Mitigation of Explosions in a Vented Vessel Connected to a Duct

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The evacuation of gases released from the vessel during a vented explosion is a matter of great importance for the security of industrial plants. In many cases it would be desirable to conduct the gases away from the protected area using a duct added to the vent. Unfortunately, as experiments carried out during the last twenty years demonstrate, the presence of a duct to discharge the explosion products results in a considerable intensification of the combustion in the vessel, associated with an increase of overpressures by factor of 10 or more, when compared to those in a simply vented vessel. Furthermore, deflagration to detonation transitions are likely to occur over smaller distances than in the case of a duct alone.

This intensification of the combustion in the vessel is driven by an impulse generated during a burn-up in the initial part of the duct, shortly after the flame penetrates into it [1]. When relatively narrow ducts are used with a sharp vessel-duct area change, the flame front entering the duct can be temporarily extinguished due to stretch and cooling through turbulent mixing with unburned gas [1, 2], which brings about stronger burn-up (with higher pressure amplitudes) during reignition. However, the enhancement of the explosion overpressures in the vessel does not depend directly on the strength of the burn-up in the duct [1]. So, using a smooth, profiled vessel-duct passage or increasing duct/vessel diameter ratio may weaken (but not suppress) the burn-up without attenuating the pressure rise in the vessel. Obviously, the problem disappears when the total extinction of flame in the duct is obtained, for example by spraying water as demonstrated in [3].

In the present work a solution has been studied aiming not to completely extinguish the flame but rather to retard its propagation at the beginning of the duct and delay an eventual burn-up in order to sustain quiet evacuation of the gases from the vessel, with a smooth combustion inside. For this purpose, the above-mentioned tendency to temporary quenching, naturally present in the process, was reinforced by means of wire-net inserts (in form of scroll) placed at the entrance of the duct.

Several inserts of different length and number of rolls were tried out, all made of steel wire (0.5 mm diameter) with mesh 2.0 mm about. The experiments were performed in a steel, cylindrical vessel (length L_C = 0.4 m, diameter ϕ_C = 0.108 m), closed at one end and fitted at the other with a PVC transparent tube (ϕ_T = 36 mm, L_T = 1.6 m) or steel tube (ϕ_T = 53 mm, L_T = 1.5 m) simulating the uncovered vent and its discharge duct open to the atmosphere. The apparatus and technics were essentially those described in [1] but the flame propagation in the tube ϕ_T = 36 mm was recorded with a high framing rate video camera (Kodak Ektapro).

Figs. 1 and 2 present examples of, respectively, pressure histories in the vessel, and flame front movement in the duct, both obtained for the tube ϕ_T = 36 mm and propane-air stoichiometric mixture. Curve **a** correspond to the vessel alone, **b** – vessel + duct and **c1**, **c2, d** to the vessel + duct with different inserts. In Fig. 1 t_0 indicates the instant of flame entry into the duct for particular cases. As it can be seen, with an appropriate insert (**d**) the maximum overpressure was reduced by more than half and it was only 25% higher than the pressure losses (0.6 bar) in the duct without insert (**b**), measured at the instant t_0 i.e. before pressure amplification. At the same time, the average flame front speed in the last meter of the duct fell from 520 m/s to 250 m/s about (curves **b** and **d** in Fig. 2). In the case **d** the flame front was retarded by the insert for more than 8 ms (Fig. 2), while it took only 0.5 ms to run over an equivalent distance without insert (**b**). Camera recordings showed that, before passing definitely down the duct, the flame front stayed for about 4 ms in the insert (the end of the insert is marked in Fig. 2 by the horizontal line), then leaved it but was stopped few centimeters downstream, for another delay of 4 ms.

It was possible to extinguish completely the flame in the duct by using longer or/and more tightly packed inserts and accepting higher overpressures in the vessel. Such a case (**e**) is presented in Fig. 3 relative to the duct ϕ_T = 53 mm. The maximum overpressure on curve **e** is only 10% higher than that obtained with the best (among tested for this duct) insert **f**.

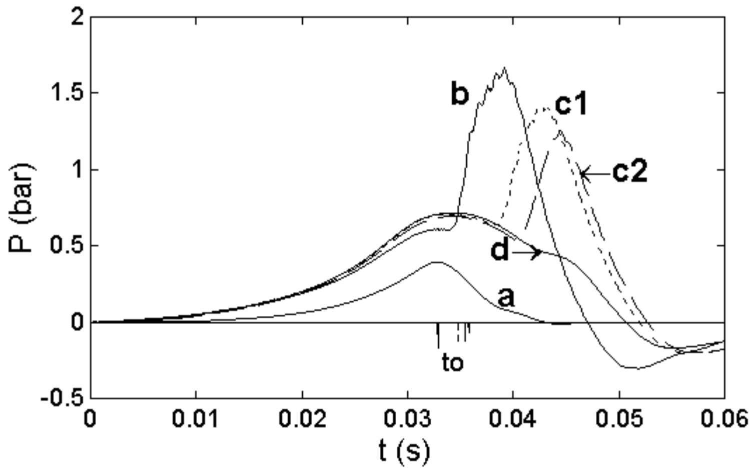

Fig. 1 Pressure variation in the vessel. Tube 36 mm. Propane-air.

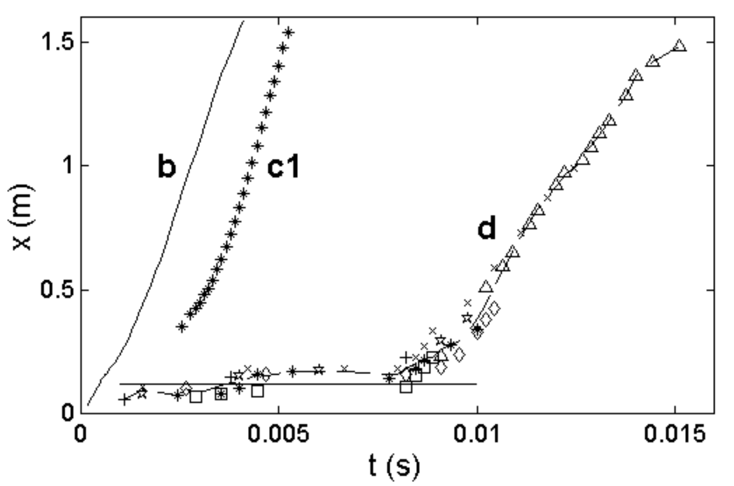

Fig. 2 Flame front movement in the duct. Tube 36 mm. Propane-air.

For correctly chosen wire-net inserts the maximum possible attenuation of pressure in the vessel is limited by pressure losses in the insert and the duct. Using shorter and less compact inserts may further reduce the pressure losses but it leads to development of a second pressure maximum as a consequence of intensification of the combustion in the vessel. This situation is shown in Fig. 3 for the insert **g**. (The gap between the rolls of this insert was 8 mm about). The second pressure maximum grows as the insert becomes shorter and the gap larger but there is always some flame front retardation which extends the phase of quiet evacuation from the vessel. In the performed experiments the maximum pressures obtained with the inserts never exceeded those without insert even if the flame speeds in the duct were sometimes comparable or slightly higher (see **c1** and **c2** in Fig. 1).

The wire-net inserts were also tested for the ethylene-air stoichiometric mixture and some results are shown in Fig. 4 (obtained for ϕ_T = 53 mm). As in other figures, **a** and **b** correspond respectively to the vessel alone and vessel+duct only, **h** and **i** to different inserts. The results prove that the mitigation effect is still present. The average flame speeds in the duct measured between x = 50 cm and x = 1 m were reduced from 400 m/s for **b** to 290 m/s (**h**) or 240 m/s (**i**), and those in the last 50 cm from 780 m/s (**b**) to 475 m/s (**h**) or 310 m/s (**i**).

Experiments are being prepared to verify the effect of scale.

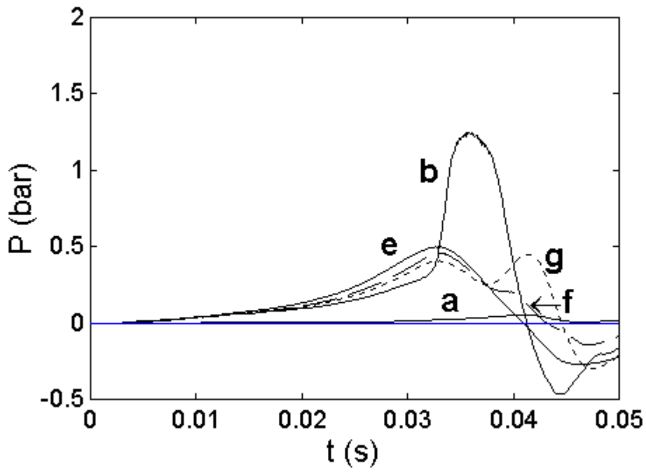

Fig. 3 Pressure variation in the vessel. Tube 53 mm. Propane-air.

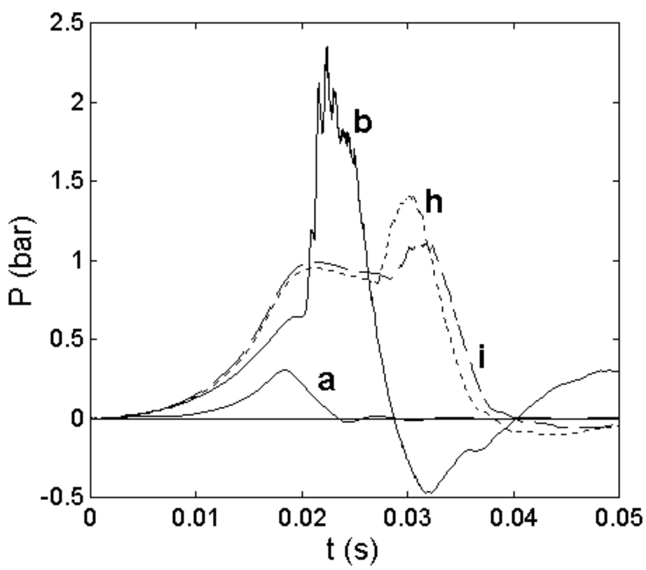

Fig. 4 Pressure variation in the vessel. Tube 53 mm. Ethylene-air.

References :

[1] B. Ponizy, and J. C. Leyer, Combust. Flame, 116: 259-271 and 272-281, 1999.
[2] N. Iida, O. Kawaguchi, and G. T. Sato, Combust. Flame, 60: 245-255 and 257-267, 1985.
[3] V. V. Molkov, V. P. Nekrasov, A. N. Baratov, and S. A. Lesnyak, Fiz. Goreniya Vzryva 20: 28-33, 1984.