The Experimental Study of Fuel Economy & Emission Characteristics for the Heavy-Duty DME Bus

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University of Ulsan
CONTENTS

1. INTRODUCTION
2. OBJECTIVES
3. EXPERIMENTAL DEVICES
4. EXPERIMENTAL METHOD
5. RESULTS
6. CONCLUSIONS
CONTENTS

1. INTRODUCTION

2. OBJECTIVES

3. EXPERIMENTAL DEVICES

4. EXPERIMENTAL METHOD

5. RESULTS

6. CONCLUSIONS
INTRODUCTION

Why did the experiment for the Heavy-Duty DME Bus?

◆ Research Trends in the world

- Great interest on the DME bus *in Europe, US, Japan and the other countries.*

◆ Research Trends in Korea

- Korea Institute of Energy Research and some universities have been conducting initial & development researches of heavy-duty DME bus.
### Development of DME Vehicles

#### In Japan

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Displacement [cc]</th>
<th>Emission [g/kWh]</th>
<th>Project</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light-Duty Truck</td>
<td>3,600</td>
<td>D-13 Test NOx: 4.435 PM: 0.021</td>
<td>JEF</td>
<td>1995~2002</td>
</tr>
<tr>
<td>Light-Duty Truck</td>
<td>4,600</td>
<td>D-13 Test NOx: 2.83 PM: -</td>
<td>MLIT, NTSEL, NISSAN DIESEL</td>
<td>1998~2001</td>
</tr>
<tr>
<td>Heavy-Duty Bus</td>
<td>8,226</td>
<td>D-13 Test NOx: 2.17 PM: 0.026</td>
<td>MLIT, NTSEL, ISUZU</td>
<td>1998~2001</td>
</tr>
<tr>
<td>Heavy-Duty Bus (Hybrid)</td>
<td>7,961</td>
<td>D-13 Test NOx: 0.83 PM: 0.008</td>
<td>NEDO, JARI, HINO</td>
<td>1997~2003</td>
</tr>
<tr>
<td>Mild-Duty Bus</td>
<td>4,214</td>
<td>D-13 Test NOx: 3.71 PM: 0.020</td>
<td>JOGMEC, AIST, MITSUBISHI</td>
<td>2001~2002</td>
</tr>
<tr>
<td>Heavy-Duty Truck</td>
<td>6,925</td>
<td>JE-05 Test NOx: 0.5 PM: -</td>
<td>MLIT, NTSEL, NISSAN DIESEL</td>
<td>2002~2004</td>
</tr>
<tr>
<td>Light-Duty Truck</td>
<td>7,166</td>
<td>D-13 Test NOx: 2.479 PM: 0.0102</td>
<td>JOGMEC, AIST</td>
<td>2002~2003</td>
</tr>
</tbody>
</table>

(Source: 2007 Automotive Environmental Whitepaper, p 338)
The Road Test of DME Trucks

➢ In Japan

- General Driving Test
  Heavy Duty Truck

- Road Cleaning Work
  Mild Duty Truck

- Up-Slop Driving Test
  Mild Duty Truck

- Niigata Fuelling Station,
  Heavy Duty Truck

- High Speed Driving Test
  Light Duty Truck

- Kawasaki Fuelling Station,
  Mild Duty Truck
International Research Trends

The study for **thermodynamic properties** of Di-methyl ether

The study for **dynamics behavior** of DME vehicles

The study for **emission characteristics** of DME vehicles

Why did the experiment for the Heavy-Duty DME Bus?

- Research Trends in the world
  - Great interest on the DME bus *in Europe, US, Japan and the other countries.*

- Research Trends in the Korea
  - Korea Institute of Energy Research and some universities have been conducting initial & development researches of heavy-duty DME bus.
**Specification of Engine**

- **Schematic of DME engine developed by** *Korea institute of Energy Research*

<table>
<thead>
<tr>
<th></th>
<th>Base Diesel Engine</th>
<th>DME Engine</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model</strong></td>
<td>DE08Tis</td>
<td>DE08Tis</td>
</tr>
<tr>
<td><strong>No. of Cylinder</strong></td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td><strong>Bore × Stroke [mm]</strong></td>
<td>111 × 139</td>
<td>111 × 139</td>
</tr>
<tr>
<td><strong>Displacement [cc]</strong></td>
<td>8,071</td>
<td>8,071</td>
</tr>
<tr>
<td><strong>Compression ratio</strong></td>
<td>18.5 : 1</td>
<td>18.5 : 1</td>
</tr>
<tr>
<td><strong>Injection pump type</strong></td>
<td>in-line “P” type</td>
<td>Converted in-line “P” type</td>
</tr>
<tr>
<td><strong>Injection nozzle type</strong></td>
<td>Multi-hole type</td>
<td>Converted Multi-hole type</td>
</tr>
<tr>
<td><strong>After-treatment Systems (DOC, DPF)</strong></td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>
Performance Evaluation of Engine

**NOx, DME << Diesel**
- Diesel: higher NOx emissions.
- DME: lower NOx emissions.
- Hot EGR 20% and Cooled EGR 20% shown.

**CO, DME >> Diesel**
- Diesel: lower CO emissions.
- DME: higher CO emissions.

**THC, DME < Diesel**
- Diesel: higher THC emissions.
- DME: lower THC emissions.
- Hot EGR 20% and Cooled EGR 20% shown.

**Experiment Conditions**
- Constant Engine Speed Mode.
- Use diesel and DME as a fuel.
- Engine Dynamometer Load is 60%.
- Fuel injection timing is 3° BTDC.
- Conducted by Korea institute of Energy Research.
Performance Evaluation of Engine

Experiment Conditions:
- Constant Engine Speed Mode.
- Use diesel and DME as a fuel.
- Constant RPM condition: 1,800 rpm
- Fuel injection timing is 3° BTDC
- Conducted by Korea institute of Energy Research.
Domestic Research Trends

The study for the development of DME bus
- Youngdug Pyo, Ohseuk Kwon, Gangchul Kim, Seunghun Yu, Jungin Ryu and Youngjae Lee,
“Development of Medium-Duty DME Bus(1)” KSAE 30\textsuperscript{th} Anniversary Conference, KSAE08-S0071, pp.433~437, 2008

The study for engine performance of DME vehicles
- Sedoo Oh, Jungkwon Park, Hokil Lee, Geesoo Lee, Youngdug Pyo and Soojin Lee,

The study for emission characteristics of DME vehicles
- Youngdug Pyo, Youngjae Lee, Munheon Kim, “Improvement od Emission Performance in a 3.3 liter Direct Injection Diesel Engine by Using dimethyl Ether Fuel”
KSAE Conference, Vol. 15, No. 4, pp. 178~185, 2007
CONTENTS

1. INTRODUCTION

2. OBJECTIVES

3. EXPERIMENTAL DEVICES

4. EXPERIMENTAL METHOD

5. RESULTS

6. CONCLUSIONS
OBJECTIVES

- Compare the affects of Ultra-low Sulfur diesel and DME on DME bus.
- Conduct the experimental test for the heavy-duty DME bus in **JE-05 emission test mode** using the chassis dynamometer, exhaust gas analyzers and PM measurement system.

Obtain the following results:

- **Dynamics Behavior** in case of diesel and DME fuel through vehicle speed.
- **Emission Characteristics** such as THC, CO, CO₂, NOx and PM.
  (without after-treatment systems)
- **Fuel Economy** of heavy duty DME bus fuelled with diesel and DME.
Why use the DME as a fuel for the Heavy-Duty Bus?

It is easy to apply existing CI engine and can reduce the PM mainly

<table>
<thead>
<tr>
<th></th>
<th>DME</th>
<th>Diesel</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical structure</td>
<td>CH$_3$OCH$_3$</td>
<td>C$<em>n$H$</em>{1.8n}$</td>
<td>Oxygenated fuel (34.8 wt%)</td>
</tr>
<tr>
<td>Cetane number</td>
<td>&gt;&gt; 55</td>
<td>40~55</td>
<td>Compression ignition</td>
</tr>
<tr>
<td>Auto ignition temp.</td>
<td>235</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Low heating value</td>
<td>28.8</td>
<td>42.7</td>
<td>67% Energy density</td>
</tr>
<tr>
<td>Boiling point</td>
<td>-25.0</td>
<td>180/370</td>
<td>Fast evaporation</td>
</tr>
<tr>
<td>Latent heat</td>
<td>467.13</td>
<td>300</td>
<td>Low flame temp</td>
</tr>
<tr>
<td>Specific heat</td>
<td>0.667</td>
<td>0.831</td>
<td>Low flame temp</td>
</tr>
</tbody>
</table>
1. INTRODUCTION

2. OBJECTIVES

3. EXPERIMENTAL DEVICES

4. EXPERIMENTAL METHOD

5. RESULTS

6. CONCLUSIONS
## Specification of Heavy-Duty DME Bus

<table>
<thead>
<tr>
<th>Model</th>
<th>BM 090 Royal Midi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allowance Weight [kg]</td>
<td>8,000</td>
</tr>
<tr>
<td>Full Length [mm]</td>
<td>8,990</td>
</tr>
<tr>
<td>Full Width [mm]</td>
<td>2,490</td>
</tr>
<tr>
<td>Full Height [mm]</td>
<td>3,220</td>
</tr>
<tr>
<td>Wheel Base [mm]</td>
<td>4,200</td>
</tr>
<tr>
<td>The number of DME Fuel Tank</td>
<td>2</td>
</tr>
<tr>
<td>Capacity of DME Tank [L]</td>
<td>125</td>
</tr>
</tbody>
</table>
# EXPERIMENTAL DEVICES

## Chassis Dynamometer

<table>
<thead>
<tr>
<th>Measurement Targets</th>
<th>Model No.</th>
<th>Specification</th>
<th>Manufacturer</th>
</tr>
</thead>
</table>
| Fuel Economy & Emissions    | 2WD In-line 540 | - Motor type: AC IGBT Vector  
- Max. Power: 540 kW from 52.6 kph  
- Max. Tractive force: 36.985 N  
- Inertia Simulation range: 1000~40,000 kg  
- Roller Diameter: 1828.8 mm (72")  
- Max. Test Speed: 150 kph  
- Max. Permissible axle load: 25,000 kg  
- Vehicle Cooling Fan: 144,000 m³/h                                                                 | AVL          |
1. INTRODUCTION

2. OBJECTIVES

3. EXPERIMENTAL DEVICES

4. EXPERIMENTAL METHOD

5. RESULTS

6. CONCLUSIONS
Running Resistance Calculation

Running Resistance [kgf] = \( \mu_r W + \mu_a A \times (\text{Vehicle speed}^2 \text{[km/h]}^2) \)

\( \mu_r W = 0.005125 \times \text{Vehicle weight (half load)}[\text{kg}] + 17.601 \)

\( \mu_a A = 0.002990 \times (\text{full height} \times \text{width})^2[\text{m}^2] + 0.0008324 \)
Emission test mode

**JE-05 Exhaust Gas Test Mode**

- New transient driving mode for emission test of the heavy-duty vehicle
- Mode cycle time: 1830 sec (30 min 30 sec)
- Maximum vehicle speed during the JE-05 test mode: 87.6 km/h
CONTENTS

1. INTRODUCTION
2. OBJECTIVES
3. EXPERIMENTAL DEVICES
4. EXPERIMENTAL METHOD
5. RESULTS
6. CONCLUSIONS
RESULTS

[Graph showing results of exhaust gas tests, including NOx, CO₂, and vehicle speed over time for DME and Diesel fuels.]
RESULTS

Emissions in JE-05 Exhaust Gas Test

- **CO₂** [g/km]
  - DME: 802
  - Diesel: 832
  - ↓ 3.6%

- **NOx** [g/km]
  - DME: 3.48
  - Diesel: 3.84
  - ↓ 9.3%

- **PM** [g/km]
  - All diesel: 0.0648
  - Diesel: ↓ 95%
RESULTS

Emissions & Fuel Economy in JE-05 Exhaust Gas Test

- THC [g/km]:
  - Diesel: 1.91 (↓78%)
  - DME: 0.42

- CO [g/km]:
  - Diesel: 2.65 (↓27%)
  - DME: 3.66

- Fuel Economy [liter/km]:
  - Diesel: 2.94
  - DME: 3.15 (↓6.7%)

7th Asian DME Conference
November 16-18, 2011
Niigata Toki Messe Convention Center, Niigata, Japan
1. INTRODUCTION
2. OBJECTIVE
3. EXPERIMENTAL DEVICES
4. EXPERIMENTAL METHOD
5. RESULTS
6. CONCLUSIONS
We conducted experimental test for the heavy-duty DME bus in JE-05 emission test mode using the some devices such as chassis dynamometer, exhaust gas analyzers and PM measurement system.

Through this experiment, we obtained results as following:

1. In terms of maximum speed and acceleration of heavy duty DME bus, using DME was achieved equivalent dynamics behavior comparing with using diesel.

2. Using two fuel conditions, tendency of CO$_2$ & NOx emission showed similarity. In case of DME, However, due to chemical characteristic, THC & CO was relatively lower than diesel. Although DME bus was not equipped with DPF, PM was barely generated when DME was used as a fuel.

3. DME fuel economy calculated from lowering heating value was lower than diesel.
Thank You for Your Kind Attention.
APPENDIX
## Exhaust Gas Analyzer

<table>
<thead>
<tr>
<th>Measurement Targets</th>
<th>Analysis method</th>
<th>Model NO.</th>
<th>Specification</th>
<th>Manufacturer</th>
</tr>
</thead>
</table>
| CO, CO₂             | NDIR            | MEXA-7200D | 1) CO low Analyzer  
- Range : 0-50 / 5,000 ppm, standard  
or 0-100 / 5,000ppm, optional  
2) CO2 Analyzer - Range : 0-0.5 / 20%  
3) THC Analyzer - Range : 0-10 / 50,000 ppmC  
4) NOx / NO Analyzer  
- Range : 0-22 / 1,000ppm, standard  
or 0-10 / 2,000ppm, optional  
5) Methane Analyzer  
- Measuring Range : 9 ranges  
- Range : 0-5 / 2,500ppmC, standard  
or 0-10 / 2,500ppm, optional | HORIBA |
| THC                 | FID             |           |               |              |
| NOx                 | CLD             |           |               |              |
| Air Dilution Sampling |                | CVS-7400T | 1) Primary Tunnel - Diameter : 18inch  
- Effective length : 10D  
- Calculation of the orifice  
Peynolds number.  
Re ≥ 4,000  
2) 2nd Tunnel 2sets - For EU Regulation  
- For CFR-1065 | |
| Quantity of PM      | Using Dilution Tunnel  
(Single particle counting from 0 to 10,000 particles/cm²) | CPC-3790 | 1) Measured value : Number concentration of  
non-olatile particles  
2) Measuring range CPC :  
- 0~10,000 P/cm³ : single counting mode  
- 10,000 ~ 50,000 P/cm³ : photometric mode | TSI |
RESULTS

![Graph showing various emissions and vehicle speed over time]

- DME
- Diesel

JE-05 Exhaust Gas Test

The Number of PM [particle/cm³]

NOx [ppm]

CO₂ [ppm]

Vehicle Speed [km/h]

Time [sec]
DME와 같은 에테르계는 대부분 고무류(Elastomer)와 반응하므로 연료의 실링재에 대한 교체가 요구되기 때문에 [그림 4-2]와 같은 연료분사펌프의 실링 부위는 불소계 및 동 재질로 교체하였다. 또한 DME연료는 가압상태로 공급되므로 기존 디젤엔진의 연료 공급라인을 스테인리스 재질의 밸브 및 핀팅류로 교체하였으며, 연료 리턴부분 또한 DME가 가압상태로 연료통으로 순환되므로 공급측과 동일하게 교체하였다.

DME연료는 높은 압축성에서 기인하여 연료라인내의 압력저하가 발생되기 때문에 상기와 같이 인젝터 노즐경을 키우고 개변압력만을 낮추는 것만으로는 원하는 분사압력과 분사량을 확보할 수 없어 목표 출력을 얻을 수 없다. 따라서 참여기업인 주식회사 두원 정공의 지원을 받아서 [그림 4-4]와 같이 연료분사펌프의 플런저를 새로 가공하여 연료분사펌프의 유효행정을 증가시켜 용량을 증대시킴으로써 경유 사용시와 동등한 전부하 출력을 확보하였다.