# Detonation propagation characteristics according to the fuel injector shape of rotating detonation engine

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## 1 Introduction

Recently, as the efficiency improvement of the propulsion engine reaches its limit, the detonation engine with the Humphrey having high efficiency compared to the Brayton cycle has been actively studied during the last decade[1,2]. Injectors affecting the mixing of fuel in non-premixed combustion affect the efficiency of the propulsion engine. Moreover, detonation propagation characteristics in a rotating detonation engine(RDE) are affected by geometry, propellant mixture, etc[3]. In particular, the propellant mixture is a factor determined by the injector, and in terms of the efficiency of the RDE, the pressure loss in the propellant injection process must be reduced. Research on injectors should be carried out, including for this reason, and studies are being conducted[4,5].

In this study, gaseous ethylene(GC2H4) was used as a fuel, and gaseous oxygen(GO2) was used as an oxidizer. And the experimental conditions were as follows: the mass flow rate range was 31.26 ~ 50.21 g/s and the equivalent ratio was 0.7 ~ 1.44. The injector of the oxidizer was fixed with a slit, and the shape of the four injectors of the fuel was changed.

## 2 Experiments apparatus

The RDE used in the experiment is shown in fig 1 (a). The channel length of RDE is 70 mm, the inner diameter is 50 mm, and the channel width is 4.5 mm. The oxidizer is injected into the exit direction through a slit and fuel is injected into the oxidant transversely from the RDE center body to the channel.

In order to determine the behavior of the detonation wave, the PCB-type transmitter(PCB Piezotronic,113B24) was measured through a scopecorder(Yokogawa, DL850e) at 10MS/s through an amplifier. In addition, high-speed photography was performed using a high-speed camera(Phantom, v2512) at 75,000 fps and 512  512 resolution.

The experimental procedure is as follows: when the experiment starts, the propellant of the RDE and the pre-detonator is supplied. After 200 milliseconds when the fuel supply stabilizes, it ignites through the spark plug of the pre-detonator. At the same time, through the TTL signal, the scopecorder

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measurement and high-speed camera photography are started. Thereafter, the experiment progressed for 800 milliseconds. It then finishes with a nitrogen gas purge.

The total number of fuel injectors used in the experiment is 4, and the detailed size is shown in table 1. The injection area of all injectors is 47 mm2 to equalize the experimental conditions. The four injectors were designed to be changeable and were assembled with a torque of 10 N・m

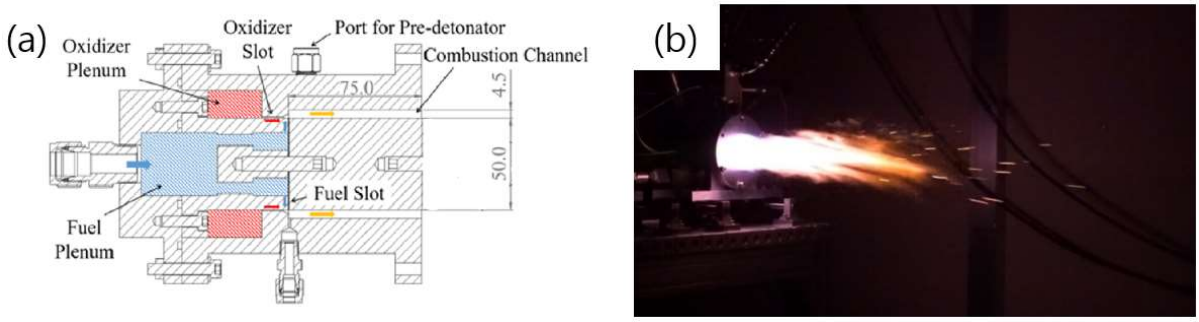


Figure 1 (a): Configuration of RDE (unit: mm)[6] (b): Hot flow test which it takes a photograph by using the digital camera

Table 1: Size of each injector

| | Depth (mm) | Width (mm) | Num of holes | Area (mm2) | Material |
|---|---|---|---|---|---|
| Slit | 0.3 | - | | 47.13 | SUS316 |
| Inj01 | 0.5 | 2.0 | 47 | 47 | C1020 |
| Inj02 | 1.0 | 1.0 | 47 | 47 | C1020 |
| Inj04 | 2.0 | 0.5 | 47 | 47 | C1020 |

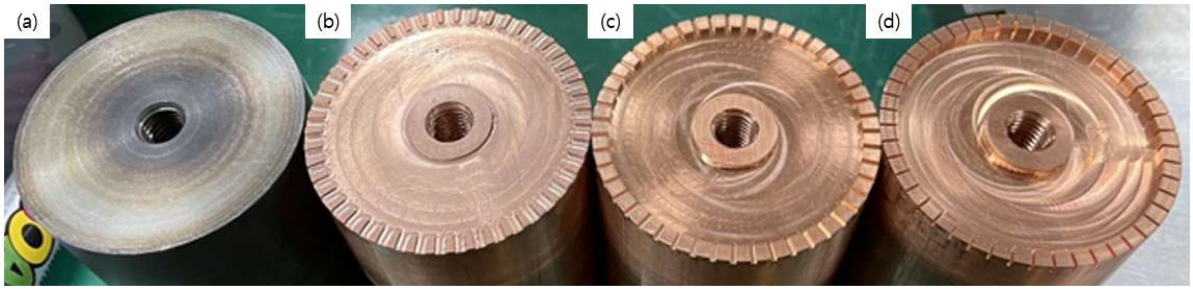


Figure 2 (a): Slit injector (b): Inj01 (c): Inj02 (d): Inj04

# 3 Experiment results

The results of the experiment according to the shape of the injector are shown in table 2, and the FFT graph for one case per injector is fig 3. Experiments were conducted three times for each type of injector, and a total of 12 experiments were conducted. The mass flow rate range was 31.26 ~ 50.21 g/s, and the equivalent ratio ranged from 0.7 to 1.44.

Based on the experimental results, the frequency was obtained by performing FFT analysis in fig 3. Detonation velocity was calculated based on the frequency and wave number obtained afterward. When the wave number is 2 or 3, the velocity is written in the table when there are 3 waves

In the case of the slit injector, two waves were maintained until the end like in Fig 4. when comparing case 2 and case 3, it can be seen that the detonation wave speed also increases when the flow rate is large under similar experimental conditions. Inj01, two waves were rotated in the same way as the slit injector, but it was confirmed that the detonation velocity was higher overall. In particular, when comparing Case 2 and Case 6, the experimental conditions are almost identical, but the detonation velocity of case 6 is larger, which is considered to be the result of the difference in injector shape affecting fuel mixing.

In the experiment of Inj02, we can see that the number of detonation waves is 2 or 3, unlike the previous cases. In particular, around 456 ms, one wave started to rotate clockwise, and then three waves were rotated clockwise. When cases 6 and 7 with similar conditions were compared, case 7 showed a lower result than case 6 at 1618 m / s in 2 wave mode, but 3 wave mode began to appear. In the case of Inj04, the experimental conditions were somewhat different, so it was difficult to directly compare with the above cases, but three waves were maintained and showed different patterns

Table 2 Experiment results

| Case | Type | $\dot{m}$ (g/s) | Φ | Frequency (Hz) | Wave num. | $V_{detonation}$ (m/s) |
|---|---|---|---|---|---|---|
| 1 | Slit | 31.26 | 1.44 | 17,897 | 2 | 1,475 |
| 2 | Slit | 43.20 | 0.86 | 18,372 | 2 | 1,514 |
| 3 | Slit | 42.25 | 0.86 | 18,215 | 2 | 1,504 |
| 4 | Inj01 | 41.13 | 1.11 | 20,347 | 2 | 1,677 |
| 5 | Inj01 | 44.41 | 0.99 | 20,351 | 2 | 1,677 |
| 6 | Inj01 | 44.13 | 0.86 | 20,362 | 2 | 1,678 |
| 7 | Inj02 | 44.90 | 0.90 | 24,565 | 2 or 3 | 1,350 |
| 8 | Inj02 | 44.40 | 0.70 | 25,075 | 2 or 3 | 1,378 |
| 9 | Inj02 | 44.01 | 1.18 | 25,331 | 2 or 3 | 1,392 |
| 10 | Inj04 | 50.21 | 0.96 | 25,877 | 2 or 3 | 1,422 |
| 11 | Inj04 | 48.19 | 0.99 | 25,874 | 3 | 1,422 |
| 12 | Inj04 | 49.30 | 0.98 | 26,173 | 3 | 1,438 |

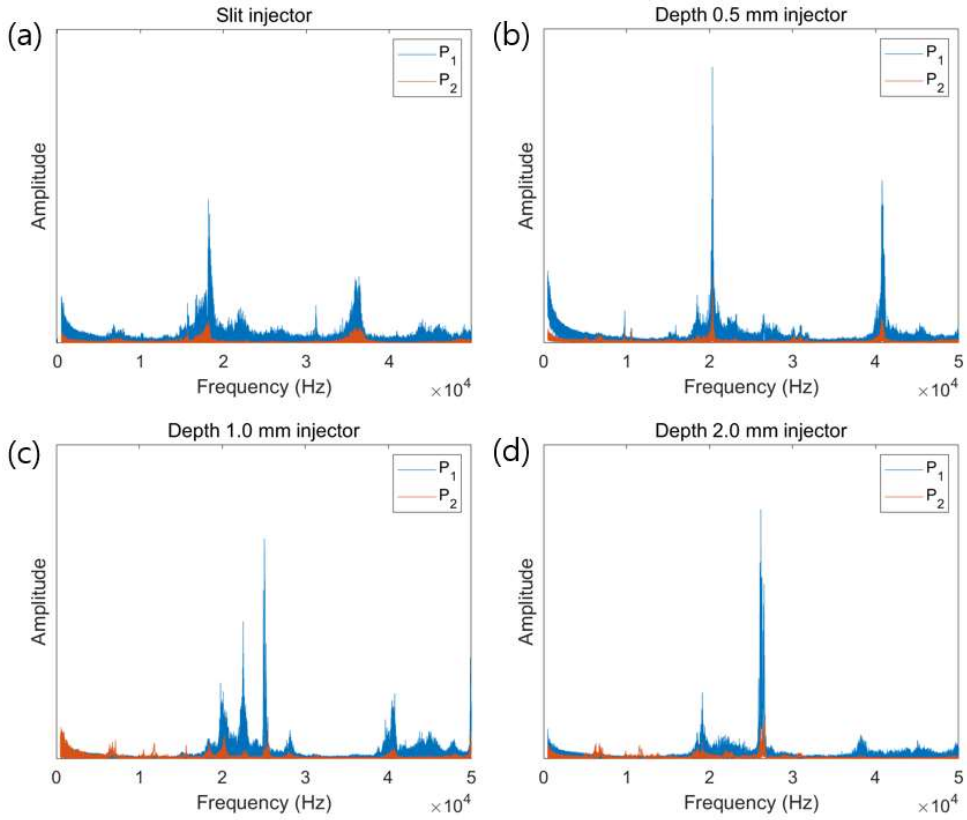


Figure 3: FFT graphs (a): Slit injector, case 3 (b): Inj01, case 4 (c): Inj02, case 9 (d): Inj04, case 11

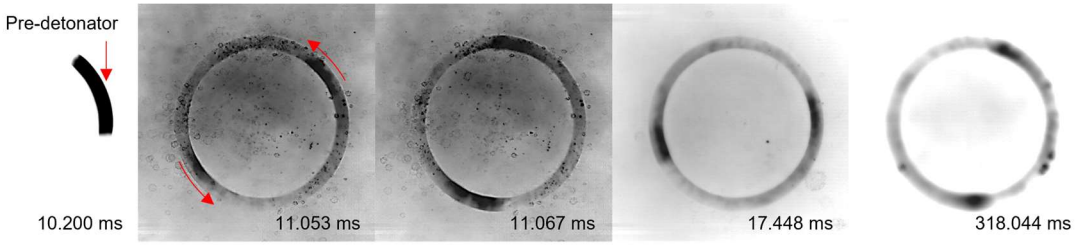


Figure 4: High speed photographys of case 3

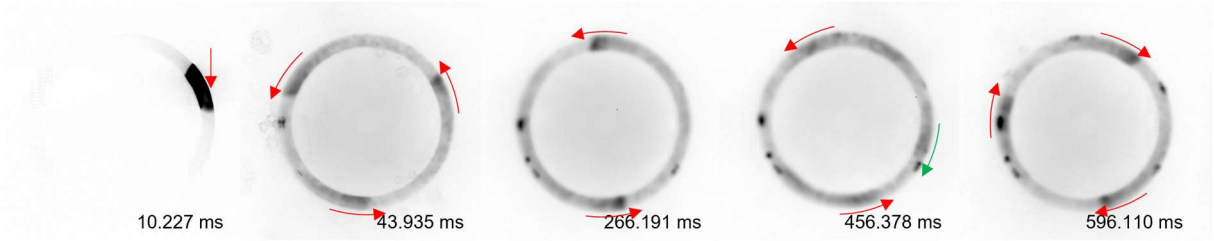


Figure 5: High speed photographys of case 9

## 4 Conclusion and future works

- In order to improve the efficiency of the RDE, the injector shape was used as a variable. Slit, Inj01, Inj02, and Inj04 were experiments conducted three times for each injector shape. The mass flow rate range was 31.26 ~ 50.21 g/s, and the equivalent ratio was 0.7 ~ 1.44

- Comparing cases 2 and 6, which have similar conditions, it can be seen that the detonation speed of Inj01 is higher than that of the slit injector. These results suggest that the fuel mixing is relatively good and the combustion efficiency is higher.

- Comparing cases 6 and 7, Inj01 showed a detonation speed of 1,678 m/s at 2 wave mode, which was 60 m/s faster than Inj02's 1,618. However, the 3 wave mode, which was not seen in Inj01, started to be seen in Inj02. And even in Inj04, 3 wave mode was maintained.

- In future work, the experiment will be carried out in various ranges of equivalence ratios, and the data are accumulated through various cases to compare the results in a wide range.

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