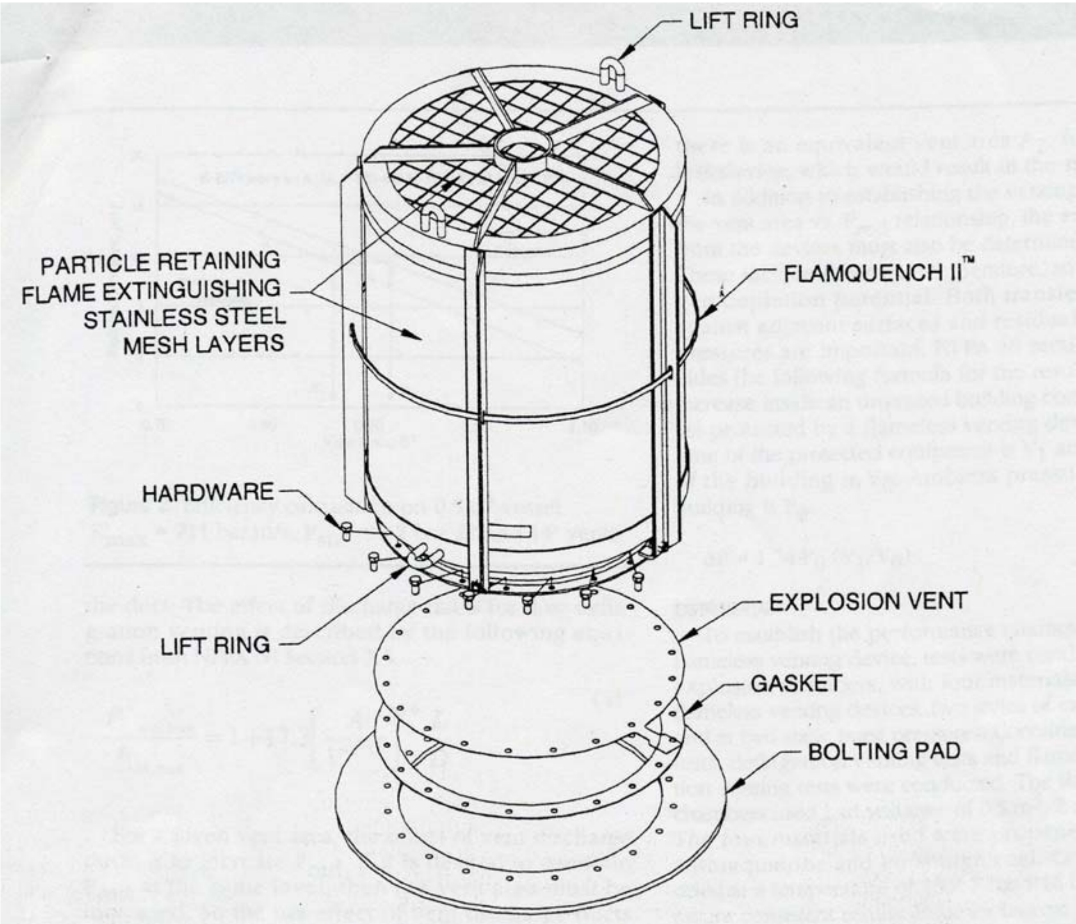

Figure 6: Fike device
(Used with permission from Fike)

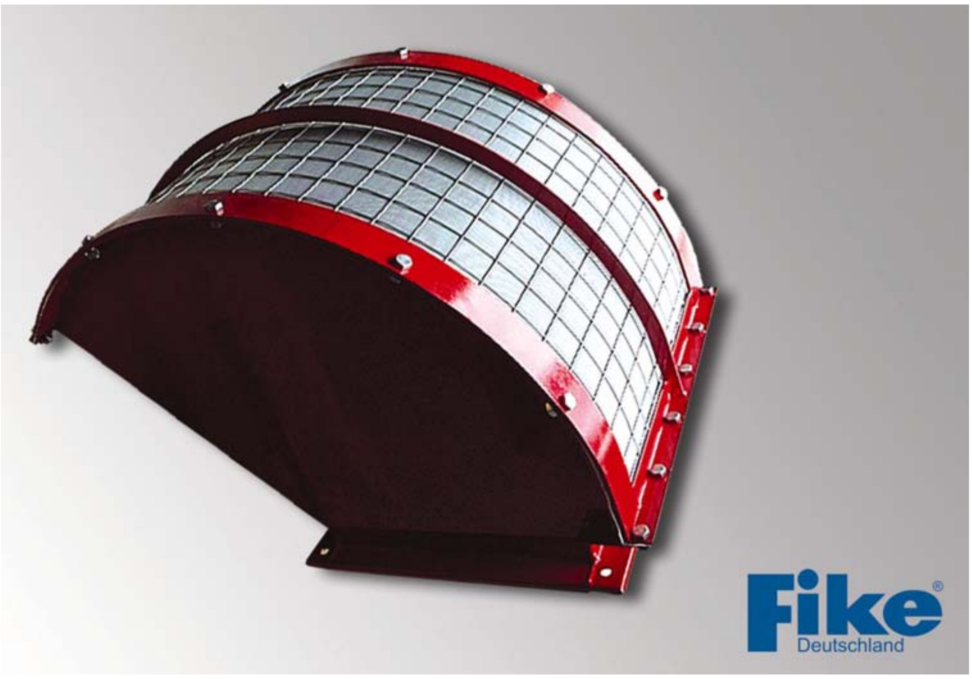

Figure 7: Fike FlamQuench II SQ device

(Used with permission from Fike)

Figure 8: Fike Ele-Quench device

(Used with permission from Fike)

3.4 HOERBIGER

Hoerbiger manufacture explosion relief devices designed to offer effective protection against dust explosions. The devices were originally designed for the protection against oil-mist explosions in the shipping industry. The design (Figure 9) differs significantly from the other manufactures in that a bursting disc is not used; instead, it incorporates a spring-loaded circular steel plate. This normally sits against a soft seal and has a standard opening pressure of 50 mbar. In the event of an explosion the explosion pressure acts against the plate and forces it open. Hot combustion products and flame enter the valve where they encounter the mild steel flame-arrestor that cools and extuinguishes the flame and vents the pressure to atmosphere. As the pressure decays following the explosion, the valve re-closes. A sensor monitors the vent cover plate activation to trigger a warning signal.

There is a range of sizes with vent areas within the range 59.4 cm^2 to 3905 cm^2. The surface area of the flame-arrestor appears to be much smaller than that of the competitors for a given vent area. Based on estimated dimensions from the manufacturer's literature the smallest unit has an outer surface area of approximately 250 cm^2 and the largest 1300 cm^2. Hoerbiger have verbally quoted a venting efficiency of 55-80% with the highest efficiencies corresponding with higher P_{red} values.

Discussions with a company representative established that the device has a limiting maximum vessel volume of 10 m^3 per device and the maximum K_{St} of 300 bar m/s with a Pmax of 10 bar g. The valve can be used in temperatures of up to 100 degrees C with the standard O-ring.

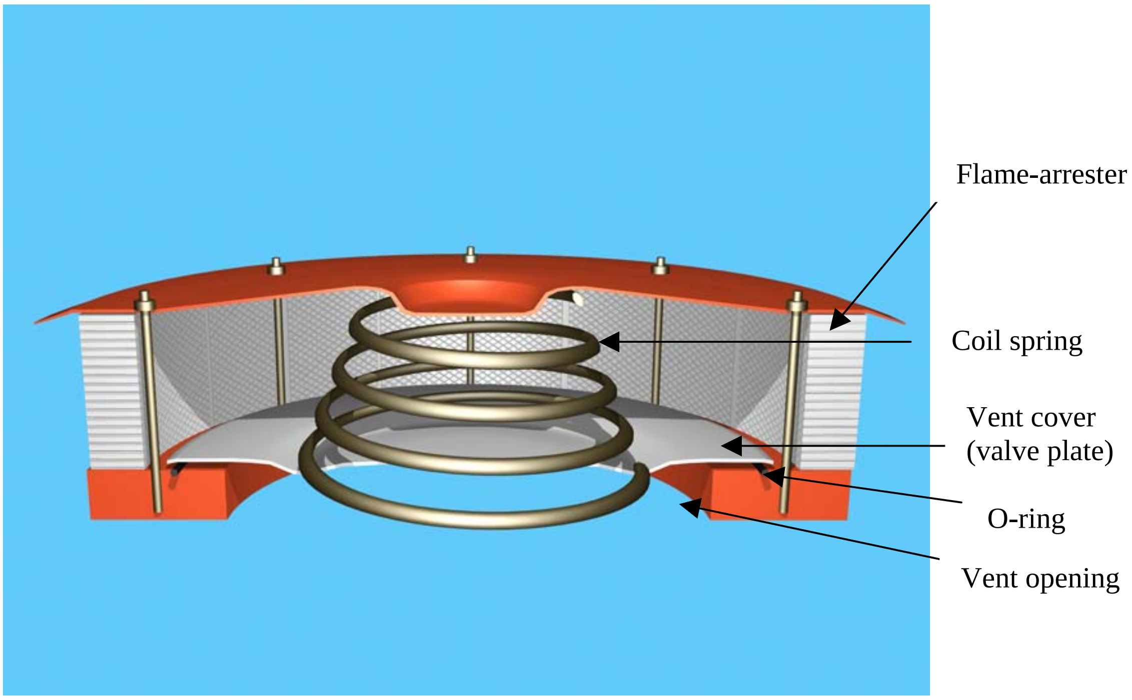

Figure 9: Principal features of the Hoerbiger device

4 TESTING AND CERTIFICATION

4.1 GENERAL

Manufacturers refer to various standards and other documents either verbally, in their literature or in their internet web sites.

Rembe report that the Q-Rohr device is recognised by NFPA68 and accepted by VDI-3673; prEN 14797.

According to the Brilex web-site the Brilex IndoorVent has been tested by well-known institutions and is certified according to the ATEX 100a Directive.

The Fike internet site report compliance with NFPA 68 and the ATEX directive.

Hoerbiger indicate that the device is tested with conformity to EN 1127-1 (1997) and VDI 3673 part 1 (1995).

An EC-Type Examination Certificate, issued by a notified body, normally accompanies a certified device. Typically a certificate includes the following:

1) Statement that confirms the certificate is a EC_Type Examination Certificate.
2) Equipment and protection systems intended for use in potentially explosive atmospheres Directive 94/9/CE.
3) Certificate number.
4) Protection apparatus or system identification.
5) Manufacturer and address.
6) The protection system or equipment are described in an annex to the certificate
7) Statement that the device achieves Essential Health and Safety Requirements by conformity with appropriate standard i.e. EN 1127-1 (1997) and VDI 3673 part 1 (1995).
8) Reference to the report in which the tests are described.
9) A statement that if the sign “X” is placed after the certificate number, it indicates that the protective system is subject to special conditions for safe use mentioned in the annex of the certificate.
10) Marking applied to the device.

4.2 STANDARDS

4.2.1 Proposed new standard

It is proposed that a Type-C standard for flameless venting devices will be developed as part of the CEN *Technical Committee* 305. The technical support for compliance with the Essential Health and Safety Requirements (EHSRs) has been formulated in a set of European Harmonised Standards. The mandate for preparing standards was given to CEN TC 305 which has five working groups and it is Working Group 3 that covers devices and systems for explosion prevention and protection when explosive atmospheres containing flammable dust are a hazard. The aim is to develop a standard that describes the basic requirements for the design and application of flameless explosion venting devices and will consider explosions of flammable dust-air mixtures only. The standard will cover:

- Testing/demonstrating the efficiency of the flameless vent in comparison to unrestricted (open) venting, allowing sizing according to **prEN14491 Dust explosion venting protective systems**. This standard briefly refers to flameless venting and notes that the area immediately surrounding the vent can experience overpressure and radiant energy. Venting indoors has an effect on the building that houses the protected equipment due to the increased pressurisation of the surrounding volume. Expected overpressures need to be assessed in relation to the building strength and building venting may need to be considered.

- Testing/demonstrating that the device is effective at dust retention and prevention of flame release.

- Testing/demonstrating the influence of presence of fibrous dust, other product related effects or any material from the device itself (heat shield fragments, insulating material) which may hinder the venting action and thereby influence the venting efficiency.

- Determination of the application range in diameter, fuel type and maximum vessel volume to be protected.

- Determination of safety distances for personnel with respect to noise and residual pressure and flame effects.

- Determination of the increase in pressure inside rooms where flameless explosion venting devices may vent.

- Special applications of flameless venting devices including elevators, diverters, etc.

- Installation and maintenance requirements.

- Marking.

4.2.2 Existing standards

The following is a summary of flameless venting information contained in the standards and documents referenced by the manufacturers.

ATEX Directive

On 1 July 2003 the EC directive 94/9/EC, commonly known as the ATEX Directive, came into force. Included within this directive are dusty atmospheres with potential for explosion and Essential Health and Safety Requirements (EHSRs) that include steps to be taken to limit the effects of an explosion or to extinguish it in its early stages. Additionally, Directive 137 – Minimum Requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres (ATEX 1999/92/EC) – will require the production of an "Explosion Protection Document" which shall show that explosion risks have been determined and assessed.

A set of European Harmonised Standards are being prepared to provide technical support for compliance with the EHSRs. One of these standards, number **prEN 14797 Explosion venting devices**, considers the properties of the venting device and refers to flameless venting devices as being treated in a separate standard. However, prEN 14797 states that the performance capability of an explosion venting device is defined by:

- the static activation pressure (P_{stat});
- the maximum K_{St} value specified by the manufacturer;
- the maximum reduced pressure (P_{red});
- the maximum venting efficiency of the device.

Tests are described to determine or prove these parameters for:

- Flame break-through. The standard indicates that this test can be performed at the same time as the tests for venting efficiency and mechanical strength by viewing the device by at least two video cameras. No flame is permitted external to the venting device, otherwise the device is deemed to have failed the test. The appearance of a few external sparks is not sufficient reason for failing the device.
- Venting efficiency. This is measured across the full range of specified K_{St} values and is determined by explosion tests. The complete device is compared to an inertia-free venting device (e.g. rupture foil) of the same size and geometry without obstructions.
- Mechanical strength. Assessment can be by an explosion test using an explosion with K_{St} not less than that provided by the manufacturer as the maximum value for which the device is designed and a reduced explosion pressure not less than 1.1 x the maximum value that the device is designed to withstand.

EN 1127-1 Explosive atmospheres – Explosion prevention and protection. Part 1 Basic concepts and methodology.

This is a harmonised standard and describes the basic concepts and methodology of explosion prevention and protection. It specifies methods for the identification and assessment of hazardous situations leading to explosion and the design and construction measures appropriate for the required safety. The requirements for the design and construction of equipment, protective systems and components to reduce the effects of an explosion are specified. The standard describes the essential requirements of explosion relief venting but does not specifically refer to flameless venting with respect to dust explosions. However, it does make reference to features that may be relevant to flameless venting:

a) Bursting discs, vent panels or explosion doors, for example, can be used as relief devices. Safety valves are not suitable for this purpose.

b) Whenever possible, the pressure relief should follow a straight path.

c) Explosion relief into work-rooms shall not be permitted unless there is proven evidence that persons cannot be endangered (e.g. by flames, flying debris or pressure waves). The effects of the discharge on the environment shall be considered.

d) With respect to prevention of explosion propagation the standard gives details of flameless venting devices that are suitable for gases, vapours and mists. It states that some of the devices cannot be used with dusts, owing to the risk of blockage.

VDI 3673 Part 1 - Pressure venting of dust explosions

This German standard is concerned with mitigation of the effects of dust explosions by explosion pressure relief venting. It includes the selection and design of pressure venting devices. In the 2002 issue it discusses many features of explosion venting but in particular it makes reference to the following aspects that are relevant to flameless venting:

a) Flame propagation from explosion pressure vented equipment can be stopped, under certain conditions, by using approved flameless pressure venting devices (quench device with dust barrier).

b) Inertia-free pressure venting devices correspond with a venting efficiency $E_f = 1$ and essentially do not obstruct venting. With other types of venting devices the design or its mass may affect the venting efficiency. Figure 10 defines the venting efficiency E_F of a pressure venting device (vent area A_E) compared with an inertia-free bursting foil. This effect shall be tested with regard to the determination of the venting efficiency. The standard refers to the Directive 94/9/EC in that all pressure venting devices are protection systems and have to be subject to a EC suitability test from 1 July 2003.

c) All parts that are exposed to the explosion pressure must meet the design strength. Where the explosion pressure is not released directly but through a duct (or flameless venting device) into the open, there will be an increase in the maximum reduced explosion overpressure in the vessel being protected which will increase the design strength requirements of the vessel.

d) Explosion venting devices have to be installed in such a way that nobody will be endangered. Also, the operation of any equipment which is important with regard to safety, shall not be restricted.

e) Regarding maintenance, the standard points out influences that may restrict the performance of venting devices. In addition to following the recommendations of the manufacturers, rupture discs are subject to corrosion, cycling loads, mechanical abrasion, aging and incompetent maintenance (e.g. gumming up with paint). A regular inspection is necessary.

f) An increase in the static activation overpressure due to dirt, snow load, excessive friction or a decrease due to corrosion or metal fatigue may jeopardise the performance and venting efficiency.

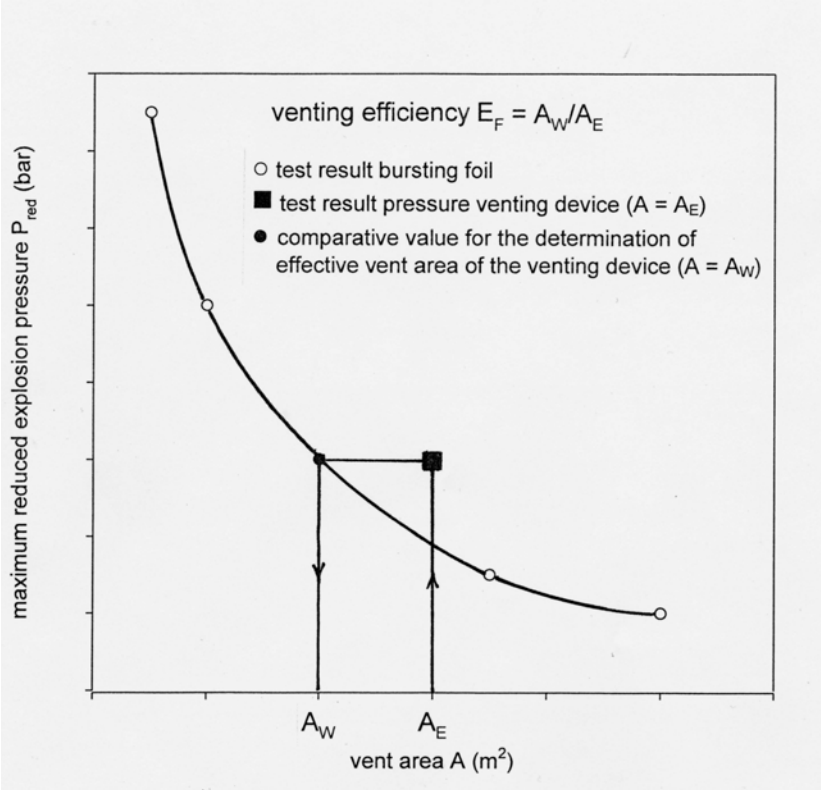

Figure 10: Venting efficiency

NFPA 68 Guide for venting of deflagrations

This standard is produced by the National Fire Protection Association in the USA. It is applicable to the design, location, installation, maintenance, and use of equipment that vents deflagrations from enclosures to minimise structural and mechanical damage. Dust explosion (or deflagration) protection using flameless venting devices are addressed:

a) Flameless venting devices - called flame-arresting vent systems and particulate retention vent systems - are described in the standard. Limitations and safety considerations are discussed and it points out that that consideration should be given to the proximity of personnel, volume of the room, possibility of combustible mixtures exterior to the equipment and possible toxic emissions.

b) It is stated that gases are cooled, no flame emerges and near-field blast effects (overpressure) are greatly reduced outside the system.

c) The guide points out that the user should work closely with the manufacturer to ensure that these parameters are addressed.

d) When venting within a building even with complete retention of flame and particles, the immediate surrounding area around the vent can experience overpressure and radiant energy. The expected overpressure must be considered in relation to the strength of the building and building venting should be considered to limit overpressures.

5 INSTALLED UNITS

Manufacturers and suppliers of flameless venting devices have indicated the numbers of units installed in the UK.

Rembe have estimated that approximately 100 Rembe units have been sold in the UK whereas Brilex thought that only 2 Brilex units have been sold in the UK. Both companies have supplied units to companies that have fitted them to dust-handling equipment that may have been subsequently sold into the UK.

Hoerbiger could not provide any information on units sold in the UK. They state that units have been purchased by manufacturers outside the UK for installation on equipment (e.g. filtration equipment) that may subsequently be sold into the UK. During discussions with Stuvex they estimate that they have supplied around 100 units.

Fike estimate that approximately 200 units have been sold into the UK with most of the units of the circular canister design. Since most vent panels are now rectanglar rather than circular, they anticipate that in the future the rectanglar section design will become more popular.

6 OPERATIONAL EXPERIENCE

6.1 DEVICES IN THE FIELD

Information relating to a range of installations has been obtained.

6.1.1 Coal Mill

Rembe report that the Q-Rohr system has been on the market for many years and in this time incidents with the system have occured. Because of non-disclosure agreements it is not possible to supply details. However, an explosion incident in Poland demonstrated the successful venting of a coal dust explosion. This occurred in coal mill operating in a cement plant. The mill was protected by a DN600 Q-Rohr system. The Q-Rohr operated successfully and prevented damage to the equipment. Following the incident the Q-Rohr was cleaned, the relevant parts were replaced and the plant was returned to service.

6.1.2 Sewage sludge drying plant

In 2002 an explosion occurred in a sewage sludge drying plant in South Wales. Although the filter was provided with a flameless venting device, the vessel suffered considerable damage. At this stage it has not been possible to make a full and fair assessment of the performance of the flameless venting device although anecdotal evidence suggests that flameless venting may have contributed to the failure. Following the incident the issues that may have been contributory were addressed including the vent design, strength of the vessel, and the obstruction of the vent path by the filter bags. Lessons were learnt and the plant was subsequently modified including the introduction of a stronger replacement filter vessel. HSE Operational Circular OC 847/9 includes information relating to flameless venting on sewage sludge drying plant. The document states that explosion relief venting is currently only feasible for a fixed dryer body. The vents must be correctly sized and installed. An explosion will produce both a pressure wave and a fireball requiring venting to a safe place, such as outside the building, by means of suitable ducting. If this is not possible, quench pipes can be used. These devices consist of a bursting disc and packing matrix. Whilst substantially reducing both the pressure and thermal energy of the explosion their outlet should be placed away from easily accessible areas such as walk ways. Consideration may also have to be given to the outlet proximity to parts of the building which could still be damaged by the reduced pressure wave exiting the quench pipe e.g. wall cladding. The manufacturers advice should be sought on suitable separation distances. It should be appreciated that that once used the quench pipe will require replacing before the plant can again become operational. Both explosion vent panels and quench pipes are ATEX equipment. They should have been 3rd party tested, and be Ex and CE marked. The basis for the design size should be documented.

6.1.3 Bucket elevator

In 2004 an explosion occurred in a bucket elevator at the Sugar Australia Glebe Island Terminal, Sydney, Australia.

Two elevators were operated at the terminal and were originally built and commissioned in 1994. They had been in operation for almost ten years before the explosion occurred in Reclaim Elevator 02 in April 2004. The belt and bucket twin-leg design had rotary valves at the product inlet and outlet. The dimensions were: boot height 1.544 m, head height 1.551 m, overall height 50.050 m, width 0.420 m, leg cross sectional area 0.13 m^2. The trunking was fitted with eleven DN300 explosion vents complete with bursting panels and flameless venting devices. The venting devices were manufactured with an activation pressure of 100 mbar and rated for a maximum pressure of 500 mbar. They were located on the outside front face (not on the sides of the casing). Five were fitted to the upleg and six to the downleg but none were fitted directly to the boot or the head. They were spaced at approximately even intervals on the face of the upleg and the downleg. A vent was located approximately 3 m from the head on the upleg and the downleg. A vent was located at approximately 1.4 m on the downleg and 7.8 m on the upleg from the boot. The spacing was variable because of obstructions such as floor locations.

The elevator was running and conveying sugar at the time of the incident. It was concluded from the investigation that a belt alignment sensor, that was out of adjustment, allowed a misalignment of the belt to go unchecked. Friction of the belt and buckets on the elevaror head side wall resulted in a hot spot at the elevator head and thus provided the primary energy source for ignition. The resulting explosion was not adequately vented and caused the downleg to completely rupture (Figure 11). The upleg was relatively undamaged. After the explosion it was observed that there was a build-up of hard sugar on the inside (product side) of the vent panels. Sugar dust, a hygroscopic material, had adhered to the inner surface of the elevator casing and the explosion vent panels and formed a hard layer due to the absorption of atmospheric moisture. Inspection of the flameless vents revealed that as the vents opened this material was vented into the flameless venting device causing blockage of the flame arrestor element thus increasing the reduced explosion pressure in the elevator which the elevator was not able to withstand.

The K_{St} of the dust was determined to be 133 bar.m/sec by testing at the SIMTARS laboratory in Queensland, Australia in June 1997. The venting calculations were considered adequate when re-checked in 2000. However, the more recent IChemE guidance published by Barton (2002) would have provided greater protection. This states that i) a vent should be located at the head and as close as practicable to the boot and ii) the vents should have an area at least equal to the elevator leg cross sectional area.

Faced with the need to rebuild the damaged elevator and upgrade the explosion protection Sugar Australia had the following concerns in respect of flameless venting:

- Maintenance of the venting system would be necessary if flameless vents were used again with hygroscopic products such as sugar. The flameless venting devices weigh approximately 100 kg and could therefore present difficulties during removal of the devices for cleaning.

- The suitability of flameless venting was of concern in an application where, during an explosion, the product (sugar in this case) melts and is forced into the flameless vent arrestor, blocking the arrestor thus probably totally changing its operating characteristics.

Both elevators at the Sugar Australia Glebe Island Terminal were subsequently refitted with chemical suppression and isolation systems.

Figure 11: Ruptured elevator casing

6.1.4 Hopper

In discussions with one supplier he was aware that one of their devices fitted to a hopper had been activated by process plant pressure. This had caused the vent panel to partially rupture. The rupture warning device was activated. Removal and inspection of the device revealed that a large quantity of process product had entered the mesh canister, penetrated the mesh and hence had reduced its effectiveness. It is conceivable that, without activation of the rupture warning device, the mesh canister would have continued to fill with product thus further reducing effectiveness of the device. This demonstrated that a rupture warning device is essential for the safe operation of a flameless venting device and should be checked as part of a regular maintenance procedure.

6.1.5 Food industry

Two plants were visited to witness typical flameless venting device applications.

6.1.5.1 Biscuit factory

Four vessels located within the plant had devices installed either on the roof or on the side of the vessels (Figure 12 and 13). The vessels were intermediate flour storage vessels each with an approximate volume of 10 m^3. Flour was conveyed into and discharged from the vessels using pneumatic conveying systems. The stainless steel venting devices were approximately 4 years old and were attached to the vessels using DN400 or DN500 flanged connections. The devices were the cylindrical flame arrestor canister type and were visually in good condition. Activation sensors appeared to be wired into the plant control system. However, there was no history of activation and no maintenance problems were reported.

Figure 12: Venting device in a biscuit factory

Figure 13: Venting device in a biscuit factory

6.1.5.2 Flat bread factory

A flat bread factory was visited where five Hoerbiger devices were installed to a range of vessels. A batch bin (Figure 14) having a volume of approximately 6 m^3 was filled via a pneumatic conveyor and discharged via a rotary valve. The bin was used for the storage of a powdered food mixture that included flour, milk, rice and sugar. The Hoerbiger device was installed on the roof of the bin (Figure 15) and was thought to be a 565 model. Although the device had the provision for an activation proximity switch, none appeared to be installed. The device was installed approximately 18 months prior to the visit and no activations nor operational problems were reported.

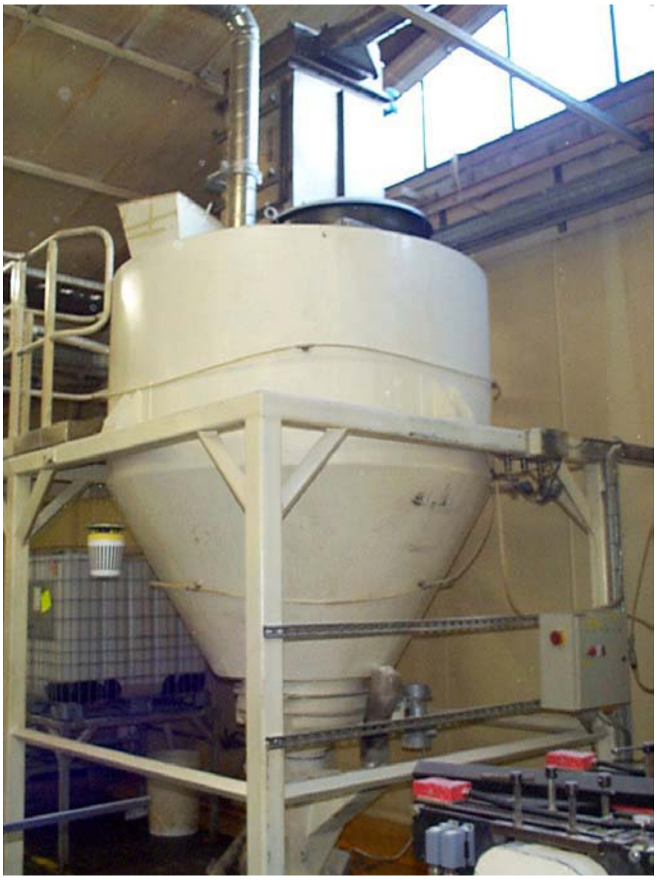

Figure 14: Flameless venting device fitted to a batch bin

Figure 15: Flameless venting device fitted to a batch bin

Similar devices were installed to a range of smaller cylindrical flour bins, all with volumes of approximately 3 m^3 (Figure 16). Vent ducting was precluded due to the presence of structural steel supports in the roof of the factory.

Figure 16: Flameless venting devices fitted to flour bins

6.2 INSTALLATION AND LOCATION OF DEVICES

Individual manufacturers provide their own design guide for use in conjunction with a recognised vent design procedure such as the VDI3673 or NFPA68.

Applications are on a wide variety of equipment include explosion protection of of indoor installations of storage bins, hoppers, dust collectors, fluid-bed driers, bucket elevators and silos. They are also used in combination with other protection systems. Rembe market a bucket elevator protection system (Figure 17) that incorporates flameless venting devices at the elevator head and boot but without intermediate vents. Infrared sensors detect a propagating flame and activate a specialized water mist suppression system to extinguish the flame and prevent explosion propagation.

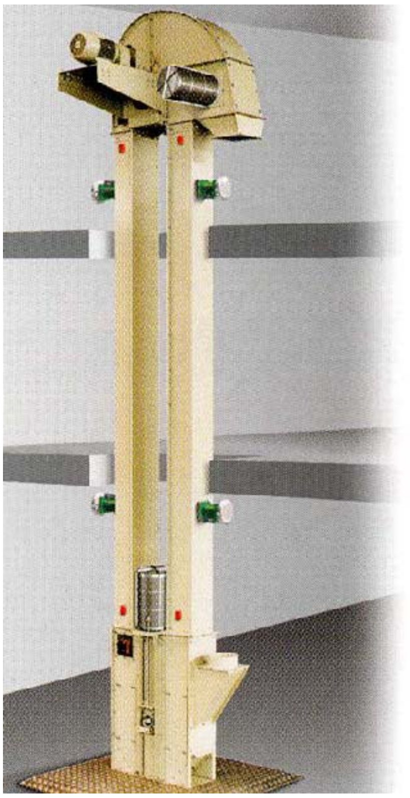

Figure 17: Bucket elevator with flameless venting
(Used with permission from Rembe GmbH)

Device position

The installed orientation is generally either horizontal or vertical. Hoerbiger have indicated that their device can be mounted in any orientation. Vertical or upward installation is recommended by Rembe. Devices are often installed horizontally.

Vessel volume

Rembe give some guidance on vessel volumes. The maximum explosion volume for a single unit is shown in Table 1. The maximum allowable volume can be increased by using more than one unit. For example:

Installed units: 3 x Q-32

Maximum volume per unit: 40 m^3

Maximum total volume: 120 m^3

Table 1: Maximum volumes

Type	Volume (m^3)
Q-8 Q-Rohr Quenching System DN200	1.2
Q-12 Q-Rohr Quenching System DN300	4
Q-16 Q-Rohr Quenching System DN400	7
Q-20 Q-Rohr Quenching System DN500	18
Q-24 Q-Rohr Quenching System DN600	24
Q-28 Q-Rohr Quenching System DN700	32
Q-32 Q-Rohr Quenching System DN800	40

The ratio of the room volume to vented vessel volume is given as 15:1.

Device location

Rembe state that the siting of the device with respect to the location of walls, other equipment, fencing, and location of personnel all need consideration. In their operating instructions, Rembe state that a safety zone of 2.5 m must be marked and shall not be entered during operation of the system. It is not stated whether this distance is based on noise, blast or dust emissions.

The distance of the device to walls or nearby equipment must be a minimum of 500 mm to guarantee total venting and the function of the device. This covered area shall not be larger than 50% of the total surface. Installation of flammable or temperature sensitive equipment is not allowed within this area.

Installation orientation of the Fike FlamQuench II device is not specified but Fike specify a safe distance of 2.5 m for personnel and 1 m for equipment. In common with the Rembe, the device must be kept free of deposits.

6.3 MAINTENANCE

Manufacturers make reference to keeping the devices clear of deposits. Clearly the efficiency could be seriously impeded and possible problems that need consideration are:

a) Long term build-up of debris within the flame arrestor that may not be noticed.

b) If one of these devices was located outside snow/ice cover could completely seal the flame arrestor. A weak/friable cover may protect the unit from snow/ice formation but may present backpressure problems.

c) Items placed on the device could partially block the arrestor.

Manufacturers generally claim that the flameless venting device is maintenance free. However, devices should be regularly checked and the outside of the device must be kept free of dust deposits. It is recommended that installation shall be such that no dust accumulations in front of the bursting disc occur. Any accumulation must be removed during shut-down using a soft brush and/or a vacuum cleaner. The installed system should not be wet-cleaned.

After an explosion the integrity of the flame arrestor element of the device needs to be checked. According to Rembe, the device has the capability to be cleaned in place and reused. The Brilex device is available with a refurbishing kit which can be installed by the user. Brilex state that the device can be re-used after changing the filter cartridges and the explosion vent which should take approximately 30 minutes.

Cotton covers intended to reduce cleaning procedures are marketed by Rembe. It is claimed that venting is guaranteed by air ventilating material and opening devices around the cover. It is not clear whether or not the effect on venting efficiency has been tested. Brilex also offer a similar cover.

Stuvex publish maintenance information on the Hoerbiger device. It is fitted with a manual facility that allows the testing of the device in situ. After an explosion the device should be removed from the vessel, cleaned, and inspected. Stuvex do not expect that major part replacement is required following an explosion.

6.4 RESEARCH AND PAPERS

Flameless pressure relief of dust explosions has been reported by Bartknecht and Vogl (1994). Flameless venting devices fitted with a pressure bursting disc with a static opening pressure (P_{stat}) of 0.1 bar were investigated. They were tested for dust explosion ignition transmission in a 1 m^3 vessel and a 60 m^3 vessel. Double strip safety devices were used which comprised parallel rolls of smooth and grooved steel strips. These were made into discs with a large number of strips with gap widths of 0.7 mm and 0.9 mm and with a gap lengths of 10mm. It is not clear which dusts were used but it was reported that the device was successful up to a reduced explosion pressure (P_{red}) of 3 bar. The upper limit of 3 bar was necessary because the ignition transmission tests with homogeneous dust/air mixtures revealed that at higher values of P_{red} there is a risk that the barrier effect of the double strip safety device is terminated. Bartknecht and Vogl point out that although the test results refer to a homogeneous dust/air distribution, it may be assumed that inhomogeneous dust/air mixtures does not intensify the ignition transmission behaviour.

The performance of flameless venting devices was assessed in an experimental programme carried out by Going and Chatrathi (2003). Five devices with diameters of 8”, 14”, 20”, 24” and 36” were used and were all manufactured by Fike (FlamQuench II). They were tested using explosion chambers having volumes of 0.5 m^3, 2m^3 and 4 m^3. The test dusts were cornstarch, anthraquinone and Pittsburgh coal. Propane gas was also used. It was reported that:

a) Video observation showed that the flameless device prevented flames emerging from the vessel. Gasoline soaked rags located on the outside and a layer of cornstarch on top of the device did not ignite. The autoignition temperatures quoted were 220°C and 380°C for gasoline and cornstarch respectively.

b) Efficiency was evaluated and was within the range 84-100%. Explosion pressures were measured in the test vessel with an inertia-less vent panel and with the flameless venting device. For example with the 0.5 m^3 vessel and an 14" diameter vent and cornstarch with a K_{St} of 211 bar m/s was used. The comparison showed that the P_{red} was approximately 4.9 psi and 7.1 psi for the inertia-less panel and the flameless venting device respectively. A few tests were done with the largest vessel which had a volume of 4 m^3 and a 24" diameter vent which indicated a reduction in efficiency with the Pred 8.1 psi and 12.3 psi for the inertia-less panel and the flameless venting device respectively. There is a possibility that with increasing vessel volumes and associated increased mass of dust there is the potential for the quenching chamber to retain more material and hence reduce its efficiency. To explore this potential tests are needed with larger vessel volumes than were used in these tests.

c) External surface temperatures of the venting device were measured. The highest recorded temperature was relatively low at 57°C.

d) Noise measurements were made at a distance of 5 m from the side of the vent. Generally, venting tests produced higher noise measurements than flameless venting tests. The smallest vents (14" diameter) produced the highest noise measurements at 134 dB for an inertia-less vent cover and 121 dB for the flameless venting device. The average noise levels for flameless venting were within the range 100 to 120 dB. Noise levels are likely to be greater with larger vessel volumes.

e) The dynamic face-on external pressure was measured at a distance of 2 feet and 8 feet from the 20" device fitted to the 2 m^3 vessel. Peak pressures of 0.12 psig and 0.06 psig were measured at the side at 2 feet and 8 feet respectively; a pressure of 0.27 psig was measured 2 feet from the top.

Stevenson (1998) has discussed the Q-Rohr in the Process Safety Progress publication. The "effectivity" of venting is described as 70%-90% of that of a free vent with the variation dependent on overall size of the Q-Rohr as well as the materials of composition of the mesh selected for the application. This allows the calculation of the Q-Rohr using conventional methods. A table is presented by Stevenson that lists twenty sets of data with the the names of test institutes, Q-Rohr types/sizes, vessel volumes, dusts and numbers of tests. It is stated that approval is given by FM (USA), Ciba, FSA, IbexU, DMT (Europe). The listed test dusts represent St1 and St2 dust groups and were predominantly St1 cornstarch.

7 CONCLUSIONS

(a) Four manufacturers have been identified: Rembe, Fike, Brilex and Hoerbiger.

Rembe, Hoerbiger and Brilex products are sold in the UK by agent companies. Fike and Hoerbiger have their own UK based company offices.

(b) Based on the figures supplied by the manufacturers and suppliers the number of devices sold into the UK is in the order of 400. This could be greater since units have been sold to manufacturers outside the UK for installation on dust-handling equipment that may subsequently be sold into the UK.

(c) An EC-Type Examination Certificate would normally be provided with a device.

Rembe report that their Q-Rohr device is recognised by NFPA68 and accepted by VDI-3673; prEN 14797.

According to the Brilex web-site the Brilex IndoorVent has been tested by well-known institutions and is certified according to the ATEX 100a Directive.

The Fike internet site reports compliance with NFPA 68 and the ATEX directive.

Hoerbiger publish a copy of a test certificate in their brochure. The certificate indicates that the device achieves Essential Health and Safety Requirements by conformity with EN 1127-1 (1997) and VDI 3673 part 1 (1995).

(d) Manufacturers have quoted testing in accordance with the following: ATEX Directive, VDI 3673, prEN14797, EN 1127-1, and NFPA 68. Generally, devices are suitable for dusts with K_{St} values up to 250-300 bar m/s. Venting efficiency is variable but is typically in the order of 55-80%.

(e) Research and certification testing are normally carried out under ideal conditions, i.e. new and clean flameless venting device and controlled explosion conditions. However, devices are used on a wide range of industrial applications, including sewage sludge drying plants, bucket elevators and product storage bins where the conditions encountered may be severe. Many food manufacturers store materials that are a potential problem i.e. fine sugar. Examples of operational experience demonstrate that the problem of the flame arrestor element becoming blocked is potentially a serious issue. The effect of blockages will be to decrease the venting efficiency with a corresponding increase in the explosion pressure.

The device could become blocked by:

- Over a period of time product may adhere to the inside of the vent bursting disc and may take the form of large agglomerated pieces. During an explosion this material will be blown into the arrestor and could result in a severe blockage.

- Powdered product may leak into the device over a period of time via a partially open or a damaged vent bursting disc. This may form a relatively large layer of deposit in the flame arrestor element and form a blockage. A sensitive rupture warning device should always be installed to indicate a minor break in a bursting disc. This is essential for the safe operation of a flameless venting device and should be checked as part of a regular maintenance procedure.

- External obstruction of the element may occur as a result of dust deposits penetrating the element over a period of time or the accumulation of ice or snow deposits.

- When ignition occurs at the rear of a vessel and where the flameless venting device is located at the front of the vessel, the pressure wave will push unburnt dust ahead of the flame and may enter the flameless venting device as a very rich dust cloud with the potential to block the flame arrestor.

No examples were identified where a device was found to be unserviceable during maintenance checks.

(f) A potential problem relates to the blockage of a device. A severe blockage could lead to a rupture of the protected equipment. The effect of potential blockages needs to be carefully considered both at the design stage and during maintenance. At the design stage an assessment of the dust being handled will identify whether or not the dust may have the potential to form deposits over the vent panel or block the flame arrestor element. For example will it form a sticky or cohesive layer on the inside of the vent bursting disc. Consideration of potential blockage needs to be addressed in the maintenance procedures and may require regular inspection of the vent covers and flame arrestor element to ensure that the element does not become blocked.

(g) Detailed information on performance is limited. Manufacturers have commissioned testing for the purpose of certification and Fike have published research results. However, apart from this, reports are not generally available. Consequently the performance and efficiency is difficult to assess and we can only base this on information released by manufacturers. The following is recommended:

- A programme of work is required to evaluate the effectiveness and limiting conditions of the devices under the wost-case conditions that are likely to be encountered in a real industrial explosion. These conditions should include worst-case dusts that will enable the following characteristics to be explored a) agglomerating dusts, b) coarse or flakey dusts, c) dusts with a tendency to melt. Also, ignition at the rear of a vessel should be explored; this may push a large quantity of unburnt material into the device ahead of the flame. These effects should be produced in explosion trials and the results used to establish realistic effectiveness and the limiting capabilities of devices.

- Devices may perform very effectively with specific materials, for example materials that are dry and do not agglomerate easily either before or following combustion. Performance and certification testing of devices should use appropriately severe materials established in a programme such as that described above.

- Devices are often installed in fairly confined spaces. Some manufacturers publish information relating to the safety distances for personnel relative to a device, location of obstacles and volumes of the surroundings. However, there is little freely available technical data to validate the information. Without this information, poor installation could result in serious injury to personnel, for example, by blast or noise. Research is needed to explore these parameters.

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