Fuel Injection Equipments for DME Fueled Engines

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Outline of presentation

Aim: To review FIE in 2000s and improvement of the FIE performance

1. What is DME?
2. Review DME Development in 2000’s
3. DENSO’s Fuel Injection Equipment (FIE)
1. What is DME?
DME (Dimethylether)?

**Characteristics**
① Gaseous fuel easy to liquefy
② High cetan number suits for Diesel engine
③ Contain no sulphur → Creates no SOx
④ NOx is less than Diesel fuel
⑤ PM ≒ 0 (Oxygenated fuel & no C-C bond)
⑥ Can be manufactured various sources
   (NG, coal, biomass · · ·)

Promising alternative fuel for Diesel engine

*DENSO*
### DME Physical Properties and Concerns

<table>
<thead>
<tr>
<th>Property</th>
<th>DME</th>
<th>Diesel fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk modulus of elasticity</td>
<td>100MPa~1000MPa Depend on Temp. &amp; Pres.</td>
<td>1400MPa</td>
</tr>
<tr>
<td>Vapor pressure @25dC</td>
<td>610kPa(3MPa@90dC) Depend on Temp.</td>
<td>—</td>
</tr>
<tr>
<td>Density@20dC</td>
<td>667kg/m³</td>
<td>830kg/m³</td>
</tr>
<tr>
<td>Calorific value</td>
<td>28.8(MJ/kg)</td>
<td>42.7(MJ/kg)</td>
</tr>
<tr>
<td>Viscosity@25-80dC</td>
<td>0.25-0.15cSt</td>
<td>3cSt</td>
</tr>
<tr>
<td>Specific heat@80dC</td>
<td>2090J/kg/K</td>
<td>2247</td>
</tr>
<tr>
<td>Critical point</td>
<td>127dC, 5.3MPa</td>
<td>—</td>
</tr>
</tbody>
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**Concern: FIE Performance & dimension**

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**DENSO**
2. Review DME development in 2000s

   Review Papers of IDC ADC & SAE

Review points

(1) Target Fuel Pressure & Air Excess Ratio

(2) Emission performance:

   Type of FIE & after-treatment System
(1) Target fuel pressure & Air Excess Ratio

<table>
<thead>
<tr>
<th></th>
<th>Target fuel pressure</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISUZU</td>
<td>60MPa&lt;</td>
<td>BSFC and power</td>
</tr>
<tr>
<td>Nissan Diesel &amp; NTSEL(*)</td>
<td>40MPa 35MPa</td>
<td>Power vs. exhaust</td>
</tr>
<tr>
<td></td>
<td></td>
<td>temperature</td>
</tr>
<tr>
<td>Volvo</td>
<td>60MPa</td>
<td>-</td>
</tr>
<tr>
<td>AVL</td>
<td>80MPa</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Required air excess ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVL</td>
<td>Air Excess Ratio&gt;1.5 at full load</td>
</tr>
<tr>
<td></td>
<td>Air Excess Ratio &gt;5 at low load</td>
</tr>
<tr>
<td>NTSEL(*)</td>
<td>To get 80% NOx reduction</td>
</tr>
<tr>
<td></td>
<td>Air Excess Ratio &gt;1.7 at full load &amp; Intake O₂ % &lt; 16%</td>
</tr>
</tbody>
</table>

NTSEL(*) National Traffic Safety and Environment Laboratory

Considering NOx and PM emission, 40MPa might be sufficient. OEMs look for 80MPa. Trade-off of NOx vs BSFC & CO HC.

**DENSO**
## (2) Emission Performance

<table>
<thead>
<tr>
<th></th>
<th>FIE, After Treatment</th>
<th>Tail Pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ISUZU</strong></td>
<td>CR (Common Rail FIE), FP= 15 MPa (→60 MPa) DOC(?)</td>
<td>NOx=2.17g/kWh(→0.3g/kWh)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PM=0.03g/kWh</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(D13 mode→JE05 mode)</td>
</tr>
<tr>
<td>*<em>NSTEL(<em>1)</em></em></td>
<td>P-L-N (Pump Line Nozzle), FP=40 MPa, EGR + NSR(*2) + DOC</td>
<td>NOx=0.11g/kWh/h</td>
</tr>
<tr>
<td>Nissan Diesel</td>
<td></td>
<td>PM=0.001g/kWh (JE05)</td>
</tr>
<tr>
<td><strong>Hino</strong></td>
<td>CR, FP = 35 MPa, (→70 MPa) EGR+DOC</td>
<td>NOx=0.80g/kWh (D13)</td>
</tr>
<tr>
<td><strong>Volvo (IDC5)</strong></td>
<td>CR, FP=40 MPa→60 MPa, SCR?</td>
<td>NOx=1.66g/kWh</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PM=0 (EU5)</td>
</tr>
</tbody>
</table>

*1 NTSEL National Traffic Safety and Environment Laboratory

*2 NSR = NOx Storage Reduction Catalyst

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Summary of Review 2000s

1. Emission after treatment:
   - DPF is not required
   - NOx (and HC/CO) reduction strategy is based on each OEM
     EGR + Charging + DOC might be solution for PNLT
     EGR + Charging + NSR is main truck for PPNLT
   - No after treatment with EGR & TC
   - or with SCR for EU6
2. FIE: Performance and Type

Considering NOx and PM emission, 40MPa might be sufficient. OEMs look for 80MPa. Trade-off of NOx vs BSFC & CO.

Pump-Line-Nozzle System (40MPa)

Limitation: install dimension, delivery quantity, pressure, leakage & injection control. Retrofit P-L-N from diesel to DME has difficulty

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Common rail system (80MPa)

Reply to requested high pressure, lower leakage & precise control, but HP still has difficulty in install dimension and delivery quantity. Injectors have to be developed helping the high pressure pump.
3. Fuel injection Equipment
Fuel Injection System

Common Rail FIS

Common Rail & high pressure line

Fuel Tank

Leak line

High Pressure Supply Pump

Injector

Leak line

Nozzle Tip

Fuel spray and flame

Combustion chamber

Engine piston

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Engine Performance Improvement by Injection Pressure

DME: Soot=0, NOx=40% of Diesel

DME combustion has been improved under 1/3 injection pressure of Diesel

Fuel Efficiency & Power Improvement

DME

Higher pressure, efficiency
Pressure balanced
Hydraulic servo
Direct drive

Diesel

FIE improvement:
IDI→P-L-N→CR→Higher pressure

0 30 70 100 200 300
Injection Pressure [MPa]

DME creates better performance and lower exhaust emissions than Diesel engines under just one-thirds pressure of diesel.

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**High Pressure Pump Delivery Quantity for DME**

<table>
<thead>
<tr>
<th>Property</th>
<th>Diesel</th>
<th>DME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk modulus E [MPa] @70MPa,60°C</td>
<td>1600</td>
<td>800</td>
</tr>
<tr>
<td>Density ρ [kg/m^3]</td>
<td>831</td>
<td>667</td>
</tr>
<tr>
<td>Lower calorific value Qc [MJ/kg]</td>
<td>43.5</td>
<td>28.8</td>
</tr>
</tbody>
</table>

Pump pressure $P_k = E \frac{Q_k}{V_k}$

$P_k$: DME = Diesel/2

Heat value $Q_h = ρ \cdot Q_c \cdot Q_k$

$Q_k$: DME = 1.85 Diesel

DME pressure is one half of Diesel at same $Q_k$,
DME delivery 1.85 Diesel

For same $Q_h$

If DME Pressure

$= \text{Diesel}/3$

DME $Q_k \rightarrow 1.5 \text{ Diesel}$
Injector for DME

DME Injectors have to achieve
Higher injection rate at lower injection pressure than Diesel, because
high pressure pump limit of installing and delivery

DENSO developed and have been developing Injectors
1). Direct driven needle: 35MPa

2). Hydraulic servo: 70MPa

3). Pressure balanced: 70MPa, internal leak-less
Direct Driven Type Injector

Needle Valve is directly driven by solenoid

- Needle lift: 0.155mm
- Nozzle holes: φ 0.35 × 6

Maximum Operational Pressure: 35MPa

Injection Performance

- Drive current (A)
- Injection rate (mm³/st/ms)

Engine with this injector,
Power & torque: nearly equal to Diesel
BSFC, THC, CO: worse than Diesel
→ Shorten Injection period, higher pressure
Hydraulic Servo Type Injector

Needle Valve is hydraulic driven by pressure difference

Maximum Operational Pressure: 70MPa~

- Injection Performance
  \( P = 70 \text{MPa} \), \( Q = 260 \text{mm}^3/\text{st} \)

Engine with this injector,
Power & emission: nearly equal to Diesel BSFC a little worse than Diesel ➔ reduce Internal leakage
Conclusion

1. Review DME development in 2000s

1) Considering NOx and PM emission, 40MPa might be sufficient.

2) OEMs look for 60-80MPa to achieve further improvement of performance and emission.

3) Two ways to meet Emission regulation: one is without after treatment, the other with SCR

2. FIE for DME Fueled Engines

1) Common rail system can reply to requested higher pressure, lower leakage & control.

2) High pressure pump still has difficulty in install dimension and delivery quantity. →Need 1.5times Delivery at one thirds pressure of diesel 80MPa

3) Injectors have to be developed improving engine performance & helping the high pressure pump. →Pressure balanced type injector; Internal leakage=0, Operational pressure ~100MPa