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A Study of Low Compression Ratio Diesel Engines Operated with Neat Dimethyl Ether (DME)

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ABSTRACT

A new concept of using DME as an alternative fuel in direct injection compression ignition engines with low compression ratios was presented to seek a combustion regime with the highest thermal efficiency. The concept was experimentally evaluated by a comparison of performance and emissions between a DME fueled engine and the corresponding conventional diesel engine. The result demonstrated that the DME fueled engine is superior to the conventional diesel engine in terms of thermal efficiency, emissions and engine noise particularly at low compression ratios. However NOx emission is unacceptably high and needs to be reduced by EGR or after treatment systems.

Keywords : *DME, Compression ignition engine, Ignition delay, Performance, Emissions*

1. INTRODUCTION

The use of dimethyl ether (DME) as an alternative fuel (see Table 1) appears to be a promising approach in minimizing soot emission from conventional diesel engines. The low self-ignition temperature of 508K and the high oxygen content of 34.8 % (by mass) are two major factors that characterize low soot and unburned hydrocarbon (THC) emissions [1-3]. Since the first introduction of the concept by Sorenson et al. in 1995[1], a considerable number of studies [2-7] have suggested that DME may be widely used for heavy duty engines in tracks and buses in some parts of the world where soot emission is particularly a serious problem, such as in congested urban areas. Regarding the power output, the brake mean effective pressure of a compression ignition (CI) engine fueled with DME is comparable to that of a corresponding diesel engine. Moreover, DME readily mixes with gaseous fuels such as liquefied petroleum gas because of its similar nature to alkine fuels. IC engines operated with such blended fuels offer advantages in performance and emissions as described above. From the view point of the CO_2 emission, the use of DME for small size IC engines for passenger cars are also desirable. DME has its unique advantages in its application to CI engines as described above, but there are various problems that need to be solved.

The problems encountered in the previous studies are: 1) Fuel injection tends to occur at earlier timings because of low nozzle opening pressure setting; 2) Combustion is relatively insensitive to the injection timing; 3) Despite the extremely low emissions of soot and unburned hydrocarbons, NOx emission is relatively high because of the advanced injection timing; and 4) DME tends to cause leakage and wear in the injection system because of

Table 1 Characteristics of DME and Diesel fuel

	DME	Gas-oil (JIS No.1)
Molecular Structure	$(CH_3)_2O$	$C_nH_{1.87n}$
Molecular Weight, *g/mole*	46.069	170
Boiling Point, ^oC	–24.8	180/370
Self-ignition Temperature, ^oC *(Cetane Number)*	350 (>55)	250
Heat of Vaporization, *kJ/kg*	467	300
Stoichiometric A/F, *kg/kg*	9	14.6
Liquid density @ 20 ^oC, kg/m^3	668	829.3
Lower Heating Value, *kJ/kg*	28430	43200
C *% (wt)*	52.2	86
H	13	14
O	34.8	0
S	0	0.14
Aroma	0	–
T90, ^oC	–	351.0
Critical Pressure, *atm*	52.4	–
Critical Temperature, ^oC	126.95	–

its low viscosity. The problem can be overcome by adding additives or using blended fuels composed of DME and diesel fuel mixed at desired ratios [3]. Relating to the problems 1) and 2), the effects of fuel spray characteristics on combustion and emissions will be discussed in this paper. The measures to reduce NOx emission will also be shown.

During the course of studying DME application to CI engines, the fuel was found to have potential in a wide range of applications because of its easy ignitability. That is, the fuel may be used in low-compression-ratio direct-injection engines (hereafter referred to as LCR DI-CI), which are expected to offer all the above-mentioned advantages. Such advantages of LCR CI-DI engines operated over a wide range of engine loads are considered to be even more attractive in view of various difficulties in combustion control and the high cost involved in gasoline-direct-injection (GDI) spark-ignition (SI) engines. GDI-SI engines still have difficulties in meeting the stringent emission standards, especially the fine particulate matter standard.

After some exploratory studies on LCR-CI engines, the present study is directed towards an in-depth analysis of the new concept, LCR-CI engine. Engines operated with DME are expected to retain the advantages of high efficiency and low emissions if exhaust catalytic converters as well as EG are employed in the system.

Fig.1 presents the states of DME on the P-T diagram, and the trajectories of pressure and temperature during the compression stroke of engines with various compression ratios. The pressure and temperature trajectories were estimated based on the assumption of adiabatic compression. Kapus ran his engine with a compression ratio of 15.76, but didn't employ lower compression ratios because of the increased engine noise generated by the rapid premixed combustion [3]. The temperatures on the trajectory for a compression ratio of 12.36 acquired in our experiment are well higher than the DME's ignition temperature at an atmospheric pressure. The operation of a DME fueled CI engine at this compression ratio looks possible from this figure. In our previous work, a DI-CI engine fueled with DME was operated successfully at compression ratios of 10.19 and 11.16 .

The question of classifying the channels inevitably comes up, with many conflicting views on this topic. It should be remembered that the significance of any classification based on the channel dimension is subjective, and is invariably affected by the type of fluid (liquid or gas), operating conditions (temperature and pressure), the type of flow (single phase, boiling or condensation), and the length to diameter ratio. Nevertheless, a simple classification scheme serves as a preliminary guide to relate the channels with the physical world.

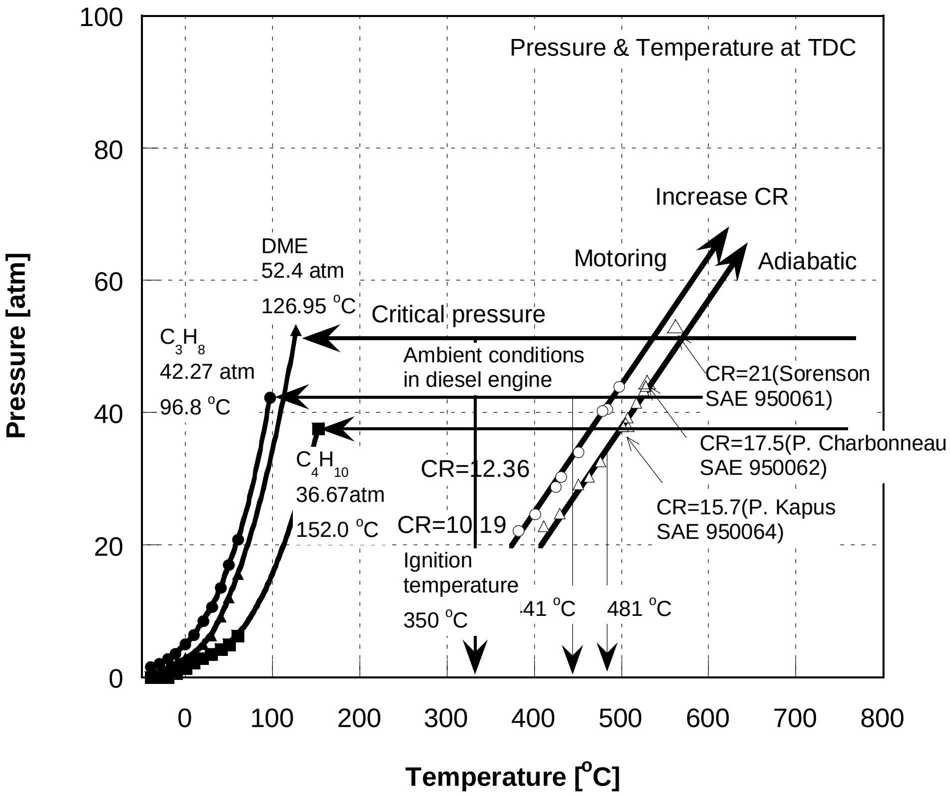

Fig. 1 PT diagram of DME.

2. EXPERIMENTAL

The present study of an LCR-CI engine operated with DME is mostly an experimental endeavor together with a thermodynamic analysis of combustion processes. The key issues in the design of an LCR-CI engine fueled with DME are reliable self-ignition and acceptable pollutants emission under stable engine operation. To investigate the factors affecting these issues, various parameters including compression ratio, start of fuel injection, injector opening pressure, and kind of fuel were changed in the experiments.

2.1 Engine and apparatus

The engine used in this study was basically the same engine as that employed in our earlier studies [5-7]. It is a typical direct-injection compression ignition engine manufactured by Yanmar Diesel Corporation with the specifications listed in Table 2. In order to vary the compression ratio of the engine, a thin copper spacer was inserted between the engine cylinder head and the cylinder block. The injection timing was altered at every 12 degrees crank angle by shifting the tooth of the injection pump gear. The injection timing given in the paper is not dynamic but nominal one. The difference between the nominal and dynamic timing is listed in Table 3. A pressure transducer to monitor the injection pressure, a needle-lift sensor, and an in-cylinder pressure transducer were installed in the engine. The engine apparatus was also interfaced with an emission measurement device (Horiba Co. MEXA-8220M) which includes measurement of total unburned hydrocarbons (THC). Since the main THC component in the exhaust was unburned DME, the response of the FID was calibrated to correct the relative molecular sensitivity [9]. A correction factor of 1.51 was used throughout the experiments.

After reviewing various methods employed for pressurizing DME in the previous studies, it was decided to use bottled nitrogen gas to maintain the fuel feed pressure at 3.43MPa. This measure was found to be effective to prevent the vapor lock within the fuel system. DME naturally absorbs the nitrogen which may increase the fuel NO formation, but there were few differences in NO emission between nitrogen and helium gas used for pressurizing DME during a short period of engine operation. With this method of fuel feeding, the engine was operated successfully with neat DME at a needle opening pressure of 8.82MPa. When DME is used as fuel, the needle opening pressure needs to be set at a lower value in comparison to that for diesel fuel, 20.1 MPa because of the lower constant of volume of elasticity with DME. One of the problems that a DME fueled DI CI engine faces on the injection system is a large amount of fuel leakage. The fuel leakage was measured under motoring condition using the same injection system as that for firing condition, and it was found that the leakage amounts to as high as 15% of the supplied fuel amount irrespective of the load. Such a leak volume was rather high, but, on the other hand, it is beneficial in the sense that the leaked fuel would help cool the injector and prevent the fuel from being prematurely vaporized in the injector. The amount of DME leakage and N_2 consumption in the container were both used in calculating the fuel consumption in the engine experiment.

Another problem in the injection system for DME is the needle lift behavior at low nozzle opening pressures. Fig.2 (a) shows the needle lift records at two nozzle opening pressures of 6.86 MPa and 8.82 MPa. As can be seen in the figure, when the nozzle opening pressure is 6.86 MPa, the needle starts to rise earlier in time and bounced with oscillation during the closing period, prolonging the injection duration. This oscillation was probably caused by the DME vapor in the pressure chamber of the injector. The nozzle opening pressure was the main factor governing the leaked fuel quantity at the injector, and the relationship between the leaked fuel quantity and the nozzle opening pressure was investigated as shown in Fig.2 (b). It is seen that the fraction of leaked fuel to the supplied fuel increases with nozzle opening pressure and that the fraction of leakage measured at firing condition doubles the leakage quantity at the injection experiment at motoring condition. The leakage quantity depends also on the design and degree of the abrasion of the injection system. It is difficult to determine the optimum nozzle opening pressure because a low nozzle opening pressure doesn't necessarily yield low injection pressures.

Table 2 Engine specification.

Engine Type	NFD-13K
Bore x Stroke	92 × 96 mm
Displacement	638cc
Original CR	17.7
Rated output	8.45kW/2600rpm
Injection pump	Jerk Type (Plunger 8mm dia)
Injector	0.26mm × 4

Table 3 The difference between nominal and actual injection timing.

Fuel	Nominal injection timing	Actual injection timing
DME	–17/–5 ^{o}CA ATDC	–12 ATDC/–1 ATDC
Diesel fuel	–17/–5 ^{o}CA ATDC	10/2 ^{o}CA ATDC

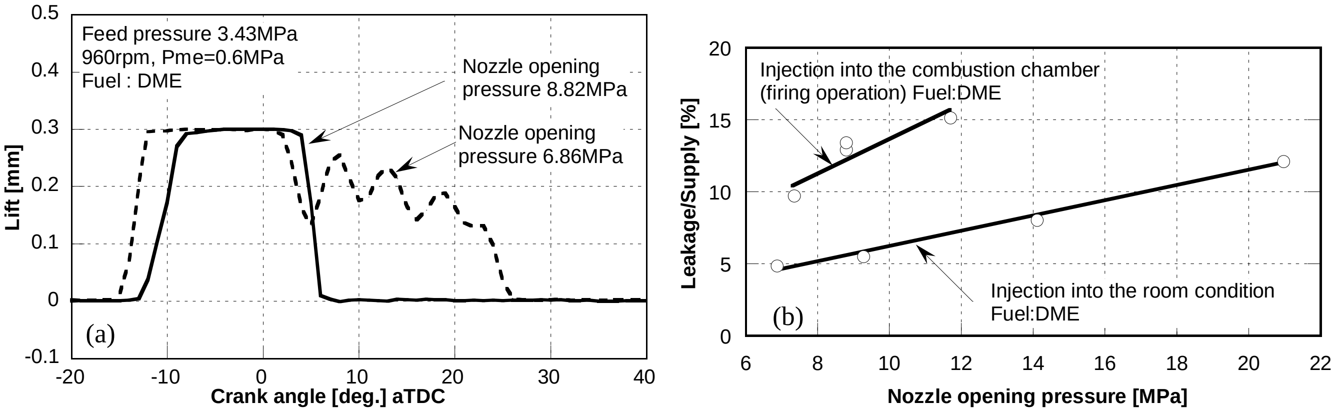

Fig.2 Effect of nozzle opening pressure on (a) the needle lift histories and on (b) the leakage of DME.

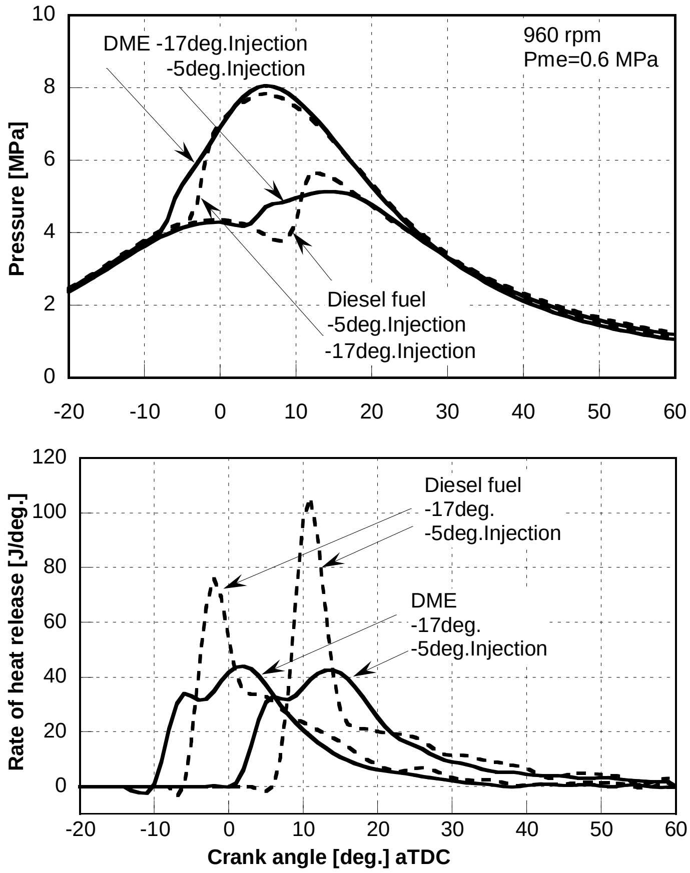

Fig.3 Pressure-time (p-t) and heat release histories of DME and diesel fuel for injection time at -17 and -5 ATDC.

2.2 Engine performance and emissions at original compression ratio

Engine performance and emissions at an original compression ratio of 17.7 are presented by comparing the results obtained with DME to those with diesel fuel. First, the pressure-time diagram and the rate of heat release at the same mean effective pressure of 0.6 MPa are compared to each other, as shown in Fig.3, for injection timings at 17 ^{o}CA and 5 ^{o}CA BTDC, respectively. For both injection timings, the start of pressure rise with DME occurred earlier in time than that with diesel fuel because of the DME's earlier start of needle lift by 4~5 ^{o}CA and short ignition delay.

The rate of heat release for DME presents a short "spike" in the initial premixed combustion stage and a moderate heat release during the diffusion combustion stage. The low peak of the rate of heat release for DME is due to the smaller amount of accumulated fuel during the ignition delay as compared with that for diesel fuel. Another reason for the weak spike and moderate heat release could be attributed to the lower mixing rate for DME. The lower initial momentum for DME spray jet must have produced a slower mixing rate for DME.

Fig.4 shows a comparison of the engine performance between DME and diesel fuel. The exhaust gas temperature and the brake specific energy consumption (BSEC) are plotted against Pme with the injection timing as a parameter. It should be noted that the exhaust gas temperature is lower for DME by around 50 ^{o}C and BSEC is lower for DME by well over 10%. The reason for the lower energy consumption with DME will be discussed later in details.

Fig.5 shows a comparison of emissions between DME and diesel fuel at various Pme at two different injection timings. As expected, soot emission was zero for DME at all operating conditions tested, while soot emission with diesel fuel increased with engine load. Similarly, THC emission was almost negligible for DME even under high loads. On the other hand, NOx emission was much higher with DME as compared to that with diesel fuel at an injection timing of 17 ^{o}CA BTDC, while it was somewhat lower with DME at an injection timing of -5 ^{o}CA BTDC.

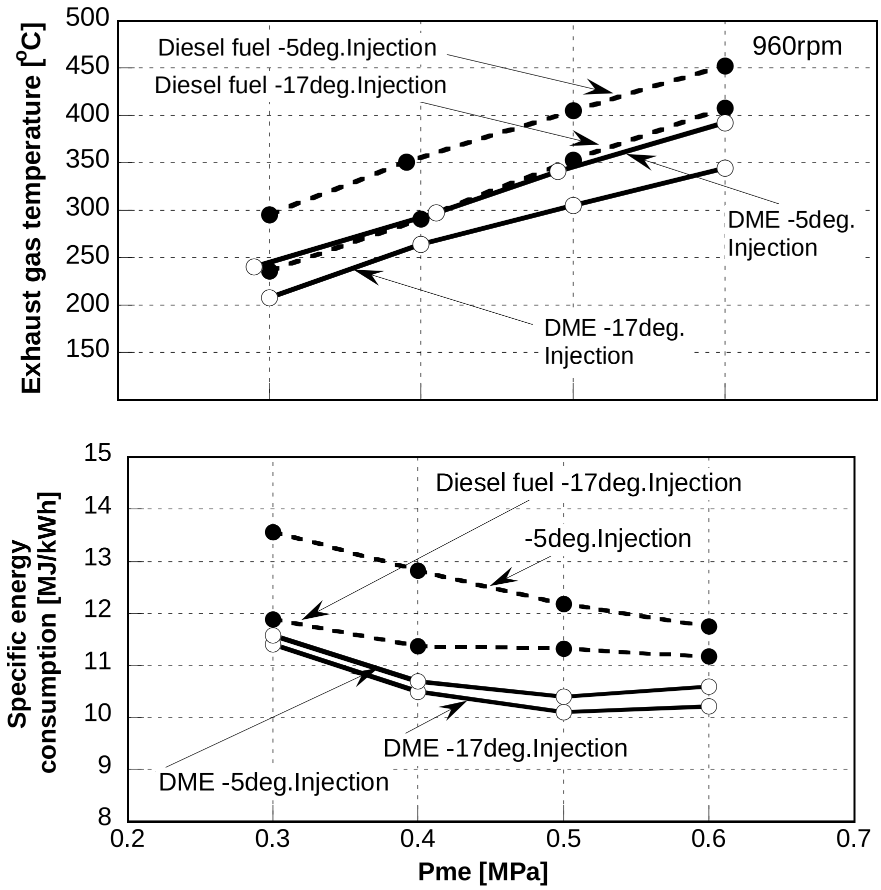

Fig.4 Exhaust-gas temperature and specific energy consumption for varied engine load.

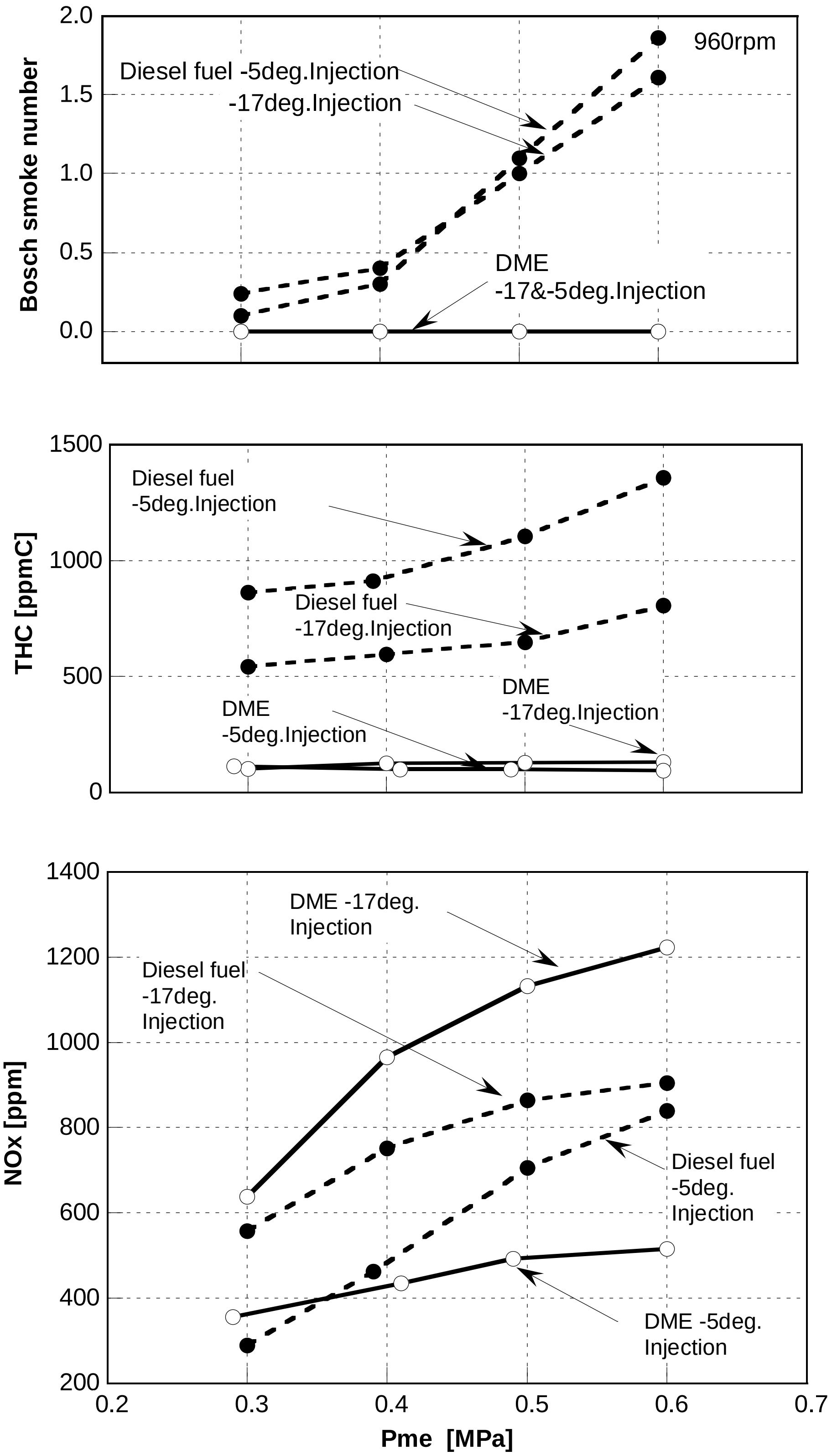

Fig.5 Smoke, THC and NOx emission when operated by DME and diesel fuel.

3. LCR-CI ENGINE AND DISCUSSION

The minimum brake specific fuel consumptions for various types of IC engine are plotted against compression ratio in Fig.6. The plots at left are the minimum BSFCs for SI engines, while the data for CI engines at right scatter at compression ratios ranging from 15 to 23. There are no data between two groups at compression ratios around 14. The facts that increased compression ratio generates knocking with SI engines and reduced compression ratio yields poor ignition with CI engines are the reasons for the lack of data in this range of compression ratio. However, the plots in the figure clearly suggest the possibility to achieve the lowest brake specific consumption at a compression ratio near 14. DME may have potential to achieve the lowest BSFC at compression ratios around 14. One of the latest models of SI engines is the direct injection type, and this type of engine could be easily modified to use DME. It might be possible to operate all types of internal combustion engines with DME. The effects of compression ratio on performance and emissions of a DME engine are discussed in this section to seek the lowest BSFC at a compression ratio around 14.

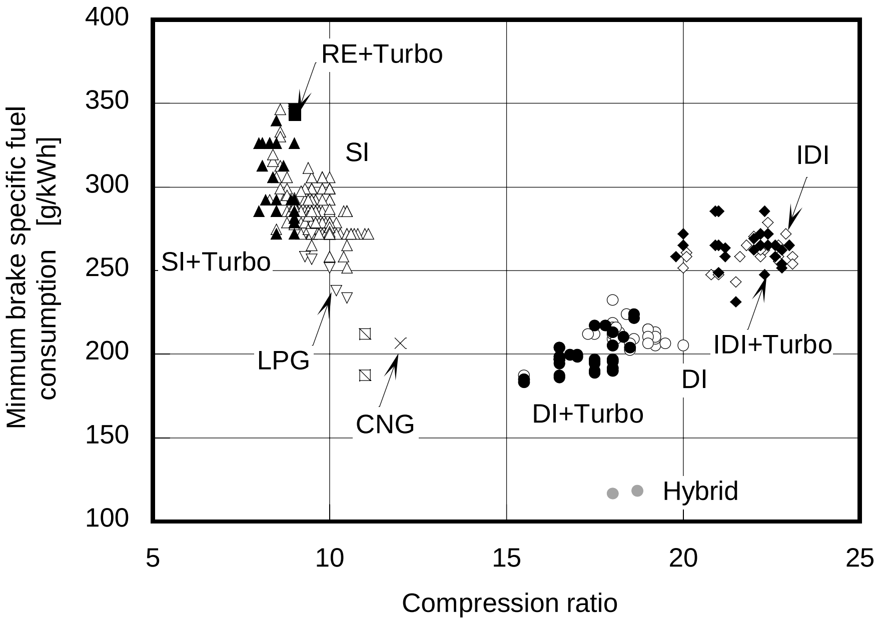

Fig.6 Relationship between the compression ratio and minimum brake specific fuel consumption.

3.1 Combustion behavior

As shown in Figs.4 and 5, the effect of injection timing on the specific energy consumption is marginal at a Pme of 0.6 MPa for both DME and diesel fuel even if the ignition timing was varied from –17 ^{o}CA to –5 ^{o}CA. Accordingly an experiment on the effects of compression ratio on performance and emissions was conducted at a fixed injection timing for both fuels. Fig.7 shows the pressure-time histories and the rates of heat release for both DME and diesel fuel at an injection timing of –12 ^{o}CA and a Pme of 0.6 Map. Unlike the steady and rapid rise in the pressure-time curves for diesel fuel, "bending points" can be observed for DME at pressures of approximately 5 MPa, which occurrs at -5 ^{o}CA, -3 ^{o}CA, and 3 ^{o}CA for compression ratios of 17.7, 13.89, and 12.36, respectively. Note that the bending points corresponded to crank angles where the peak of respective spikes in the rate of heat releases were observed. The moderate diffusion combustion occurring after the small initial pre-mixture combustion is the cause for the bending in the pressure-time records.

Fig.8 shows the ratio of the thermal efficiency, the ratio of degree of constant volume and ignition delay against compression ratio for both fuels at the same operating conditions as in Fig.7. Here the word “ratio” means a relative value to the reference one at a compression ratio of 17. Since the heat release occurs mainly near TDC and ends earlier with DME, the thermal efficiency for DME is considerably higher than that for diesel fuel at all compression ratios tested but particularly at low compression ratios. It is also seen that the thermal efficiency for DME remains almost constant regardless of the compression ratio, while it decreases for diesel fuel at low compression ratios. The higher thermal efficiency for DME is reflected from the higher ratio of degree of constant volume. When a rapid heat release occurs near TDC, it often results in a noisy operation. This, however, was not the case, as shown later. The ignition delay shown in Fig.8 is defined as the crank angle between the start of needle lift and a crank angle when the accumulated heat release reached 5 % of the total heat supplied. The ignition delay for DME is apparently shorter than diesel fuel because of the higher Cetane number of DME.

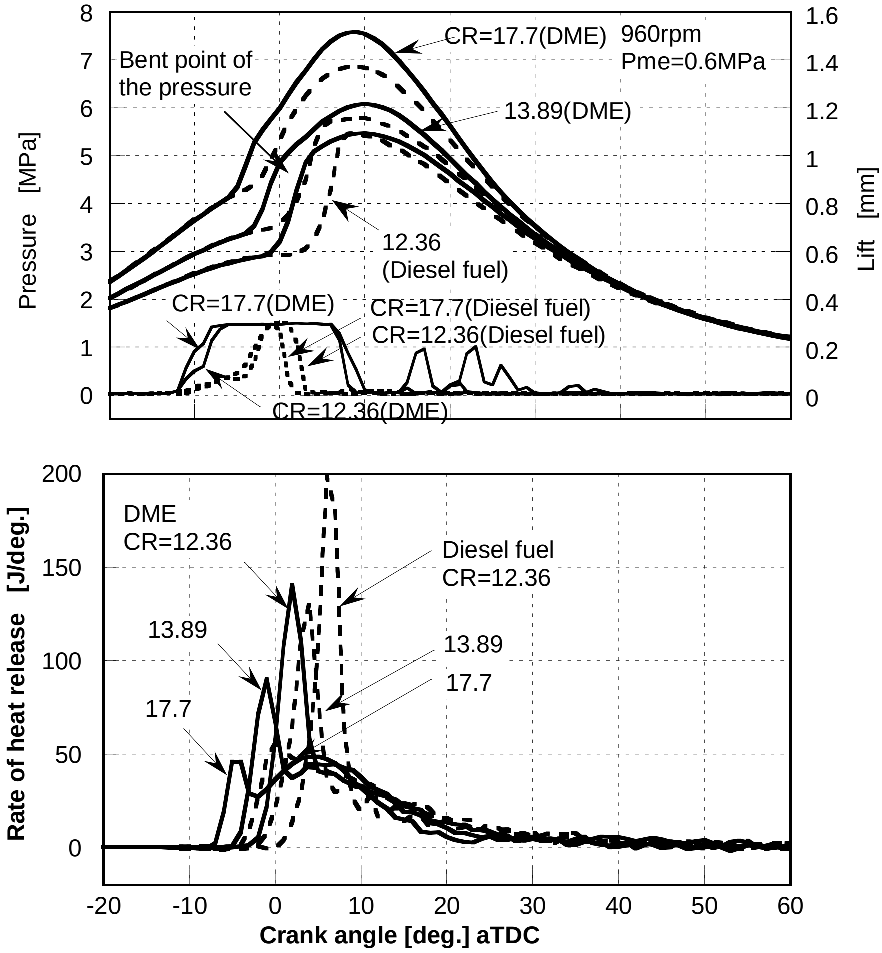

Fig.7 Pressure-time (p-t) and heat release rate histories for varied compression ratios.

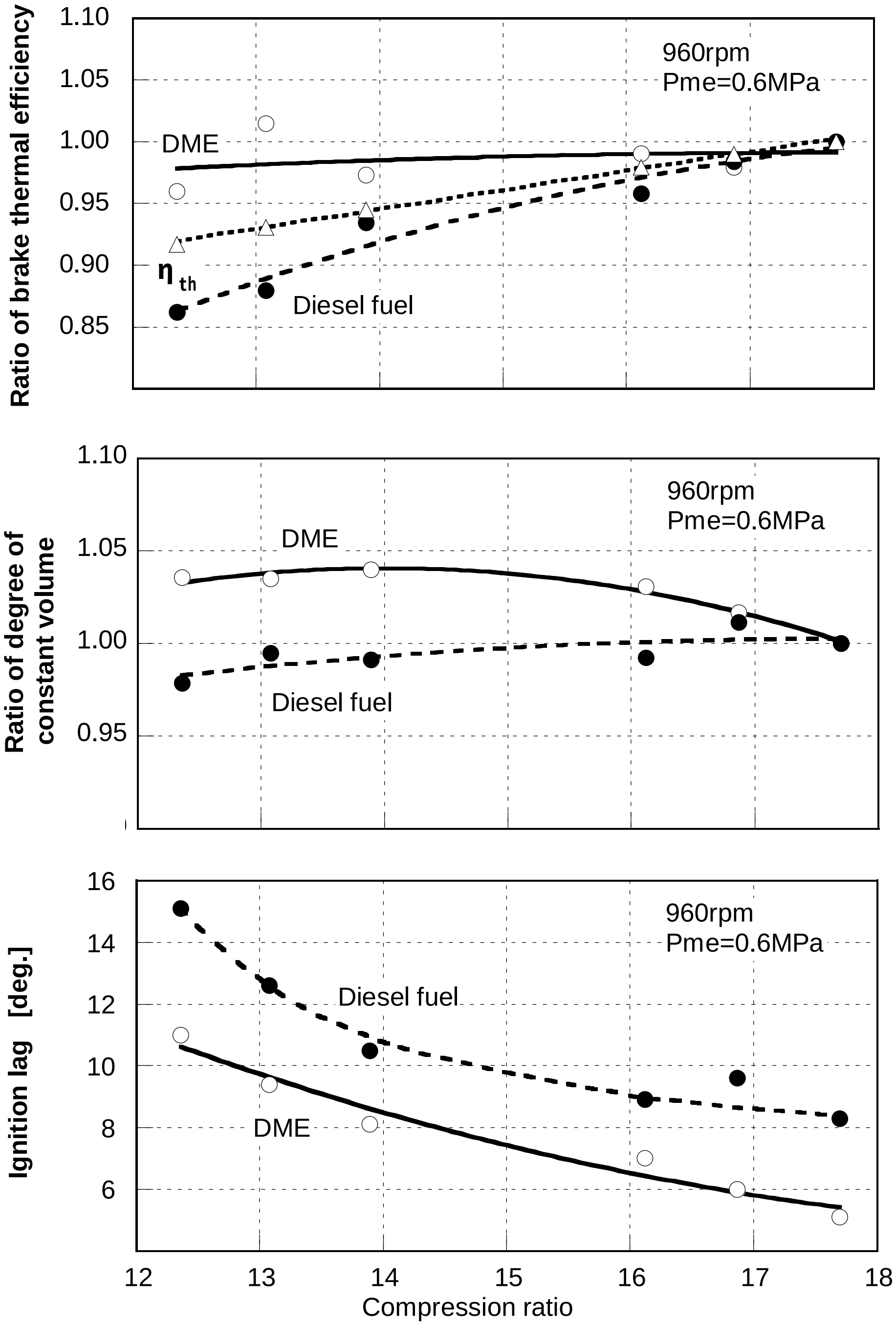

Fig.8 Relative brake thermal efficiency, relative degree of constant volume, and ignition lag for varied compression ratios

3.2 Exhaust emissions

Exhaust emissions were measured at a time when the above results were obtained. Fig.9 presents a comparison of exhaust emissions between two fuels at various compression ratios. CO and THC emissions are considerably low for DME and NOx is also lower for DME than diesel fuel. Shown in Fig.10 are the variations of exhaust-gas temperature, the fraction of the heat loss to the coolant against the input energy, and sound pressure level with compression ratio. The higher ratio of degree of constant volume shown in Fig.8, lower exhaust gas temperature and lower cooling heat loss shown in Fig.10, all support the superior thermal efficiency for DME.

The mean brake thermal efficiency is expressed as follows;

$$\eta_e = \eta_{th}\eta_{glh}\eta_b\eta_m(1-\varphi_w)$$

where

η_e *: Brake thermal efficiency*

η_{th} *: Theoretical thermal efficiency*

η_{glh} *: Degree of constant-volume combustion*

η_b *: Combustion efficiency*

η_m *: Mechanical efficiency*

φ_w *: Cooling loss ratio*

The factors affecting the brake thermal efficiency, η_e , are η_{glh} , η_b and η_w when the fuel is changed. The mechanical efficiency, η_m , is considered to be identical to both DME and diesel fuel at the same Pme condition. The degree of constant volume, η_{glh} , for DME increases with the decrease in compression ratio, as shown in Fig.8 because of the increased pre-mixed combustion. The significant low concentrations of CO and HC for DME imply a very high combustion efficiency for DME close to 99% at any compression ratios tested. Furthermore, the exhaust gas temperature for DME is lower than that for diesel fuel by 25~50 K, and the difference in the exhaust gas temperature between DME and diesel fuel becomes large at low compression ratios. The lower cooling loss to the combustion chamber walls for DME could be indebted partly to the reduced radiation heat transfer for the semi-luminous flame of DME.

As pointed out earlier, the engine operated with DME is quieter than with diesel fuel due to the shorter ignition delay for DME. Fig.10 shows that the sound pressure level for DME remains almost constant even at low compression ratios in contrast to the different trend with diesel fuel.

3.2 NO_x reduction by a catalyst

The performance of the present LCR DI-CI engine operated with DME was found to be superior to conventional diesel engines, but NOx emission was still unacceptably high. In order to demonstrate the possibility to reduce NOx emission from an engine fueled with DME, a Cobalt-aluminum base selective catalyst was tested. A small amount of DME was injected upstream of the catalyst as a reducing agent and the amount of the added DME was measured by a volume type flow meter. The concentration of THC, mainly DME, measured by FID at the tailpipe of the engine is about 1.21 times higher as compared with pure DME concentration because the relative mole sensitivity of DME is 0.62. Since the introduction of DME results in the increase in THC concentration due to the presence of un-reacted raw fuel after the catalyst, THC was measured together with NOx varying the catalyst temperature.

Fig.11 shows the result. As can be seen in the figure, a considerable reduction of NOx was achieved by the catalyst with DME injection. In particular, when DME was added in amounts ranging 4,000-8,000 ppmC, NOx was remarkably removed in a window of catalyst temperature between 300-350 ^{o}C. However, at the same time there arose another unfavorable problem, i.e. increased THC emission at low exhaust gas temperatures. The increased THC emission resulting from the DME addition needs to be reduced by an oxidation catalyst.

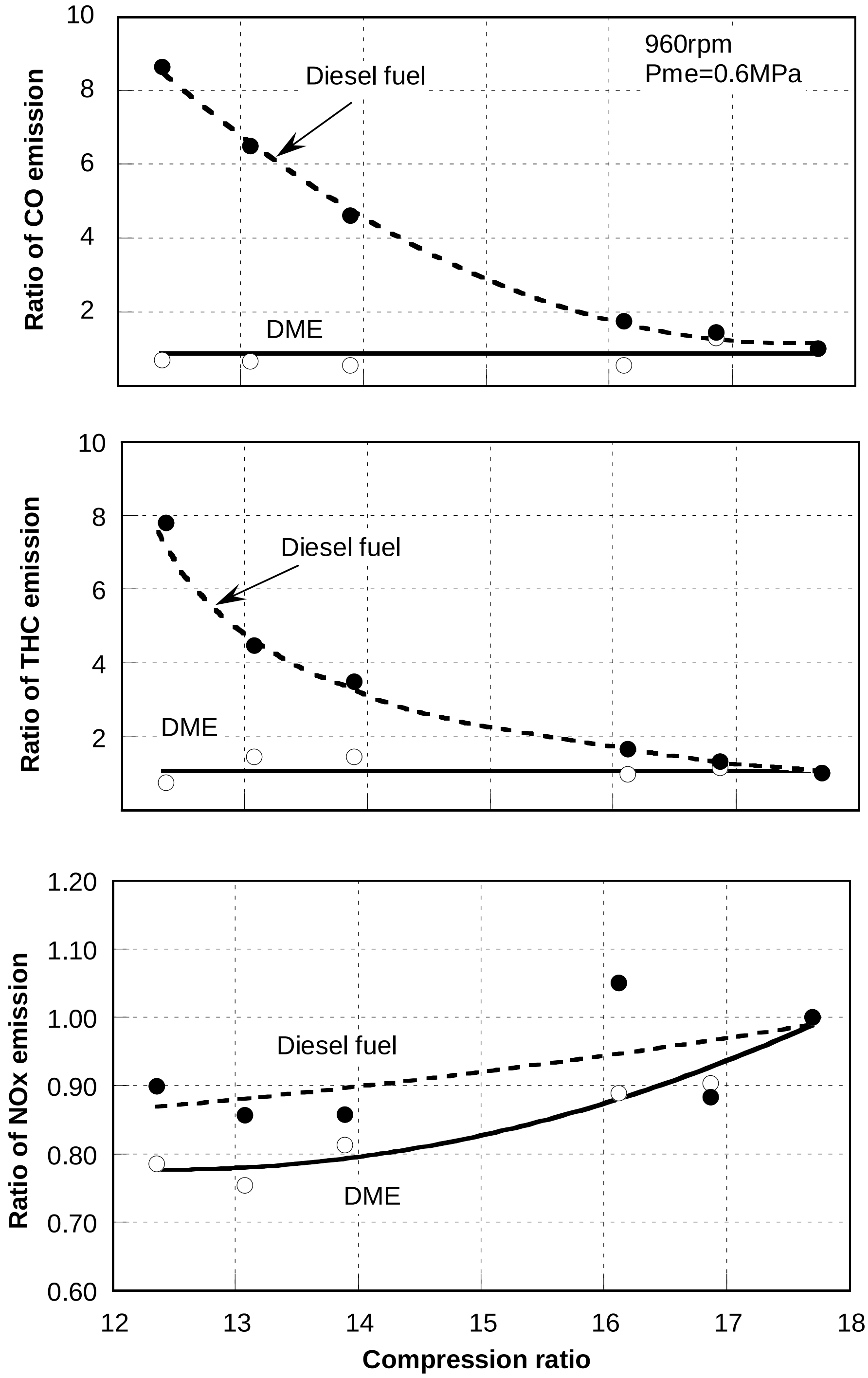

Fig.9 Carbon monoxide, THC and NOx emission for varied compression ratios.

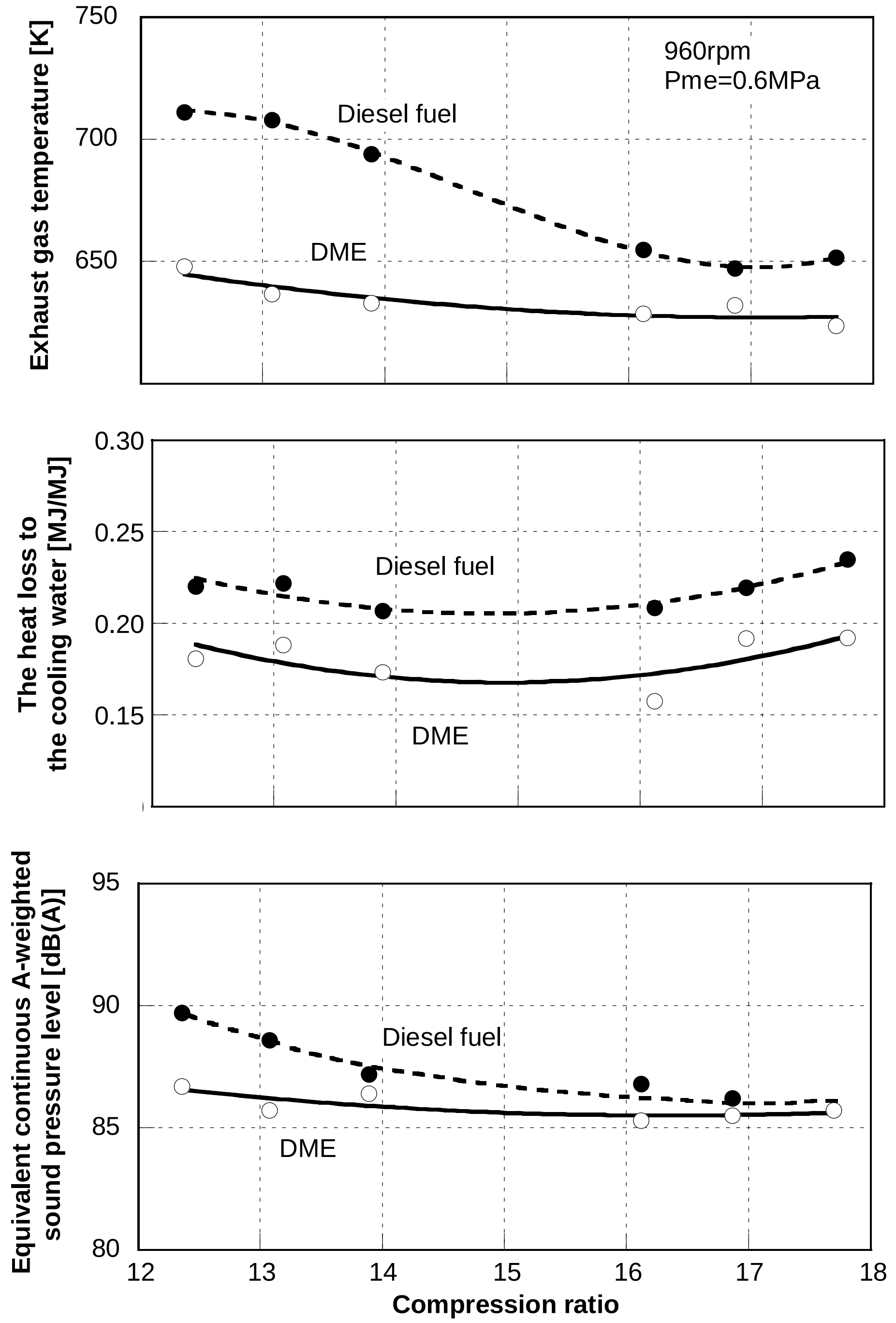

Fig.10 Exhaust gas temperature, heat loss to coolant and sound pressure measurements for varied compression ratios

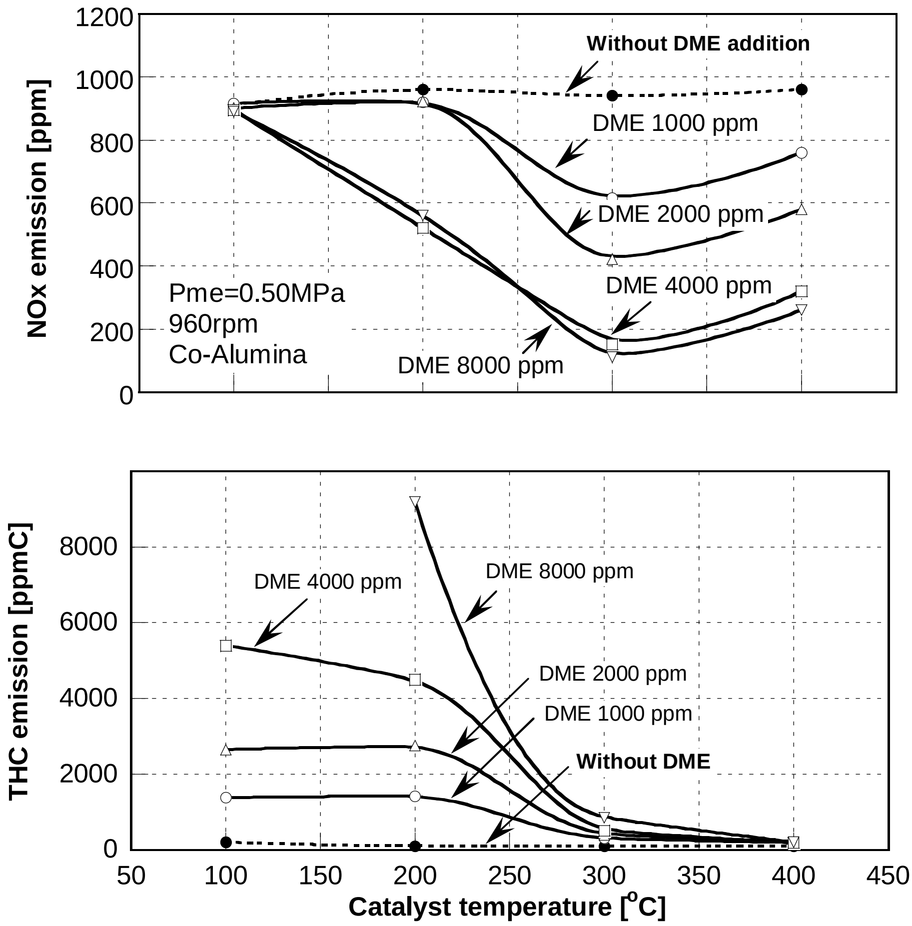

Fig.11 NOx and THC emission with variation of the catalyst temperature.

3. SUMMARY

DME may be widely used in compression-ignition (CI) engines as an alternative fuel in some parts of the world, mainly because of the low soot production. While this consideration is actively being evaluated in the field, a new methodology of using DME as a fuel was discussed in this paper, focusing on its use in low-compression-ratio (LCR) direct-injection (DI) CI engines.

As an alternative fuel to diesel fuel, it would be economical to use DME in LCR DI-CI engines because of the fuel's relatively low self-ignition temperature. The DME engine will not require complex and high-cost devices to achieve low emissions, such as an electronically controlled high-pressure injection system and exhaust traps or plasma after-treatment units. The same is true when compared with gasoline-direct-injection (GDI) spark-ignition (SI) engines, which are equipped with expensive and maintenance-demanding electric ignition system and combustion control devices.

Among the findings from the present study of DME operated LCR-CI engine are:

1. The lowest compression ratio for easy start and stable operation of the DME CI engine tested is around 12.
2. THC emission from the DME LCR-CI engine is low and remains almost constant irrespective of the compression ratio.
3. Soot emission from the DME LCR-CI engine is negligibly low at all compression ratios examined.
4. The brake thermal efficiency of the DME LCR-CI engine is almost constant over compression ratios ranging from 12.36 to 17.7.
5. NOx emission from the DME CI engine is unacceptably high and this needs to be reduced by EGR and after treatment devices.

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Current Status of R&D on DME Utilization Technologies

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1. INTRODUCTION

DME is one of the GTL products to be produced via syngas from such resources as natural gas, crude oil, asphalts, coal, biomass, etc., as each contains H2 and carbon. The physical properties of DME are similar to those of LPG. These days, DME is being highlighted as a future fuel, although it has been utilized only as a chemical product, consumed at a rate of about 150,000 tons/year worldwide. The reasons for such appreciation of DME are:

(1) Regarding the oil upstream, DME production is a promising measure for developing stranded gas reserves. The production process of DME is relatively simple and has higher thermal efficiency than that of GTL, which will make the cost of DME per one thermal unit cheaper than that of GTL.

(2) As for its transportation, DME is transportable by tankers similar to the ones used for conveying LPG, and the transportation cost will be lower than that of LNG tanker.

(3) LPG distribution infrastructure in the consuming countries will be easily adjusted for DME distribution by making only minor infrastructural changes.

(4) DME has a superior quality in usage as fuel, which will be described hereafter.

The acute point for the wide utilization of DME as a fuel lies in the distribution infrastructure and utilization technologies. In this sense, JNOC has been tackling the R&D of DME utilization technologies since FY 2001. This paper will introduce JNOC's challenge, focusing on the equipment development in which DME can be used practically.

2. DME UTILIZATION TECHNOLOGIES

2.1 Utilization of DME and JNOC's R&D

DME has the potentiality to be a versatile material as fuel, in contrast to GTL, which seems to be used mainly for transportation fuel. The usage of DME as fuel is divided into two categories, one for combustion of DME and the other for the reformed gas of DME. The apparatus and machines operated by DME combustion are boilers and turbines intended for large-scale power plants, diesel engines directed for distributed power generation and vehicles, micro gas turbines, and home stoves, etc. The machines utilizing the reformed gas of DME are SNG equipment making substitute natural gas and H_2 generation equipment for PEFC.

JNOC has carried out the R&D of DME utilization technologies since FY 2001. Table 1 summarizes the research themes and allotment of the researchers provided for the various JNOC Projects. Described in the following session are the target points and some results of the turbine and diesel engine as combustion-related technologies and the SNG and H2 production equipment for PEFC as reforming-related ones.

2.2 DME TURBINE

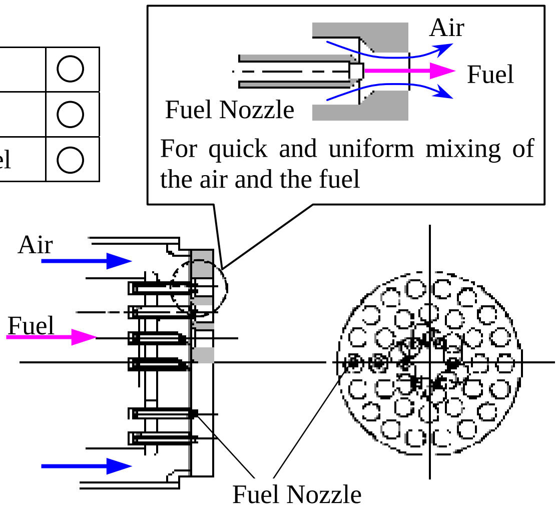
In the case of converting an LNG power plant into a DME one, the key parts to be replaced in its System are those for the storage/vaporization equipment, compressor, and combustion apparatus. The important points to take note of when using DME for the turbine combustion apparatus are not only to reduce NOx in exhaust but also to provide multi-fuel-use flexibility by consuming DME in addition to LNG and LPG.

As a burner which can attain low NOx emission and multi-fuel use spontaneously with trouble-free combustion of DME, which has low self-ignition temperature and fast combustion velocity, we have developed and have been improving the co-axial jet cluster nozzle burner which is depicted in Fig. 1. The developed burner is designed so that it is possible to reduce the pre-mixed distance of air and fuel to avoid burning in the pre-mixing room.

Table 1 JNOC DME Utilization Technology – Themes and Players –

Group		Theme	Research Organization	Start	Period
Combustion	Centralized Power	High Efficiency Combustion System for Fuel Grade DME	Hitachi, Ltd., et al.	2001	2 years
		Verification of Low NOx Combustion Technology for DME Fueled Gas Turbine	Hitachi, Ltd.	2003	1 years
		Development of Retrofit DME Boiler	Mitsubishi Heavy Industries, Ltd.	2002	2 years
	Distributed Power (Cogeneration)	DME Application to Diesel Engines and Micro Gas Turbines	Mitsubishi Heavy Industries, Ltd., et al.	2001	2 years
		Improvement of Lubrication Property for DME Diesel Engine	Mitsubishi Heavy Industries, Ltd., et al.	2003	2 years
		DME Diesel Engine for Co-generation Systems	Yanmar, Co., Ltd., et al.	2001	2 years
	Vehicle	Development of Retrofit DME Diesel Vehicle	Iwatani International Corporation, et al.	2001	2 years
		R & D Heavy Duty DME Diesel Vehicle	COOP EcoVehicle Development Co., Ltd., et al.	2002	2 years
		Practical Durability Fleet Test R&D of DME Vehicles	COOP EcoVehicle Development Co., Ltd., et al.	2003	2 years
Reforming	SNG	Production of Substitute Natural Gas (SNG) from DME	JGC Corporation, et al.	2001	2 years
	Fuel Cell	DME Application to PEFC as Stationary Power Generator	Mitsubishi Heavy Industries, Ltd., et al.	2001	2 years
		Development of Advanced DME Reforming System for PEFC	Osaka Gas, Co., Ltd., et al.	2001	1 years
		Development of Advanced DME PEFC system		2002	2 years
		Development of DME reforming system for fuel cell vehicle	Osaka Gas, Co., Ltd., et al.	2003	4 years
Infra.	Components	R&D for Components Utilized in DME Facilities for Fuel DME Spread	Liquefied Petroleum Gas Center, et al.	2001	1 years

Low NOx Emission	○
Prevention of Flush Back	○
Acceptability of Multi Fuel	○



Development of Co-axial Jet Cluster Nozzle Burner

Fig. 1 DME High-Efficiency Combustion System

2.3 DME DIESEL ENGINE

(1) Problems involving diesel engine for DME use

DME is suitable as diesel fuel due to its high cetane number. The produced exhaust gas, following the combustion of DME, is smokeless and contains low Particulate Matter levels. Moreover, it can bring about such various merits as low noise in engine operation and no need of expensive high-pressure fuel injection apparatus. In order to adopt a diesel engine that is optimized for diesel oil to DME, the fuel injection system (injection pump, nozzle, valve, etc.) and EGR in terms of thermal efficiency and exhaust composition should be mainly reformed.

(2) DME diesel engine for distributed power

Fig. 2 shows the exhaust composition of a 43-kW diesel engine adjusted to DME in burning DME. The combustion of DME in pressurized supply generates the same amount of engine power as that generated by the combustion of diesel fuel in pressurized supply. It is smokeless in the entire operational range and has a scarce volume of the non-combusted materials of CO and HC. From these data, the DME diesel engine is ascertained to have the potentiality of high thermal efficiency and clean emission.

[Conditions of Combustion]

- S4S Direct Injection Type (φ94×120, 43 kW/1800rpm)
- Fuel Injection Pump — dpl = φ9
- Fuel Injection Valve — φ0.26×4^N
- Fuel Supply Pressure — 1.6 MPa
- Fuel Injection Timing — 12° B (Gas Oil), 18° B (DME)

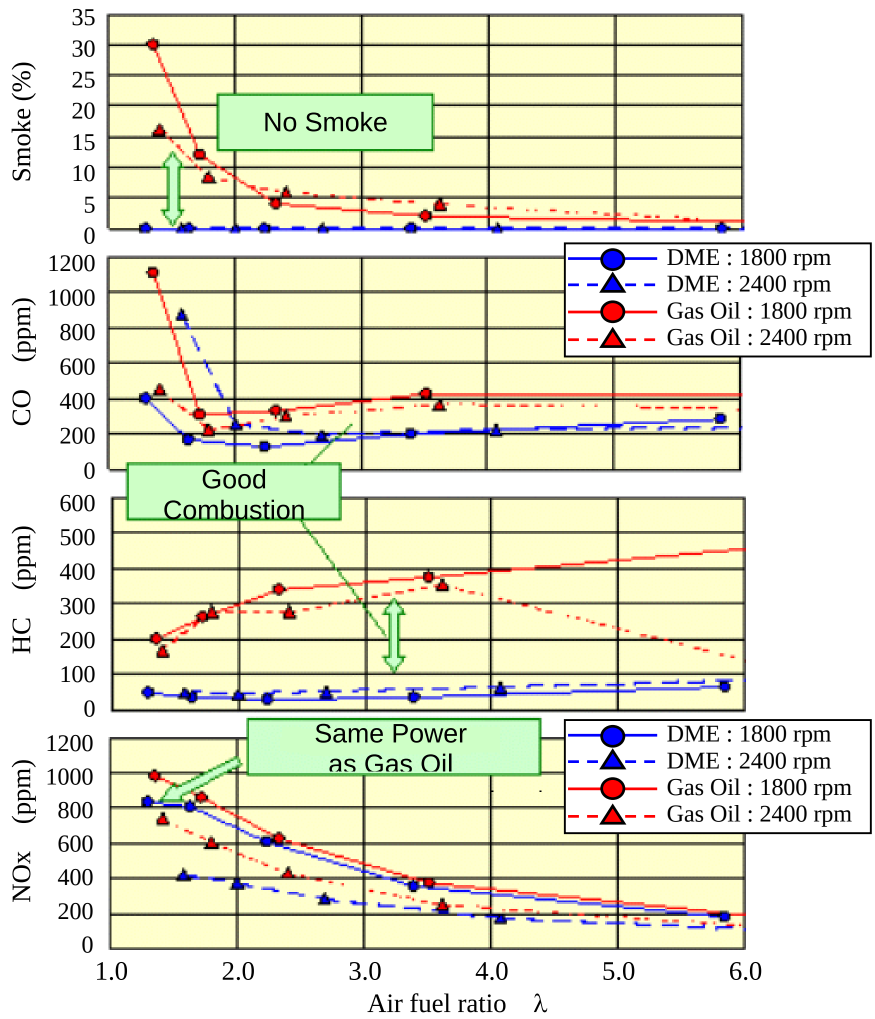


Fig. 2 Emission Characteristics of DME Diesel Engine

(3) DME diesel engine for vehicles

We have made an experimental DME vehicle out of an existing 2-ton truck by reforming the fuel supply system, comprising of the fuel tank and pipes, which was installed in its diesel engine. The injection system of the diesel engine utilizes the rotary distributor fuel injection pump. A driving test has been carried out in this trial vehicle.

2.3 UTILIZATION OF DME REFORMING

(1) Reaction

In the utilization of DME reforming, there are two categories, one to utilize SNG to be produced by reforming DME to methane and the other to utilize PEFC fuel to be produced by reforming DME to hydrogen. The required Catalysts and reaction conditions are different in each use. In the case of DME to be reformed to methane, the reaction conditions are a temperature of 300 - 400 °C and 1-2 MPa of pressure with Ni base catalysts. In the case of DME to be reformed to hydrogen, the reaction conditions are a temperature of 350 - 450 °C and 0.1-0.3 MPa of pressure with noble metal or Cu/Zn base catalysts.

(2) Reforming DME for SNG (Substitute Natural Gas)

SNG production equipment is one method to reform LPG and naphtha into methane by steam reforming in order to supply natural gas in areas where natural gas from LNG cannot be provided. DME-SNG production equipment, which reforms DME to methane, is more promising than the existing LPG- or naphtha-SNG production equipment in the following two points. In the first point, DME can be reformed to methane at a lower temperature than LPG or naphtha. In the second point, the existing SNG production equipment requires a de-sulfur unit because of the weakness of the reforming catalysts required for eliminating sulfur contained in LPG and naphtha. Because no sulfur is contained in DME, DME-SNG production equipment can eliminate the de-sulfur process, further simplifying and reducing the cost of the total system..

However, methane production efficiency of DME is, on the feed weight base, about 60% of that of LPG. As a result, the development of DME catalysts to reform DME efficiently into methane under moderate conditions is the critical point of the R&D. Fig. 3 shows the result of DME-SNG reforming experiments using the developed Ni-based low-temperature steam reforming catalyst. In all experimental conditions, 1.5 mol methane and 0.5 mol CO_2 are stoichiometrically produced from 1 mol DME. The process flow is designed to produce 100,000 m^3/D of methane, which can supply natural gas in a city with a population of 100,000.

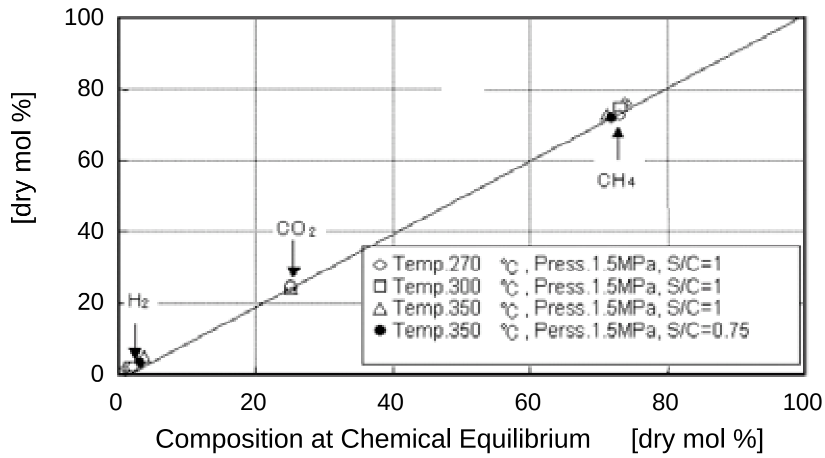
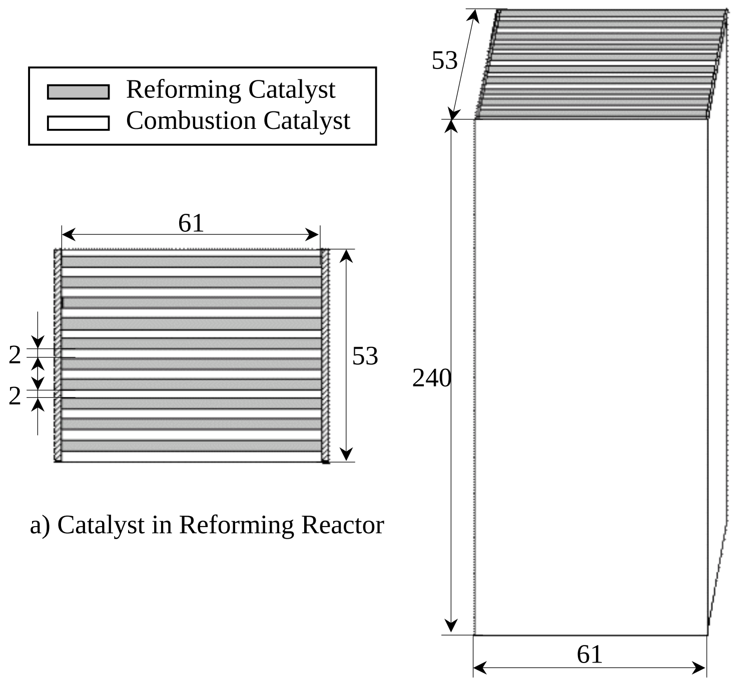


Fig. 3 Comparison of Test Data and Calculation Data.

(3) Reforming DME for PEFC

PEFC is expected to be applied particularly for domestic use and in vehicles because it has the potentiality of reduced production cost with easy handling of its electrolyte and quick operation for low temperature start-up. There are two typical sources of H_2 generation for PEFC, one from natural gas and the other from methanol. In the case of reforming natural gas, a reforming temperature of over 700 °C is required. Moreover, a CO shift and CO removal unit is necessary after its reforming in order to suppress CO concentration under 10 ppm. As a result, compact packaging of the reforming system is difficult. On the contrary, in the case of reforming methanol, the reforming temperature is as low as 200 °C. Moreover, it is easy to make the reforming system compact because the reforming and CO shift unit will be unified in one process, in which the Cu/Zn reforming catalyst has the CO shift activity, and the reforming and CO shift temperature is almost the same. However, methanol has a poisonous characteristic. Non-poisonous DME is promising as a hydrogen source for PEFC because the reforming temperature is relatively low and the Cu/Zn catalyst can be used as the same as methanol. This will enable the reforming system to be downsized. The durability of the developed Cu/Zn/Al_2O_3 catalyst has been carried out in the DME reforming. The performance is stable over 1000 hours. It is feasible to convert almost 100% DME into H_2, CO and CO_2. CO concentration out of the DME reforming/CO shift unit is about 3%, and the output gas is then introduced into the selective CO oxidation unit with a high-efficiency heat removal device so that such CO concentration may be reduced to less than 10 ppm. Fig. 4 shows the DME reforming/CO shift unit for a 1-kW PEFC. The 50-kW reforming and selective CO oxidation units are very compact in size, and such downsizing implies the possibility that the on-board styled DME reforming apparatus may be mounted on the vehicle.



a) Catalyst in Reforming Reactor

b) External Appearance of Reforming Reactor

Fig. 4 Concept of Reforming Reactor in 1 kW DME Fuel Cell (PEFC).

Report of International Conference

ICOPE-03 (International Conference on Power Engineering) Precious experience (facing ICOPE-03 participation)

Mr. Takashi YOSHIYAMA

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This is the first time for me to join the International Conference of Power Engineering (ICOPE-03), which held in Kobe in November, and I made a presentation before the audience who came from various countries. Although I had several chances to present in the domestic societies until now, I felt fresh atmosphere in the international conference interchanged with foreign researchers speaking English. I describe below what was felt under such circumstances especially this time.

At first participating in the international conference I was able to hear other researchers, especially foreign researchers. So it is very important that I have foreign researchers to opinions and questions asked to our research directly. Moreover, participating not only as the audience at the conference but as a presenter and an author of the paper brought me the results that I considered its contents of research in details more than usually. As a result I thought that there was an effect which raised its understandings.

Secondarily I felt how important English would be as a common language. It was not just the keenly recognition of the necessity for linguistic study that I could not speak English. For example, although I could not speak Chinese at all and I was faltering of speaking English, but I could exchange opinion with the researcher of the China graduate which was studying in Germany each other using English as common language. Moreover, I thought that it would lead also to the efforts to tell rather to a partner carefully that it was not a native language mutually.

Thirdly although it may be a way of speaking with this paradoxical -- I felt it very secure that there are many researchers in the field of energy, many researches are carried out and important results from researches have been made all over the world. Although the problem of the present energy resources is a common problem the whole world over, the method of solution may not be sure clearly yet. If there is cooperation of many researchers, I will think that the solution method may be found.

The reception and party after a lecture meeting think that they greatly contributed to promoting international exchange as man who is between the researchers of the same energy field, and lives on the same earth. This experience was very precious to the young persons like me.

Now I thank organizers, chairmen, presenters and all persons supported of this conference.

Takashi Yoshiyama (KAWASAKI HEAVY INDUSTRIES,LTD.)

The 2nd author and a presenter of

No.168 LOW NOx COMBUSTION METHOD OF SLAG-TAP FIRING BOILER (TEILKAMMER BOILER)

ISMNT-1 (1st International Symposium on Micro & Nano Technology)

Prof. Koji Miyazaki

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The 1st International Symposium on Micro & Nano Technology was held in Honolulu on March 14-17, 2004. I was able to have a good opportunity to discuss my research with some friends at the conference because Honolulu is familiar to Japanese. We saw many researchers from Japan as well as 12 countries.

At the conference I was able to study many applications of Micro & Nano technology from industries. It is very difficult for me to have that kind of opportunity. I would like to thank Dr. Inoue (Komatsu Electronics Inc.) and Prof. Ishizuka (Toyama Pref. Univ.) for organizing the conference. I guess that they ask researchers of industry to attend the conference. I think that the conference was good meeting for discussion between industry and academia.

I was impressed the researches presented at the keynote lectures. They introduced their interesting results, and they emphasized advantages of Micro & Nano technology. I understood that the Micro & Nano technologies have been already applicable to industry. I was able to have a lot of information on this field from industry, but I am not sure whether I could provide interesting results for industry. I should try to give significant results to industry at the next time as one of the meetings for cooperation between industry and academia.

I saw also a lot of presentations of Japanese master course students including foreign students. Of course they talked their researches in English, and they explained results clearly at the discussions. I was impressed their works. My research group also should try the presentation in English to keep up with their internationalization.

The 2nd International Symposium on Micro & Nano Technology will be held in Taiwan in 2006. I expect that the next conference becomes the good opportunity to study Micro & Nano Technology in Asia like the interesting 1st symposium.

ISMNT-1 (1st International Symposium on Micro & Nano Technology)

Prof. Kazuyoshi Fushinobu

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An international symposium, ISMNT-1 (1st International Symposium on Micro & Nano Technology), has been organized in Honolulu, Hawaii, dated March 14 to 17, 2004. According to the symposium homepage, 154 technical papers have been submitted and accepted from 12 countries, and 8 keynote lectures have been provided. Four session rooms are prepared. After each keynote lecture that is presented at the beginning of either morning or afternoon session, the general sessions have been scheduled in parallel.

There are number of, so called, micro- or nano- related conferences organized within various frameworks, and this specific symposium can be characterized by two aspects that be made possible due to the enthusiastic effort by the Symposium Chair (Dr. Inoue, Komatsu Electronics Inc.) and Co-Chair (Prof. Ishizuka, Toyama Pref. Univ.): (1) Almost all the participants are from Japan, and some from other East Asian countries. (2) Relatively large number of people from industry. Majority of the attendees from Japan know each others very well, and we could have a very good opportunity in a friendly atmosphere.

Wide variety of topics are discussed in the symposium. The session titles include MEMS, Bubble, Materials processing, μTAS, Molecular dynamics, Thermoelectric cooling, Micro flow visualization, Microfluidics, Heat transfer, Biomedical, Thermal management of electronics, Biosensor. I am quite wondering whether there is any attendee who joined the discussions in all these areas, however, the annual Thermal Engineering Conference of JSME and the annual Heat Transfer Symposium of HTSJ also have this sort of wide spectrum of research topics, and this was an opportunity for me to realize the activity of the thermal engineering field in Japan.

Most of the administrative issues have been conducted by a convention company, and I did not have to do much as an organizing committee member. However, the effort provided by the Chairs, Mr. Onishi of Komatsu Ltd., Prof. Nakagawa of Toyama Pref. Univ., those who brought various equipment all the way to Hawaii and number of people who have committed to the symposium management must be appreciated.

Meeting Calendar

[2004], [2005], [2006]

- 2004 -

ICMF-2004, International Conference on Multiphase Flow
31 May - 3 June 2004, Yokohama, JAPAN

International Conference on Thermal Engineering Theory and Applications
31 May - 4 June 2004, Beirut, LEBANON

ITherm 2004: Ninth Intersociety Conference on Thermal and Thermo Mechanical Phenomena in Electronic Systems
1 - 4 June 2004, Las Vegas, Nevada, USA

2004 ASME Summer Annual Meeting
13 - 17 June 2004, La Jolla, California, USA

Second International Conference on Fuel Cell Science, Engineering and Technology
14 - 16 June 2004, Rochester, NY, USA

Second International Conference on Microchannels and Minichannels
17 - 19 June 2004, Rochester, NY, USA

RAD04, Fourth International Symposium on Radiative Transfer
20 - 25 June 2004, Istanbul, TURKEY

2004 ASME Heat Transfer/Fluids Engineering Summer Conference
11 - 15 July 2004, Charlotte, North Carolina, USA

Second International Symposium on Micro/Nano- scale Energy Conversion and Transport
11 - 17 July 2004, Seoul, S. KOREA

12th International Symposium on Applications of Laser Techniques to Fluid Mechanics
12 - 15 July 2004, Lisbon, PORTUGAL

2004 ASME Pressure Vessels and Piping Conference
25 - 29 July 2004, San Diego, California, USA

5th International ASME/JSME/KSME Bi-Annual Symposium on Computational Technology (CFD) for Fluid/Thermal/Chemical/Stressed Systems with Industrial Applications
25 - 29 July 2004, San Diego, California, USA

30th International Symposium on Combustion
25 - 30 July 2004, Chicago, Illinois, USA

The 7th Asian Thermophysical Properties Conference (ATPC2004)
23 - 28 August 2004, Hefei & Huangshan, Anhui, CHINA

World Renewable Energy Congress VIII & Expo
28 August - 3 September 2004, Denver, Colorado, USA

6th Gustav Lorentzen Natural Working Fluids Conference - Current Applications and Opportunities
29 August - 1 September 2004, Glasgow, UK

13th International Heat Pipe Conference
21 - 25 September 2004, Shanghai, CHINA

3rd International Symposium on Two-Phase Flow Modeling and Experimentation
22 - 24 September 2004, Pisa, ITALY

6th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, Operations and Safety
4 - 8 October 2004, Nara, JAPAN

International Conference on Energy, Environment & Technological Innovation (EETI2004)
4 - 7 October 2004, Rio de Janeiro, BRAZIL
Submission of Abstract : 15 May 2004

3rd International Heat Powered Cycles Conference
11 - 13 October 2004, Larnaca, CYPRUS

Transport Phenomena in Micro and Nanodevices
17 - 21 October 2004, Kona, Hawaii, USA
Submission of Abstract : 31 May 2004

ASME Internal Combustion Engine Division 2004 Fall Technical Conference
24 - 27 October 2004, Long Beach, California, USA
Submission of Abstract : 25 May 2004

AIChE 2004 Annual Meeting
7 - 12 November 2004, Austin, Texas, USA
Submission of Abstract : 12 May 2004

2004 ASME International Mechanical Engineering Congress and Exposition - IMECE
14 - 19 November 2004, Anaheim, CA, USA

International Forum on Heat Transfer (IFHT2004)
24 - 26 November 2004, Kyoto, Japan

International Mechanical Engineering Conference
5 - 8 December 2004, KUWAIT
Submission of Abstract : 1 May 2004

International Conference on Computational Methods
15 - 17 December 2004, SINGAPORE
Submission of Abstract : 31 May 2004

- 2005 -

The 6th KSME-JSME Thermal and Fluids Engineering Conference
20 - 23 March 2005, Jeju, Korea
Submission of Abstract : 31 May 2004

The Second Call for Papers

ASME Power Conference
5 - 7 April 2005, Chicago, Illinois, USA

Heat Transfer in Components and Systems for Sustainable Energy Technologies: Heat-SET 2005
5 - 7 April 2005, Grenoble, FRANCE
Submission of Abstract : 1 September 2004

ExHFT-6, 6th World Conference on Experimental Heat Transfer, Fluid Mechanics and Thermodynamics
17 - 21 April 2005, Matsushima, JAPAN
Submission of Abstract : 15 October 2004

Fourth International Conference on Computational Heat and Mass Transfer
17 - 20 May 2005, Paris-Cachan, FRANCE
Submission of Abstract : 30 September 2004

World Renewable Energy Congress - Innovation in Europe (Regional Meeting)
22 - 27 May 2005, Aberdeen, Scotland, UK
Submission of Abstract : 15 September 2004

Heat Exchanger Fouling and Cleaning - Challenges and Opportunities (ECI conference)
5 - 10 June 2005, Irsee, GERMANY

Heat and Mass Transfer in Spray Systems
5 - 10 June 2005, Antalya, TURKEY
Submission of Abstract : 15 November 2004

18th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems (ECOS 2005)
20 - 23 June 2005, Trondheim, NORWAY
Submission of Abstract : 15 October 2004

Computational Fluid Dynamics in Chemical Reaction Engineering IV (ECI conference)
26 June - 1 July 2005, Barga, ITALY

5th International Symposium on Multiphase Flow, Heat Mass Transfer and Energy Conversion
3 - 8 July 2005, Xi'an, CHINA

The Sixteenth International Symposium on Transport Phenomena (ISTP-16)
29 August - 1 September 2005, Prague, CZECH REPUBLIC
Submission of Abstract : 30 November 2004

ASME/ATI/UIT Symposium on Thermal Fluid Dynamics and Energy Engineering
18 - 22 September 2005, Rome, ITALY

Eleventh International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-11)
2 - 6 October 2005, Avignon, FRANCE
Submission of Abstract : 1 May 2004

2005 ASME International Mechanical Engineering Congress and Exposition - IMECE
13 - 18 November 2005, Orlando, Florida, USA

- 2006 -

7th ISHMT/ASME Heat and Mass Transfer Conference
1 - 4 January 2006, Guwahati, INDIA
Submission of Abstract : 30 December 2004

Heat and Mass Transfer in Biotechnology
June 2006, TURKEY (organized by ICMHT)

13th International Heat Transfer Conference
13 - 18 August 2006, Sydney, AUSTRALIA

World Renewable Energy Congress IX (WREC-2006)
26 August - 1 September 2006, Yokohama, JAPAN

Others

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