Acceleration of Unconfined Flames in Congested Areas

J. Grune[1], A. Veser[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 propagation, flame acceleration, DDT, unconfined gaseous explosions

Introduction

It is well known that obstructions along the path of a flame play a key role defining the rate of the flame acceleration (FA) and sometimes the possibility for a significant FA per se. Unconfined flames are especially sensitive to obstructions, because without confinement and obstacles there are no powerful physical mechanisms that can provide comparable growth of the flame surface and the turbulence ahead of the flame. The density of obstacles and a characteristic size of the obstacles can influence the processes of FA. It is therefore important to better understand the role of obstacles on acceleration of unconfined flames. In the present paper we present results of experiments on propagation of unconfined flames in a system of grids with variable density and grid sizes. Grids with characteristic sizes, which are much greater than the laminar flame thickness, were used in the tests.

Recently the effect of obstacle geometry on FA in tubes was studied [1]. The problem addressed in [1] was the minimum run-up distance necessary for development of supersonic flames. It was found that in channel geometry with dense obstructions, with blockage ratios from 0.3 to 0.75, the geometrical factor (increase of the flame surface) is the leading factor responsible for the flame acceleration. On this basis a simple model was suggested that describes evolution of the visible flame speed in a channel with obstacles. In the present study similar approach for description of the flame speed evolution is tested for the case of unconfined flames propagating through dense grids.

Experimental

Experiments were performed using a cubical volume (cube side of 0.55 m) of stoichiometric hydrogen-air mixture enclosed in a thin plastic film. The cube was placed on the ground in a test site. A weak electrical spark was used to ignite the mixture in the centre of the cube. The internal volume of the cube was filled with a system of grids as shown in Fig. 1. The number of the grid layers and the size of the grid were varied in the tests. The grids were made of steel wires of 4 mm, 1 mm, and 0.65 mm fixed to form rectangular cells with cell sizes, dx, equal to 40 mm, 13 mm, and 6.5 mm correspondingly. All experiments were made at normal initial conditions (T = 20°C, p = 1 atm). Collimated photodiodes were used to determine the arrival times of the flame as a function of distance from the ignition point inside the cube. Fast response piezoelectric pressure transducers were used to measure overpressures an impulses in the air blast wave outside the cube.

Figure 1: Assembly of the cube. System of grids 40 x 4 mm with 4 layers (left) and 12 layers (right)

Summary of Results

Figure 2 summarises the measured flame speed versus distance in the cube for different grids and number of the grid layers. The flame speeds were found to increase with the number of grid layers. Generally, but less evident, the flame speeds also increase with the decrease of the grid size.

In the case of the finest grid with 48 layers the flame speed inside the cube reached the value of about 700 m/s as recorded by photodiodes. It is remarkable that the flame was able to accelerate from the laminar speed to 700 m/s after propagating just about 0.2 m. Moreover, flame evolution in this particular test resulted in the transition to detonation. Transition to detonation occurred outside the initial volume of the cube. During the subsonic stage of flame propagation some portion of the mixture was pushed out of the cube due to the expansion of the combustion products. This mixture portion appeared to lie in between the grids and the plastic bag. A detonation was formed in this outer layer of the mixture. The occurrence of the detonation was confirmed by the fine strips of the plastic bag and by the pressure records outside the cube.

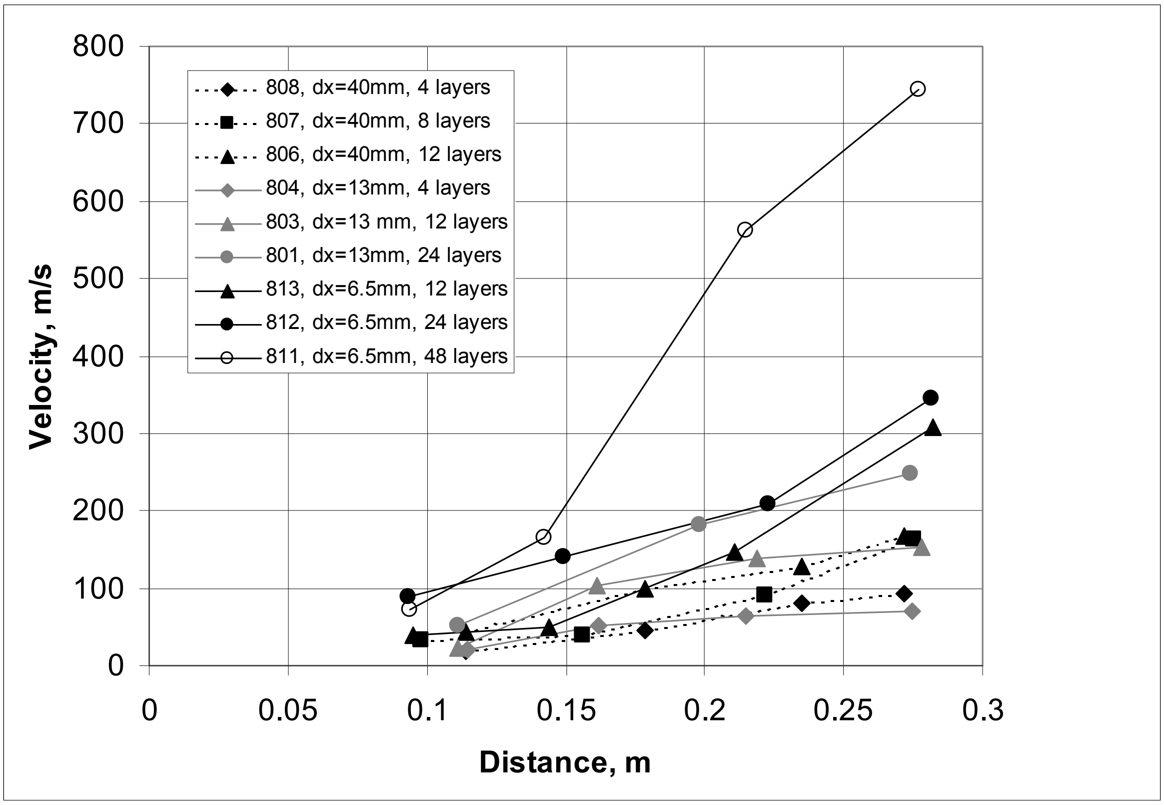

Figure 2. Flame speeds versus distance in the cube for different grids and number of layers.

The approach to evaluate the flame speed increase with distance through the increase of the flame surface was tested using the present data. To derive a simple analytical description of the flame speed evolution, it was assumed that the flame surface increases as a result of flame propagation through each grid layer. The ratio of the flame surfaces between two grid layers separated by a distance Δ was assumed to be proportional to the ratio of the area of the grid cell, and the surface area of a flame pyramid based on the grid cell and of the height equal to Δ. The visible speed of the leading flame edges, V, after passing through n grid layers, should be proportional to the effective turbulent burning velocity in respect to unburned gas, S_T, mixture expansion ratio, σ, and the flame surface. This yields in the following approximate expression:

$$V = k\sigma S_T \left(1 + \frac{(n-1)n(2n-1)}{6}\frac{\Delta^2}{\delta^2}\right)^{1/2} = k\sigma S_T X', \qquad (1)$$

where k is a constant and $\delta = dx/2$ is the half of the grid cell size. To test this model, the experimental values of the flame speeds were plotted against dimensional distance X'.

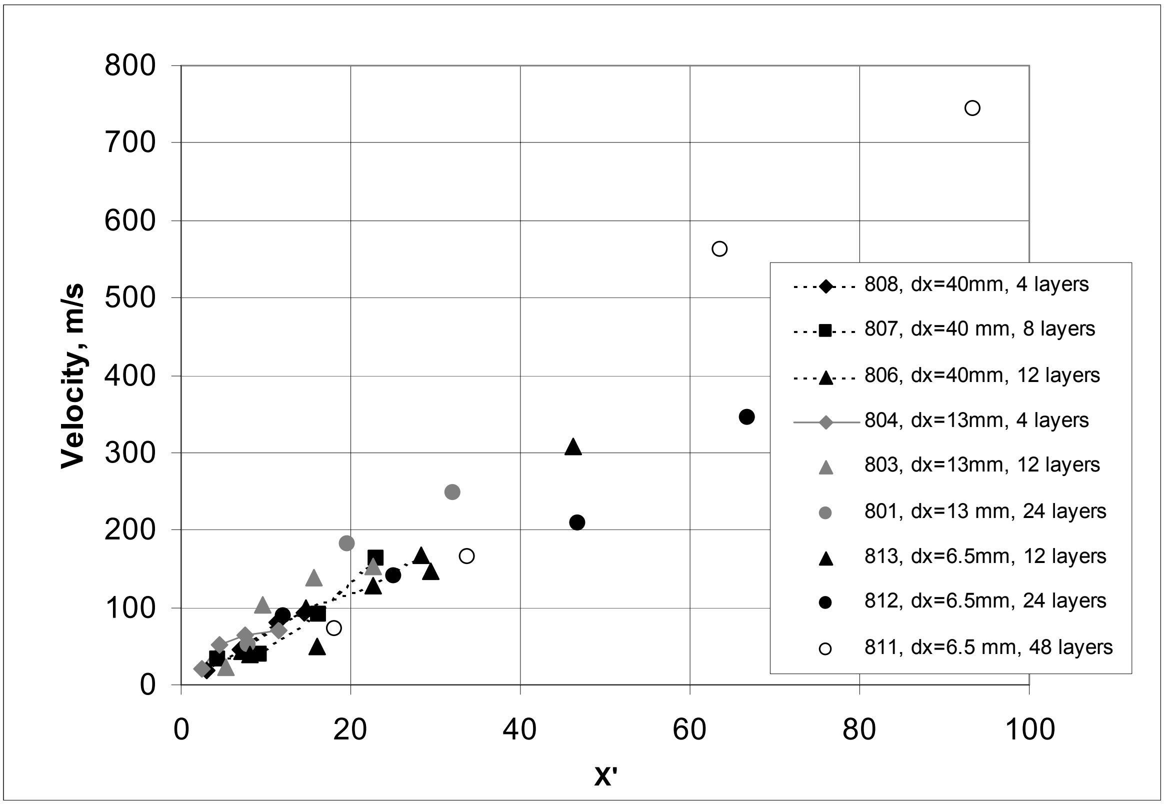

Figure 3: Flame speed versus dimensionless distance X'

Such a plot is presented in Fig. 3. It is seen that a linear dependence of the flame speed with *X'* is observed. This means that the increase of the flame surface pays a role of the leading factor responsible for FA in the present tests. The value of S_T should generally increase with turbulence generated by grids, but it easily reaches its maximum saturation value (an order of magnitude higher than laminar burning velocity) in the system with dense obstructions. After that S_T can be considered to be nearly constant and further flame acceleration should mainly be result of the flame surface growth.

The data compression compared to Fig. 2 is rather good with a scatter of about ± 20%. Supersonic and nearly sonic flame speeds are in line with the general tendency in Fig. 3, although compressibility was not accounted for in the model. Generally, such a simple model gives rather good description of the experimental results presented here. It may be suggested that the approach to evaluate the flame speed increase with distance through the increase of the flame surface can be useful in a number of situations where the flame propagates through areas with dense obstructions. At the same time this cannot be used as a general description for a wide variety of FA processes.

Reference

1. A. Veser, W. Breitung, S. B. Dorofeev, Run-up distances to supersonic flames in obstacle-laden tubes, *J. Phys. IV France*, Vol. 12, No 7, pp. 333-340, 2002