Development of the partial flow diluter for the measurement of particle size distribution and the investigation of nuclei mode particle during the transient cycles

Sousuke Sasaki, Yoshio Tonegawa
Japan Automobile Research Institute
Objectives

- Optimize the measuring method of \textit{real world} PM size distribution from vehicles
- Evaluate vehicles for nuclei mode particles

\textbf{Real world : Short time after tailpipe emission} \\
Secondary aerosol formation is not included
Presentation overview

1. Partial flow diluter (PPFD-II)
2. Key factors for nucleation mode measurements
3. Investigation of nuclei mode during the transient cycles
4. Effects of after-treatments on nucleation mode particles
5. Conclusion
6. Further Study
PPFD-I
for investigation of dilution processes
1. Partial flow diluter (PPFD-II)
1. Partial flow diluter (PPFD-II)

**PPFD-II Controller**
- **Operation mode**
  - Const. Dilution ratio
  - Const. Split ratio
- **Suction flow rate**: 65 to 130 L/min
- **Dilution air**
  - Flow rate: 65 to 130 L/min
  - Temperature: 5 to 35°C
  - Relative humidity: 20 to 80%
- **Residence time**: 0.9, 1, 2, 3, 6 sec

**Instrument**
- SMPS (CPC3025)
- DMS

**Exhaust gas measurement system**
- 200 Hz sampling
Sampling probe of PPFD-II
1. Partial flow diluter (PPFD-II)
1. Partial flow diluter (PPFD-II)

Sampling probes

Additional residence tube; 6 sec
Set up of the PPFD-II for CD test

1. Partial flow diluter (PPFD-II)

Light duty diesel truck

Passenger car
Main Measuring Instrument

2 Key factors for nuclei mode measurements

– Scanning Mobility Particle Sizer
  • DMA (differential Mobility Analyzer + CPC (Condensation Particle Counter)
    – 90 sec/1 data scan) 10nm to 400nm
    – TSI Model 3081 + 3025

– DMS for transient mode analysis
Comparison of SMPS vs. DMS

2 Key factors for nuclei mode measurements

CAST generated particle: bimodal mode

17th August 2004 8th International ETH-Conference on
Combustion Generated Nanoparticles
# Vehicle and Engine Specifications

## 2 Key factors for nuclei mode measurements

<table>
<thead>
<tr>
<th>Symbol</th>
<th>G1</th>
<th>G2</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>E1</th>
<th>E2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle or Engine</strong></td>
<td><strong>Gasoline Passenger car</strong></td>
<td><strong>Gasoline Passenger car</strong></td>
<td><strong>Diesel Passenger car</strong></td>
<td><strong>Diesel Truck</strong></td>
<td><strong>Diesel Truck</strong></td>
<td><strong>Diesel Truck</strong></td>
<td><strong>Diesel Engine</strong></td>
<td><strong>Diesel Engine</strong></td>
</tr>
<tr>
<td><strong>Fuel S (ppm)</strong></td>
<td>11</td>
<td>10</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td><strong>Gross vehicle weight (kg)</strong></td>
<td>1765</td>
<td>1655</td>
<td>2125</td>
<td>4535</td>
<td>4555</td>
<td>5675</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total displacement (L)</strong></td>
<td>2.5</td>
<td>2.0</td>
<td>3.0</td>
<td>4.6</td>
<td>4.3</td>
<td>5.2</td>
<td>9.2</td>
<td>8.6</td>
</tr>
<tr>
<td><strong>Fuel system</strong></td>
<td>DI</td>
<td>MPI</td>
<td>DI-Common Rail</td>
<td>DI</td>
<td>DI</td>
<td>DI</td>
<td>DI-Common Rail</td>
<td>DI-Common Rail</td>
</tr>
<tr>
<td><strong>After treatment</strong></td>
<td>TWC</td>
<td>TWC</td>
<td>OxiCat</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>none</td>
</tr>
</tbody>
</table>

17th August 2004

8th International ETH-Conference on Combustion Generated Nanoparticles

JARI
Key Factors for Nuclei Mode Measurements

- Formation of Nuclei mode particle
  - Idling Heavy Duty Diesel Engine
    Light duty truck
  - Deceleration period without fuel injection
    Heavy Duty Diesel Engine
    Light duty truck
  - High temperature on Oxidation Catalyst
    Diesel passenger car with Oxi.Cat.
Humidity effects on nuclei mode
Oxi.Cat Passenger diesel at high load condition

2 Key factors for nuclei mode measurements

D1: Diesel Passenger Car with Oxi.Cat.
3400 rpm, 6% gradient
Fuel S : 28ppm
PPFD-II
DR:40
Dilution air: 20°C, 30-80%RH
SMPS
Dilution effects on nuclei mode
Oxi.Cat Passenger diesel at high load condition

2 Key factors for nuclei mode measurements

D1: Diesel Passenger Car with Oxi.Cat.
3400 rpm,
6% gradient
Fuel S: 28ppm
PPFD-II:
DR: 18 to 85
Dilution air:
20°C, 80%RH
DMS
Deceleration period without fuel injection
no effects of humidity

2 Key factors for nuclei mode measurements

![Graph showing average particle size distribution during negative driving force.]

- **D2**: Diesel Light duty truck JE05 mode
- **Fuel S**: 28ppm
- **PPFD-II**: DR:200
- **Dilution air**: 25°C, 20-80%RH
- **DMS**
Test Cycles

3 Investigation of nuclei mode during the transient cycle

CD34; Passenger Vehicle from 2008

JE05; HD from 2005

17th August 2004 8th International ETH-Conference on Combustion Generated Nanoparticles
Definition

3 Investigation of nuclei mode during the transient cycle

Total PM = \( \sum \frac{dN}{d\log Dp} \) / 16
- DMS 5nm to 1000nm

PM emission rate [N/sec]
= PM number concentration [N/cc] \( \times 10^6 \)
  \( \times \) exhaust flow rate [m\(^3\)/sec]
Example of DMS result

D2: Light Duty Diesel Truck, DR=200, Temp 25°C, 50%RH
3. Investigation of nuclei mode during the transient cycle
Averaged PM size distribution during transient mode

- **D2**: DI
- **D1**: Oxi.Cat.
- **G1**: SIDI
- **G2**: MPI

Mode: Transient
- **D2**: JE05
- **D1, G1, G2**: CD34
- **Fuel S**: 28ppm
- **PPFD-II**
- **DR**: 40
- **Dilution air**: 25°C, 50%RH
- **DMS**

17th August 2004

8th International ETH-Conference on Combustion Generated Nanoparticles
Effect of Oxidation Catalyst

4 Effects of after-treatments on nucleation mode particles

Averaged PM size distribution

- With Oxi.Cat.
- Without Oxi.Cat.

D2: Diesel truck
Mode: JE05
Fuel S: 28ppm
PPFD-II
DR: 200
Dilution air: 25°C, 50%RH
DMS
Effect of Oxidation Catalyst

4 Effects of after-treatments on nucleation mode particles
Effect of Oxidation Catalyst

4 Effects of after-treatments on nucleation mode particles

Averaged PM size distribution

D4: Diesel truck
Mode: JE05
Fuel S: 28ppm
PPFD-II
DR:200
Dilution air: 25°C, 50%RH
DMS

Mobility Diameter [nm]
Effects of After-Treatments on Nuclei Mode Particle OxiCat and DPF

Effects of after-treatments on nucleation mode particles

E2: Heavy Duty Diesel Engine Mode ;JE05 Fuel S : 28ppm PPFD-II DR:200 Dilution air: 25°C,50%RH DMS
Conclusion

- PPFD-II is developed.
- Higher dilution ratio and certain humidity is required to have stable result especially for nuclei mode.
- Nuclei mode particle can be reduced by the after-treatment such as oxidation catalyst.
- DPF is effective for reduction of both nuclei mode and accumulation mode particle.
Further Study

- Data base of other vehicles and engines
- Traceability for particle number measurements
- Background effects on nuclei mode
- Chemical analysis of nuclei mode particle
Acknowledgement

Thank you to Mr. Higuchi of HORIBA Ltd. for modifying the micro tunnel and JAMA working group on fine particle measurements for the collaboration.

Thank you for your kind attention