10th ETH-Conference on Combustion Generated Nanoparticles
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JCAP II Cross Check Tests on High-speed Particle Sizing Instruments

- JCAP Unregulated Material Working Group -
Tomoaki Ikeda
Yasunori Iwakiri

<Abstract>

The phase 2 of Japan Clean Air Program, called JCAP II, or a research program for the improvement in air quality in Japan, started in 2002. Unregulated Material Working Group, one of the working groups under JCAP II, carries out researches to investigate two key areas: 1) to clarify appropriate measuring method of fine particles and unregulated emissions through evaluation and comparison of various measuring methods, and 2) to show the direction for engine and fuel technologies aiming to achieve near zero emissions of fine particles and air toxics. In this poster presentation, we describe measurement results of particles emitted from a same source by using two types of high-speed particle size distribution analyzers (14 units including 6 Differential Mobility Spectrometers (DMS) and 8 Engine Exhaust Particle Sizers (EEPS) from 12 institutes), and the result of study on measurement accuracy. Principal results of the study were; 1) For difference between same types of analyzers, coefficient of variation (COV) of mode diameter and geometric mean diameter was 10% at maximum, while COV of particle number concentrations 20% at maximum, 2) Particle number concentrations and size distribution measured by both types of analyzers showed a certain correlation with those by Scanning Mobility Particle Sizer (SMPS), however, particle number concentrations detected by the two types of analyzers were higher than those by SMPS, and 3) Particle number concentrations detected by the two types of instruments vary by a factor of two at maximum, which indicates that a simple comparison is not applicable to measured data using different types of instruments.

JCAP II
JAPAN CLEAN AIR PROGRAM

For better air quality,
further challenges of automobile and fuel

JCAP II Cross Check Tests on High-speed Particle Sizing Instruments

Ikeda, T Iwakiri, Y

-JCAP Unregulated Material Working Group-

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10th ETH Conference
on Combustion Generated Nanoparticles, 2006

Background and Objectives of cross check test

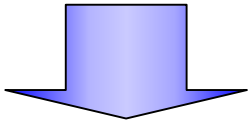
<Background>

During FY 02-04, JCAP II Unregulated Material WG studied a method for measuring ultrafine particles from motor vehicles, and established a method applicable to not only steady speed but transient driving conditions and enabling reproduction of ultrafine particles behavior at air emission in an almost complete manner (reported at the 2005 ETH Conference).

During FY 05, the WG has studied repeatability of the measurement method and understanding of instrumental error of High speed particle sizing instruments to confirm accuracy of the measurement method established.

<Objectives>

Simultaneous measurement of particle size distribution of ultrafine particles emitted from a single particle source using High speed particle sizing instruments of different types, and comparison in terms of particle size distribution, mode diameter and particle number concentrations



Define instrumental error for each type of instruments and difference between the instrument types

Participants and Apparatus

< Participants >

Number of participating institutes :12

< Apparatus >

DMS		EEPS	
Identification Code	Previous Maintenance	Identification Code	Previous Maintenance
AD	Before 7 month	AE	Before 6 month
BD	Before 12 month	BE	Before 5 month
CD	Before 14 month	CE	Before 5 month
DD	Before 2 month	DE	Before 6 month
ED	Before 7 month	EE	Before 6 month
FD	Before 6 month	FE	Before 6 month
		GE	Before 6 month
		HE	Before 6 month

DMS : 6 EEPS : 8 and SMPS : 1

Ultrafine particle source

- Diesel LD truck

Model Year	2002 / 03
Correspondence emission regulation year	1998
Engine Type	Water Cooling L4
Compression Ratio	18.5
Displacement	4325 cc
Max. Power	90 / 3100 kw/rpm
Max. Torque	294 / 1500 Nm/rpm
Fuel Injection	DI
Transmission Type	5 MT
Aspiration	NA
Intercooler	Non
EGR	Non

- CAST (Combustion Aerosol Standard, Matter Engineering AG)

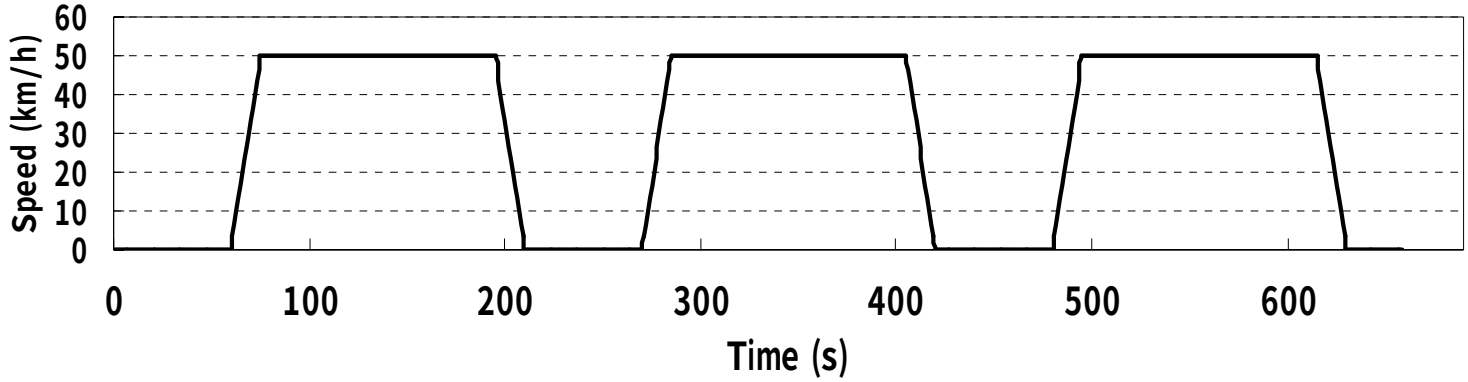
Test cycle

Test Condition	Test Time (sec)	Note
zero	300	Ambient air filtered HEPA filter
Dilution Tunnel BG	600	Dilution Tunnel Air
50km/h-4th High Concentration	600	All exhaust gas is induced to dilution tunnel
50km/h-4th Low Concentration	600	3/5 of exhaust gas is induced to dilution tunnel
CAST-Bimodal Low Concentration	600	Particle generated by CAST is diluted with 5m3/min
CAST-Bimodal High Concentration	600	Particle generated by CAST is diluted with 2m3/min
Trapezoidal profile mode (Top Gear: 3rd)	690	
Trapezoidal profile mode (Top Gear: 4th)	690	
JE05 mode (Japan engine Test mode 2005)	1830	

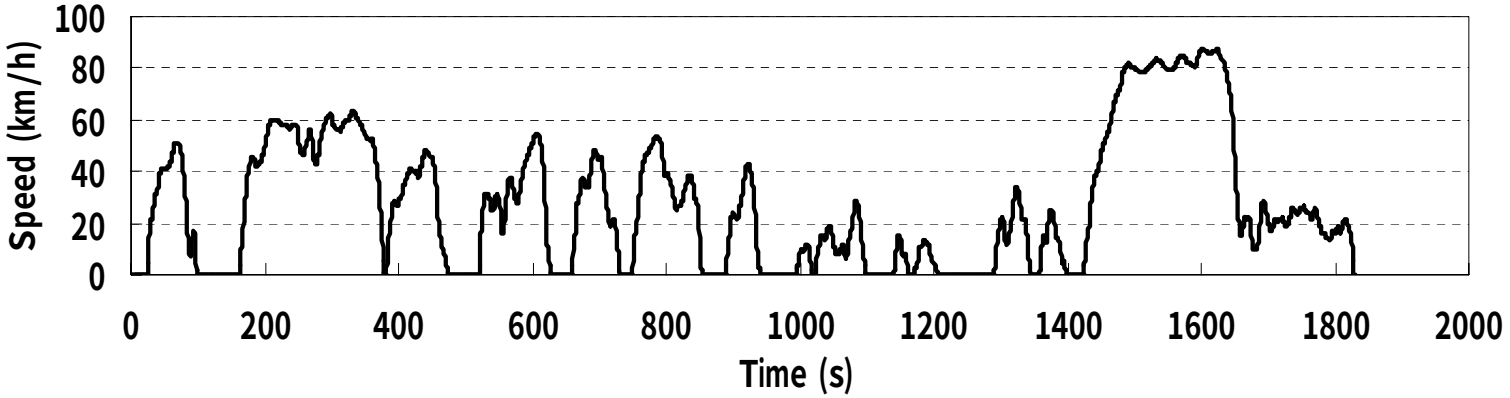
(Note) The test cycle was repeated for three days.

Test mode

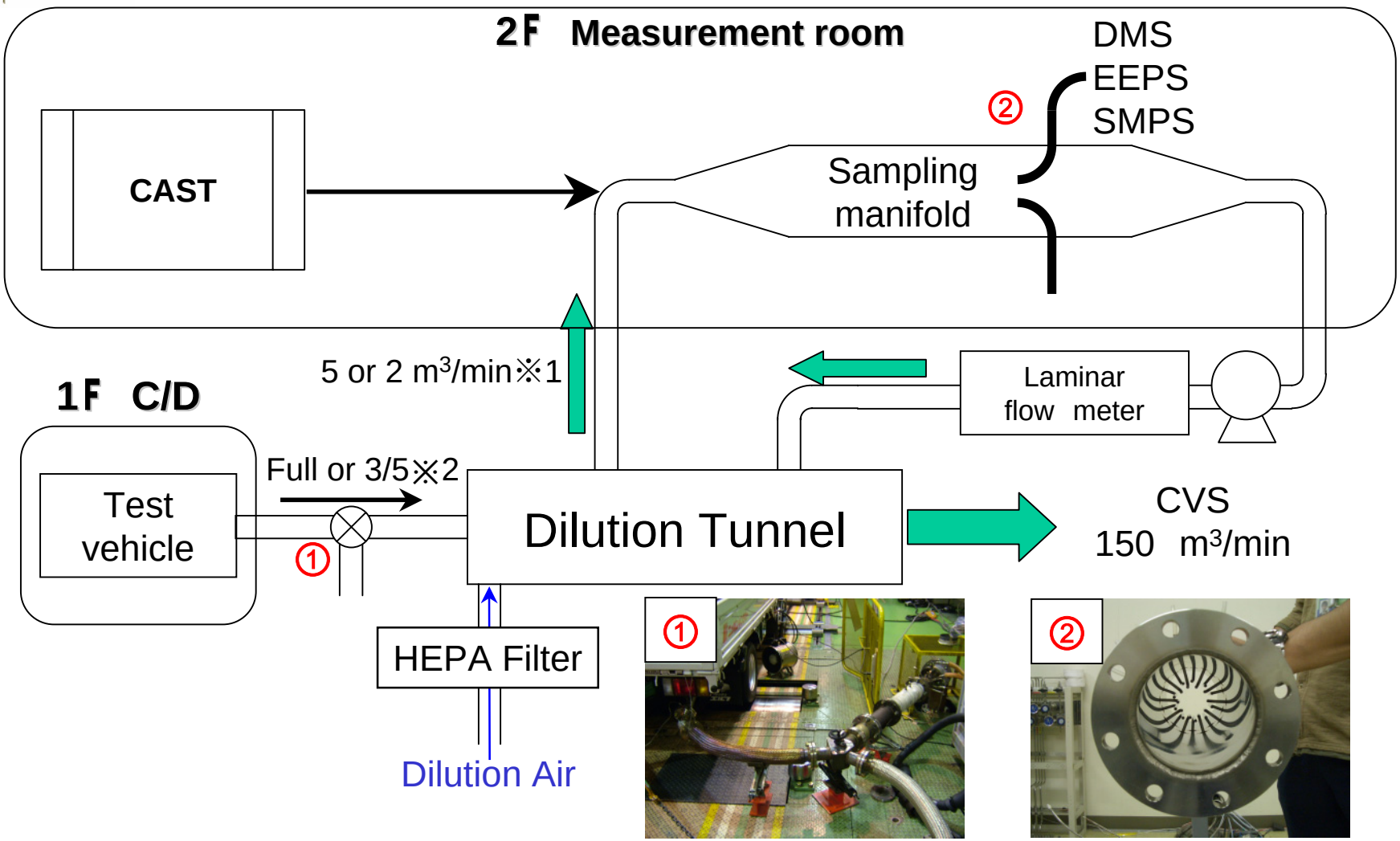
Trapezoidal profile mode



JE05 (Japan engine Test mode 2005)



Scheme of test facility



※1 5m³/min; Diluted vehicle emission and Dilution Air@CAST(Low concentration conditions)
2m³/min; Dilution Air@CAST(High concentration conditions)
※2 Full; High, Trapezoidal profile mode and JE05 mode, 3/5; Low concentration conditions

List of data

Day	DMS					
	AD	BD	CD	DD	ED	FD
1	○	○	○	×	○	○
2	○	○	○	×	○	○
3	○	○	○	○	×	○

Day	EEPS							
	AE	BE	CE	DE	EE	FE	GE	HE
1	○	○	○	○	○	×	○	○
2	○	○	○	○	○	×	○	○
3	○	○	○	○	○	×	○	○

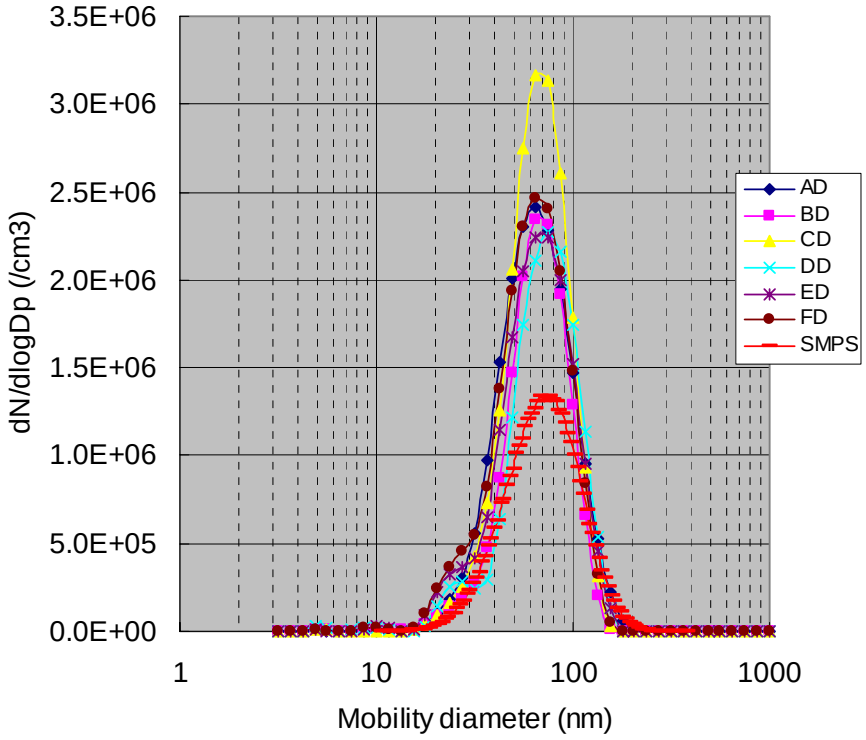
Day	SMPS
1	○
2	○
3	○

- Part of data of DD and ED were discarded because of instrument condition (X in the list).
- All data of EF were discarded because of instrument failure.

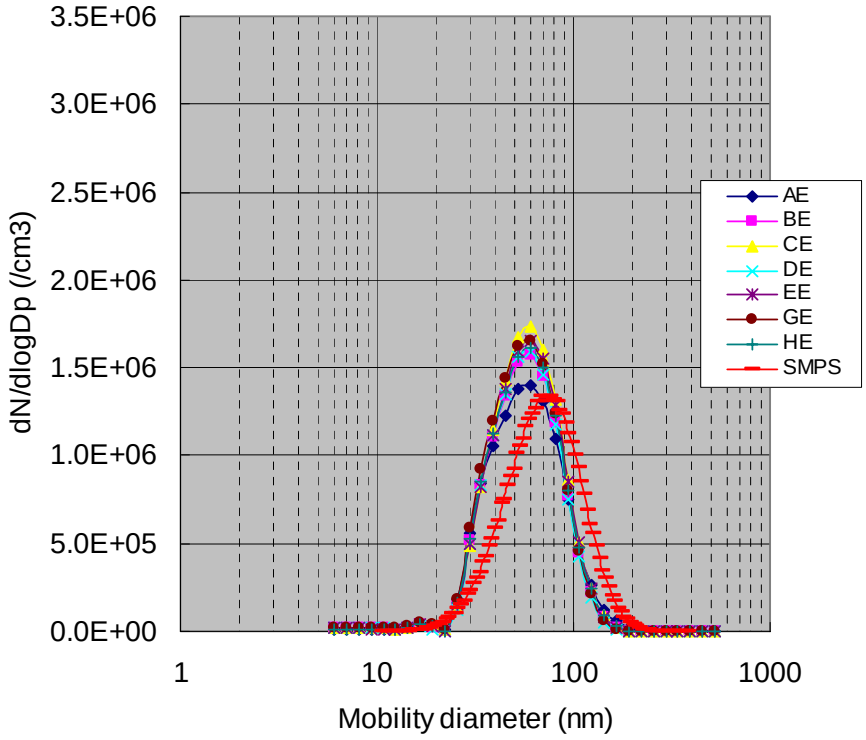
50km/hr, High concentration conditions

Comparison of Particle number size distributions

< DMS >



< EEPS >



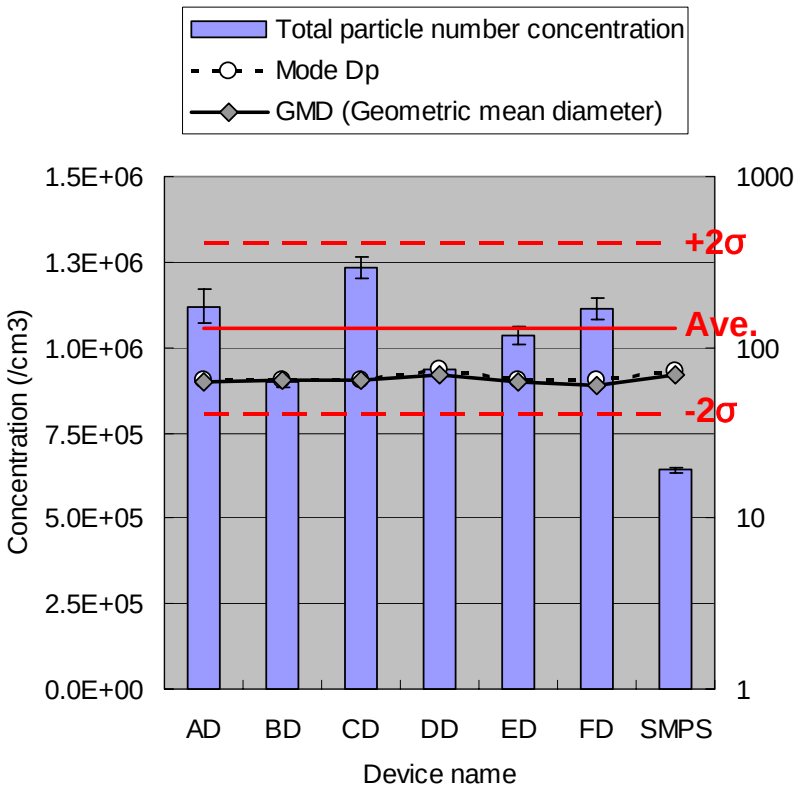
- Almost similar particle number size distribution profiles are observed for instruments of same type.
- For both types, mode diameter tends to be smaller than that for SMPS.
- Maintenance is required on Instrument CD (DMS).
- Under low concentration conditions, variation increases, but tendency is almost same.

(Note) Measuring frequency at 1 Hz, data plotted are averages of measured data over 600 sec.,
For SMPS data, same data are plotted in the above graphs.

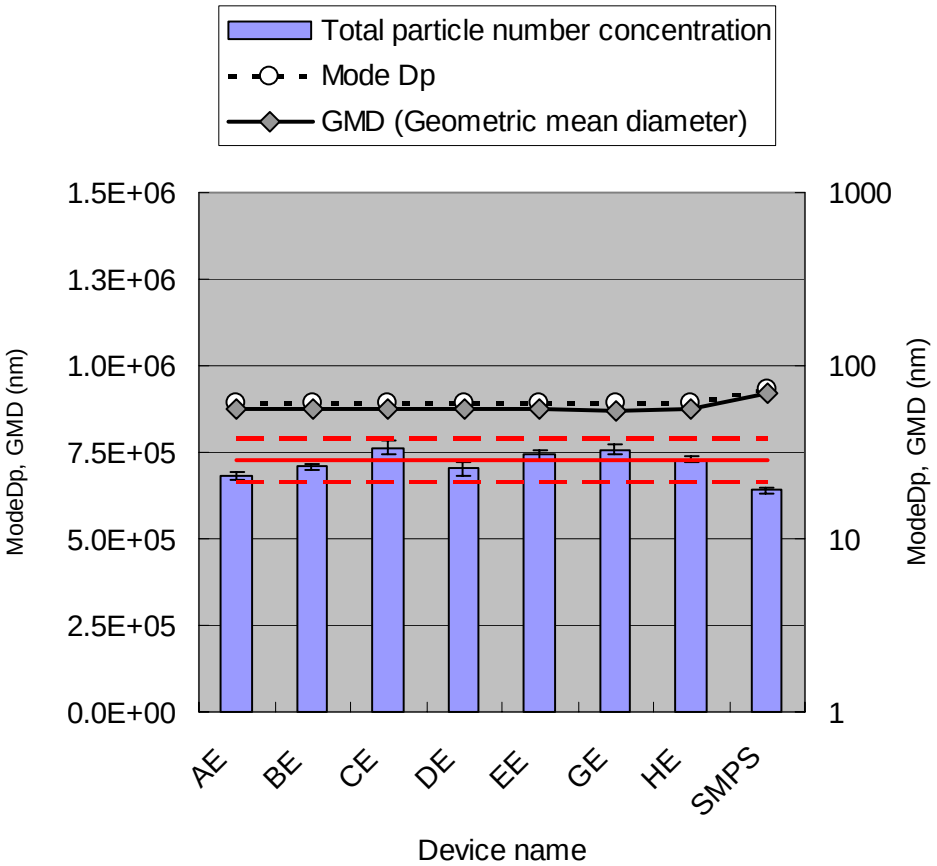
50km/hr, High concentration conditions

Comparison of Total particle number concentrations, Mode diameter and Geometric mean diameter

< DMS >



< EEPS >



——— : Average of Total particle number concentration(All of device)

– – – – : 2σ of Total particle number concentration(All of device)

(Note) Measuring frequency at 1 Hz, data plotted are averages of measured data over 600 sec.

Coefficient of variation(COV)@50km/hr

<High concentration conditions>

	DMS	EEPS
Total prticle number concentration	12%	4%
Mode diameter	6%	0%
Geometric mean diameter	4%	1%

<Low concentration conditions>

	DMS	EEPS
Total prticle number concentration	18%	3%
Mode diameter	6%	0%
Geometric mean diameter	4%	1%

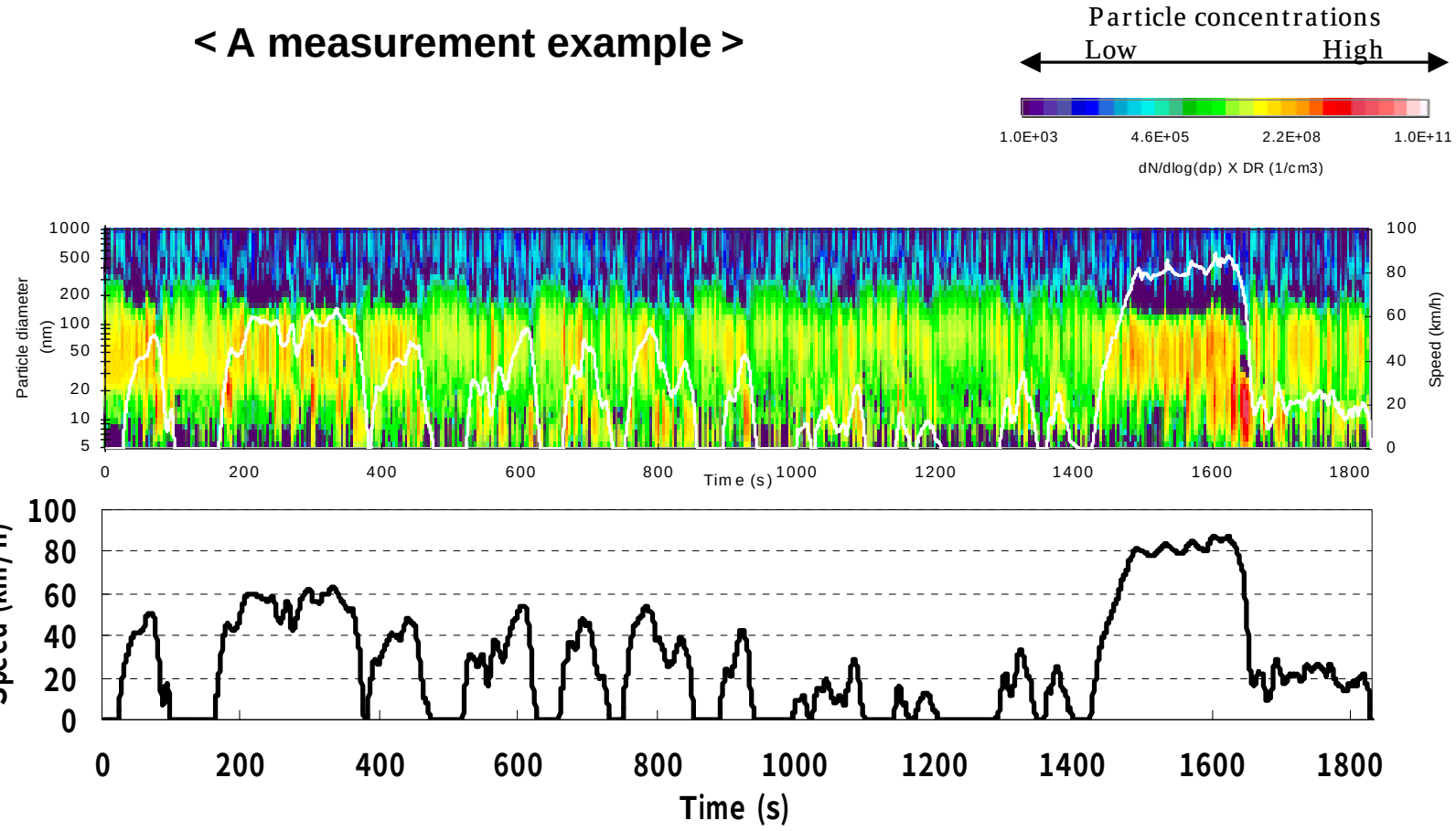
(Note) Each COV is calculated with the averages of each instrument for three days

JE05 mode (Japan engine test mode 2005)

Difficulty exists in the analysis of transient mode

⇒ Comparison with average of JE05 mode data and analysis of measurement results in trapezoidal profile mode

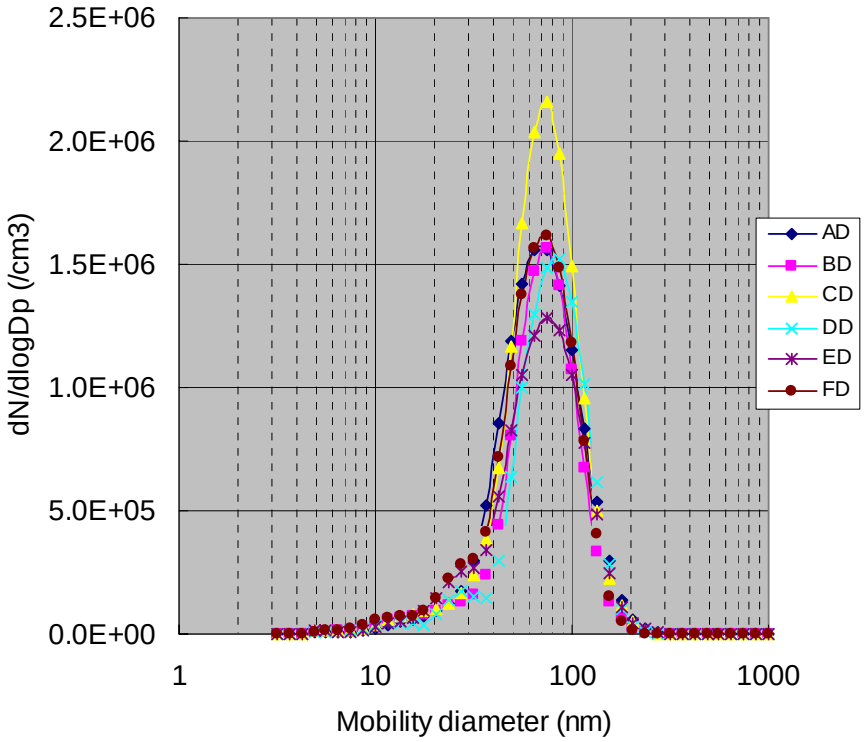
< A measurement example >



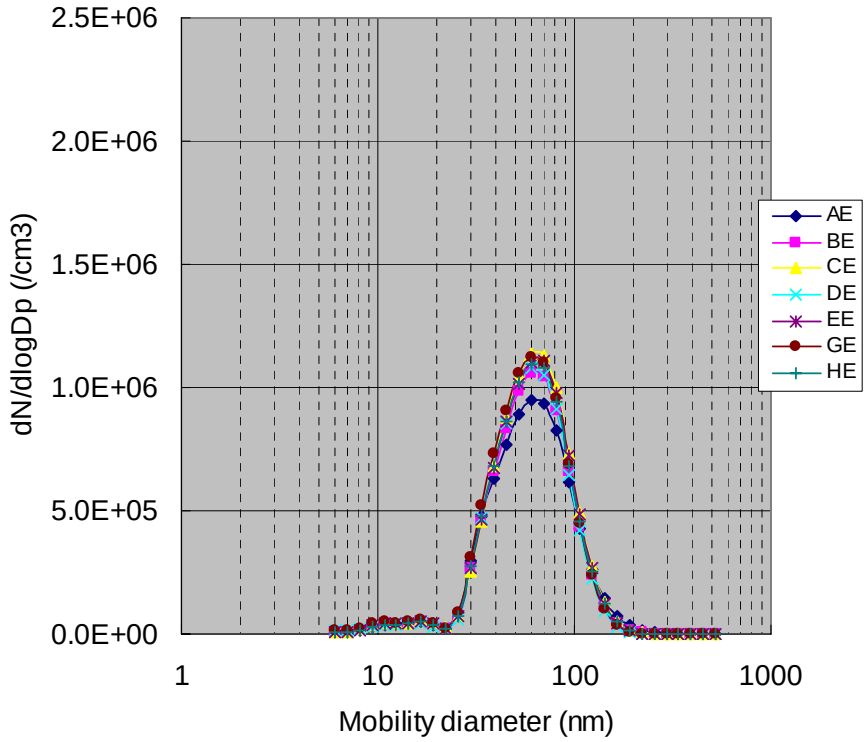
JE05 mode (Japan engine test mode 2005)

Comparison of Particle number size distributions

< DMS >



< EEPS >



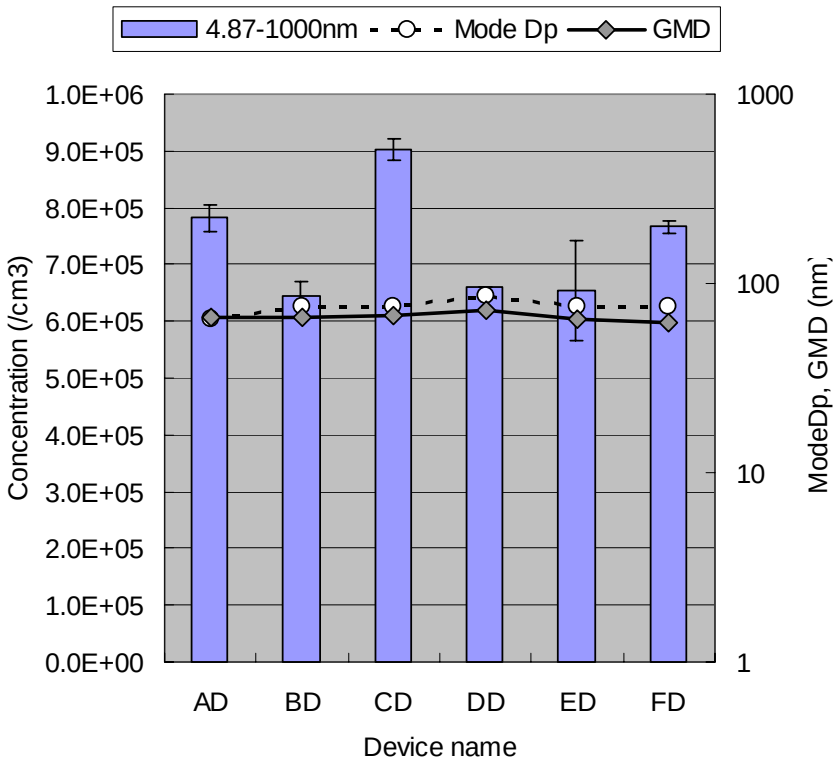
- For DMS, almost similar particle number size distribution profiles are observed except for Instruments CD.
- For EEPS, particle number size distribution profiles overlap virtually completely .

(Note) Measuring frequency at 1 Hz, data plotted are averages of measured data over 1830 sec.

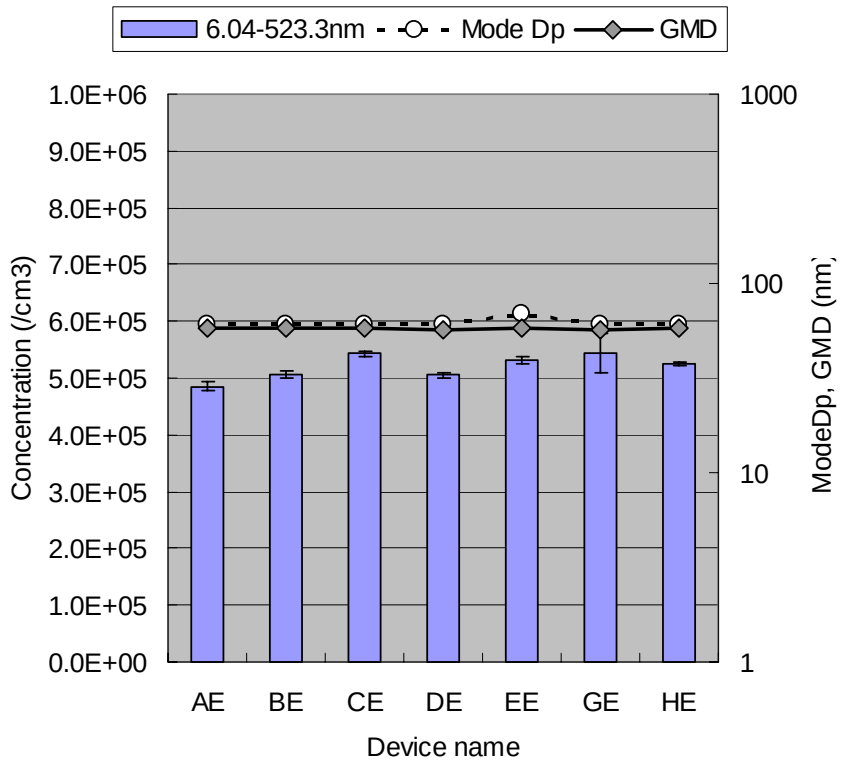
JE05 mode (Japan engine test mode 2005)

Comparison of Total particle number concentrations, Mode diameter and Geometric mean diameter

< DMS >



< EEPS >



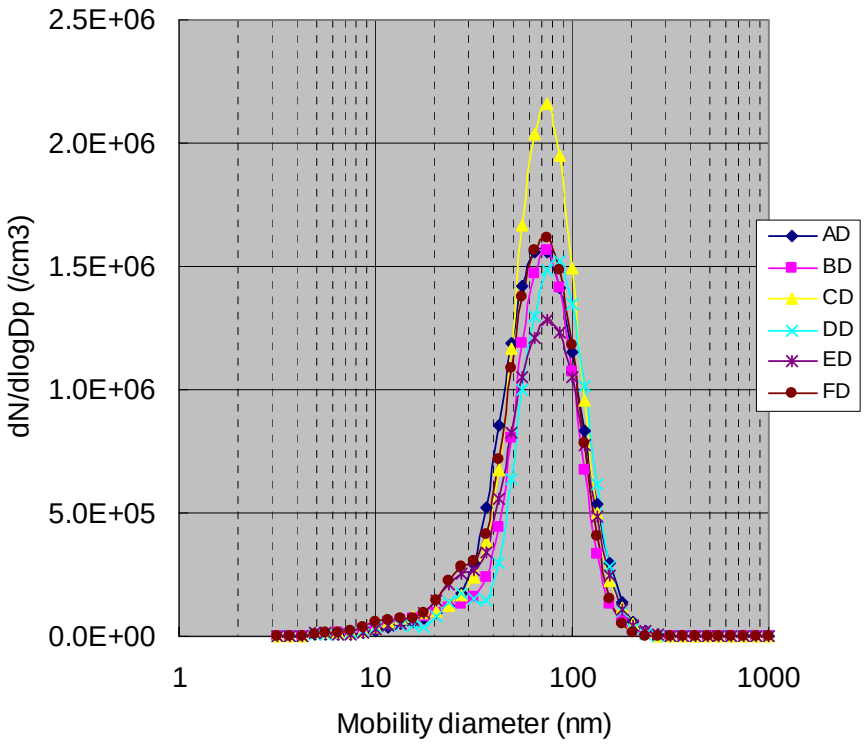
- Average total particle number concentrations levels are almost same for instruments of same type. DMS tends to vary greatly in the three parameters in comparison with EEPS.
- Mode diameter for EEPS tends to be smaller than that for DMS.

(Note) Measuring frequency at 1 Hz, data plotted are averages of measured data over 1830 sec.

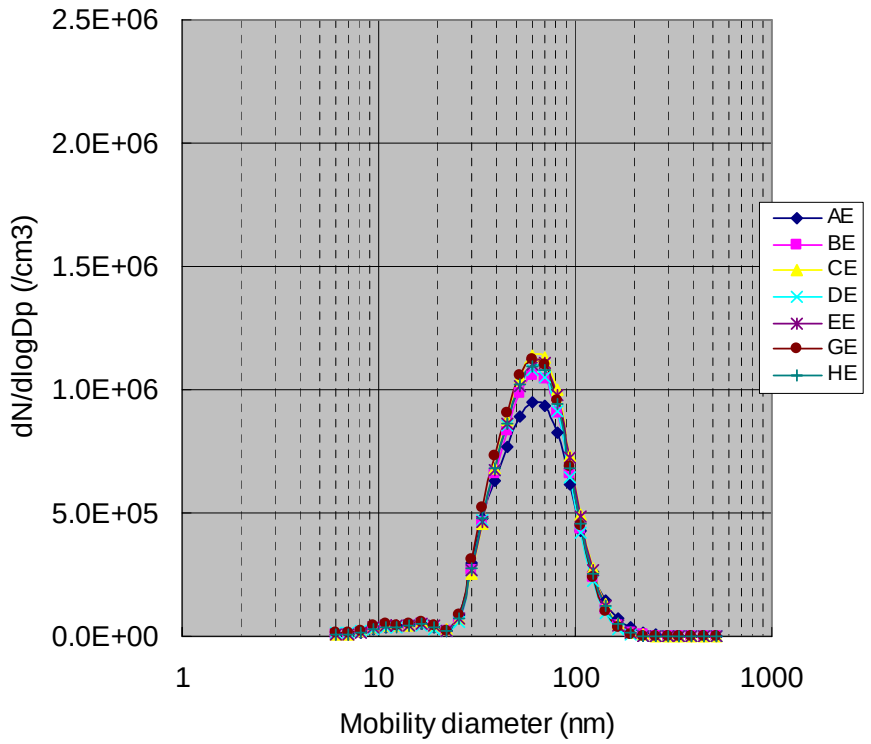
Trapezoidal profile mode (Top Gear: 4th)

Comparison of Particle number size distributions

< DMS >



< EEPS >



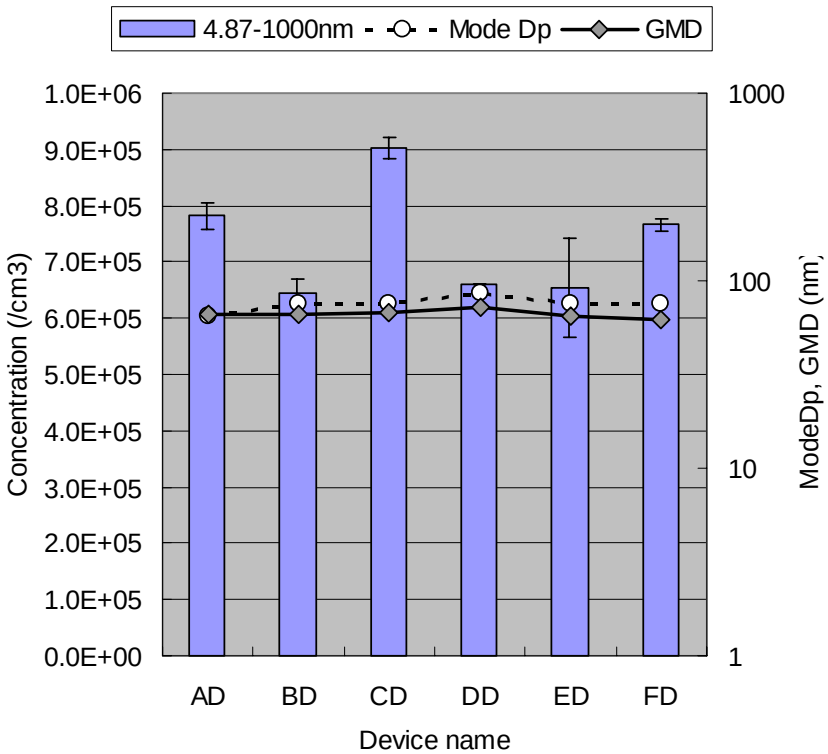
- For DMS, almost similar particle number size distribution profiles are observed except for Instruments CD. For EEPS, particle number size distributions overlap virtually completely.
- Particle number size distribution profiles at 3rd gear also show a similar tendency.

(Note) Measuring frequency at 1 Hz, data plotted are averages of measured data over 690 sec.

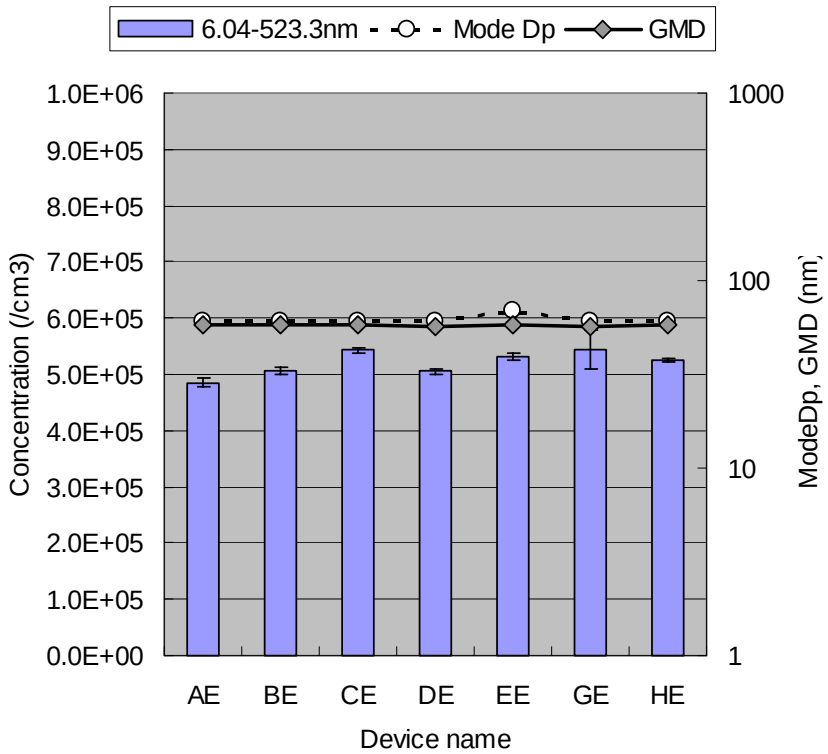
Trapezoidal profile mode (Top Gear: 4th)

Comparison of Total particle number concentrations, Mode diameter and Geometric mean diameter

< DMS >



< EEPS >



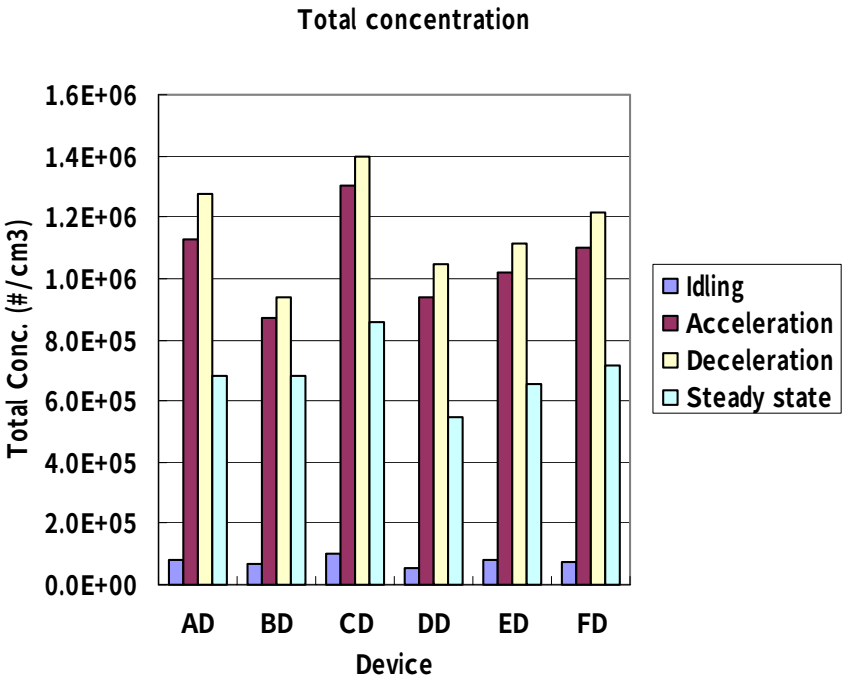
- Average total particle number concentrations levels are almost same for instruments of same type. DMS tends to vary greatly in the three parameters in comparison with EEPS.
- Geometric mean diameter for EEPS is smaller than that for DMS.

(Note) Measuring frequency at 1 Hz, data plotted are averages of measured data over 690 sec.

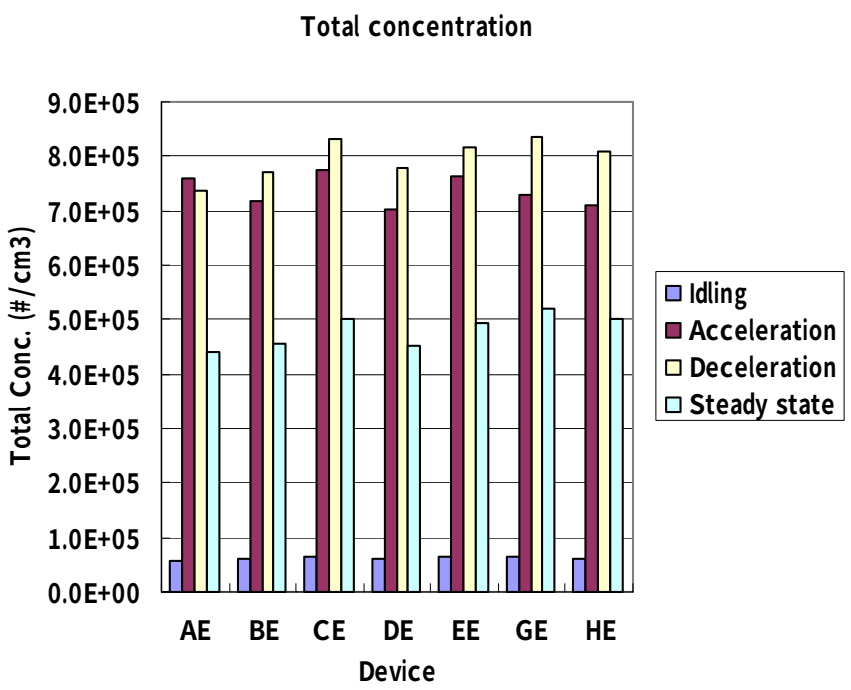
Trapezoidal profile mode (Top Gear: 4th)

Comparison of Particle number concentrations on Trapezoidal profile mode divided into four parts: idling, acceleration, deceleration and steady state driving

< DMS >



< EEPS >



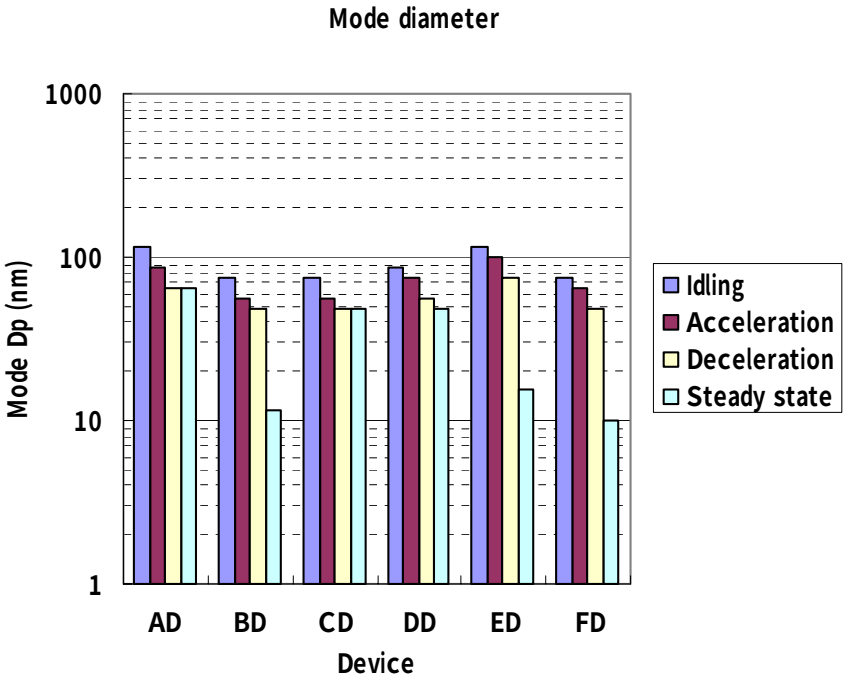
- Average total particle number concentrations levels are almost same in each driving conditions for instruments of same type.
  DMS tends to vary widely in comparison with EEPS.

(Note) Measuring frequency at 1 Hz, data plotted are averages of measured data over 690 sec.

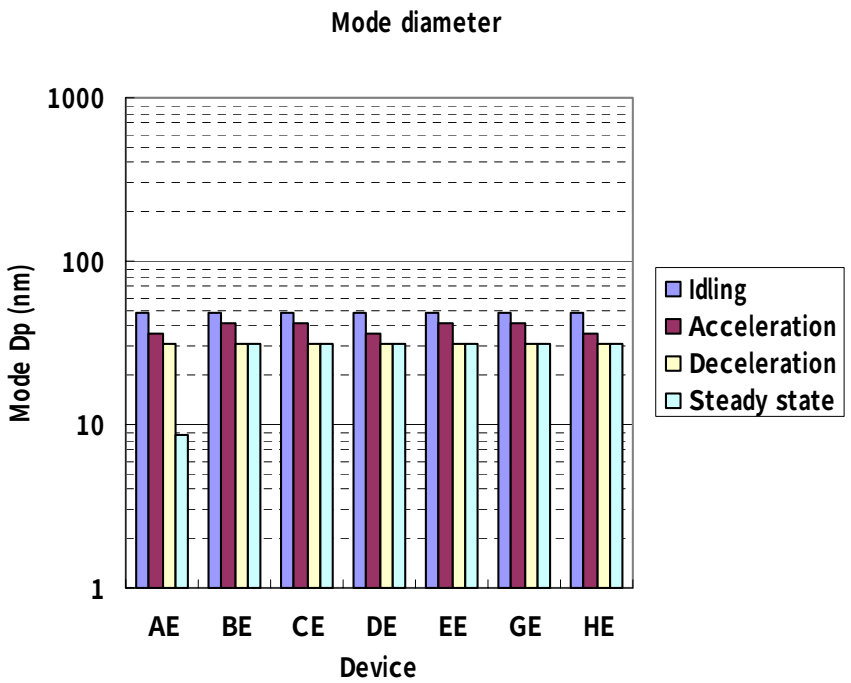
Trapezoidal profile mode (Top Gear: 4th)

Comparison of Particle number concentrations on Trapezoidal profile mode divided into four parts: idling, acceleration, deceleration and steady state driving

< DMS >



< EEPS >



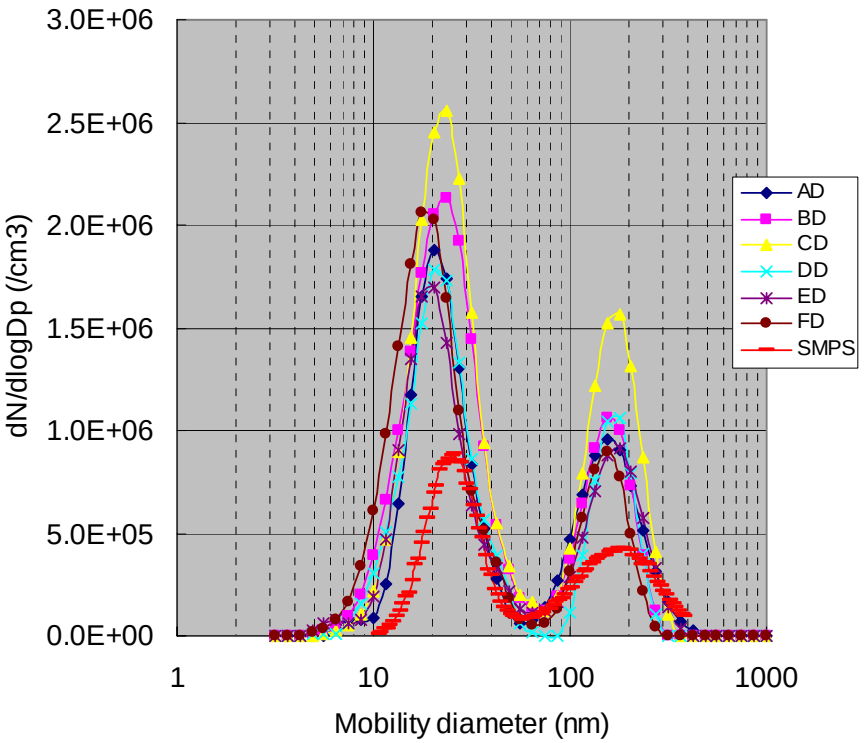
- Mean mode diameters in each driving conditions are almost same for instruments of same type. EEPS tends to be smaller in mode diameter in comparison with DMS.

(Note) Measuring frequency at 1 Hz, data plotted are averages of measured data over 690 sec.

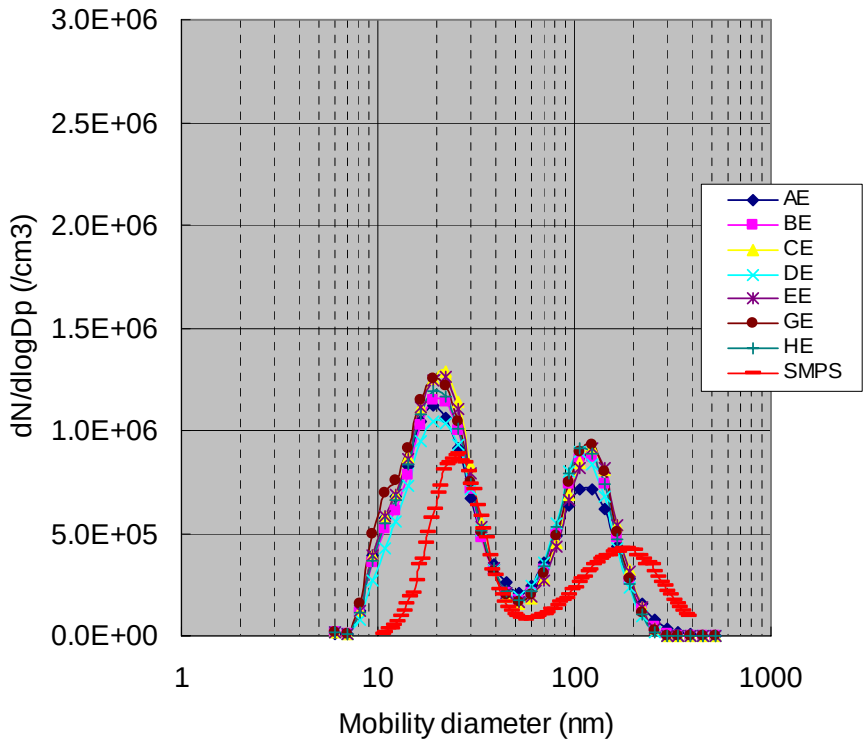
CAST (Bimodal, High concentration conditions)

Comparison of Particle number size distributions

< DMS >



< EEPS >



-For both instrument types, particle number size distributions are similar to SMPS, while mode diameter varies from that for SMPS as in the case of emission data from chassis dynamometer testing.
- Under low concentration conditions, almost same tendencies are observed.

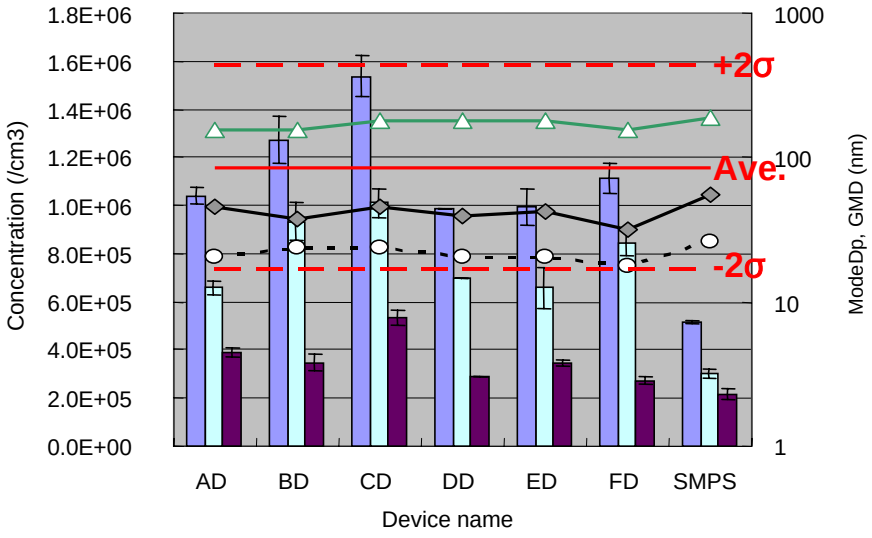
(Note) Measuring frequency at 1 Hz, data plotted are averages of measured data over 600 sec.

CAST (Bimodal, High concentration conditions)

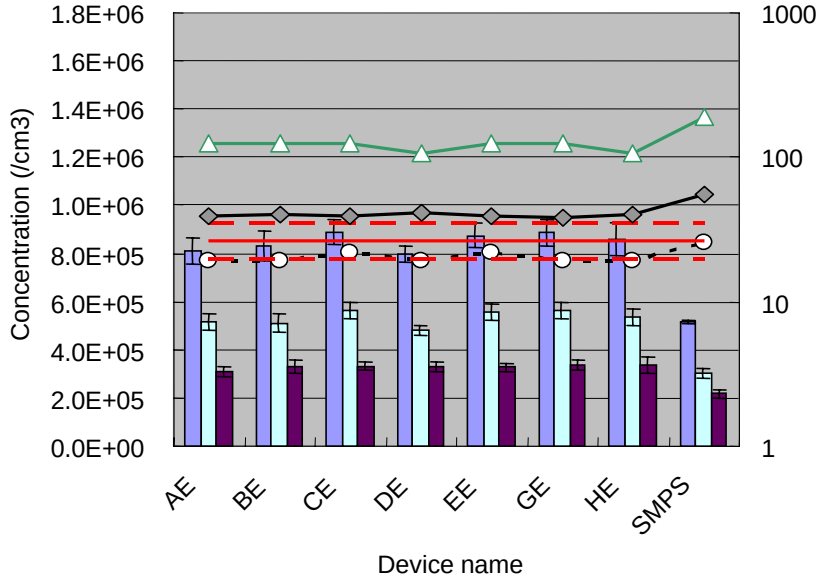
Comparison of Total particle number concentrations, Mode diameter and Geometric mean diameter

Total particle number concentrations
Summarized particle number concentrations of smaller diameter peak on bimodal number size distribution
Summarized particle number concentrations of larger diameter peak on bimodal number size distribution
Particle mode diameter of smaller diameter peak on bimodal number size distribution
Particle mode diameter of larger diameter peak on bimodal number size distribution
GMD (Geometric mean diameter)

< DMS >



< EEPS >



——— : Average of Total particle number concentration(All of device)

– – – - : 2σ of Total particle number concentration(All of device)

Coefficient of variation(COV) @CAST (Bimodal)

<High concentration conditions>

		DMS	EEPS
Total prticle number concentration	TOTAL	18%	4%
	Bimodal smaller diameter peak	19%	6%
	Bimodal larger diameter peak	26%	3%
Mode diameter	TOTAL	11%	7%
	Bimodal smaller diameter peak	11%	7%
	Bimodal larger diameter peak	8%	7%
Geometric mean diameter	TOTAL	13%	3%
	Bimodal smaller diameter peak	—	—
	Bimodal larger diameter peak	—	—

<Low concentration conditions>

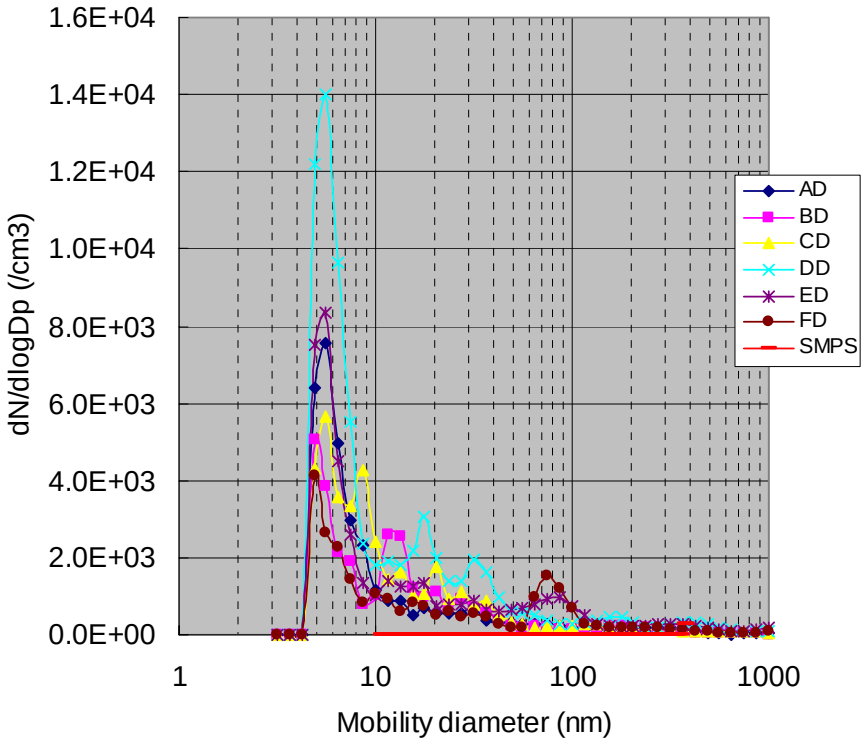
		DMS	EEPS
Total prticle number concentration	TOTAL	19%	4%
	Bimodal smaller diameter peak	19%	6%
	Bimodal larger diameter peak	26%	3%
Mode diameter	TOTAL	8%	8%
	Bimodal smaller diameter peak	8%	8%
	Bimodal larger diameter peak	8%	8%
Geometric mean diameter	TOTAL	13%	2%
	Bimodal smaller diameter peak	—	—
	Bimodal larger diameter peak	—	—

(Note) Each COV is calculated with the averages of each instrument for three days

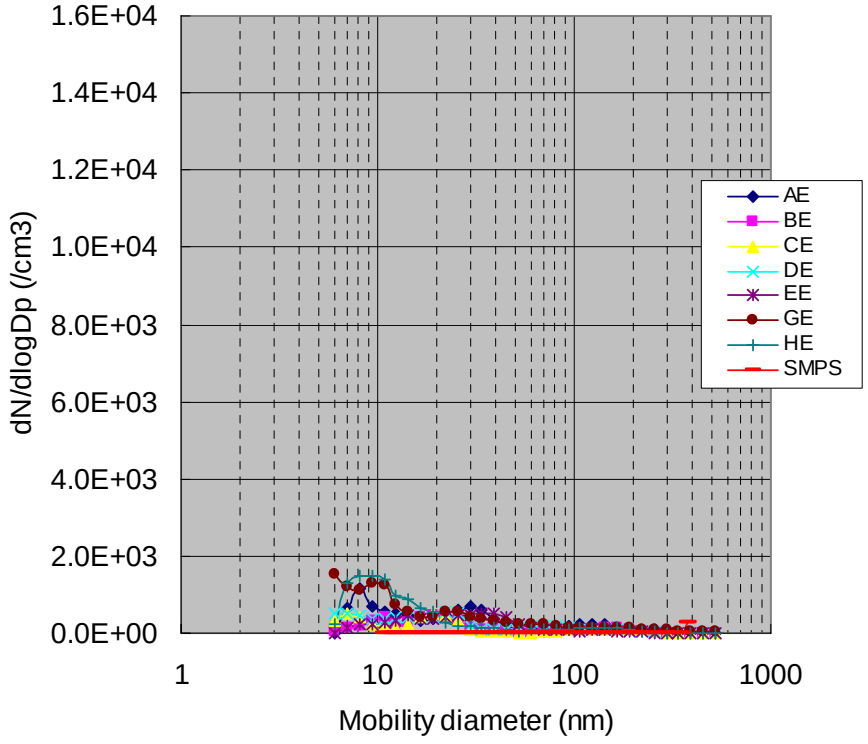
Dilution Air filtered with HEPA filter(Blank)

Comparison of Particle number size distributions

< DMS >



< EEPS >



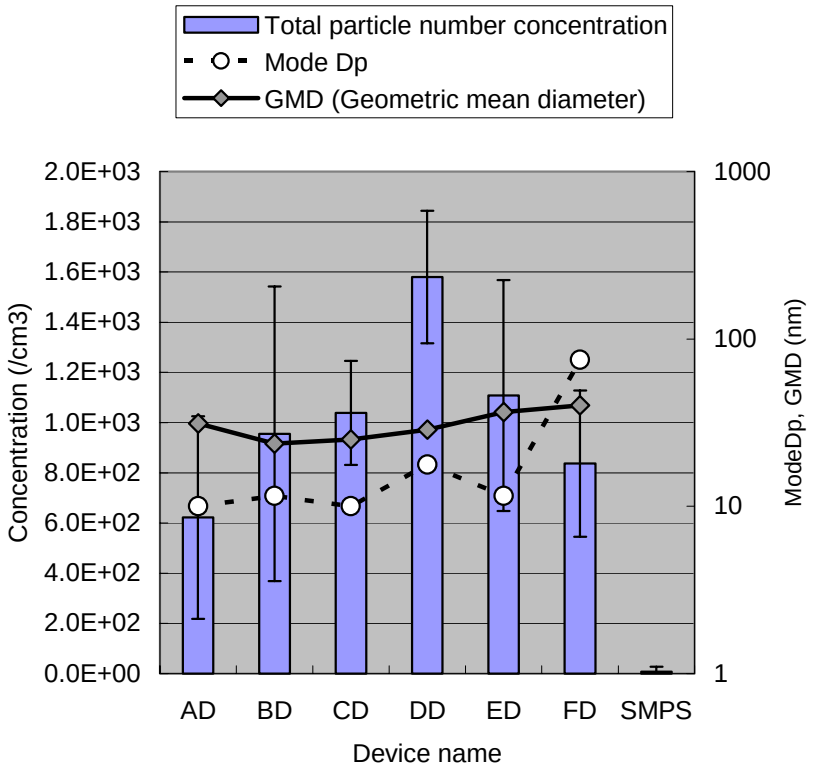
- Particle number size distribution profiles are almost same for instruments of same type.
- For both instrument types, particle number concentrations tend to increase as particle diameter gets smaller.
- Since particle number is not counted by SMPS, particle number counted by either of the instrument types is inferred to be electrical noise.

(Note) Measuring frequency at 1 Hz, data plotted are averages of measured data over 300 sec.
DD (DMS) was an instrument that was malfunctioning and adjusted during the test.

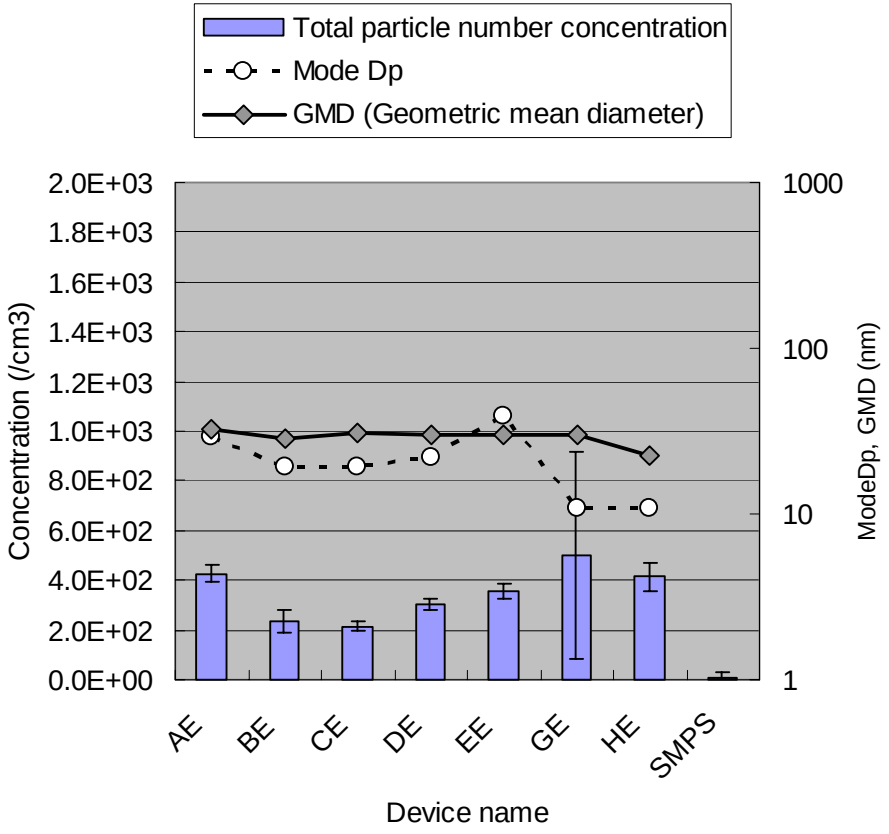
Dilution Air filtered with HEPA filter(Blank)

Comparison of Total particle number concentrations, Mode diameter and Geometric mean diameter

< DMS >



< EEPS >

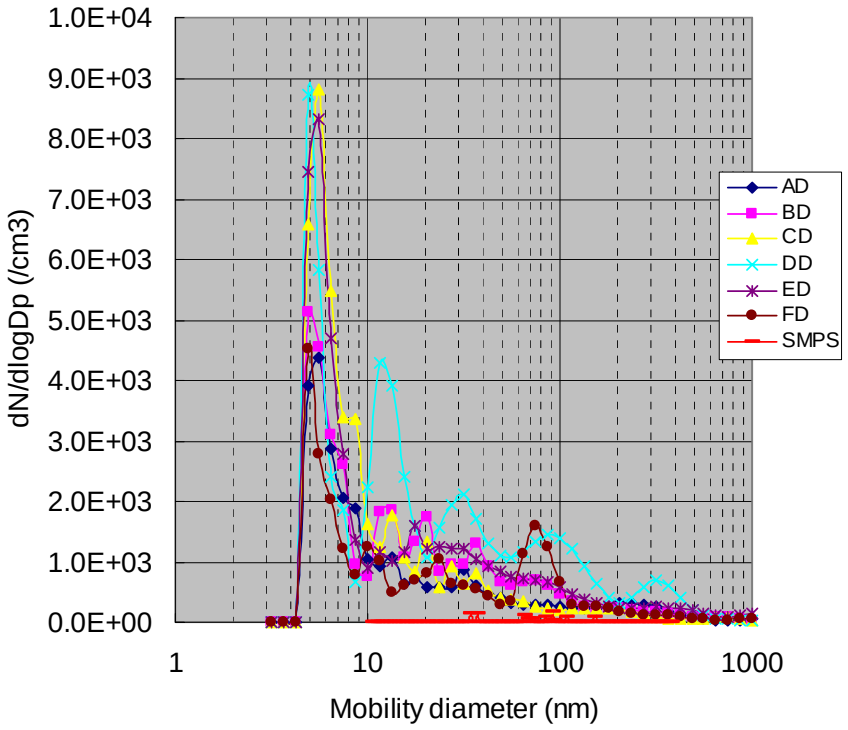


(Note) Measuring frequency at 1 Hz, data plotted are averages of measured data over 300 sec.
DD (DMS) was an instrument that was malfunctioning and adjusted during the test.

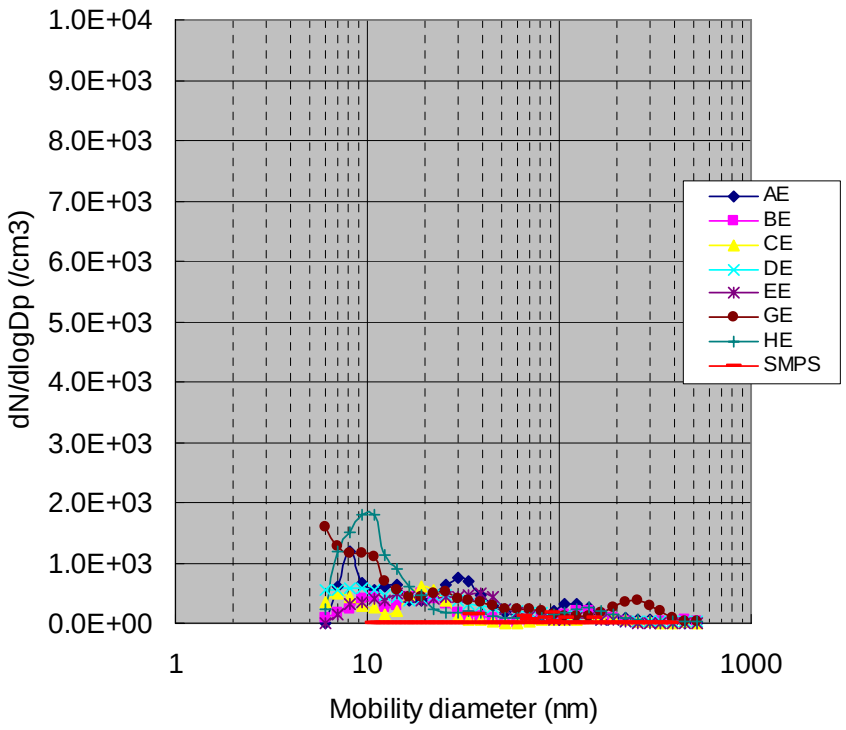
Dilution Air filtered with HEPA filter in Full-Flow Dilution tunnel

Comparison of Particle number size distributions

< DMS >



< EEPS >



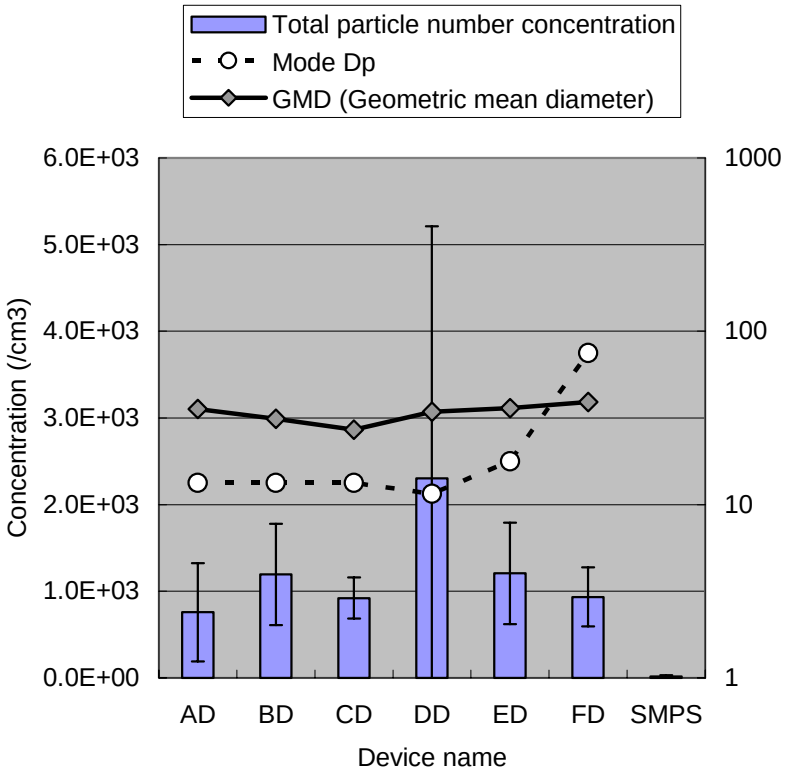
- The tendencies observed are similar to the measured data of diluted air after passage of a HEPA filter, so that it is confirmed that no particle emission from the dilution system is detected.

(Note) Measuring frequency at 1 Hz, data plotted are averages of measured data over 300 sec.
DD (DMS) was an instrument that was malfunctioning and adjusted during the test.

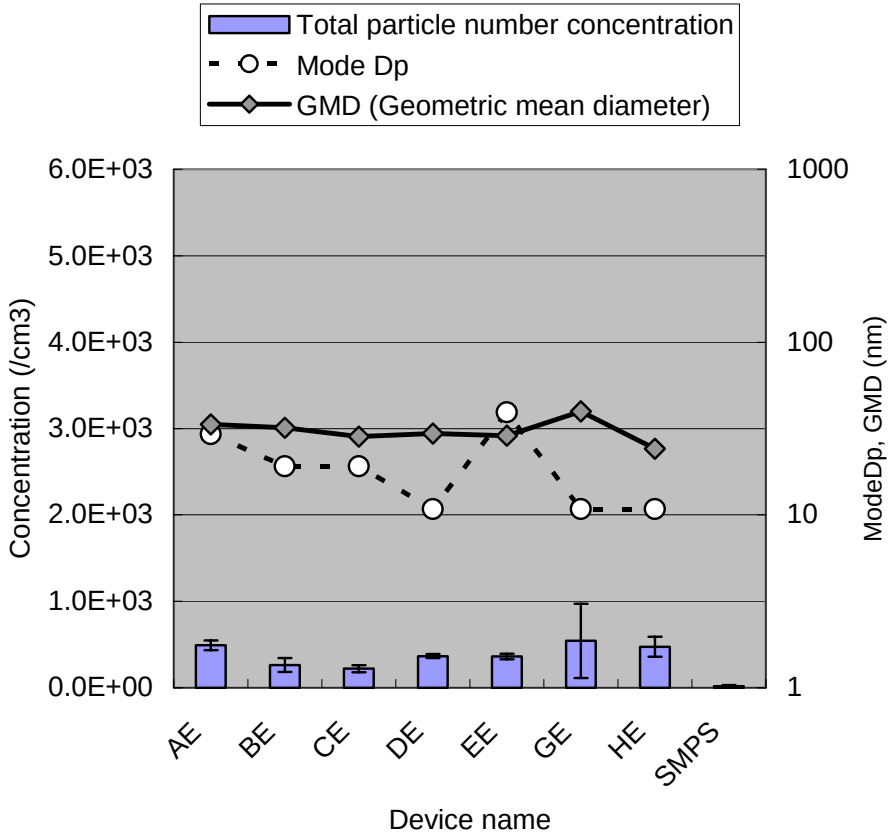
Dilution Air filtered with HEPA filter in Full-Flow Dilution tunnel

Comparison of Total particle number concentrations, Mode diameter and Geometric mean diameter

< DMS >



< EEPS >



-The tendencies observed are similar to the measured data of diluted air after passage of a HEPA filter. It is verified that no particle emissions from the dilution system are detected.

(Note) Measuring frequency at 1 Hz, data plotted are averages of measured data over 300 sec.
DD (DMS) was an instrument that was malfunctioning and adjusted during the test.

Summary of this study

Principal results of the study are:

1) For difference between instruments of same type, coefficient of variation (COV) of mode diameter and geometric mean diameter is 10% at maximum, while COV of particle number concentrations 20% at maximum.

2) Particle number concentrations and size distribution measured by high speed particle sizing instruments show a certain correlation with those by Scanning Mobility Particle Sizer (SMPS), however, detected particle number concentrations are higher than SMPS.

3) Particle number concentrations detected by the two types of instruments vary by a factor of two at maximum, which indicates that a simple comparison is not applicable to measured data using different types of instruments.

4) Even under a condition in which no particle emissions are detected by SMPS, electrical noise might be detected as particles by High speed particle sizing instrument, where noise detection increases as particle diameter gets smaller.

5) It is clear that maintenance-interval severely affects detection accuracy.

6) It is critical to establish an accuracy control method for measuring method and user maintenance.

What is JCAP (Japan Clean Air Program)?

- **Collaborative study** by **automobile** and **oil industries**
  - Find the best combination of automobile and fuel technologies to improve the air quality of Japan
  - Provide technical data to policy makers in Japan
  - Supported by METI (the Ministry of Economy, Trade and Industry)

- JCAP I:1997 –2001 (Budget: Approx. 5.4 billion yen)

- **JCAP II: 2002 –2006** (Budget : Approx. 5.6 billion yen)
  - Determination of **future automobile/fuel technologies** for **near Zero Emissions**
  - **Prediction of air quality improvement** due to the introduction of novel emission control technologies

Appendix : Objectives of Unregulated Material WG

For ultrafine particles and unregulated materials in exhaust emissions from motor vehicles, of which health effects are concerned

(Step1) 2002-2004

Establish appropriate measuring methods

(Step2) 2005-2006

Determine the direction of automobile and fuel technologies development for near zero emissions