Effect of Ignition Location, Vent Size and Obstacles on Vented Explosion Over-Pressures in Propane-Air Mixtures

C. Regis Bauwens, Jeff Chaffee, Sergey Dorofeev,

FM Global, Research Division, Norwood, USA

Venting is a method commonly used to prevent or minimize damage to an enclosure by relieving the pressure generated within the volume during a combustion process. Analytical models and empirical correlations have been developed (see, e.g., [1, 2, 3, 4]), to estimate the vent size requirements for a certain locations with some of the correlations being included in engineering guidelines [5]. These correlations however, can often have conflicting recommendations. This is due to the complex nature of the process itself, and the influence of other factors that can affect the peak over-pressure, such as size and shape of the enclosure, the mixture being burned, the type of vent and vent deployment pressure, congestion or obstacles inside the chamber and ignition location.

Because of the limited reliability of the current methods for prediction of pressure generation during vented explosions, a research project was initiated at FM Global with the goal of generating a set of experimental data focusing on the effects of mixture composition, ignition location, vent size, obstacles and scale on vented explosion overpressures. The set of data will be used to develop and validate a computational code that will be further extended to assist in the development of new models and engineering tools.

FM Global's 64 m^3 large scale explosion test chamber was used to generated the set of experimental data. The test chamber had overall dimensions of 4.6 x 4.6 x 3.0 m and square vent with a surface area of either 5.43 m^2, or 2.73 m^2 located on one of the chamber's vertical walls. The overall geometry of the chamber and location of instrumentation is shown below in Fig. 1. Four chamber pressure transducers were mounted to the chamber, twenty flame arrival thermocouples were used to track the time of arrival of the flame front for locations both inside and outside of the chamber. In addition, four low speed and one high speed cameras were used to observe the tests, directed either into the chamber or outside to observe the external explosion.

Ignition was supplied using a carbon rod igniter attached to the line of thermocouples running the length of the chamber. For each test, one of three locations ignition locations was used, either at the center of the chamber, 0.25 m from the center of the wall opposite the vent (later referred to as back-wall ignition), or 0.25 m from the center of the vent (later referred to as front-wall ignition) as shown in Fig. 2.2. For the tests performed with obstacles eight 40 x 40 cm square obstacles spanning the full height of the chamber were uniformly distributed in two rows of four with 75 cm of spacing between obstacles. The rows of obstacles were aligned with the thermocouple line running along the middle of the chamber parallel to the wall containing the vent.

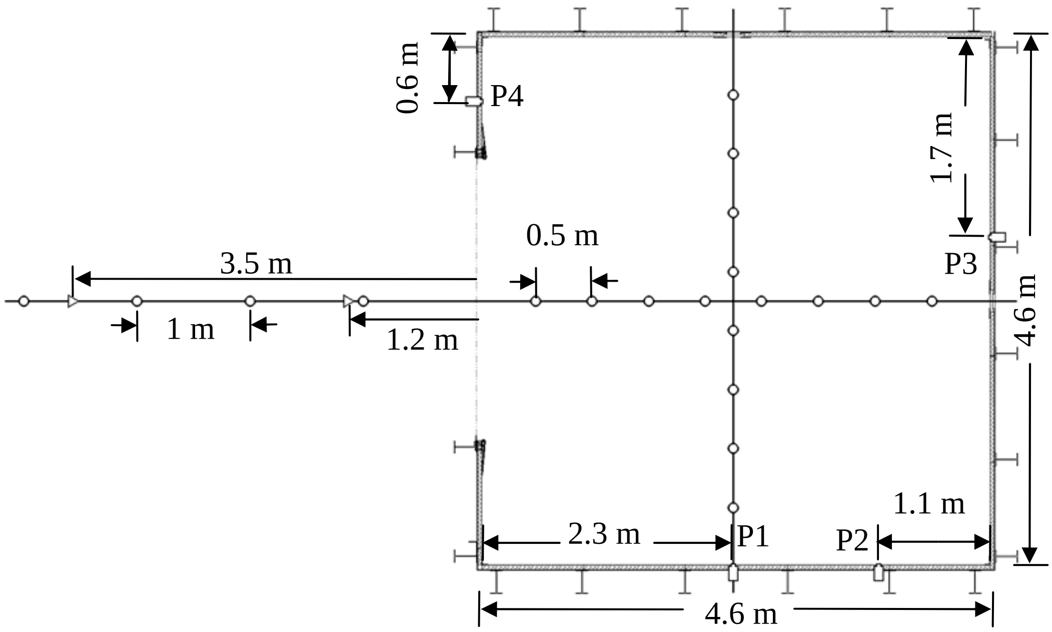

Figure 1. Illustration showing the locations of pressure transducers, (rectangles), flame arrival thermocouples (circles), blast-wave pressure transducers (triangles).

Two large peak over-pressures generated during vented explosions were observed in this study, a first peak, P_1, generated by a combination of the external explosion and Helmholtz oscillations and a second peak, P_2, generated by interactions between the flame surface and the structure of the chamber itself that reaches a maximum when a maximum flame surface area is achieved in the chamber. Table 1 below summarizes the results for various combinations of vent size, ignition location and presence of obstacles. Figures 2, 3 and 4 below show comparisons of filtered results for different ignition locations, vent sizes and obstacles.

Table 1: Summary of peak pressure results from propane tests.

Test #	Obstacles	Vent Size (m^2)	Ignition Location	Concentration (% Vol.)	P_1 (bar)	P_2 (bar)	P_{max} (bar)
1	0	2.73	Back-wall	4.11 ± 0.20	0.134	0.125	0.134
2	0	2.73	Center	4.01 ± 0.08	0.041	0.161	0.161
3	0	2.73	Front-wall	4.02 ± 0.08		0.196	0.196
4	0	5.43	Back-wall	4.05 ± 0.20	0.056	0.009	0.056
5	0	5.43	Center	4.06 ± 0.20	0.025	0.023	0.025
6	0	5.43	Front-wall	4.04 ± 0.08	0.003	0.005	0.005
7	8	2.73	Center	4.01 ± 0.08	0.104	0.047	0.104
8	8	2.73	Front-wall	4.00 ± 0.08	0.004	0.049	0.049
9	8	5.43	Back-wall	4.12 ± 0.08	0.186		0.186
10	8	5.43	Center	4.02 ± 0.08	0.031		0.031
11	8	5.43	Front-wall	3.98 ± 0.08	0.003	0.010	0.010

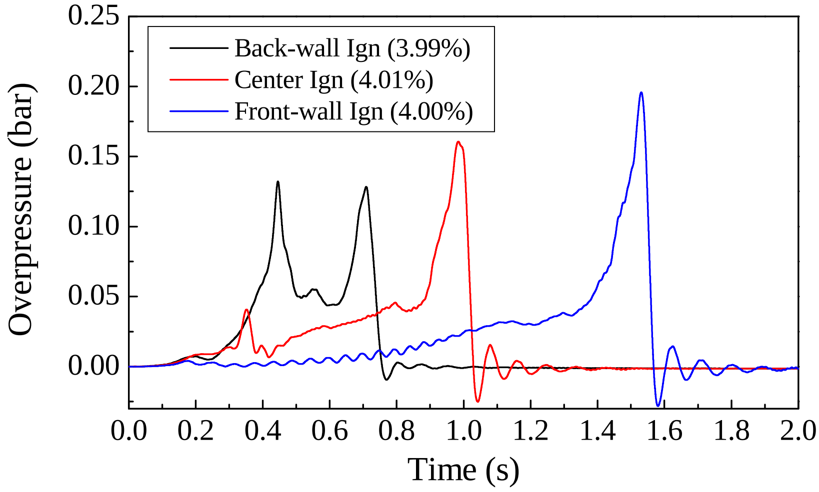

Figure 2. Effect of ignition location for stoichiometric propane-air mixtures with 0 obstacles with a 2.73 m^2 vent.

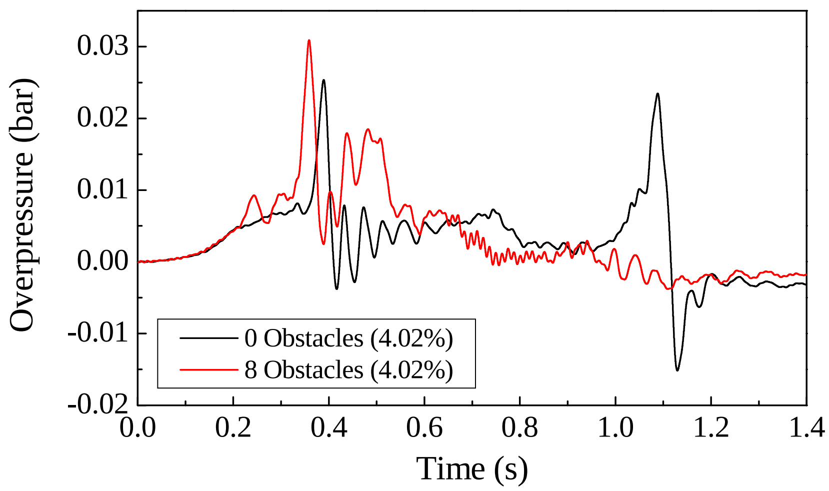

Figure 3. Effect of obstacles for stoichiometric propane-air mixtures with center ignition and a 5.43 m^2 vent.

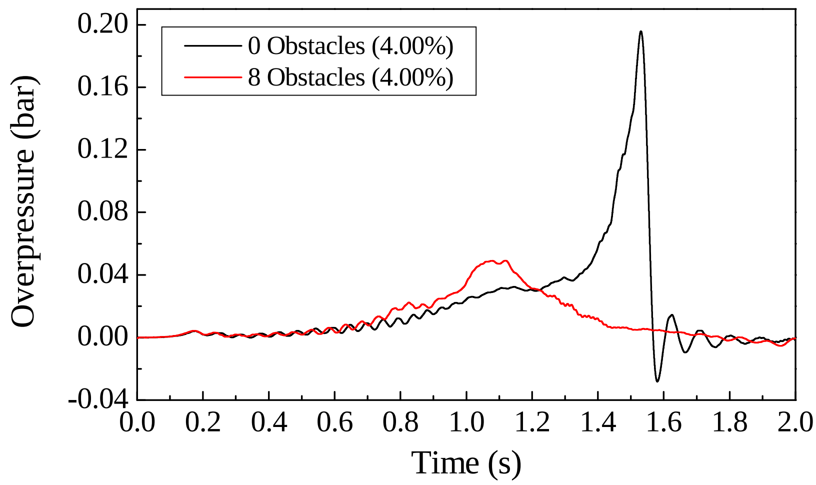

Figure 4. Effect of obstacles for stoichiometric propane-air mixtures with front-wall ignition and a 2.73 m^2 vent.

Results of tests on vented explosion obtained in a room-size enclosure with and without obstacles for stoichiometric propane-air mixtures have been presented. The main physical phenomena responsible for pressure generation under this range of initial conditions were identified. It was found that, for the geometry and mixtures studied, two physical phenomena are mainly responsible for the overall peak pressure rise in the vented enclosure. The first is a pressure transient that occurs due to a combination of Helmholtz oscillations, the external explosion, and the Taylor instability. These effects result in the first major pressure peak observed in the tests. The second major pressure peak is a pressure transient, driven by feedback between acoustics generated by the structure of the chamber and the combustion process.

In general, it was found that back-wall ignition increases the strength of the first peak, while reducing that of the second and that front-wall ignition does the opposite. It was also found that a smaller vent reduces the relative strength of the first pressure peak while increasing that of the second pressure peak. Generally, the presence of obstacles was found to greatly amplify the pressure generated in the first peak while greatly attenuating the pressure generated by the second peak for most cases.

For the configuration studied, no one worst case ignition location was found. For the obstacle configuration and ignition locations studied, the presence of obstacles did not necessarily increase the pressures generated within the chamber and only did so in half of the cases. Acoustic coupling between the structure of the chamber and the flame front can generate significant pressure loads; and the increase of loads caused by this coupling may be stronger than those caused by obstacles. These results show that future analysis and resulting engineering correlations may need to be focused on each individual peak rather than on a single general over-pressure level.

References

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