Control of Flame Transmission from a Vessel to a Discharge Duct

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Introduction

Premixed gaseous flames propagating from a vented vessel into a duct has received great attention since the beginning of the 1980s. Several studies ([1], [2], [3] and [4]) have demonstrated that the addition of a duct to the vessel to discharge the explosion products promotes a secondary explosion at the initial part of the duct, associated with a forward and backward propagating impulse, which perturbs evacuation of the gases from the vessel, intensifies the combustion process inside the vessel, and consequently enhances the explosion overpressures.

A solution allowing quiet evacuation of the explosion gases from the vessel has been studied by Ponizy and Veyssière [5]. It consists in placing a wire-net insert at the duct entrance in order to delay flame penetration into the duct and prevent the occurrence of the burn-up. The results have demonstrated that with correctly chosen inserts the maximum vessel overpressures as well as the flame speed in the duct can be reduced approximately by half. For longer or/and more tightly rolled inserts it was possible to obtain total extinction of the flame in the duct, with only slightly higher vessel pressures. Unfortunately, detailed processes which occur in this mitigation are not fully understood and prediction of the flame behavior as function of insert characteristics is still impossible.

The aim of the present work is to carry out experiments in order to get a better understanding of the phenomenon (especially by observing the propagation of the flame within both the vessel and the duct) and to collect data necessary to develop a numerical model. The insert is supposed to influence the behavior of the flame in two different ways :

(i)   it absorbs the heat from hot gases and decreases their temperature.
(ii)   it turbulizes the flow and accelerates mixing of hot reacting gases with cold unburned ones.

In the model we focus on the first effect, considering the insert as a heat exchanger.

Experimental

The experiments were performed in a cylindrical plexiglas transparent vessel (length L_V = 0.385 m, inner diameter $\emptyset_V$ = 0.1 m), closed at one end and fitted at the other with a PVC transparent tube (L_D = 1.6 m, $\emptyset_D$ = 0.036 m) simulating the uncovered vent and its discharge duct open to the atmosphere. Ignition was achieved by a small electrically heated wire, placed on the axis near the closed end of the vessel. Instants of the flame front birth and flame arrival at the tube entrance were monitored by ionization gauges. The flame propagation from the vessel into the tube was recorded with a high framing rate video camera (Kodak HS 4540). All the experiments were performed with a stoichiometric propane-air pre-mixture at initial atmospheric temperature and pressure.

Inserts were made of steel or brass wire (0.5 mm diameter), with mesh 2.0 mm about, and characterized by their total surface S of wire-net (length [cm] x number of rolls [rs]). They were located at the beginning of the tube, just after the vessel-duct area change.

Results and discussion

Typical sequences of flame propagation are shown in the case without insert (Fig. 1a) and with insert (Fig. 1b).
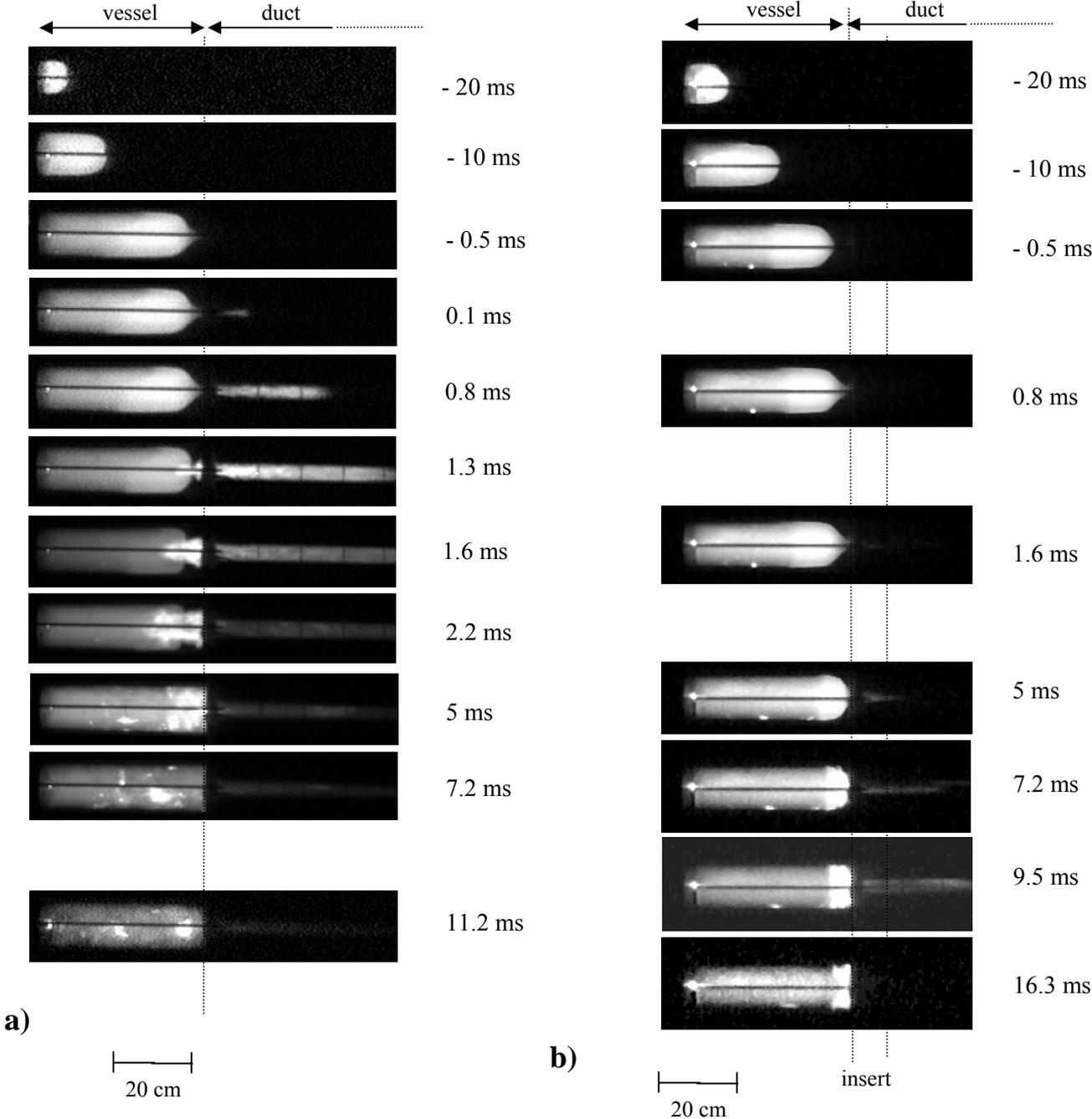
Fig. 1 : Selected frames from camera records showing flame propagation in the vessel and along the duct : **a**, without insert, 18000 fr/s; **b**, with insert 9 cm x 3 rs (S=157 cm²), 4500 fr/s.

In Fig. 1a, after a period of quiet evacuation of unburned gases into the duct, the laminar quasi-hemispherical front flame is stretched while approaching to the region of vessel-duct area change, carried away by cold gases. When the front flame penetrates into the duct (t = 0 ms), some pockets of unburned gases are "trapped" in corners of the vessel, near the duct entrance. In the duct, the secondary explosion (described in [4]) occurs and leads to a backward flow of burned gases into the vessel. At this moment (t = 1.2 ms about), the pressure in the vessel starts to increase rapidly, see curve **a** in Fig. 2. It is clear from Fig. 1a that this second pressure rise results from accelerated combustion of the gases in the pockets, turbulized by the backward flow mentioned above. One notices that the pressure reaches its maximum when all the cold trapped gases have been burned (t ≈ 5 ms).

When the insert is placed at the duct entrance, the flame penetrating into the duct is weakened and slowed down in the insert. In the experiment presented in Fig. 1b, the flame passes through the insert after 5 ms about but without any secondary explosion (curve **b** in Fig. 2). The images in Fig. 1b confirm that no backflow of hot gases enters in the vessel, and so the cold gas trapped in the corners burn out quietly in a quasi-laminar flame.
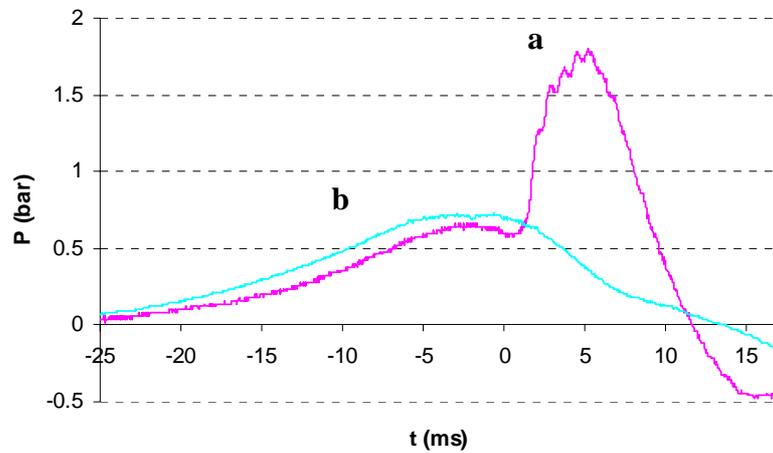

Fig. 2 : Pressure variations in vessel : **a**, vessel and duct without insert; **b**, with insert 9 cm x 3 rs (S=157 cm²)

Numerical model

As mentioned in the introduction, the aim of the modeling was to evaluate the magnitude of thermal losses encountered by the flame when passing through the insert. For this purpose, only the mechanism mentioned in (i) is considered in the model, i.e. the insert is treated merely as a heat absorber.

The numerical model is based on the "nodal method". The principle consists in creating elementary volumes, called nodes, connected by conductances which represent the exchanges of energy (by conduction, convection, or radiation). The boundary conditions (temperature, mass flow and flame velocity) at the duct entrance were evaluated from experimental data. The simulation program ESACAP was used to solve the equations of the problem.

The effect of the heat transfer coefficient h was first studied in a parametrical way.

Figs. 3 and 4 present the gas temperature distribution inside the insert 9 cm x 3 rs, at the moment when the flame reaches the end of the insert.
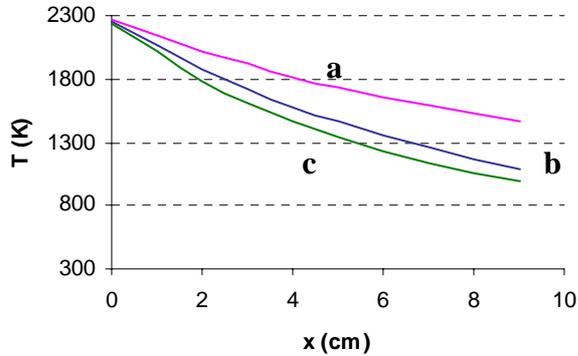

Fig. 3 : Calculated gas temperature distribution along the axis of the insert : **a**, with h = 200 W/(m².K); **b**, with h = 500 W/(m².K); **c**, with h calculated according to the insert geometry (rolled or longitudinal wires)
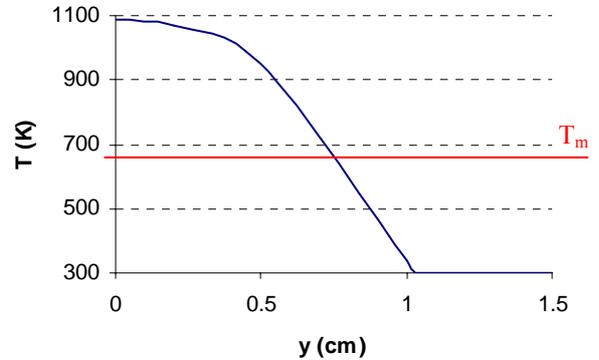
Fig. 4 : Calculated radial profile of gas temperature at the exit of the insert, with h = 500 W/(m².K). T_m – average calculated temperature

In Fig. 3, one can see that for h = 200 W/(m².K) the temperature of gases along the axis decreases from 2300 K to 1450 K during the propagation throughout the insert (curve **a**). Increasing h up to 500 W/(m².K) results in a drop of gas temperature through the insert down to 1100 K (curve **b**). Consequently it proves the importance of thermal losses generated by this type of insert, but also the importance of correct choice of the heat transfer coefficient h. Fig. 4 presents the radial profile of gas temperature at the exit of the insert.

These first results indicate that more precise estimation of h is necessary. This improvement have been achieved by taking into account the particular topology of the insert. It was considered as an assembly of longitudinal and transversal wires, which leads to more realistic heat exchange with the gas flow. It appears that the effective value of h results in values of gas temperature (curve **c**) even smaller than in case **b**.

As mentioned above, the mixing process was not considered in the model. However, in order to evaluate the possibility of flame extinction in the insert, it has been introduced artificially by calculating an average gas temperature T_m at the insert exit (cf. Fig. 4). This temperature can be compared to the ignition temperature of the propane-air stoichiometric mixture, T_{ig} (close to 800 K, see [6]). Thus, during the venting explosion, if T_m is higher than T_{ig}, one can conclude that the flame passes through the insert, and so the downstream mixture will be ignited. At the opposite, if T_m decreases under T_{ig}, the flame may be extinguished in the insert (or several centimeters later), but not necessarily.

These preliminary results of the simulations are quite consistent with experiments, even if assumptions concerning several parameters (heat transfer coefficient, flame speed at the duct entrance) are rather simplified. This aspect should recquire particular attention to improve future calculations.

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References

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