Deflagration to Detonation Transition in Narrow Channel with For-chamber

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1 Introduction

Nowadays environmentally friendly sources of power attract a great attention of the researchers. One of the most available sources is power of hydrogen burning. The most efficient regime of hydrogen combustion is detonation of mixture with oxygen or air and air mixture is preferable for technical applications at that despite of less detonability.

Gaseous detonation can be initiated by different ways for example by direct initiation, shock induced detonation transition (SDT) and deflagration to detonation transition (DDT). In fact for practical applications DDT is the only reasonable way to produce detonation wave because the initial energy of the others is comparable with the releasing one.

However some characteristic problems appear when detonation channel diameter decreases. It is well known that classical Chapmen-Jouguet detonation propagation in channels with diameter three times less than the detonation cell (critical diameter of stationary detonation) is impossible. Moreover if we consider flame front in detonation process which propagates with a very high speed, heat losses into tube walls are minimal but at the initial stage of DDT process speed of flame is much slower which results in increase of heat losses and finally can prevent transition to detonation.

Propagation of detonation waves in narrow tubes has been investigating since 1960s [1]. This works mainly consider propagation of the detonation generated before entering the channel. When the diameter of the channel less than the critical some propagation modes like spinning, galloping and low speed detonation can be observed [2]. In numerical researches [3] it was shown that occurrence of DDT in narrow channels is possible, and proposed that heat losses into walls and momentum losses through viscous sticking play important role on the flame acceleration.

To obtain deflagration to detonation transition in narrow channels for-chambers of greater diameter were used by some researchers [4, 5]. Because of less heat losses in wide for-chamber the flame at the initial stage of propagation is able to accelerate that provides greater speed of flame at the entrance of the narrow tube. Moreover expanding combustion products push flame front downstream the channel that also accelerates flame front and decreases heat loses into walls. Due to this DDT in narrow channel can be achieved.

Detonation in narrow channels can be usable for practical applications in set of areas up to medicine. In work [6] authors discussed the possibility of creation needleless injection device founded gas detonation. Detonation channel should be narrow in a similar device. It’s necessary for maintenance of small device physical sizes. For-chamber technique allows

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receiving a detonation wave with minimum power input and as close as possible to an initiation point.

In the present work deflagration to detonation transition in hydrogen-oxygen and hydrogen-air mixtures in 3 mm channel was investigated. Transition to detonation in hydrogen-air mixture was obtained in channel with the diameter less than the critical (for air mixture is equal to 3.7 mm [7]). The dependence of run-up distance on for-chamber volume was considered in terms of additional energy of burning gas in for-chamber.

2 Experimental setup

The major part of experimental setup is cylindrical detonation channel of 3 mm diameter (Fig. 1). It composed of four identical opaque sections of 84 mm length and one transparent plexiglas section of 36 mm length for high speed camera optical observation. Each opaque section is equipped by photodetector. Measurement accuracy of average speed of flame front was defined by measurement accuracy of time intervals and distance between photodetectors and equals 2%. For-chamber of 14.5 mm diameter was placed at the one end of the detonation channel. On the opposite face of the channel pressure transducer was placed. Mixture was ignited in for-chamber with an electric spark with energy no more than 0.1 J. The for-chamber length L was changeable, thus for-chamber volume too. The experiments were carried out with stoichiometric hydrogen-oxygen and hydrogen-air mixtures at initial pressure equal 1 and 2 bar. Before experiments for-chamber and detonation channel were evacuated to 0.5 torr and then filled with combustible mixture up to required pressure.

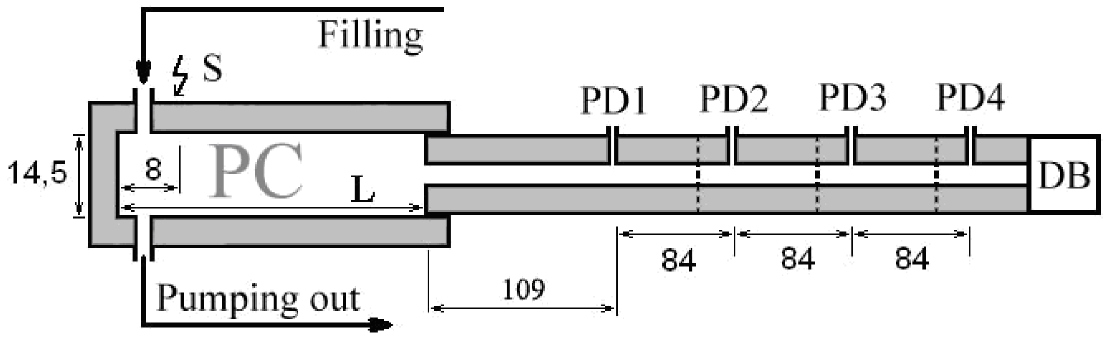

Figure 1. Experimental setup scheme. S – spark; PC - prechamber; L – length of prechamber; PD1, PD2, PD3, PD4 – photodetectors; DB – diaphragm block.

3 Obtained results

Series of experiments with hydrogen-oxygen and hydrogen-air mixtures at initial pressure equals 1 and 2 bar for four values of for-chamber length have been carried out. Average speed of flame front in hydrogen-oxygen and hydrogen-air mixture at four sections of the channel is presented in tables 1 and 2.

Table 1. Average speed of flame front at different sections of channel (Ws-1 – between spark and PD1; W1-2 - between PD1 and PD2; W2-3 - between PD2 and PD3; W3-4 - between PD3 and PD4) for different values of prechamber's length in hydrogen-oxygen mixture at initial pressure equals 1 and 2 bar.

Mixture pressure, bar	PC length, mm	W_{s-1}, m/s	W_{1-2}, m/s	W_{2-3}, m/s	W_{3-4}, m/s
1	49	450	3060	2670	2730
	38	400	3010	2680	2740

	30	400	3100	2760	2720
	22	410	3070	2720	2720
2	49	601	2876	2718	2820

Table 1 shows that deflagration transition into detonation in stoichiometric hydrogen-oxygen mixture at initial pressure equals 1 bar occurs on the distance of 36 calibers from the beginning of the channel for all investigated for-chamber lengths and initial pressures. Detonation speed exceeds stationary value on length from 36 to 64 calibers. It means that the recompressed detonation exists in this section. Detonation speed attains a stationary value on the length of 92 – 120 calibers in all cases.

In the case of hydrogen-air mixture detonation occurs in front of the first measuring section when for-chamber length is equal to 49 mm. Therefore the predetonation distance is less than 109 mm. One can see from the table that predetonation distance increases while for-chamber length decreases and the growth of the initial pressure leads to predetonation distance reduce.

On the length of 92-120 calibers flame speed exceeds the value of Chapman-Jouguet which means that the stationary detonation mode does not appear at this channel length.

Table 2. Average speed of flame front along the channel (Ws-1 – between spark and PD1; W1-2 - between PD1 and PD2; W2-3 - between PD2 and PD3; W3-4 - between PD3 and PD4) in hydrogen-air mixture at initial pressure equals 1 and 2 bar.

Mixture pressure, bar	PC length, mm	W_{s-1}, m/s	W_{1-2}, m/s	W_{2-3}, m/s	W_{3-4}, m/s
1	49	94	2205	2122	2045
	38	101	2061	2137	2005
	30	105	1358	1823	2115
	22	107	1104	1729	2140
2	49	109	2431	2114	2120
	38	115	2360	2127	2044
	30	117	1777	2188	1938
	22	120	1442	1801	2010

Use of for-chamber makes it possible to obtain the deflagration to detonation transition before 36 calibers in the 3 mm diameter channel in stoichiometric hydrogen-air mixture at initial pressure 1 bar and higher.

Obtained pressure at detonation front corresponds to results of calculations based on Chapmen-Jouguet parameters. Maximal pressures in detonation wave reflecting from channel face is equal to 50 and 76 bar for hydrogen-oxygen mixture and 32 and 50 bar for hydrogen-air mixture at initial pressures 1 and 2 bar respectively.

By comparing above described results with the data of optical observations the dependence of run-up distance on additional energy of burning mixture in for-chamber (fig. 2) was obtained. Additional energy was calculated as heat of reaction of burning gas in for-chamber without losses.

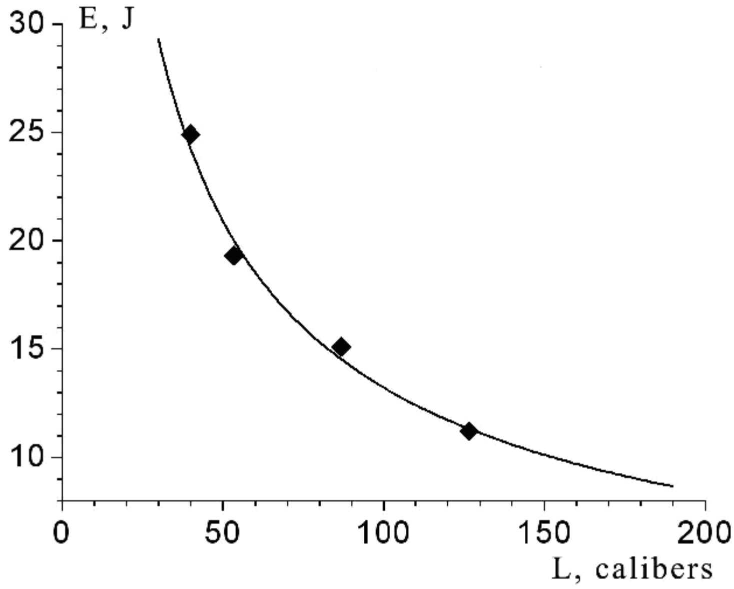

Figure 2. Dependence of run-up distance on additional energy of burning mixture in for-chamber in hydrogen-air mixture at initial pressure 1 bar.

4 Discussion

The experimental research has shown the possibility of deflagration to detonation transition in narrow channels in hydrogen-oxygen and hydrogen-air mixtures. Formation of the detonation against on for-chamber volume at initial pressure of 1 and 2 bar was investigated. In channel of 3 mm diameter the run-up distance did not exceed 47 calibers in stoichiometric hydrogen-oxygen and hydrogen-air mixtures at initial pressure equals 1 bar.
The experimental research has shown the possibility of deflagration to detonation transition in narrow channels at the expense of flame acceleration at the initial stage of propagation. But explanation of the mechanisms of DDT requires advanced study. Speed of a detonation exceeds stationary value that speaks about the recompressed detonation. Further there is a reduction of speed to value corresponding to a Chapman-Jouguet detonation. Certainly, dissipative energy loss won't allow stationary detonation propagation, and sooner or later the detonation will slowly go out.

The dependence of run-up distance on additional energy produced by burning mixture in for-chamber was obtained. Curve fitting to experimental data shows potential minimal values of run-up distance and additional energy when DDT in narrow channel occurs.

5 Acknowledgements

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