Flame Acceleration in Vented Explosion Tube

A. Veser[1], J. Grune[1], G. Stern[1], W. Breitung[2], S. Dorofeev[2]

[1] ProScience GmbH, Parkstr. 9, 76275 Ettlingen, Germany

[2] Forschungszentrum Karlsruhe, P.O. Box 3640, 76021 Karlsruhe, Gemany

email: dorofeev@iket.fzk.de

Key words: flame acceleration, DDT, gaseous explosions, venting

Introduction

When a combustible mixture is formed and ignited during an accident, the consequences strongly depend on the ability of the flame to accelerate, resulting in supersonic deflagrations and detonations. Many practical cases involve accidental releases of flammable gases into a partially vented, partially confined geometry. These cases are relatively less understood compared to combustion events in a confined geometry, where flame acceleration (FA) and deflagration-to-detonation transition (DDT) were studied extensively (see, e.g. [1-4]). Studies of gaseous explosions in vented tubes can be considered as a bridge between cases of explosions in closed tubes and cases of unconfined explosions in congested areas. The critical conditions for FA and DDT in tubes with lateral venting were investigated in the recent study by Alekseev, et al. [5]. The present work is a continuation of the study [5]. It is focused on the effects of vent geometry and fuel type (H_2, CH_4, C_3H_8) on FA and DDT in a vented tube surrounded by either air or combustible mixture.

Experimental

Two different types of experiments were made. In the first one, flame propagation was studied in a vented tube surrounded by air (Configuration 1, Fig. 1). In the second one the same tube was surrounded by a combustible gas (Configuration 2, Fig. 2). The explosion tube was 4.6 m long with an internal tube diameter of 0.1 m and with a blockage ratio (BR) of the orifice plates of 0.6. The venting was provided by a set of rectangular orifices in the cylindrical surface of the tube. These orifices were partially closed by rotating brackets fixed on the outer surface of the tube. The angle of rotation was varied from 0° (closed tube) to 40° (the ratio of the vent area to the total area of cylindrical surface, $\alpha = 0.43$). The venting was arranged in two different ways: either all brackets were opened by the same angle (vent 1), or every second orifice along the tube was closed (vent 2). In Configuration 2 the vented tube was placed into a thin plastic bag filled with the same combustible mixture as inside the tube. Hydrogen-air, methane-air, and propane-air mixtures were used in the test. A weak electrical spark was used to ignite the mixtures at one end of the tube. Fast response piezoelectric pressure transducers and photodiodes were used to measure pressure and flame time-of-arrival.

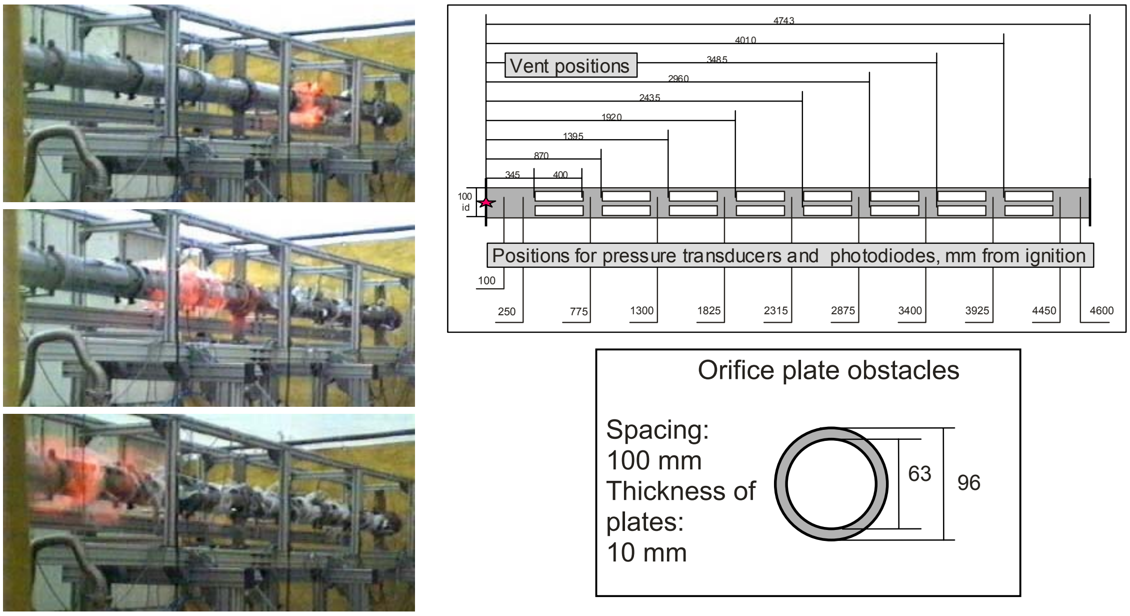

Figure 1: Experimental set-up in Configuration 1.

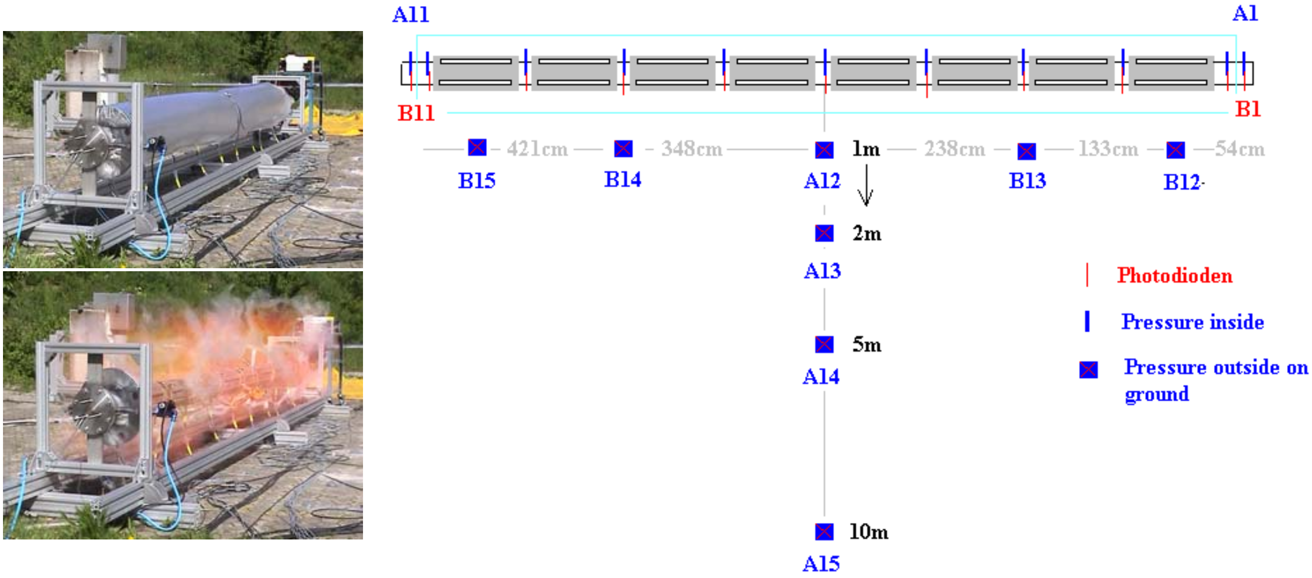

Figure 2: Experimental set-up in Configuration 2

Summary of Results

Four typical flame propagation regimes were observed in the tests (see left graph of Fig. 3 as an example). The first one is essentially subsonic. In the second regime the flame propagates at a speed that is slightly higher than the sound speed in reactants. If the venting is relatively small compared to the blockage provided by the orifice plates, the flame can propagate at a speed close to the sound speed in the products, or transition to detonation can be observed. The possibility for a fast flame to propagate in a vented tube with two characteristic values of the flame speed (in addition to quasi-detonations) is a new feature revealed in the present tests. This effect was not observed in [5], where relatively large vent ratios were used.

While fast supersonic regimes were observed for a range of the vent ratios in hydrogen mixtures, flames in methane and propane mixtures were very sensitive to the vent ratio. A very small venting with the vent ratio of about 0.025 was sufficient to suppress supersonic flame propagation in methane and propane mixtures. This is illustrated by the right part of Fig. 3.

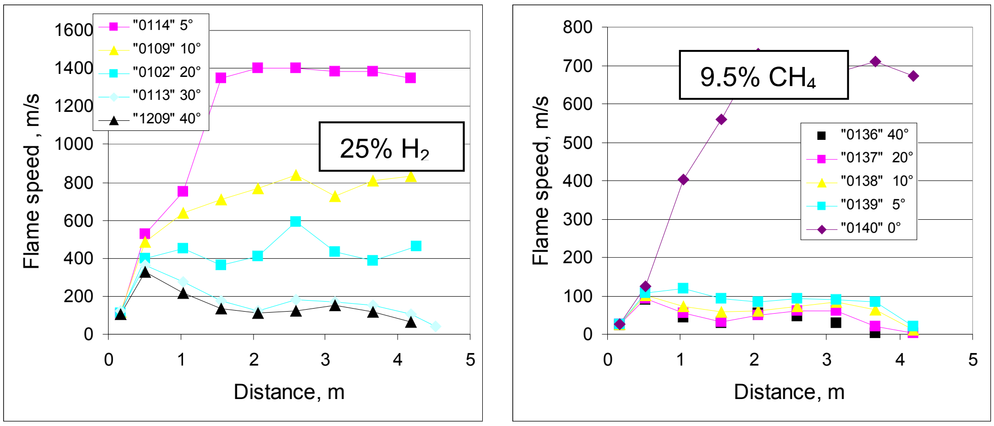

Figure 3: Flame speeds versus distance for different venting degrees.

It has been shown (see, e. g., [3, 4]) that the ratio of densities of reactants and products (expansion ratio, σ) should exceed a certain minimum critical value of σ^* in order for a flame to accelerate to supersonic regimes in closed tubes with obstacles. In the case of tubes with venting, the critical value σ^* was shown to increase proportionally with the vent ratio [5]. The results of the present tests show a similar effect (see Fig.4). It was also found that the geometry of the vents had an effect on the critical conditions for the development of supersonic flames. In the case of continuous lateral venting along the tube (vent 1) the critical value of σ^* was found to be high compared to the case when the vent orifices was separated by portions of the closed tube (vent 2 and results of [5]).

Tests in Configuration 2 showed that the flame propagation regimes were, in most cases, the same for the tube surrounded by air and by combustible gas. However under certain conditions the presence of the combustible mixture outside the vented tube resulted in a stronger combustion regime, compared to the venting into air. Figure 5 shows an example of DDT observed in the test with balloon, while there was no DDT in similar cases without balloon. The pressure measurements outside the tube showed, as expected, much stronger air blast waves in Configuration 2 compared to those in Configuration 1.

Acknowledgement

This work was performed within a framework of the EC project EIHP-II.

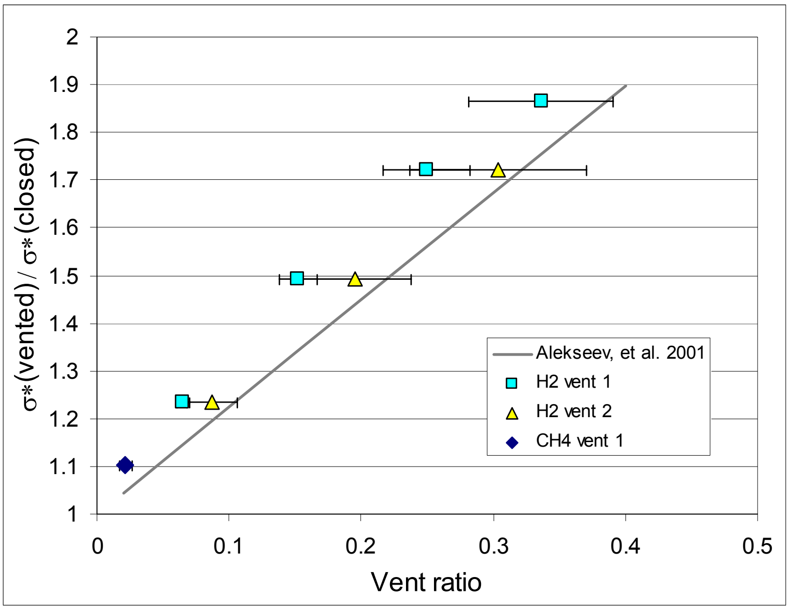

Figure 4. Ratio of the critical expansion ratios in vented and closed tube versus vent ratio.

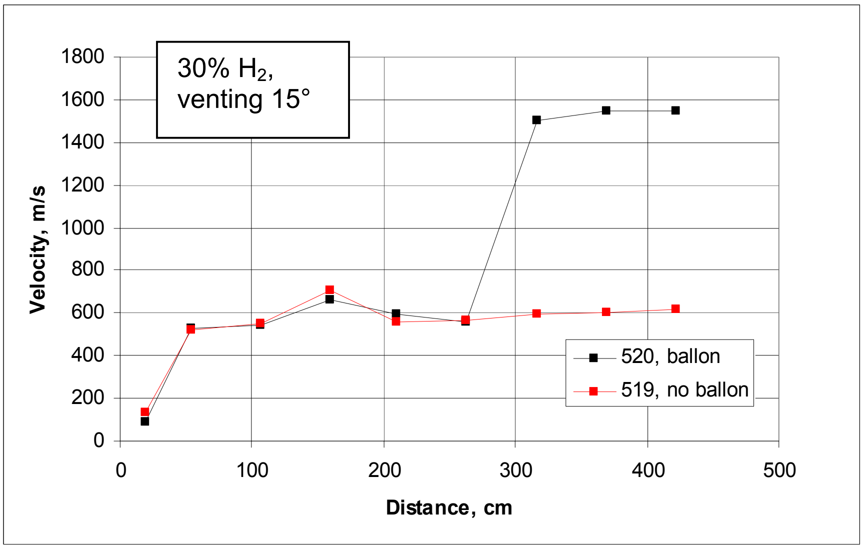

Figure 5: Flame speed inside the tube versus distance

References

1. Lee, J.H., Knystautas, R., & Chan, C.K. (1984), *20th Symposium (Int.) on Combustion*, The Combustion Institute, Pittsburgh, PA, 1663-1672
2. Peraldi, O., Knystautas, R., & Lee, J.H. (1986), *21st Symposium (Int.) on Combustion*. The Combustion Institute, Pittsburgh, 1629-1637.
3. S. B. Dorofeev, M. S. Kuznetsov, V. I. Alekseev, A.A. Efimenko, and W. Breitung, *Journal of Loss Prevention in the Processes Industries*, 2001, Vol. 14/6 pp 583-589
4. M. Kuznetsov, V. Alekseev, Yu. Yankin, S. Dorofeev, *Combustion Science and Technology*, 2002, Vol. 174 (5-6) pp 157-172
5. V. I. Alekseev M. S. Kuznetsov, Yu. G. Yankin, and S. B. Dorofeev, *Journal of Loss Prevention in the Processes Industries*, 2001, Vol. 14/6 pp 591-596