Fundamental Study on Detonation Wave Characteristics of Acetylene-Oxygen Mixture for Pulse Detonation Engine

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1 Introduction

A pulse detonation engine (PDE) is a cycling engine that uses periodic detonation waves that consist of a supersonic flame with a shock front. The PDE has been studied in several organizations as a highly efficient next-generation engine with a high specific impulse and wide operating range [1-3]. However, one problematic issue remains for the PDE: detonation initiation in a short tube. The detonation wave can be generated in very long tube, but a longer tube causes the engine to be heavier. Thus a deflagration to detonation transition (DDT) device is commonly used to initiate the detonation wave in a short tube. In this study, a fundamental reanalysis of the PDE was undertaken. Specifically, single shot and pulsed shot experiments were conducted to better understand the detonation initiation characteristics of an oxygen-acetylene mixture. In addition, ethanol addition study was conducted and the faster detonation velocity was estimated in the case of additive propellants.

2 Experimental Apparatus

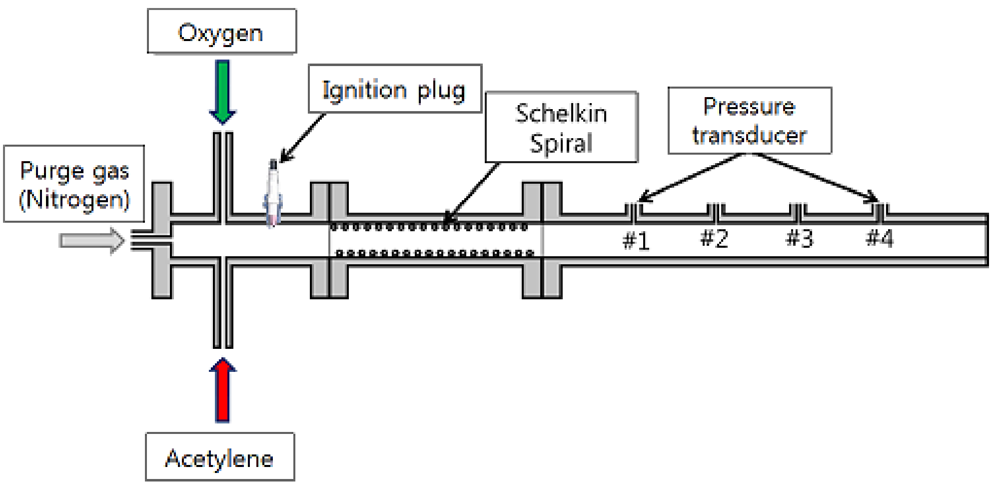

Figure 1. Schematic of detonation tube and DDT device

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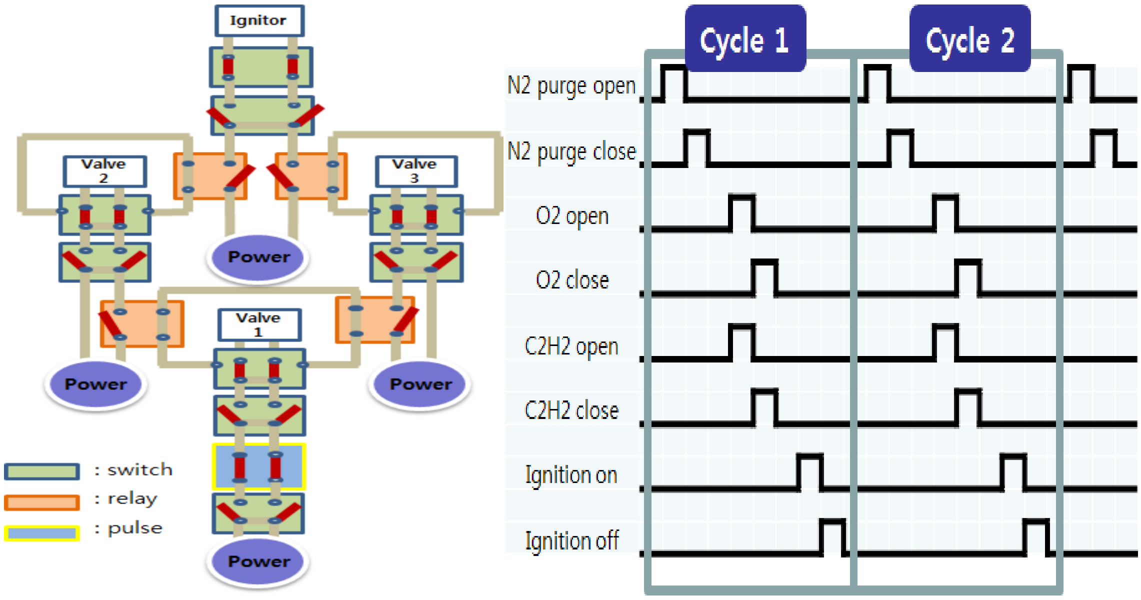
In order to perform the experiment, an oxygen-acetylene mixture was chosen as the propellant because of its highly detonative characteristics [4]. The detonation tube shown in figure 1 was used to study three single shot detonation wave characteristics: the mixture ratio, tube length and DDT device. From previous studies, it was established that the tube diameter should be larger than 13 times the size of the detonation cell [5]. The tube diameter in this study was 24.4 mm, about 24 times the width of detonation cell of the oxygen and acetylene mixture. This ratio was chosen because the methane/air mixture was a focal point of this study. The tube length for the short tube case was 920 mm and 1,250 mm for the long tube. The propellants were injected via 1 mm diameter single-hole injectors from opposing sides. The DDT device, a Shchelkin spiral [3], as shown, was used to compare the DDT device effects. The spirals had a length of 150 mm and 300 mm with a blockage ratio of 49.8%. In the single shot cases, the acetylene was injected for 1 sec at 1 bar pressure and the oxygen for 1 sec at 1 bar to 5 bar pressure. Ignition was started 0.1 sec after the injection by a single spark plug at the tube wall. For the pulsed shot study, a cyclical operating system was established, as seen in (a) of figure 2, and the operating sequence was determined, as seen in (b) of figure 2.



(a) Control system schematic (b) operating sequence

Figure 2. Control system for pulsed shot experiment

3 Results

The detonation characteristics were determined by the study of wave velocities , which were calculated from measured combustion pressures. When a flame moved from the closed end of the tube to the opened end, dynamic pressures were measured using a PCB dynamic transducer from two points at the same axis with a 300 mm distance, as shown in figure 1. The measured pressures, which are shown in figure 3, have one spike-like peak and one hill-like peak for each PCB. The spike-like peak is a von Neumman spike of the ZND model, and the hill-like peak is the detonation pressure [6]. The first peaks of PCB 1 and PCB 2 had a small time difference. The flame wave velocity was calculated from the time difference with the distance of two measuring points such as PCB 1 and PCB 2. Equivalent ratios of injected propellants were calculated from the injection pressures of the propellants. The velocity and pressure results are shown in figure 4 and figure 5, and the results were compared with the theoretical results. The theoretical velocity and pressure were calculated using the Chapman-Jouguet (C-J) condition using the CEA code [7]. The maximum C-J condition was shown at an equivalent ratio of approximately 2.4.

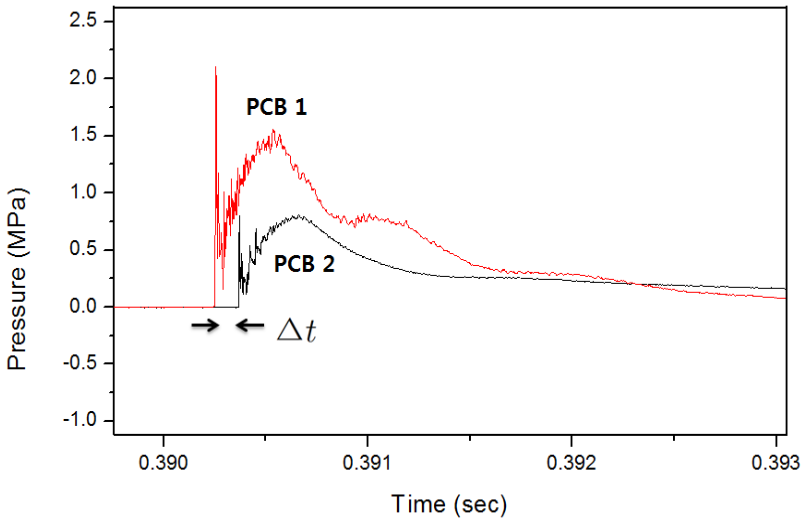


Figure 3. Measured pressure peaks and time difference

As depicted in figure 4, the experimental velocities have maximum values near the maximum C-J condition. Additionally, the overall values were slightly lower than the C-J velocity at low and high equivalence ratios. For the long tube cases (1,250 mm), the longer DDT device caused a higher velocity over the equivalence ratio of 2.5, while the velocities were similar under the equivalent ratio of 2.0. Moreover, the short tube (920 mm) generated a faster wave velocity than the long tube.

The peak pressures shown in figure 5 were also compared. However, the measured pressure was about 0.5 times the C-J pressure because the pressure was measured from an extended Teflon tube. The combustion pressure was not significantly affected by the DDT device or the tube length. The pressure of the long tube was slightly higher than that of the short tube. In addition, the DDT device worked to inhibit the pressure from rising, so the case without the DDT device showed the highest pressure.

Figure 6 shows the measured pressures from the cycling operation at the equivalent ratio of 1.7. The pressure peak became lower when the cycle was repeated after the first shot. This was due to the fact that the propellant feeding pressure was not sufficient to fill the tube with in the short interval of time.

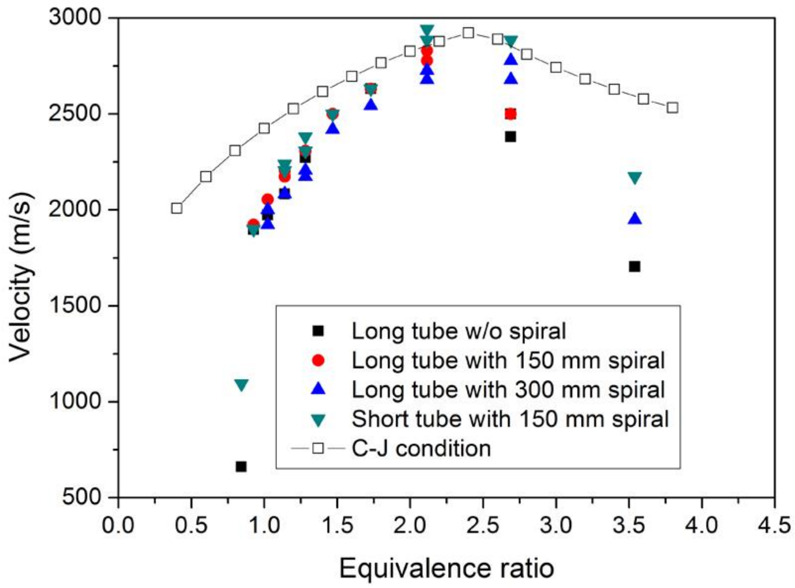


Figure 4. Estimated wave velocity with C-J velocity as equivalence ratios

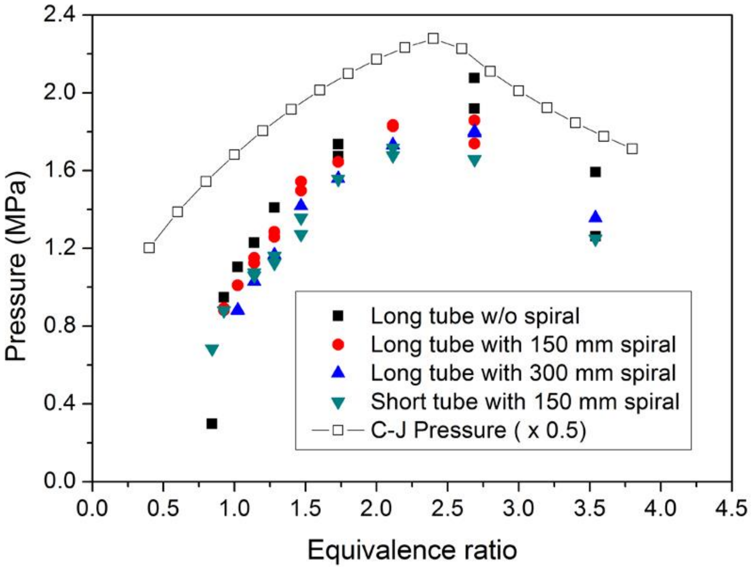


Figure 5. Measured pressures with C-J pressure as equivalence ratios

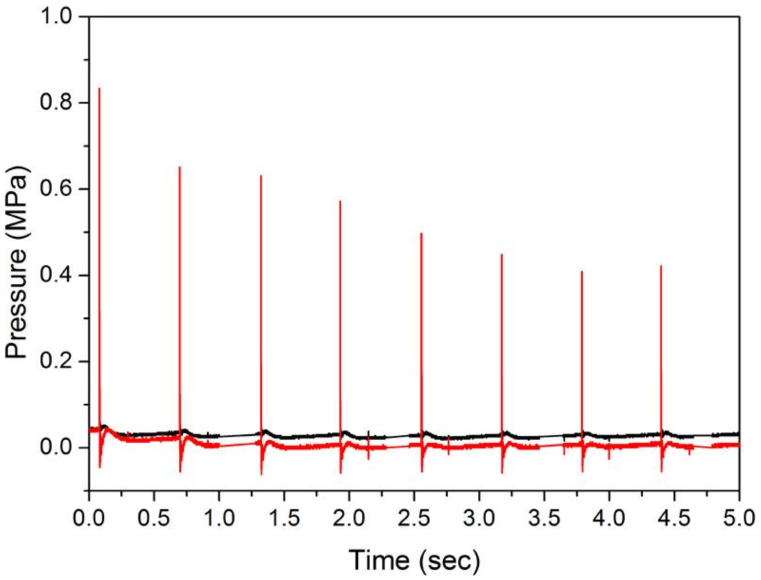


Figure 6. Measured pressures for 1.6 Hz pulsating operation

4 Ethanol Addition

An ethanol addition experiment was also conducted and studied as well.. For the ethanol injection, a GDI injector, the part of automobile of KIA motors, was adopted as larger detonation tube which was 72 mmby diameter and 762 mm by length. The tube facility was as shown in figure 7. The two PCB transducers were used to measure the pressure peaks for calculating detonation velocity. Figure 8 shows an injection system for the ethanol addition with acetylene and oxygen mixture. The ethanol was injected at the center while oxygen and acetylene were injected at tangential direction. All the propellants were mixed by strong swirling of the gas injection. In a condition shown in figure 9, the ethanol was injected at 20 bar pressure with various equivalence ratios of the acetylene and oxygen mixture when the mass flow rate of ethanol was 7.8 g/s. For the addition cases, the detonation velocities below 1.8 of equivalence ratio were slightly faster than non-addition cases. Further studies should be conducted for detailed characteristics.

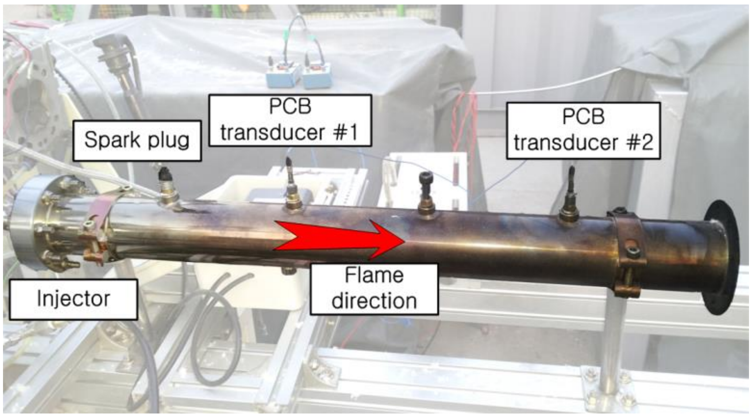


Figure 7. Detonation tube for ethanol additive study

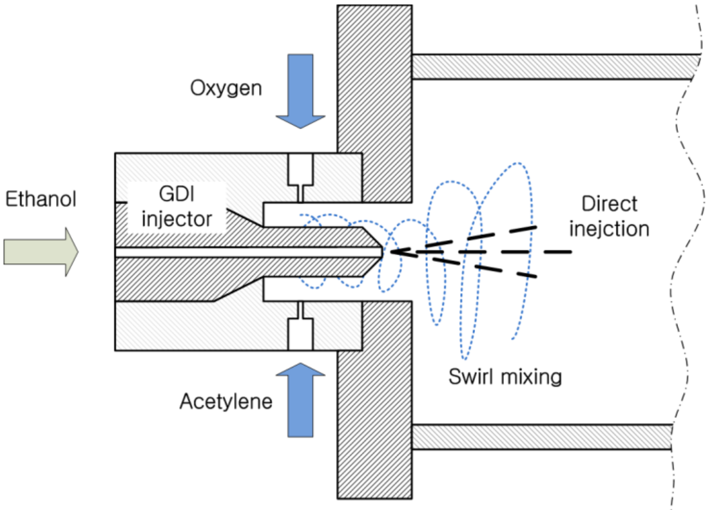


Figure 8. Injection system for ethanol additive using GDI injector

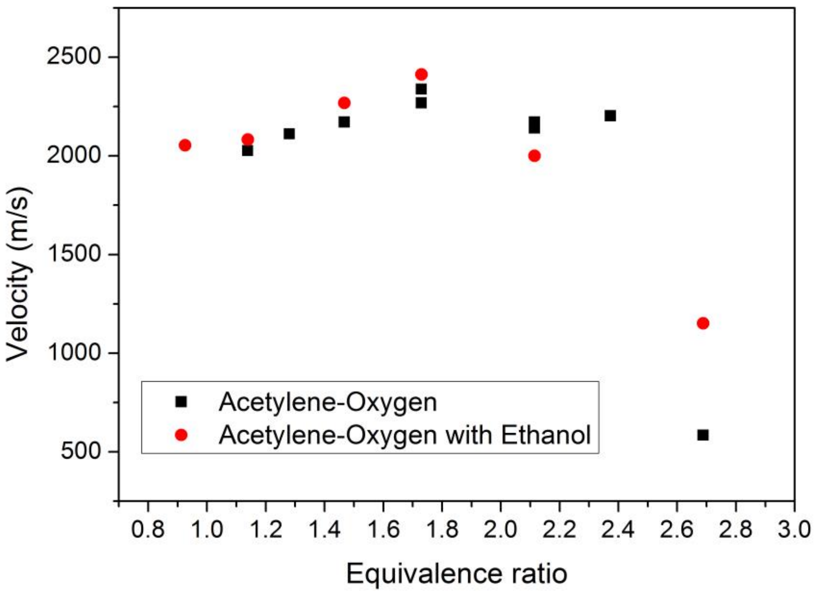


Figure 9. Measured velocity of additive mixture

5 Conclusion

In order to develop a high frequency PDE, a fundamental study was performed on a detonation tube with acetylene and oxygen as propellants. The detonation pressure was measured by using PCB dynamic transducers in accordance with the equivalent ratio, tube length and DDT device. In addition, the wave velocity was calculated from the time difference of measured pressures at different points. The maximum condition was determined at the equivalence ratio of about 2.4. For the wave velocity, the shorter tube and longer DDT device were effective. In contrast, a longer tube without a DDT device constituted the best condition for the measured pressure. Additionally, as the result of the pulsating test at 1.6 Hz, it was determined that the propellant feeding pressure should be increased to achieve a high frequency. The results of this study will be used as the basis for the development of a pulse detonation engine in future research.

Acknowledgement

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References

[1] F.R. Schauer et al. (2005). Detonation initiation of hydrocarbon-air mixtures in a pulsed detonation engine. 43rd AIAA Aerospace Sciences Meeting. AIAA 2005-1343.

[2] Chiping Li and K. Kailasanath. (2003). Detonation initiation in pulse detonation engine. 41st Aerospace Sciences Meeting and Exhibit. AIAA 2003-1170.

[3] T. H. New et al. (2006). Experimental study on deflagration-to-detonation transition enhancement methods in a PDE. 14th AIAA/AHI Space Planes and Hypersonic Systems and Technologies Conference. AIAA 2006-7958.

[4] M. Kaneshige, J. E. Shepherd. (1997). Detonation Database. GALCIT Technical Report FM97-8.

[5] W. Fickett, W. C. Davis. (1979). Detonation: Theory and Experiment. Courier Dover Publications (ISBN 0486414566).

[6] Kunio Terao. (2007). Irreversible Phenomena: Ignitions, Combustion, and Detonation Waves. Springer (ISBN 3540499016).

[7] S. Gordon, B. J. McBride. (1994). Computer Program for Calculation Complex Chemical Equilibrium Compositions and Applications. NASA-RP-1311.