A Study on Deflagration to Detonation Transition in Injected Hydrogen/Air Mixtures

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1 Introduction

The problem of transition from deflagration to detonation (so called DDT) is one of the most important problems of combustion science and technology. The problem has been attacked by many combustion scientists and engineers from a long period of time. But the problem has not been solved yet because it includes many complex but fundamental physico-chemical phenomena such as an acceleration of flame, a formation of shock wave and interaction of chemical kinetics with the shock wave. Urtiew and Oppenheim [1] had shown clear pictures of the "explosion in explosion" in the DDT process. Obara et al.[2] had performed a photographic study on the whole DDT process in an oxyhydrogen mixture and had observed the shock induced combustion process before the detonation had established. Kuznetsov,et al.[3] had observed a behavior of detonation waves in non-uniform hydrogen/air mixtures. Thomas and Bambrey [4] had observed an explosive ignition wave from a turbulent flame brush. Effects of obstacles, which enhance the DDT process, are well known as Shchelkin spirals and had demonstrated by many researchers. Teodorczyk[5] had studied experimentally on the scale effects of the DDT process in hydrogen-air mixtures. From the authors' point of views, which may be common for the other researchers, the most important one may be a generation of the hot spot within an unburned mixture between the shock front and flame front.

Because many studies on the DDT were performed from a fundamental point of view, then they assumed a uniform mixture at rest before ignition. But in many practical situations, such as the pulse detonation engine (PDE) as well as the accidental explosion hazards in the pipelines, mixtures may not be uniform and still. In the PDE, fuel and oxidizer will be injected directly into the combustor, then they will be mixed inside the chamber and they will be ignited before they become uniform and at rest. As far as the authors know, there was no study concerning on the DDT in such non-uniform mixtures. The present study, aiming at obtaining a fundamental aspect on the DDT in a non-uniform mixture with some turbulence, was conducted by using a detonation tube equipped with high-speed solenoid valves which inject a fuel gas and an oxidizer gas. Obstacles which enhance the DDT were installed

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near the ignition region. Hydrogen and air were selected as a mixture and an initial pressure was atmospheric.

2 Experimental

Figure 1 shows a schematic of the present experimental apparatus. The tube has a rectangular cross-section of 25 x 30 mm and 3000 mm in length. At the igniting end of the tube, there installed two fast action solenoid valves injecting fuel and oxidizer gases. Mass flow rates of the injection were measured before the main experiments. There are six measuring ports, P1 through P6, quipped with pressure transducers and ionization probes along the tube. A Shchelkin spiral with a pitch of 25 mm and a blockage ratio of 0.35 is inserted at the most upstream position in length of 500 mm.

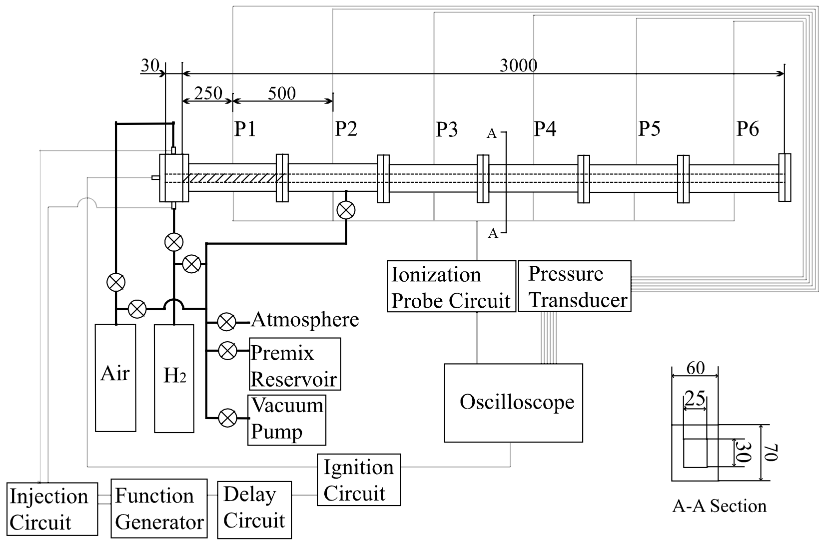

Fig.1 Schematic of Experimental Apparatus

Table 1 shows a present experimental condition. A hydrogen/air mixture is selected as a test mixture to compare with the PDE experiments. The overall equivalence ratio, which is calculated from the mass flow rates of the injected gases, was varied within the detonability limits. The mass flow rates of the gases are varied with varying opening duration times while the reservoir pressures are fixed. These opening times are determined to fill the whole volume of the tube with a pressure of 100 kPa. A time between the injection end and the ignition is 25 or 100 ms. Times are controlled with a function generator and a delay circuit which is illustrated in Fig.2. A position of igniter is varied as 0, 630 and 925 mm from the end plate.

Table 1 Experimental Conditions

Fuel	H_2
Oxidizer	Air
Overall Equivalence Ratio, ϕ	0.5 - 4.5
Initial Pressure, p_0[kPa]	100
Ignition Time[ms]	25 , 100
Ignition Position[mm]	0

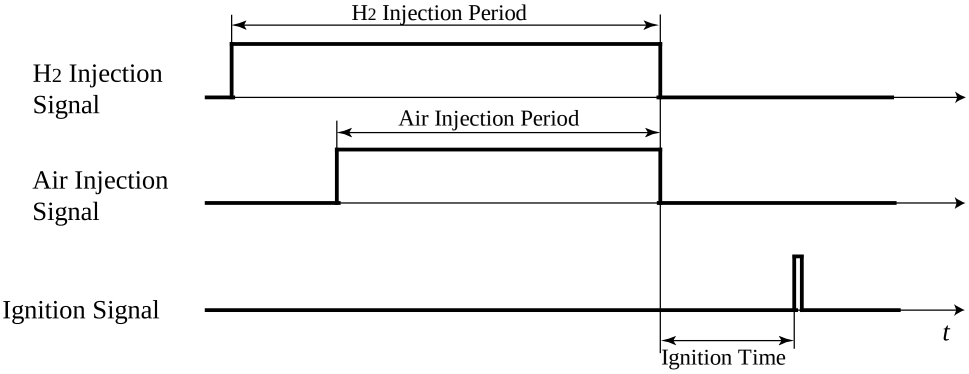

Fig.2 Time sequence of the event

3 Results and discussion

Typical records of pressure and ionization current are illustrated in Fig.3.

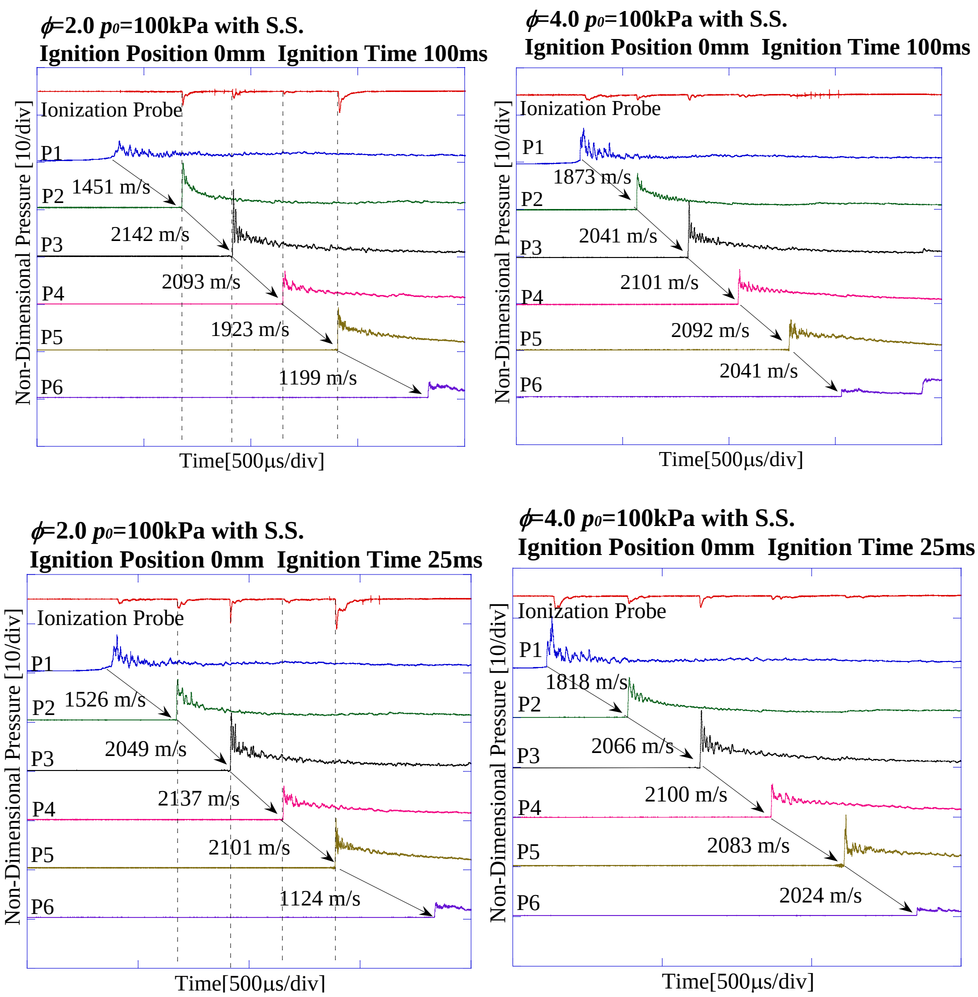

Fig.3 Pressure and ionization current for ϕ=2.0, 4.0 and ignition time 100 and 25 ms

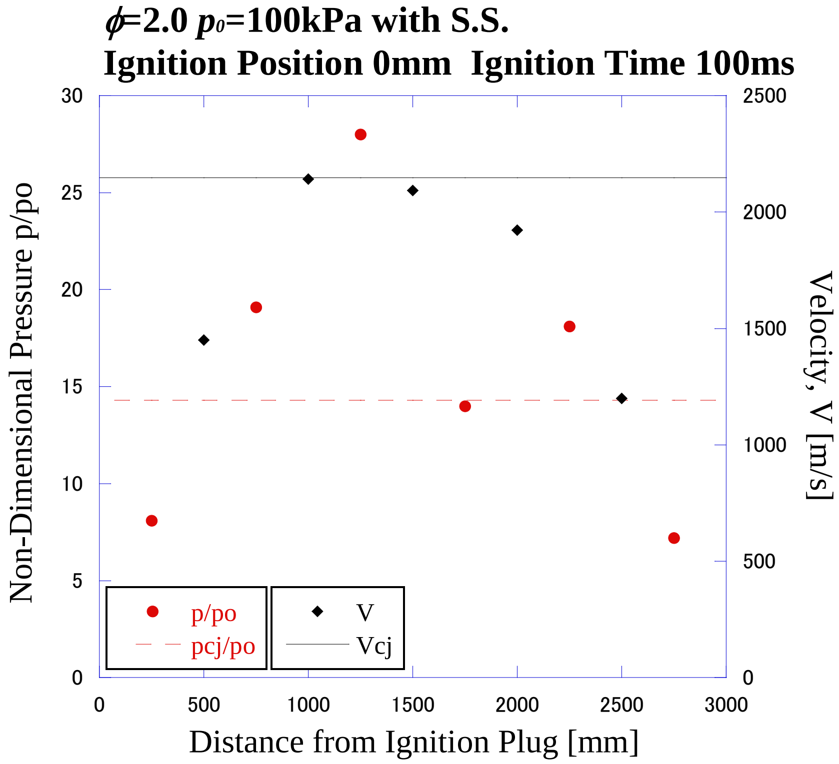

Fig. 4 Variations of peak pressure and propagation velocity along the tube

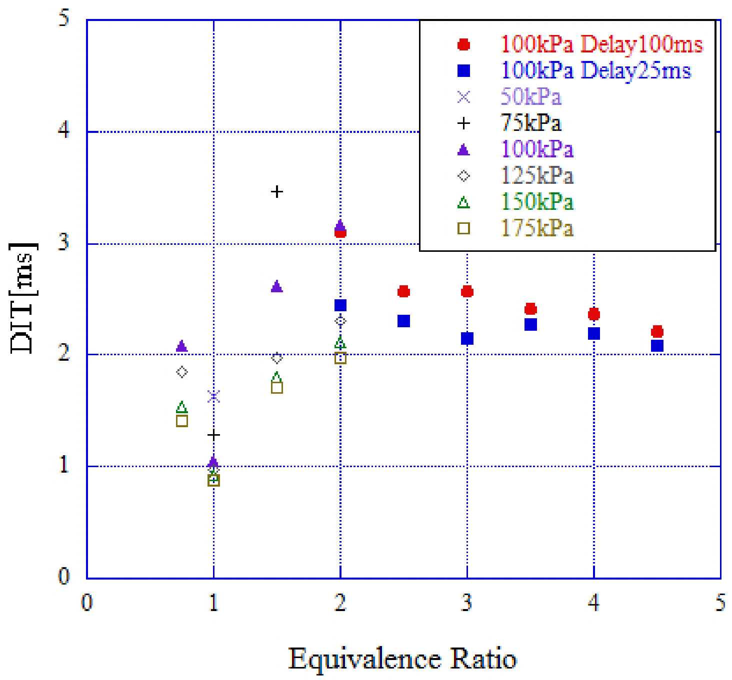

Fig. 5 Variation of detonation induction time with overall equivalence ratio

In the cases illustrated in Fig.3, detonation waves are quickly initiated ate the position P2 where the shock front and the reaction front are coupled within a few microsecond. At P1 where the obstacles are situated, a somewhat gentle rise in pressure before a sharp pressure peak was observed to show a pressure wave generated by a deflagration and the local explosions. After the detonation wave is established the propagation velocity and the peak pressure are in the order of the CJ values but they have a considerable fluctuation as shown typically in Fig.4. And it should be mentioned that the waves decay to an inert shock wave at P6 where a combustible mixture may not exist.

Figure 5 shows variations of detonation induction time (DIT) which is determined as a time elapsed from the ignition to the first detonation observation in the tube with the overall equivalence ratio. Data are added for uniform hydrogen/air mixtures prepared in a mixing tank with an initial pressure as a parameter. For the uniform mixtures, the detonation was not initiated for the equivalence ratio above 2.0 and the DIT shows a minimum value near the stoichiometric mixture, while, for the injected mixtures of the present experiments, it was not initiated for the overall equivalence ratio less than 2.0 and the DIT slightly decreased as the overall equivalence ratio increases. For the injected cases, the local equivalence ratio should not be equal to the overall equivalence ratio and the distribution of concentration is important for this DDT process.

4 Conclusions

The experimental study was performed on the DDT processes of hydrogen-air mixtures injected in a tube. The following conclusions are derived:

(1) The detonability limits obtained are quite different from those obtained for uniform still mixtures. For 100kPa, the equivalence ratio of the lean limit lies near 2.0 and that of the rich limit is larger than 4.5, while for the uniform still mixture, the detonable region lies between 0.7 and 2.0.

(2) The detonation waves observed are not completely steadily propagated detonation and the propagation velocity changes considerably with a distance.

(3) The detonation induction distance is increased with the injected equivalence ratio.

(4) A little influence was observed on the ignition delay time of 25 and 100ms on the detonation induction distance.

References

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