Nanoparticle characteristics with the latest after-treatment systems on the market
-Urea SCR systems and DPNR-

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1. INTRODUCTION

Resent stringent regulation for automobile exhaust brings us many kinds of after-treatment systems on the market. Particle size is one of the important factors for evaluating the health effects of its new technologies. In this report, nanoparticle emissions from a heavy duty diesel truck equipped with an urea SCR system(SCR-HDV, complied with 2005 exhaust regulation) and a light duty diesel engine equipped with DPNR system (DPNR-LDE, Complied with 2003 exhaust regulation) which technologies will be expected to glow its demand in the future were investigated.

2. EXPERIMENTAL METHODS

Particle size distributions from urea SCR system and DPNR system were measured with the partial flow dilution system (PPFDII) which was designed to reproduce dilution process in the atmosphere. Temperature and relative humidity of dilution air were controlled at 25 degree C and 50 % respectively. Double dilution system was employed and dilution ratio was fixed by 200 (15 x 13.4). Particle size distributions were measured by DMS500. SCR-HDV (25t , 9.2L with SCR system, complied with 2005 exhaust regulation) ,
HDE (as a reference engine, same type of 9.2L engine without after-treatment system, complied with 1999 exhaust regulation) and DPNR-LDE (4L,complied with 2003 exhaust regulation) were investigated. Test fuel was commercial diesel fuel which sulfur content was 6 ppm by weight. These engines and vehicle were derived under the Japanese transient test mode i.e. JE05. Cold start and hot start test were conducted to observe the particle behavior under these conditions. Nano particle characteristic of SCR-HDV was observed with the thermo denuder. Effect of urea water on particle size was also investigated under the artificial condition in which urea water was injected outside of the SCR system without changing ECU control. Particle emissions of forced regeneration period were observed after low load and middle speed driving by DPNR-LDE.

3. RESULTS AND DISCUSSION

3.1 SCR system

Particle size distribution of SCR-HDV were compared with HDE complied with 1999 regulation. Nuclei mode particles which were usually observed with HDE at the deceleration period were reduced well by the effect of two oxidation catalysts located in both side of SCR and whole particles were decreased in SCR-HDV. Mean diameter of average size distribution for SCR-HDV was smaller than that for HDE. There were no differences between cold start and hot start driving on it particle size distributions. Injection of urea water for the reduction of nitrogen oxides did not affect on the size distributions. Thermo-denuder test for volatility of particles at the temperature of 300 degrees and changes of relative humidity for dilution air from 20% to 80% did not show the significant change of size distribution. Therefore these particles from SCR-HDV can be solid and non-hygroscopic particle. The condition of cold start did not change the size distribution .

3.2 DPNR system

Particle number concentration of DPNR system was very low and close to noise level of DMS measurement. Forced regeneration period of DPNR, concentration of particles is increased temporarily, and then it reduces at the level of before regeneration in next fifteen minutes. Frequency of forced regeneration was estimated by the literature data as once par 220 km diving under the condition that did not allow continuous PM oxidation.

4. CONCLUSION

Nanoparticle emissions from the latest after-treatment systems i.e. SCR-HDV and DPNR-LDE on the market were investigated. Average size distribution of SCR-HDV under the transient test cycle showed that these particles were mainly accumulation mode particle and nuclei mode particles were not observed. Influential factors on size distribution for the SCR-HDV, i.e. warm-up condition (cold and hot start), relative humidity of dilution air and injection of urea water hardly affect particle size distributions.

Particle number concentration of DPNR-LDE was very low. Forced regeneration period of DPNR, concentration of particles was increased temporarily, and then reduced at the level of before regeneration in next fifteen minutes.

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Introduction

- Feature of Selective catalytic reduction system (SCR)
  - PM and fuel consumption can be reduced by improving of combustion with engine modifications. NOx is reduced by SCR system separately.
- Feature of Diesel Particulate –NOx Reduction system (DPNR)
  - Simultaneous reduction of NOx and Particulate
- → More detail analysis is required on number concentration

Objective

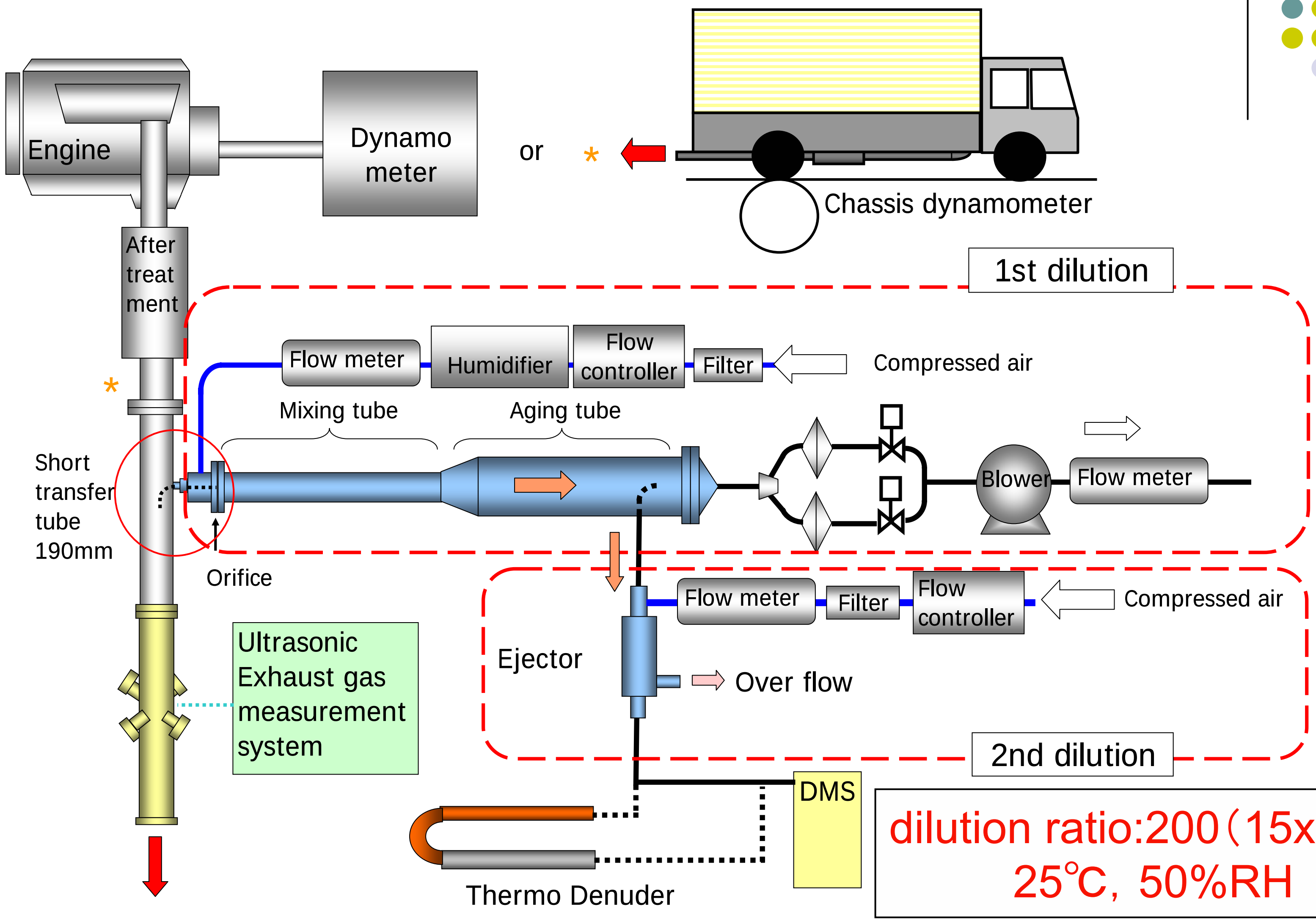
- Investigation of nanoparticle characteristics from the SCR system and DPNR system under transient test cycles
  - Size distribution, Average diameter, Particle number concentration
  - Cold start, Hot start
  - Specification of nanoparticles
  - Effect of urea water on nanoparticles（SCR）

Test procedure

- Test vehicle and engine
  - SCR: Heavy duty diesel truck (25t,9.2L,2005)

    Ref: Heavy duty diesel engine (9.2L,1999)
  - DPNR: Medium duty diesel engine (4.0L,2003)
- Fuel :market diesel fuel (Sulfur 6 wt ppm)
- Test mode : Transient mode (JE05)
  - trial of cold start test
  - applied for C/D test

Experimental setup (PPFDII)



dilution ratio:200（15x13.3）
25℃, 50%RH

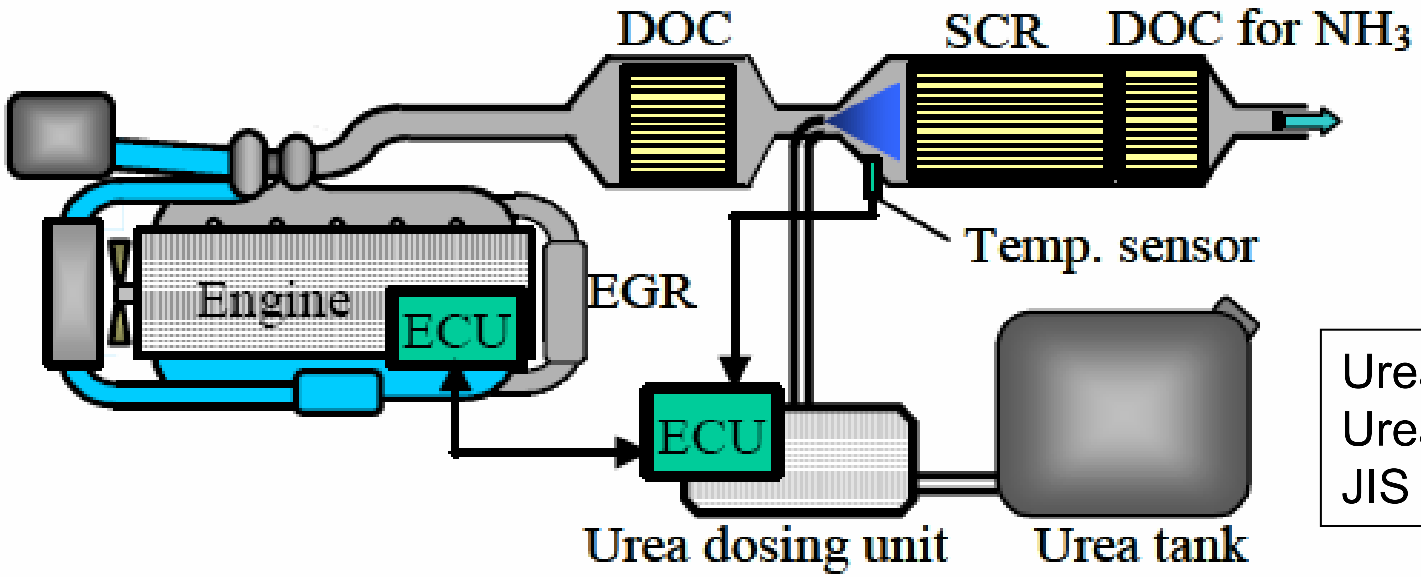
View of experiment

Without urea injection

Result SCR

- Nanopraticle behavior
  - Size distribution, Average diameter, number concentration
- Average size distribution
  - Cold start, Hot start
- Specification of nanoparticle
  - Effect of humidity on size distribution
  - Evaporative specification by thermo denuder
- Effect of urea water on nanoparticle

Urea SCR System



Urea water
Urea: 32.5wt%
JIS K2247-1

$$CO(NH_2)_2+H_2O \rightarrow 2NH_3+CO_2 \quad (1)$$

$$4NO+4NH_3+O_2 \rightarrow 4\ N_2+6H_2O \quad (2)$$

$$6NO_2+8NH_3 \rightarrow 7N_2+12H_2O \quad (3)$$

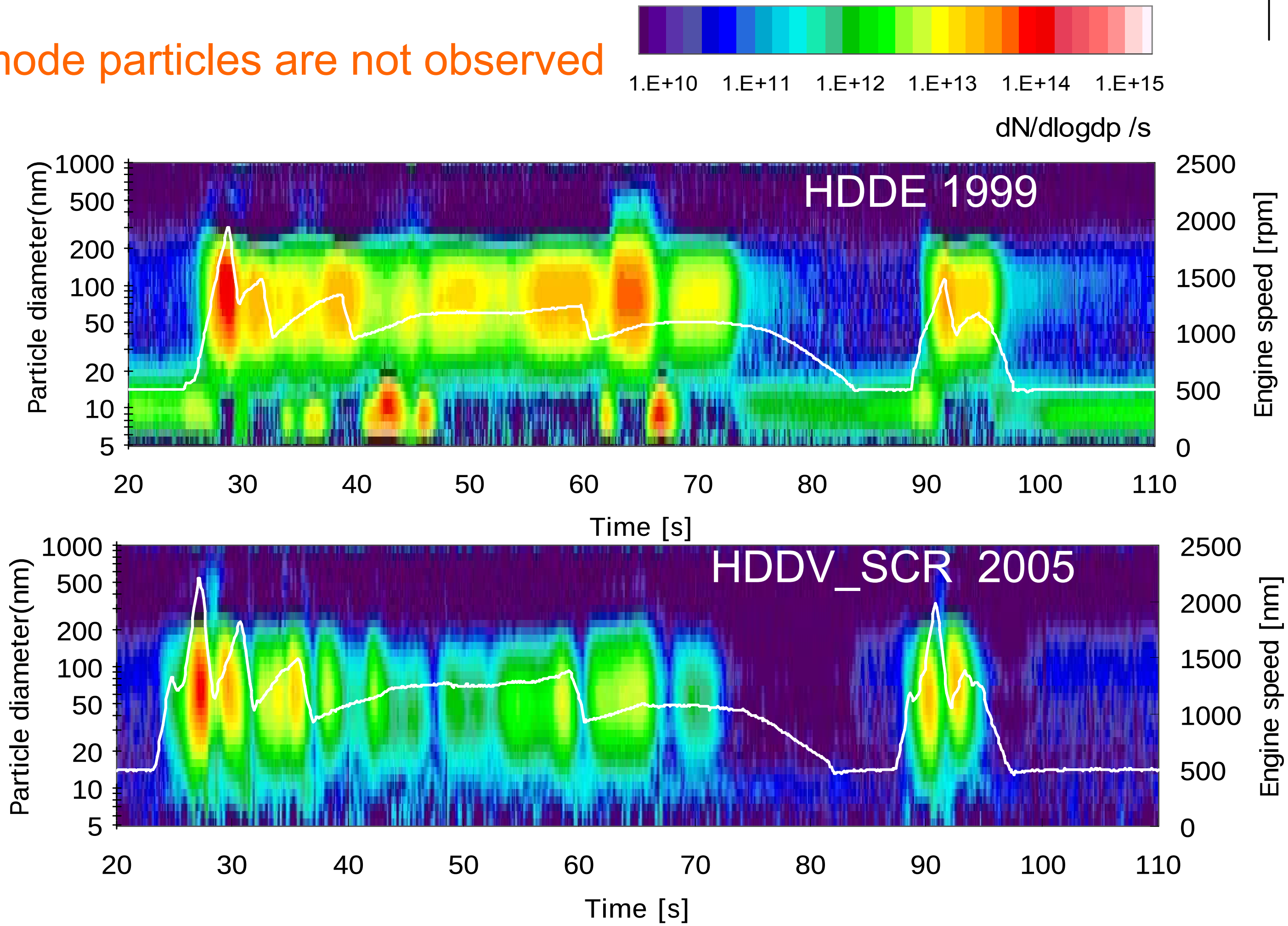
$$NO+NO_2+2NH_3 \rightarrow 2N_2+3H_2O \quad (4)$$

Source ：Hirata et al. SAE 2005011860

Nanopraticle behavior

Detail analysis1 Size distribution

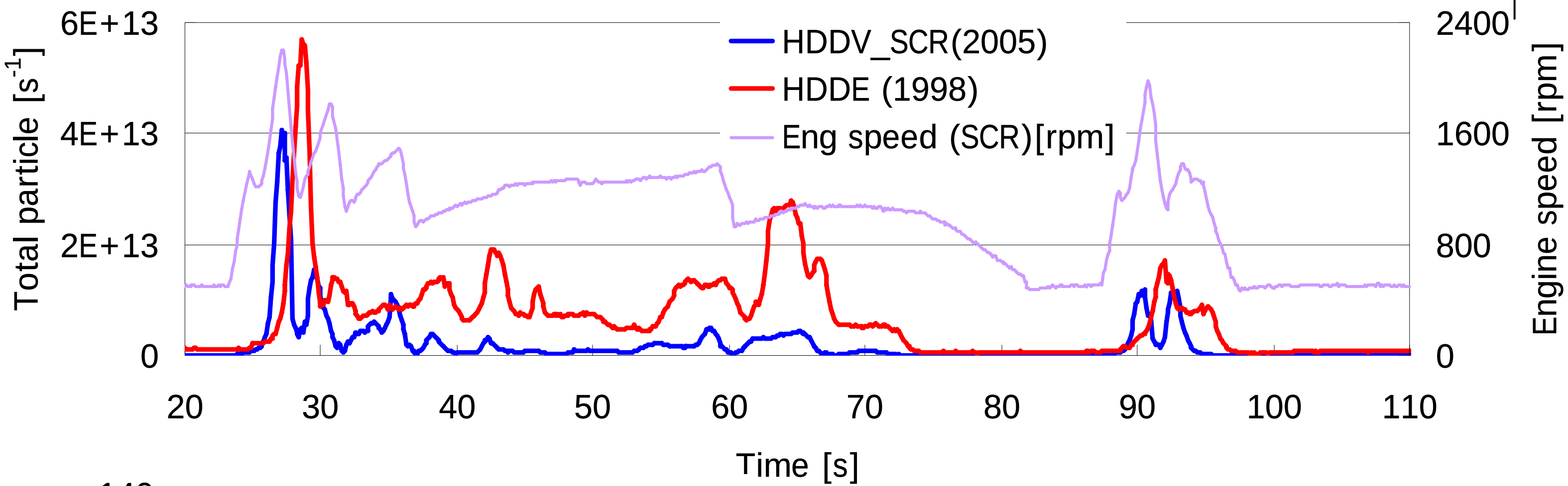
Nuclei mode particles are not observed

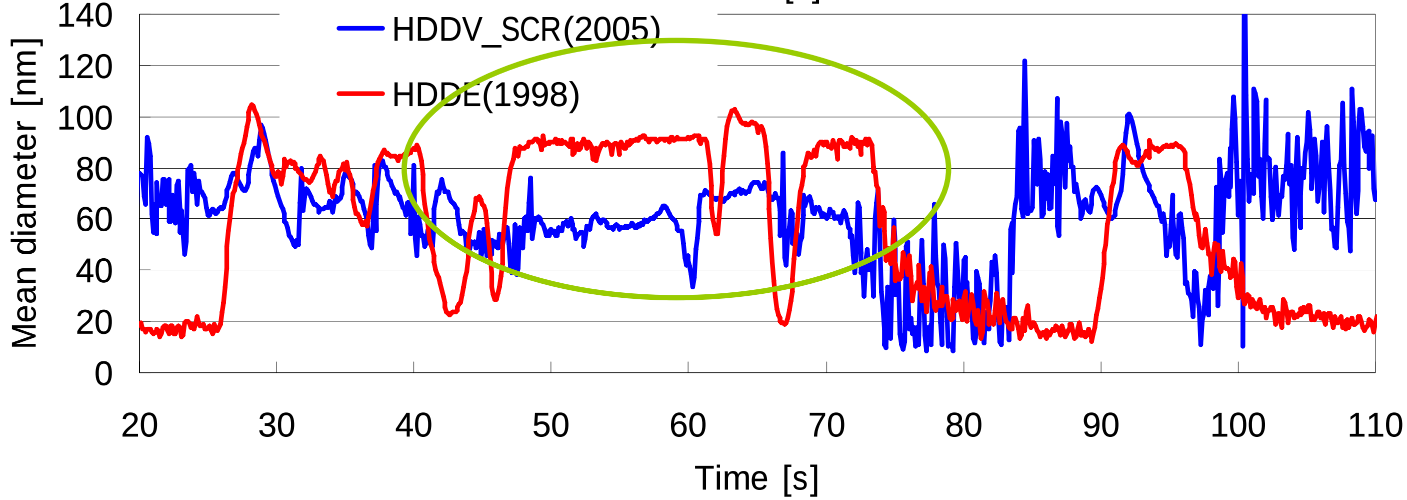


Nanopraticle behavior

Detail analysis1　Number and Mean diameter

Comparison with 1999 engine, # is reduced and particle size is smaller



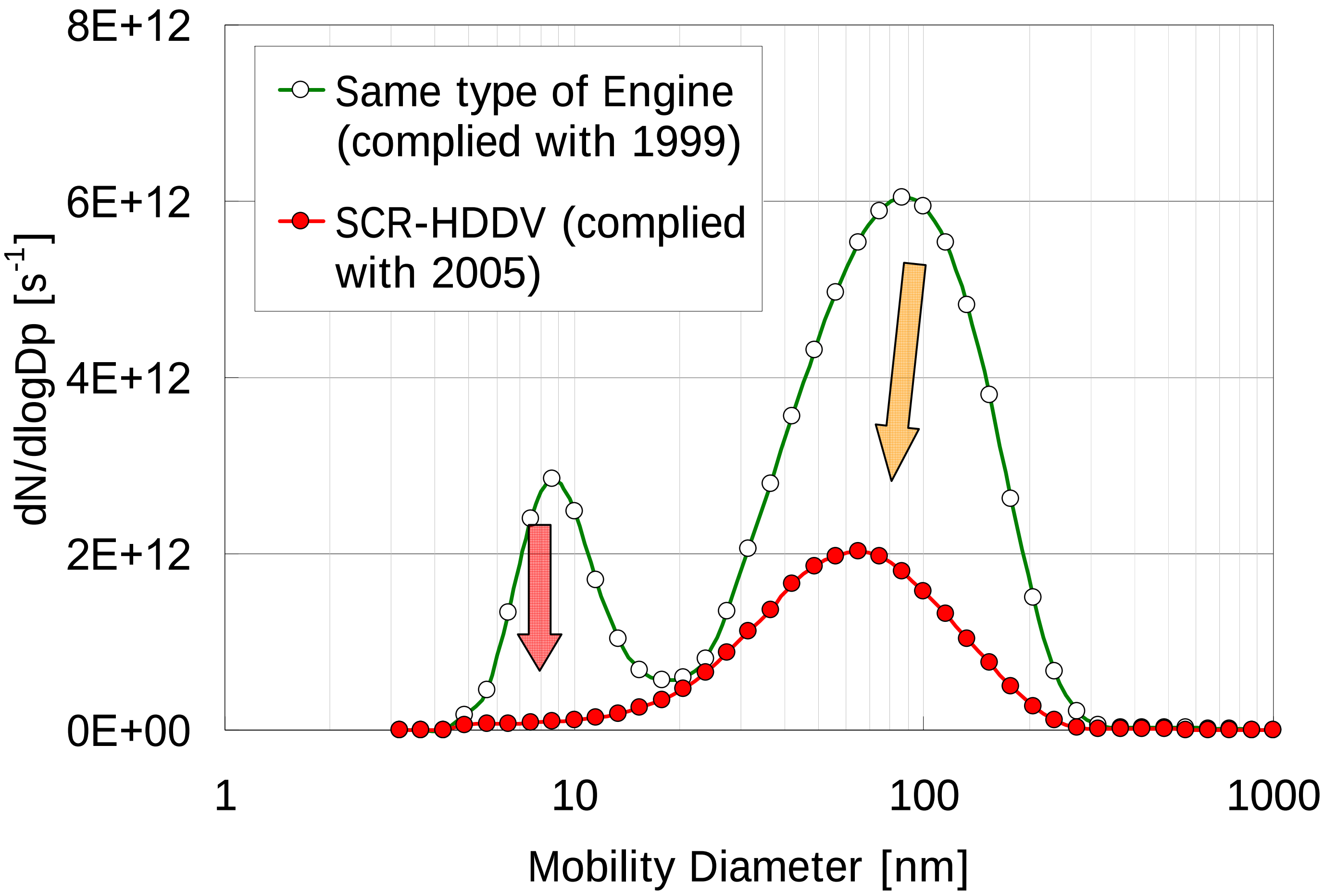


Result Urea-SCR

- Nanopraticle behavior
  - Size distribution, Average diameter, # concentration
- Average size distribution
  - Cold start, Hot start
- Specification of nanoparticle
  - Effect of humidity on size distribution
  - Evaporative specification by thermo denuder
- Effect of urea water on nanoparticle

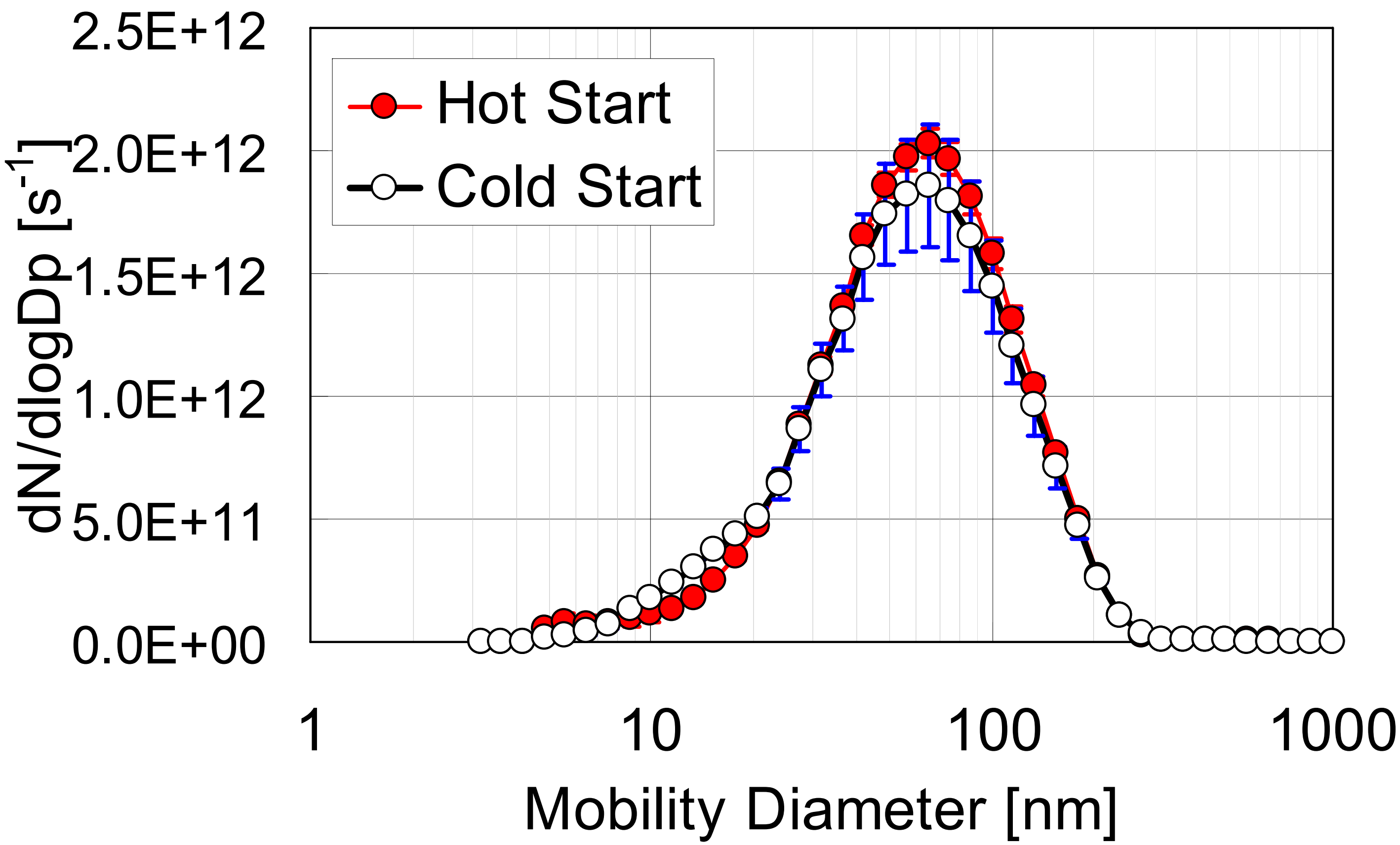
JE05 Average size distribution under the transient test cycle

Nuclei mode particles disappear and accumulation mode particles are reduced



Comparison of cold start and hot start

Differences are negligible



Result Urea-SCR

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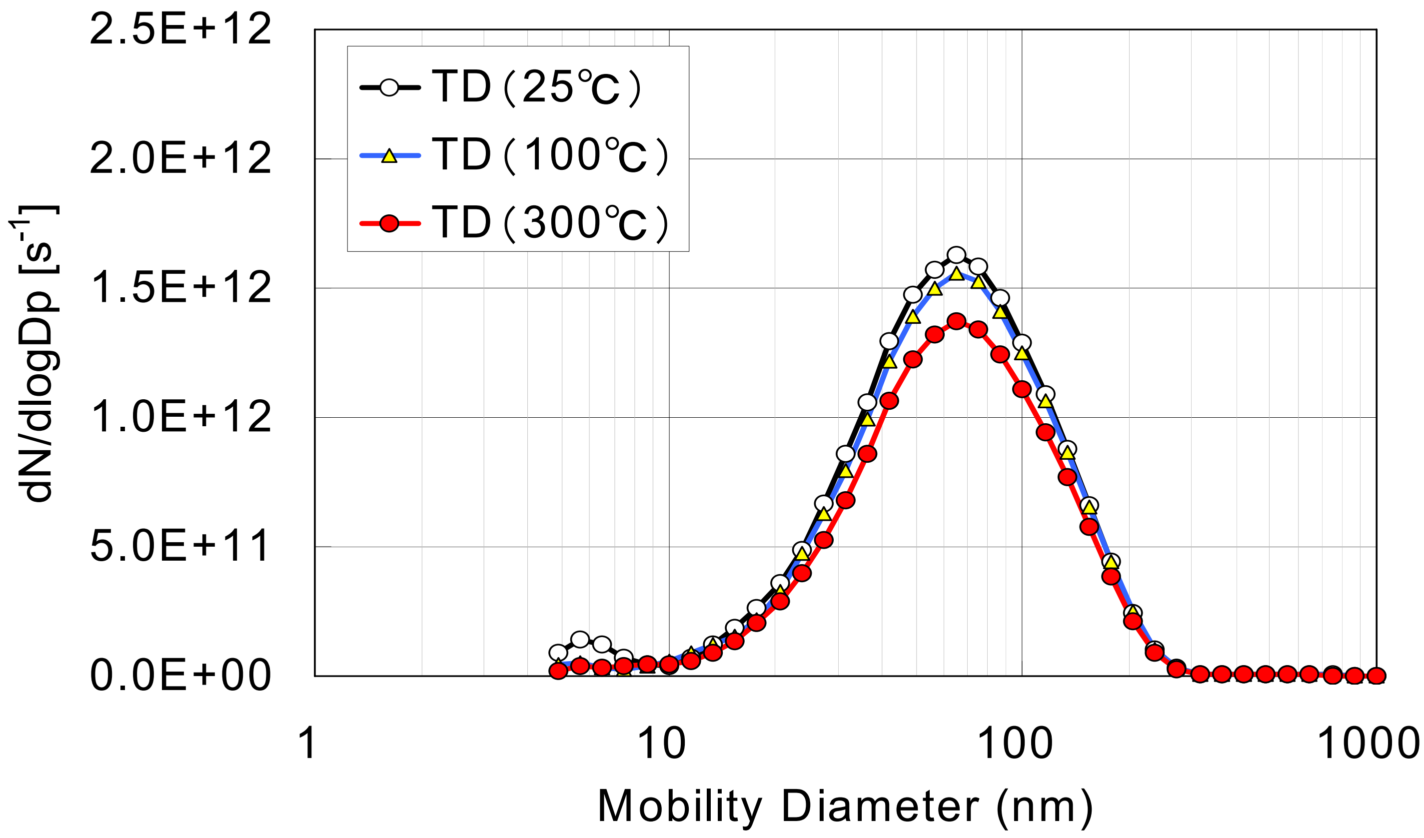
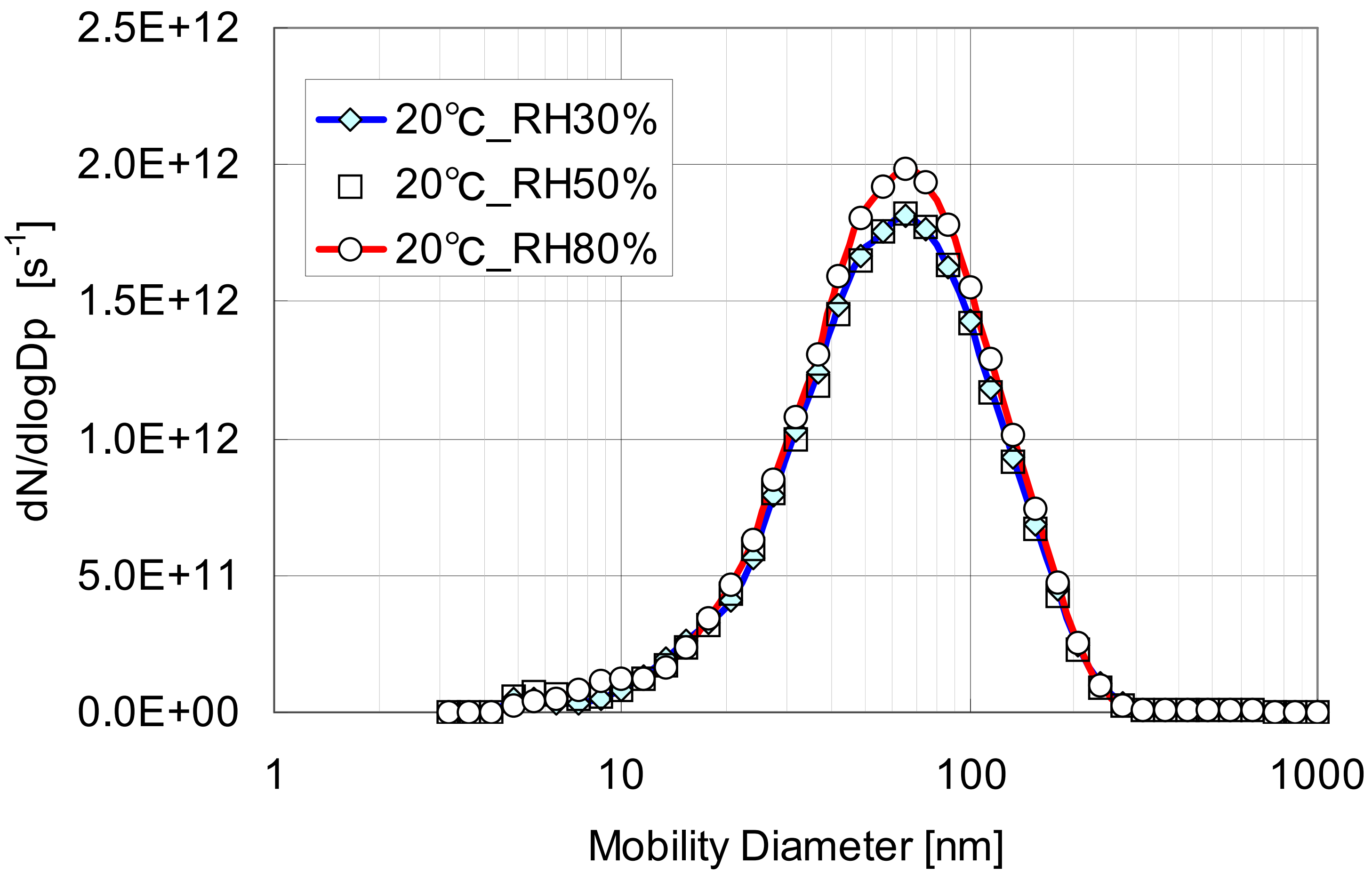
Volatile specification by thermo denuder

Main components are solid or higher volatile particles



Effect of relative humidity on size distribution

Relative humidity does not affect size distribution (RH 30% to 80%)
⇒These particles are not hygroscopic particles



Result Urea-SCR

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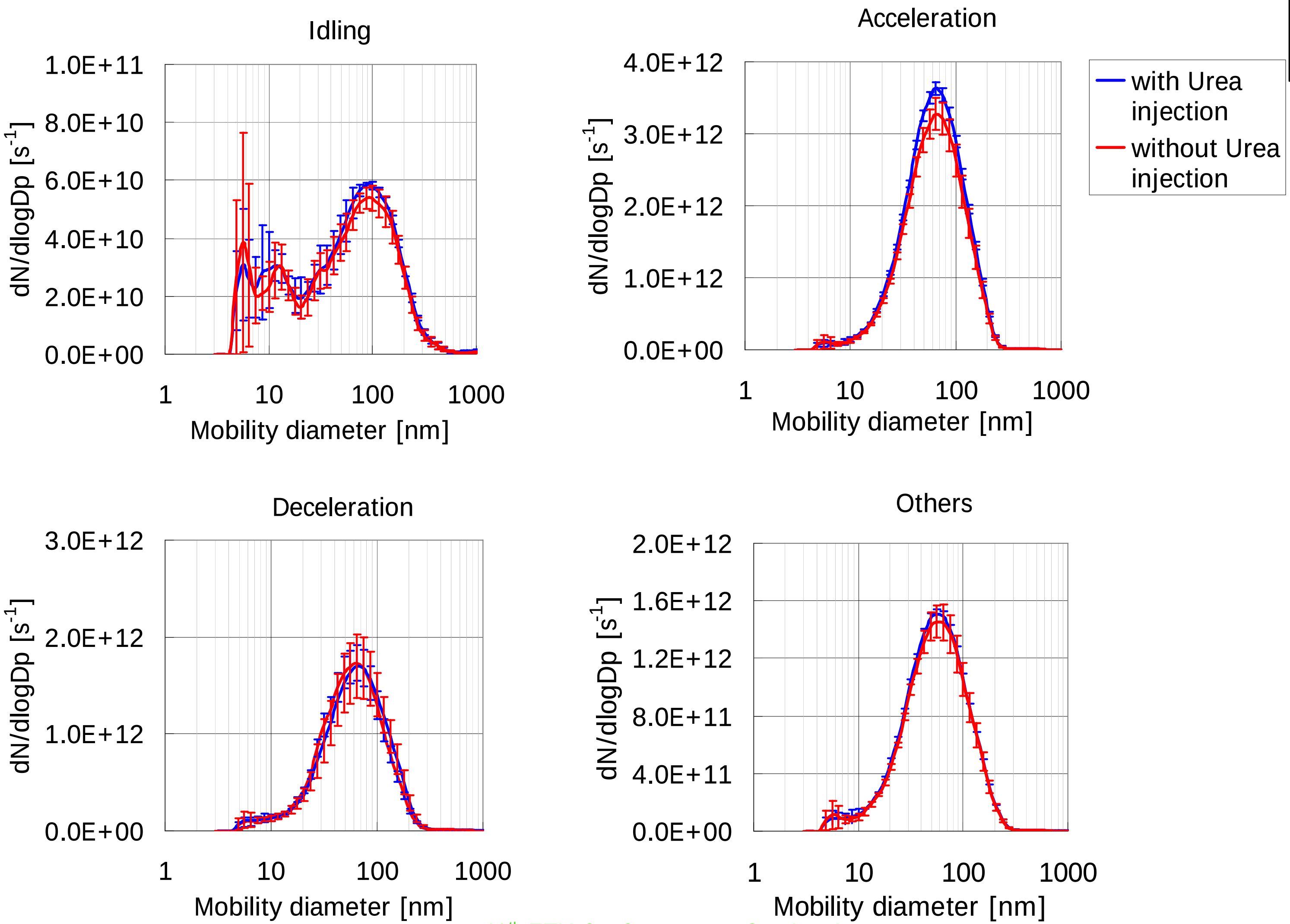
Effect of urea water on nanoparticles

no effects on size distribution



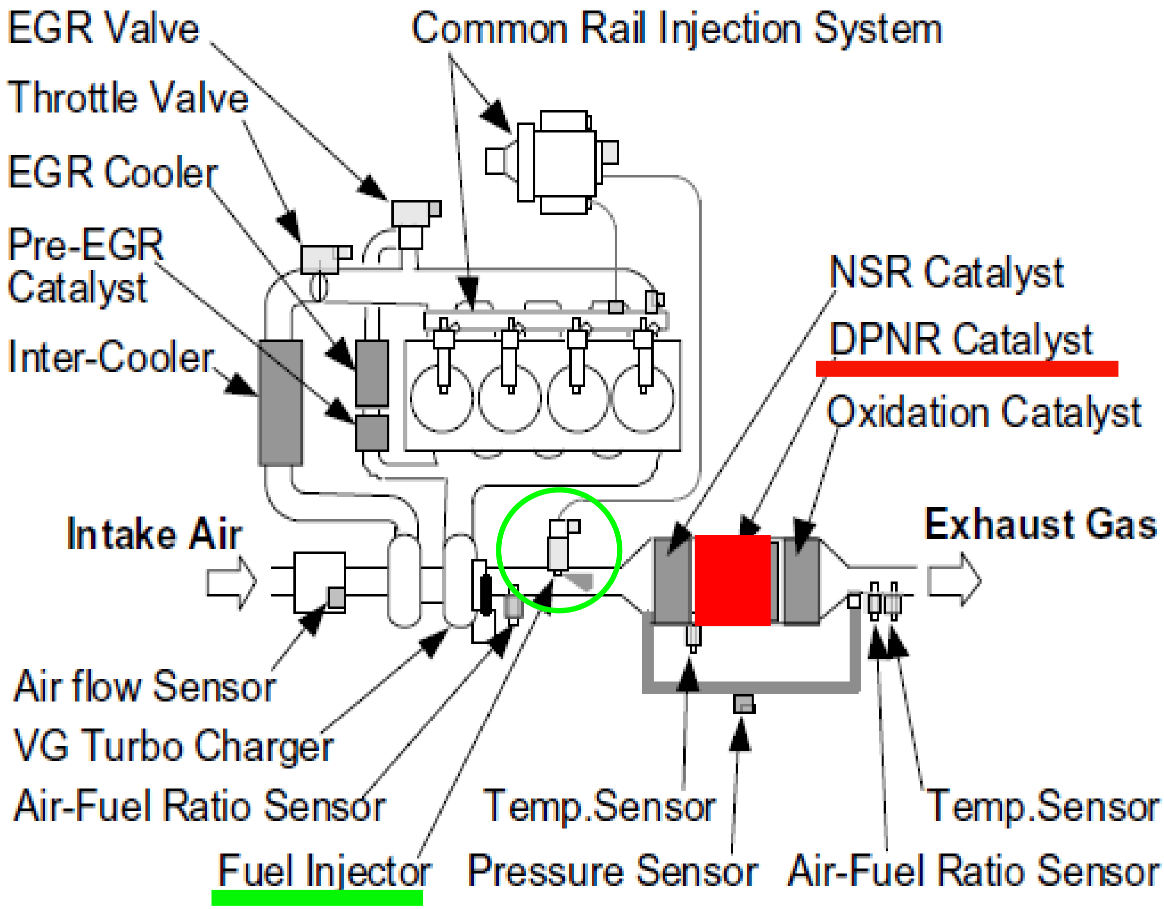
Conclusion - Urea SCR system

- Accumulation mode are main particles from Urea-SCR system
- Nuclei mode particles are not observed even the deceleration period. (Oxidation catalysts work effectively).
- Injection of Urea water does not affect size distribution

Result-DPNR

- Average size distribution
  - Cold start, Hot start
- Regeneration

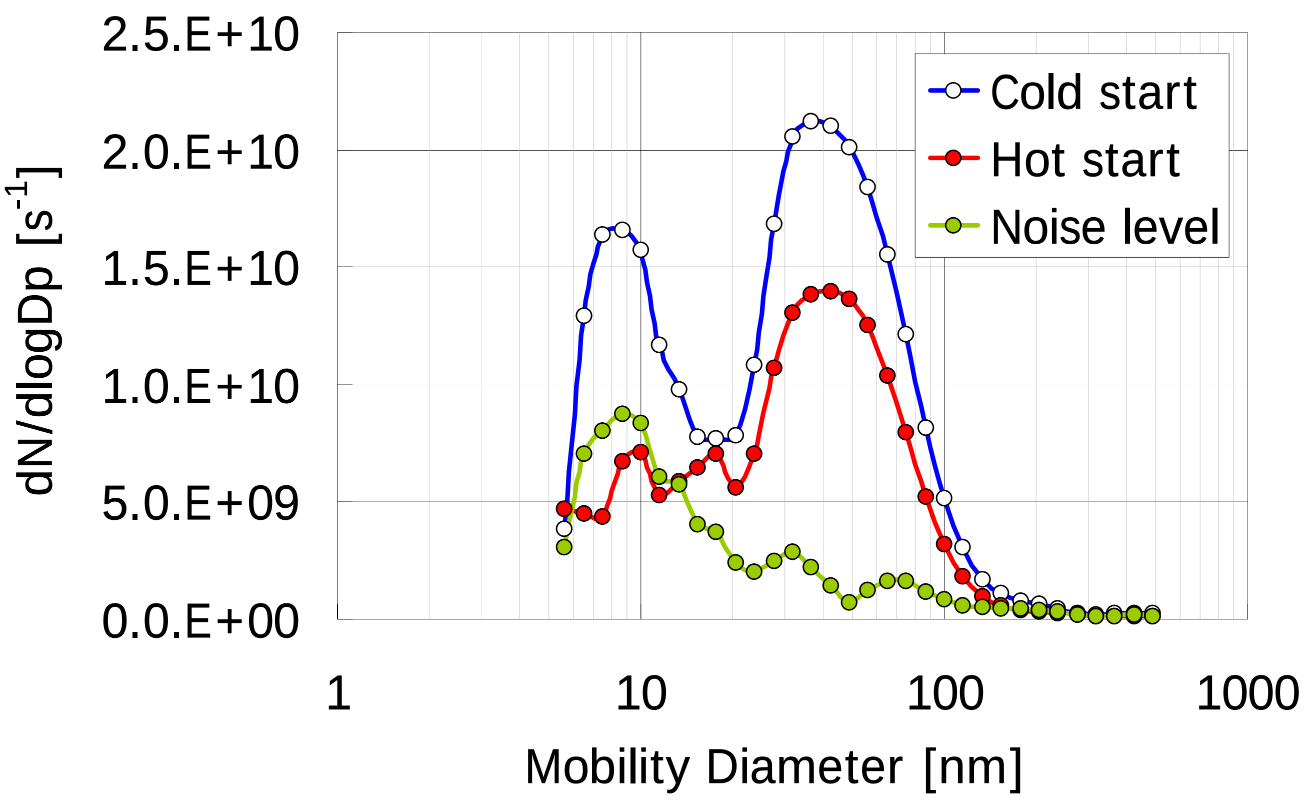
DPNR System



Source: SAE2004-01-0579, Shoji et al.

Average size distribution DPNR

JE05 test cycle



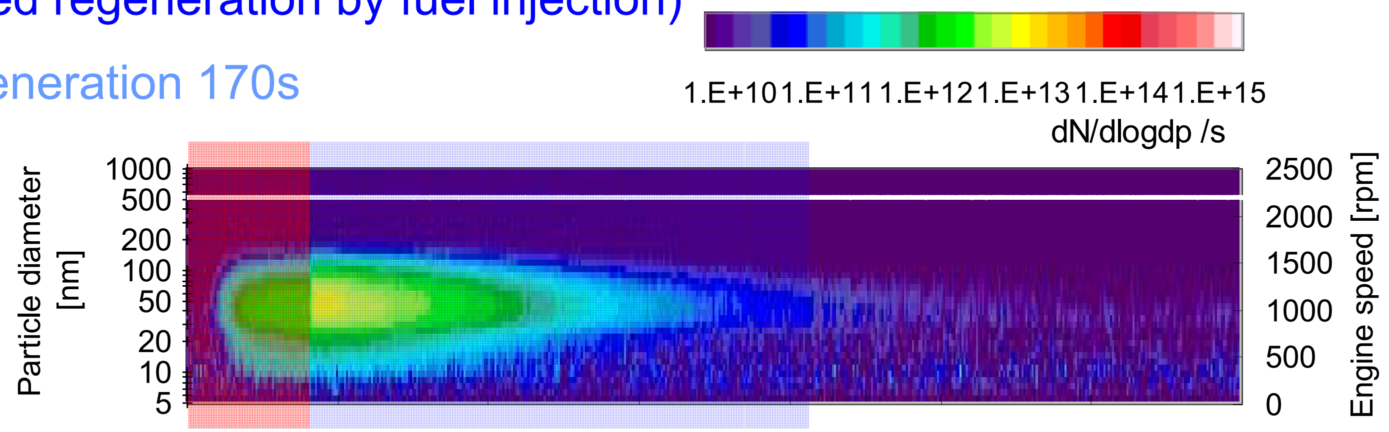
Result-DPNR

- Average size distribution
  - Cold start, Hot start
- Regeneration

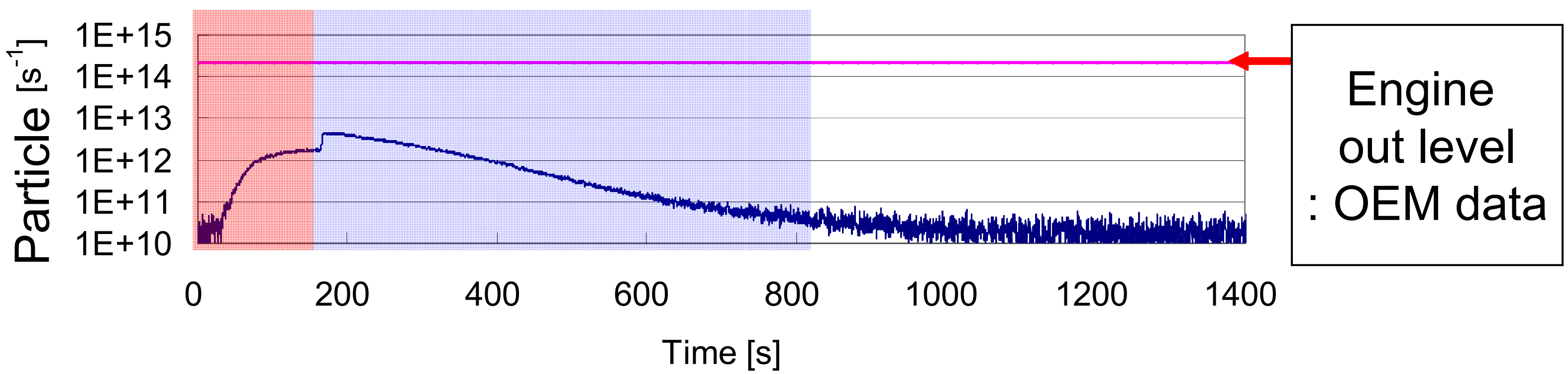
Nanoparticle behavior during and after regeneration

Low load driving for 2hrs causes automatic regeneration
(forced regeneration by fuel injection)

Regeneration 170s



Temporally, particles are emitted but reduced to the initial level in a short time



Estimation for the frequency of regeneration w/o continuous PM oxidation

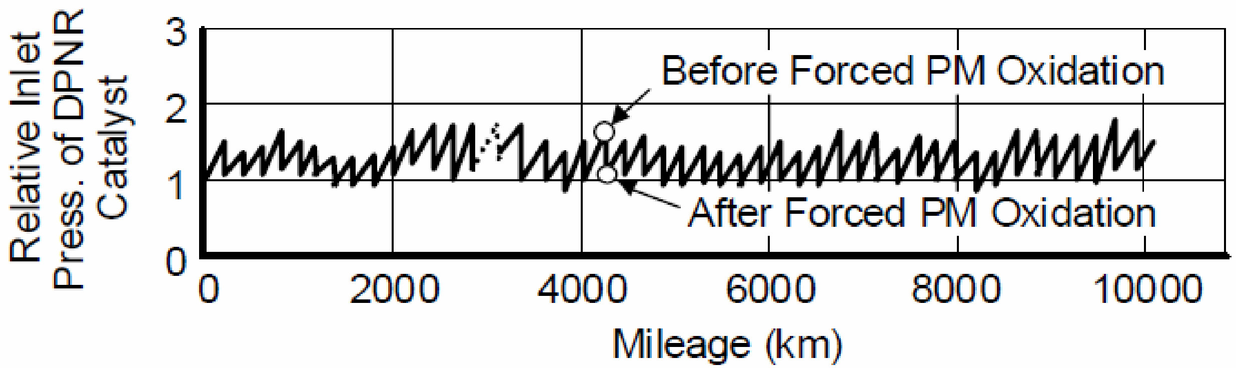


Figure 9. Pressure Loss Transition of DPNR

Created running pattern at an average vehicle speed of 12 km/h to simulate driving on a congested urban road.
The temperature of the DPNR catalyst during the driving in the range from approximately 100 degrees C to 150 degrees C under the condition that did not allow continuous PM oxidation.
Source :A.Shoji et al. (Toyota). SAE2004-01-0579

45 times regeneration during 10000 km driving
= about one regeneration / 220km

Conclusion- DPNR

- Concentration of particles are very low
- Forced Regeneration after low load driving,
  - Particles emit for some period during regeneration and just after regeneration
  - Frequency of forced regeneration is low and average particle number per km is negligible

Thank you for your kind attention

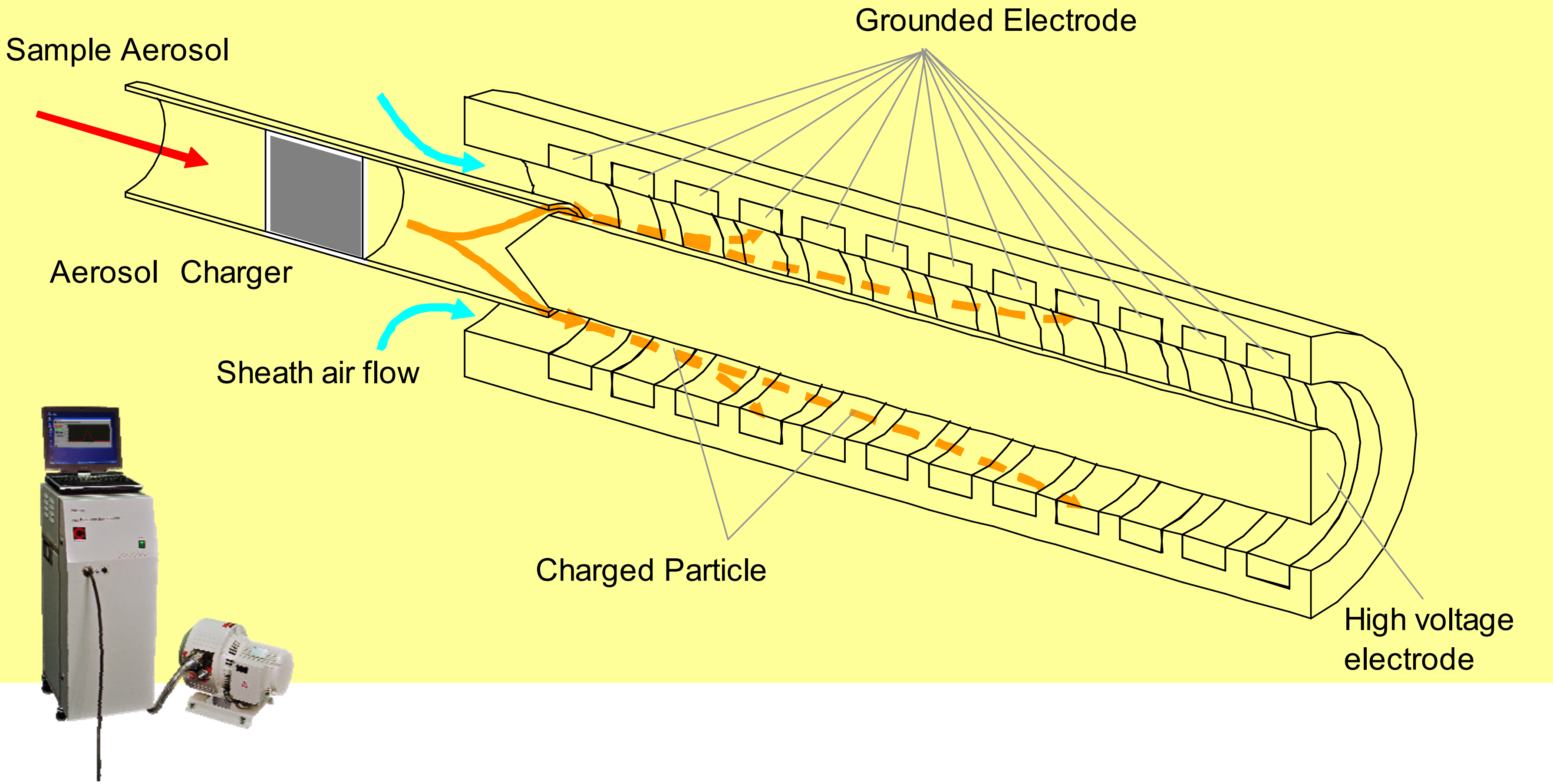
Fuel specification

Density	15℃g/cm^3	0.8279
Flash Point	PM℃	71.0
Kinetic Viscosity	mm^2/s@30℃	3.734
Pour Point	℃	-15.0
Sulfur	Mass %	0.0006
Distillation Properties	℃ 90 %	339.5
Cetane Index		57.3
Total Calorimetric Value	J/g	45890
C.F.P.P	℃	-8

Specification of test engines and vehicle

Type	HDDE	HDDV	HDDE
After treatments	DPNR	Urea SCR	non
Exhaust gas regulation	2003	2005	1999
Gross vehicle weight	—	24840 kg	—
Engine displacement	4.0L	9.2L	←
Fuel injection	Common rail DI	Common rail DI	←
EGR system	Cooled EGR	Cooled EGR	←

DMS: Differential Mobility Spectrometer



Urea water

Urea	32.5 mass%
Water	67.5 mass%
Standardized	JIS K2247-1

Measuring condition

Dilution ratio (DR1xDR2)	200 (15 x 13.3)
Temperature of dilution air	25 ℃
Relative humidity of dilution air	50 %RH
DMS sampling rate	10 Hz

Calculation of emission ratio

dN/dlogDp [/s]

=dN/dlogDp [m^{-3}] x Exhaust flow rate [m^3/s]

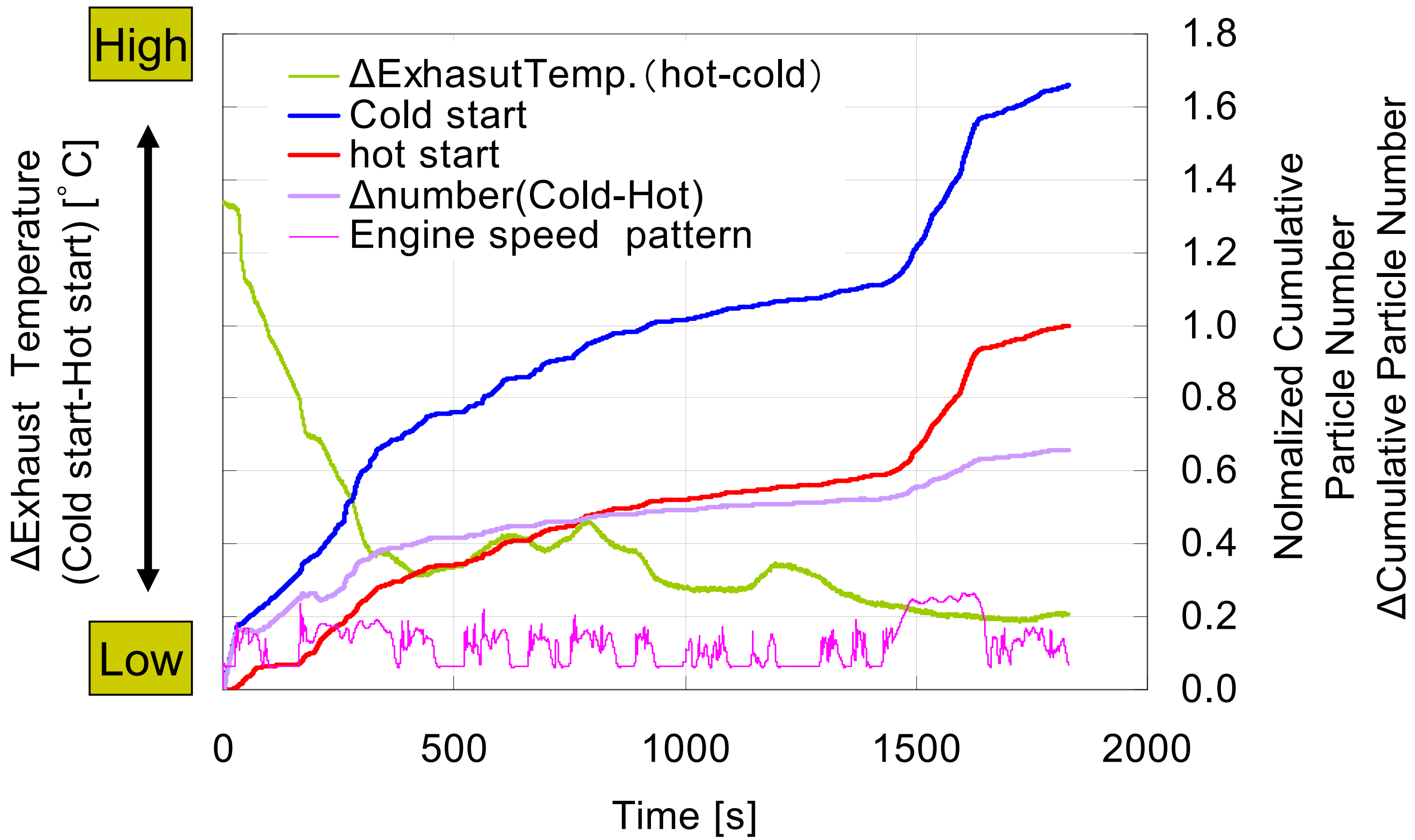
x Dilution ratio

Time schedule of preconditioning

	DPNR engine	Urea-SCR Vehicle		
Test mode	JE05 (min)			JE05 Without Urea
Start	Hot	Hot	Cold	
Warming up	20	20	20	With Urea
Full load/speed	20	10	10	With Urea
Engine stop	10	10	10	
Dummy mode	30.5	30.5	30.5	Without U
Engine stop	10	10	Soak	Without U
Measurement	30.5	30.5	30.5	Without U

JE05 mode is applied for a vehicle test
Preconditioning is partly changed, Trial of cold start test

Differences between cold and hot start



Differences between cold and hot start SCR