DME FUELED COMMERCIAL VEHICLE WITH A FUEL-CELL HYBRID SYSTEM

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ABSTRACT

Dimethyl ether (DME) has received a lot of attention recently as a possible alternative to diesel engines for little environmental effects and stable distribution. DME can be made from various resources in large quantities and easily transported. It has the same cetane number as that of diesel fuel and emits no smoke from diesel engines. Moreover it is also expected to be a fuel for fuel cells because much hydrogen can be obtained by steam reforming. This paper focuses on a hybrid power system for commercial vehicles with a diesel engine and a fuel cell fuelled with DME as a single fuel. The system obtains a driving power by diesel engines with DME combustion and at the same time generates electricity by a fuel cell with hydrogen generated from DME reforming. The electric power can be supplied to a refrigerator or batteries. The total energy loss will be less in DME reforming by recovering the exhaust heat from the engine. It is possible to drive the system suitably on various load conditions, because the system can match a fuel cell power with an engine power for situations. Because the system is estimated to reduce emitted greenhouse gases and to have high efficiencies, the system in vehicles can be also used for an air-conditioner, an audio utility or a light for long idling stops even if the vehicles have a refrigerator.

Keywords: *CO_2 emission, idling stop, commercial vehicle, dimethyl ether, fuel cell.*

1. INTRODUCTION

Twenty percent of total carbon dioxide (CO_2) emitted to atmosphere is released from a transportation sector, and 80% of CO_2 in the transportation sector is from passenger cars. Therefore, research and development of low emission vehicles have been carried out such as hybrid vehicles and compressed natural gas (CNG) vehicles, and also zero emission vehicles such as electric vehicles, fuel cell electric vehicles and so on. In addition, alternative fuels for diesel engines are developed such as dimethyl ether (DME).

The authors have proposed a hybrid system which combines a fuel cell with a diesel engine for small or medium-sized commercial vehicles with a freezer [1]. In this study, environmental effects such as CO_2, NOx and particular matters (PM) are elucidated, when DME is supplied to the system as a both fuel of a diesel engine and a fuel cell.

2. DME AS A FUEL

2.1. Fuel Choice

There are two methods for supplying hydrogen to fuel cell vehicles. One is supplying directly from a high-pressure hydrogen bottle or a liquid hydrogen tank. The other is reforming fuel which contains hydrogen atom. However, the former method has many problems such as a hydrogen storage technology, a hydrogen manufacturing technique and short cruising ranges for a filling bomb. These issues take a lot of time to be able to use hydrogen fuel practically for vehicles. Therefore, hydrogen is also obtained from reforming a variety of fuels such as methanol, gasoline, natural gas, ethanol, LPG, DME and so on. This paper focuses on DME as an alternate fuel for diesel engines and fuel cells.

2.2. Characteristics of DME

DME has a molecular weight of 46.07 and the molecular formula is CH_3OCH_3. It is the ether with a few numbers of carbons and an artificially manufactured secondary energy. Then, the characteristic is often called the clean fuel of multi source [2].

DME has a characteristic below.

1. DME can be manufactured easily from organic carbon such as coal, natural gas, biomass and plastics.
2. DME can easily change between gas and liquid phases.
3. DME has high combustibility and generates no PM.
4. DME can be supplied to diesel engines, because its cetane number is enough for them.
5. DME can be reformed at low temperatures.

It can be expected as a clean fuel in the next generation for fuel cells, diesel engines, gas turbines and so on.

2.3. DME for Fuel Cell

DME can be reformed at low temperatures of less than 400°C. Also, the cost of the reforming catalyst is less, because Copper-Zinc catalyst for DME is less expensive than precious metal catalyst. In addition, there is an advantage of very low toxicity and high content hydrogen rate. Therefore, DME is very promising as a hydrogen carrier for the fuel cell.

The reforming process to fuel cells (PEFCs) is described as shown in Figure 1. DME and water are controlled to the proper flow rate by mass flow controllers and are heated and vaporized respectively to the reforming appropriate temperature. Then, they are mixed and send to the reformer. The CO concentration of the reformed gas is high after reforming. In case of PEFC, if the CO concentration is more than 10 ppm, a high polymer film of fuel cell is damaged. So, the reforming gas must pass a CO converter. Then, the reformed gas after the converter is supplied to the anode of the fuel cell. Atmospheric air is supplied to the cathode. The reformed gas is humidified in a humidifier, because the polymer film must be always kept at wet condition.

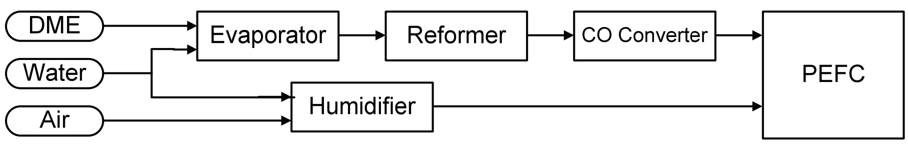

Figure 1: Reforming process

3. DME DIESEL ENGINE

3.1. Exhaust Gas

Conventional diesel engines need expensive processing systems after engines such as NOx catalyst, a diesel particulate filter (DPF) and so on. However, there is no PM in exhaust gas from DME engines because DME includes oxygen molecules. So the DME engines can clear the regulation easily with the simple processing systems such as exhaust gas recirculation (EGR), oxidation catalyst and so on, if only NOx is reduced.

Occlusion reduction catalyst of NOx is extremely effective to largely reduce NOx. However, small diesel engines can obtain a little activity of the catalyst because of the low exhaust temperature. So a large quantity of EGR can be valid for NOx reduction there. Actually, it has been elucidated that the DME engine releases less NOx and PM than the base diesel engine [3].

3.2. Performance

The output performance of the DME engine was more than that of the conventional diesel engine [4]. Specifically, the DME engine can increase the torque at low-speed region because of no smoke limits at any torque. Then the DME engine is very expected for clean exhaust gas and high output. However, there are some problems:

- DME have to increase the capacity of a fuel tank because of the low heating value in the half of diesel fuel.
- Abrasion is easily occurred in the fuel supply system because of the low viscosity of DME.
- There is an influence of the imbibitions on seal material and resin parts.
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4. DELIVERY IN A CITY IN JAPAN

The present work focuses mainly on commercial vehicles. Specifically, the hybrid system on DME proposed here is investigated to be adaptable to the special installation vehicles such as a dump, a mixer, a crane, a refrigerated truck and so on. These vehicles cannot stop idling operation, because the electric devices are operated by the engine power. For example, a mixer must continue to turn a dram and a refrigerated truck must keep a constant temperature.

There are many convenience stores in Japan and the urban area in East Asia. They are the retail stores which handle many kinds of commodity in a small space. There are 5,000 stores or more in Tokyo. Small or medium sized refrigerated trucks are mainly used for delivery of food to the stores. But, it is difficult to keep a constant temperature in a container, because the transfer time among the stores is short and the container is frequently open as shown in Figure 2 and 3. Cooling unit operation is specially admitted on the Idling stop ordinance in Tokyo.

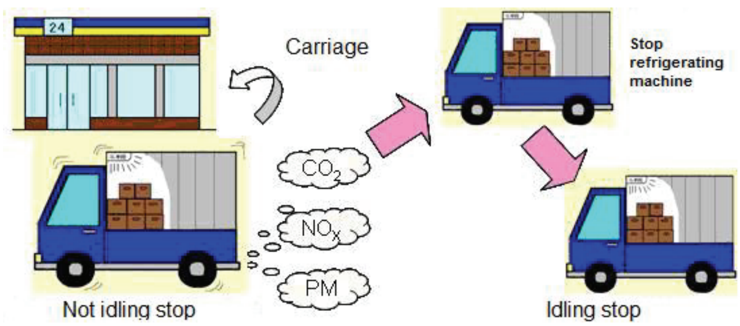


Figure 2: Diagrammatic illustration

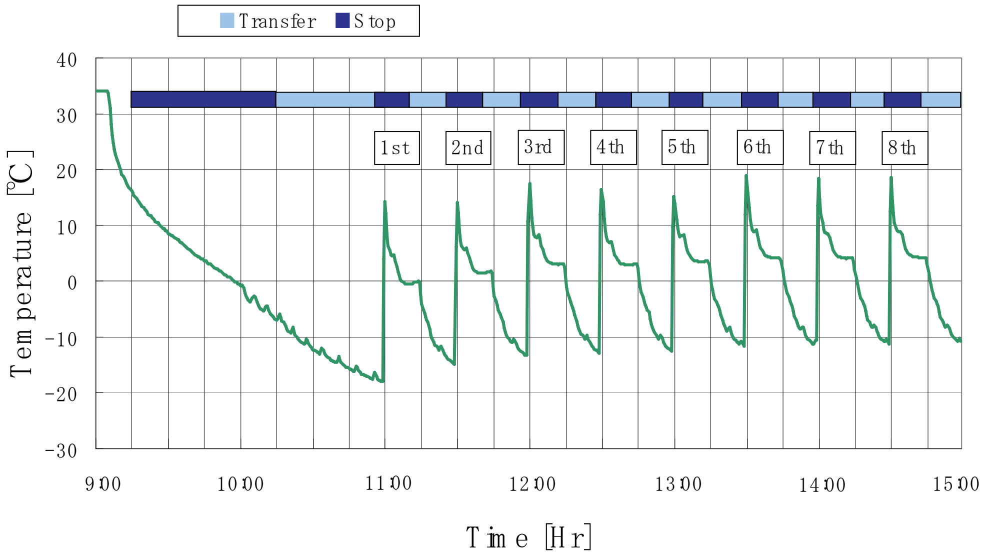


Figure 3: Temperature in container for delivery pattern

5. DME FUELLED HYBRID SYSTEM

The authors propose a new system that supports commercial vehicles in delivery conditions to convenience stores. The hybrid system with a fuel cell and a diesel engine is shown in Figure 4. The output of the system is obtained from both of the diesel engine and the fuel cell. Hydrogen obtained by DME reforming with recovering diesel exhaust heat generates electricity with the fuel cell. The electric power is distributed to the motor, the electric devices and battery charging. The electric power of battery is also supplied to the freezer. When the vehicle stays at a store on delivery, the system is worked with the electric power charged in the Battery. The waste heat from the engine is supplied to the evaporator and the reformer. When the necessary heat cannot be sufficiently supplied only by the waste energy of the engine, it can be supplied by burning DME with the burner.

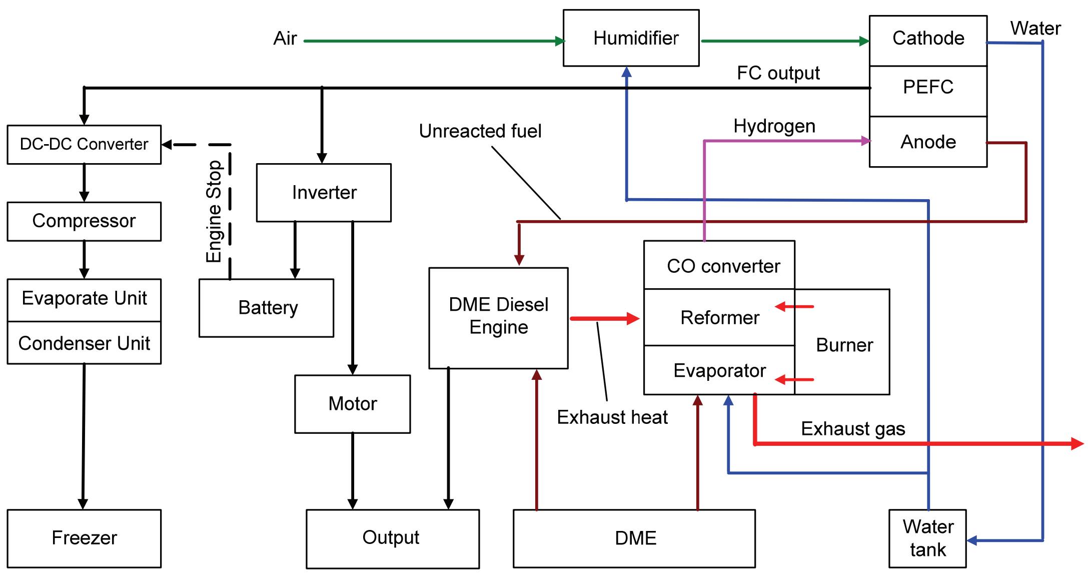


Figure 4: Composition of hybrid system

There are three kinds of driving patterns as the following.

(A) The system image at normal driving

- The vehicle runs by the output of the DME diesel engine.
- DME is reformed by engine exhaust heat.
- The generation electricity of a fuel cell is supplied to a refrigerator.
- Surplus electricity is charged to battery.

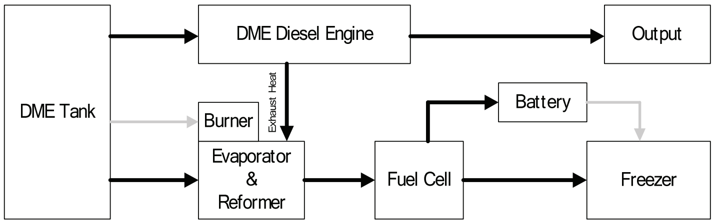


Figure 5: Normal driving

(B) The system image at idol stopping for a short time

- Electricity charged in the battery is supplied to a refrigerator.

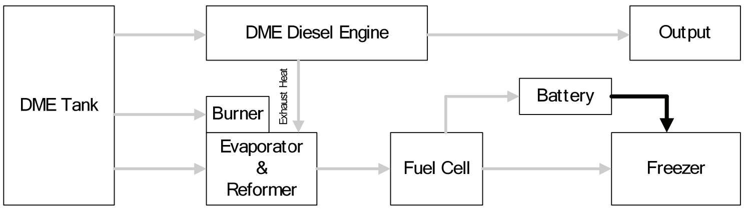


Figure 6: Idol stopping for a short time

(C) The system image at idol stopping for a long time

- DME is reformed by the heat of DME combustion by a burner.
- The generation electricity of a fuel cell is supplied to a refrigerator.

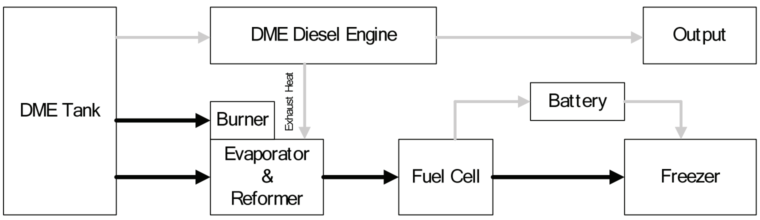


Figure 7: Idol stopping for a long time

This system can obtain two kinds of power source from DME fuel, and can expect improvement of energy efficiency because of recovery of engine exhaust heat. In addition, it is a stable power supply to use a fuel cell for the refrigerator. The refrigerator is used even at engine shutdown without any problem, so that the system can reduce CO_2 emission.

6. SYSTEM ASSESSMENT

The system assessment was simulated in the exhaust of CO_2, NOx, and PM based on the fuel consumption both of the fuel cell and the engine. The average output of the engine was constant at 30kW. The exhaust gas was calculated by using the delivery pattern in Table 1.

Table 1: Carriage simulation

content	Time (minute)		Drive
Precoolin・Cargo	60		Stop
go to the delivery region	40	Drive	185 miunte
Shop 1 ・Discharge	15	Short Stop	120 minute
go to the next shop	15	Long Stop	60 minute
Shop 2 ・Discharge	15		
go to the next shop	15		
Shop 3 ・Discharge	15		
go to the next shop	15		
Shop 4 ・Discharge	15		
go to the next shop	15		
Shop 5 ・Discharge	15		
go to the next shop	15		
Shop 6 ・Discharge	15		
go to the next shop	15		
Shop 7 ・Discharge	15		
go to the next shop	15		
Shop 8 ・Discharge	15		
go to the freght distribution center	40		

Table 2: CO_2 coefficient and fuel consumption

	CO_2 emission coefficient	Fuel consumption in diesel engines
Diesel fuel	3.13 kg-CO_2/kg	0.00183 kg/s
DME	1.91 kg-CO_2/kg	0.00267 kg/s

The amount of the CO_2 emission can be calculated by the fuel consumption and the emission coefficient. Each emission coefficient and the fuel consumption of the diesel engine with diesel fuel and DME are shown in Table 2. The amount of the exhaust of each running condition is calculated by these values. The base diesel engine of a past refrigeration vehicle was compared with the amount of a total exhaust. The calculation result of the amount of the exhaust of CO_2 in driving for ten minutes is shown in Table 3.

(A) Normal driving: The fuel consumption of the diesel engine with diesel fuel was deteriorated by +10% because of a freezer.

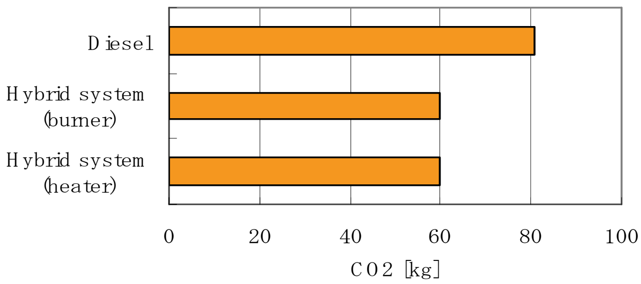
(B) Idol stopping for a short time: 0.01L/min = 0.0084 kg/min

(C) Idol stopping for a long time: DME is reformed with by heat with the heater or the burner.

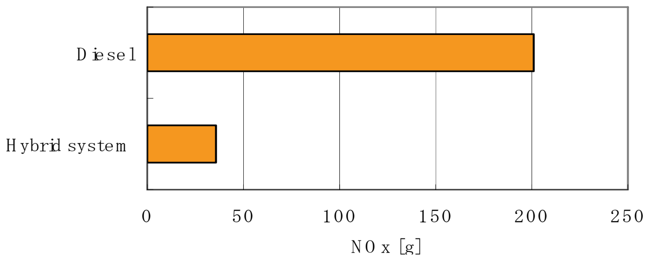
The amount of the exhaust of CO_2, NOx and PM in the delivery patterns during a day are shown in Figure 8. By adopting this system, CO_2 can be expected to decrease by 25.9%, NOx by 82.5%, and PM by 68.8%. The engine stop is effectively to reduction of emissions by using the fuel cell and the battery and by changing from diesel fuel into DME.

Table 3: CO_2 emissions for 10 minutes in 3 patterns

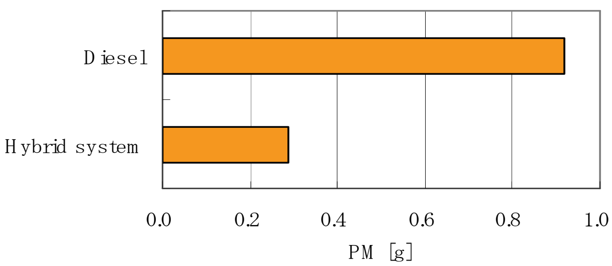
	Diesel fuel	DME	Decrease ratio
Normal driving	3.78 kg	3.21 kg	15.2 %
Short idol stopping	0.61 kg	0 kg	100 %
Long idol stopping	0.61 kg	0.11 kg (burner) 0.09 kg (heater)	82.3 % (burner) 85.3 % (heater)



(a) CO_2 emission



(b) NOx emission



(c) PM emission

Figure 8: Emissions comparison for 1 day

7. CONCLUSIONS

The new hybrid system with DME has been evaluated and the following conclusions can be drawn:

- Exhaust gas of the diesel engine is clean with DME fuel. Moreover, it becomes cleaner in the hybrid system with decrease of the engine load. So it can be expected to reduce greenhouse gases in the system.
- The system has possible for operation of electric devices at stopping the engine. Therefore, it can be also expected for NOx and CO_2 reduction, and solution of noise problem.
- The system can be adapted to a wide range of vehicles and equipments.

8. REFERENCES

1. M. Uehara, T. Yugami, T. Saika, “DME Fuel-Cell Hybrid System Combined with Diesel Engine for Commercial Vehicles with Electric Devices”, SAE Technical Paper 2007-01-3495, pp. 1-6, 2007.
2. Japan DME Forum, “DME Handbook.” (in Japanese), Ohm-sha, pp.3-4, 2006.
3. Sato, Y., et al., “Development of DME engines for Light-Duty Trucks meet JAPAN 2009 Emissions Regulation” (in Japanese), 2006 JSAE Spring Convention Proceeding, No.54-06, pp.7-11, 2006.
4. Sato, Y., et al., “The Performance of a Diesel Engine for Light-Duty Truck Using a Jerk-Type, In-Line DME Injection System”, SAE Technical Paper 2004-01-1862, 2004.

ACKNOWLEDGMENTS

Support of our work by Mr. Shigeo Sato and Mr. Tatsuaki Hayashi of Ryojyu Coldchain Company, and Mr. Yasumi Kanda and Mr. Yasuhiro Suzuki of Hino Motors Ltd. is gratefully acknowledged.