A study of Combustion Characteristics of Heterogeneous Combustion Field by Impinging Injection and Multiple Fuel Injections

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1 Instruction

Nowadays, global environmental problems become serious, and it is a common belief that the internal combustion engines are the main causes. Due to the depletion of natural resources and environmental problems, it is necessary to achieve low emissions and low fuel consumption for internal combustion engines, especially automotive diesel engines. From the viewpoint of improvement fuel consumption, the thermal efficiency, and the reduction of NO_x, CO, and HC emissions, DI (Direct Injection) has been widely used in internal combustion engines. Except DI, there are several techniques were developed, such as EGR, lean combustion, and HCCI. Previous research[1] indicated that impinging injection can help with the unburned components adhere to the wall surface by using the collision between the fuel spray.

In this study, the experiments have been carried out to examine the influence of the injection type and injection timing difference to ignition on combustion characteristics such as maximum burning pressure, total burning time and ratio of heat release by using impinging injection and multiple fuel injections.

2 Experimental apparatus and conditions

Experimental apparatus and schematic diagram show in Fig.1. The two combustion chambers, show in Fig.2. The experimental apparatus consist two combustion chambers, data sampling control system, injector and ignition system and its delay circuit. In Fig.2, combustion chamber A is used for examining combustion characteristics, combustion chamber B is used for observation of flame behavior. The volume of chamber A is approximately 2500 cc. It is possible to observe the pressure during combustion process by using a

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piezo-electric pressure transducer which is fitted on chamber A. The volume of chamber B is approximately 450 cc. Acrylic plates with a thickness of 30 mm are attached on chamber B to observe the flame behavior. Panasonic digital video camera HC-VX985M with frame rate of 120 fps is used for observation. Schlieren system (Mizojiri-opt.co: SCHLLIEREN COMPACT200) is used for the observation of droplets.

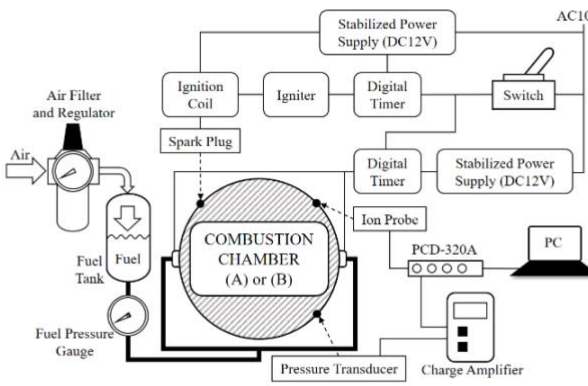

Figure 1. Experimental apparatus

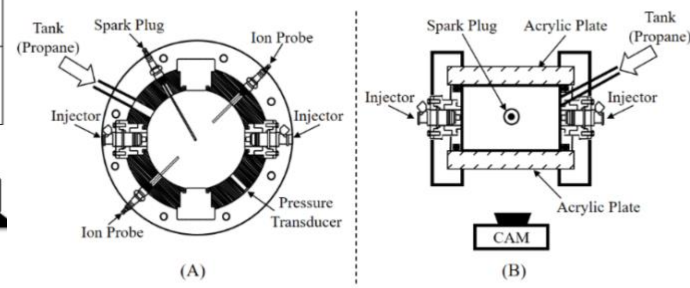

Figure 2. Combustion chamber

In these experiments, after evacuating the interior of the combustion chamber, the propane-air mixture which is in a predetermined equivalence ratio is used as a substitute for air. Through switches and delay circuit, by conducting fuel injection and spark ignition, we observed the combustion field which simulated the heterogeneous combustion. The n-hexadecane is used as injection fuel.

Table 1. Experimental conditions

Injection timing difference to ignition [sec]	One side	Single inj.	±0.000
	Impinging	Single inj.	-0.040 ~ +0.040
		MFI Ⅰ	-0.030 / ±0.000
		MFI Ⅱ	-0.030 / +0.030
		MFI Ⅲ	±0.000 / +0.030
Injection amount ratio of MFI (First, Second)		A	23%, 77%
		B	40%, 60%
		C	77%, 23%

Experimental conditions are shown in Table 1. In these experiments, the overall equivalence ratio is $\Phi = 0.95$, the equivalence ratio is $\varphi = 0.7$, and fuel injection pressure is set at 0.3 MPa. In these experiments, we investigated the combustion characteristics when changing the injection timing against ignition timing. The injection timing which the ignition begins when fuel starts collision at the center of the chamber is set as a reference timing (±0.000 sec). Experimental conditions change as previous injection timing (-0.010~0.040 sec), post injection timing (+0.010~+0.040 sec), and MFI (Multiple Fuel Injections). The MFI has three conditions set for injection amount ratios.

3 Results and Discussion

Fig.3 shows the movement of droplet for impinging injection, taken by schlieren system. At the center picture, it can be seen that the fuel spray come out from right and left side, collided on the center of chamber and then the diffusion of fuel droplets can be seen on the right side figure.

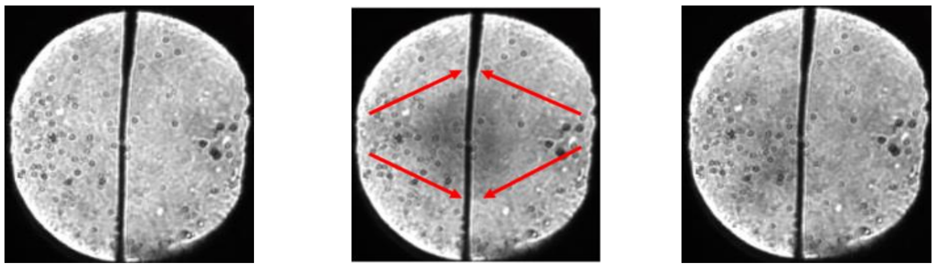

Figure 3. Collision of fuel droplets and diffusion on the chamber (After injection)

Fig.4 shows flame behaviors for single side injection (above) and impinging injection (below). Both of their injection timings are reference timing. On the single side injection, it can be seen that fuel sprayed out from left side of nozzle. Through the spark, fuel droplet burning rapidly and after the collision with the right wall, few of fuel jumped against from the right side. On the last combustion stage, the diffusion of flame on the right side of wall surface also can be confirmed. On the other hand, the impinging injection shows below, at the center of chamber, the collision of fuel spray can be confirmed on the initial combustion stage. After the collision, the fuel droplets which came from the center of chamber can be observed. This fact indicated that according to the impinging injection the atomization of fuel is promoted, the fuel adhesion to the wall surface can be reduced. It is also suggested the combustion improvement effect on heterogeneous combustion field.

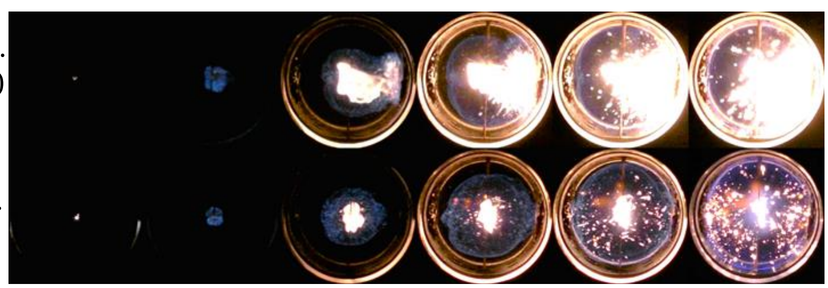

Figure 4. Flame behavior of different injection methods

Fig.5 shows Maximum Burning Pressure (MBP) and Total Burning Time (TBT) with different injection timing under single impinging injection. At the previous injection, against to the reference injection, the increase of MBP and the reduction of TBT can be confirmed. By injection occurs earlier than ignition, the atomization of fuel droplets happened, which can be seen as the cause of the promotion of pre-mixture and the reduction of latent heat of vaporization. Against to the -0.03 injection timing, MBP for the -0.04 injection timing is merely reduced and TBT is in an increase. Along with the previous injection, before burning, the spray fuel adhere to the wall surface, which considered as a cause for the reduction of contribution of fuel to combustion. Besides, the increase of MBP, which also is shown at the previous injection condition, can be confirmed at the post injection condition. Especially under the +0.03 and +0.04 injection timing, the increases are remarkably confirmed. The fact is caused by the combustion improvement by later sprayed n-Hexadecane and the reduction of unburned fuel that according to the combustion of propane-air mixture, increase of chamber's internal temperature happened. Reduction of TBT is not as much as in the previous injection condition do. At the post injection condition, the difference of temperature increase ratio on the internal of chamber, influenced by the injection timing, can be seen as a factor.

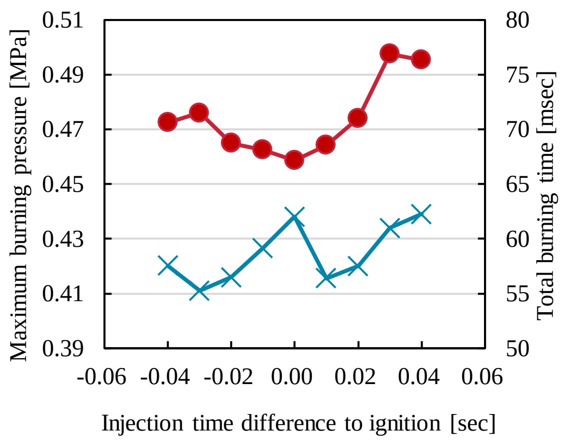

Figure 5. MBP and TBT
[Single injection,
(Φ=0.95, φ(Propane)=0.7)]

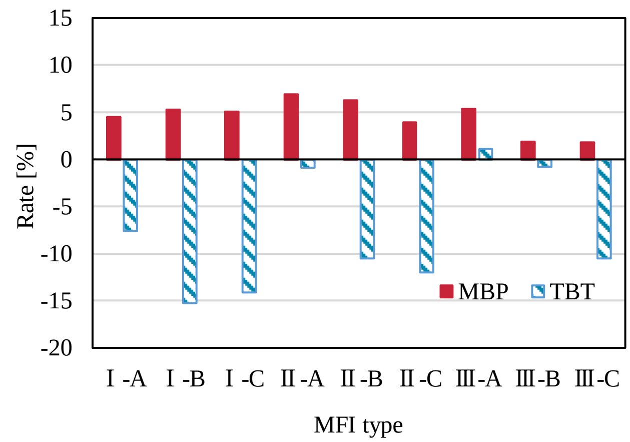

Figure 6. Percentage of changing of MBP and TBT
[MFI, (Φ=0.95, φ(Propane)=0.7)]

Fig.6 shows that against to the reference injection of single impinging injection, the increase-decrease rate of MBP and TBT under MFI with different injection timing and injection amount ratio. Against to the reference injection, the increase of MBP and the reduction of TBT can be observed. This fact indicated and being one of the combustion improvement effects by using MFI. And, focusing on the influence of injection timing, the reduction of TBT under the condition of previous injections which accompanying with earlier injection, and the increasing effect of MBP under the condition of post injection which accompanying with delayed injection can be also confirmed. It is obvious that the influence of the formation radio belongs to propane-air mixture at the time of ignition which influenced by injection timing are the cause of the different influence on MBP and TBT. It is necessary to do further detailed observation of flame behaviors.

On the other hand, focus on MFI, by changing the injection timing of first and second injection stage, under the same fuel amount ratio, the improvement of MBP and TBT can be confirmed. Since the improvement promoted more than the previous conclusion which only the injection timing of impinging injection acted as the cause of improvement, either MFI I or MFI II and MFI III's injection timings, when the amount ratio of first stage is less than the second stage (part A), the reduction of improvement effect is obviously to compare with part B and C which added the amount ratio on the first stage. It is clearly that about the improvement effect of TBT, research about heat release rate at the initial combustion under MFI is necessary.

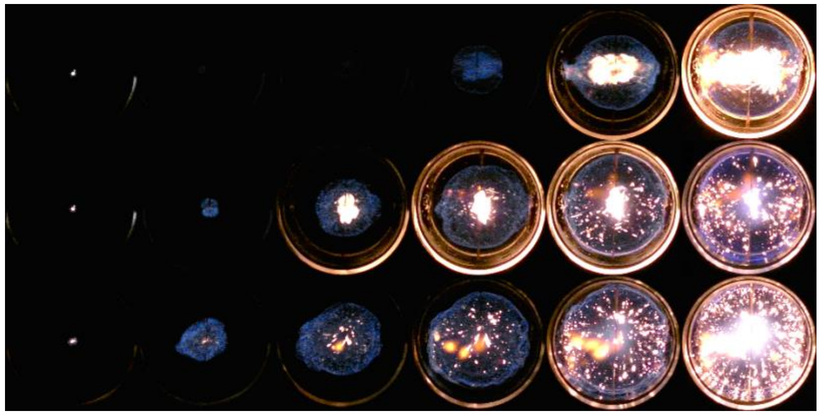

Figure 7. Flame behavior of impinging injection

Fig.7 shows the flame behavior under single impinging injection with different injection timing. For studying the improvement effect of MBP and TBT under impinging injection with injection timing. As seen from this figure, under previous injection, atomization of droplet around the center of chamber which influenced by the propane-air mixture's flame behavior can be confirmed at the initial combustion stage. Around 41 msec, the combustion was almost finished. Besides, about the post injection, after fuel sprayed against to the flame surface of propane-air mixture, the sprayed fuel droplets burned rapidly. This fact indicated that the improvement effect of TBT under impinging injection with previous injection is affected by the combustion improvement effect under diffusion combustion zone as cause of atomization of droplets by impinging injection.

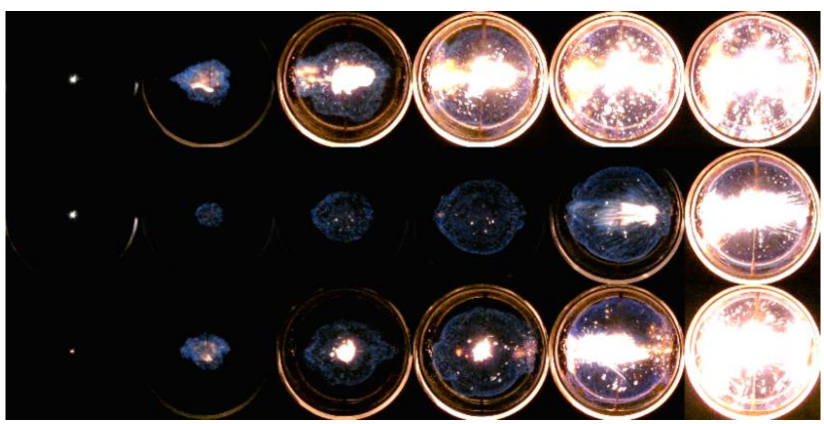

Figure 8. Flame behavior of MFI

Fig.8 shows flame behavior under MFI, with different injection timing. From the premixed promoting effect by first injection of previous injection, rough estimated flame diameter under initial combustion from ignition time enlarged than the flame diameter which only on the condition of impinging injection. This fact obviously indicated that the most suitable conditions exists for combustion improvement under the premixed promoting effect by previous injection at the initial combustion. Especially the combustion improvement right after the spray of fuel is also confirmed under MFI I, which suggested both the efficacy of multiple fuel injection.

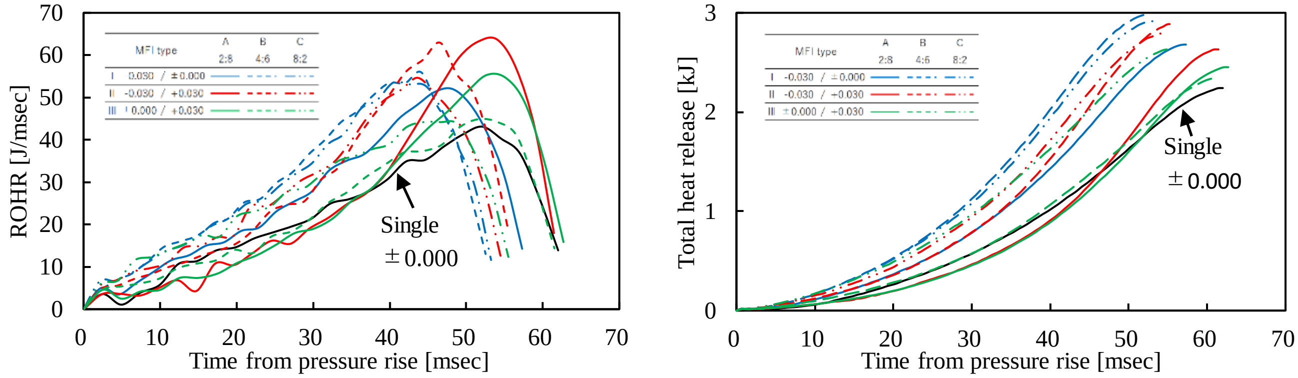

Figure 9. ROHR and Total heat release

Fig 9 shows the heat release rate (left) from the time where the pressure started increasing under each injection conditions, and the total heat release (right) calculated by the heat release rate. As suggested in this figure, against to the reference injection of impinging injection, all injection conditions show the rapidly combustion and an increase on the total heat release. Especially compared with other impinging injection and MFI conditions, the MFI I (part B, C), do have obviously actualized the rapid combustion, which coincide with the conclusion of flame behavior. Also, the rough estimated total heat release has been the largest one. In another words, about the combustion improvement under heterogeneous combustion field, it is necessary to do more study on the combustion improvement of initial premixed combustion part which bringing with rapid combustion. Henceforward, we plan to do investigation about under high pressure the multiple fuel with MFI.

4 Conclusions

In this study, we made a discussion about that under the heterogeneous combustion field, the influence of injection timing and multiple fuel injection on the combustion improvement effect, through the observation of combustion characteristics and flame behaviors at the condition of impinging injection. The main conclusion are as follows: 1) It is possible to have combustion improvement at heterogeneous combustion field by change the combination of impinging injection and multiple fuel injection. 2) The most suitable conditions of combustion improvement exist for investigating the injection amount ratios under the multiple fuel injections.

References

[1] Terakado S, Kawakami T. (2018). A study of the Combustion Characteristics of the Heterogeneous Field in a Closed Vessel. Proc. JSME KB. GS0505.