Study on Detonation Initiation in Hydrogen/Air Flow

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1 Introduction

Recently, hydrogen is one of the most attractive fuels as alternatives to fossil fuel. However, it has the dangerous characteristics such that the minimum ignition energy of hydrogen is extremely low, its flammability limits are wide, and burning velocity is faster compared to other fuels. To disseminate this energy, a standard of safe usage should be established. From this perspective, fundamental research and application are progressed. Particularly, in the case of that an axis scale is far larger than other two (e.g. duct, tunnel), there is possibility of occurrence of deflagration to detonation transition (DDT), and it may cause great damage to lives or things in the tube. In this study, a situation is assumed that hydrogen leaks in a tunnel by an accident of a tank truck which carries liquefied hydrogen, diffuses into the tunnel area, ignites and finally leads to DDT or accidental ignition on ventilation duct with exhausting leakage hydrogen. While a great number of hydrogen detonation studies under static condition were carried out, experimental examples on simple flowing system are very few. So far, researches for influence of initial gas velocity on the rate of formation of detonation on hydrogen-oxygen, Methane-oxygen[1] and propane-oxygen-nitrogen mixture[2] have been conducted. In these studies, hydrogen-oxygen and propane-oxygen-nitrogen mixture show that DDT distance decreases as the Reynolds number increases. Flame propagation behaviour in tunnel model have been carried out and those effects were considered[3]. To examine DDT conditions on hydrogen leak in a flowing system of hydrogen-Air mixture, more experiments have to be performed. In this research, DDT conditions are observed with changing detonation tube diameter, flow ratio, hydrogen concentration, and flow type.

2 Experimental setup

Schematic experimental set up is shown in Fig. 1. Detonation tube length is 1m and diameters are 25mm, 50mm, and 100mm. Maximum tube lengths can be changed to 8-9m by attaching tubes. One tube end is open, and hydrogen and air are flowed through the tube from another end. There are two flow types; a) premixed type, and b) non-premixed type. In the premixed type, hydrogen and air are mixed in a tube upstream the detonation tube. The mixture is streamed thorough the tube. In the non-premixed type, air is flowed from the tube end and

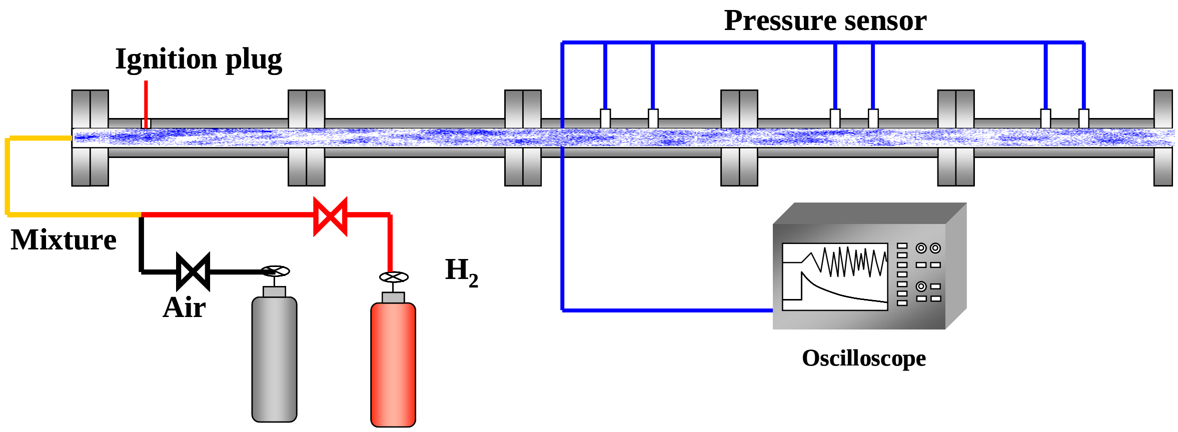

Fig. 1. Experimental setup

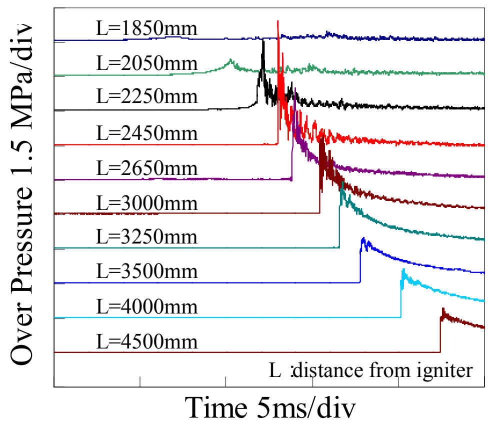

Fig. 2. Pressure history at premixed type ; 25mm diameter, equivalence ratio ø=1.

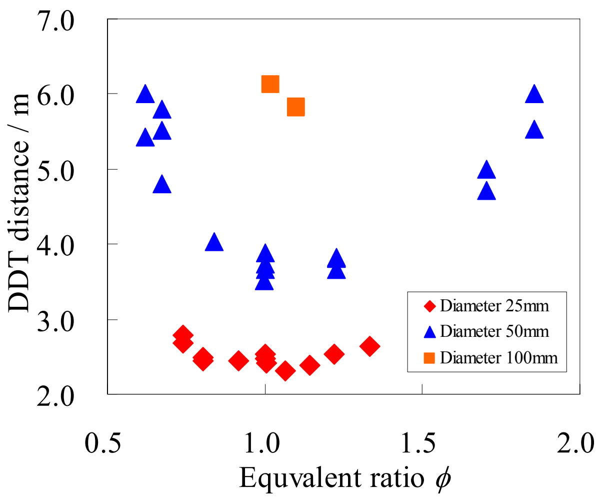

Fig. 3. DDT distance distribution with equivalence ratio on 25mm, 50mm, 100mm diameter.

the tube where hydrogen flows is connected to the detonation tube directly. Hydrogen concentration is controlled by varying the hydrogen-air flow ratio. In both types, the total amount of air and hydrogen flow rate which are regulated by an area flow meter in low flow rate and mass flow meter in large is 10~140 ℓ/min. In the premixed type, the concentration of hydrogen at the piping before the detonation tube is measured. Experiment is carried out after the mixture flowing from hydrogen inlet mixture tube to the open end. Ignition is charged by a discharge from electrode. Ignition positions are 250mm from the mixture inlet when the 25mm and 100mm tube are used, and 400mm when the 50mm tube is used. In the non-premixed type, hydrogen inflow position is 100mm from the air inlet, and ignition position is 250mm when the 25mm tube is used. To measure the pressure, several PCB 111A24 sensors are used and installed on the tubes of outer wall.

3 Results and discussion

3.1 Premixed type

The example of pressure profiles obtained by the experiment of premixed type, where the tube diameter is 25mm and the equivalence ratio ø is 1.0, is shown in Fig. 2. The horizontal axis is time, and the vertical axis isover pressure, where L is the distance from the igniter. At L=2450mm, the pressure profiles show the sharp

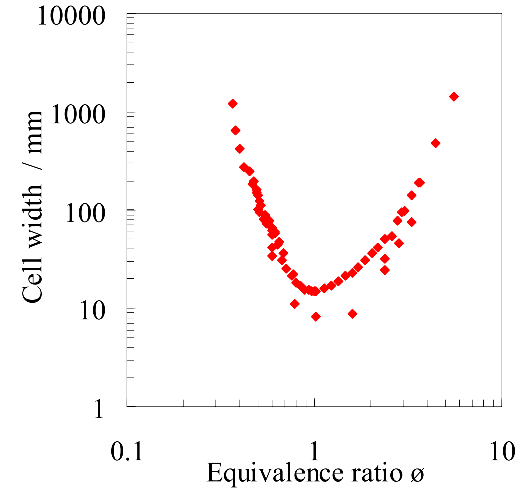

Fig.4. Cell width distribution for each equivalence ratio.

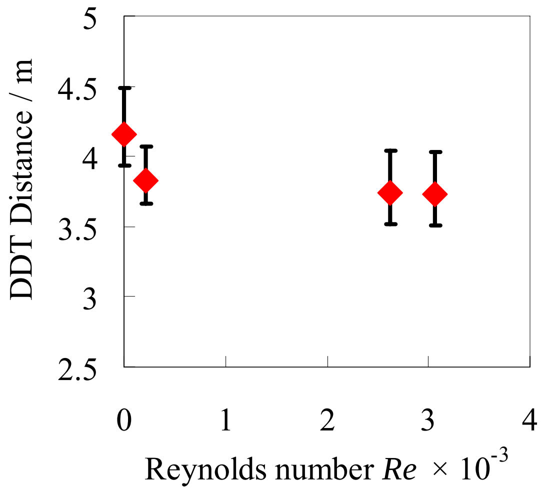

Fig. 5. Variation of DDT distance with flow rate of H_2-air mixture on 50mm diameter, equivalence ratio ø=1.0.

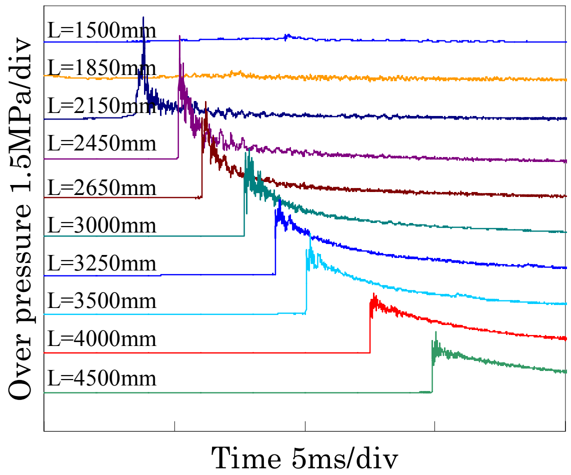

Fig. 6. Pressure history at non-premixed type; 25mm diameter, equivalence ratio ø=1.0.

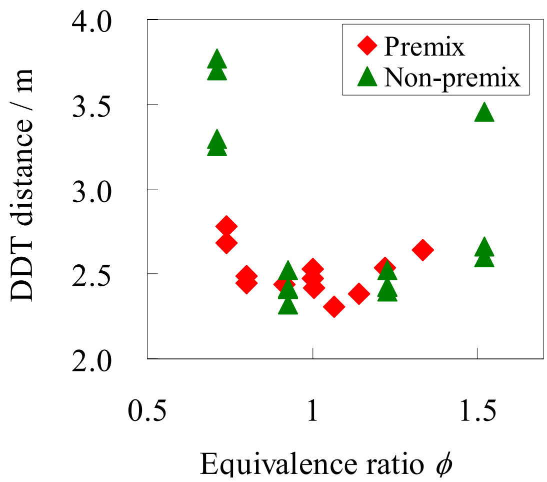

Fig. 7. Comparison with DDT distance distribution between premixed and non-premixed type.

rising, detonation transition is confirmed and the pressure value exceeds 5.7MPa. As the detonation wave Propagates into the tube, the pressure and propagation speed decrease and finally stabilize to the C-J value. The distance for stabilization is about 7250mm.

The DDT distance vs. the equivalence ratio for each diameter is shown in Fig. 3. In this study, experiment on 100mm tube diameter was carried out at only near the stoichiometric condition (ø =1.0). The horizontal axis is the equivalence ratio and the vertical axis is DDT distance. These results show that the equivalence ratio of 1.0 is the concentration which leads minimum DDT distance. The minimum DDT distance is 2.3m the tube of 25mm in diameter, 3.7m for 50mm tube and 5.8m for 100mm tube. However, the non-dimensional number L_D/D, ratio of DDT distance L_D to tube diameter D, was 96.7 for 25mm tube,73.3 for 50mm tube, 61.3 for 100mm tube. The L_D/D decreases as the tube diameter increases. As the equivalence ratio comes to lean or rich from the stoichiometric condition, the DDT distance becomes longer. The concentration distribution which can be confirmed DDT on 25mm diameter was ø=0.74~1.33 and 50mm ø=0.56~1.85. As a result, large diameter cause expansion of DDT limit concentration. This is because on the leaner or richer side, the detonation cell width becomes bigger as shown in Fig. 4[4] and as the tube diameter enlarges, the allowable cell width is broadened. From this discussion, although the rich limit is still not measured, it would expand, too. Therefore if the tube length is long enough, the larger diameter tubes which cause the expansion of limit concentration have a greater risk of DDT.

Fig.5 represents the variation of DDT distance with changing the Reynolds number on 50 mm diameter, where flow rate 10 ℓ/min is Re=200, 120 ℓ/min is Re=2600, 140 ℓ/min is Re=3100, and Re=0 means static system. The result of flowing system shows shorter average DDT distance than that of static system like hydrogen-oxygen case. The differential between static and flowing system is 400mm. In flowing system, the results of Re=2600 and Re =3100 show 100mm reduction of average DDT distance compared to that of Re=200, and large Reynolds number flow shows dispersion of result and the minimum DDT distance is 3.5m. Higher Reynolds number experiment which makes turbulence should be carried out to examine flow influence.

3.2 Comparison of the premixed type with the non-premixed type

The pressure profile of the non-premixed type is shown in Fig. 6. As an experimental condition, the tube diameter is 25mm and hydrogen-air flow ratio is 2.5:7.5. There is not much difference between this and the premixed type diagram.

Fig. 7 represents a comparison of the premixed type results with the non-premixed type using the 25 mm diameter tube. The horizontal axis is the equivalence ratio and the vertical axis is DDT distance. Although the results show about the same value in both flow types at around the equivalence ratio of 1.0, while the DDT is observed at the richer concentration in the non-premixed type than that at the rich limit concentration of the premixed type. In addition, at around the limit concentration, the DDT distance shows a scattering result and despite of the same condition, probability of DDT has dispersion. One of the possible explanations is the influence of mixture concentration distribution which can not be observed in the premixed type in the tube. In the future, the distribution in the detonation tube will be measured experimentally and calculated by numerical simulation.

4 Conclusion

In this work, the experiments about the DDT of hydrogen-air mixture in flow system are carried out changing the tube diameter, equivalence ratio, and flow type. From the premixed type experiment, the larger tube diameter causes the extension of DDT distance, reduction of L_D/D (ratio of DDT distance to tube diameter), and expansion of DDT limit concentration by spread of allowance cell width. In flowing system, DDT distance become shorter than that of static system, and high Reynolds number produce dispersion of result and minimum DDT distance. The result of the non-premixed type shows about the same value with the premixed type at around equivalence ratio of 1.0 and the fluctuations of DDT distance and occurrence at DDT limit concentration.

Acknowledgement

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