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Influences of fuel additives on the low temperature reaction of DME HCCI engine
DME 예혼합압축착화 기관의 저온산화반응에 미치는 첨가연료의 영향

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Key Words : 디메틸 에테르 (DME), 첨가연료 (Fuel additives), 저온산화반응 (Low temperature reaction), 예혼합압축착화 (HCCI)

Abstract : DME HCCI기관의 단점은 디젤 엔진에 비해 기관부하 영역이 굉장히 좁다는 것이고 이는 저온산화반응이 너무 빨리 일어나서 노크를 발생시키기 때문이다. 저온산화반응을 억제하기 위해서 DME 연소에 미치는 천연가스의 영향을 실험한 결과, 천연가스가 DME의 저온산화반응을 억제시키기 때문에 기관부하영역이 확대된다는 것을 알았다. 본 연구에서는 서로 다른 세탄가를 가진 첨가연료가 DME 저온산화반응에 미치는 영향을 실험적으로 조사하였다. 그 결과 저온산화반응의 최고 열발생율은 세탄가에 의존하지 않지만 착화온도는 세탄가에 의존한다는 사실을 밝혔다.

1. 서 론

Since dimethyl ether(DME) that is synthetic fuel attracted public attention as alternative energy of gas oil and clean energy, many researchers about it have studied and forecast increase in its usage[1~3]. On the other hand a homogeneous charge compression ignition(HCCI) engine has been substantially studied because it offers a number of benefits such as much lower NOx emissions, higher combustion efficiency and zero particulate. If DME is applied alone to HCCI engines, combustion pattern is separated 2 parts as a low temperature reaction (LTR) and high temperature reaction (HTR). The LTR and HTR are known as cool flame and hot flame, respectively. The problem in DME-HCCI engines is a smaller engine load because the start of LTR is fast, resulting in knock. In order to introduce DME to HCCI engine, some technologies were needed like to control the LTR. Then reduction in a compression ratio, introduction of exhaust gas recirculation (EGR) and some kinds of additive are applied in order to control the start of LTR. More than all, NG could extend the engine load range of DME-HCCI engines. The reason is clarified that a low cetane index of NG controls the start of LTR[4~9]. In this study, Methanol(MeOH) and Gasoline(GS) having different a cetane index beside NG were adopted in the DME-HCCI engine, its effect on LTR of DME was accomplished experimentally.

2. EXPERIMENTAL APPARATUS

The tested engine was a single cylinder high-speed naturally aspirated direct injection diesel engine, the type NFD 170-(E) manufactured by YANMAR in Japan. The principal particulars are

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shown in Table 1; the bore is 102 mm, the stroke is 105 mm and the compression ratio is 17.8. Properties of test fuels are shown in Table 2. DME is 99.9 % in purity. NG is a city gas named “13A” in Japan, which consists of about 88 % of CH4 and others of C_2H_6, C_3H_8, and etc. MeOH is the one for an industrial use with 99.9% inpurity. GS is available on the market in Japan. The cetane index of the base fuels were about 60 for DME, 0 for natural gas, 3 for methanol and 15 for gasoline respectively. The cetane index of blended fuels is calculated based on each mole fraction of DME and fuel additives as following formula.

Table 1 Specifications of tested engine

Engine type	YANMAR NFD170-(E)
Cycle	4
Cooling system	Water
Bore x Stroke [mm]	102 x 105
Displacement volume [cc]	857
Compression ratio	17.8
Maximum power [kW/rpm]	12.5/2400

Table 2 Tested fuels properties

	DME	MeOH	NG	GS
Chemical structure	CH_3O-CH_3	CH_3OH	CH_4 etc	C_3H_8 etc
Cetane index	60	3	0	15
Molecular mass	46	32	19	106
wt.% Carbon	52.2	37.5	75.0	87.7
wt.% Hydrogen	13.0	12.6	25.0	12.3
wt.% Oxygen	34.8	49.9	0.0	0.0

$$CI_{blend} = M_{DME} \times CI_{DME} + M_{add} \times CI_{add} \quad (1)$$

where CI is the cetane index and M is the mole fraction of each fuel, add. in subscripts means each fuel additives.

A fuel supply system is shown in Fig. 1. DME and NG were charged into a mixing chamber upstream of the intake manifold at the pressures of 0.12 and 0.1 MPa respectively after measuring each flow rate. MeOH and GS were injected along the axis of a suction pipe through a single gasoline injector with a pressure of about 0.5 MPa. In the combustion test system, attention was paid for obtaining a homogeneous charge as possible. The combustion tests were carried out at a constant engine speed of 1200±5 rpm and constant intake gas pressure of 0.1013 MPa. The intake gas pressure at the engine inlet was adjusted at the standard atmospheric pressure by using the motor-driven blower. The intake charge temperature at the suction port was adjusted to the specified temperatures of T_{IN} = 40 and 60 ± 0.5°C by using electric heater installed upstream of the suction pipe as shown in Fig. 1. An equivalence ratio of each fuel was changed at several engine loads available.

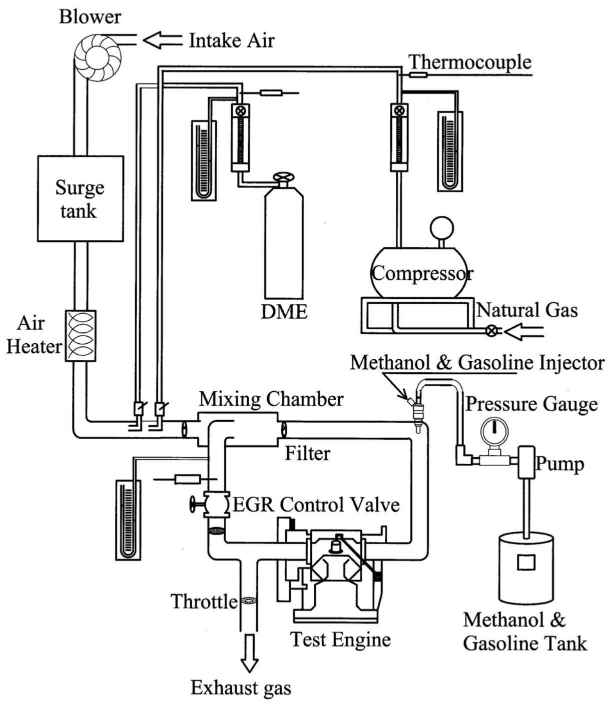

Fig. 1 Combustion test system

3. RESULTS AND DISCUSSIONS

Fig. 2, 3 and 4 show combustion time-history under the constant DME amount condition that makes each the maximum engine load range at the same intake charge temperature of 60℃. Each graph above shows the combustion pressure “P” and below shows the HRR “dQ/dϕ”. And the LTR portion in HRR graph is enlarged bottom because it is too small to discern. The maximum HRR of LTR is defined by the vertex in LTR. When there is no inflection point as shown in the case of NG and MeOH, its value is defined by 0, it means there is not the occurrence of LTR.

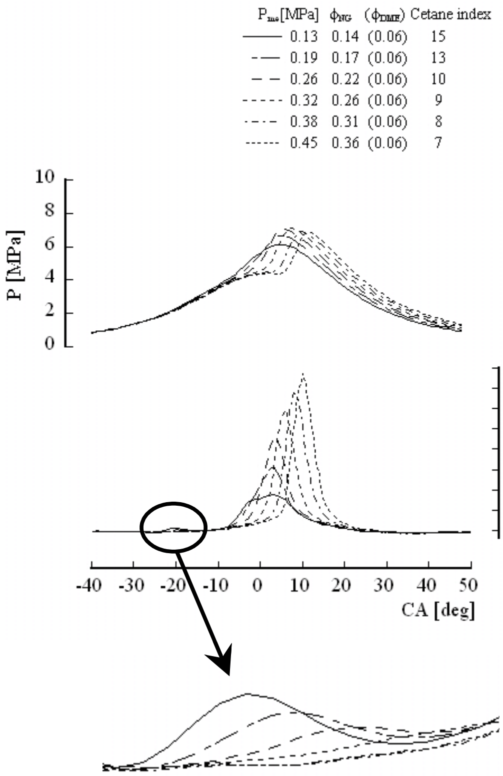

Fig. 2 Change in combustion history due to engine load under the constant DME amount condition in case of NG(TIN=60℃)

P_{me} and ϕ in the legend of figures are a mean effective pressure and an equivalence ratio, respectively. As both the equivalence ratio of NG and MeOH increases, LTR is suppressed and delayed markedly as shown in Fig. 2 and 3, whereas there is no effect with increase in the equivalence ratio of GS as shown in Fig. 4. It is assumed because GS has also LTR and HTR like DME in the HCCI enigne.

The maximum engine load, P_{me}=0.45 MPa is achieved in the case of NG, P_{me}=0.37MPa in case of MeOH and P_{me}=0.22MPa in the case of GS. It seems that the maximum engine load range is depended on cetane index because the maximum

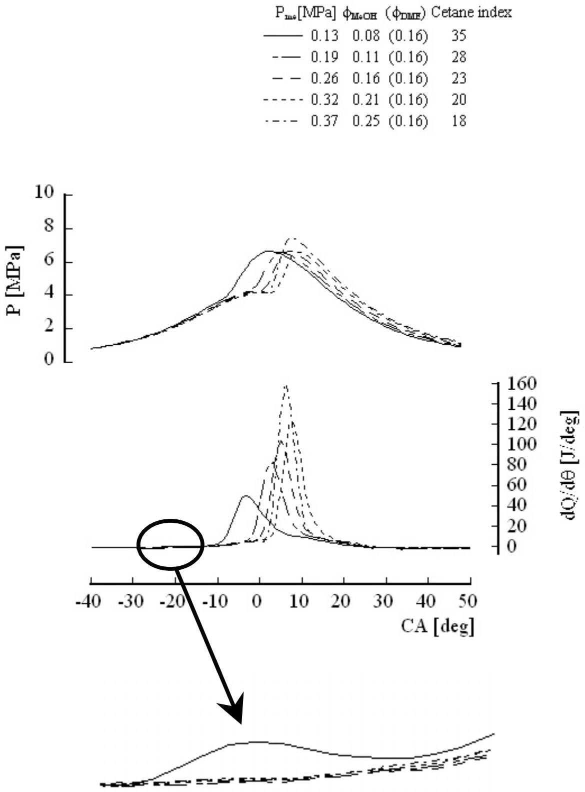

Fig. 3 Change in combustion history due to engine load under the constant DME amount condition in case of MeOH(TIN=60℃)

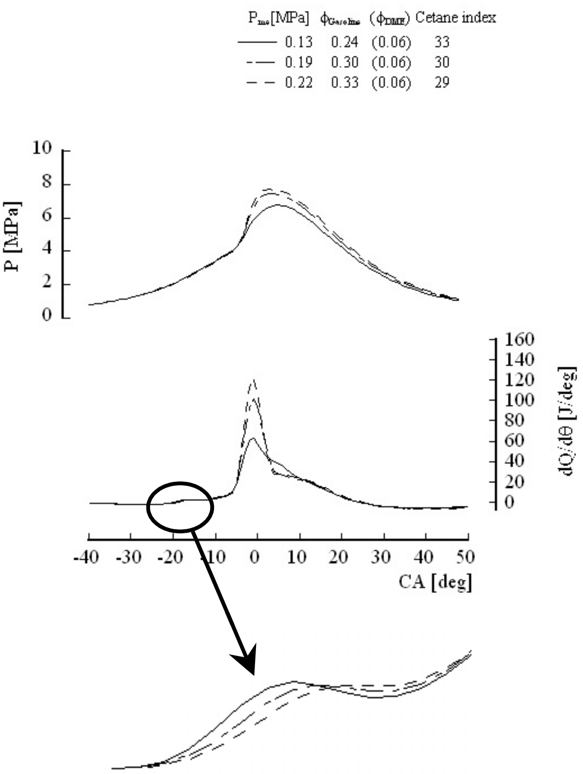

Fig. 4 Change in combustion history due to engine load under the constant DME amount condition in case of GS(TIN=60℃)

engine load is achieved smaller with larger cetane index.

Fig. 5 shows the relationship between the cetane index of mixed fuels and the maximum HRR in LTR calculated Fig. 2-4. Black circles, triangles and squares represent in case of GS, MeOH and NG, respectively. All the maximum HRR of LTR is decreased according to the degradation of cetane index. In the cases of NG and methanol, if the cetane index is smaller than 10 and 35 respectively, the maximum HRR of LTR becomes almost 0, however it is not zero in the case of GS. It is assumed that GS is burned simultaneously with DME because a flash point of GS is low and GS has LTR and HTR in the HCCI engine as explained above. Therefore, it is considered that the maximum HRR of LTR depends on not only the cetane index, but also the chemical composition and molecular structure of fuel.

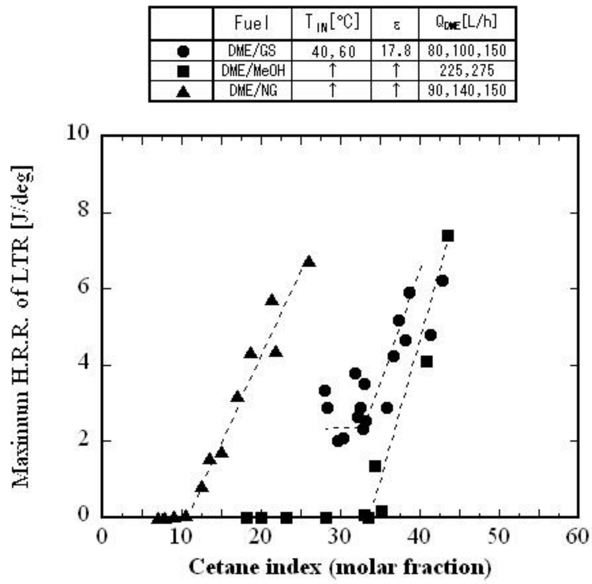

Fig. 5 Relationship between maximum heat release rate in LTR and cetane index

Fig. 6 shows the relationship between the cetane index of mixed fuel and ignition temperatures at the beginning of LTR. It is calculated at the beginning of LTR by using the ideal gas equation taking into account of in-cylinder gas composition. In the case of DME alone, the ignition temperature of LTR is 715 K. The ignition temperature of LTR increases monotonously as the cetane index decreases regardless of the intake temperature. In other words, all ignition temperatures of LTR are dependent only on the cetane index of fuel.

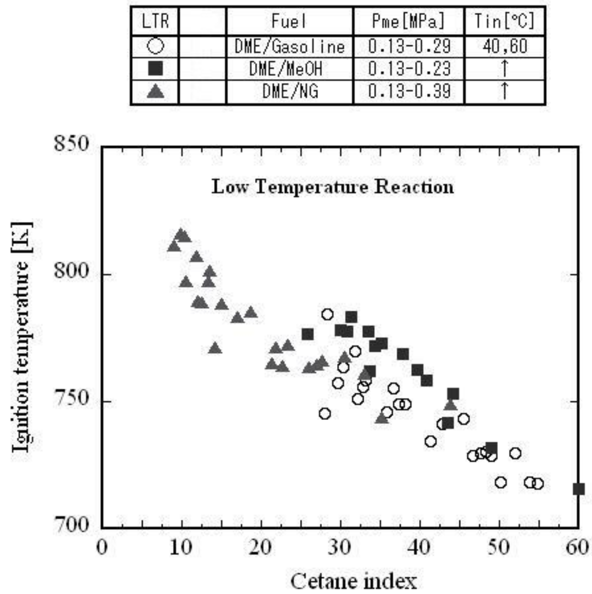

Fig. 6 Relationship between ignition temperature of beginning of LTR and cetane index

4. CONCLUSIONS

In order to clarify low temperature reaction of HCCI combustion assisted by a small amount of DME, combustion tests were accomplished with natural gas, methanol and gasoline in the diesel engine. The concluding remarks obtained are as follows;

1. The maximum engine load range depends on cetane index.
2. The maximum HRR of LTR depends on not only the cetane index but also the chemical composition and molecular structure of fuels.
3. Ignition temperatures of LTR are dependent only on the cetane index of fuel, in other words, it is higher as cetane index is higher.

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