Recent Progress of PM research and its Activities in Japan

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International Seminar on Recent Trend of Engine Combustion Field
Energy Conversion Research Center
Doshisha University, Japan

Recent Progress of PM research and its Activities in Japan

1. PM and Nano-PM Problem
2. Trend of Nano-PM Research
3. PM Measurement
4. Fundamental Research of PM
5. Diesel Combustion and PM
6. Tail Pipe PM
7. Aftertreatment
8. PM Research Activities in Japan
9. Summary

PM size distribution (diesel engine emission and cigarette smoke)

PM Emission from typical diesel engine

Figure 17 – Effect of injection timing on base boost particle size distributions

SAE-2005-01-0194

PM Emission from cigarette

Nano-size PM and Diesel Particulate Emission

Road Side PM in Japan NIES)

- Ikegami-shinmachi
- Kitanomaru
- Umeshima
- Ayase
- Tsukuba (NIES)

Particles Invisible – Mission Possible

Risk Management for Nano-Size Particulate Problem

Invisible Mission for the Risk of Invisible-Emission

- Alarm for Risk
  - Characteristics of Risk, Possibility of Risk,
- Measurement of Risk
  - Measurement Method and Instrument for Risk Substance
  - Identification, Formation and Removal Mechanism
- Evaluation of Risk
  - Tail-pipe Emission, Environment Effect, Health Effect
  - Relative Strength of Risk
- Reduction of Risk
  - Fuel and Engine Improvement, After-treatment
  - Regulation of Risk Substance
- Compensation for Risk
  - Prevention against Risk, Recover from Injury
  - Alternative Compensation for Injury
- Cost of Management
  - Reduction Cost, Compensation Cost
  - Prevention is better than care.
- Disclosure of Risk Management
  - Information with Scientific Uncertainties

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GRPE-PMP

Programme Principles and Schedule of PMP Activity

Phase I: Dec. 2000 - June 2002
Development of Candidate Systems

Phase II: June 2002- July 2003
Testing Programme and Validation of Candidate Systems

Phase III-1: July 2003 – March 2007
LD Inter-Laboratory Correlation Exercise

Phase III-2: April 2007 – Present
HD Inter-Laboratory Comparison Exercise

Japan PMP JPMP)

Collaborative Working Scheme

Emission Reduction Strategy (Strategies in 2003-2004)

2003-01-0039

Year of Introduction	Heavy Duty Regulation and Technology	Light-Duty Regulation and Technology
2005	Japan: DPF	Japan: DPF Euro IV: DPF for >1.7 tonnes
2006	Euro IV: SCR; DPF or DOC	US Tier 2: DPF+LNT
2007	US2007 (1st phase): DPF; DPF+LNT	
2008		Possible Euro V: DPF+LNT
2009	Euro V: SCR; DPF or DOC	
2010	US2007 (full): DPF+LNT	Euro V: DPF+LNT

TABLE 1. General overview of diesel regulations and expected emission control technologies. The dates referred to the mandatory date of the regulation. Incentives or commercial considerations may result in earlier introductions. DPF is Diesel Particulate Filter. SCR is Selective Catalytic Reduction. LNT is Lean NOx Trap. DOC is Diesel Oxidation Catalyst.

2004-01-0070

Year of Introduction	Heavy Duty Regulation and Technology	Light-Duty Regulation and Technology
2005	Japan 2005: DPF Euro IV: SCR; DPF or DOC	Japan: DPF Euro IV: DPF for >1.7 tonnes
2006		US Tier 2: DPF+LNT
2007	US2007 (1st phase): DPF; possibly DPF+SCR	
2008	Euro V: SCR; DPF or DOC	
2010	US2007 (full): DPF+LNT; DPF+SCR	Euro V: DPF+LNT (earlier with incentives)

TABLE 1. General overview of diesel regulations and expected emission control technologies to be used. DPF is Diesel Particulate Filter. SCR is Selective Catalytic Reduction. LNT is Lean NOx Trap. DOC is Diesel Oxidation Catalyst.

2003-01-0039
Diesel Emission Control in Review – The Last 12 Months
Timothy V.Johnson (Coming Incorporated)
2004-01-0070
Diesel Emission Control Technology - 2003 in Review
Timothy V. Johnson, (Corning Inc.)

General Review: Topics in Past SAE World Congresses

SAE 2003 World Congress (March 3-6)

PM size distribution (Nuclei, Accumulation and Coarse modes)
Effect of sampling condition on PM size distribution
PM instruments and characterization (SMPS, ATOF-MS, LII, TEOM, MEXA)

SAE 2004 World Congress (March 8-11)

Nano-PM sampling method (Hot dilution, Mini-diluter,)
DPF (Material and structure,
Aftertreatment system (DPF+LNT, DPF+SCR)

SAE 2005 World Congress (April 11-14)

PM reduction strategy (HCCI, PCCI, LTC, Φ-T map)
PM formation (Nuclei mode particle) and oxidation mech nisms
DPF regeneration (Post 80 injection, Fuel penalty)
Transient mode measurement

SAE 2006 World Congress (April 3-6)

Total energy problem and PM (WTW, WTP and PTW, IC Vehicle and FC Vehicle)
PM and NOx reduction strategy (LTC, EGR, Φ-T map)
Aftertreatment system with engine system control

SAE 2007 World Congress (April 16-19)

PM number of $5x10^{11}$ (1/km) is compatible with PM mass of 3 (mg/km) ???
PM instruments for PMP protocol and transient mode operation of vehicle
Aftertreatment system and PM deposits

Particulate Mass and Particulate Number

PM number of $5x10^{11}$ (1/km) is compatible with PM mass of 3 (mg/km) ???

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GRPE-PMP Activity on PM Measurement

from HOROBA Automotive test Systems

? Investigation of New Approach
? Modification of Conventional

? **Development has been accelerated**

? **CPC/CNC- Condensation Particle Counter**
? **DCS - Diffusion Charging Sensor**
? **EDB - Electrical Diffusion Battery**
? **PASS - Photo Acoustic Soot Sensor**
? **ELPI - Electrical Low Pressure Impactor**
? **LII - Laser Induced Incandescence**
? **PAS - Photoelectric Aerosol Sensor**
? **TEOM - Tapered Element Oscillating Microbalance**
? **QCM - Quartz Crystal Microbalance**
? **DMS - Differential Mobility Spectrometry**
? **MEXA -1370PM : PM mass by gas analysis**
? **EPA-2007 “style“ GRAVIMETRIC as Reference**

Candidate for ILCE

Particle Number Counting Instruments

from Tokyo Dylec

(Manufacturers and Representative in Japan)

	SMPS	TSI Inc. USA)	Tokyo Dylec Corporation
		MSP Corporation USA)	KANOMAX JAPAN INC.
		WYCKOFF Co., Ltd.(Japan)	
	EEPS	TSI Inc. USA)	Tokyo Dylec Corporation
	DMS	Cambustion UK)	Tsukasa Sokken Co., Ltd.
	ELPI	Dekati Ltd. Finland)	KANOMAX JAPAN INC.
Classifier			
	DMA	TSI Inc. USA)	Tokyo Dylec Corporation
		SIBATA	SIBATA
		MSP Corporation USA)	KANOMAX JAPAN INC.
		WYCKOFF Co., Ltd.(Japan)	
Number Counting			
	CPC	TSI Inc. USA)	Tokyo Dylec Corporation
		Dekati Ltd. Finland)	KANOMAX JAPAN INC.
		MSP Corporation USA)	KANOMAX JAPAN INC.
Other			
	Nano-Meter Aerosol Sampler	TSI Inc. USA)	Tokyo Dylec Corporation
	Hi-Mass CAST(REXS)	Matter-Engineering AG	Tokyo Dylec Corporation
	Nano-Particle Generater	SIBATA	SIBATA
	Sampling system	HORIBA, Ltd. (Japan)	HORIBA, Ltd.

Prototype Partial Flow Diluter (PPFD), JARI

Sousuke SASAKI, Yoshio TONEGAWA and Toru NAKASHIMA
Analysis of Nanoparticle Behavior in Transient Mode, JARI Research Journal, Vol 7, No.12, 3-6, 2005.

Hot Dilution and Model of Nano-PM (NTSEL Japan)

Fig. 5 Effect of dilution temperature on nano-particle number distribution (Idling: 550 rpm, 0 N-m), (MD: Rotary-Type Diluter Temperature °C), ThC: Thermo-conditioning temperature °C)

Figure 1: Schematic of the experimental system

2005-01-0187
Thermal Conditioning of Exhaust Gas: Potential for Stabilizing Diesel Nano-Particles
Rahman M.Montajir, Terunao Kawai, Yuichi Goto and Matsuo Odaka (National Traffic Safety and Environmental laboratory, Japan)

Dilution Method -1 (Aristotle Univ.)

Figure 2: Schematic of the FPS. It consists of a porous dilutor followed by an ejector dilutor. T, P correspond to temperature and pressure sensors respectively, which are needed to calculate the DR.

FPS: Fine Particle Sampler

Figure 3: Schematic of the MD19-2E rotating disc dilutor. The transfer of aerosol from the aerosol channel to the dilution gas channel by means of cavities in the rotating disc provides exhaust dilution.

Figure 6: Two configurations of the sampling setup. The dilution units (FPS, MD19) sample from the probe with the pre-separator in configuration A, used also for PM sampling. In configuration B, isokinetic probes were used for the FPS and MD19 and the pre-separator for PM samples. All probes measured at the same tunnel cross-section.

Thermo-Dilution (Steady and Unsteady Particle)

Fig. 11: Phase diagram as Fig. 5, showing the phase paths for thermo-dilution (G-V-H-N), and post-dilution thermo-conditioning (G-N-H-N).

PMP Recommended Method

from HOROBA Automotive test Systems

ILCE: Inter-Laboratory Correlation Exercise for LD vehicles at NTSEL

Name	Golden Vehicle	JV-1	JV-2
Transmission	6 speed	Automatic	5 speed
Engine Type	DI, Common Rail Diesel +DPF	Gasoline Direct Injection	DI, Common Rail Diesel + DPF,
Displacement	1997cc 4cylinder	2998cc V6	1998cc 4cylinder
Market	EU	JP	JP

Solid Particle Sampling System (SPSS) from SwRI

Figure 1. Solid Particle Sampling System Basic Operation

Figure 12. Vortex Tube layout

Figure 13. Stand-Alone Solid Particle Measurement System (SPSS)

Principle and Performance of SPSS
Heated oxidation catalyst (catalytic stripper: commercially available DOC)
Molecular and particle diffusion in catalytic stripper
Micro dilution tunnel (refrigerated compressed air dryer and vortex tube)
Filter-based solid and total (solid + volatile)
Check by sodium chloride particle
98% removal of volatile
No artificial particle
SPSS+SMPS=Particle Number Measurement

PM Measurement Equipments

from HOROBA Automotive test Systems

Model	MEXA-1000SPCS
Conformed standard	ECE draft proposed by PMP
Lower particle size limit	23 nm (±3) 50% counting efficiency
Measuring scale	0~10000 up to 50000 #/cm^3
PND_1 Dilution factor	10~700
PND_2 Dilution factor	10~50
Evaporation unit temp	300~400 deg C
80nm solid particle penetration	> 80% (Typically 90%)
30nm C40 particle removal	>99%
Accuracy of dilution factor	> 10% (Typically 7%)

Super-Low Level PM Analyzer

Model	MEXA-1370PM
Concept	Vaporization, Oxidation, De-oxidation
Detector	NDIR
Components	Soot, VOF, SO_4, Total PM
Lower detection limit	SOF: 0.2 microgram Soot: 0.2 microgram SO_4: 8.0 microgram
Analysis time	4 minutes
Correlation with gravimetric	Higher than 95%

Oxidization & Deoxidization Method

Transient Performance of DPF via Light Extinction and Scattering Methods

Figure 3. Optical layout for the scattering measurements

Figure 6. Temporal change in filtration efficiency under an acceleration test from low idle to high idle condition (Engine A)

Table 1. Specifications of test engines and diesel particulate filters

	Engine A	Engine B	Engine C
Type	L6,TDI	L4,TDI	L4,TDI
Displacement [L]	11.0	3.0	4.0
Filter volume [L]	22.3	5.0	5.8
Cell density [Cell/in^2]	300	200	200

Figure 9. Scattering intensity and mean radius of gyration of soot aggregates measured before particulate filter (1500 rpm, Engine B)

DPF

Figure 10. Scattering intensity and mean radius of gyration of soot aggregates measured after particulate filter (1500 rpm, Engine B)

07NAPLES-144

Evaluation of Transient Performance of Diesel particul e Filters via Light Extinction and Scattering Methods

T.Kamimoto, M.Shimono and A. Takahashi (Tokai University) , T.Minagawa (Tsukasa Sokken Co.Ltd.)

Dual Mode DMA for Nuclei and Accumulation Mode PMs

WYCKOFF, Japan

Continuous Time of Flight Aerosol Mass Spectrometer (C-TOFAMS)

from Sasaki, JARI

Typical result of C-TOF-AMS

from Sasaki, JARI

Size distribution for each component

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Multi-step Model for Soot Formation

Four-step model

Fuel →Condensation →PAH

PAH → Poly-condensation → PM precursor (Oligomer/dimer, trimer etc.)

PM precursor → Nucleation → Nuclei-mode PM

Nuclei-mode PM→ Accumulation→ Accumulation-mode PM

Growth of PAH$^+$ and formation of charged soot in the burned gas

Fig. 4.4. Compressed mass spectrum of charged species in a sooting acetylene/oxygen flame at the beginning of the soot formation zone; C/O = 1.0, v_u = 24 $cm\ s^{-1}$, p = 2.7 kPa, h = 12 mm

Silke loffler, Philipp Loffler, Petra Weilmunster and Klaus H. Homann: Growth of Large ionic Polycyclic Aromatic Hydrocarbons in Sooting Flames:H.Bockhorn (Ed): Soot Formation in Combustion, Springer-Verlag (1994), p66-82.

Pool combustion system for fundamental research

Simple flame for PM research

LIF and GC analysis on propane diffusion flame

(GU, Japan)

PM Formation from Diffusion Flame of Liquid Fuel

(GU, Japan)

Fig.6 Flame photographs of diesel fuel

PM Research with Laser Induced Fluorescence System (GU, Japan)

LIF with KrF Excimer (248nm)

LIF with KrF-Dye Excimer (290nm)

GC results on the flame center axis (GU, Japan)

The PAHs exists even in the sooting region on the flame center axis.

Gas Chromatography (SHIMADZU GC-14BP + GC-14BPF)		
Column	Capillary column	
Ditecter	**FID**(Flame Ionization Detecter)	
Analyzable spesies	Benzene	C_6H_6
	Toluene	C_7H_8
	Naphthalene	$C_{10}H_8$
	Butylbenzene	$C_{10}H_{14}$
	Diphenyl	$C_{12}H_{10}$
	Fluorene	$C_{13}H_{10}$
	Pyrene	$C_{16}H_{10}$

Geometrical Characterization for PM -1

(Argonne National Lab. USA)

Figure 1. Image of burner under study with x-rays

Table 1. Conditions for different premixed flames

Flame	Ethylene SLPM	Oxygen SLPM	Argon SLPM	Speed mm/s	C/O
#1	0.16	0.28	0.93	80	0.58
#2	0.19	0.28	0.93	81	0.67
#3	0.23	0.28	0.93	84	0.82
#4	0.30	0.28	0.53	64	1.07

Figure 3. Differential size distribution of PM calculated from the SAXS profiles shown in Figure 2. For clarity, the distribution for the primary particles has been divided by ten.

Soot Burnout Rate (NASA Glenn Research Center)

Figure 1—Experimental schematic.

Figure 2—Dependence of soot mass burnout rate with excess O_2 percentage (O_2/air, v/v %) in the post-flame gases with the air flow being fixed at the value (flow rate) to produce complete combustion. The NSC rate is also shown for comparison. The measured oxidation temperature was 750 °C, as was also used in the NSC calculation. See text for details.

Soot (Benzene) ------- Soot (Ethanol) ------- Soot(Acetylene)
Short ----------Graphene Segment----------Long
Disordered Carbon ---------- Graphitic Structure

Oxidation Rate of Carbon-black (Printex-U) Temperature Programmed Oxidation

$$\text{Carbon oxidation rate } (\mu g/\text{sec}) = \frac{(CO+CO_2)(ppm)\times M_{W,carbon}(g/mol)\times \dot{V}_{total}(l/\text{sec})}{\text{molar volume}(l/mol \text{ at std})} \quad (1)$$

$$-\frac{dC}{dt} = k_1(T)\times C^{n_{C,1}} \times P_{NO_2}^{n_{NO_2,1}} + k_2(T)\times C^{n_{C,2}} \times P_{NO_2}^{n_{NO_2,2}} \times P_{O_2}^{n_{O_2,2}} \quad (2)$$

$$k(T) = A\exp\left[\frac{-E_a}{R_U T}\right] \quad (3)$$

$$\ln(k) = \ln(A) - E_a / R_U T \quad (4)$$

Figure 1 Schematic diagram of the reactor and the sample deposition

$$\ln\left(\frac{dC}{dt}\right) = n_c \ln(C) + \ln(k(T)P_{NO_2}^{n_{NO_2}}) \quad (5)$$

$$-\frac{1}{C^{n_C}}\frac{dC}{dt} = k(T)P_{NO_2}^{n_{NO_2}} \quad (6)$$

$$-\frac{dC}{dt} = k_1(T)\times C^{n_C} \times P_{NO_2}^{n_{NO_2}} \times \left(1+\frac{k_2}{k_1}P_{O_2}^{n_{O_2}}\right) \quad (7)$$

$$y = C_n(1+ax^b) \quad (8)$$

m_C : the sample soot mass undergoing reaction
n_C, n_{O2}, n_{NO2} : reaction order of carbon, oxygen and nitrogen dioxide
P_{NO2}, P_{O2} : partial pressure of nitrogen-dioxide, oxygen
k : specific reaction rate constant
E_a : activation energy
R_u : universal gas constant
T : temperature(K)

Figure 9 Specific reaction rate vs. temperature. Printex-U 10mg, NO2 900ppm, dT/dt=5°C/min □ no oxygen, ○ O_2 2%, △ O_2 5%, ▽ O_2 7%, ◇ O_2 10%.

Figure 10 Specific reaction rate at T=400°C, Printex-U 10mg, ■NO2 900ppm, ●NO2 500ppm, ▲NO2 200ppm, x – axis spans for O2 concentration

Diesel PM Generator for DPF Development

Figure 1: Diagram of the PM generator.

Figure 2: Comparison of the particle size distributions from a 2002 diesel Ford Focus to the soot generator's 57 nm setpoint.

Figure 3: Comparison of the particle size distributions from a 2002 diesel Ford Focus to the soot generator's 76 nm setpoint.

2007- 01- 0322
A Soot Generator for DPF Qualification Studies
Standip D.Shah ad Douglass A.Dobson (Ford Research and Innovation Center

Nano-size PM from diffusion flame of diesel fuel (GU, Japan)

Diesel PM for fundamental study and calibration

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Diesel PM (GU, Japan)

Fundamental PM Study: In-Cylinder PM
Low Temperature Combustion 1/2

Figure 1. Schematic diagram of the optically accessible DI diesel engine and optical setup.

Figure 2: Top view of piston, showing bowl-rim cut-out, laser sheet illumination, and periscope field of view.

Figure 5. Full camera field of view relative to in-cylinder features.

2006-01-0079

Multiple Simultaneous Optical Diagnostic Imaging of Early-Injection Low-Temperature Combustion in a Heavy-Duty Diesel Engine

Mark P. B. Musculus (Sandia National Laboratory)

Fundamental PM Study: In-Cylinder PM
Low Temperature Combustion 2/2

Figure 14: Schematic representation of the features in the jet cross-section of the extension of the conceptual model for diesel combustion to low-load, early-injection, low-temperature conditions.

2006-01-0079

Multiple Simultaneous Optical Diagnostic Imaging of Early-Injection Low-Temperature Combustion in a Heavy-Duty Diesel Engine

Mark P. B. Musculus (Sandia National Laboratory)

Spectral Analysis of Soot Formation Process via Excitation-Emission Matrix (1/2 TIT, Japan)

Reference EEM

Measured EEM

Soot Formation Process at Different Ambient Temperatures (2/2 TIT, Japan)

Fuel effect on PM nano-structures

Table 2. Detailed Chemical Compositions of Fuels

Fuel	sulfur (wt ppm)	n-paraffins (%)	iso-paraffins (%)	naphthene (cyclo-paraffin) (%)	aromatics (%)
HF328	110	11	20	47	21
AF1	500	36	57	7	0
AF2	110	36	57	7	0
AF3	110	75	21	3	0
AF4	110	35	25	40	0
AF5	110	35	25	3	35

Figure 1. Thermophoretic sampling apparatus mounted on a light-duty diesel engine: (1) sampling probe/chamber, (2) solenoid-valve assembly unit, and (3) electronic timing/trigger unit.

30nm, one nucleus near the center

15nm, multiple nuclei

Figure 11. HRTEM images of two different particu collected at 2500 rpm/50% load condition, (a) AF5 AF2.

Figure 12. Size distribution of aggregate particles for two different particulates collected at 2500 rpm/50% load condition (a) AF5 (b) AF2.

Rg: Radius of gyration

Sulfate and Nano-PM (280 ppm Sulfur and Ramp-up/down Test)

$$SO_2 + \frac{1}{2} O_2 \leftrightarrow SO_3 \qquad (1)$$

Figure 3: Particle size distributions at different operation speeds during the dynamometer tests (average of two scans for 90, 100 and 110 km/h and four scans for 120 km/h). The top panel corresponds to higher dilution air temperature and longer residence time than the bottom one. Exact sampling conditions are given on the legend. "Up" and "down" as in Figure 2 caption.

igure 4: Real time emission rates from ELPI (solid particles) and CPC otal particles) for the speed ramp tests. Several NEDC cycles have reeded the initiation of the speed ramp test.

Figure 8: SO_2 to SO_3 conversion estimation by combining data from different studies. Noble metals/washcoats considered: Pt/SiO_2 (Xue et al. [25]), Pt_2/Al_2O_3 (Wyatt et al. [27]), Pt/Al_2O_3 with different compositions (Deeba et al. [28]), Pt/Al_2O_3 (Horiuchi et al. [29]).

2007-01-1110
Effect of Speed and Speed-Transition on the Formation of Nucleation Mode particl m a Light Duty Diesel Vehicle
Barouch Giechaskiel, Leonidas Ntsiachristos, and Zissis Samaras (laboratory of Applied Thermodynamics, Aristotle University, Thessaioniki, Greece), Robert Casati, Volker Scheer and Rainer Vogt (Ford Forshungszentrum Azchen GmbH, Aachen, Germany)

General Review: Diesel Engine Strategy for Low Emission Vehicle

2005-01-1091

Figure 2. LTC and PCCI concept on ϕ – T map

2006-01-0030

Figure 4. Principle of advanced combustion, wherein the flame temperature and equivalency ratio, , are kept away from NOx and PM formation regimes using injection timing and EGR (12).

2005-01-1091
New Diesel Emission Control Strategy to Meet US Tier 2 Emissions Regulations
Gray D.Neely. Shizuo Sasaki, Yiqun Huang, Jeffrey A.Leet and Daniel W.Stewart (Southwest Research Institute, SwRI)

2006-01-0030
Diesel Emission Control in Review
Timothy V. Johnson (Corning Incorporated)

PM Emission: EGR and Engine-out Smoke

Fig. 3 Effect of large ratios of cold EGR on particulate matter (Q_f = 32 mm³/stroke)

(b) Smoke

2006-01-1147

Characteristics of Diesel Combustion in Low Oxygen Mixtures with Ultra-High EGR

Hideyuki Ogawa and Noboru Miyamoto (Hokkaido University), Hajime Shimizu (Toyota Motor), Shingo Kido (Kanto Auto Works)

SOF components and Lubricant oil

A. Chromatograms of Fuel and Lube Oil

B. a Chromatogram of a Sampled SOF

Figure 4 SOF Components of Fuel and Lubricant Oil Origin

Figure 7 PM Components with EGR Rate

Figure 8 PM Components with BMEP

Figure 10 PM Components with BMEP using Oxidation Catalyst

2007-01-0123
SOF Components of Lubricant Oil on Diesel PM in a High osted and Cooled EGR Engine
Hideaki Osada, Yuzo Aoyagi and Kazuaki Shimada (New ACE Institute Co.,Ltd), Kenichi Akiyama (Japan Automobile Research Institute), Yuichi Goto and Hisakazu Suzuki (National Traffic Safety & Environment Laboratory)

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Environmental PM Problem: Operation Mode and PM

Figure 1 Partial flow dilution system for particle size measurement

Acceleration: Δ rpm >25rpm/s, Deceleration: Δ rpm < - 25rpm/s, Idle: rpm< averaged rpm of idling + 3 σ

Figure 7 Categorized particle size distribution of the heavy duty diesel engine under JE05 mode.

PM Size Distribution: Engine-out and Tail-pipe PM Emission

Figure 8: Effect of a DOC and of a PM-Cat on the particle size distribution of a bus traveling at 20 km/h and 60 km/h.

2006-01-0866

Diesel Particle Exhaust Emissions from Light Duty Vehicles and Heavy Duty Engines

Leonidas Ntziachristos, Athanasios Mamakos and Zissis Samaras (Laboratory of Applied Thermodynamics, Aristotle university Thessaloniki), Martin Rexeis and Stefan Hausberger (Institute for Internal Combustion Engines and Thermodynamics, Graz university of Technology)

Ultrafine Solid Particle from Clean Diesel Truck

Figure 4. Sampling locations. 1 Pre-trap partial flow sampling. 2. Post trap partial flow sampling. 3. Full flow sampling (post trap).

Figure 7. Particle size distribution measured at location 1 (pre-trap), 2 (post trap) and 3a (post trap, directly from CVS and prior to thermal conditioning). Blue signifies 'cold' dilution with no heating of the primary dilution air nor the ET. Red signifies 'hot' dilution with heating of both the primary dilution air and the use of the ET. Green signifies heated primary dilution air, but no heating with the ET.

Figure 8. Cumulative normalized size distribution measured at location 2 (post-trap) using the PMP protocol (heated primary dilution air and evaporation tube). 25-75% of solid particles are smaller than 20 nm and are not counted by the PMP.

Figure 9. Gravimetric and post trap Partial Flow PMP particle number measurements (Location 2). The gravimetric measurement is the average of 10 repeated CBD cycles. The particle number measurements are averages of total particle count for only three measurements, two with the ET heated and one with the ET unheated.

PM Composition (SOF, Sulfate, Elemental Carbon and Ash)

MEXA-1370
SOF: Soluble Organic Fraction
SO4: Sulfate Fraction
SOL: Insoluble Fraction
(Elemental Carbon + Inorganic Ash)

Figure 9. Pre-DPF PM composition at 1682 rpm, 25% load, with a trap inlet temperature between 270-280 ℃.

Figure 10. Post-DPF PM composition at 1682 rpm, 25% load, with a trap inlet temperature between 270-280 ℃.

Figure 19. TGA profile for typical pre-DPF PM sample collected at 1682 rpm, 25% load.

TGA (Thermo-Gravimetric Analysis)
High Volatile Fraction: 160?C in N2
Medium Volatile Fraction: 650?C in N2
Combustible Fraction: 650?C in Air
Ash Remaining

Figure 20. PM composition as determined by TGA for pre-DPF PM at 1682 rpm, 25% load.

Figure 22. Typical STEM spectrum of ash generated from PM entering DPF at 1682 rpm, 25% load.

STEM (Scanning Transmission Electron Microscopy)

2007-01-0318
Detailed Chemical and Physical Characterization of Ash Species in Diesel Exhaust Entering Aftertreatment Systems
Alexaander G. Sappok and Victor W. Wong (Massachusetts Institute of Technol oan Automotive Laboratory)

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Progress of Diesel Particulate Filter Simulation (CERTY/CPERI)

Figure 2. DPF simulation has to face multiple scales, Figure from [9].

$$C + NO_2 \rightarrow CO + NO \qquad (12)$$

$$NO + \frac{1}{2}O_2 \leftrightarrow NO_2 \qquad (13)$$

Figure 26. Cross section of filter channels showing the front view of tl CFD computational domain.

Figure 20. Schematic of the two-layer model of catalytic coating.

Figure 41. (a) 3-D simulation of a DPF placed downstream of a 45° bend in the exhaust. (b) Soot mass and velocity distribution at the inlet face at different soot loads of the filter. (c) Evolution of radial soot mas profile (along the dotted line) at different soot loads of the filter and resulting pressure drop.

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Progress in Diesel Filter Particulate Filter Simulation
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Two-layer Soot Oxidation Kinetics with Fuel-burne Catalyst

Figure 1. Schematic illustrating the DPF wall, catalytic coating influenced Layer I and the top Layer II, not in the sphere of influence of the catalyst.

$$\frac{dm_1}{dt} = (-k_{cat}\beta m_1 - k_{th}(1-\beta)m_1)(1-\xi) \quad (1)$$

$$\frac{dm_2}{dt} = -(k_{th}m_2 + \xi(\beta k_{cat}m_1 + (1-\beta)k_{th}m_1)) \quad (2)$$

Table 2. Kinetic parameters of Two-Layer model for all materials

	Material	$k_{0,th}$	$k_{0,cat}$	E_{th}/R	E_{cat}/R	β	ξ
1	F6014PS					0.032	0.195
2	F6007PV	1.31E+05	1.20E+06	21410	17893	0.075	0
3	F6012PV					0.064	0.642
4	F8012A					0.008	0.133
5	F8015P1					0.024	0.133
6	F80M6U	1.93E+07	8.62E+05	21725	16927	0.0014	0.127
7	F8016W					0.147	0.290
8	F8018A					0.019	0.343
9	F100M4A	1.43E+05	3.55E+05	22219	15983	0.017	0.213
10	M	6.20E+04	3.95E+06	21375	20182	0.214	0.013
11	T	4.65E+01	7.19E+03	16176	11494	0.0006	0.013

Figure 5 Simulated curve for soot oxidation based on the two-layer model.

Figure 7. Comparison of the Two-Layer model with the experimental data for the F8012A material.

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Soot Oxidation Kinetics in Diesel Particulate Filters
Athanasios G. Konstandopoulos, Margaritis Kostoglou, Souzanna Lorsentzou, Chrysa Pagkoura and Eleni Papaionnou (Aerozol & Particle Technology Laboratory, CERTH/CPERI), kazushige Ohno, Kasutake Ogyu and Tomokazu Oya (ibiden Co.Ltd.)

DPF: Temperature Distribution and Thermal Stress

Figure 4. Comparison of Temperature Profile during Regeneration

Figure 12. Tensile Stress Distribution

Figure 13. An Example of Radial Crack

2006-01-1527

The Study for Structural Design of the Segmented SiC-DPF

T.Mizutani, M.Ito, N.Masukawa, S.Ichikawa, K.Yuuki and H.Kurachi (NGK Institute, Ltd.), T.Toyoshima, T.Ito, I.Lappas, A.Schaefer-Sindlinger and C.D.Vogt (NGK Europ GmbH)

DPF: PM Oxidation Behavior

Figure 13. Test Rig to Observe PM Combustion

Figure 17. Combustion Process of Particulate on the Test Specimen at Several Seconds in Gas Containing 10 Percent Oxygen

2006-01-0878

DPR with Empirical Formula to Improve Active Regeneration of a PM Filter

Toshikatsu Muramatsu, Tetsuichi Kominami, Jinichi Minamikawa and Munetomo Matsunami (Hino Moters, Ltd.)
Junji Komatsu (Hitachi Metals, Ltd.) Jun Ozawa (Tokyo Roki Co., Ltd.)

DPF: Catalyst Oxidation of PM Layer

Figure 4 Axial Zoning Designs of a CSF: uniform coating vs zone coating

Figure 14 Soot regeneration efficiency of uncoated, zoned and uniform CSF tested at two different temperatures (10 g/dm³ soot loading, 30 min at temperature)

Figure 13a Soot in the inlet channel of the rear zone in a catalyzed soot filter: soot layer thickness: 70 µm

Figure 13b Soot in the inlet channel of the rear zone in a non-catalyzed soot filter: soot layer thickness: 170 µm

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Catalyzed Soot Filters in Close Coupled Position for Passenger Vehicles

Alfred Punke, Gerd Grubert, Yuejin Li, Joseph Dettling and Torsten Neubauer
Engelhard Corporation

PM Trap Efficiency of DPF and Pressure Drop

Figure 7. Particle size distribution for raw exhaust

Initial Breakthrough

Figure 19. Total concentration upstream (US) and downstream (DS) of the filter with the pressure drop (Mode 3, Filter C)

Figure 11. Conceptual model of the pressure drop during DPF filling [19]

Greenfield gap

Figure 25. Fractional filtration efficiency downstream of a DPF (Mode 3, Filter B)

2007-01-0320

Detailed Diesel Exhaust Particulate Characterization and Real-Time DPF Filtration Efficiency Measurements Suring PM filling Process

Ekathai Wirojsakunchai, Eric Schroeder, Christopher Kolodiej and David E.Foster (University of Eisconsin – Engine Research Center), Niklas Schmidt and Thatcher Root (university of Wisconsin – Madison), Terunal Kawai (National Traffic Safety and Environmental laboratory), Toshiyuki Suga (Honda R&D. Inc.), Tim Nevius and Takeshi Kusaka (Horiba Instrument, Inc.)

New DPF System: Photocatalyst-Plasma and Honeycomb

Figure 1 (a) Schematic of a PPH converter

Figure 3 Emission Results of D13 Mode Test with O-PPH + Bare DPF

$$TiO_2 \xrightarrow{hv} TiO_2(h^+) + e^- \qquad \text{(Eq. 1)}$$

$$H_2O + TiO_2(h^+) \rightarrow OH^{\bullet} + H^+ + TiO_2 \qquad \text{(Eq. 2)}$$

Figure 1 (b) Plasmas generated on a photocatalyst coated ceramic honeycomb monolith substrate

Figure 2 Assembled O-PPH and PP-DPF Converter

2006-01-0876

PM Reduction in Diesel Exhaust Gases with a Photocatalytic DPF Reactor

Geon Seon Son, Cheon Seog Gwak, Eui Rak Choi and Cheol Won Hwang (Neophotech Inc)
Soong Kee Kim and Ki Kyoung Bae (GM Daewoo Auto & Technology)

Electric Diesel Particulate Trap (E-DPT) (GU, Japan)

Schematic of Urea-SCR System

from Nissan Diesel

Urea Hydrolysis

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

NO$_x$ Reduction

$$4NO + 4NH_3 + O_2 \rightarrow 4\,N_2 + 6H_2O$$

$$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O$$

$$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$$

After treatment system of NOx and PM

DPNR

H.Ohmori, JAMA Mar.2005, 3rd Asia Petroleum Technology Symp. Kuala Lumpur Malaysia

Control System of DPF: Aftertreatment Control Strategy

Figure 1. An example of a future integrated soot-NO_x emission control system. DPF stands for Diesel Particulate Filter. Sensory inputs of temperature (T), pressure (P), pressure drop (ΔP), soot and NO_x concentration will be required along the exhaust pipe.

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Summaries: Issues of Diesel PM Problem

1. PM and Nano-PM Problem
   Health effect mechanism, Special effect of Nano-PM
2. Trend of Nano-PM Research
   Laser diagnostics ⇒ In-cylinder PM
   ⇒Nano-PM ⇒ EC+OC ⇒ PM characterization
   DMA+CPC ⇒Tail pipe PM ⇒ DPF ⇒ PM oxidation
3. PM Measurement
   Engine out PM, Calibration method of equipment
   Solid Particle Sampling
   Nano-PM characterization for health effect
4. Fundamental Research of PM
   PM characterization, Formation and oxidation mechanism
5. Diesel Combustion and PM
   PM formation and oxidation schemes for simulation
6. Tail Pipe PM Emission
   Mandatory limit of mass and number concentrations of PM
7. Aftertreatment
   Engine control for simultaneous reduction of NOx and PM
   New aftertreatment system

Thank You for Your Kind Attention