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# Evaluating the overall efficiency of a flameless venting device for dust explosions

Jenny Chao*, Sergey B. Dorofeev

*FM Global, Norwood, USA*

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ABSTRACT

Results from cornstarch explosion tests using a flameless venting device (mounted over a burst disc) on an 8 $m^3$ vessel are presented and used to determine the overall efficiency of the device, which is defined as the ratio between its effective vent area and the nominal vent area. Because these devices are comprised of an arrestor element mounted over an impulsively-actuated venting device (such as a burst disc), the functional form of the overall efficiency is taken as the product of the area efficiency (i.e., the ratio between the effective vent area of the entire assembly to that of the venting device without the arrestor element) and the burst efficiency (i.e., the ratio of the effective vent area of the venting device without the arrestor element to the nominal vent area). The effective vent areas are calculated from measured overpressures using three different empirical correlations (FM Global 2001, NFPA 2007, and VDI 2002). Furthermore, due to significant variations in the effective reactivity from test to test, a correction factor proportional to the initial flame speed is applied when determining the area efficiency. In general, it was found that the FM Global and NFPA methodologies yield consistent results with less scatter than VDI 3673.



## 1. Introduction

It is well-established that venting is a very effective means to reduce potentially-damaging overpressures that can develop inside an enclosure during an accidental explosion (for example, see Bradley and Mitcheson, 1978; Zalosh, 1979; Eckhoff et al., 1987; Hey, 1991; Tamanini, 2001). As a result of the venting process, however, several hazards are generated outside of the enclosure such as an external explosion (of the vented-unburned explosive mixture), a high-velocity flame jet, and blast-wave effects. For dust explosions, a flameless venting device can be used to minimize these external hazards (for example, see Stevenson, 1998; Snoeys et al., 2012; Holbrow, 2013). This device is essentially a cylinder or a box that is made of layers of wire mesh and is installed over an existing vent. As a dust explosion is vented through the device, the layers of wire mesh retain a portion of the burned and unburned dust and act as a heat sink, arresting the vented explosion by reducing the reaction-zone temperature.

Because the venting device retains a portion of the ejected dust, it acts as an obstruction that can increase the reduced overpressure inside the enclosure (compared to venting without the device), which effectively decreasing the available vent area. Given an otherwise sufficiently-designed vent, the addition of a flameless venting device can potentially result in a reduced overpressure that exceeds the design strength of the protected enclosure.

The type and reactivity of the dust can also enhance this effect. For example, fibrous or melting dusts can severely clog the wire mesh, which can further decrease the effective vent area (compared to a non-fibrous, non-melting dust such as cornstarch). In some cases, this can even cause the device to fail catastrophically. It is, therefore, essential to evaluate the overall performance of a flameless venting device in order to ensure its proper use.

In general, the overall performance of a flameless venting device is determined by its ability to successfully quench a vented explosion (such that no visible flame is transmitted downstream) while maintaining its structural integrity. Limitations and safety considerations for these devices are outlined in NFPA 68 (2007) and require the end user to collaborate with the manufacturer to

* Corresponding author. 1151 Boston-Providence Turnpike, Norwood, MA 02062, USA.
*E-mail address:* jenny.chao@fmglobal.com (J. Chao).

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address these concerns. However, its performance should also be quantitatively characterized by its efficiency, which can be defined as the ratio of the effective vent area (with the device) to the nominal vent area (without the device).

Although the definition of efficiency is fairly straightforward, the evaluation of this parameter is not trivial and requires full-scale testing where the reduced overpressure using a flameless venting device is compared to a baseline case. In the European Standard EN 16009 (2011), the reduced overpressure using a flameless venting device is compared to the case of an open vent. However, a flameless venting device is mounted over a burst disc with a specific mass and an actual burst pressure that differs from the rated static pressure. This is not taken into consideration in the EN Standard. Therefore, in the present investigation, the reduced overpressures of flameless venting devices (mounted with burst discs) are studied experimentally and compared to cases where only the burst discs are used. From these results, a methodology to evaluate the performance of a flameless venting device was developed, which has since been adopted in the new FM Approvals Standard on Explosion Venting Devices (Class Number 7730, 2014). In this new methodology, both the burst efficiency and the effective vent area are considered in the total efficiency of these devices. It should also be noted that the effective vent area cannot be measured directly from experiments and must be calculated using an empirical vent-sizing correlation. Three different vent sizing methodologies – Tamanini (2001), NFPA 68 (2007), and VDI 3673 (2002) – are used to determine the effective vent area, and the corresponding efficiencies are compared.

## 2. Experimental details

All experiments were performed in FM Global's 8 $m^3$ steel explosion vessel with a nominal diameter of 2 m and height of 2.9 m (shown in Fig. 1). Venting occurred through the top flange. Either a burst disc with a nominal diameter of 0.76 m or a flameless venting device/burst disc assembly (with the same nominal diameter) was mounted on the top flange. The static burst pressure of the burst disc was $\Delta p_{burst} = 0.1$ bar, and the actual vent area of the burst disc was 0.44 $m^2$.

In all tests, 6 kg of cornstarch (for a concentration of 750 $g/m^3$) was injected into the vessel at two different locations through 0.05-m dispersion nozzles using a Martin Engineering BB4-28-48 air cannon. Prior to any given experiment, the dust container (see Fig. 1) was filled with dried cornstarch and the vessel was partially evacuated to a pressure of about 0.85 bar. The air cannon was subsequently discharged, dispersing cornstarch and air into the vessel such that the initial pressure prior to ignition was 1 bar. Ignition of the cornstarch-air mixture was effected by a 10 kJ Sobbe pyrotechnic igniter placed in the centre of the vessel.

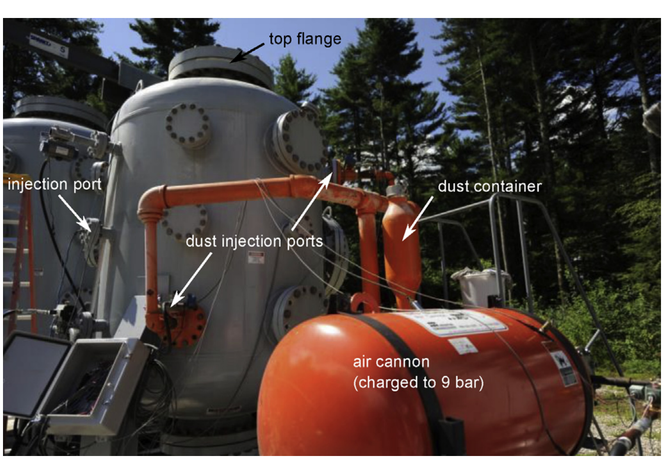


**Fig. 1.** FM Global's 8 $m^3$ explosion vessel with the dust-dispersion system.

A sketch of the locations of the different diagnostics is shown in Fig. 2. For all tests, two Stellar Technologies piezoresistive pressure transducers (GT1600) were used to measure the pressure histories inside the vessel. The ranges of the pressure transducers were 0–10.3 bar and 0–3.4 bar for unvented and vented tests, respectively.

For all vented tests, a burst indicator on the burst disc itself was used to determine the burst time and pressure. For tests conducted with a burst disc only, the rupture time was also corroborated with a high-speed camera (at 1000 frames/s) and an electric match synchronized with ignition (as a visual indicator for the camera). The high-speed camera was also used to monitor flame transmission through the venting device.

## 3. Experimental results

Three different series of experiments were conducted. The first series consisted of unvented tests in order to establish the reactivity of the dust in the particular facility that was used in the present study. Vented tests using burst discs only were conducted in the second series of experiments, which was used in conjunction with the results from the third series of tests using a flameless venting device mounted with a burst disc to determine the overall efficiency of the venting device.

### 3.1. Unvented explosions

A parametric series of unvented tests was first conducted in order to establish the required ignition delay times to emulate ST1 and ST2 reactivity classes for cornstarch. A typical pressure history of an unvented explosion is shown in Fig. 3a. For $t < 0$ s, it can be seen that the pressure increases from about 0.85 to 1.0 bar due to the high-pressure injection of cornstarch into the vessel. Once an initial pressure of $p_0 = 1.0$ bar is reached, ignition occurs at $t = 0$ s and the maximum pressure that is developed inside the vessel is found to be about $p_{max} = 8.4$ bar. The corresponding $dp/dt$ history can be found from the slope of the pressure history and is shown in Fig. 3b. The maximum value of $dp/dt$ is used to find the effective reactivity of the unvented explosion (for e.g., $K_{eff,unv} = V^{1/3}(dp/dt)_{max} = 186$ bar/s).

A summary of $K_{eff,unv}$ as a function ignition delay time is shown in Fig. 4 for all the ignition delay times that were used. The ranges of dust classes ST1 and ST2 are denoted by the shaded areas in the figure. It can be seen that the effective reactivity decreases as ignition-delay time increases. As well, for a given ignition delay, there exists fairly significant variability in the value of $K_{eff,unv}$. Nevertheless, based on these results, ignition delay times of $\tau = 1.55$ and 1.44 s were used to simulate the behaviour of ST1 and ST2 dust classes.

### 3.2. Vented explosions

A sequence of images from the high-speed camera are shown in Figs. 5 and 6 for tests conducted using a burst disc only and using a flameless venting device with a burst disc, respectively. In both cases, ignition occurred at $t = 0$ s. In the first frame of Fig. 5 at $t = 0.116$ s, the burst disc ruptures and unburned cornstarch can be seen to begin to vent from the vessel. In the next frame at $t = 0.129$ s, a significant cloud of cornstarch is formed and is ignited when the expanding flame inside the vessel reaches the threshold