Observation of High Temperature Combustion by Using Rapid Compression and Expansion Machine

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ABSTRACT

In order to observe the combustion process in the heat insulated engine as precisely as possible, a rapid compression and expansion machine (RCEM) has been developed. We confirmed that the observation of the combustion are possible by using the RCEM at low speed to high speed which is the equivalent to engine 4500rpm with controlled air temperature, combustion chamber wall temperature and intake air swirl speed.

We observed the phenomena of high temperature combustion process by using this RCEM. As the results, a fuel spray didn't penetrate to the cylinder wall, and diffusion of the flame didn't extend uniformly in the combustion chamber and soot was formed here and there in the flame.

As we could realize that the phenomena of the combustion process in the RCEM is same as those in an engine, the development of combustion chamber of the heat-insulated engine has been started satisfactory.

1. Introduction

The heat-insulated engine which we have developed has features of a no cooling system, and higher thermal efficiency due to a heat insulation and exhaust gas energy recovery system to regenerate the higher exhaust gas energy (1)(2). However, as the intake air is heated by the high temperature inner wall of the cylinder, compressed gas temperature at the top dead center rises to 200-300°C higher than conventional water-cooled engines. This reduces the combustion speed in the heat-insulated engine and makes the thermal efficiency deteriorate(3).

In order to observe the combustion process, high speed camera was used in the single cylinder engine(4)(5). In the second place an approach of the observation using the newly developed rapid compression and expansion machine (RCEM) was carried out, which is possible to observe the combustion at 4500rpm, controlling heat insulation rate and intake air swirl. As the results, high temperature combustion was observed using the rapid compression and expansion machine and the method of improving the combustion was found.

2. Features and Construction of RCEM

In order to observe the combustion process simulating practical operated engine as same as possible, we have developed a new type of RCEM which can control temperature of combustion chamber wall, inlet air swirl and inlet air temperature. The features of the RCEM is following.

[1] The piston of the RCEM is moved at a maximum speed equivalent to 4500rpm of the actual engine; [2] the piston of the RCEM is moved in the same manner as the engine piston does, and it is easy to control it's speed; [3] the temperature of the combustion chamber wall is controlled at will; [4] The swirl speed of the intake air is controlled; [5] the temperature and pressure of the intake air are adjusted; [6] it is possible to utilize the same fuel injection systems as actual engine for the test; and [7] a variable bore and stroke can be selected in the unit.

Fig. 1 shows the outline of the RCEM unit, which consists of the observation cylinder and observation piston, the driving cylinder with a driving piston which drives the observation piston, a crank shaft to connect the observation piston with driving piston, the air compressor to supply the higher air pressure to driving cylinder, the intake air pressure control valve, heater, and the drive shaft for the fuel injection pump.

Fig. 2 shows details of the observation systems. Driving cylinder has 300mm diameter, which is filled beforehand with 0.5-3MPa compressed air supplied from the air compressor so that the piston is driven at a required speed. The crank shaft is connected to a disk brake, which makes the piston in the driving cylinder stop at 1-2 degrees after the top dead center, and is released to start moving the observation cylinder. The RCEM unit developed this time is equipped with a pneumatic braking mechanism to immediately stop the RCEM by using leakage hole at the driving room and the braking room of the driving cylinder.

As the temperature of the intake air directly influences the temperature of the compressed air at the top dead

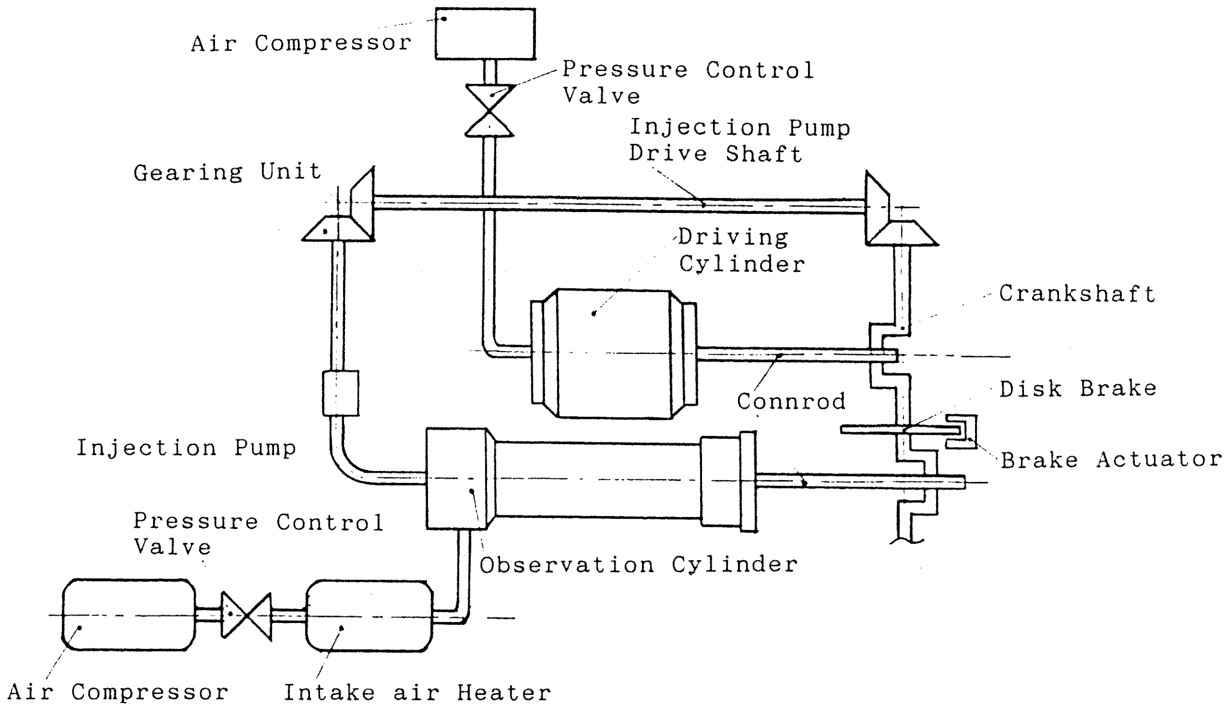

Fig. 1 Outline of the Rapid Compression and Expansion Machine

center, the RCEM is provided with a temperature and pressure control mechanism so that the temperature of the engine can be reproduced.

After passing through the intake valve, the intake air contacts with the high temperature combustion chamber wall, it is heated and the temperature rises. The ignition delay depends on the temperature and pressure of the compressed air near the top dead center, and pre-mixed combustion depend on the amount of the air-fuel mixture produced in the delay period. Therefore, the RCEM includes a mechanism to control the wall temperature so that the combustion process of the engine is exactly simulated. Behind the combustion chamber wall embedded heater are equipped tb heat the components and to control the desired temperatures before starting it.

The swirl generated in the cylinder has extremely significant influence on mixing of fuel and air. In this RCEM, the combustion occurring in the cylinder can be observed from not only below the position of piston but also above near the cylinder head, because the intake air port which makes air flows into the cylinder is located on a lateral side of the cylinder. Guide vanes arranged outside of the suction port to make the air spirally flow into the cylinder. It is possible to control the swirl ratio at will by changing the angle of vanes.

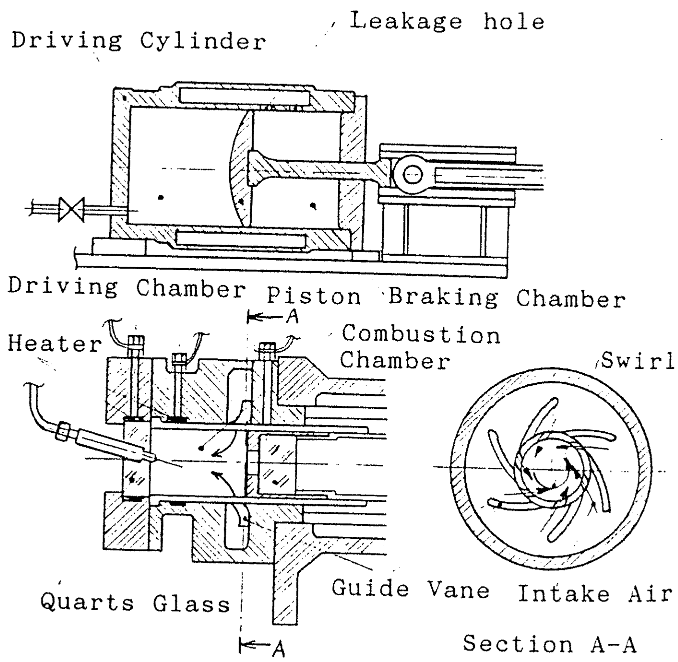

Fig. 2 Details of the Rapid Compression and Expansion Machine

3. Test Results

Fig. 3 demonstrates equivalent instantaneous speeds of observation piston driven by different air pressures of the drive cylinder. The figure shows that the air pressure fed into the drive cylinder can control observation piston speeds equivalent to 1000-

4500 rpm of engine. It is also confirmed that the instantaneous equivalent piston speed is stable between crank angle of 30 degrees before the top dead center and 60 degrees after the top dead center which duration is very important for observing the combustion process.

In order to coincide the swirl ratio of RCEM with that of engine, air speeds are measured in the engine cylinder and the RCEM cylinder by use of laser doppler velocimeter. And the swirl ratio in the observation cylinder was adjusted to the engine by regulating the inclination of guide vanes located outside of the cylinder.

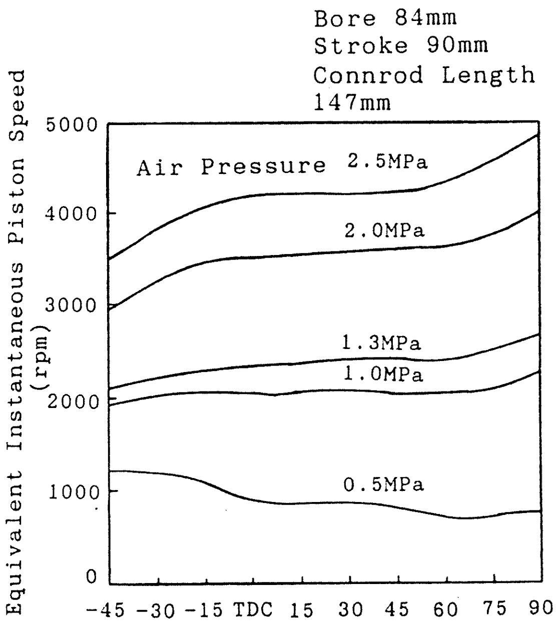

Fig. 3
Instantaneous Piston Speed Calculated from RCEM Crankshaft Speed on various Changed Air Pressure

The fuel injection rate between the engine and the RCEM were arranged similar shown as Fig. 4.

Fig. 5 shows the indicator diagram of RCEM compared with that of an engine without fuel injection, in which the intake air and cylinder wall has the same temperature and intake air has also the same pressure as an engine. After We confirmed it, we measured indicator diagram of RCEM with combustion. Fig. 6 shows the comparison of those between the RCEM and the engine which history of pressure and ignition delay period are extremely similar.

4. Results of Observation of Combustion

Using the RCEM we have observed combustion process and measured in-cylinder pressures in the conventional water-cooled engine and the heat-insulated engine. Table 1 shows test conditions for combustion observation tests. Compared with the water-cooled engine,

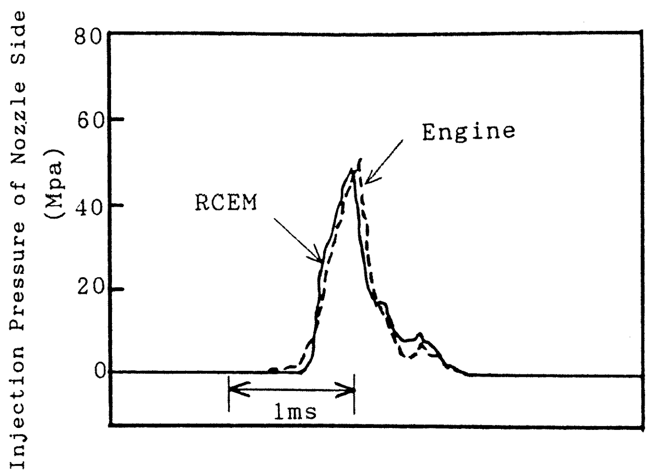

Fig. 4 Comparison of History of Injection Pressure between RCEM and Engine

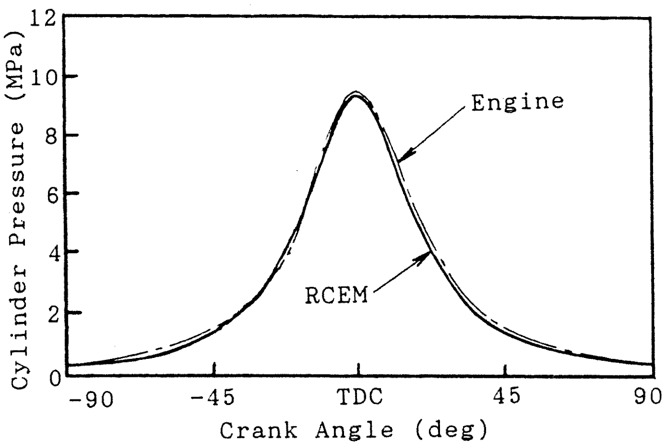

Fig. 5 Correlation of Indicator Diagrams between RCEM and Engine (with no Fuel Injection)

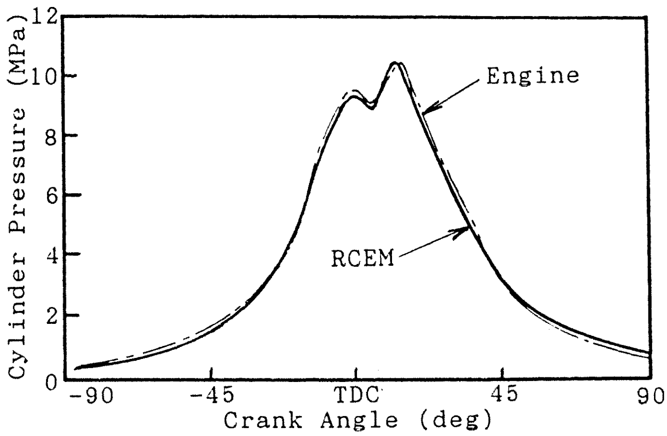

Fig. 6 Comparison of Indicator Diagrams between RCEM and Engine (Full Load)

air temperature of the heat-insulated engine were approximately 170K higher at the top dead center, which imply increasing in the coefficient of viscosity and the coefficient of kinematic viscosity by 10% and 32%, respectively. The optical system to observe the combustion process is shown in Fig. 7.

Table. 1 RCEM Experimental Conditions

	Water Cooled Engine	Heat Insulated Engine
Bore	8 4 mm	8 4 mm
Storke	9 0 mm	9 0 mm
Swept Volume	4 8 7 cm^3	4 8 7 cm^3
Compression Ratio	1 7 . 5	1 7 . 5
Cavity Type	Deep Toroidal	Deep Toroidal
Injection Nozzle Hole	ϕ 0 . 2 8 × 5	ϕ 0 . 2 8 × 5
Instantaneous Speed at T.D.C	2 0 0 0 r p m	2 0 0 0 r p m
Intake Air Temperature	3 3 3 K	3 5 3 K
Intake Air Pressure	1 7 7 K P a	1 7 7 K P a
Equivalence Ratio	0 . 7	0 . 7
Swirl Ratio	2 . 0	2 . 0
Piston Head Temperature	5 2 3 K	8 7 3 K
Cylinder Head Temperature	5 2 3 K	7 7 3 K
Cylinder Liner Temperature	3 7 3 K	4 2 3 K

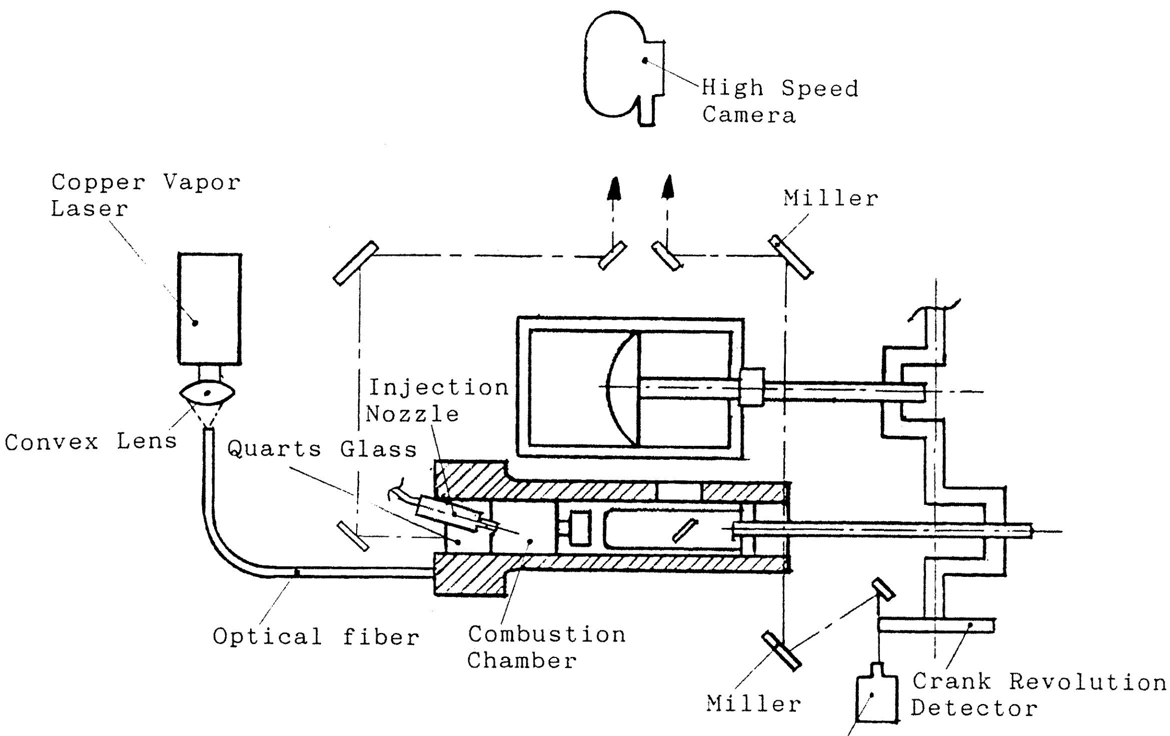

Fig. 7 Experimental Arrangement for Observation of Combustion

Photographs of combustion process of the conventional water-cooled engine and heat-insulated engine are shown in Fig. 8.

In the conventional water-cooled engine, the fuel spray reached the combustion chamber wall during the 1.1-1.2msec. which is long ignition delay, and part of those spray overflowed into the top clearance. Immediately after ignition, the initial flame occurred near the nozzle hole and 1.3-1.4msec. later whole of the injection spray was wrapped by flame. There was a little or no significant amount of soot appearing at the tip of the flame. The fire quickly reached the cylinder wall, and 1.6msec. later, flame spread across the entire cylinder. Thereafter, the luminous flame disappeared first at the center of the cylinder and disappeared part expanded slowly toward the cylinder wall, leaving little soot. The combustion completely ended 3.6msec. later.

The ignition delay period of the fuel spray in the high-temperature air was 0.6 msec., with less penetration during the ignition delay period than those of the water-cooled engine, and the fuel spray volume was smaller.

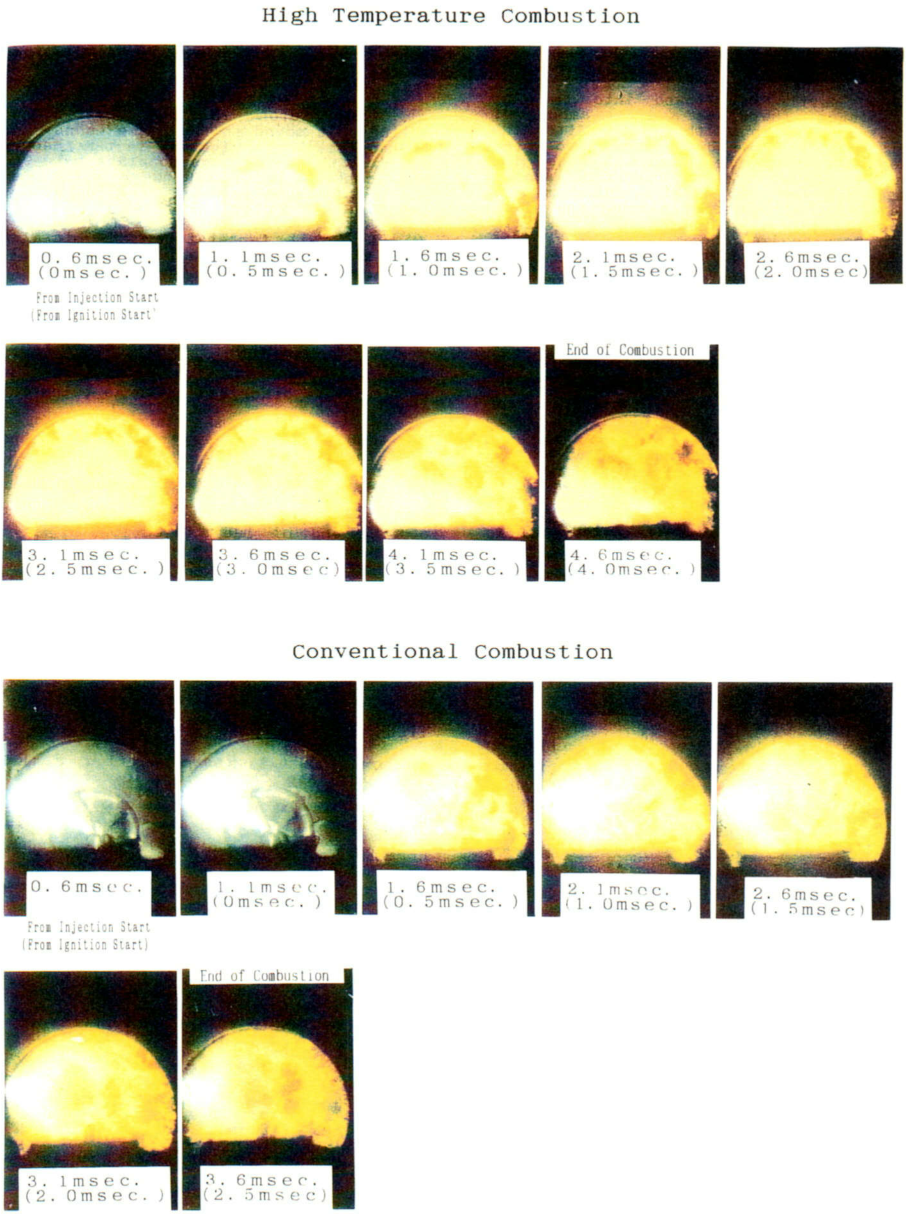

Fig. 8 Photographs of Conventional Combustion and High Temperature Combustion

Initial flames appeared from place to place on the periphery of the fuel spray, which burst into large flames 0.7msec. later. The tip of the flame was wrapped by fire and reached the combustion chamber wall, and a part of the flame partly overflowed into the top clearance. There was a great amount of soot at the tip of the flame. After the tip of the flame overflowed into the top clearance, the flame was once discontinued, and soon after got out again. Although the tip of the flame slowly reached the combustion chamber wall, the soot initially generated at the flame tip remained on the cylinder wall long time during the combustion.

The above results of observation well coincided with reported observations of combustion process of the conventional water-cooled engine and the actual heat-insulated engine (5). This proves that the RCEM is useful to reproduce burning conditions in the combustion chamber.

Fig. 9 depicts the indicator diagrams and the rate of heat release derived from the indicator diagrams of the conventional water-cooled engine and the heat-insulated engine. As shown here, the combustion of heat-insulated engine has features of smaller ignition delay period and less pre-mixed combustion, as well as smaller peak values of heat release associated with diffusion combustion, implying an extremely low combustion speed.

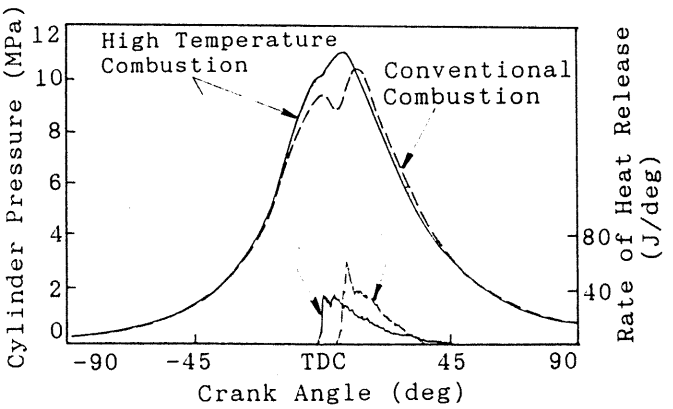

Fig. 9 Comparison of Indicator Diagrams and Heat Release Rate between High Temperature Combustion and Conventional Combustion

5. Summary

(1) The RCEM unit with observation cylinder driven by pneumatic drive cylinder were arranged in order to observe the combustion phenomena,and we took the following results.

① As results of observation using the RCEM well coincided with those of combustion process in the engine, it was understood that the RCEM is useful to observe the combustion process.

② The RCEM covered a range of the operating speed equivalent to 1000-4500 rpm of the engine by controlling device which can change the regulating pneumatic pressure fed into the drive cylinder.

③ The piston in the observation cylinder is moved in the same manner as the engine. The equivalent instantaneous speed of the piston was constant between the crank angle of 30 degrees before the top dead center and 60 degrees after the top dead center.

④ The wall temperature, the intake air temperature and the intake air swirl ratio were controlled same as those of the engine.

(2) Comparisons in observations of combustion between the conventional water-cooled engine and the heat-insulated engine were carried out and significant differences in the combustion process were described shown as below.

① The ignition delay period of the heat-insulated engine was shorter than those of the conventional water-cooled engine.

② The penetration of the fuel spray at the end of fuel injection of the heat-insulated engine was smaller than the conventional water-cooled engine.

③ The volume of the fuel spray in the heat-insulated engine was observed to decrease greatly because the penetration of the spray was deteriorated.

④ In the heat-insulated engine the fuel spray was covered with burned gas immediately after the fuel injection, disturbing mixing of the fuel with fresh air.

⑤ As a result, the combustion of the heat insulated engine was deteriorated by the un-uniform mixture of the air and fuel, we estimated.

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