Detonation Initiation in Semi-Confined Area

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1 Introduction

Detonation transmissions are of significance for a variety of safety tasks and detonation initiation problems. Theoretical and empirical correlations between detonation parameters and chemical kinetics rates responsible for different scenarios of the transmission process were proposed and established by various authors [1-3]. These empirical correlations were confirmed for a number of enriched [4] and selected [5] fuel-air mixtures.

As a rule, the direct detonation initiation requires a powerful external energy source that is out of the range of the most practical situations. Usually, the onset of detonation in various confinements is a consequence of the deflagration to detonation transition (DDT) events. In these cases, the energy release in the mixture itself self-sustains the detonation genesis in the system. A terminating phase of the DDT is the formation of a combustion-driven shock wave that cumulates the entropy release excess produced at the early stages of flame acceleration in a post-shock gas. The potentiality of such a transient reaction complex for the detonation initiation at transmission into unconfined and confined volumes is open to question [6].

The objective of this work was to elucidate the effectiveness of transmission of shock wave – deflagration for detonation initiation in a semi-confined area.

2 Experimental setup

Experiments were carried out in a 2.76 m driver tube of 30 mm inner diameter attached to a stainless steel detonation vessel or a test section of 142 mm inner diameter and 0.4 m long (figure 1). Such geometry provided the area expansion ratio $D^2 / d^2 = 22.4$ where D is the diameter of the vessel and d is the inner diameter of the driver tube. A stoichiometric propane-oxygen mixture with 50 % of nitrogen dilution $C_3H_8+5O_2 + 6N_2$ at initial pressures of 0.1- 2.0 atm was used as a test gas. Explosions of oxyacetylene mixture, which was separated from the driver tube by a brass diaphragm, produced transient deflagration and detonation. Gas mixtures were prepared by the method of partial pressures from commercial grade acetylene (C_2H_2), propane (C_3H_8), oxygen (O_2) and nitrogen (N_2) of 99.9 % purity and were kept, at least, one day before use. The changing of pressure between the igniting mixture and test gas govern to different intensities of the primary shock wave initiated in the driver tube and, consequently, to different DDT run-up distances. In spite of a high sensitivity of DDT distance and DDT time to initial and initiating conditions, this method ensured realizing the variation of propagation regimes of combustion in the driver tube at the moment of transmission into the main detonation vessel. Two pressure meters controlled a pressure difference between the initiating and driver tubes and also initial pressures with an accuracy of ± 0.4 mm Hg (figure 1).

A 50-cm long end section of the driver tube was equipped with 20 ionization probes for reaction flow velocity measurements. The probes were placed in 4 lines across tube axe. The distance between each probe was 90 mm. Such a setup allowed determining not only the velocity but also the shape of the reaction front over different cross sections of the tube. Two pressure transducers located over the same with ion probes cross sections (figure

1) simultaneously controlled an intensity of a leading shock wave and a length of the detachment zone between shock and reaction fronts near the exit plane of the driver tube. The distance between the pressure transducers was 90 mm.

A main test section was equipped with two pressure transducers located at a distance of 125 mm from the exit plate of the driver tube; the distance between them was 100 mm. In addition, five ionization probes placed in 50 mm intervals in the test section controlled the reaction front arriving time and detonation or the deflagration velocities (figure 1).

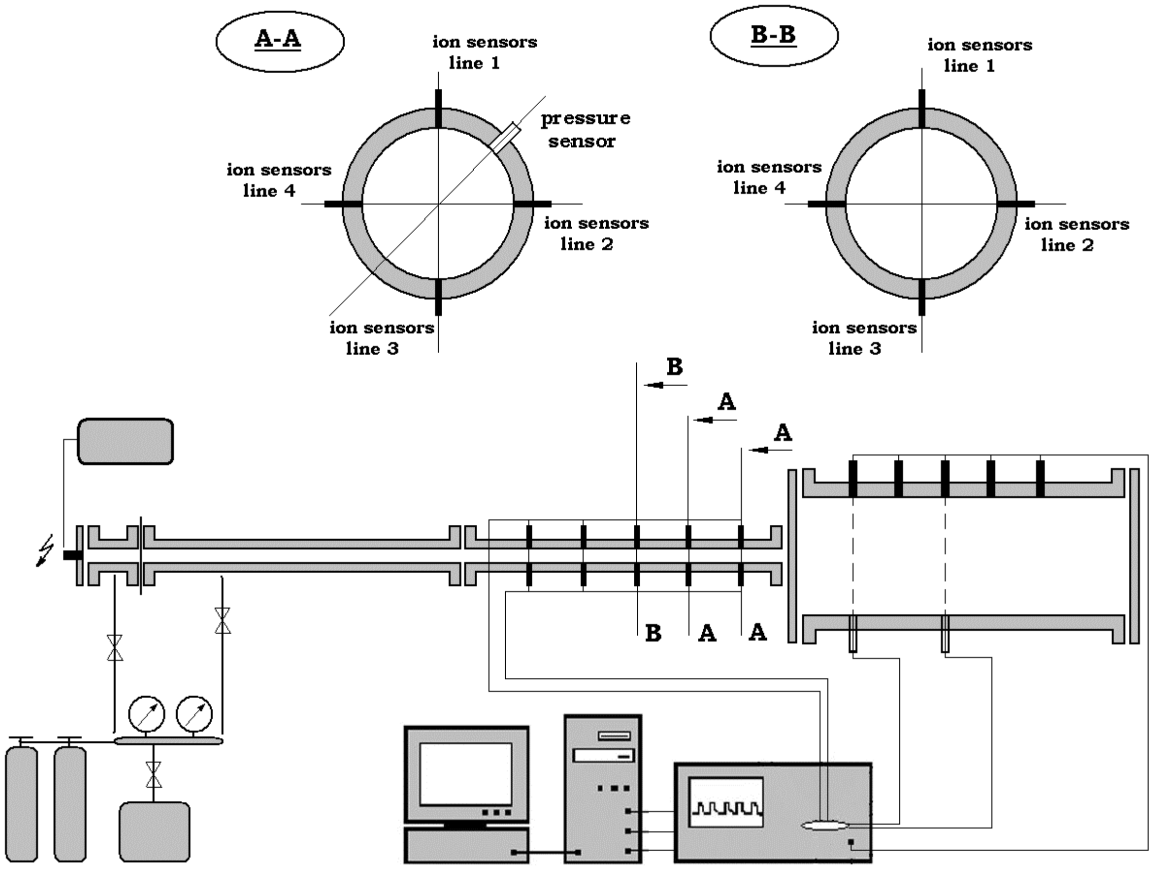

Figure 1. Schematic of the experimental setup.

3 Results and discussion

Several transmission scenarios depending on the initial conditions and initiation regimes in the driver tube were observed in our experiments. There are the transmissions of a shock wave followed by deflagration or detonation, detonation and overdriven detonation transmissions.

Figure 2 presents the results on a critical transition of a shock wave with a velocity of 1084 m/s, followed by supersonic deflagration with a velocity of 1565 m/s (figure 2 a, b). The initial pressure is 0.4 atm. The Chapman - Jouguet (CJ) detonation velocity for this mixture is V_{CJ} = 2030 m/s. As seen in figures 2 c, d, the re-ignition occurs somewhere between the exit of the driver tube and first pressure and ion sensors. The formed detonation propagates steadily without decay along the volume of the main vessel (figure 2 c, d).

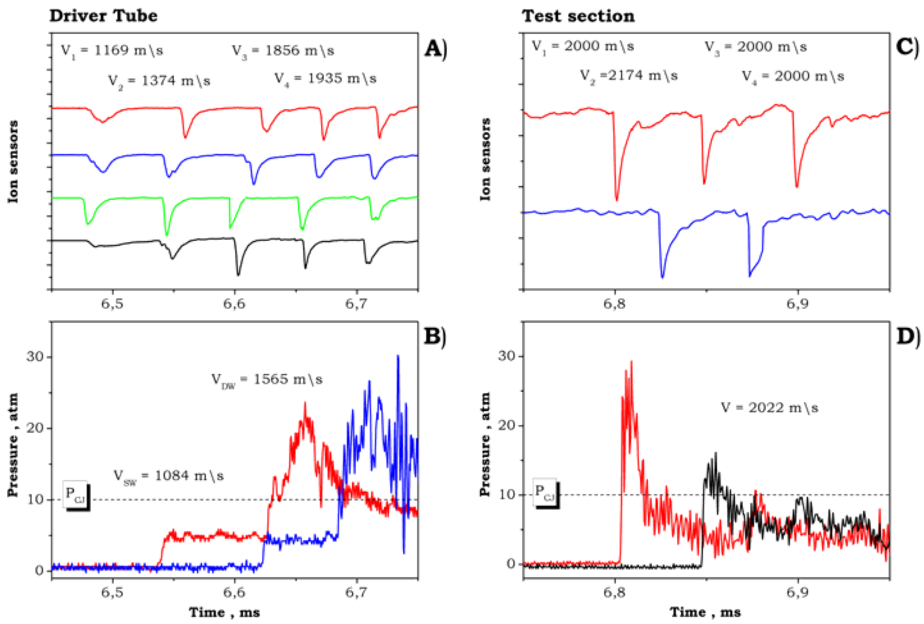

Figure 2. Transmission of a shock wave / deflagration complex. Pressure (a) and ion current (b) records in the driver tube, pressure (c) and ion current (d) records in the main detonation vessel. The initial pressure is 0.4 atm.

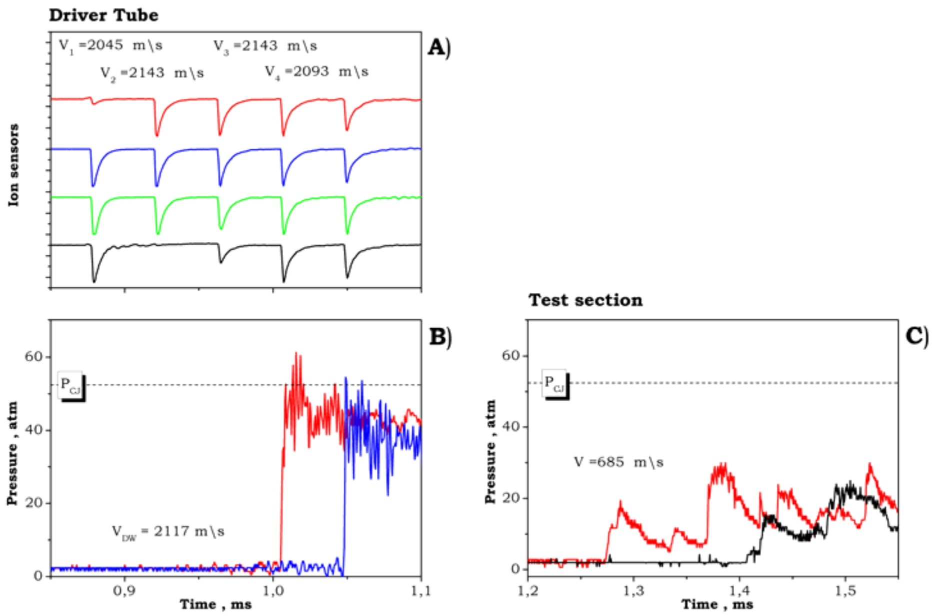

Figure 3. Transmission of planar CJ detonation. Pressure (a) and ion current (b) records in the driver tube, pressure (c) records in the main detonation vessel. The initial pressure is 2 atm.

Figure 3 illustrates the other sequence of events for the same experimental geometry – direct detonation transmission. The initial pressure of a propane/oxygen /nitrogen mixture is 2 atm, that is 5 times higher than for the shock wave-deflagration transmission case discussed above (figure 2). As seen in figure 3 c, the emerging detonation (figure 3 a, b) fails and does not re-establish explosions in the main vessel.

Thus, the experiments evidence that the transmissions of shock wave followed by deflagration in pre-detonation states are much more effective [6] for the detonation initiation in a large semi-confined area in comparison with the initiation by a planar detonation wave.

4 Conclusions

It was found that the transmission of a nonstationary complex of a shock wave followed by deflagration into a semi-confined area could essentially facilitate the following detonation re-ignition and reduce the sensitivity and requirement for driver tube mixtures. The transmission of such a complex could produce the successful detonation initiation in a large volume, at least, five times lower initial pressure than for the classical direct detonation transmission case.

Acknowledgements

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