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DME AS AN ALTERNATIVE FUEL FOR DIRECT INJECTION DIESEL ENGINE

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Abstract The rapid increase of energy demand will lead to the shortage of fossil fuel of the world within next few decades and searching for a new suitable alternative fuel is necessary. The strong potential of Dimethyl Ether (DME) as an alternative fuel is, that the DME can be produced from natural gas, coal, and biomass. In this reports DME demonstrated as a fuel for compression ignition (CI) engine and the findings from the present study shows that oxygen content of DME molecule and absence of direct C-C bond enabled soot-less combustion of DME inside the engine cylinder. Regarding other emissions such as THC and CO were less compare to Diesel combustion. However, NO_X emission was comparable to Diesel fuel. Applying NO_X reduction catalyst also reduced this NO_X emission.

Keywords: Alternative Fuels, Emissions, Diesel Engine, Catalyst

INTRODUCTION

Gasoline and diesel fuel are both produced from crude oil, that is, petroleum. The most familiar transportation fuels in the world are gasoline and diesel fuel. Together, gasoline and diesel fuel power almost 99 percent of the world transportation system. Internal Combustion Engines operating on today's diesel and gasoline are of great concern for its tail pipe exhaust emissions. Because the emissions coming out are responsible for global warming, human health hazard and complex mixtures of compounds that lead to the formation of ground level ozone, many of these compounds are also toxic. A lot of researches have been done to reduce automobile pollution, from development of innovative emission control technologies to establishment of inspection and maintenance programs, vehicle emission control system involving catalytic converters, onboard computers, and other hardware system. However, the fuel composition and types of fuel are also important factor in the clean vehicle technology. The Clean Air Act of 1990 explicitly recognizes that changes in fuels as well as in vehicle technology must play an important role in reducing air pollution from the transportation sector.

The exhaust emissions regulation of heavy-duty diesel vehicles in Japan, U.S.A. and Europe are shown in Fig. 1. As shown in the figure, the future emissions regulation becomes stringent than the present situation. Especially, NO_X and particulate matter (PM) are becoming extremely severe for the diesel engine. The increase of traveling automobile and the step rise of the motor fuel demand; moreover with sharp decrease of the worldwide petroleum resource and the heavy pollution by the automobile tail pipe exhaust gas to our living environment. In this context, every country in the world is speeding up to seek and develop new alternative energy sources specially, for automobile.

Today, the hopeful substitute fuel energies for low soot emission are alcohol fuels (Methanol and ethanol), natural gas (Methane), LPG (Liquid petroleum gas such as propane, butane), dimethyl ether (DME), diethyl ether (DEE), dimethoxy methane (DMM), diethyl glycol dimethyl ether (DGM), H_2, and so on. Alcohol fuels are liquid fuels, so we can use them easily by former petroleum systems, the systems may not be changed, and the economic merit is large. However, the toxicity of methanol is a problem for practical use. Especially, DME is the most promising alternative for automotive fuel from the standpoint of energy security, because it can be industrially produced from coal, natural gas and many kinds of biomass fuels. The main advantage is that DME can still be produced when crude oil and other fossil fuels resources are no longer available or only to a limited extent and that it permits an efficient transition to solely regenerative systems.

The low self-ignition temperature (-235 ^oC) and higher cetane number (> 55) of DME compared to conventional Diesel fuel are the inherent properties for Diesel engine combustion. The vapor pressure of DME is lower than that of LPG. In addition, almost all hydrocarbon fuels can be mixed with DME. The cetane number of LPG is about five and it is necessary to enhance the cetane number when it has to be used as a fuel for CI engine. From this point of view, LPG can be mixed with DME to enhance the cetane

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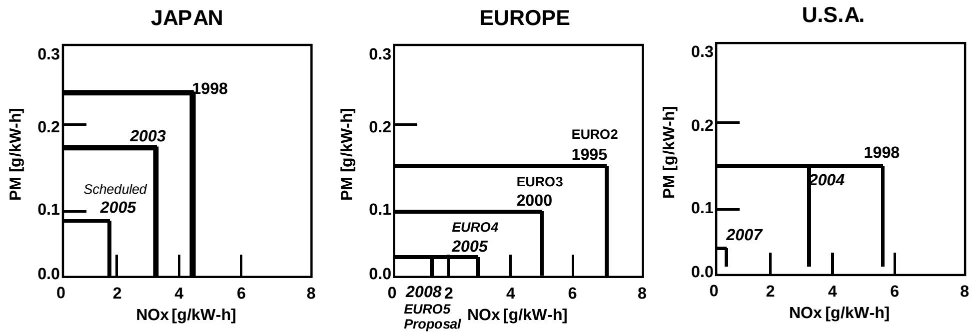


Fig. 1 Exhaust emissions regulation of heavy-duty Diesel engines

Table 1 Properties of DME, propane, methane and Diesel

	DME	C3H8	CH4	Diesel Fuel
Boiling Point	-24.8	-42	-161.5	180-360
Vapor Pre. Atm. (20C)	5.3	8.3	-	-
Explosion limit (vol.%)	3.4 - 17	2.1 - 9.4	5 - 15	0.6 - 7.5
Auto Ign. Temp. C	235	470	650	250
Cetane number	55 - 60	5	0	38 - 53
Octane number	-	112.1	120	-
C (wt.%)	52.5	82	76	86
H (wt.%)	13	18	24	14
O (wt.%)	34.8	0	0	0
Lower cal. Value, (MJ/kg)	28.8	46.36	49	42.7
Theoretical air fuel ratio, (kg/kg)	9	15.68	16.86	14.6
Liquid viscosity, (kg/ms)	0.12 - 0.15	0.2	-	2 - 4
Liquid density, (g/cm^3) 20C	0.67	0.49	0.42	0.84

number for smooth operation, advantageous performance and emission characteristics with a wide range of engine load is also possible. A DME-Diesel blended fuel shows soot emission can be reduced largely and details will be discussed later of this paper.

Next is the infrastructure of DME and according to TNO Report [1], the energy consumption of DME production is 5% lower compared to methanol production, for plant with a similar production capacity. The production of DME is 9% more efficient than the production of methanol [1]. The NKK, Japan is trying to build a production plant to fulfill the internal requirement of DME. In Japan, presently there are 36,000 refueling stations for conventional fuels and among them 2,000 stations are handling LPG. The ratio of conventional fuels refueling stations to LPG refueling stations is not very attractive though it is increasing due to the use of LPG is increasing day by day. Since the handling characteristics of LPG and DME is almost similar therefore it can be expected that the refueling station for DME is just a time being and can be switched over to DME.

We are looking for new fuels to serve our daily needs and the fuels can have the capability of reduce air pollution. DME is such a new fuel by which we can solve our all purposes as a source of energy. DME can be produced from variety of sources and not only it can be transported by pipelines but also can be supplied as a city gas. It might be used for power generation, fuel cell and in diesel cycle as well as hybrid vehicles. On the other hand, pollution might be less compared to the conventional fuel system.

DME AS A FUEL – PROPERTIES

In the study DME was used as a fuel, which has the chemical formula CH_3-O-CH_3. Currently, most DME is being produced by dehydrogenation of methanol. A roughly worldwide usage of DME is about 150,000 tons per year and in Japan, it is about 10,000 tons per year. DME is being used to substitute chlorofluorocarbons as propellant in spray cans. Table 1 shows the specific properties of DME, propane, methane and Diesel.

DME has a high cetane number, which makes it ideal for use in a CI engine. The low liquid density and the low calorific value (due to bound oxygen) require a high volume of DME to be injected compared to Diesel. A quick evaporation of the fuel after injection and a short ignition

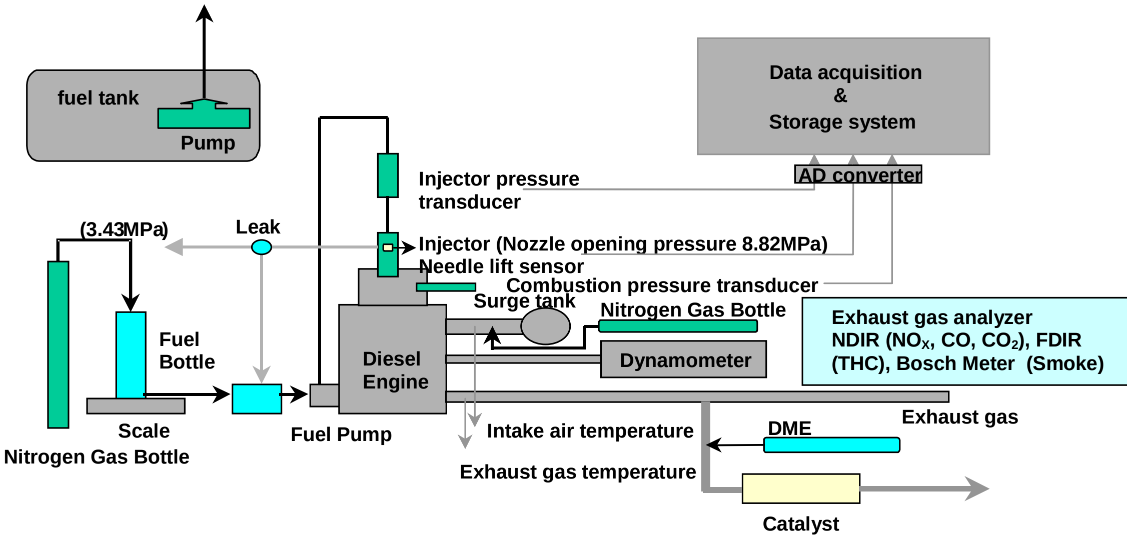


Fig. 2 Schematic diagram of the experimental system

delay result in a smoke free combustion of DME. Because of simple molecular structure of DME, it is expected that no significant emissions of polycyclic aromatic hydrocarbons, benzene and toluene take place. The SO_2 formation will be zero or low, because of the absence of sulfur in DME.

Table 1 shows that physically, DME has much in common with LPG. The storage, handling and safety aspects of DME are very similar to those of LPG, due to the similar physical properties of these fuels. The lower heating value and lower liquid density of DME compared to Diesel fuel, lead to the requirement of approximately a double sized fuel tank for an equivalent number of operating hours with DME.

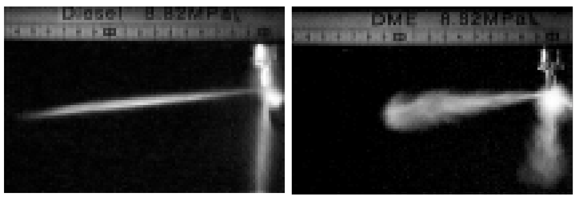
DME is a liquid gas with handling characteristics very similar to propane and butane. It has currently been used as a very safe and environmental friendly propellant for spray cans, primarily for the cosmetics industry. Several different **Fig.** experiments were conducted with SI and CI methanol engine, where converted DME from methanol was used as a fuel since DME can be made out from methanol [2, 3]. After that, DME was used as an ignition improving aid for methanol engine [4, 5]. Besides the production of DME from methanol, other production routes for DME exist. The economical production routes that can be considered for large scale DME production is to produce synthesis gas by using coal and natural gas [6].

EXPERIMENTAL SETUP

Fig. 2 represents schematic diagram of the experimental system. The DME fuel tank was pressurized at 3.43MPa by nitrogen gas to avoid leakage and vapor lock of the fuel system. Experiments were conducted with a single cylinder, naturally aspirated, four strokes, water cooled, direct injection diesel engine. Specifications of the engine and injector are bore X stroke 92mm X 96mm, displacement 638 cm^3, compression ratio 17.7, rated output 15.6kW @ 2600rpm, injection pump plunger 8mm dia (Boost type), injector four-hole nozzle @ 0.26mm hole dia.

The engine was instrumented sufficiently for implementing the objective of the study, including installation of an injection pressure transducer; a needle lift sensor, a cylinder pressure transducer and interfacing the engine with exhaust gas analyzer.

INJECTION CHARACTERISTICS



(a) **(b)**

fig.3 Spray characteristics of (a) neat Diesel and (b) neat DME

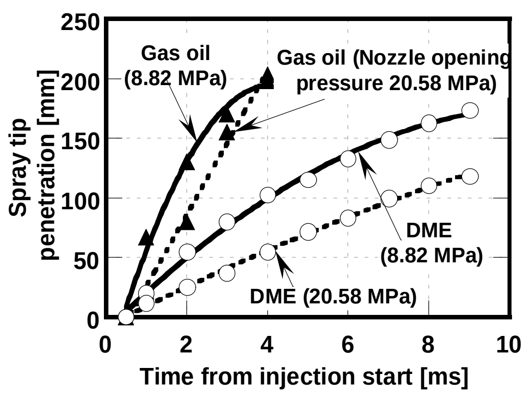


Fig. 4 Spray tip penetration

The boiling point of DME (-25 ^{o}C) is much lower than the Diesel fuel. In order to obtain some insight into the spray formation in the cylinder, the fuels were injected under atmospheric pressure, which are shown in Fig. 3 (a) Diesel fuel, (b) neat DME. The nozzle opening pressure for the fuels were set at 8.82MPa. While the spray penetration with Diesel fuel is rather long and spray angle is narrow, those with neat DME were short and wide, respectively. Figures 4 and 5 represent spray tip penetration and spray angle with Neat DME and Diesel where, injector nozzle opening pressure was set at 20.58MPa and 8.82MPa respectively. The spray tip penetration is shorter and spray angle is wider with DME compared to Diesel fuel at any time after the injection start. It can be assumed that the spray formation inside the engine cylinder with DME might be lean.

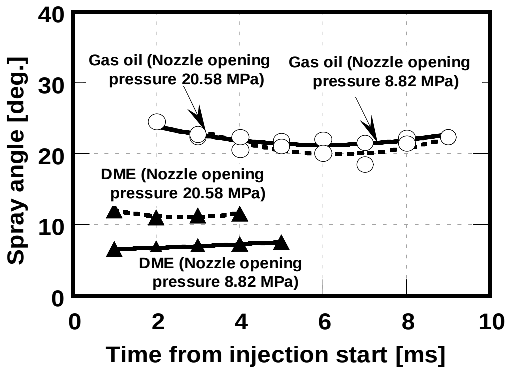


Fig. 5 Spray angle

COMBUSTION AND EMISSION

In this experiment engine was operated at a constant speed of 960RPM with variation of engine load for both the DME and Diesel. Following points can be concluded with the DME powered Diesel engines when compared to Diesel fuel operation. 1) Thermal efficiency is almost same. 2) No soot emission or soot is negligible with DME. 3) Exhaust total hydrocarbon emission is low. 4) CO emission is also low. 5) Thermal efficiency decreases with retarded injection. 6) NO_X emission is comparable or higher. 7) Needs lubricating additive. 8) Lower viscosity tends to leakage pump plunger and injector nozzle. 9) Problem with the DME left in the fuel pipe after shut down the engine. 10) Dynamic injection timing retards with increase in nozzle temperature. 11) Ignition delay is shorter due to the low boiling point, higher cetane rating and low self-ignition temperature.

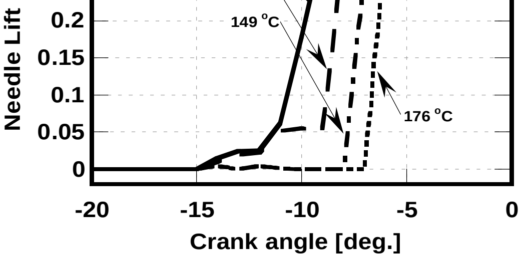


Fig. 6 Effect of temperature on needle lift

Fig. 6 represents the effect of temperature on needle lift. The needle lift retarded with increase in temperature, which is possibly due to the high vapor pressure of DME at higher temperature. The effect of feed pressure on needle lift is shown in Fig. 7. It can be pointed out that the early start of injection occurred with the increased feed pressure of DME. In addition, the increased nozzle opening and bouncing was observed due to the low injector opening pressure. At high

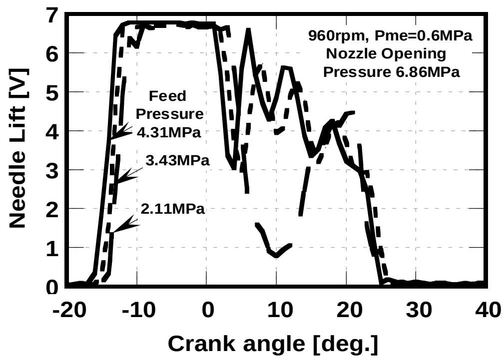


Fig. 7 Effect of feed pressure on needle lift

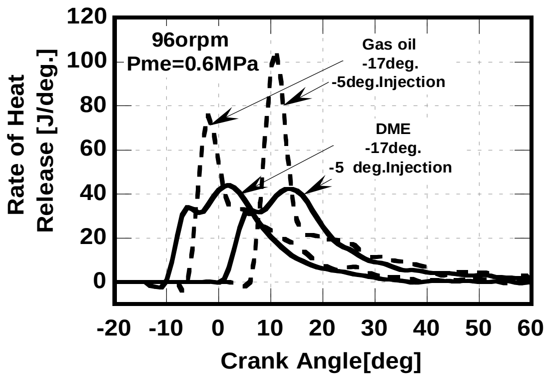


Fig. 8 Rate of heat release for 0.60MPa

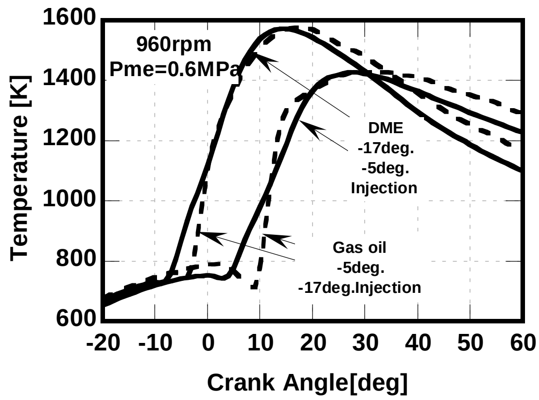


Fig. 9 Average cylinder temperature

load, premixed combustion stage was milder (Fig. 8) and comparable average cylinder temperature was observed with DME compared to Diesel (Fig. 9). One of the main advantages of DME is the soot free combustion when burned in a DI-CI engine (Fig. 10) and this soot-less combustion of DME might be due to the lean fuel-air mixture formation at the engine cylinder. THC emission

(Fig. 11) was much lower than the Diesel and the reason is similar as explained earlier that the lean combustion of DME. Next is the NO_X emission is shown in Fig. 12. NO_X emission was higher with DME when engine was operated at retarded injection timing. Possible reason for high NO_X emission with DME is the early start of combustion and more after compression of combustion products leads to a higher temperature. However, advancing the injection timing reduced NO_X well below the Diesel operation.

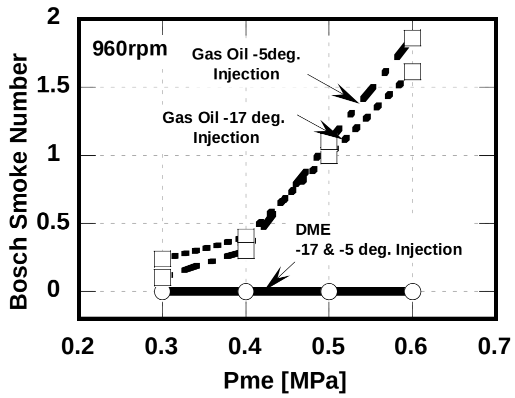


Fig. 10 Exhaust soot emission

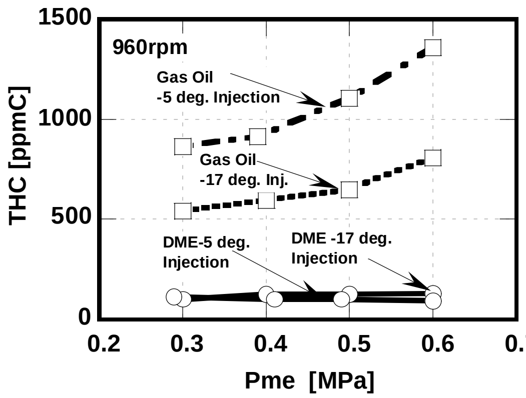


Fig. 11 Exhaust THC emission

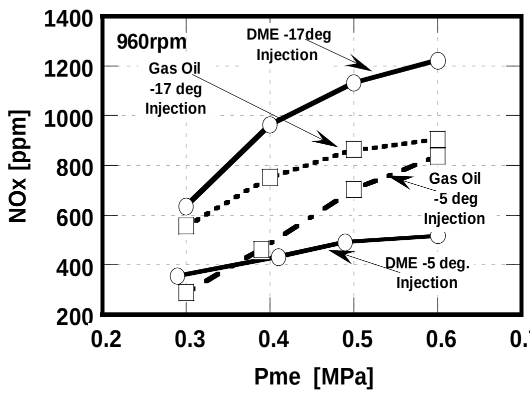


Fig. 12 Exhaust NO_X emission

NO_X REDUCTION OF DME ENGINE

One of the major problems with DME engine is the NO_X emission. It is necessary to reduce NO_X of the DME engine to meet the future emission standard. Exhaust gas re-circulation (EGR) is a well-known technology presently being used for NO_X reduction. In case of Diesel fuel, it will be necessary to use EGR, high-pressure injection, DPF (Diesel Particulate Filter) to meat the future emission standard. However, for DME, there is no soot emission and virtually there is no emission of SO_2. Catalytic reduction of NO_X is a well-known technology for the reduction of NO_X in case of SI engines. A NO_X reduction catalyst might be suitable for the reduction of NO_X from DME powered diesel engine.

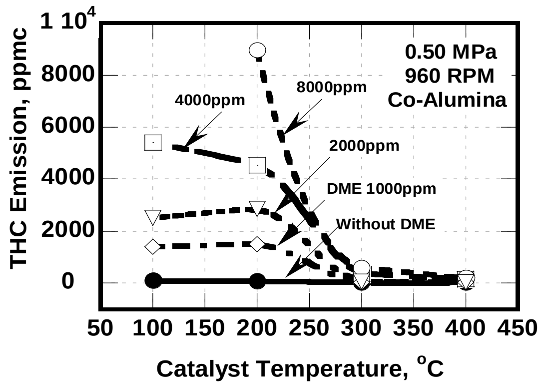


Fig. 13 THC emission for varied catalyst temperature

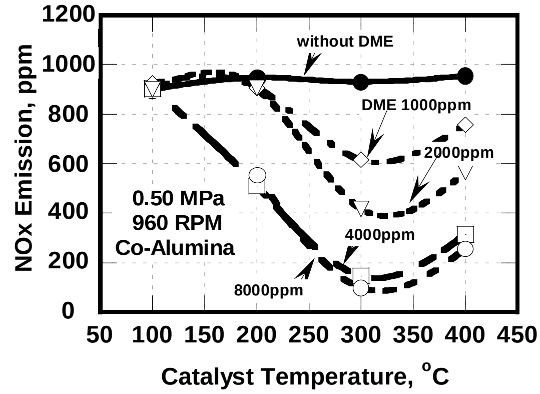


Fig. 14 NO_X emission for varied catalyst temperature

The exhaust gas of the DME engine did not show any formation of soot all through the operational region (Fig. 10), which is a great advantage for using a catalyst for NO_X reduction. However, the main parameter for catalytic reduction of NO_X with catalyst is a reducing agent or total hydrocarbon, which is very small for DME operated Diesel engines, as presented in the previous Fig. 11. One of the possible methods for increasing reducing agent is common rail injection system where a secondary injection of DME into the exhaust gas making it reducing agent rich. Therefore, experiments were conducted with increasing the reducing agent by introducing DME into the exhaust gas before entering into the catalyst. Figures. 13 and 14 show the total hydrocarbon (THC) and NO_X emission after the catalyst. It can be concluded that a high NO_X and THC could be reduced when catalyst temperature is about 300 ^{o}C. At low temperature catalyst does not perform well however, EGR can be well suited at low temperature NO_X reduction and at high temperature NO_X reduction catalyst can be employed to reach the future emission standard.

CONCLUSIONS

Experiments were carried out to check the performance and emissions of a DI Diesel engine operated with DME. The findings from the present study can be summarized as follows:

1. Soot emission with DME engine was not observed through the entire engine operational region. NO_X emission with DME engine was slightly higher than with the Diesel fuel operation.
2. Low total hydrocarbon emission with DME engine showed a small NO_X reduction performance, because the shortage of reducing agent suppressed the NO_X reduction reaction, which is an inherent characteristic of DME engine. With increasing DME into the exhaust gas, a high NO_X reduction is possible just by increasing catalyst temperature.

FUTURE RESEARCH

DME engine is in its research and development stage. There are great possibilities and scopes to improve the engine performances and exhaust emissions with DME. It is necessary to carry out the following researches for implementing DME as a suitable alternative fuel for reducing exhaust emissions from diesel engines.

1. One of the major challenges with DME fuel is its lower viscosity compared to diesel fuel. This characteristic will increase high rate of leakage through the small clearance of injection pump plunger and injector nozzle. It is necessary to know the effects of elevated pressure and temperature on the viscosity of DME. A viscometer can be used to perform the test.
2. Lubricity, sometimes referred to as film strength, is the ability of a liquid to lubricate. This is very relevant to the satisfactory operation of a diesel engine, which rely on the fuel to lubricate many of the moving parts of the fuel injection system. Viscosity is also directly related to the lubricity and DME has a lower lubricity compared to diesel. It is not possible to operate a DME diesel engine without adding any lubricating additive for a long time. A suitable lubricating additive is also another concern for improving lubrication of the plunger and nozzle of the fuel system. The additive should not have any detrimental effect on in-cylinder combustion of DME and it will not increase engine out exhaust emissions.
3. A suitable fuel return system has to be developed to bring back the injector return into the fuel tank or need to check the performance of a NO_X catalyst when return can be used as a reducing agent for producing a NO_X reduction environment.
4. Energy density of DME is lower than that of diesel fuel and it is necessary to inject large volume of DME required for the same amount of power output. By using the same original pump plunger and orifice diameter will lengthen the diffusion combustion stage without affecting the start of combustion. Increasing the orifice diameter will increase both the discharge coefficient of orifice and the injection rate of DME. Also the total mass of air entrainment of spray increases because the injection rate of DME increases. Therefore it would be possible to improve fuel economy and reduce emissions.
5. Spray formation, ignition delay and rate of heat release suggest that the combustion process of DME should be different from that of diesel fuel and it is necessary to investigate the combustion process of DME diesel engine by in-cylinder visualization or spectroscopic method.
6. DME engine can be operated with large amount of Exhaust gas re-circulation (EGR) system as an effective method to reduce NO_X. Soot-less combustion of DME eliminates the problem of excessive particulate emissions and shorter ignition delay of DME in a low oxygen environment reduces the deterioration of combustion. However, high rate of EGR make HC and CO emissions higher and oxidation catalyst is necessary to reduce those emissions. Moreover, there is a possibility of formaldehyde formation during the oxidation of unburned hydrocarbons and careful observation or testing is necessary.
7. Low total hydrocarbon emission with DME engine showed a small NO_X reduction performance with alumina based NO_X reduction catalyst. Because the shortage of reducing agent suppressed the NO_X reduction reaction, which is an inherent characteristic of DME engine. With increasing DME into the sampled exhaust gas, a high NO_X reduction rate is possible just by increasing catalyst temperature. It is necessary to check the performance of a prototype catalytic reactor without any external heater where catalyst temperature will be controlled by the engine load or exhaust gas temperature. A common rail DME injection system might be suitable where a secondary injection into the exhaust gas making it reducing agent rich.

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