CHEMICAL ENGINEERING TRANSACTIONS, Volume 13, 2008
Edited by Simberto Senni Buratti

Mitigation Of Gas Explosions In High-Strength Vessels At Different Initial Conditions

Salzano E. [1,*], Cammarota F.[1], Di Benedetto A.[1], Russo P.[2]
[1] Istituto di Ricerche sulla Combustione, Consiglio Nazionale delle Ricerche
Piazzale Tecchio 80, 80125 Napoli, Italy
[2] Dipartimento di Ingegneria Chimica e Alimentare,
Università di Salerno, 84084 Fisciano (SA), Italy

1. Introduction

The mitigation of gas explosion in process equipment is generally obtained by venting hot combustion products to the external atmosphere, possibly through ducts (NFPA68, 2007). To this aim, the vent section, the type of safety valve, the strength of vessel structure and vent set pressure should be designed keeping into account that initial conditions may be different than atmospheric conditions, due to the process T,P and due to the turbulence induced by geometry or process flow. Nevertheless, venting correlations which take into account initial pressure only have been proposed in the open literature (Molkov, 2001), but however the lack of experimental data, even at lab scale, is still evident. Furthermore, only empirical suggestions are given for initial turbulence produced by obstacles or geometrical configurations as for instance considering common hydrocarbon/air as over-reactive hydrogen/air mixtures.
In this paper, experimental results obtained in lab scale cylindrical vessel for ducted vented explosion of methane/air at initial pressure up to 6 bar and temperature of 300 K are showed. Results may allow the refinement of existing design correlation in real process conditions and give useful information on the use of duct venting systems for high strength enclosures. To this regard, it is worth noting that NFPA68 gives empirical correlations for vent section which do not consider pressurized equipment in the case of gas explosion, as the validity of equation is restricted to 2 bar.

2. Experimental Setup

The experimental setup consists of a cylindrical chamber with volume V = 5 lt (Figure 1), tested for explosion up to 400 bar, 200 bar working pressure. Initial temperature of the combustion chamber is 300 K for all tests as an external heater is installed. Mixture composition is stoichiometric, obtained by partial pressure method. When testing vented explosion, a Swagelok relief valve has been installed, vent section of 4.8 mm diameter. The vent is then connected to open atmosphere by means of flexible steel tube with total length L = 3 m, with a diameter of 6 mm just after the connection with the relief valve. Both top and central spark ignition have been adopted. The two electrodes are located at a distance of 1 mm. A common neon electrical transformer, 220-230 V e 50Hz with 3.0 KV and 25/30 mA discharge current has been used.

The entire set of experiments have been produced also for initial non-quiescent conditions obtained by using mechanical stirring, with rotating shaft velocity of 480 r.p.m.. All data reported in the following are the average of three tests. Average error is less than 3% for pressure measures and rate of pressure rise.

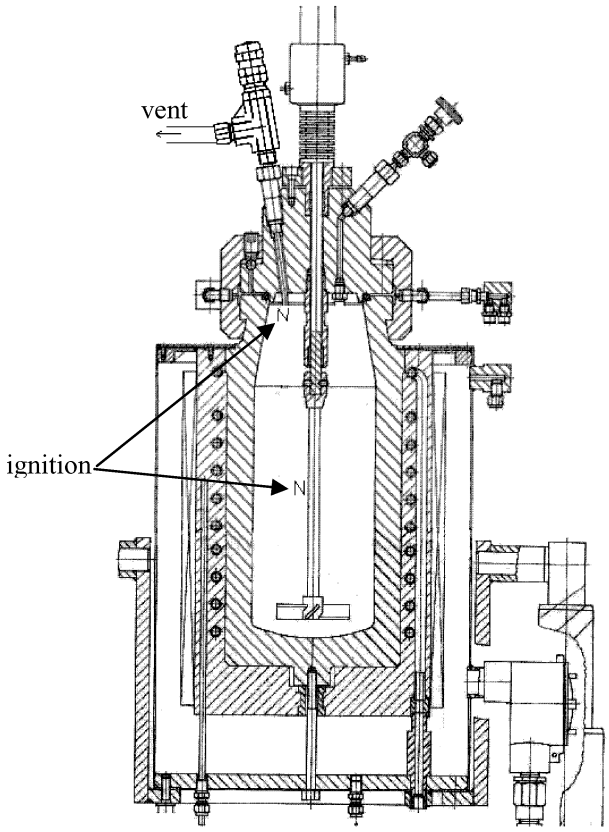

Figure 1. The experimental setup.

3. Results And Discussions

In the following the experimental results in quiescent and turbulent methane air mixture of both unvented and duct-venting explosion are showed.

3.1 Closed vessel

3.1.1 Effect of initial pressure

In Figure 2, the pressure history as obtained in the closed vessel at central ignition at different values of the initial pressure are shown.

The rate of pressure rise, and hence the deflagration index (K_g), increases with increasing the initial pressure almost linearly up to an initial pressure of 6 bar for both central and top ignition, as shown in Figure 3.

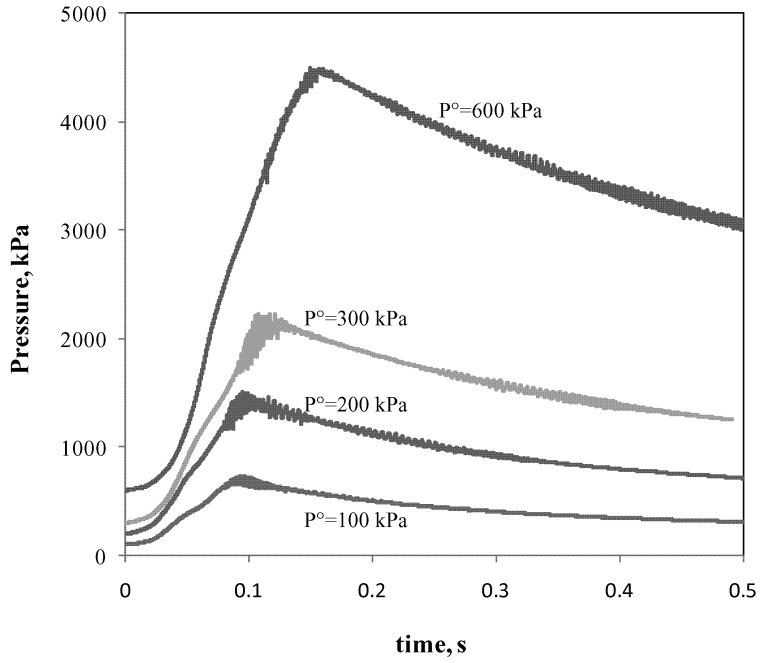

Figure 2. Pressure/time for the explosion of quiescent methane air mixture at different initial pressure P°. Zero time is scaled to the effective ignition time of mixture.

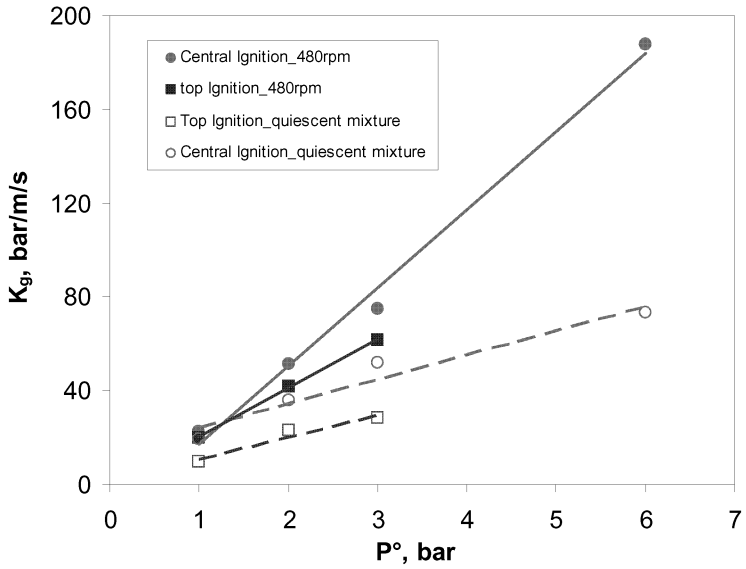

Figure 3. Deflagration index (K_g) with respect to initial pressure, for central (circle) and top ignition (square) in closed vessel. Filled symbols: 480 rpm; Empty symbols: quiescent mixtures.

3.1.2 Effect of initial turbulence

Initial turbulence has been obtained by mechanical stirrer at shaft velocity of 480 rpm. Flow velocity has been measured by hot wire anemometer in terms of absolute velocity. Turbulent intensity has calculated as the standard deviation of velocity measured each second for 100 seconds by considering a grid of about 10 cm^3, for the entire length and radius of the vessel. Results are reported in Figure 4. Central axis section does not show velocity for the presence of the shaft. Mean turbulent intensity in the entire vessel is about 0.022 m s^{-1} for the provided rotation speed.

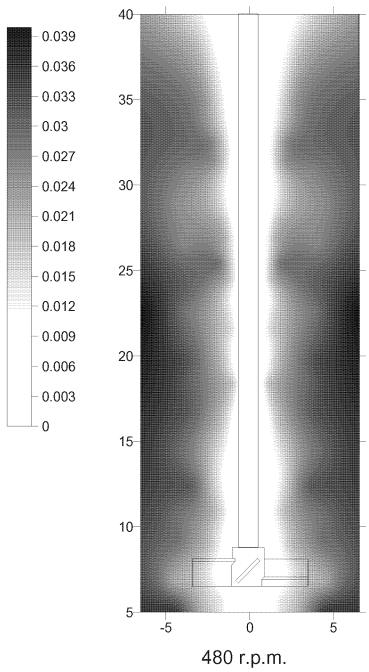

Figure 4. Maps of the turbulent intensity (m s^{-1}) induced by mechanical stirrer into the vessel.

The turbulent intensity affects the heat exchange as flame speed is increased (i.e. the combustion rate); indeed, the characteristic total duration of the entire explosive phenomenon is shorter. However, small differences are observed for the maximum pressure in closed vessels between quiescent and turbulent systems, and results are not reported here for the sake of brevity. On the other hand, as expected, the rate of pressure rise are strongly affected by turbulence, as showed in Figure 3 in terms of deflagration index (K_g). In the same figure, results obtained for the quiescent mixture are reported for comparison. In this and next figures, error bars are omitted as they are always smaller than symbol dimension. In the case of top ignition, turbulence effects are more pronounced than for central ignition at lower P°. However, at lower P° the position of ignition is more critical than turbulence. Finally, the turbulence effects are consistent, and very high reactive systems have been found, when centrally ignited and high pressure (6 bar) are considered.

3.2. Vented vessel

3.2.1. Effect of initial pressure

For the aims of this analysis, the effectiveness of venting can be defined as follows:

$$\mathrm{Eff}(\%) = 100\left(\frac{P_{max,closed} - P_{red}}{P_{max,closed}}\right) \quad (1)$$

where P_{red} is the maximum vented pressure measured at any initial T, P conditions and turbulence and $P_{max,closed}$ is the maximum pressure measured at the same conditions in the closed vessel. $P_{max,closed}$ may be lower than the maximum adiabatic pressure P_{ad} depending on the heat losses.

Figure 5 shows the effectiveness of duct venting and the K_g values measured in initial quiescent explosion tests for both central and top ignition. Different vent set pressure P_v have been adopted.

The ability of vent to mitigate is effective at initial high pressure and lower ratio of vent set pressure P_v over P_o, where the higher values of K_g are measured. Quite interestingly, the plot shows that for top and central ignition the vent effectiveness are almost superposed thus helping for conservative option when designing vent section.

In the view of vent design, it is very important the linear increase of K_g with initial pressure by using the same vent set pressure at 3.5 bar (Figure 5). This effect can be usefully applied for the evaluation of K_g in the NFPA correlations or more generally for the definition of vent section in the case of high strength vessel/enclosures.

3.2.2. Effect of initial turbulence

Turbulence induced by obstacles or geometry may affect the effectiveness of the vent. These effects are clearly showed in the Figure 6 for both top and central ignition, if compared with same results in quiescent mixture (Figure 5).

A reduction of vent effectiveness is observed in all range of initial pressure investigated, and it is higher for central than top position of ignition.

Moreover, turbulence may affect the severity of vented explosion as appear from results reported in Figure 7. In the presence of vent, the turbulence increases the rate of pressure rise and its effect is higher for top than central ignition, as already observed for closed vessel (Figure 3). Once again, the turbulence is more effective increasing the initial pressure (6 bar).

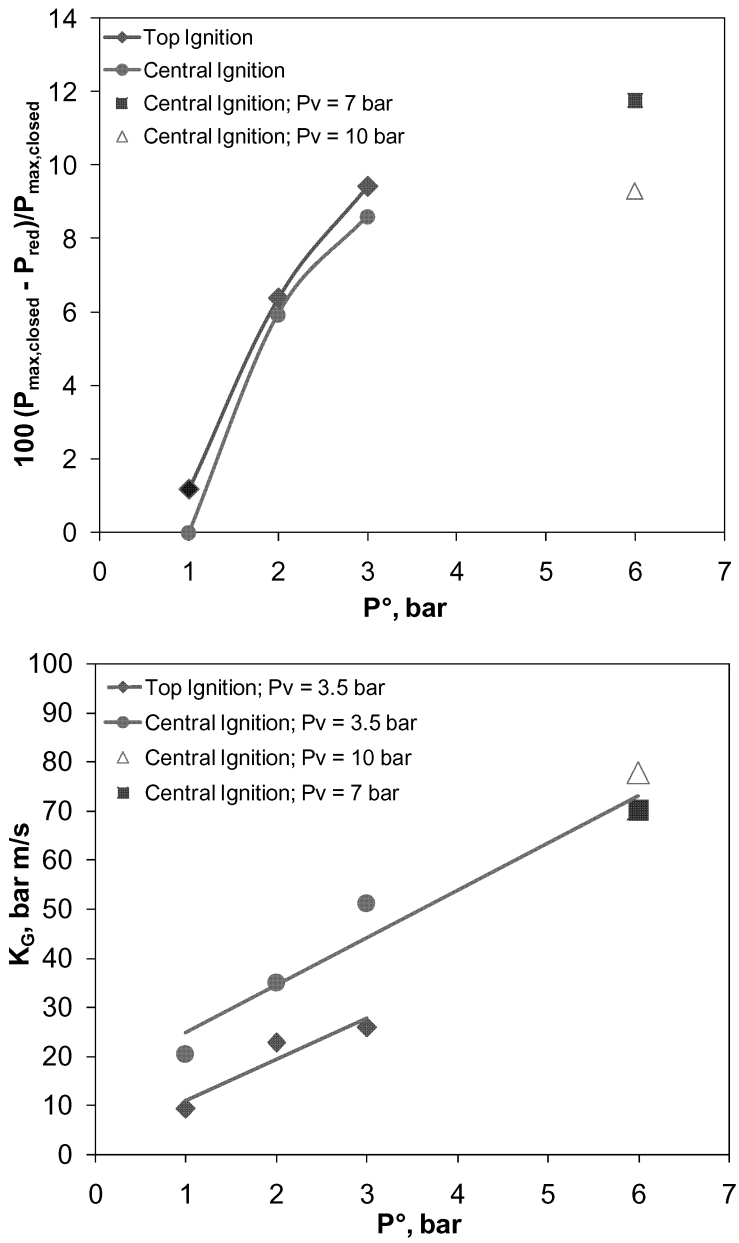

Figure 5. Vent effectiveness and K_g with respect to initial pressure P°, for central ignition (circle), and top ignition (diamonds), quiescent mixture.

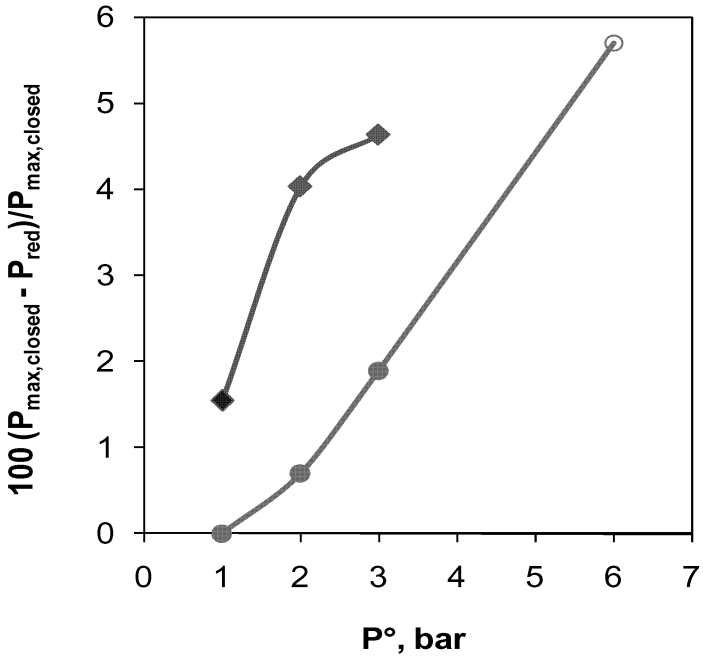

Figure 6. Vent effectiveness with respect to initial pressure, for central ignition (filled circle: P_v = 3.5 bar; empty circle: P_v = 7 bar), and top ignition (diamonds: P_v = 3.5 bar). Turbulent initial conditions: 480 r.p.m.

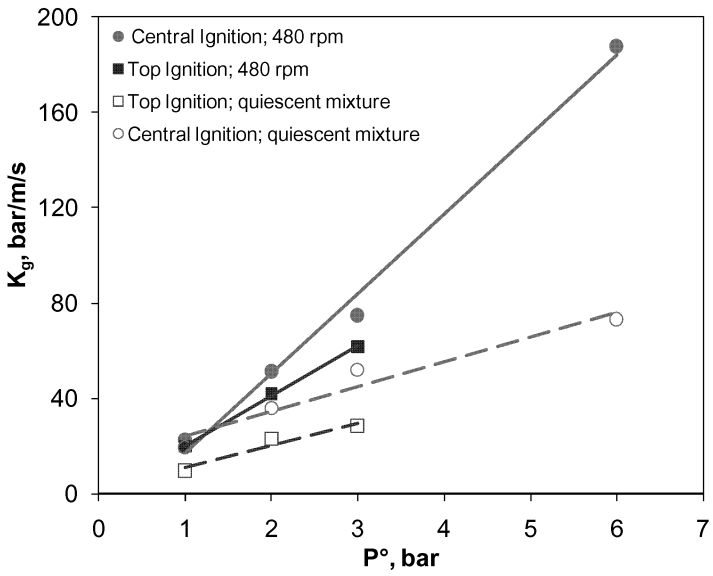

Figure 7. K_g with respect to initial pressure, for central ignition , and top ignition . P_v = 3.5 bar. For the P°= 6 bar tests, P_v = 7 bar (diamond) and P_v=10 bar (triangle).

These results show the inconsistency of venting correlation in real cases where complex geometry or objects are considered. Anyway, central ignition is still conservative with respect to top ignition in agreement with results for closed vessel. Indeed, the ignition point near the vent assures that hot combustion products can be vented out at an early phase of the explosion.

4. Conclusions

The experiments reported in this paper can address the development of engineering correlation for the correct design of vent for high strength enclosures.

5. Acknowledgments

The authors acknowledge the regional Center of Competence “Analisi e Monitoraggio del Rischio Ambientale” AMRA for financial support.

6. References

Molkov, V.V., 2001, Unified correlations for vent sizing of enclosures at atmospheric and elevated pressures, Journal of Loss Prevention in the Process Industries, 14, 567-574.

NFPA 68, Standard on Explosion Protection by Deflagration Venting, National Fire Protection Agency, 2007.