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Research Article

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A Study on the Smoke Reduction of Methanol-Diesel Engine by Fumigation Methanol Fuel Supply Method

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Abstract Diesel engine smoke emissions are known to occur when the injected fuel is not sufficiently mixed with oxygen. A study on the reduction of smoke emission in diesel engines due to the strengthening of environmental pollution regulations is under way. In this study, the cause of smoke emission of diesel engines is aimed.

Therefore, the purpose of this study is to analyze the relationship between smoke concentration and experimental variables in terms of combustion engineering by adopting the engine speed and methanol concentration as experiment variables.

Keywords Diesel, Methanol, Bake Horse Power, Smoke, Heat Release, Diffusion Combustion, Fraction of Diffusion Combustion

Introduction

The emission of smoke from a diesel engine is a combustion product produced by injecting light oil from a compression end to a high-temperature and high-pressure combustion chamber and burning the injected fuel in a state where it is not sufficiently mixed with oxygen. It is necessary to clarify the cause of smoke emission of diesel engines at first when study on reduction of smoke emission which is unnecessary combustion product of diesel engine due to strengthening of environmental pollution regulation is proceeding [1-3].

Generally, the smoke emission of a diesel engine is governed by the atmosphere in the combustion chamber, i.e., the pressure and temperature within the combustion chamber. Also, the temperature and pressure of the combustion chamber are changed in accordance with the change of each factor. Since the atmosphere in the combustion chamber influences the ratio of smoke generation and oxidation to change the amount of smoke emission, factors that directly affect the influence of pressure and temperature in the combustion chamber should be identified [4-5].

In order to understand the atmosphere inside the combustion chamber, it is necessary to obtain the pressure, temperature and heat release rate in the combustion chamber. In addition, the smoke emission is the main factor of the smoke generation in the state where the air and the fuel are not mixed, and the pyrolysis of the fuel is the characteristic of the diffusion combustion. Therefore, the emission of smoke is proportional to the amount of diffusive combustion, and diffusive combustion is also dominated by the amount of premixed combustion. Therefore, in this study, the main purpose of this study is to analyze the relationship between smoke concentration and experimental variables in terms of combustion engineering. It also determines which factors directly affect the smoke emissions as the engine speed changes. In general, we know that if we add alcohol (Methanol or Ethanol) fuel to the engine, we can reduce the emissions. However, adding alcohol to a diesel engine is not an easy task [6-7].

In this study, the correlation between the amount of smoke emission from the diesel engine and the type of heat generation in the combustion chamber was investigated and analyzed to find quantitative comparison of diffusive combustion in the heat generation rate curve for the engine parameters. Also, it is considered that the cause of the reduction of the smoke of the diesel engine as containing methanol.

Experimental Apparatus and Test Methods

The engine used in this experiment is a single-cylinder water-cooled direct injection type diesel engine. The major specifications are as shown in Table 1. The combustion chamber shape is toroidal type, the piston has a cavity volume of 31.5 cc, and the squish area ratio is 70%.

Fig. 1 is a schematic diagram of the experimental setup. The engine was directly connected to a DC dynamometer (7.5 kW) and power was measured. The temperature and pressure of the intake system and the exhaust system were measured. The intake air amount was measured by an orifice flow meter (12 mm). The fuel flow rate was measured by measuring the time spent to consume fuel by installing 20 CC burette and three-way cock. The air fuel ratio was calculated from the ratio of air flow rate to fuel flow rate. Also, the coolant outlet temperature was kept constant at 80℃, and the discharged smoke was measured by an automatic smoke measuring device (SOKKEN Co.). In order to obtain the heat release rate curve, the combustion chamber pressure must be measured.

In order to measure the pressure in the combustion chamber, a pressure transducer (KISTLER, 601A) was inserted into the cylinder head at the upper end of the injection nozzle and an average pressure value of 100 cycles was obtained using a combustion analyzer (ONOSOKKI, CB366). The signal from the pressure transducer is input to the combustion analyzer through the charge amplifier. Simultaneously, the crank angle is measured with a detector to synchronize the crank angle with the pressure in the combustion chamber. In addition, methanol is supplied to the intake pipe in the form of fumigation.

In order to clarify the smoke emission characteristics, the engine speed by injection quantity control was adopted as engine variable. The amount of injected fuel was adjusted by adjusting a rack adjusting device to adjust the head of the plunger barrel in the injection pump. The amount of fuel supplied to the injecting nozzle was changed by changing the rack adjusting device step by step. The injection timing is designed to be changed by a change in contact timing between the roller tappet of the injection pump and the injection pump drive cam of the camshaft by inserting the gasket into the connection portion between the injection pump and the crankcase and changing the thickness of the gasket. It is only about 3 degrees at an angle. In order to analyze the smoke emission characteristics with respect to the injection timing change, a device capable of varying up to 45 degrees was manufactured and the injection timing was changed. The injection timing was determined by selecting the optimal injection timing, determining the optimal torque sensing point, and determining the injection timing.

The engine speed change is the same as in the case of the engine running, and the dynamometer load is maintained constant. The injection timing for each rotation number change is optimized injection timing and the position of the injection pump is adjusted The engine speed was experimented from 800 rpm to 1000 rpm, 1200 rpm, 1400 rpm, 1600 rpm, 1800 rpm and 2000 rpm. At this time, the optimum injection timing was selected, and the air fuel ratio was selected as the optimum air fuel ratio. The focus of the study is on smoke for diffusion combustion. The optimum injection timing and the smoke emission characteristics for the air fuel ratio were identified. The smoke emission characteristics for the engine speed variation were obtained in accordance with the same conditions as when the engine was running.

The amount of methanol was calculated as the volume ratio of methanol and diesel supplied to the engine. The steady-state operation limit was set when the mixing amount of methanol increased during the engine operation and the engine speed reached 300 kPa/degree, which is the knocking limit at which the engine rotation speed fluctuates by more than ± 30 RPM or partial misfire occurs.

Table 1.Specifications of engine used

Items	**Specifications**
Cooling system	Water-Cooled
Displacement	632 cc
Bore × stoke	92 × 95 mm
Compression ratio	19.0
Cylinder number	Single
Combustion chamber	Toroidal chamber
Fuel injection pump	KP-PER 1KZ, 75/1 NP K2
Injection nozzle	Pintle type, 4 holes, 0.28mm
Nozzle opening pressure	21.5MPa

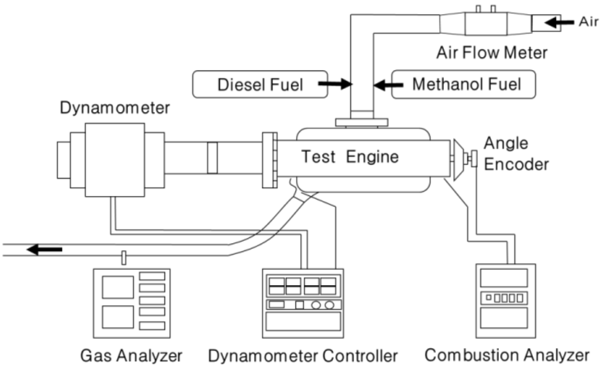

Figure 1: Schematic diagram of experimental apparatus

Diffusion Combustion Analysis by Smoke Emission and Heat Release Curve

The diesel engine has a combustion characteristic in which diffusive combustion occurs by injecting fuel into a combustion chamber of high temperature and high pressure, has a jet shape because it needs to supply fuel in a short time, and can be divided into three regions.

The fuel injected at the latest of the injected fuel is present in the rich core region which is not mixed with the air. This area is composed of fuel that is not evaporated, that is, fuel droplets. When these droplets are already burned and brought into contact with a hot flame band that releases heat (premixed combustion heat), pyrolysis of light oil which is a hydrocarbon fuel occurs. As described above, the smoke generation first occurs after the pyrolysis reaction of the hydrocarbon fuel, and then the smoked nucleus is formed.

The theory of smoke nucleation is based on three types of smoke nucleation theory, the growth process after the formation of smoke. The growth process of the smoke grows into a chainlike characteristic after surface nucleation after the formation of the smoke nucleus. When the particles are agglomerated, the respective smoke particles stop the growth of the surface and the number of the particles decreases.

Emissions of smoke are the result of smoke generation and oxidation, and can be expressed in terms of phenomenology. As mentioned earlier, pyrolysis of the fuel occurs in an atmosphere where the fuel droplet contacts with the flame and the air is insufficient. This pyrolysis decomposes the hydrocarbon fuel to form the nucleus of the smoke, and after completion of the condensation, polymerization and dehydrogenation reaction, it completes the growth process and the oxidation process. Especially, those which have not been oxidized are discharged into the atmosphere during the exhaust process as smoke.

Generally, the heat generation mode of a diesel engine can be divided into premixed combustion and diffusion combustion. Premixed combustion is a phenomenon in which a combustible mixture of air and fuel in a period of ignition delay generates heat in a short period of time and diffusive combustion generates heat due to pyrolysis of fuel in a state where fuel in the rich core region is not sufficiently mixed with air. Pyrolysis of these fuels is the main cause of smoke generation, which depends on the size of diffusion combustion.

Therefore, it is necessary to analyze the heat generation rate curve in order to grasp the quantitative relation of diffusive combustion according to the engine parameters of the diesel engine and to identify the relationship between smoke emission and diffusive combustion.

The heat release rate of the diesel engine can be expressed by the heat release rate equation using the combustion chamber pressure and the combustion chamber volume change rate using the first law of thermodynamics.

$$\frac{dQ}{d\theta} = \frac{k}{k-1}\,P\,\frac{dV}{d\theta} + \frac{1}{k-1}\,V\,\frac{dP}{d\theta} \quad (1)$$

k: specific heat ratio, Q: heat quantity, θ: crank angle, P: pressure, V: volume

The premixed combustion and the diffusive combustion can be divided from the heat release rate curve thus obtained, and the diffusion combustion amount can be obtained from this.

Therefore, we define the fraction of diffusion combustion, F_{diff} as follows to investigate the relationship between the diffusion combustion amount and the smoke emission for the engine parameters of the diesel engine. Q_{diff} is the amount of heat generated by diffusive combustion, and Q_t is the total heat generated.

$F_{diff} = \frac{Q_{diff}}{Q_t}$(2)

The emission of smoke from a diesel engine is governed by the amount of heat of diffusive combustion, and the amount of diffusive combustion is changed by the amount of heat of premixed combustion generated first. To identify the relationship of smoke emissions to premixed combustion, the premixed combustion rate F_{pr} is defined.

$F_{pr} = \frac{Q_p}{Q_t}$ (3)

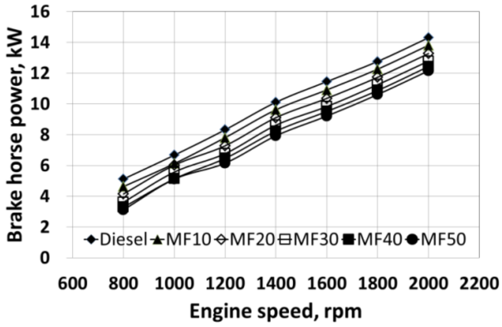

Figure 2: Brake horse power versus engine speed for various fuels

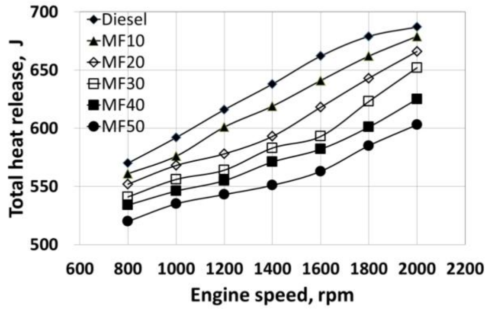

Figure 3: Total heat release versus engine speed for various fuels

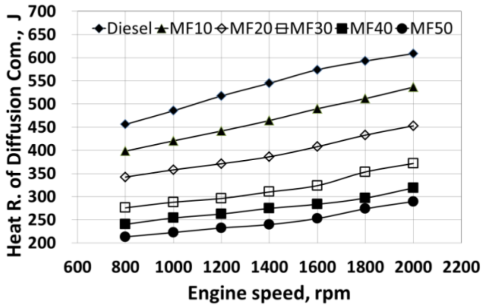

Figure 4: Heat release of diffusion combustion versus engine speed for various fuels

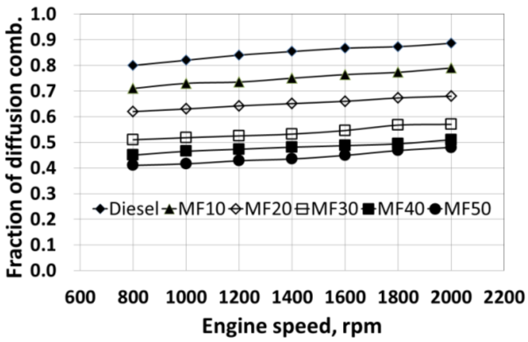

Figure 5: Fraction of diffusion combustion versus engine speed for various fuels

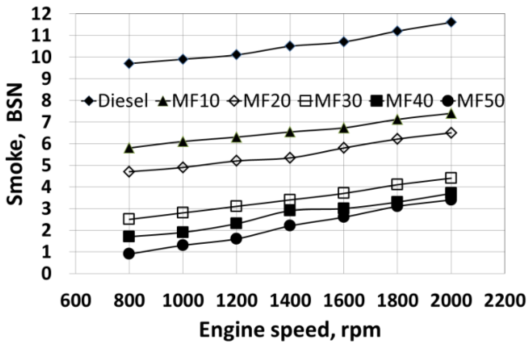

Figure 6: Smoke versus engine speed for various fuels

The diffusion combustion rate can be defined by the following equation.

$F_{pr} = 1 - F_{pr}$ (4)

Fig. 2 is a graph showing the output power for various types of fuel with respect to the engine speed change. Brake horse power increases as torque and engine speed increase. However, the effect of the increase in engine speed is much greater than the effect of torque. Also, since the amount of heat generated by diesel fuel is large, the output gradually decreases as the amount of methanol increases.Diesel, MF10 (Methanol 10%), MF20 (Methanol 20%), MF30 (Methanol 30%), MF40 (Methanol 40%) and MF50 (Methanol 50%) were tested.The output is gradually reduced.However, the exhaust gas is expected to decrease with increasing methanol, rather than the negative that the output decreases with increasing methanol.

Fig. 3 shows total heat release, Fig. 4 is the heat release of diffusion combustion and Fig. 5 is the experimental result showing the fraction of diffusion combustion with respect to the engine speed variation.

As the engine speed increases, the diffusive combustion amount and the diffusive combustion rate also tend to gradually increase, and the smoke emission amount and the diffusive combustion rate according to the engine speed change have the same tendency.

These results are shown in Fig. 6 shows the smoke emission concentration according to the change in the amount of methanol (Vol,%) with respect to the change in the engine speed, and it shows that the smoke concentration decreases proportionally as the amount of methanol is increased.

Fig. 6 shows the smoke emission according to the amount of methanol mixed with the engine speed. The methanol content was changed to 0% (Diesel 100%), 10%, 20%, 30%, 40%, 50%. For each fuel, the injection timing of the fuel supply was performed in an optimal state. As shown in the figure, the smoke emission is reduced as the amount of methanol mixed in each engine speed is increased, and the smoke emission due to the increase of methanol content in each engine speed is also decreased.

As the amount of methanol is increased, there is a stable operation limit. As the amount of methanol increases, the amount of methanol fuel injected into the intake pipe increases, and a large amount of methanol fuel flows into the combustion chamber. The temperature is lowered and it is predicted that misfiring occurs because the light oil injected as the cause of ignition does not absorb the heat amount required for evaporation.

From the heat release rate curve according to the amount of methanol mixture (See Fig. 3), as the amount of methanol is increased, the smoke emission is reduced.

Based on the above results, the smoke emission and diffusive combustion rate as a whole are shown in Fig. 6 From this figure, it can be seen that the smoke emission and the diffusion combustion rate are directly proportional, which is the data supporting that the emission of smoke to the engine parameters of the diesel engine is directly affected by the diffusion combustion.

Conclusion

Experimental results on the composition of diffusive combustion for smoke emission are summarized as follows:

As the engine speed increases, the emission of smoke increases, because the premixed combustion rate gradually decreases because the air fuel ratio becomes rich, and accordingly, the diffusion combustion rate is relatively increased. In addition, as the engine speed increases, the injection timing is advanced, and the premixed combustion rate increases proportionally.

As the injection timing is advanced, the ignition delay period becomes longer due to the lower temperature and pressure in the combustion chamber at the injection timing.
As the amount of methanol is increased, the smoke emission concentration decreases linearly. This is because the premixed combustion rate is increased due to premix formation of methanol and air, and the diffusion combustion rate is relatively decreased. Based on this relationship, we could reveal the relationship between premixed combustion rate and smoke emission according to the amount of methanol.

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