Combustion and Performance in Diesel Engines with Carbureted Ethanol

The Effects of Intake Air Heating, Compression Ratio, and Water Content in Ethanol

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Abstract

With the method of injecting alcohols into the intake manifold, the so-called the carbureted method, knocking or misfiring developes when a large proportion of alcohol is introduced. This paper investigates the effects of intake air heating, compression ratio, and water content in ethanol on this kind of knocking and on general engine performance of a diesel engine with ethanol injection into the intake manifold.

As a result, it was found that the extent of ethanol vaporization in the intake manifold does not affect the engine performance so much. The reduction in compression ratio increases output levels unaffected by knocking to only a limited extent. It was also recognized that the engine performance is not affected by the water content in the ethanol, at least up to 40 vol-%.

1. Introduction

From production and technical points of view, alcohol has been considered as a promising alternative to gasoline and diesel fuel. Although the utilization of alcohol fuels is relatively easy in spark ignited engines, it is quite difficult in diesel engines because of poor self-ignition characteristics.

A number of investigations have been carried out on the use of alcohol fuels in diesel engines with the injection of alcohol into the intake manifold,[1,2,3,4] the injection of a diesel oil-alcohol emulsions,[5,6,7] and direct injection of alcohol and diesel oil into the combustion chamber.[8,9,10]

The method of injecting alcohols into the intake manifold, the so-called the carbureted method, has a merit in that it does not require any modification of engine configuration and it can be used with gaseous fuels as well as liquid fuels. However, this method develops knocking or misfiring when a large proportion of alcohol is introduced. The authors previously showed that this knocking can be reduced significantly by decreasing the volumetric ratio of pre-chamber to total clearance

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volume.[4] The present investigation was carried out to examine the effects on the engine performance of heating of intake air, compression ratio, and water content in ethanol.

It was found that heating of intake air has a favorable effect on exhaust gas pollutants, but it decreases power output. The reduction in compression ratio increases output levels unaffected by knocking, knock limited-output, to only a limited extent. It was also recognized that the engine performance was not affected by the water in the ethanol, at least up to 40 vol-%.

2. Experimental Apparatus

The engine used for the investigation was a single cylinder, water cooled, vertical, 4-stroke, pre-combustion chamber diesel engine. The main specifications of the engine are listed in Table 1.

Table 1. Engine spehifications

Engine name	Mitsubishi DV-4
Bore × Stroke	95 × 110 mm
Piston displacement	780 cc
Volume of pre-chamber	18.4 cc
Compression ratio	19.0
Rated power	13.4 kW/3200 rpm
Volumetric ratio of pre-chamber to clearance volume	0.425
Area ratio of connecting passage to the section of cylinder	0.00572
Nozzles for main and auxiliary fuel injection	DN4SD, (throttle nozzle)
Nozzle opening pressure	12 MPa

Denatured ethanol with a purity of 95% was used as the main fuel, and diesel oil was used as a pilot fuel. The main fuel was injected into the intake manifold, and the pilot fuel was injected into the pre-combustion chamber. In practical operation the injector of the main fuel can be replaced by a carburetor or a pressurized tank.

The intake air was heated by 2 kW electric heater installed in the intake manifold. The ethanol was also heated by electric heating wires wound around the injection pipe, and the temperature was measured with a thermocouple placed in the nozzle holder.

The compression ratio was varied from 19.0 to 12.0 by placing spacers with different thicknesses under the cylinder block, resulting in changes in the volume of the main combustion chamber.

The exhaust gas was analyzed for NOx by using a CLD analyzer, total hydrocarbon and unburned ethanol were analyzed on a FID analyzer, and total aldehyde was found by the MBTH method.

The engine was operated at 2000 rpm with a coolant inlet temperature of 90 °C and the lubricating oil temperature at 60 °C in the sump.

The proportion of ethanol, ϕe, is defined as the calorific ratio of ethanol to the total energy supplied.

3. Experimental Results

3.1 The influence of vacuum-boiling of ethanol and the heating of intake air

It was observed that a large portion of injected ethanol flowed into the cylinder in the liquid phase along the wall of the intake manifold. In order to examine the effect of changes in the state of the intake mixture, vacuum-boiling and heating of the intake air were investigated.

Figure 1 shows the specific heat consumption, total excess air factor, smoke density, exhaust gas temperature, and engine noise as functions of ethanol temperature in the nozzle holder.

As can be seen from the figure, the heating of ethanol in the injection pipe did not affect the engine performance to a great extent, although the liquid fuel adhered to the inside of the intake manifold vaporized when it was heated to over 200°C. Thus, it seems likely that the state of vaporization of ethanol in the intake manifold does not affect the engine performance.

Figure 2 shows the engine performance as a function of intake air temperature before the mixing with ethanol. The specific heat consumption, smoke density, and engine noise become worse with the increasing temperature of the intake air. This may be partially due to early ignition of pilot fuel resulting from fixed pilot injection

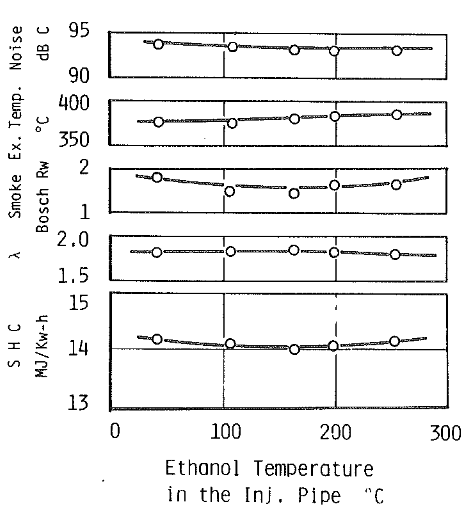


Fig. 1 Effects of ethanol temperature in the injection pipe
(BMEP: 0.44 Mpa, ϕe=23%)

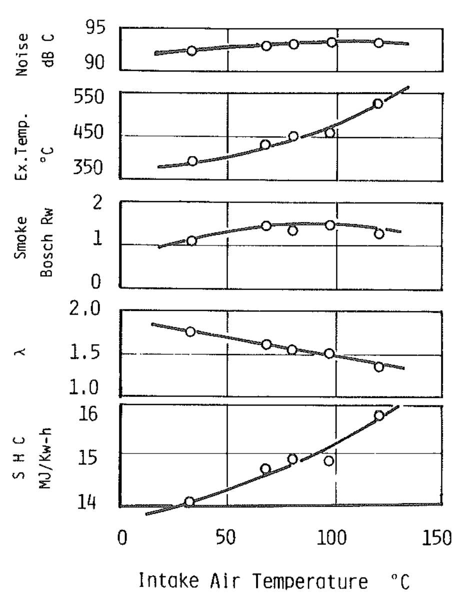


Fig. 2 Engine performance with heating of intake air
(BMEP: 0.44 MPa, ϕe=23%)

timing in spite of a shorter ignition lag. When the intake air was heated, the power output decreased significantly due to a decrease in volumetric efficiency.

Figure 3 shows total hydrocarbon, unburned ethanol, and total aldehyde emissions as functions of intake air temperature for partial loads. All of these pollutants decrease considerably with the increase in the intake air temperature.

Thus, it can be said that the heating of intake air improves emission, but it reduces the power output.

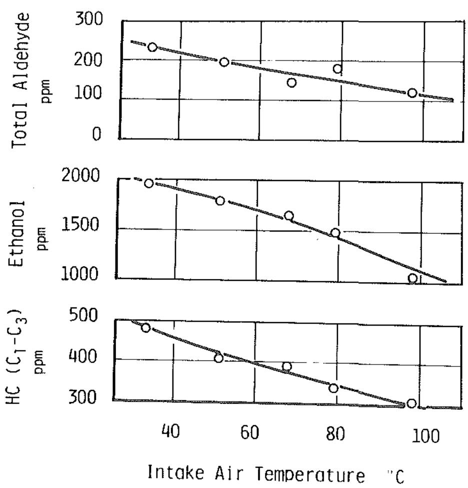


Fig. 3 Exhaust gas emissions with heating of intake air (BMEP: 0.15 MPa, ϕe=60%)

3. 2 The effect of compression ratio on the engine performance

The amount of ethanol injected into the intake manifold is limited by the development of knocking similar to auto-ignition in spark ignited engines. In order to reduce knocking, a reduction in the compression ratio was investigated.

Figure 4 shows the maximum brake mean effective pressure limited by knocking, the excess air factor for ethanol, and combustion characteristics versus compression ratio. In the figure the load was varied by the amount of ethanol fuel, while the pilot fuel was kept constant at 8.3 g/min. The maximum pressure decreases and knock limited-output increases with decreasing compression ratio. However, the increase in the knock limited-output is saturated at a compression ratio of about 13, and further reduction of compression ratio causes misfiring due to a considerable increase in the ignition lag of the pilot fuel.

Figure 5 shows the pressure curves and the burning rates for compression ratios of 19.0 and 12.0. Most of the heat release is due to the premixed combustion and the maximum rate of heat release is very large compared with conventional diesel combustion, namely 4-5 kJ/mol°CA compared with 2-3 kJ/mol°CA. Therefore, when the compression ratio is reduced, the maximum rate of heat release increases in proportion to the increase in the amounts of ethanol, and diesel-knock becomes significant.

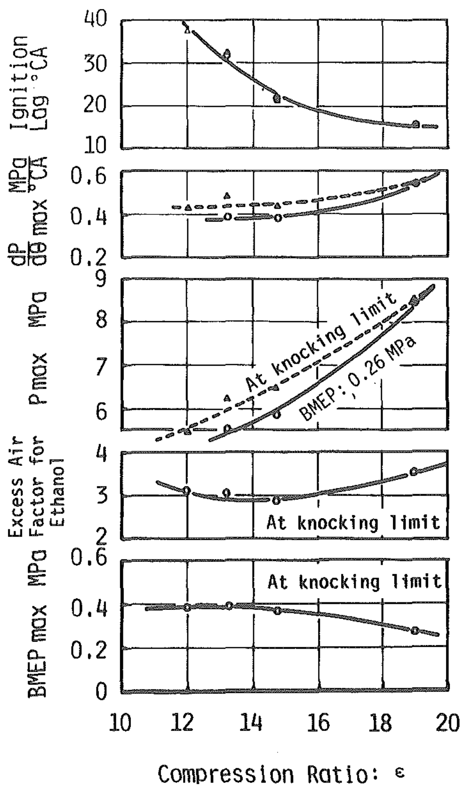


Fig. 4 Knock limited-output for different compression ratios (Amount of pilot fuel is fixed at 8.3g/min., corresponding to about $\phi e = 60-70\%$)

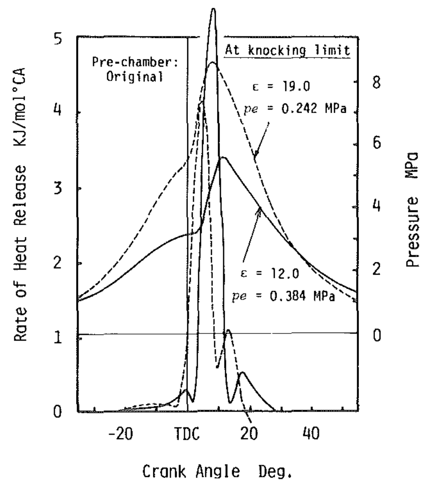
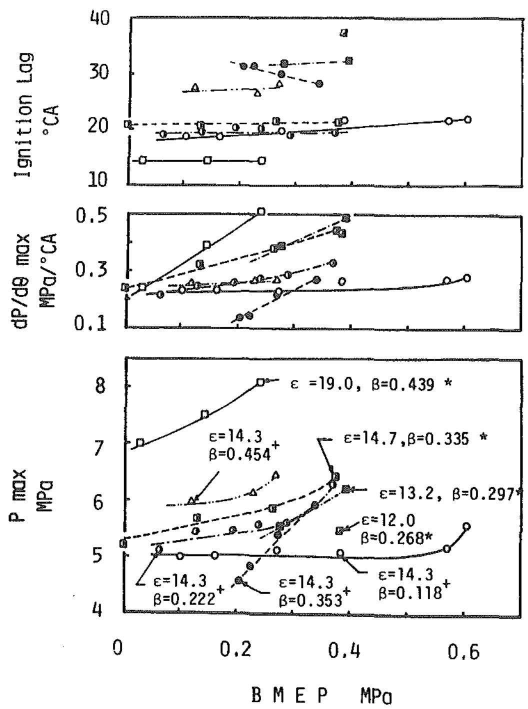


Fig.5 Comparison of pressure curves and burning rates for compression ratios of 19.0 and 12.0

When the volumetric ratio of the pre-chamber to the total clearance volume was reduced, the heat release corresponding to diffusive combustion rather than premixed heat release increased.[4] Consequently the increase in the knock limited-output, by reducing the compression ratio, was not significant compared with the increase caused by the reduction of the volumetric ratio of the prechamber.

This tendency is also seen in Figure 6, in which maximum combustion pressure and rate of pressure rise are plotted for the different compression ratios and for different volumetric ratios of pre-chamber, β. The maximum combustion pressure and the rate of pressure rise are almost constant for $\varepsilon = 14.3$ and $\beta = 0.118$ over the wide range of the brake mean effective pressures, i.e. with a wide increase in ethanol. This indicates that the diffusive heat release rather than the premixed part increases. When the compression retio is reduced by increasing the volume of the main combustion chamber,* in the figure, the maximum combustion pressure and the rate of pressure rise increases with the increase in the brake mean effective pressure, in agreement with the increase in the premixed heat release as explained in Figure 5.

Thus, the knocking in the carbureted method is characterized by two types of knocking; one is auto-ignition as seen in gasoline engines and the other is diesel-knock. The two types of knocking may occur and they are influenced by compression ratio, volumetric ratio of pre-chamber to clearance volume, and area ratio of



* denotes that the pre-combustion chamber is the original one with the volume of 18.4 cc.

\+ denotes that the pre-combustion chamber is modified as explained in the reference (4).

Fig. 6 Combustion characteristics for different compression ratios, ε, and for different volumetric ratios of pre-chamber to clearance volume, β.
(Amount of pilot fuel is fixed at 8.3 g/min.)

the connecting passage to the section of the cylinder.[4] It is likely that a reduction of the volumetric ratio of the pre-chamber is necessary as well as a reduction of compression ratio in order to reduce diesel-knock and also to prevent auto-ignition.

3. 3 The effect of water in ethanol

Ethanol with a purity of 95% was used in the foregoing experiments. In practice, however, ethanol containing more water would be used. Figure 7 shows the effects of water in ethanol. The ignition lag increases with the increase in water content. For example, the ignition lag becomes 30 degrees with the water content 40 vol-%, while it is 20 degrees with water free ethanol. However, a water content up to 40 vol-% does not affect the knock limited-output, the specific heat consump-

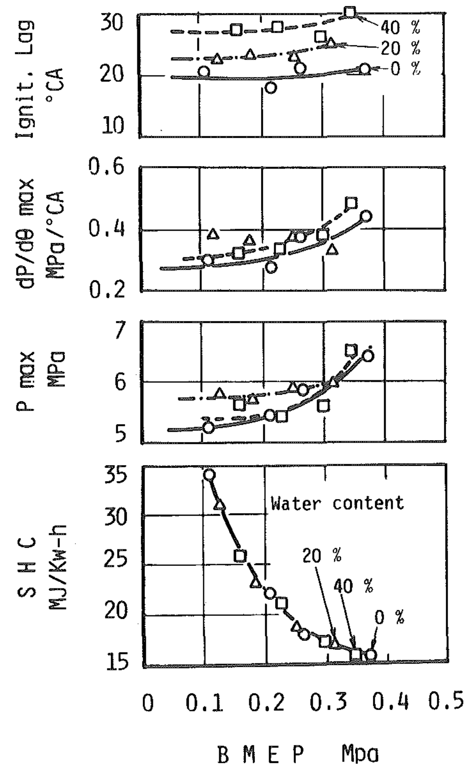


Fig. 7 Effects of water content in ethanol on engine performance ($\varepsilon=14.7$, $\beta=0.311$, Amount of pilot fuel is 8.3 g/min.)

tion, the maximum combustion pressure, and the rate of pressure rise. Therefore, it can be said that water in ethanol does not affect the engine performance up to at least 40 vol-%.

4. Conclusion

With the method of injecting alcohol into the intake manifold, the carbureted method, knocking or misfiring developes when a large proportion of alcohol is introduced. By modifying combustion chamber configurations, about 80% of diesel oil could be substituted by ethanol, while, in conventional diesel engines, the knock-free limit in the proportion was about 40%.

In the present experiment, the effects of compression radio and the states of the injected ethanol on the knocking and on general engine performance were investigated, and the following results were obtained;

(1) The extent of ethanol vaporization in the intake manifold does not affect the engine performance to a great extent.

(2) Heating of intake air decreases the power output, but it improves exhaust gas emissions.

(3) A reduction of the compression ratio increases the knock limited-output to a limited extent. In order to obtain a considerable increase in the knock limited-output, reduction of the volumetric radio of the pre-chamber to clearance volume is necessary, as well as a reduction of the compression radio.

(4) Water content, at least up to 40 vol-%, does not cause change in the engine performance.

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