# Initiation of gasoline-air mixture with PDE initiator

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Abstract

The detonation initiation of liquid fuel-air mixture was studied. Initiator was used to initiate the detonation effectively. The initiator with the mixture of hydrogen-oxygen and gasoline-oxygen were tested to initiate the gasoline-air mixture. The initiator with hydrogen-oxygen mixture was firstly tested. The fully developed detonation was observed in the initiator. However, the detonation could not initiate the gasoline-air mixture. This is assumed to be the result of the low Neumann peak pressure of hydrogen-oxygen detonation compared to the gasoline-air mixture. The initiator with gasoline-oxygen mixture, of which the Neumann peak pressure is twice higher than gasoline-air mixture, was tried next. Additionally, pre-evaporator was equipped to enhance the evaporation of gasoline. The detonation of gasoline-air mixture was successfully initiated using the gasoline-oxygen initiator and pre-evaporator.

## 1. Introduction

Liquid fuel has great advantages for the PDE use, because of its' larger density of energy than gaseous fuel[1]. However, there are great difficulties to initiate the liquid fuel. Therefore, the special method to initiate the detonation of liquid fuel has been quested[2-5]. Some factors, such as evaporation of the fuel, mixing condition of fuel-air, geometry of the combustion chamber and the input energy and others, are the effective to initiate. The initiator, which can effectively generate the large input energy, has been developed for better initiation in our group. The effects of the input energy were investigated by using different kind of fuel for the initiator. $H_2$-$O_2$ mixture, which is easy to initiate the detonation, and gasoline-air mixture, which has large heat release, are tested as initiator mixture.

## 2. Experimental apparatus

Liquid fuel PDE at Hiroshima University consists of the main combustor and initiator. Schematic diagram is shown in figure1. Diameter and length of the

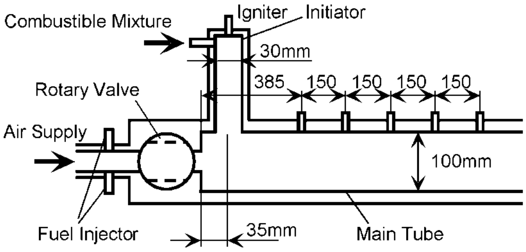
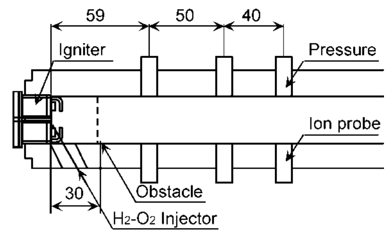
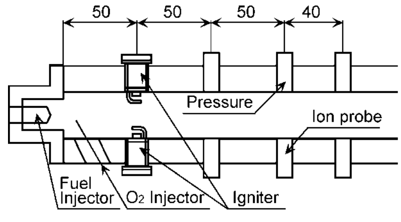



Fig1 Schematic diagram of experimental




(a) $H_2$-$O_2$ initiator




(b) Gasoline-$O_2$ initiator

Fig2 Schematic diagram of initiator. Diameter of initiator is 30mm.

main combustor are 100mm and 2185mm respectively. Fuel is injected at upstream of the rotary valve, which cuts the flow periodically. The initiator, of which the diameter is 30mm and the length is 200mm, has fuel-oxidizer injector and igniter. There are two kinds of initiator, hydrogen-oxygen [figure2(a)] and gasoline-oxygen[figure2(b)]. The hydrogen-oxygen initiator has the obstacle to generate the strong turbulence to shorten the DDT length. The obstacle is made from 2mm diameter rods arranged in rake shape. Igniter and liquid fuel injector for commercial automobile are used in this system. According to the officially announced data, droplet diameter of the injected liquid fuel at 100atm of injection pressure is 18μm. Injection, ignition and closing motion of electric valves are controlled by the basis of the rotational angle of the rotary valve. The rotary encoder detects the rotational angle, and the personal computer control the whole system via digital I/O board.

## 3. Results and discussion

### 3.1 Experimental conditions

White gasoline produced by the Coleman Inc. is used as liquid fuel. Usual automotive gasoline contains additives to elevate the ignition temperature. On the other hand, white gasoline does not such additives, thus the ignition temperature is 545K, which is as low as diesel fuel. The low ignition temperature expects high sensitivity to the initiation. Additionally, the boiling temperature is relatively low (333-413K), so this fuel has good evaporativity. Therefore, it can be thought that white gasoline is suitable fuel for the liquid fuel PDE.

Table1 shows the calculated properties of detonation of stoichiometric n-octane and hydrogen mixture. While white gasoline includes not only n-octane but also another chemical spices, it can be assumed that the difference of the detonation property between gasoline and n-octane is not so large, because the most part of the property is determined by the heat release.

### 3.2 Initiation by hydrogen-oxygen initiator

Three pares of pressure transducer and ion probe are set in the initiator shown in fig.2 to observe the propagation of the detonation. Result is shown in figure3. Pressure transducer P1 and ion probe I1 are set at 59mm from the ignition point, and P2,I2 and P3,I3 are set at interval of 50 or 40mm. Ion sensors are gathered up by using the transistor, thus ion signal is shaped like steps. Pressure histories of P1 and P2 slide 2.0 and 4.0MPa respectively. Obstacle is set at 30mm from the ignition point. Pressure P1 and ion probe I1 rise simultaneously, however detonation is not initiated at this point, because of the gradual pressure increase. The pressure rising at the 2nd and the 3rd measuring point is more than 4.0MPa. This indicates that the detonation is initiated between the 1st and the 2nd measuring point.

Table1 Calculated properties of detonation of n-octane and $H_2$ at stoichiometric mixing.

| | n-oct. -$O_2$ | n-oct. -Air | $H_2$-$O_2$ | $H_2$-Air |
|---|---|---|---|---|
| Initial Condition | To=298K, Po=0.1MPa | | | |
| Propagation velocity m/s | 2344 | 1780 | 2843 | 1949 |
| Pressure at CJ state MPa | 3.83 | 1.76 | 1.81 | 1.49 |
| Neumann peak pressure MPa | 7.84 | 3.37 | 3.31 | 2.74 |

Table2 Experimental Conditions

(a) Main Combustor with $H_2$-$O_2$ Initiator

| Initiator | |
|---|---|
| Injected mixture | $2H_2+O_2$ |
| Injection duration | 18ms(240cc) |
| Ignition | Just after the end of injection |
| **Main Combustor** | |
| Supplied Air | 8.0L/cycle |
| Injected fuel | White gasoline |
| Injected fuel mass | 1.34g |
| Ignition timing | 10 deg after valve close |

(b) Main Combustor with $H_2$-$O_2$ Initiator

| Initiator | |
|---|---|
| Injected fuel | White gasoline |
| Fuel injection | 0.29g |
| Injected oxidizer | $O_2$ |
| Oxidizer injection | 40ms(625cc) |
| Ignition | Just after the end of injection |
| **Main Combustor** | |
| Supplied Air | 6.0L/cycle |
| Injected fuel | White gasoline |
| Injected fuel mass | 2.93g *unclear |
| Ignition timing | 35 deg after valve close |

The experiment of initiation of gasoline-air mixture was conducted by the hydrogen-oxygen initiator mentioned above. There are five measuring stations along the main combustion tube as shown in fig.1, and the pressure transducer or ion probe can be set at each point. One pressure transducer is set at the 3rd measuring point and the four ion probes are set at the rest points. Experimental conditions are shown in table2(a), and the results are shown in figure4. Fig.4 shows the pressure history at the 3rd and the recorded signal from the ion sensor at the points of 1,2,4 and 5. The signal from the ion probe is amplified by the transistor, and is gathered up with 0.5ms width by multiplexer. Pressure rising at P3 can be seen before I1 rising. This indicates that the shock wave from the initiator travels the main combustion tube without coupling with the reaction of combustion.

3.3 Initiation by gasoline-oxygen initiator

It can be assumed that the initiator with gasoline-oxygen has great advantage, because Neumann peak pressure of n-octane-oxygen mixture shown in table1 is more than twice that of hydrogen-oxygen. The development of

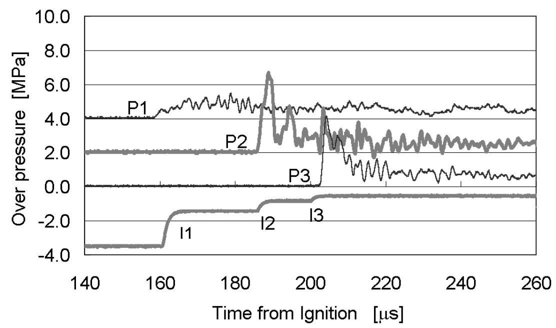



Fig3 Propagation of shock wave (pressure transducer) and flame (ion probe) in $H_2$-$O_2$ initiator.

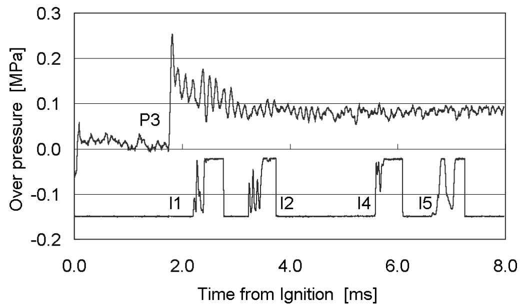



Fig4 Propagation of shock wave (pressure transducer) and flame (ion probe) in gasoline-air mixture in main tube, using $H_2$-$O_2$ initiator.

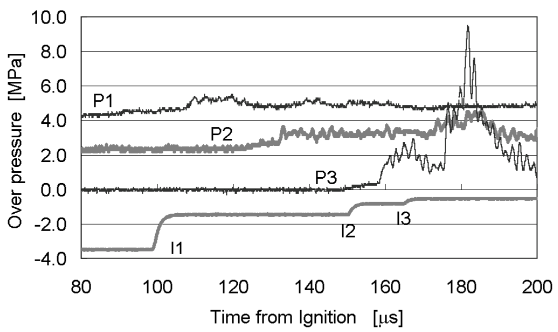



Fig5 Propagation of shock wave (pressure transducer) and flame (ion probe) in gasoline-$O_2$ initiator.

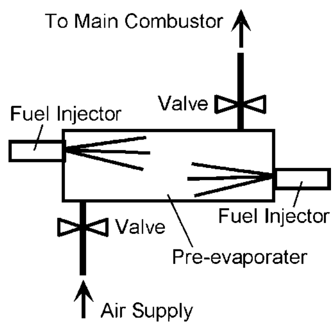



Fig6 Schematic diagram of pre-evaporator

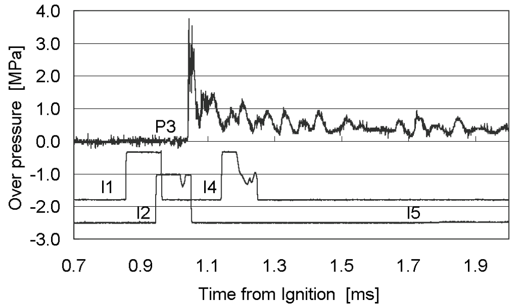



Fig7 Propagation of shock wave (pressure transducer) and flame (ion probe) in gasoline-air mixture in main tube, using gasoline-$O_2$ initiator and pre-evaporator.

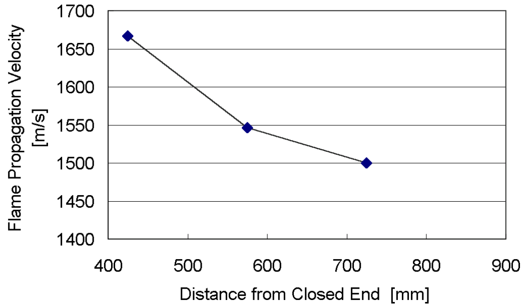



Fig8 Flame propagation velocity in the main tube partially filled with gasoline-air mixture ,using gasoline-$O_2$ initiator.

the flame and shock wave in initiator were observed by the three sets of pressure transducer and ion probe. Recorded signal from pressure transducer and ion prove is shown in figure5. The pressure rise (P1 at 110μs, P2 at 130μs and P3 at 160μs) can be seen after the small pressure rise (P1 at 90μs, P2 at 120μs and P3 at 150μs) in all measuring points. Initial pressure rise comes from the pressure wave formed in front of the flame. The pressure P3 increases at 175μs abruptly, and the maximum pressure is 9MPa. This might come from the explosion, which can start the detonation. Accordingly, detonation in the initiator is not fully developed but overdriven detonation.

The initiation of gasoline-air mixture was conducted with the initiator mentioned above. Pre-evaporator shown in figure6 is installed to improve the condition of fuel evaporation. Pre-evaporator is the container of 300cc heated with the electric heater of 800W. Fuel is injected into the pre-evaporator and evaporated. Evaporated highly rich mixture is pushed out to the upstream of main combustor by pressurized air. Injected rich mixture is mixed with the air to suitable concentration. The possibility of the backfire to the pre-evaporator is not so large, because the equivalence ratio of mixture in pre-evaporator is more than 10. However, the pre-evaporator itself has enough strength to endure the pressure of explosion. The problem of using pre-evaporator is uncertainty of the equivalence ratio of the mixture in main combustor, because a part of fuel remains in the pre-evaporator after pushing out by air.

Flame propagation was observed by the five measuring points. One pressure transducer is set at the 3rd measuring point, and the four ion probes are set at the rest points. Figure7 shows the propagation of the shock wave and the flame in the main combustion tube. The shock wave and the flame are in near, because the ion signals I1 and I2 rise before rising of P3 by shock wave. The peak pressure of P3 is 3.8MPa, which is slightly larger than the theoretically calculated value shown in table1. Ion signal I5 rises slightly at 1.8ms. The propagation velocity from the 1st to 4th point is shown in figure8. The average propagation velocity between first two points is 1667m/s and 1500m/s at the last section. The detonation seems slightly decayed, but is still kept. Detonation is completely decayed at the 5th point. This is because the mixture is not filled up to this position.

## 4. Conclusion

Experiment on initiation of gasoline-air mixture was conducted, using the initiator with hydrogen-oxygen mixture or gasoline-oxygen mixture. In case of using hydrogen-oxygen initiator, shock wave and flame separate each other and detonation was not generated. It is assumed that the initiation energy provided by the hydrogen-oxygen mixture is inherently shorted to initiate the gasoline-air mixture. Secondary, experiment of gasoline-air initiation was conducted, using gasoline-oxygen initiator and newly developed pre-evaporator for improving the condition of fuel evaporation. Gasoline-air mixture could be successfully initiated with this method. The next goal of the future study is the multi cycle operation.

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