Concentration Limits of Detonation Re-Initiation behind a Multi-Orifice Plate

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1 Introduction

Detonation wave in homogeneous gaseous mixture propagating in a tube can be quenched by the multi-orifice plate [1, 2]. The conditions of re-initiation after detonation failure depend on the plate characteristics and mixture sensitivity. Multi-orifice plate is characterized by the parameter referred to as the open area ratio *OAR* ($OAR=Nd^2/D^2$, where *N* and *d* are the number and diameter of the holes, and *D* is the diameter of the tube). The detonation cell size λ is usually used as a measure of the mixture sensitivity. The cell size of gaseous fuel-air mixture depends not only on fuel concentration, but also on initial pressure and temperature, the cell size being smaller with pressure or temperature growth. The concentration limits of gaseous detonation re-initiation depend on the diameter of the holes at constant *OAR* and fixed initial pressure of hydrogen-air mixture as it was shown in [3]. The process of detonation initiation investigated in [3] is similar to the direct initiation of detonation because a thin membrane was placed ahead of the multi-orifice plate from the side of a driver section. The present paper reports the results of experiments performed in hydrogen-air mixtures to investigate the re-initiation of detonation after its interaction with multi-orifice plates with a different *OAR* and under variable initial pressures.

2 Experimental Details

The experiments were carried out in two detonation tubes of 106 mm and 141 mm inner diameters divided into two sections. In the first section, a steady self-sustained detonation is initiated and propagates toward the tube end, where it interacts with multi-orifice plates with different open area ratios *OAR*. In the first section of the 106-mm tube initiation is achieved with the help of a booster disposed at the tube entrance, in which a stoichiometric ethylene oxygen mixture is detonated. To initiate the detonation in the 141-mm tube an exploding wire for ignition and equidistantly placed rings were used. The detonation re-initiation is observed in the second section (test section) beyond the multi-orifice plate. This section in the 106-mm tube is equipped with piezo-electric pressure gauges and a semi-cylindrical smoked plate for recording soot trackings of the detonation cellular structure.

The length of the smoked plate is about 10 diameters of the tube. The equipment of the second section of the 141-mm tube consists of piezo-electric pressure gauges and ionization probes. Three multi-orifice plates with constant diameter of the holes (*d*=6) mm and different *OAR* values (0.42, 0.44 and 0.46) were used.

Different hydrogen-air mixtures were prepared by partial pressure technique in a separate vessel (mixer), where the mixing time was at least 24 h. The tube was initially evacuated to get vacuum (approximately 1 to 3 mbar) and then it was filled from the mixer. The same mixture filled both sections of the tubes in all the experiments.

Evidence of re-initiation of the detonation in the 106-mm tube is obtained from soot tracks records. The values of cell sizes were compared with Detonation Data Base [4] values or with the calculated ones by the model of [5]. In the case of the 141-mm tube the measured shock wave velocity was compared with the calculated detonation velocity.

3 Results and Discussion

Figure 1 represents the concentration limits of the detonation re-initiation. This figure compiles the results of experiments in the 106-mm and 141-mm tubes at different initial pressures and values of *OAR*. These diagrams give clear evidence on the substantial increase of the limiting concentration of hydrogen with increasing value of *OAR*. This figure also demonstrates strong dependence of the lean concentration limit on initial pressure. For *OAR*=0.46, as an example, the decrease of the hydrogen concentration from 28% to 26% leads to the increase the initial pressure that is required for re-initiation from 0.45 bar up to 1.6 bar. This corresponds to nearly two times decrease of the cell size λ (from λ=23.5 mm to λ=11 mm).

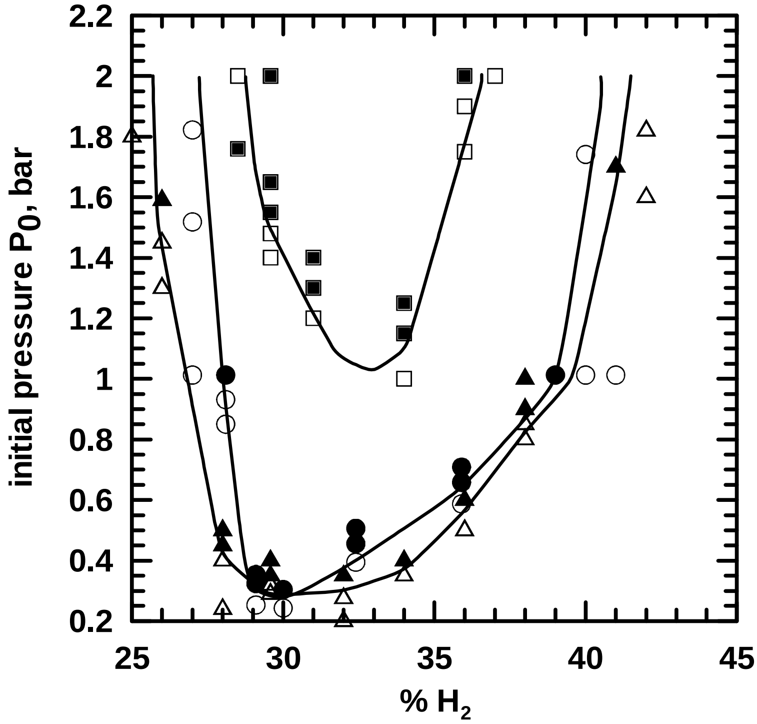


Figure 1. Results of detonation re-initiation (solid symbols) and failure (open symbols) vs. initial pressure and hydrogen content in air for different values of *OAR*. ■ – *OAR*=0.42, tube 106 mm; ● – *OAR*=0.44, tube 141 mm; ▲ – *OAR*=0.46, tube 106 mm.

Therefore for different values of the constant initial pressure we can plot the individual dependence of the concentration limits of detonation re-initiation on the value of *OAR*. Such dependence for the initial pressure of 2 bars is represented in fig. 2. It is seen, that the minimum of this dependence is shifted to the side of rich hydrogen mixtures that is the typical for the direct initiation of detonation.

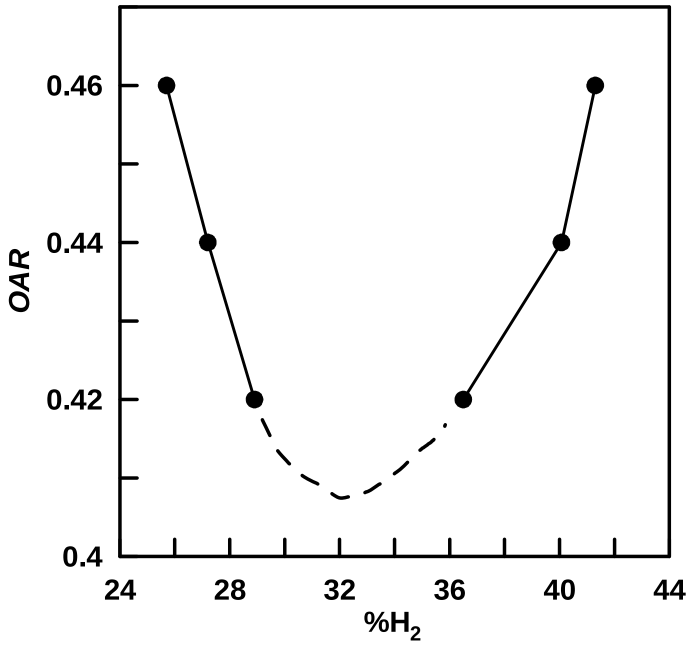


Figure 2. Concentration limits for detonation re-initiation corresponding to different values of *OAR* at P_0= 2 bar

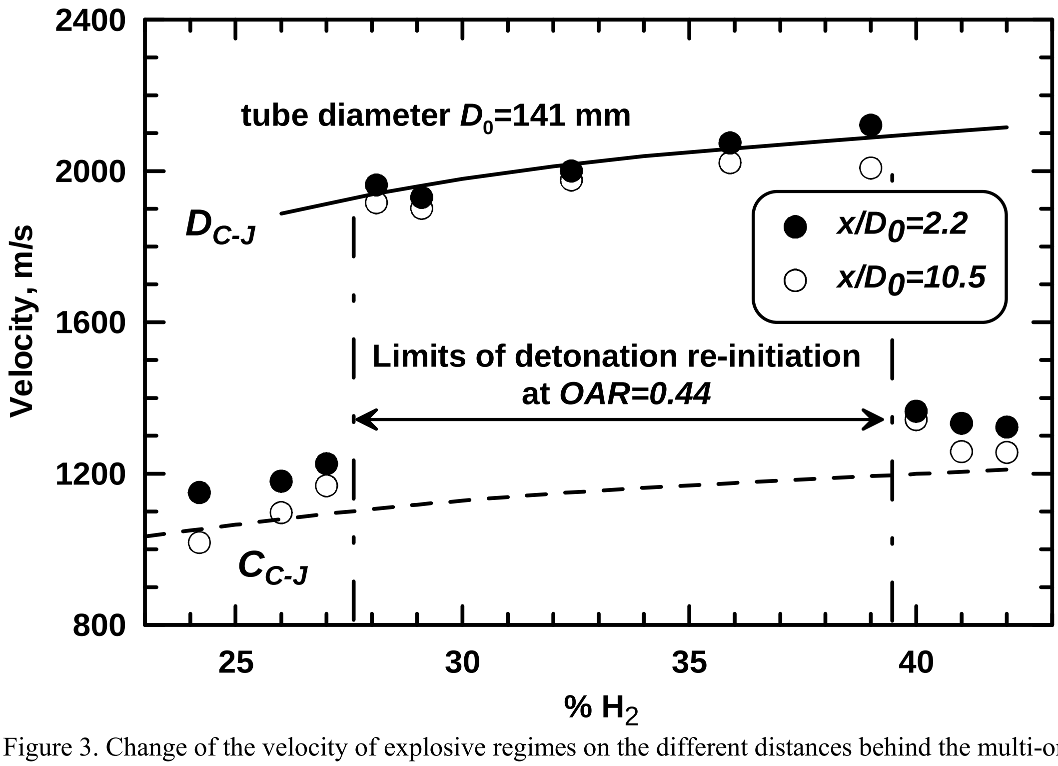
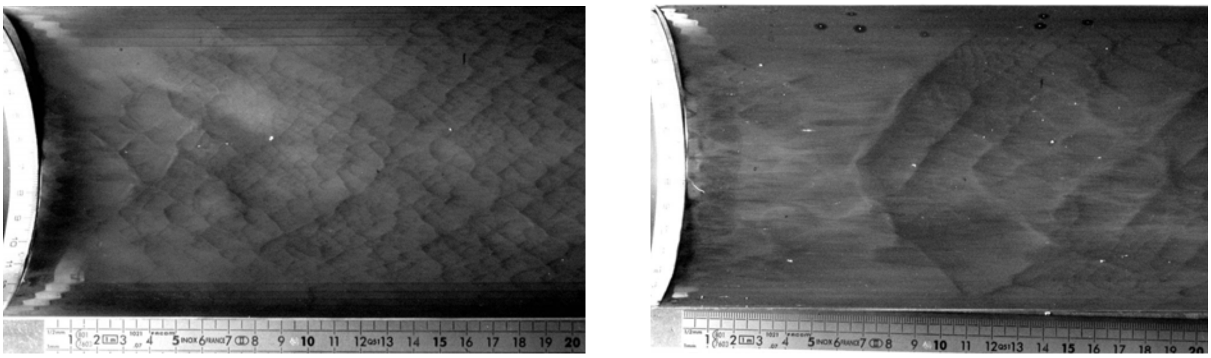


Figure 3. Change of the velocity of explosive regimes on the different distances behind the multi-orifice plate in hydrogen-air mixture.

The pressure gauges located along the 141 mm tube downstream the multi-orifice plate allow to determine the velocities of the explosive regimes near the concentration limits. These velocities are plotted in fig. 3 for the multi-orifice plate with *OAR*=0.44.

It is seen from fig. 3 that detonation wave is over-compressed near concentration limits of detonation re-initiation at the distance of x/D_0=2.2. At the distance of x/D_0=10.5 the observed



a) b)

Figure 4. Detonation re-initiation of stoichiometric hydrogen-air mixture in the tube of a 106 mm diameter at *OAR*=0.46, a) P_0=1 bar, λ≈10 mm, b) P_0=0.4 bar, λ≈23 mm.

velocities become smaller than $D_{C\text{-}J}$. Just outside re-initiation limits it is observed a quasi-steady propagation of a complex consisting of flame and leading shock wave [2].

The soot records in fig. 4 demonstrate the difference in the processes of re-initiation following the initial pressure far from the limit (fig. 4a) or close to the limit (fig. 4b). In the first case fast re-initiation takes place at the distance about (5-7) *d* from the plate and the detonation wave becomes steady state at the distance about $2D_0$. Some tracks corresponding to the shock waves collisions are clearly seen in the interval between 0 and (5-7) *d* downstream the multi-orifice plate. At initial conditions closer to the limit (fig. 4b) re-initiation occurs suddenly after some delay and the flow pattern looks like detonation re-initiation after the strong ignition mode.

4 Concluding Remarks

The performed experiments allow to establish the dependence of concentration limits for hydrogen-air mixtures of detonation re-initiation behind a multi-orifice plate on mixture composition and initial pressure. It was shown that initial pressure has strong influence on the value of concentration limit, especially for lean hydrogen-air mixtures. On the basis of soot records it can be supposed that fast re-initiation occurs due to collision of shock waves emerging from neighboring holes.

Acknowledgements

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References

[1] Chao J, Lee JHS. (2002). Detonation initiation at a turbulent interface. Proc. of 2002Spring Technical Meeting, The Combustion Institute Canadian Section, University of Windsor.

[2] Medvedev SP, Khomik SV, Olivier H, Polenov AN, Bartenev AM, Gelfand BE. (2005). Hydrogen detonation and fast deflagration triggered by a turbulent jet of combustion products. Shock Waves. 14(3). 193-203.

[3] Chao J, Lee JHS. (2005). An investigation of the conditions for detonation initiation at a 1D turbulent mixing interface. Proc. of 21 ICDERS on CD-ROM. Montreal.

[4] Kaneshige M, Shepherd JE. (1997). Detonation Database. Explosion Dynamics Laboratory Report FM97., California Institute of Technology. Pasadena..

[5] Gavrikov AI, Efimenko AA, Dorofeev SB. (2000). A model for detonation cell size prediction from chemical kinetics. Combust. And Flame. 120. 1. 19-33.