Development status of DME vehicle in Japan

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ISUZU ADVANCED ENGINEERING CENTER, LTD.
1. The latest technology in our clean diesel engine
Research Target* as the Future Diesel Engine

*This research project was conducted from 2004 to 2010.

Research Target (PPNLT)
- NOx : 0.4[g/kWh]
- PM : 0.01[g/kWh]
- Fuel Economy : 10% improvement

Emission regulations

Japan

- New Short Term / 2003-04
  - Steady State (D13 Mode)

- New Long Term / 2005
  - Transient Mode (JE05 Mode)

- Post New Long Term / 2009

Dual Mode Combustion System

- High BMEP for Fuel Economy
  - Conventional Combustion + After treatment Devices
  - PCI Combustion at low load condition.

Engine speed

PCI Combustion: Premixed Compression Ignition Combustion
Key Technologies to meet PPNLT regulation

1) Ultra High Pressure Injection

2) Variable Valve Actuation

3) Multi-stage Boosting

4) Massive EGR with Precision Control

5) Engine Control

6) DPF

7) SCR

8) HEV

Cam-less system

3-stage turbocharger

300MPa common rail fuel injection system

Low pressure EGR

Engine control algorithms

Improvement of conversion efficiency of aftertreatment devices at low temperature condition
Current Status of our Research Works

We have met our target. However, the cost of diesel engine will be increased to meet future regulations. Next our challenges are to reduce cost and fuel consumption.

![Diagram showing NOx-FC Trade-off with variables including Variable Valve Actuation, After treatment (DPF,SCR), Injection system, 3-stage Boosting + Massive EGR, Base Engine, and Target improvements.](image-url)
2. Next generation vehicles
Next Generation Vehicles

- LPG vehicle
- CNG vehicle (on sale)
- HEV (on sale)
- DME vehicle (Monitoring)
- Plug-in HEV (Monitoring)
- EV Bus (Developing)

http://www.isuzu.co.jp/world/technology/low/index.html
The use of hydrogen and battery are possible for passenger cars, but light oil and DME are the main fuel as for commercial vehicle.

The next generation battery (Forecast in 2030)
Comparison between CO₂, fuel consumption and exhaust emission of JE05 mode

- DME can reduce NOx with same thermal efficiency level for light oil.
- DME has good potential to be highly efficient and clean with cost effective.

New long term Engine
There is a limit for thermal efficiency improvement to realize the CO₂ reduction target in Japan. It is predicted that the shifts to new energy from about 2020 are indispensable.

DME vehicle is low cost because DPF and De-NOx catalyst are not necessary.

For further reduction of CO₂, replacing energy to bio-mass or electricity will be essential.
3. Development of DME Vehicle
Outline of our DME vehicle development

Ministry of Land, Infrastructure, Transport and Tourism project
“EFV”; Environmentally Friendly Vehicle

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2005</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Next-Generation EFV Development and Commercialization Project</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Public Road Test</td>
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<tr>
<td></td>
<td></td>
<td>Verification Road Test for Commercial freight</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Domestic DME Promotion Plant (80,000 tons/year in Nitgata, 2008)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Overseas Commercial Plant (Co-Production of DME and Methanol)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Overseas Commercial Plant (DME Single Production)</td>
<td></td>
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</tr>
</tbody>
</table>

Development of DME engine and trucks

Developed DME engines and DME vehicles in IAEC

DME 6HH1 engine

Medium-Duty DME City Bus

DME 4HL1 Engine

Medium-Duty 3.5 ton DME Crane Truck

Commercial Use

Medium-Duty 3.5 ton DME Truck (Niigata)

Medium-Duty 3.5 ton DME Truck (Chiba)

Light-Duty 2 ton DME Truck
DME injection system

Injector

Supply pump

DME spray

Comparison between DME & Diesel spray

Test Rig

Konno, SAE paper 2010-01-0880
Medium duty truck for commercial use

Two Medium duty DME trucks have developed and the operating-tests has conducted within EFV21 project since 2009. DME trucks were used by two trucking companies for actual transportation service in two areas of Japan.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th></th>
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<tbody>
<tr>
<td>GVW</td>
<td>7940kg/7930kg</td>
<td></td>
</tr>
<tr>
<td>Payload</td>
<td>3500kg</td>
<td></td>
</tr>
<tr>
<td>Fuel Tank</td>
<td>135L × 2</td>
<td></td>
</tr>
<tr>
<td>Displacement</td>
<td>5193cc</td>
<td></td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>17.5:1</td>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Engine</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge Type</td>
<td>VGS with Intercooler</td>
<td></td>
</tr>
<tr>
<td>EGR System</td>
<td>HPL-EGR</td>
<td></td>
</tr>
<tr>
<td>Fuel Injection System</td>
<td>Common Rail for DME</td>
<td></td>
</tr>
<tr>
<td>After Treatment Device</td>
<td>Only DOC</td>
<td></td>
</tr>
<tr>
<td>Exhaust Gas Regulation</td>
<td>Post New Long Term</td>
<td></td>
</tr>
</tbody>
</table>

Ref. : Hara, SAE paper 2011-01-1961
Demonstration area of medium duty trucks

- DME truck’s demonstration experiments have been conducted in the regions on the following map.

Running distance was approx. 250km/day

Running distance is approx. 200km/day

Ref. : Hara, SAE paper 2011-01-1961
Result of Kanto area truck

The truck test data at the end of March 2010 in Kanto area.

<table>
<thead>
<tr>
<th>Kanto Area</th>
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<tbody>
<tr>
<td>Start Date of Running</td>
</tr>
<tr>
<td>Days of Running</td>
</tr>
<tr>
<td>Kind of Course</td>
</tr>
<tr>
<td>Load Capacity</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Average Running Distance per Day</td>
</tr>
<tr>
<td>Total Running Distance</td>
</tr>
<tr>
<td>Total Fill Ration of Fuel</td>
</tr>
<tr>
<td>Fuel Consumption for DME</td>
</tr>
<tr>
<td>Fuel Consumption Converted into Diesel Oil</td>
</tr>
</tbody>
</table>

The truck in Kanto area mainly ran on urban road and highway.
Its fuel consumption rate was around 7.24km/L which is almost equal to the mileage standard level.
This truck was also used for Bio-DME demonstration at Yokohama.

Ref.: Hara, SAE paper 2011-01-1961
The truck test data at the end of March 2010 in Niigata area.

<table>
<thead>
<tr>
<th>State of Running Test</th>
<th>Niigata Area</th>
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</thead>
<tbody>
<tr>
<td>Start Date of Running</td>
<td>18 November 2009</td>
</tr>
<tr>
<td>Days of Running</td>
<td>310days</td>
</tr>
<tr>
<td>Kind of Course</td>
<td>Urban, Highway</td>
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<tr>
<td>Load Capacity</td>
<td>Outward: 1700kg (Average) Return: Empty</td>
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<tr>
<td>Average Running Distance per Day</td>
<td>200 km</td>
</tr>
<tr>
<td>Total Running Distance</td>
<td>62,000km</td>
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<tr>
<td>Total Fill Ration of Fuel</td>
<td>16.590L</td>
</tr>
<tr>
<td>Fuel Consumption for DME</td>
<td>3.76km/L</td>
</tr>
<tr>
<td>Fuel Consumption</td>
<td></td>
</tr>
<tr>
<td>Converted into Diesel Oil</td>
<td>7.0km/L</td>
</tr>
</tbody>
</table>

The truck in Niigata area has mainly run on urban road and highway in which it snows in winter.

Its fuel consumption rate was less than that in Kanto area because the rolling resistance of tires are higher (“winter tires”).

Ref.: Hara, SAE paper 2011-01-1961
4. Further Study for lower Emissions DME Vehicle
Further improvement of NOx and BSFC trade off

- In LPL-EGR system, the working gas at the turbine increased compared with that in HPL-EGR system, when EGR was used.
- Soot free feature of DME enables the LPL-EGR system to take EGR gas after the turbine outlet.

<HPL (High Pressure Loop) -EGR system>

<LPL (Low Pressure Loop) -EGR system>

Ref. : Hara, SAE paper 2011-01-1961
Comparison of EGR system at steady state operation

- The changing EGR system from “HPL” to “LPL” improved the NOx-BSFC trade-off.
- BSFC on the LPL-EGR system decreased by 6% in around 0.7g/kWh of NOx compared with that of the HPL-EGR system.

Subscript "DME" indicates BSFC for DME. Subscript "DO" indicates BSFC converted into Diesel Oil.

1600rpm, 150mm³/st (85% Load)  
Pinj=40MPa, VGS=60%

EGR rate reached 40% in the LPL-EGR system

6% BSFC improved

*BSFC : Brake Specific Fuel Consumption
Comparison of EGR system at transient operation (JE05 mode)

Hara et al. “ ” SAE paper 2011-01-
Thank you for your kind attention.