

Studies of Fuel Droplets Behavior and Flame Propagation in Combustion Chamber on S.I. Engine Using Laser 2-D Visualization

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ABSTRACT

The behavior of fuel droplets charged into a combustion chamber of an automobile spark ignition engine affects combustion characteristics through fuel vaporizing and fuel air mixing processes inside a combustion chamber. Fuel droplets behavior during intake and compression strokes and flame behavior during combustion stroke during a single engine cycle were visualized by a high speed image intensified video system. Image of fuel droplets was based on the intensity of the light scattered from fuel droplets crossing the laser sheet beam introduced into the combustion chamber. The results demonstrated that fuel droplets which are not completely vaporized survive at the intake valve side at the final stage of compression stroke. The flames shifted in the exhaust valve direction and an end-gas region was formed at the intake valve side.

INTRODUCTION

Understanding the processes occurring inside a combustion chamber of a spark ignition engine is indispensable to reducing the exhaust emission of pollutants and to improving fuel economy. Visualization and imaging inside a combustion chamber are very effective and helpful techniques to understand the combustion processes and characteristics inside the combustion chamber and ultimately to enhance engine design and development.

The combustion process in the spark ignition engine includes many physical processes, such as mixture formation, ignition and combustion. Many studies of spark ignition engine combustion have used visualization techniques (1)-(4) for combustion analysis of a part of the combustion process in an engine cycle. There is little information, however, of the relationship of each process occurring in the combustion chamber and on the overall combustion process over a single engine cycle.

It has been widely recognized and the mixture formation process has a dominate effect on the subsequent processes of ignition, flame propagation and formation of undesirable pollutants in the combustion chamber. Further, fuel droplets inside the combustion chamber which are resultant from the injection of fuel

into the intake port play an important role in the formation of a fuel vapor concentration field inside the combustion chamber. Previous studies have also shown that fuel droplets affect the ignitability and flame speed of fuel vapor-air and fuel droplets-air mixture (5)-(6).

In this work the history and distribution of the fuel droplets inside the combustion chamber during the intake and compression strokes and flame propagation in one engine cycle were visualized by a high speed image intensified video system. The relationship between fuel droplets behavior and flame propagation under cold operating condition is discussed. Gasoline droplets images were based on the intensity of the light scattered from droplets crossing the laser sheet beam which was introduced into a combustion chamber having a transparent piston and cylinder.

EXPERIMENTAL APPARATUS

To observe fuel droplets and flame propagation in the combustion chamber, a couple of transparent piston and cylinder engine was

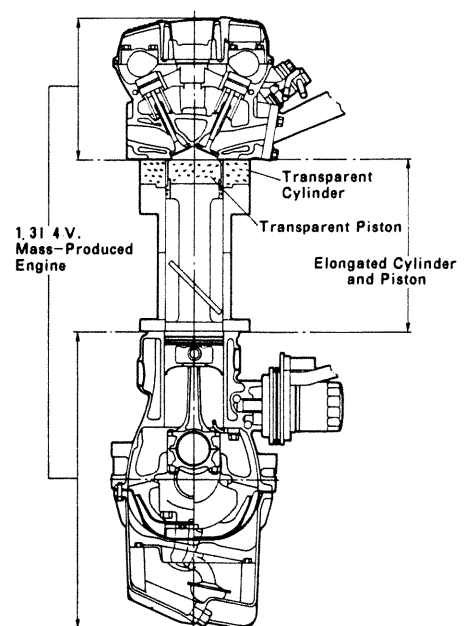


Fig. 1 Transparent Cylinder and Piston Engine

prepared as shown in Fig. 1. The engine was modified for optical access through the bottom and side of the combustion chamber. To obtain these bottom and side views, an elongated cylinder liner and an elongated piston to which a transparent cylinder liner and a transparent piston crown were attached, were installed in a mass-produced engine.

The specifications of the engine used for this work are shown in Table 1. The basic engine was an in-line 4 cylinder, 1.3 l, 4 valve mass-produced spark ignition engine with a bore of 78 mm and stroke of 67.5 mm. The combustion chamber shape was a pentroof type with a center spark plug.

A schematic diagram of the experimental apparatus is shown in Fig. 2. The images of fuel droplets in the combustion chamber were visualized by means of the laser sheet 2-dimensional visualization technique, with an Ar-ion laser used as a light source. The laser beam was focused onto the sheet by a cylindrical

lens and a convex lens. The approximately 1 mm thickness laser sheet was introduced into the combustion chamber through the transparent cylinder.

The fuel was injected into an intake port, and then charged with air into combustion chamber. The light scattered from fuel droplets crossing the laser sheet beam inside the combustion chamber was recorded by a high speed video system (framing rate; 1000 frames/sec) equipped with an image intensifier (Kodak ECTAPRO 1000) using optical access through the transparent piston. Throughout the same engine cycle the combustion flame was recorded. The recorded image data were converted into 8-bit gray-scale digitized images. The digitized images were transferred to an image processor and a mini-computer system for image processing and graphics output of the results.

Table 2 shows the experimental conditions for the visualization of fuel droplets and flame images. Experiments were carried out under a cooling water temperature of 300 K to observe combustion under a cold operating condition of the engine. The engine was operated at engine speed of 1000 rpm. The overall air/fuel ratio was nearly 13. Throttle valve fully opened. Fuel injection and ignition timing were 16 degrees before top dead center (BTDC). Used fuel was gasoline.

Table 1 Engine Specifications

Displacement	1.31
Number of Cylinders	4 (1)
Bore	78.0mm
Stroke	67.5mm
Compression Ratio	8.9
Combustion Chamber Shape	Pentroof Type
Number of Valve (Intake, Exhaust)	4 (2,2)
Valve Timing	
IN. Open-Close	13° BTDC-43° ABDC
EX. Open-Close	55° BBDC-5° ATDC
Fuel Injector	EGI (145 cc/min)

Table 2 Experimental Conditions

Engine Speed	1000rpm
Air/Fuel Ratio	13
Throttle valve	Full Open
Fuel Injection Timing	16° BTDC
Ignition Timing	16° BTDC
Injected Fuel	Gasoline

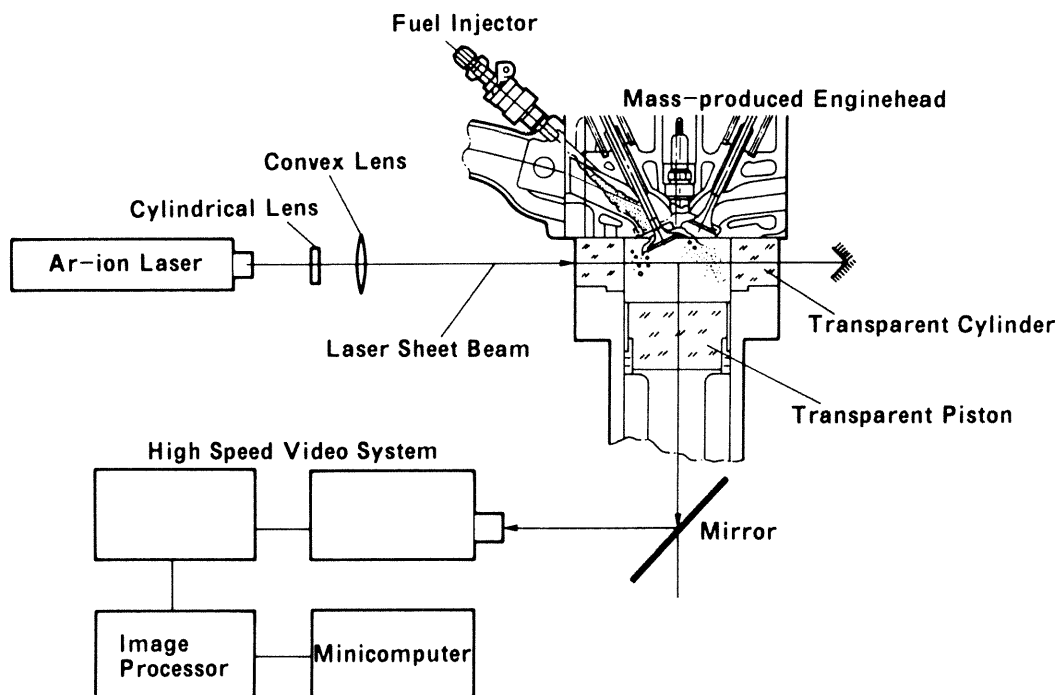


Fig. 2 Schematic Diagram of Experimental Apparatus

FUEL DROPLETS IMAGES

An example of a fuel droplet image and a visual field are shown in Fig. 3. The laser sheet was introduced on the horizontal plane 8 mm below the lower surface of the cylinderhead. The diameter of the visual field through the transparent piston was 65 mm. The piston crossed the laser sheet plane at about 40 degrees BTDC and ATDC. Therefore, fuel droplets images could be observed from 40 degrees after intake TDC to 40 degrees before compression TDC. In this work, results of the fuel droplets images are presented three dimensionally based on the intensity (I_d) of the light scattered from the fuel droplets. In this plot, the outer circle represents the visual field with the lower part being the intake valve side and the upper part being the exhaust valve. The laser sheet passed through the combustion chamber from left to right.

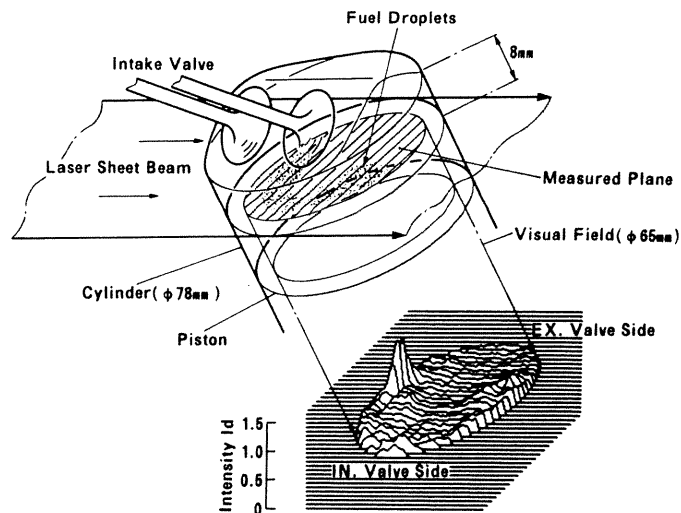


Fig. 3 Example of Result and Visual Field (fuel droplets image)

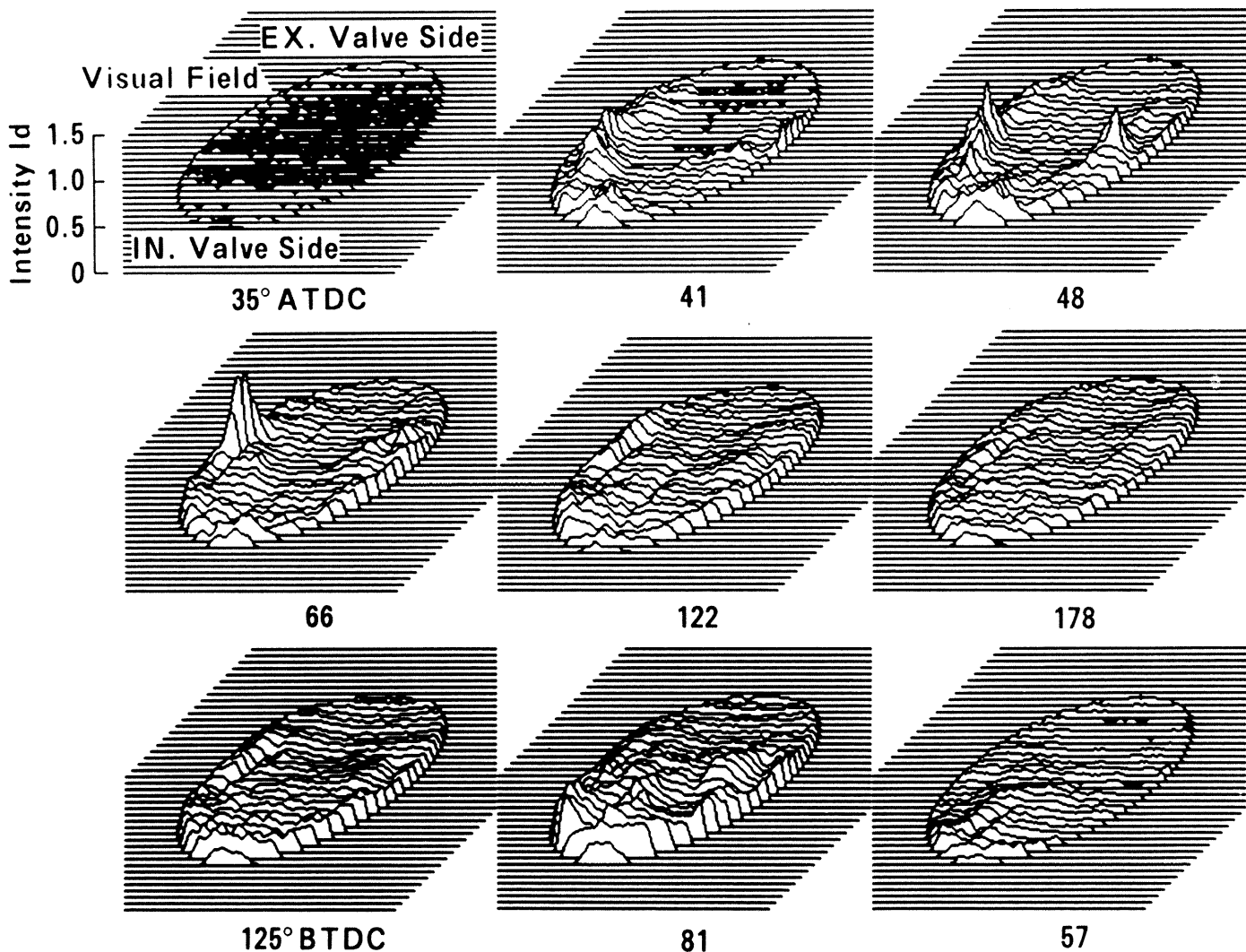


Fig. 4 Fuel Droplets Images (during intake and compression stroke)

early stage of the intake stroke, there were two high intensity zones at the intake valve side. When opening the intake valves increased air flow speed around the intake valves, the high intensity zones shifted to exhaust valve direction and the intensity level increased. In the later period of the intake stroke, the intensity level decreased. It is considered that the fuel which had adhered to the intake valve surface was atomized by the air flow around the intake valve during the intake stroke. Air flow speed greatly affected the level of fuel atomization.

It was also found that the scattered light increased on the intake valve side during the compression stroke, and still remained on the intake valve side at 50 degrees BTDC. It is considered that the fuel droplets could not be completely evaporated under such a cold operating condition, and that the droplets traveled to the intake valve side in the combustion chamber carried in the tumbling air flow in axial the direction.

Figure 5 shows a scattered light intensity cross-section during the intake and compression strokes in one cycle. Section A1-A2 is the center line of the combustion chamber ($X=0$ mm) and Section B1-B2 is parallel to the center line of the combustion chamber ($X=-18$ mm). It is clear that the scattered light was strong near the intake valve in the early stage of the intake stroke. During the compression stroke, the light intensity reached a peak, after which it decreased at the intake valve side.

COMBUSTION FLAMES

Combustion flames were also observed over one engine cycle using the high speed video system. An example of the flame images and a visual field are shown in Fig. 6. The flame light was recorded from bottom through the transparent piston which had a visual field diameter of 65 mm. Measured results of the flame images are presented from the three dimensional perspective based on flame light intensity (I_f) as were the fuel droplets images in Figs. 3 and 4.

Figure 7 illustrates the result of computer processing the flame images. After ignition spark, flame rapidly extend with an increase of flame light intensity and extends over the combustion chamber by 19 degrees ATDC. It is observed that the unburned end-gas region is formed at the intake valve side. The flame images are shifted to the exhaust valve direction.

Figure 8 shows the flame light intensity cross-section and the flame front arrival distance with the crank angle on the Y axis (section A1-A2) and the X axis (section B1-B2). In the case of cross section A1-A2, flame front reaches the cylinder wall of exhaust valve side more early than the intake valve side. But, in the case of cross section B1-B2, the flame front reaches both sides of combustion chamber wall at same time. It indicates the difference in a flame propagation between the intake valve direction and exhaust valve direction.

The combustion color photographs were also taken by the high speed camera under the same operating condition as shown in Figs. 4 and 7. The film speed is 1000 frames/sec. The

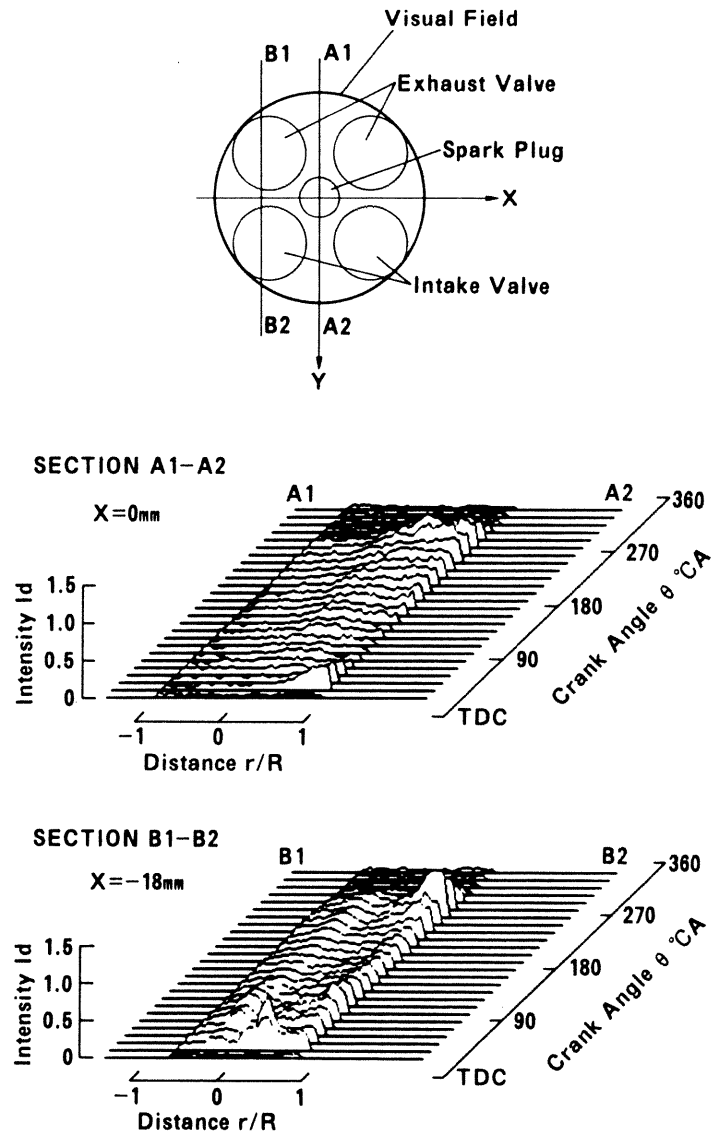


Fig. 5 Scattering Light Intensity Cross Section (fuel droplets image)

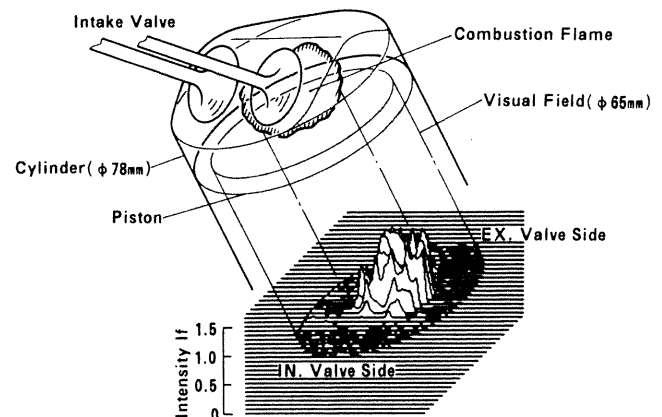


Fig. 6 Example of Result and Visual Field (flame image)

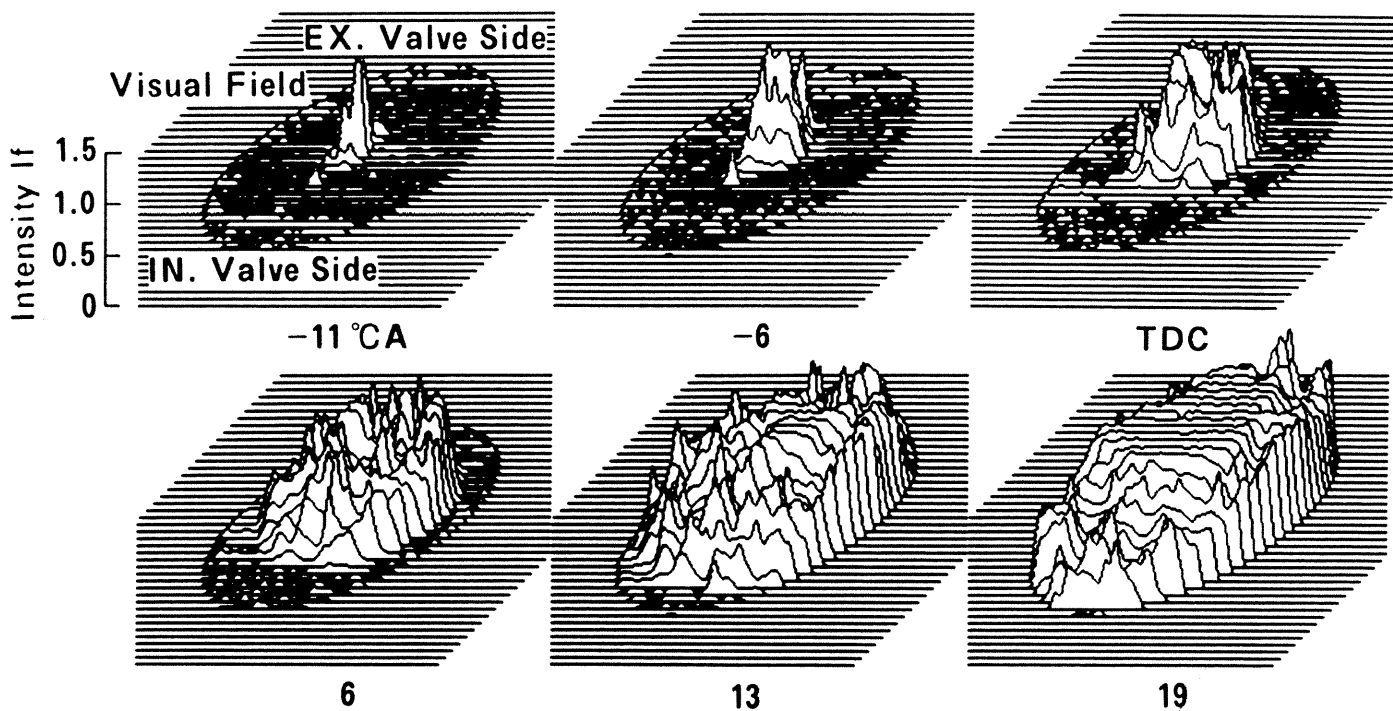


Fig. 7 Combustion Flame Images

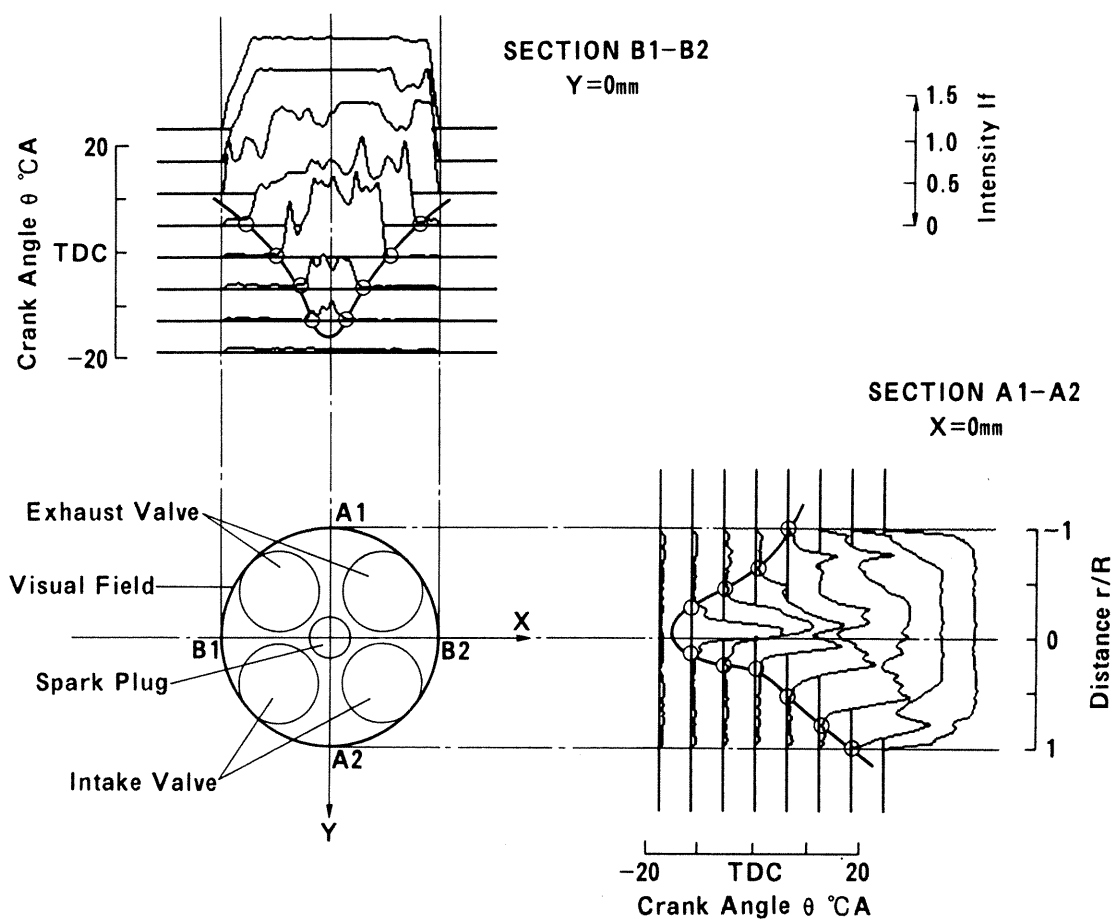
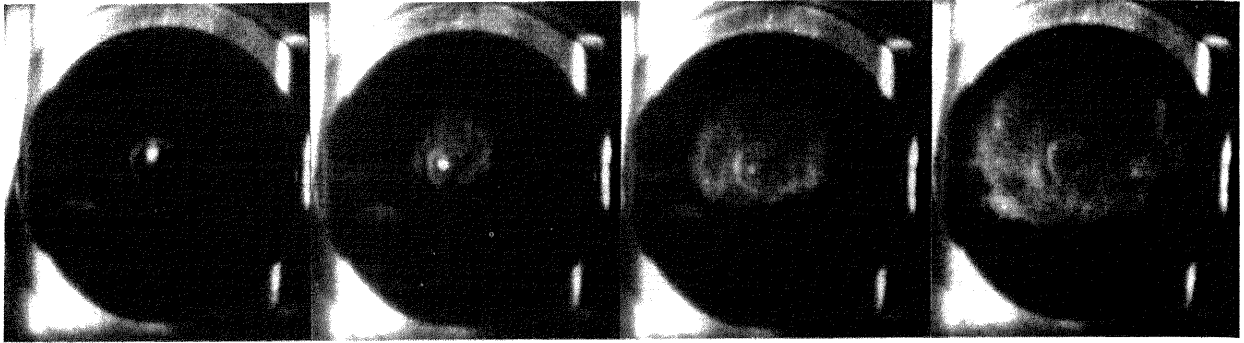


Fig. 8 Flame Light Intensity Cross Section and Flame Front Arrival Distance

EX, Valve Side

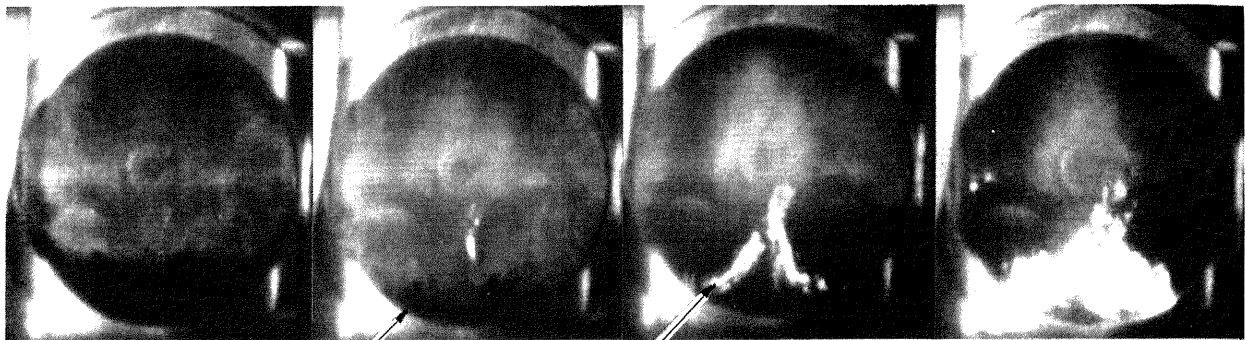


IN, Valve Side - 9 °CA

-5

TDC

5



8

13

19

28

End-Gas Region

Yellow Luminous Flame

Fig. 9 Combustion Photographs

combustion photographs are shown in Fig. 9. A blue-colored flame had extended over the combustion chamber by 19 degrees ATDC. The flame had clearly shifted to the exhaust valve direction and the end-gas region had formed on the intake valve side at 8 and 13 degrees ATDC.

This phenomenon is related to the unevaporated fuel droplets which survived near the intake valve side through the last stage of the compression stroke, as was shown in Figs. 4 and 5. It is considered that the mixture condition, including the air-fuel mixture concentration and turbulence intensity distribution of the in-cylinder flow, at the intake valve side differed from that condition at the exhaust valve side.

At 13 degrees ATDC, a yellow luminous flame appeared around the intake valve surface and gradually extended to the intake valve side during the final stage of combustion. A part of the fuel droplets floated with the air flow and were carried into the combustion chamber, but most of the fuel droplets collected on the intake valve surface and were atomized by the air flow around the intake valve. The remainder formed a fuel film on the intake valve surface. The fuel film which could not be completely vaporized caused the yellow luminous flame to appear at the final stage of combustion.

It is necessary to reduce the amount of fuel collected on the combustion chamber surface and to form an optimal mixture distribution to reduce HC emissions and obtain good fuel economy at cold operating condition.

CONCLUSIONS

Visualization using a laser sheet device and high speed video system were applied for combustion analysis during the cold operating condition. The behavior of fuel droplets during the intake and compression strokes and flame propagation during combustion stroke were visualized in the same engine cycle.

The following conclusions were found.

- (1) At the final stage of compression stroke, there were fuel droplets which had not completely vaporized at the intake valve side.
- (2) The flames shifted in the exhaust valve direction and an end-gas region formed at the intake valve side.
- (3) A yellow luminous flame appeared near the intake valve surface and gradually extended to the intake valve side during final the stage of combustion.

REFERENCES

1. S. C. Bates, SAE paper No. 890154, 1989.
2. S. Iguchi, et. al., SAE paper No. 885078, 1988.
3. S. Pischinger and J. B. Heywood, SAE paper No. 880518, 1988.
4. A. C. Alkidas, et. al., SAE paper No. 900353, 1990.
5. Y. Mizutani and A. Nakajima, Combust. Flame, Vol. 21, pp. 343-350, 1973.
6. Y. Mizutani and A. Nakajima, Combust. Flame, Vol. 21, pp. 351-357, 1973.