DDT Reduction by Perforated Plates in H_2/O_2 Mixture

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1 Introduction

Detonation has been applied to pulse detonation engine (PDE) for a long time since late 1970s. One of the major issues on PDE is defraglation to detonation transition (DDT) problem. The DDT time and distance must be reduced for the faster frequency operation and the shorter PDE[1].

Until the present many studies have been performed concerning DDT problem, especially the so called 'Shchelkin spiral' which is the spiral shaped coil installed ih the detonation tube to accelerate the DDT process. On the other hand the authors's group has studied 'jet flame' for many years, which proceed combustion very effectively and quickly. Then the jet flame ignition system was applied to ignite detonation timely to proceed PDE [2]. Now the authors applied to the main idea of jet flame ignition to reduce DDT time and distance.

This idea was applied to DDT by several researchers. One of them is Ciccarelli and Boccio [2] using a single size orifice, which actually has been used to DDT as the obstacle by John Lee's group. However their orifice has a large hole to produce a rather strong flame instead of jet ignition. Recently Sorin et al. [3] studied the effect of perforated plate, but they comvine the plate with the Shchelkin spiral together as well as the orifice. This is a mix of three kind of obstacles to get the shorter DDT time.

The present study performs the study of the effect of perforated plate on DDT time and distance to reduce them. First of all hydrogen/oxygen system is applied for this problem.

2 Experimental setup

Figure 1 shows the schematics of the present experimental system. The total length of the tube is 2570 mm and its cross section is the square of 40 mm x 40 mm. The ignition is performed by a typical automobile ignition plug. A Shchelkin spiral or perforated plates are installed just after the ignition plug. The Shchelkin spiral used has a dimension of 3.5 mm in diameter, 15 mm in pitch, and 500 mm in length. The dimension of the perforated plate used is 2 mm holes with the blockage ratios of 85 %. The mixture is premixed stoichiometricly by hydrogen and oxygen with an in initial pressure of 70 KPa. The pressure transducers are totally six and installed at two test sections to measure the flame, shock wave, and detonation wave velocities. Besides three ion sensors are also installed at the facing opposite side of the upstream first three pressure transducers. The data acquisition and control system is organized by the LabVIEW.

In order to visualize the phenomena a high speed movie is used for this research. The resolution of this movie camera has 312 (horizontal) x 260 (vertical) pixels with the colour gradation of 10 bits, recording period of 1μs to 33ms, recording speed of 33 fps to 1,000,000 fps, frame storage of 100, and exposure time of 1/2, 1/4. 1/8 recording period. The camera system is handy and the pictures are quite clear. The detonation phenomena matches with this camera speed to see its detail.

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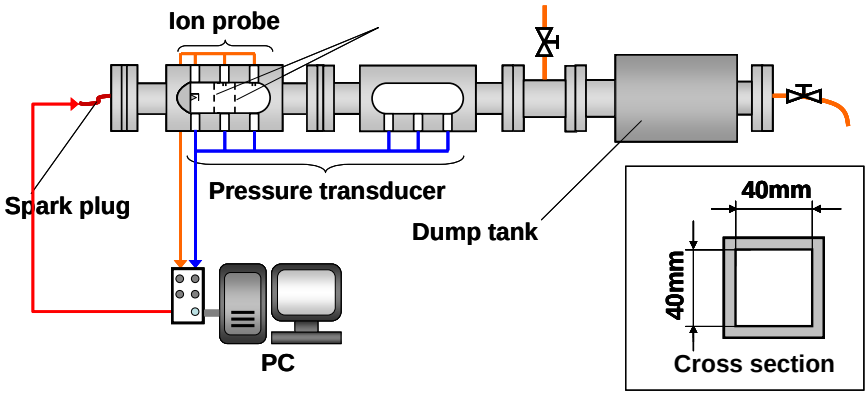


Figure 1 Experimental setup

3 Results and discussion

3.1 DDT with a Shchelkin spiral

First of all DDT time and distance are measured using the Shchelkin spiral. Figure 2 shows the v elocities at the position from the ignition plug using the Shchelkinspiral.

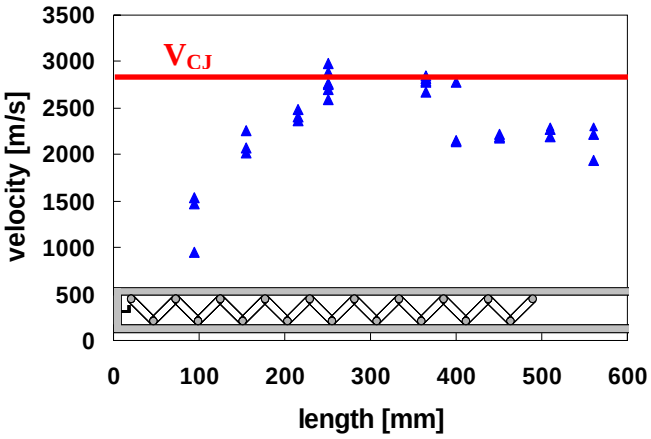


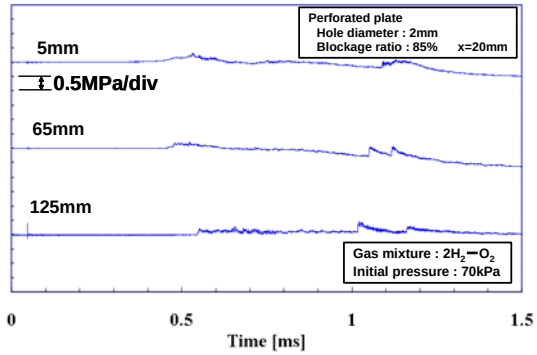
Figure 2 Propagation velocity using the Shchelkin wire for $2H_2/O_2$ cases.

Apparently the detonation reaches at about 250 mm from the ignition point with the C-J velocity of 2800 m/s and keeps its speed until about 400 mm location. Then the detonation velocity drops to about 2200 m/s due to the interaction with the spiral. From this result it is understood that this mixture condition provides a detonation with the Shchelkin spiral of 250 mm in length.

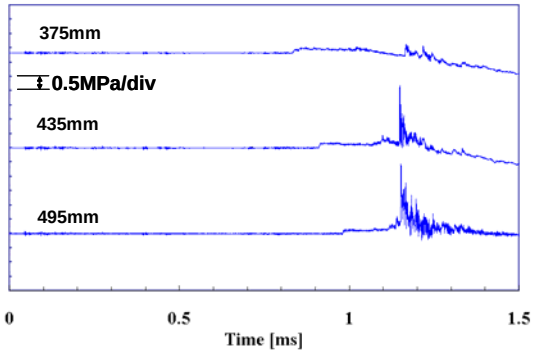
3.2 DDT with perforated plate

In order to investigate the effect of perforated plate, one and two perforated plates are installed at the location of 20 mm and 20 mm and 40 mm from the ignition plug, respectively. Figures 3-(a) and –(b) show the pressure sensor profiles at (a) 5 mm, 65 mm, and 125 mm and (b) 375 mm, 435 mm, and 495 mm. These figures explain

that detonation is reached around 435 mm due to Nuemann spike like pressure rise is obsrved at the pressure transducer of 435 mm.



(a) Pressure profiles at 5, 65, and 125 mm from the ignition point.using the Shchelkin spiral.



(b) Pressure profiles at 375 mm, 435 mm, and 495 mm from the ignition point using the Shchelkin spiral.

Figure 3 Pressure profiles in the mixture of 2H2/O2 using the Shchelkin spiral.

When two perforated plates are used the situation is changed dramatically. Figure 4 shows the case of two perforated plates that the detonation transition must have occure at the location between 65 mm and 125 mm from the ignition point. There is some difference of rising time between the pressure profile and the ion prove signal profile at the position of 65 mm, then the detonation is not established there yet. However there is a coincidence between two profiles to say that the DDT is reached at the position of 125 mm from the ignition point. This is due to the strong jet mixing and ignition together with turbulence. In this case the position of the second plate is at 40 mm and the DDT occurs just after the second plate, which is proved from the high speed Shlieren piture in Fig. 5.

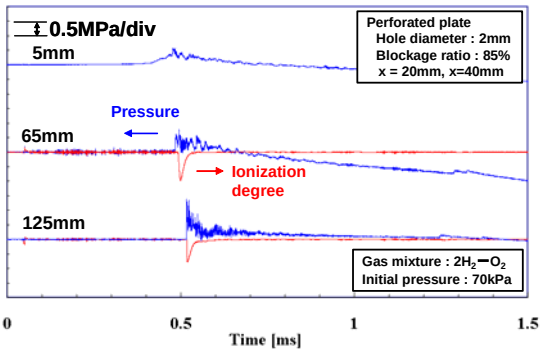


Figure 4 Pressure profiles using two perforated plates

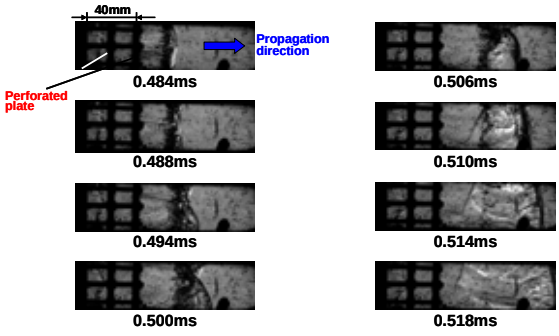


Figure 5 High speed movie photos using two perforated plates.

3.3 Effect of brockage ratio to DDT

The blockage ratio effect on DDT is studied to get the most efficient blockage ratio for DDT in the mixture of 2H2 and O2. The positions of the perforated plates are at 20 mm and 40 mm from the end of the closed end of the tube, which is the ignition point. Figure 6 shows the rising time of the pressure at the position 0f 65 mm from the ignition point. The pressure and ion prove profiles (not shown here) show that four out of five cases reach the detonation. Figure 6 says that the case using the perforated plates with the blockage ratio of 85 % provides the best DDT time which is 0.42 msec.

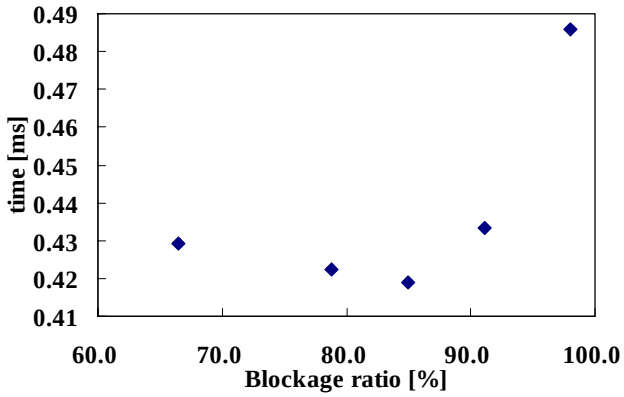


Figure 6 The blockage ratio vs DDT time for the mixture of 2H2 and O2.

5 Conclusion

In order to obtain the minimum DDT time and distance, the effect of perforated plates on DDT is studied quantitatively. The mixture used is stoichiometric hydrogen and oxygen at the initial pressure of 70 KPa and room temperature. The case using two perforated plates with its hole diameter of 2 mm and its blockage ratio of 85 % at the position of 20 mm and 40 mm from the ignition point reduces the DDT time with about 0.16 ms and the DDT distance of more than 125 mm. The H_2/air case must be studied in the future.

References

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[2] G. Ciccarelli and J. L. Boccio, "Detonation wave propagation through a single orifice plate in a circular tube", Proc. Combust. Inst; 27, pp.2233-2239, 1998.

[3] Sorin et al., Shock Waves 15, 2, 137-145, 2006.