Diesel Engine Emission Improvements by the Use of EGM-DMC-Diesel Blends Fuel

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Abstract: - Dimethyl carbonate (DMC) and ethylene glycol monoacetate (EGM) are two hopeful alternative fuels as well as fuel additives to reduce smoke emission in normal diesel engine, due to their high oxygen content. This paper presents an experimental study on their effects on the performance and emissions characteristics of a diesel engine. Test results show that the reduction of power outputs for the DMC-EGM-diesel blends are smaller than that of the DMC-diesel blends. Smoke and CO emissions can be remarkably reduced with the addition of DMC and EGM to diesel, especially at higher loads. The blends of diesel with 15% DMC and EGM by volume is the best fraction for reduction of smoke and CO emissions. HC emissions decrease gradually at all operating conditions when the content of DMC and EGM in blends increases at higher loads. But, the HC emissions of DMCEGM15 and DMCEGM20 are higher than that of diesel fuel at lower loads. The DMC-EGM-diesel blends have little effects on the NOx emissions. All these results indicate the potential of the DMC-EGM-diesel blends for clean combustion in diesel engine.

Key-Words: - Dimethyl carbonate; Ethylene glycol monoacetate; Oxygenated fuel, Diesel engine; Engine emission; Exhaust smoke

1 Introduction

Diesel engines are mainly used in industrial, transport and agricultural applications due to their high efficiency and reliability. However, they emit high smoke and NOx, and are now subjected to increasingly strict imposed emission regulations. To achieve substantial reductions in emissions, some diesel engine emission control technologies have been developed, such as common rail systems, fuel injection control strategies including multi-stage injection, exhaust gas recirculation and exhaust gas after treatment devices [1]. But these emission control technologies usually lead to cost increase highly or more fuel consumption. It is also commonly accepted that diesel engine emission can be reduced effectively by using oxygen alternative fuels, or potentially the addition of oxygen within the diesel fuel. Therefore, much research has focused on screening of oxygenated fuel additives, including alcohols, esters and ethers [2, 3].

DMC (dimethyl carbonate) is an oxygenated fuel with the oxygen content of 53.3%, which is usually used as an oxygenated additive to blend with diesel fuel to improve combustion and reduce emissions of diesel engines [4-6]. Zhang Y.S. and Reader GT conducted an experimental study on a low emission diesel engine by using diesel fuel blended with DMC, and reported that there were noticeable reductions of smoke, NOx, CO and CH [7]. Murayama et al. proved DMC to be a suitable oxygenated additive with good blend fuel properties, which reduced smoke almost linearly with its concentration, which is directly related to the oxygen content of the fuel. With 10% of DMC contained in the fuel, a smoke reduction of 35-50% was attainable, and also, apparent reductions of HC and CO densities were attained with NOx emissions increasing slightly [8].

The addition of DMC to fuels to reduce engine emissions without engine modification seems to be more attractive. However, the power output will decreases when diesel engines fueled with DMC diesel blend without engine modification, especially at condition of high loads, because the low heating value of DMC is 15.78MJ/kg, which is much lower than that of diesel fuel. To achieve substantial reductions in emissions without severely decreases of power output, this paper proposes that DMC is blended with ethylene glycol monoacetate (EGM) in order to increase the low heating value, which is another promising oxygenated fuel additive with the oxygen content of 46.1wt% and the low heating value of 26MJ/kg [9]. The objectives of this study are to experimentally investigate the performance and emissions characteristics of a diesel engine fueled with the DMC-EGM-diesel blends.

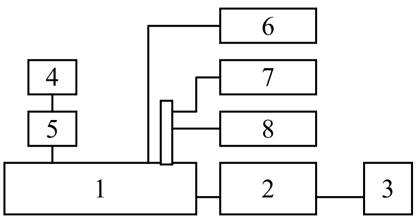
2 Experimental Apparatus and Fuel

2.1 Experimental apparatus

A commercial light-duty direct injection diesel engine 4JB1 was used in this study, made by Beiqi Foton Motor Co. Ltd, which is a 4-stroke, 4-cylinder, naturally aspirated diesel engine. Engine specifications are shown in Table 1. To give a brief comparison, the engine parameters, such as plunger diameter, fuel delivery advance, were not modified. An electrical dynamometer was used for loading the engine. A magneto-electrical speed sensor was used to measure the speed of the engine. The exhaust gas temperature was measured by a K-type thermocouple. The concentrations of NOx, HC and CO were measured by an exhaust gas analyzer (AVL DiGas 4000), and the smoke emission was measured by a partial flow smoke opacimeter (AVL DiSmoke 4000). The output power of the engine was calculated based on the data of the engine torque and speed, while the brake thermal efficiency was obtained by using the data of the engine output power and the data of the fuel consumption measured by the FC2210 mass flow meter. The schematic of the experimental setup is shown in Fig. 1. The coolant temperature was kept at 80℃ during the experiments.

Table 1 Test engine Specifications

Item	Specification
Cylinder bore (mm)	93
Stroke (mm)	102
Displacement (L)	2.771
Compression ratio	18.2
Combustion chamber	ω type
Rated speed (r/min)	3600
Rated power (kW)	57



1-Engine 2-Dynamometer 3-Tachometer 4-Fuel tank 5-Mass flow meter 6- Combustion analyzer 7- Smoke opacimeter 7- Exhaust gas analyzer

Fig. 1 Experimental setup

2.2 Test fuel

Table 2 compares some fuel properties of DMC, EGM and diesel. DMC is a combustible, innocuous, odorless liquid，its molecular formula is CHO_3OCH_3, or $C_3H_6O_3$, which is composed of C-H and C-O bonds without of C-C. The oxygen content is up to 53.3wt%. So it is usually used as an oxygenated additive to blend with diesel fuel to improve combustion and reduce emissions of diesel engines by many researchers. However, the low heating value and the boiling point of DMC are 15.78MJ/kg and 90-91℃, respectively. These are much lower than that of diesel fuel. As results, when the same volumetric fuel blends are delivered, the engine power output will decreases when fueled with DMC-diesel blend, especially at condition of high loads. The drawback of engines would be likely to occur when DMC is applied.

Table 2 Properties of DMC, EGM and diesel

Property	DMC	EGM	Diesel
Molecular formula	$C_3H_6O_3$	$C_4H_8O_3$	C_xH_y
Cetane number	35-36	0.1	40-55
Low heating value (MJ/kg)	15.78	26.0	42.5
Density (kg/m^3)	1075	1009	840
Boiling point (℃)	90-91	210-220	180-360
Oxygen content (wt%)	53.3	46.1	0

EGM is another promising oxygenated fuel additive with the oxygen content of 46.1wt%. The low heating value of EGM is 26MJ/kg, which is higher than that of DMC. The boiling point of EGM is 210-220℃, and is near to that of diesel. Therefore, it can improve the properties of diesel engines that DMC in blends is partly replaced by EGM.

In order to investigate the effects of the DMC-EGM-diesel blends on engine's performances and emissions, pure diesel and the blends of diesel with 2.5% DMC and 2.5% EGM (named DMCEGM5), 5% DMC and 5% EGM (named DMCEGM10), 7.5% DMC and 7.5% EGM (named DMCEGM15), 10% DMC and 10% EGM (named DMCEGM20) by volume were prepared and tested in these experiments. The blend of diesel with 15% DMC (named DMC15) by volume was also prepared for comparison of engine power outputs.

3 Results and Discussion

3.1 Engine performance

The energy densities of DMC, EGM and diesel are 16.9, 26.2 and 35.7J/mm^3, respectively. Because the energy densities of the blends containing DMC and

EGM decrease and the engine operating parameters are not adjusted, the engine power outputs are reduced correspondingly when DMC-EGM-diesel blends are used. Fig. 2 shows the engine power output under the full load operating conditions. The engine's power decreases, especially at high speed with the increased proportion of DMC and EGM. The volumes of the blends delivered per cycle were kept the same, but the total heat energy was decreased with the increase of DMC and EGM in the blends. The maximum reduction of power output for DMCEGM5, DMCEGM10 □ DMCEGM15 and DMCEGM20 was 1.6%, 3.4%, 4.8% and 7%, respectively, and they occurred at the speed of 3600r/min. The energy density of DMCEGM5, DMCEGM10 □ DMCEGM15 and DMCEGM20 decreases about 2%, 4%□6% and 8%, respectively. The percentages of power losses are smaller than the reductions of the energy densities. Therefore, it can be concluded that the thermal efficiency increases when fuel with DMC-EGM diesel blends.

The maximum reduction of power output for DMC15 is 7.1%, as shown in Fig. 2, it is higher than that of DMCEGM15. So, the power loss can be reduced when DMC in blends is partly replaced by EGM.

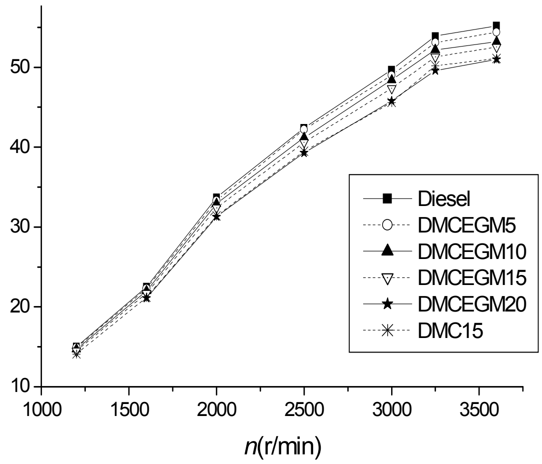


Fig. 2 Engine power at full load operating conditions

3.2 Emission characteristics

It is more effective to reduce exhaust smoke by adding oxygenates in diesel according to the studies done by other researchers. This fact was confirmed in this study. Fig. 3 illustrates the smoke emissions of the engine fueled with DMC-EGM-diesel blends under various loads at the speed of 3600r/min. It is obviously that the smoke emission can be remarkably reduced with the addition of DMC and EGM to diesel, especially at higher loads. From DMCEGM5 to DMCEGM15, the smoke emission decreases obviously with increase in the fraction of DMC and EGM in the blends. The maximal smoke reduction is more than 51% when DMCEGM10 is fueled, and about 58.8% when fueled with DMCEGM15 at full load conditions. However, the smoke emission for DMCEGM20 is nearly the same to that for DMCEGM15 at all operating conditions. This indicates that the blends of diesel with 15% DMC and EGM by volume is the best fraction for reduction of smoke emission. Further increase in content of DMC and EGM in blends can not decrease obviously the smoke emission, can but decrease the engine's power.

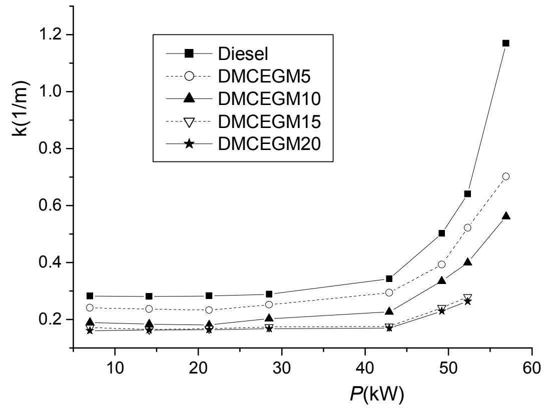


Fig. 3 Smoke emissions for various fuels

Fig. 4 gives the NOx emissions for different fuels at the speed of 3600r/min. In general, the addition of DMC and EGM in diesel has little effects on the NOx emission. At lower loads, NOx emissions of DMCEGM5 and DMCEGM10 slightly decrease in comparison with pure diesel, while they increase somewhat when fueled with DMCEGM10 and DMCEGM15. At higher loads, NOx emissions for all DMC-EGM-diesel blends increase little.

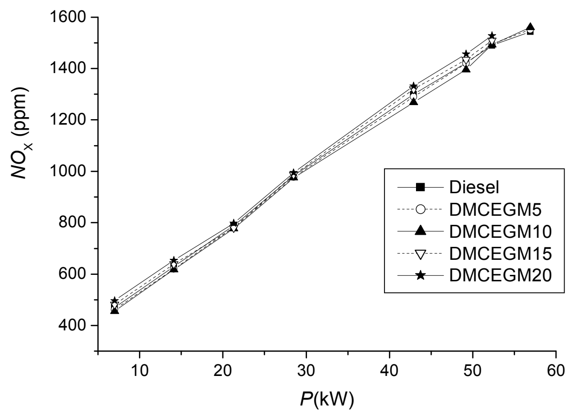


Fig. 4 NOx emissions for various fuels

Generally, diesel engines emit less CO and HC than SI engines. But CO emissions will increase quickly when diesel engines are operated under very high load conditions. Fig. 5 shows CO emission characteristics when various fuels are used. It is clear that CO emissions can be reduced significantly by using DMC-EGM-diesel blends, especially at higher loads. However, when the content of DMC and EGM in blends is greater 15%, further increase in content of DMC and EGM can not decrease obviously the CO emission by comparison the CO emission of DMCEGM15 with that of DMCEGM20. This changing trend of the CO emission curve is similar to that of smoke emission.

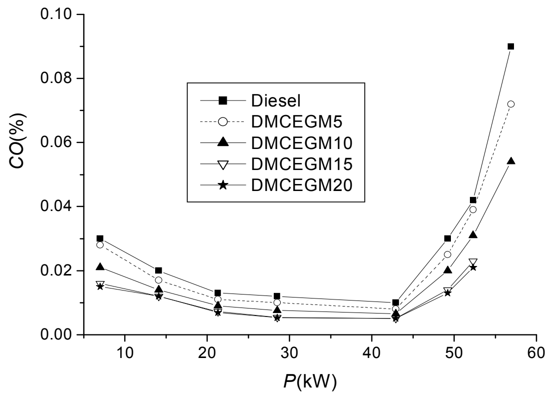


Fig. 5 CO emissions for various fuels

HC emissions of various fuels are shown in Fig. 6. It can be seen that the HC emissions decrease gradually at all operating conditions when the content of DMC and EGM in blends increases from o to 10%. However, the HC emissions of DMCEGM15 and DMCEGM20 are higher than that of diesel fuel at lower loads, while the changing trend is the other way round at higher loads. This phenomenon can be explained as follow. The latent heats of vaporization of DMC and EGM are both higher than that of diesel. At lower loads, the temperature of the cylinder surface is lower, which makes the flame front of spray abruptly quench on the surface and produces HC. The larger content of DMC and EGM in blends would further decrease the temperature, which produces more HC. At higher loads, the higher temperature of the cylinder surface makes blends evaporate quickly, the latent heat of vaporization has little effects.

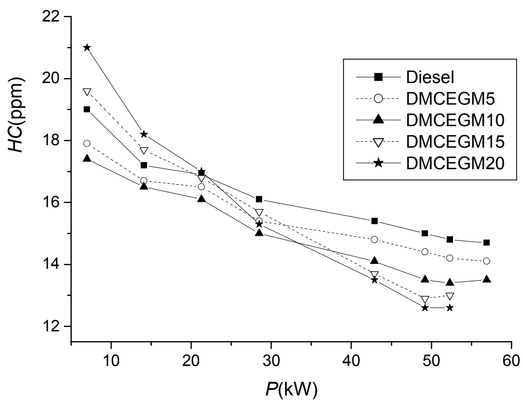


Fig. 6 HC emissions for various fuels

4 Conclusion

The performance and emissions characteristics of a diesel engine fueled with the DMC-EGM-diesel blends were investigated, and the main results are summarized as follows:

The addition of DMC and EGM to diesel fuel changes the physicochemical properties of blends. The energy density of blends decreases with the increase in DMC-EGM. While the oxygen content of the blends increases, resulting in some favorable effects on the combustion of blends. The energy density of the DMC-EGM-diesel blends is higher than that of the DMC-diesel blends. Therefore, the reduction of power output for the DMC-EGM-diesel blends is smaller by comparison with the DMC-diesel blends.

Smoke and CO emissions can be remarkably reduced with the addition of DMC and EGM to diesel, especially at higher loads. The maximal smoke reduction is about 58.8% when fueled with DMCEGM15 at full load conditions. The blends of diesel with 15% DMC and EGM by volume is the best fraction for reduction of smoke and CO emissions. HC emissions decrease gradually at all operating conditions when the content of DMC and EGM in blends at higher loads. But, the HC emissions of DMCEGM15 and DMCEGM20 are higher than that of diesel fuel at lower loads. The DMC-EGM-diesel blends have little effects on the NOx emissions. All these results indicate the potential of the DMC-EGM-diesel blends for clean combustion in diesel engine.

Acknowledgements

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