Understanding the effect of multiple adjacent vent panels on explosion overpressures

C. Regis Bauwens, Sergey B. Dorofeev
FM Global, Research Division, Norwood, USA

1 Introduction

Explosion venting is the most commonly used method to mitigate the damage caused by accidental explosions within buildings and enclosures. For explosion venting to be effective, however, the venting must be adequately sized. Predicting the pressures that develop, and accurately sizing explosion vents, is a particularly difficult problem due to a number of physical phenomena that affect flame propagation, some of which only occur at large scale. This creates a challenge to develop models and guidelines for vent size requirements of a specific enclosure.

For a typical industrial facility, multiple vent panels are often needed, and a common arrangement places them adjacent to one another. The vast majority of experimental data on vented explosions, however, utilize a single vent panel, [1, 2, 3] and only a few studies have performed a systematic study examining the effect of multiple vents [4]. It is important to note that vented explosions are complex events which generate a number of pressure peaks [1, 5], each of which can result in the maximum overall pressure [5]. Of these effects, the presence of multiple vent panels may be considered analogous to the effect of obstacles [2, 5, 6], but can also affect the strength of the external explosion [7].

The objective of this study is to perform a systematic comparison of the effect of multiple adjacent vent panels on vented explosion overpressures by varying the number of panels present while maintaining a constant overall vent area for both back and center ignition locations. These results will quantify the impact of an obstructed vent opening, as well as generate further data for the development and validation of engineering tools to predict the consequences of vented explosions.

Correspondence to: carl.bauwens@fmglobal.com

2 Experimental Setup

The experiments were performed in a 64 m^3 chamber used in previous vented explosion experiments [5] with overall dimensions of 4.6 x 4.6 x 3 m^3. To accommodate the addition of multiple vent panels, different frames were inserted into the existing 5.4 m^2 opening to reduce the open area to 3.2 m^2. Four vent configurations were examined for one, four, six, and nine total vents, as shown in Fig. 1. The vent frames were 0.06 m thick and the spacing between vent openings were kept at 0.15 m for all configurations.

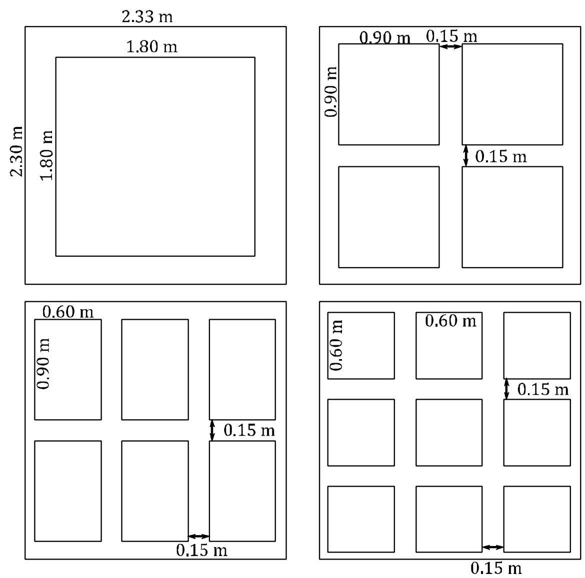

Figure 1. Dimensions of the one, four, six, and nine vent panel configurations.

Lean propane-air mixtures were used throughout this test series, with an initial concentration of 3.6% vol. and an equivalence ratio, $\phi = 0.9$. The initial mixture was prepared by injecting research grade propane from the ceiling of the enclosure, while four, 0.5 m diameter, mixing fans were used to make a uniform mixture. Concentration was monitored using a 3.39 µm laser extinction measurement system, a Stanford Research Systems BGA244 acoustic gas analyzer, and load cell measurements of the supply gas cylinders. This resulted in an overall concentration uncertainty of $\phi \pm 0.03$. The initial gas mixture was contained within the enclosure, prior to ignition, using an 0.02 mm sheet of polypropylene located immediately outside the vent frame, which was pre-cut and released pneumatically 2 seconds prior to ignition. The time between fan shut-off and ignition was controlled to generate a consistent initial turbulence intensity of $u' =$ 0.1 m/s.

Internal pressure was measured using four Stellar Technologies Inc. piezo-resistive pressure transducers arranged at four wall locations at mid-height within the enclosure. The pressure measurements across the four locations were virtually indistinguishable, except for the transducer mounted adjacent to the vent frame, which read lower pressures. For this work, pressures measured at the center of one of the walls perpendicular to the vent opening was used. External pressure was measured at two locations outside of the enclosure on a concrete pad at ground level, 1.15 and 2.30 m from the vent opening.

3 Results/Discussion

In total, 23 tests were performed with multiple repeated runs for each test configuration. For the purpose of this work, all pressure time-histories were filtered using an 80 Hz low-pass filter to isolate potentially damaging overpressures and acoustic noise.

3.1. Results of Back Ignition Experiments

Figure 2 shows the internal pressure for back ignition tests with different vent configurations. It can be clearly seen that a significantly higher maximum pressure was generated for a single vent and that increasing to a four vent configuration decreased peak pressure by more than a factor of two. Beyond the four panel configuration. however, pressure increased with the number of panels. There are a couple features that should also be noted. First, the duration of the peak is virtually unchanged between the different configurations. Second, the pressure rises faster prior to the main pressure peak in the single vent configuration, relative to the tests performed with multiple vents. This behavior was also observed in small scale experiments [4].

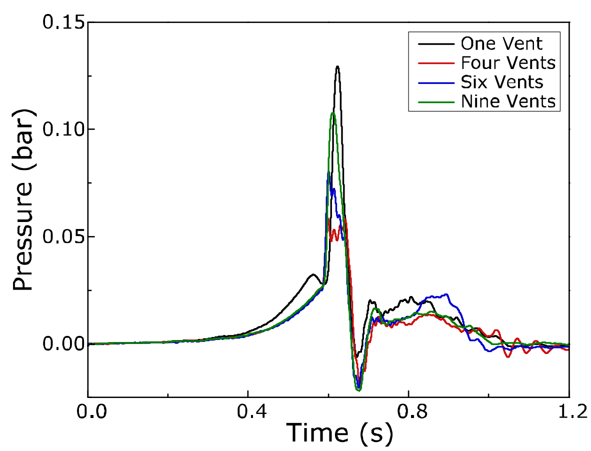

Figure 2. Internal pressure trace for back ignition tests for the different vent configurations.

To illustrate the experimental variability of the test data, Fig. 3 shows a series of repeated tests performed under the same nominal initial conditions. While some variation can be seen in the timing and peak pressure, test repeatability was generally good.

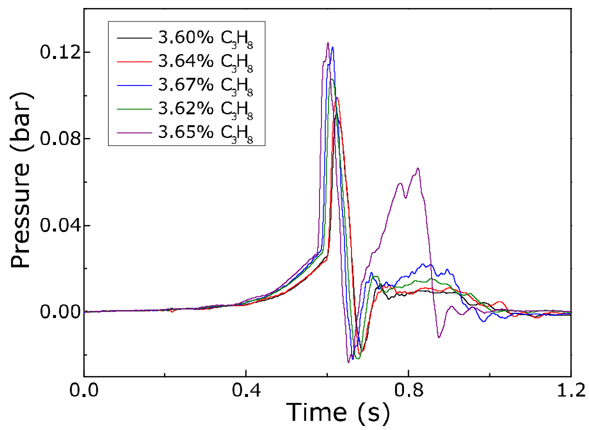

Figure 3. Experimental test repeatability for tests performed with the 9-vent configuration.

Figure 4 shows frames captured by the high speed camera of the external explosion, with background subtraction to better visualize the flame, at 15 ms intervals following the time of flame exit from the enclosure. It can be clearly seen that, while the flame propagates at roughly the same velocity perpendicular to the vent in both cases, vertical flame propagation is much more rapid when multiple vents are present. As a result, the fuel present in the external cloud is consumed at a steadier rate, compared to the single vent case where the flame rapidly grows in all directions between 60 and 75 ms after the flame exits the vent.

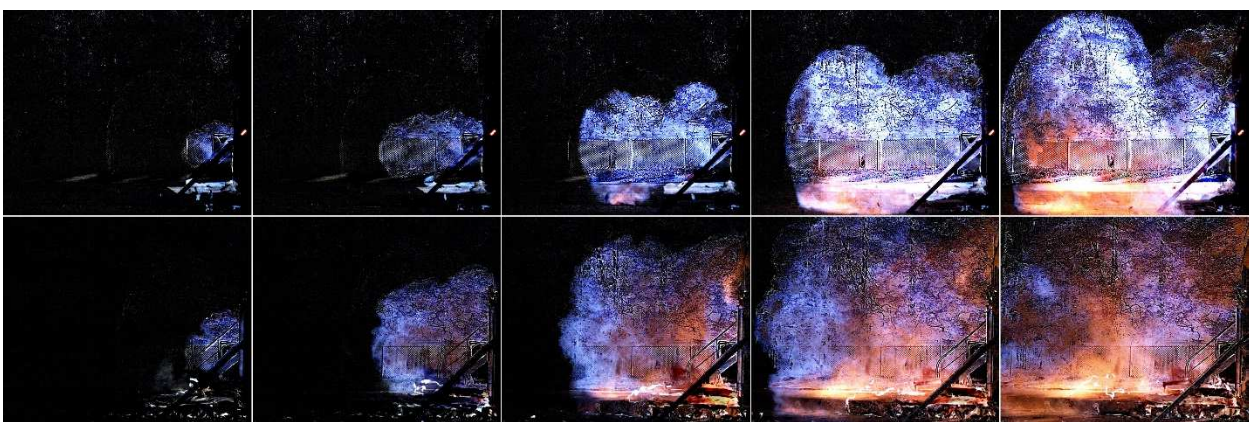
Figure 4. Background subtracted images of the external explosion for back ignition single vent (upper) and nine vent (lower) configurations. For times after flame exiting of 15, 30, 45, 60, 75 ms (left, to right)

3.2. Results of Center Ignition Experiments

The effect of the number of vent openings for center ignition cases can be seen in Fig. 5. For this configuration, it is clearly seen that increasing the number of vent panels increases the peak pressure, and the anomalous behavior of the single panel results are not observed.

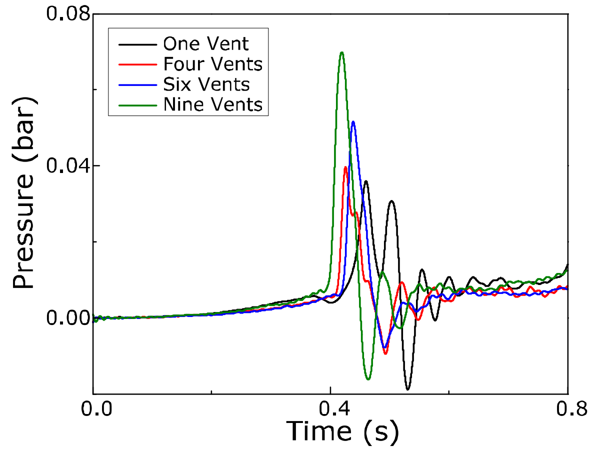

Figure 5. Internal pressure traces for center ignition tests with different vent configurations.

To examine the difference in behavior between back and center ignition cases, the internal and external pressure is compared for single panel and nine panel configurations in Fig. 6. This comparison shows that for back ignition, the external explosion occurs prior to the main pressure peak when a single vent is present, and is sharper. For the nine vent configuration, the external explosion occurs later, rising with internal pressure and results in a lower peak pressure than with a single vent. In the case of center ignition, however, the behavior of both vent panel configurations is much more similar, with pressure rising immediately after flame exits the vent.

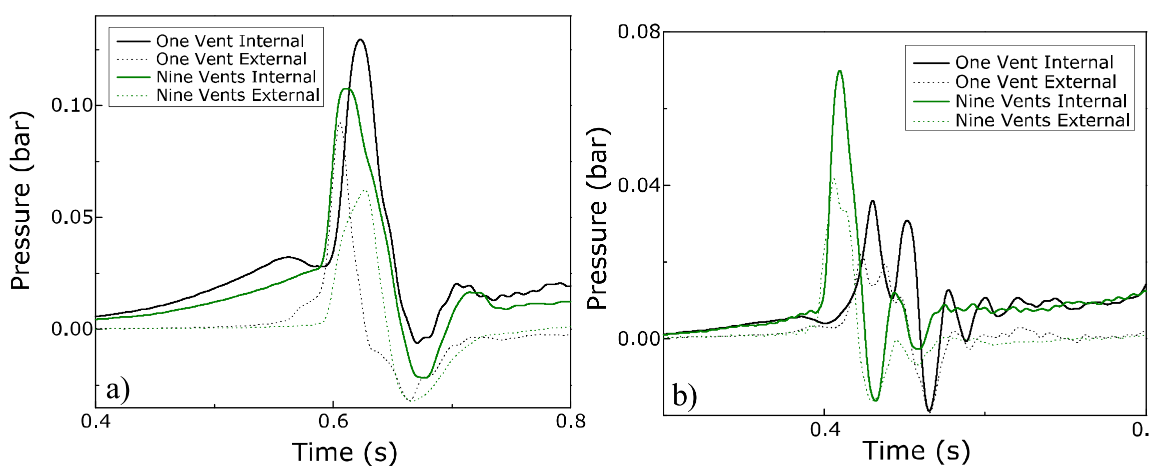

Figure 6. Comparison of internal and external pressure for one vent and nine vent configurations for a) back ignition (external pressure 0.230 m from vent) and b) center ignition locations (external pressure 0.115 m from vent).

The overall results of this study is summarized in Fig. 7, showing the clear trend where increasing the number of panels results in higher pressures, with the exception of the single panel back ignition case, and illustrating the experimental variability between the repeated tests.

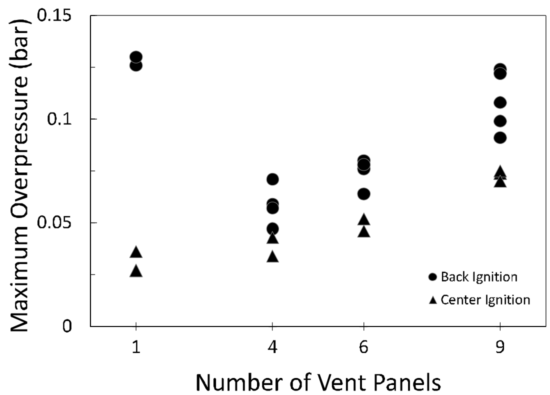

Figure 7. Summary of peak overpressures measured across the 23 experiments performed.

4 Conclusions

Experiments were performed characterizing the effect of multiple adjacent vent panels on explosion overpressures. It was found that the number of vent openings had a significant effect on peak overpressures, varying the total pressure by up to a factor of 2.5 over the range of conditions examined. With the exception of a single vent with back ignition, increasing the number of vent panels increased the peak overpressure. In the case of back ignition with a single vent, significantly higher pressures were observed, which was likely caused by the effect of multiple vents on the external explosion. These results provide an extensive set of data for model development and validation, and a challenging validation case for CFD models.

References

[1] Cooper MG, Fairweather M, Tite JP. (1986). On the mechanisms of pressure generation in vented explosions. Combustion and Flame. 65(1): 1.

[2] Bradley D, Cresswell TM, Puttock JS. (2001). Flame acceleration due to flame-induced instabilities in large-scale explosions. Combust. Flame. 124(4): 551.

[3] Solberg DM, Pappas JA, Skramstad E. (1981, January). Observations of flame instabilities in large scale vented gas explosions. Proc. Combust. Inst. 18(1): 1607.

[4] Fakandu BM, Yan ZX, Phylaktou HN, Andrews GE. (2013, May). The Effect of Vent Area Distribution in Gas Explosion Venting and Turbulent Length Scale Influence on the External Explosion Overpressure. In Paper Presented at the Seventh International Seminar on Fire & Explosion Hazards (ISFEH7), Providence, Rhode Island.

[5] Bauwens CR, Chaffee J, Dorofeev SB. (2010). Effect of ignition location, vent size, and obstacles on vented explosion overpressures in propane-air mixtures. Combust. Sci. Tech. 182(11-12): 1915.

[6] Tomlin G, Johnson DM, Cronin P, Phylaktou HN, Andrews GE. (2015). The effect of vent size and congestion in large-scale vented natural gas/air explosions. J. Loss Prevent. Proc. Indust. 35: 169.

[7] Harrison AJ, Eyre JA. (1987). External explosions" as a result of explosion venting. Comb. Sci. Technol. 52(1-3): 91.