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Propagation of a confined explosion to an external cloud

Daubech Jérôme [a, *], Proust Christophe [a, b], Lecocq Guillaume [a]

[a] Institut de l'environnement industriel et des risques, INERIS, Verneuil en Halatte, France
[b] Sorbonne Universities, Technological Univ. Of Compiègne, ESCOM, TIMR, Compiègne, France

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ABSTRACT

Since the pioneering work of Harrison and Eyre (*1986*), the existence of secondary or external explosion outside explosion vents is recognized and rather systematic. This explosion can be much more powerful (*Proust, 2004, 2010*) than the internal explosion particularly when the mixture is very reactive. But today, the understanding of the formation of the external cloud and its subsequent combustion remains largely outstanding. Very rapid burning was noticed and significant UVCE pressure effects. In some circumstances, a preexisting flammable cloud encompasses the vented vessel, like in Buncefield for instance. This paper presents experimental work and CFD simulations (OpenFoam) which investigate the aerodynamics of the flow and the flame propagation. The experimental device is composed of a 4 m^3 chamber linked to an unconfined 54 m^3 volume via a square vent. These two volumes are filled with a stiochiometric propane air mixture and ignited by a pyrotechnical match in the 4 m^3 chamber. When the vent area is small enough, the vortex bubble formed by the gas ejection is disrupted and a jet is formed entraining a significant portion of the outside atmosphere. The explosion overpressure outside can be 10 time larger as compared to the fully unconfined case (no chamber).

1. Introduction

The Buncefield accident occurred on 11th December 2005 at 6h30 inside an oil depot. 1800 tons of gasoline cascaded down the side of the tank inside the bund (5000 m^3) due to the tank overfilling. A few meters thick vapour cloud was formed and spread far away from the tank covering a zone of 120 000 m^2. The cloud was most probably ignited in the pump house, resembling a sort of concrete bunker (Buncefield investigation report, 2008).

From the damage, overpressures on the order of 1 bar should have occurred inside the cloud and window were broken up to 1.5 km from the pump house.

An important research program was launched in order to explain the damage and trace back the scenario and the phenomenology. The investigation of the acceleration of the flame by obstacles (trees) was favoured in this program but other potential mechanisms were proposed but not analyzed deeply. One of them is “the confined ignition” of the cloud inside the pump house and the transmission to the outside via some external explosion mechanism.

Apart from this specific context, the situation depicted above is quite common in the industry and there is not much information available to take it into account within the frame of safety studies.

When a gas explosion is triggered inside a vessel provided with an opening, most of the flammable cloud is expelled outside. A “bubble” of flammable cloud is formed on the axis of the vent and explodes violently when the flame penetrates this bubble. This phenomenon is called external deflagration or secondary explosion.

This was identified when designing venting methods for buildings (Cooper et al., 1986; Harrison et al., 1987; Proust and Leprette, 2010). Past experiments (Maxworthy, 1972, 1977) show that this phenomenon is almost systematic. The external explosion dominates the pressure dynamics if the vent area represents at least 20% of the inner surface of the vessel (Proust and Leprette, 2010). At least for compact vessels, the expelled cloud has all the characteristics of a “vortex bubble” as described by Maxworthy (Fig. 1). The vortex ring peripheral velocity and the bubble average propagation velocity are on the same order of magnitude than that of gas velocity at the vent exit.

These experiments also show that the external explosion occurs when the vortex ring burns. The expansion velocity of the “fireball” seems to depend more on the propagation velocity of bubble than on the reactivity of the mixture. Nevertheless, the details of the

* Corresponding author.
E-mail address: jerome.daubech@ineris.fr (D. Jérôme).

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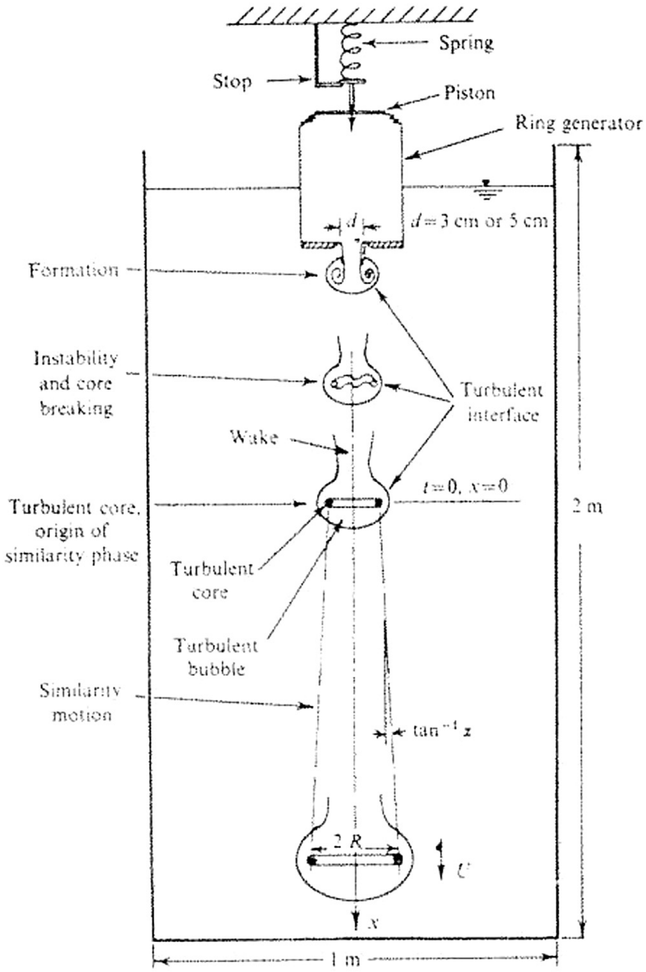

Fig. 1. Eddy bubble (Maxworthy, 1972, 1977).

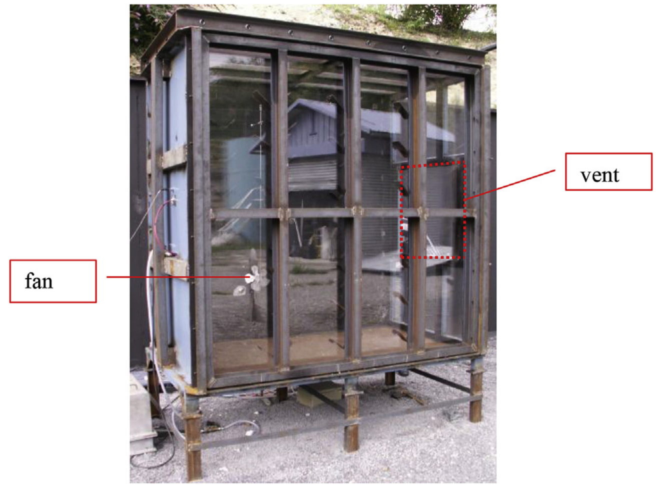

Fig. 2. The 4 m^3 chamber (2 m high, 2 m high, 1 m deep).

Fig. 3. 54 m^3 volume.

explosion mechanisms are not well known and the available data are not sufficient. They do not in particular provide means to answer the question raised.

In this paper the results of a research program are presented. Not only the flame propagation mechanism was investigated but also some numerical simulations were performed to help analyzing the data and proposing a modeling strategy for safety engineering.

2. Testing

2.1. Setup

The experimental set-up is composed a 4 m^3 explosion chamber connected to a 54 m^3 unconfined volume (Fig. 3) via a square vent. Both volumes are filled with a stoichiometric propane-air mixture. The 54 m^3 volume is approximately a 3 m × 3 m x 6 m steel frame built against a concrete wall and covered with a thin transparent plastic sheet to maintain the flammable cloud.

The explosion chamber (Fig. 2) is 2 m long, 2 m high and 1 m deep, representing an inner volume of 4 m^3. Only one central vent area was arranged on one small side (1 m × 2 m). Three sides are provided with large transparent plates (2 cm PPMA for the front side, the top, the small side containing the vent). The combustible gas is injected directly from compressed commercial bottles in the lower part of the chamber and mixed by an electrically driven fan (the fan is stopped well before ignition so that the mixture is quiescent). A similar technique is used for the 54 m^3 volume. The concentration distribution is controlled using 6 oxygen analyzers sampling the atmosphere. Three are located at the bottom, in the middle and near the top of the chamber on the opposite wall of transparent side. Three are installed on mast located on a diagonal of the volume, starting from the top left corner at the bottom right corner. To ease the observation of the vortex bubble, the mixture in the chamber is seeded with microparticles of ammonium chloride during the preparation of the mixture. Ignition is achieved using an electrical spark (10 mJ) or a pyrotechnical match (60 J). Six piezoresistive gauges (KISTLER 0–10 bar accuracy ± 0.1%) are used to measure the pressure evolution inside and outside. Further the formation of the cloud in front of the vent and the propagation of the flame are filmed using a high speed video system (PHOTRON Fastcam). The vent area is covered with a very thin plastic sheet held with magnetic tapes.

Two pressure sensors are installed inside the 4 m^3 chamber (Fig. 4): one near the ignition point and the other in the middle of the back large side. Three additional gauges are installed on profiles supports outside the explosion chamber: one on the axis of the vent at 3 m distance (so inside the 54 m^3 volume) and the two others perpendicular to the vent axis at 5 m and 10 m from the first one.

Two (square) vent sizes were studied, 0.5 m^2 (0.7 m × 0.7 m) and 0.04 m^2 (0.2 m × 0.2 m).

Six tests were performed (Table 1): five with propane-air mixtures and an additional one with a lean hydrogen-air mixture having the same burning velocity that the stoichiometric propane air mixture.

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