DIESEL COMBUSTION AND EMISSION USING HIGH BOOST AND HIGH INJECTION PRESSURE IN A SINGLE CYLINDER ENGINE

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Heavy-duty diesel engines have adopted numerous technologies for clean emissions and low fuel consumption. Some are direct fuel injection combined with high injection pressure and adequate in-cylinder air motion, turbo-intercooler systems, and strong steel pistons. Us- ing these technologies, diesel engines have achieved an extremely low CO2 emission as a prime mover. However, heavy-duty diesel engines with even lower NOx and PM emission levels are anticipated. This study achieved high-boost and lean diesel combustion using a sin- gle cylinder engine that provides good engine performance and clean exhaust emission. The experiment was done under conditions of intake air quantity up to five times that of a natu- rally aspirated (NA) engine and 200 MPa injection pressure. The adopted pressure booster is an external supercharger that can control intake air temperature. In this engine, the maximum cylinder pressure was increased and new technologies were adopted, including a monotherm piston for endurance of Pmax = 30 MPa. Moreover, every engine part is newly designed. As the boost pressure increases, the rate of heat release resembles the injection rate and becomes sharper. The combustion and brake thermal efficiency are improved. This high boost and lean diesel combustion creates little smoke; ISCO and ISTHC without the ISNOx increase. It also yields good thermal efficiency.

Key Words: Power Unit, Engine Combustion, Diesel Engine / High Boost, High Pressure Injection, Common Rail Injector, Emission

1.Introduction

Heavy-duty diesel engines have undergone continu- ous improvement in fuel consumption and exhaust emis- sions through change from a pre-chamber type to a direct-injection type, combustion modification using high- pressure injection and swirl air motion(1), adoption of turbo-intercoolers(2), (3), and alteration of piston materi- als from aluminum to iron(4). Those improvements have earned a worldwide reputation for diesel engines as the prime movers of low CO2 emission(5). However, reduc- tion of exhaust emissions such as NOx and PM is required urgently(6).

Improvement of exhaust emissions is now proceeding by adoption of a newly developed common rail fuel in- jection system that makes high-pressure injection possible and a turbo charging system that provides air to the cylin- der in large amounts. Further improvement will be carried out in this manner in the future(7) – (11). A catalyst is indis- pensable for reduction of exhaust emissions from diesel engines, but it is necessary to minimize exhaust emissions. In addition, it is important use after-treatment efficiently. This study measured the engine performance and exhaust emissions, under the condition that the fuel injection pres- sure was raised to 200 MPa using single cylinder engines. The intake air amount was raised to five times that of NA engine using high boost pressure.

Table 1 Engine specifications and test conditions

Item	Specifications
Engine type	DI single cylinder
Bore and stroke	135 × 140 mm
Displacement	2004 cm^3
Cylinder head	4 valve
Comb. chamber	D = 98 mm, shallow dish
Compression ratio	15
Swirl ratio	0.6
Air charging	External super charger with cooler, Max 501.3 kPa
Injection system	Accumulator type
Injector	Hole nozzle, 0.17 × 6
Injection pressure	200 MPa
Engine speed	1000 - 2000 rpm
Fuel	Diesel fuel JIS No.2 (Sulfur 400 ppm)

2.Experimental Condition

2. 1 Experimental single cylinder engine

Table 1 shows specifications of the engine used herein. This single cylinder engine was designed to allow it to withstand a maximum cylinder pressure of Pmax = 30 MPa. The piston used in this experiment is a monotherm piston made of steel, which can withstand Pmax = 30 MPa. The shapes of the cross sections of the piston and the combustion chamber are shown in Fig. 1. Most engine parts such as the piston pin, conrod, crank shaft, metal materials, intake and exhaust valves, cylinder head, head bolt, head gasket, cylinder block, as well as the piston, were designed to withstand Pmax = 30 MPa.

In the high boost experiment, it was considered that

Pmax would rise higher than 30 MPa. The compression ra- tio ε = 15.0 was chosen to reduce the Pmax. The regular compression ratio was ε= 16.5.

The fuel injection pressure at the performance test was 200 MPa; a regular JIS No.2 diesel fuel (Sulfur 400 ppm) was used.

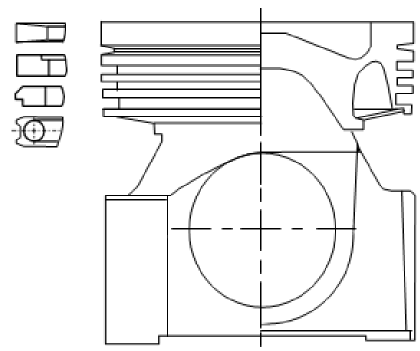

Fig. 1 Combustion chamber shape and monotherm steel piston for P_{max} = 30 MPa

Table 2 Test conditions for combustion high speed photography

Item	Specifications
Comb. chamber	D = 100 mm, flat shallow dish with transparent bottom
Compression radio	16
Charging conditions	from NA to 341.3 kPa
Injection pressure	100 MPa
Excess air ratio	3.5 constant
Engine speed	1000 rpm

TDC in real time by monitoring the heat release rate. Du- ration of the ignition delay was short under the super- charging condition; the injection timing was just before a few degrees of TDC. The supercharging system in this engine was an external super charge system driven by a motor. Its exhaust pressure was set equal to atmospheric pressure. Consequently, as the pumping work of the en- gine becomes great, the pumping work on the pressure di- agram is excluded from IMEP, leaving only the work of the combustion area as indicated mean effective pressure (kPa; IMEP). The brake mean effective pressure (kPa; BMEP) of the single cylinder engine was obtained from IMEP from results of this experiment using the motoring friction of the multi-cylinder engine.

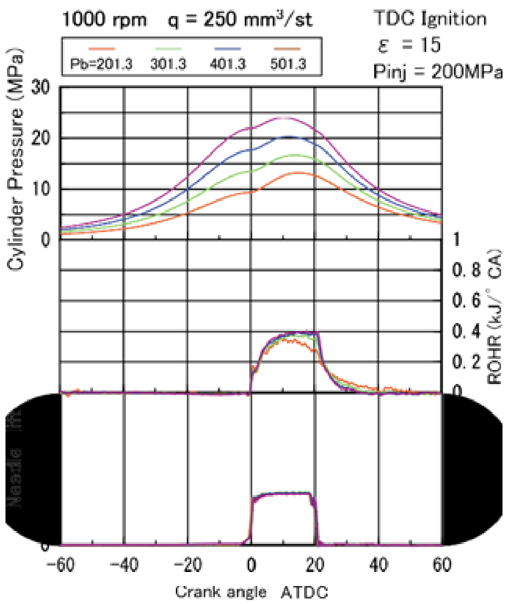

Fig. 2 E□ect of boost pressures on cyl. press. and ROHR

3.Experimental Results

3. 1 Pressure diagram and variation of heat release rate

Figure 2 shows results when changing the boost pres- sure Pb (kPa) under constant conditions of the injec- tion quantity q = 250 mm3/st and Ne = 1 000 rpm. The amount of air is twice that of the NA condition under Pb = 201.3 kPa. The heat release rate of that figure shows good burning. The burning becomes even better by in- creasing Pb; the heat release rate approaches the injection rate.

Fig. 3 Effect of fuel quantity on cyl. press. and ROHR

Figure 3 shows results when changing the injection quantity from q = 150 to 350 mm3/st under the constant conditions of boost pressure Pb = 501.3 kPa and Ne = 1 000 rpm. Because the amount of air in the cylinder was large under this condition and the injection duration was as long as 30 deg CA at q = 350 mm3/st, it was necessary to expand the total nozzle area to shorten the injection du- ration.

Figure 4 shows results when changing the engine speed from Ne = 1 000 rpm to 1 500 and 2 000 rpm under constant conditions of boost pressure Pb = 301.3 kPa and injection quantity q = 250 mm3/st. The injection duration at injection quantity q = 250 mm3/st at Ne = 2 000 rpm was as long as 40 deg CA and, as shown by the heat release rate, the burning duration was as long as 60 deg CA.

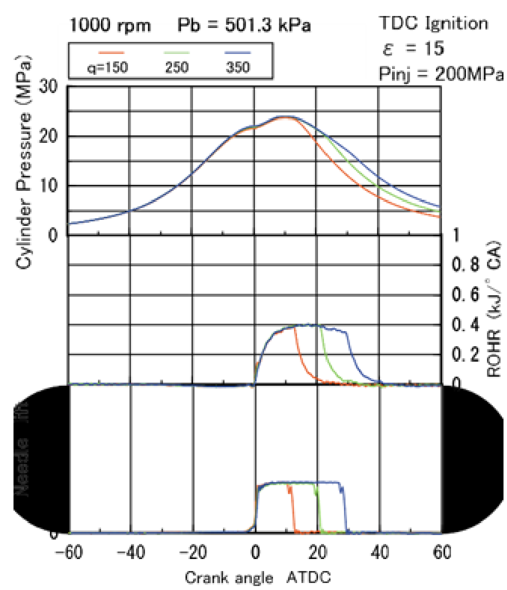

Fig. 3 E□ect of fuel quantity on cyl. press. and ROHR

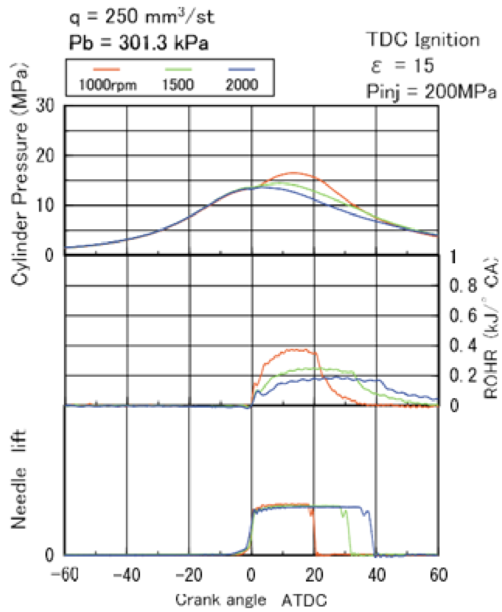

Fig. 4 Effect of engine speed on cyl. press. and ROHR

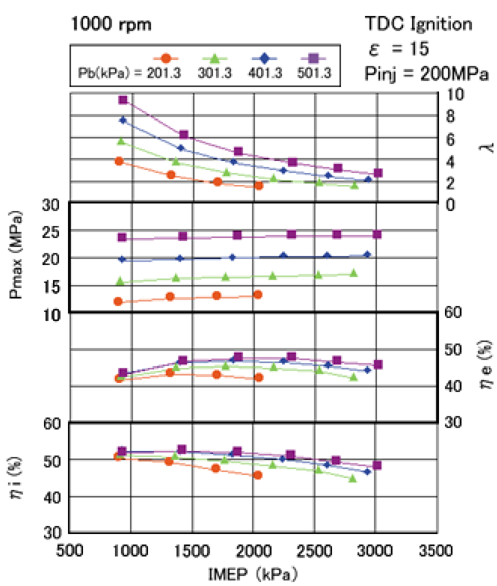

Fig. 5 Effect of boost pressures on P_{max} and thermal efficiency (Ne = 1 000 rpm)

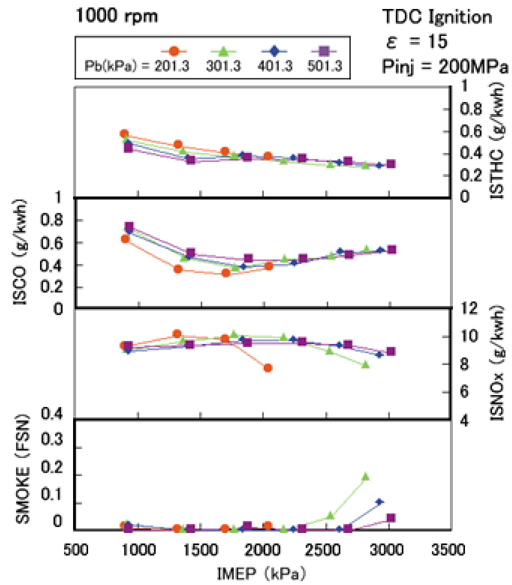

Fig. 6 Effect of boost pressures on exhaust emissions (Ne = 1 000 rpm)

Although the levels of ISCO and ISTHC per output
power were low, it was necessary to lower the level of ISTHC further, considering the required future PM.

With the excess air, the level of smoke was very low because this experiment was performed using supercharg- ing. The combustion was demonstrably good. As ex- plained before, under Pb = 201.3 kPa, the combustion was good without deterioration of smoke even at the small value of λ = 1.5 at the maximum value of IMEP, but the air excess ratio may lower to λ = 1.5– 2.0 at the condition of greater than Pb = 301.3 kPa. Thereby, the smoke would tend to increase at the maximum value of IMEP. The in- jection quantity was as large as 350 mm3/st, as it never had been before under the condition that IMEP was increased by increasing boost pressure. Consequently, the injection duration lengthened greatly. During that time, the piston would descend.

Presumably, the fuel spills from the pis- ton cavity and degrades the combustion, thereby generat- ing smoke. A combustion must be found that does not produce smoke at the λ = 1.8 level.

4. Consideration

4. 1 Pmax and brake thermal efficiency

Although supercharging boosts the intake air, Pmax is increased. At the same time, the brake thermal efficiency is also improved. By increasing Pmax, the brake thermal efficiency shown in Fig. 13 was obtained by boosting Pmax and increasing IMEP. From this result, the thermal ef- ficiency, namely, fuel consumption, can be improved by extending Pmax to 20 – 25 MPa and using the high thermal efficiency range of IMEP = 1.5– 2.0 MPa as the running range in vehicle.

5.Summary

Engine performance and exhaust emission character- istics were examined by inducing the amount of intake air up to five times that of an NA engine and by increasing the injection quantity up to 350 mm3/st under the condition of 200 MPa injection pressure.

(1) Combustion was improved by increasing the in-

take air amount. Consequently, a sharp heat release was obtained and thermal efficiency was improved. By in- creasing the amount of air and by increasing Pmax, brake thermal efficiency was improved.

(2) For high boost diesel combustion, by increasing the air amount, the NOx weight per unit of output power did not increase. Furthermore, smoke was reduced greatly by increasing the air amount. Experiments proved that re- ductions of both NOx and PM are achieved by high boost and lean combustion.

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