Combustion Observation of DI and OSKA-DH Diesel Engines by Engine Video System

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ABSTRACT

The OSKA-DH diesel engine employed a unique system (hereafter called OSKA system) which is composed of a single-hole fuel injector, an impinging disk and a re-entrant type combustion chamber.

This study is concerned with combustion observation of both OSKA-DH and conventional DI diesel engines by the engine video system. This video system enables us to take combustion photographs under the warm-up condition of the engine.

From the observation of video pictures, the shorter ignition delay with the OSKA-DH diesel engine is observed than that of a DI diesel engine.
For the OSKA-DH engine, the flame was concentrated in the center of the combustion chamber and a relatively monotonous flame intensity was observed.

THE AUTHORS HAVE DEVELOPED a new type of Direct Injection Stratified Charge Engine called "Direct Fuel Injection Impingement Diffusion Stratified Charge System" (hereafter called OSKA).
The authors have already reported the performance and exhaust emission of the methanol, gasoline and diesel engines utilizing this OSKA System (1)-(11)*.

In the previous reports(8),(9),(11), the observation of impinged fuel spray onto the impinging disk was studied by using the pressurized vessel and bottom view and side view photographs were taken at the same time. And the high-speed combustion photographs were taken for both bottom view and side view by using an experimental transparent engine. The axial diffusion of fuel spray showed the different tendency between the pressurized vessel and a transparent rig-engine.

In this report, the engine video system with a flash light illumination was used to observe the impinged fuel spray and the combustion flame of the OSKA-DH diesel engine. For reference, the combustion flame of a DI diesel engine was observed by the same video system without a flash light illumination.

The engine design parameter such as the combustion chamber configuration, compression ratio and so on were kept the same as the performance test engine.
The engine operating conditions such as the cooling water and the lubrication oil temperature were kept the same conditions of the performance test.
As the fuel spray diffusion and combustion was significantly affected by these engine operating conditions, it is very important to maintain exactly the same operating conditions as the performance test when the video pictures is taken.

CONCEPT OF THE OSKA-DH SYSTEM

Fig. 1 shows the schematic illustration of the structure of the OSKA-DH system. A single hole fuel injector was so located in the center of the cylinder head as to make the fuel jet impinging on the center of the impinging disk provided on the cylinder head. A re-entrant type combustion chamber was employed as to get a high squish flow speed. A small cavity (hereafter called dimple) was also employed in the center of cylinder head.

The OSKA-DH diesel engine depends upon a single hole fuel injector and an impinging disk for mixture formation.
And a high squish flow was used instead of intake air swirl motion for both faster mixture formation and combustion.

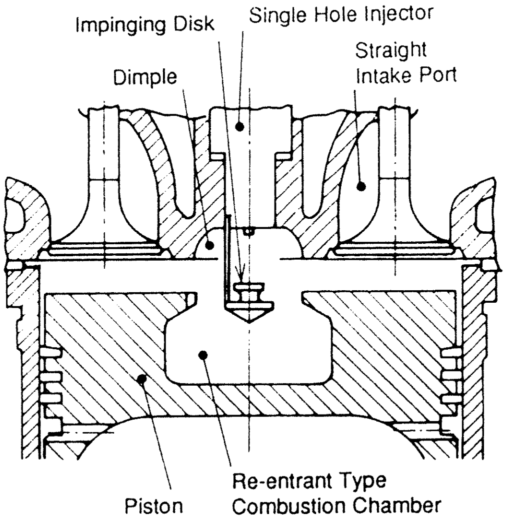


Fig. 1 Structure of OSKA-DH Diesel Engine

PROTOTYPE OSKA-DH AND DI DIESEL ENGINES

In this experiment, a commercially available DI diesel engine and a prototype OSKA-DH engine with some parts modified were used.

The specifications of DI diesel and OSKA-DH modified prototype diesel engines are shown in Table 1.

In order to shorten the ignition delay and to improve the fuel consumption under retarded fuel injection timing, a relatively high compression ratio of 20.4 : 1 was employed for the OSKA-DH engine.

A prototype pintle type fuel injector was used instead of the multi-hole injector equipped on a DI diesel engine. A comparatively low injector opening pressure, 15.3 MPa, requirement is one of the important advantages of the OSKA-DH system.

ENGINE VIDEO SYSTEM

The engine video system is composed of a flash lighting unit, CCD camera, digital frame storage unit, S-VHS video-recorder, color video monitor and control unit. The CCD camera and a flash light were connected to an air cooled endoscope system. This engine video system was manufactured by AVL List GmbH. Specifications of the engine video system is shown in Table 2.

The advantages of this video system are on-line visualization, quick evaluation of phenomena and selective storage on the video tape and easy application of picture evaluation.

Table 1 Specification of DI and OSKA-DH Diesel Engines

	CONVENTIONAL DIESEL	OSKA-DH PROTOTYPE DIESEL
Cycle	4	←
Number of Cylinder	Horizontal Single	←
BorexStroke	ø118mm x 108mm	←
Displacement Volume	1181 cc	←
Compression Ratio	16.5	20.4
Intake System	Naturally Aspirated Single Valve Swirl Port	← Two Valves Straight Port
Exhaust System	Single Valve	Two Valves
Fuel Injection System Diameter of Plunger Type of Injector Opening Pressure	 ø9.5 mm 4 Hole Nozzle 20.6 MPa	 ← Throttle 15.3 MPa
Cooling System	Water Cooled	←
Lubrication System	Forced Lubrication	←

Table 2 Specification of Video System

Framing Rate (Picture per min.)	Shutter Mode 4 - 6
Exposure Time (Minimum sec.)	Shutter Mode 1/10,000
Image Size (mm)	6.4 X 4.8
Resolution (Pixel)	752 X 582
Relative Recording Sensitivity (ASA)	4,000

The time resolution for self illuminating processes is determined by the electric shutter of the video camera.
During an engine cycle a maximum one frame can be taken.
To record a picture in the shutter mode, new frame can take a few seconds due to the necessary synchronization of the engine crank angle and the shutter of the video camera.
As a result, for the shutter mode operation, the frame recording frequency is limited few frames per every minute.

This engine video system can not allow one to take the acquisition of consecutive cycle like a high-speed cinematographic process.
However, the high-speed cinematographic process with a transparent piston allows to take the clear combustion photographs for only first few cycles with the cold start engine operation.

By selecting the endoscope window location carefully, it is possible to operate the engine for certain duration, 20 minutes or more, without sooting on the endoscope window under lower load operation. This clean endoscope window operation allows us to take clear video pictures of the completely warm-up engine operating condition.
The injected fuel spray is also visible by using the illumination of the stroboscopic flash.

Fig. 2 shows the endoscope windows location for the OSKA-DH diesel engine. Two windows were used for the CCD camera and illumination of flash light.

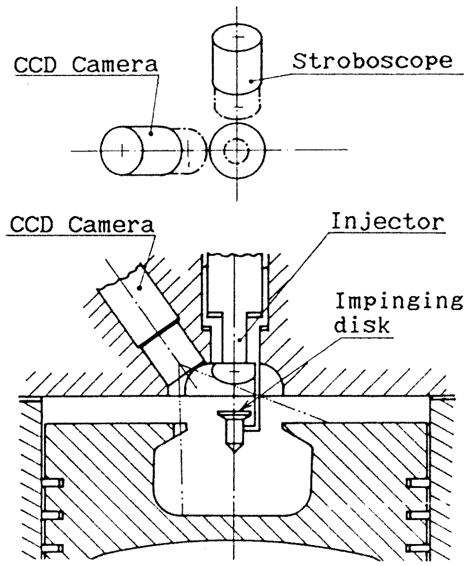


Fig. 2 Schematic Drawing of Engine Video System for OSKA-DH Diesel Engine

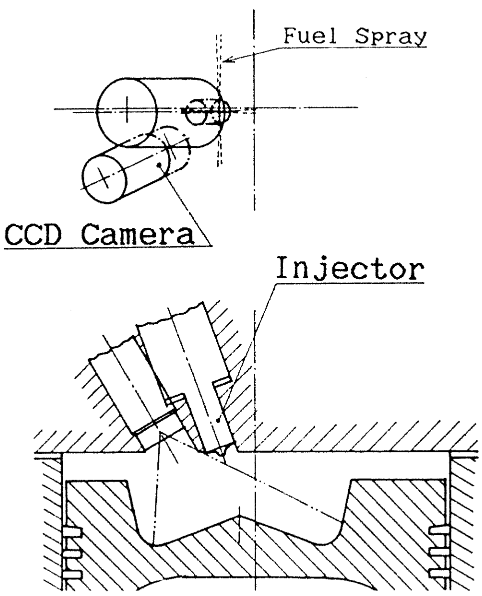


Fig. 3 Schematic Drawing of Engine Video System for DI Diesel Engine

For the DI diesel engine, one endoscope window was used as shown in Fig. 3. The only modification was done to adapt the combustion chamber window (15 mm diameter) for the endoscope in the cylinder head. All other configurations remain the same as the performance test engine.

OBSERVATION OF THE IMPINGED FUEL SPRAY AND COMBUSTION FLAME

Before setting the endoscope in the cylinder head, the engine was completely warm-up with the dummy plugs for the combustion chamber windows.

Fig. 4 shows the detail of a CCD camera view for the OSKA-DH engine in which the fuel spray and the combustion flame can be observed.

Before taking the engine video pictures, the cylinder pressure is measured with the OSKA-DH engine.

Fig. 5 shows the cylinder pressure analysis under the condition of no load and the engine speed of 900 rpm.
Because of retarded fuel injection timing, short ignition delay and smooth rate of heat release ($dQ/d\theta$) trace, the OSKA-DH engine demonstrates lower rate of pressure rise ($dP/d\theta$). The lower combustion noise is confirmed by the lower maximum $dP/d\theta$ value. The maximum $dQ/d\theta$ is observed at about 10 deg ATDC.

Fig. 6 shows the video pictures of impinged fuel spray and combustion flame of the OSKA-DH diesel engine under same operating condition of Fig. 5.
The fuel spray is observed at -1 deg ATDC and ignition starts at 3 deg ATDC.

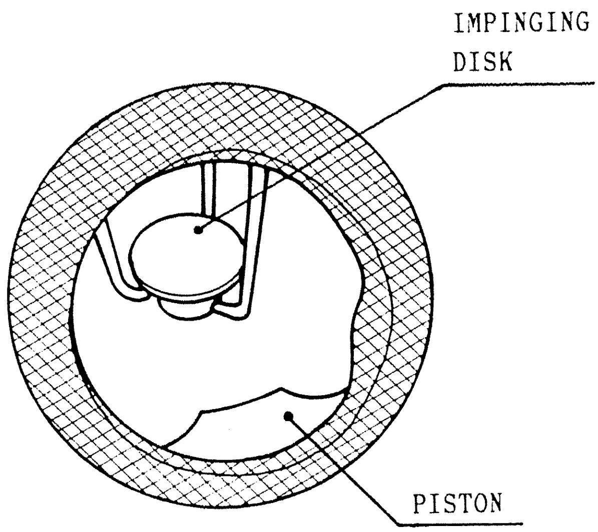


Fig. 4 Detail of Video Picture (OSKA-DH Diesel Engine)

The impinged fuel spray are diffused almost circularly around the impinging disk and shows uniform distribution in the same manner as which was observed in a pressurized vessel. The impinged fuel spray diffuses toward the combustion chamber by strong inflow squish stream. This axial fuel spray diffusion is not very similar to the observation of impinged fuel spray in a pressurized vessel (9),(11).

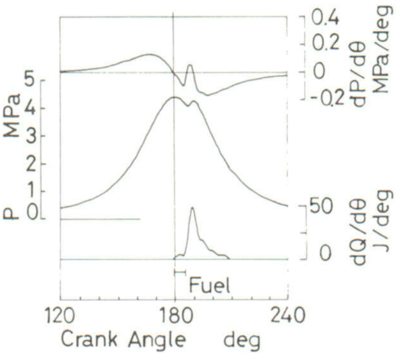
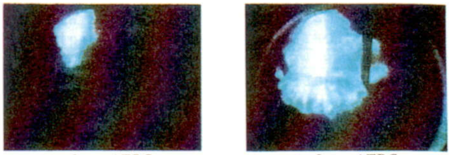
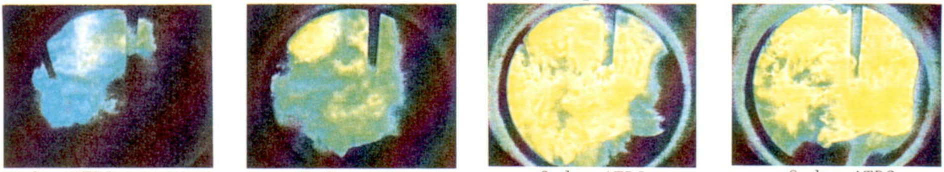


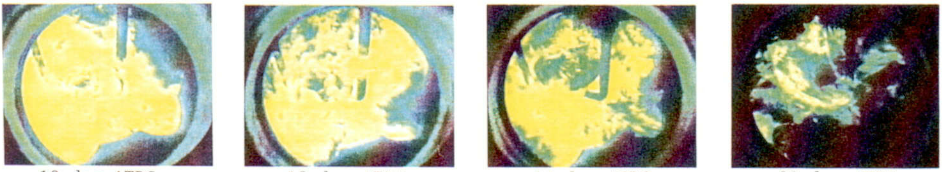
Fig. 5 Cylinder Pressure, dQ/dθ and dQ/dθ Traces (Engine Speed 900 rpm, No Load)



-1 deg ATDC　　1 deg ATDC

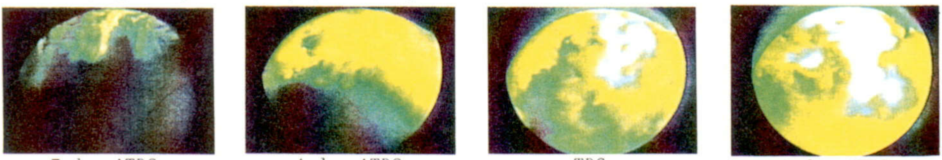


3 deg ATDC IGNITION　　5 deg ATDC　　6 deg ATDC　　8 deg ATDC

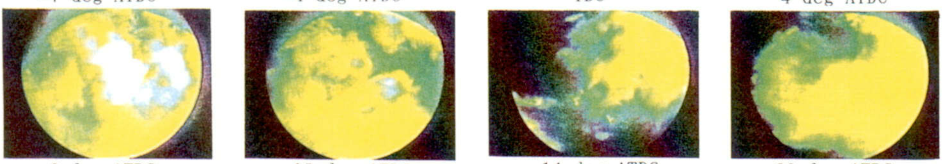


10 deg ATDC　　12 deg ATDC　　14 deg ATDC　　20 deg ATDC

Fig. 6 Video Pictures of Impinged Fuel Spray and Combustion of OSKA-DH Diesel Engine (Engine Speed 900 rpm, No Load)



-7 deg ATDC　　-4 deg ATDC　　TDC　　4 deg ATDC



6 deg ATDC　　10 deg ATDC　　14 deg ATDC　　20 deg ATDC

Fig. 7 Video Pictures of Combustion Flame of DI Diesel Engine (Engine Speed 1200 rpm, BMEP 313 kPa)

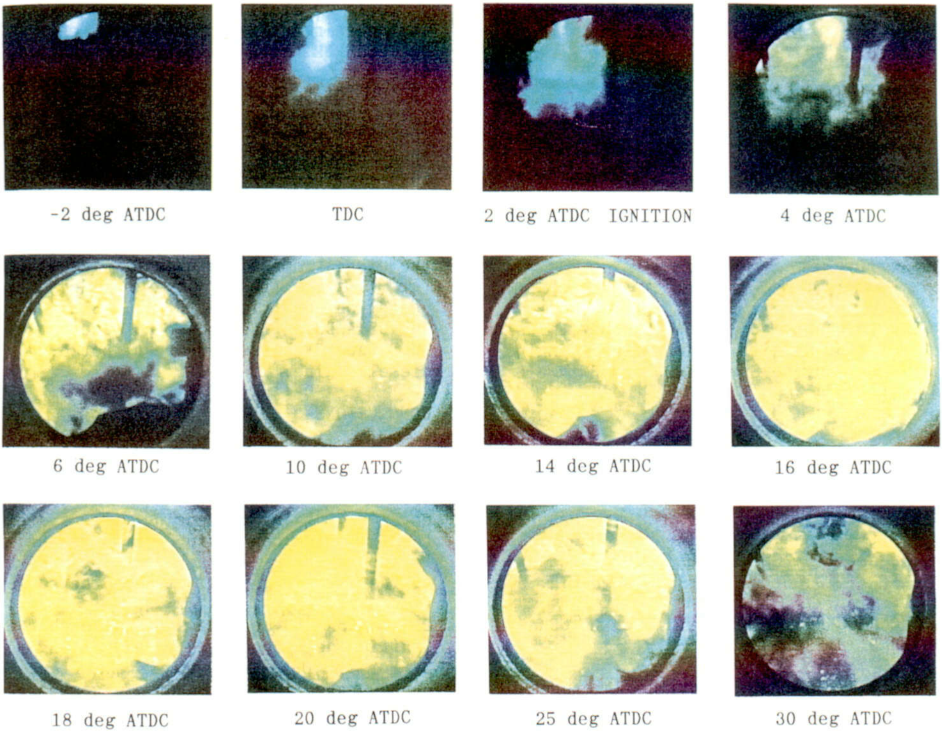


Fig. 8 Video Pictures of Impinged Fuel Spray and Combustion of OSKA-DH Diesel Engine
(Engine Speed 1200 rpm, BMEP 313 kPa)

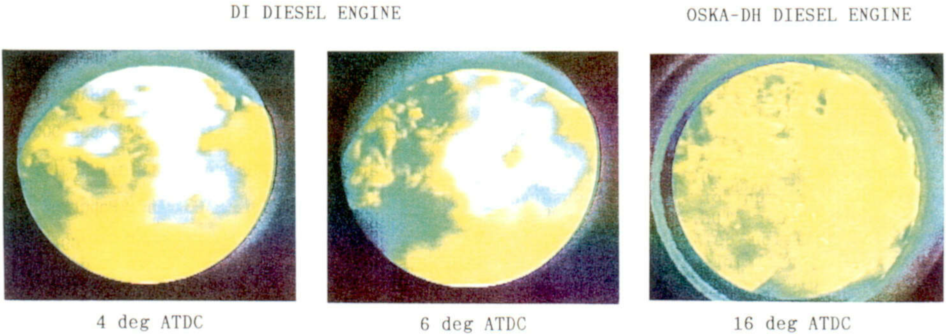


Fig. 9 Comparison of Flame Luminous Intensity of DI with OSKA-DH Diesel Engine
(Engine Speed 1200 rpm, BMEP 313 kPa)

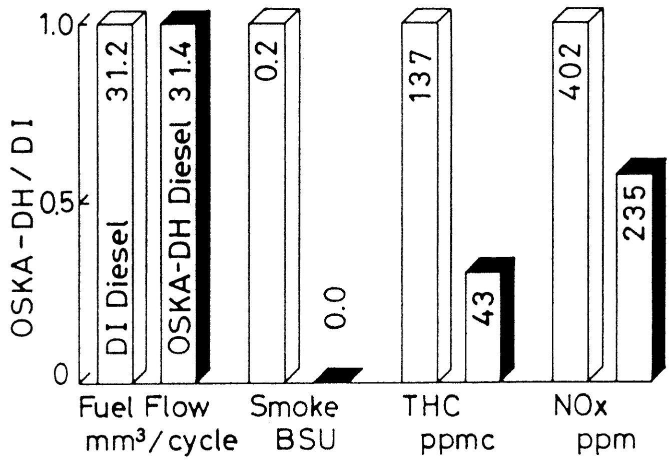


Fig. 10 Comparison of the Exhaust Emissions of DI with OSKA-DH Diesel Engine (Engine Speed 1200 rpm,BMEP 313 kPa)

The reverse squish flow is clearly seen from 6 deg ATDC in this condition. Relatively uniform flame is seen around the impinging disk from 6 to 12 deg ATDC.

The maximum flame area are observed at 8 to 12 deg ATDC. These pictures correspond with the maximum rate of heat release at 10 deg ATDC as shown in Fig. 5.

COMPARISON OF VIDEO PICTURES OF OSKA-DH WITH DI DIESEL ENGINE

Fig. 7 shows the video pictures of combustion flame of the DI diesel engine. The static fuel injection timing was set at 21 deg BTDC. The flame is observed at -7 deg ATDC and the flame is moving toward clockwise direction by the air swirl motion. The DI engine pictures show scattered flame which comes from four (4) divided injected fuel sprays.

The video pictures of impinged fuel spray and combustion flame of the OSKA-DH diesel engine are shown in Fig. 8.
The static fuel injection timing was set 5 deg BTDC. The fuel spray is observed at -2 deg ATDC and ignition starts at 2 deg ATDC. And the reverse squish flow starts at 6 deg ATDC and continues till at 25 deg ATDC. Very uniform flame is observed from 10 to 20 deg ATDC.

The ignition delay based on static fuel injection timing is observed 13 deg for the DI diesel and 7 deg for the OSKA-DH diesel engine respectively.
Because of the short ignition delay with retarded injection timing, the OSKA-DH engine produces the low NOx emission as shown in Fig. 10 afterward.

Fig. 9 show the comparison of flame luminous intensity for both engines.
The OSKA-DH engine picture shows a relatively monotonous luminous intensity.
The DI diesel engine pictures show the varied luminous intensity and higher luminous intensity, white color portion, than the OSKA-DH engine.
This luminous intensity difference comes from difference of mixture formation and fuel injection timing.

Fig. 10 shows the comparison of the exhaust emissions of a DI diesel with the OSKA-DH diesel engine under same operation condition of Fig. 7, 8 and 9.
The OSKA-DH engine shows the lower smoke, THC and NOx emissions than that of a DI diesel engine.

CONCLUSIONS

From the observation of impinged fuel spray for the OSKA-DH engine and combustion for both OSKA-DH and DI engines by using the engine video system, the following conclusions are obtained;
1. The impinged fuel spray of the OSKA-DH engine is strongly affected by the squish flow.
2. The OSKA-DH engine shows the shorter ignition delay compared with a DI engine.
3. For the OSKA-DH engine, the flame is concentrated in the center of combustion chamber and a relatively monotonous luminous intensity flame is observed.
4. For the DI engine, the flame is divided and higher luminous intensity portion is observed.

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