Nanoparticle emissions from an off-road Diesel engine equipped with a catalyzed diesel particulate filter

S. Di Iorio, A. Magno, E. Mancaruso, B. M. Vaglieco

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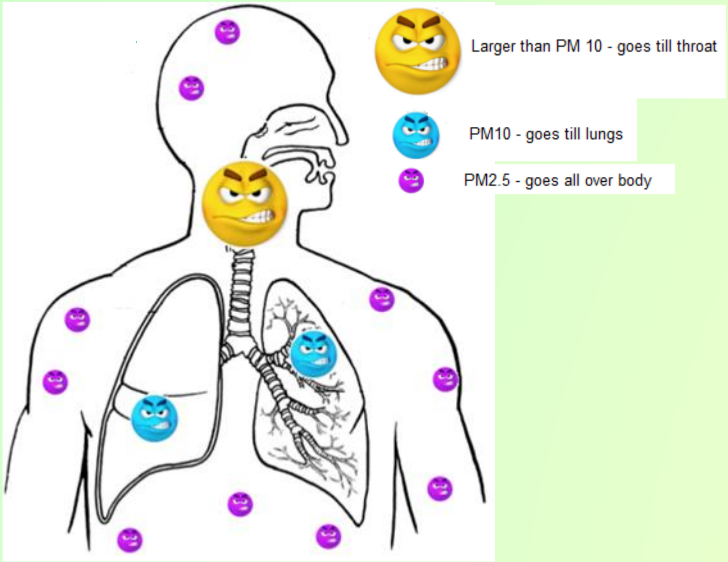
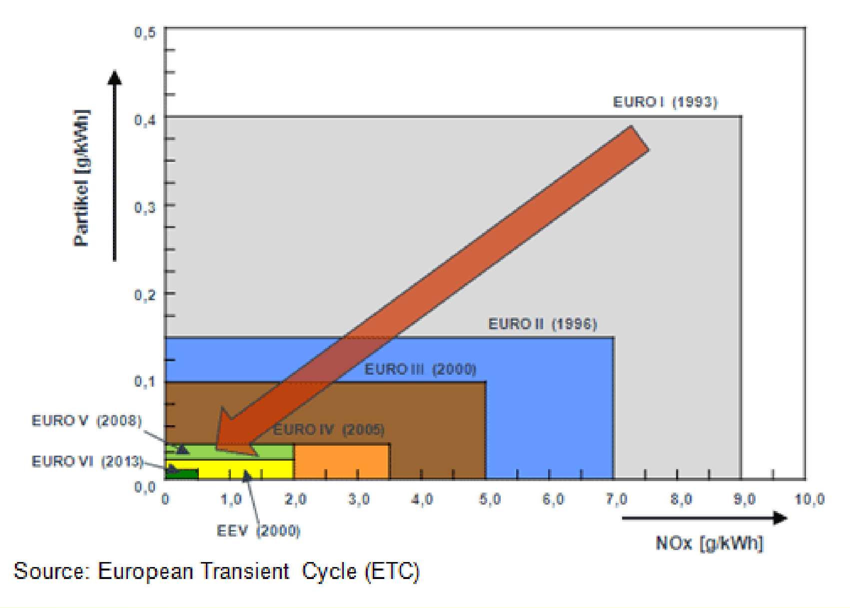
Main concerns on transportation

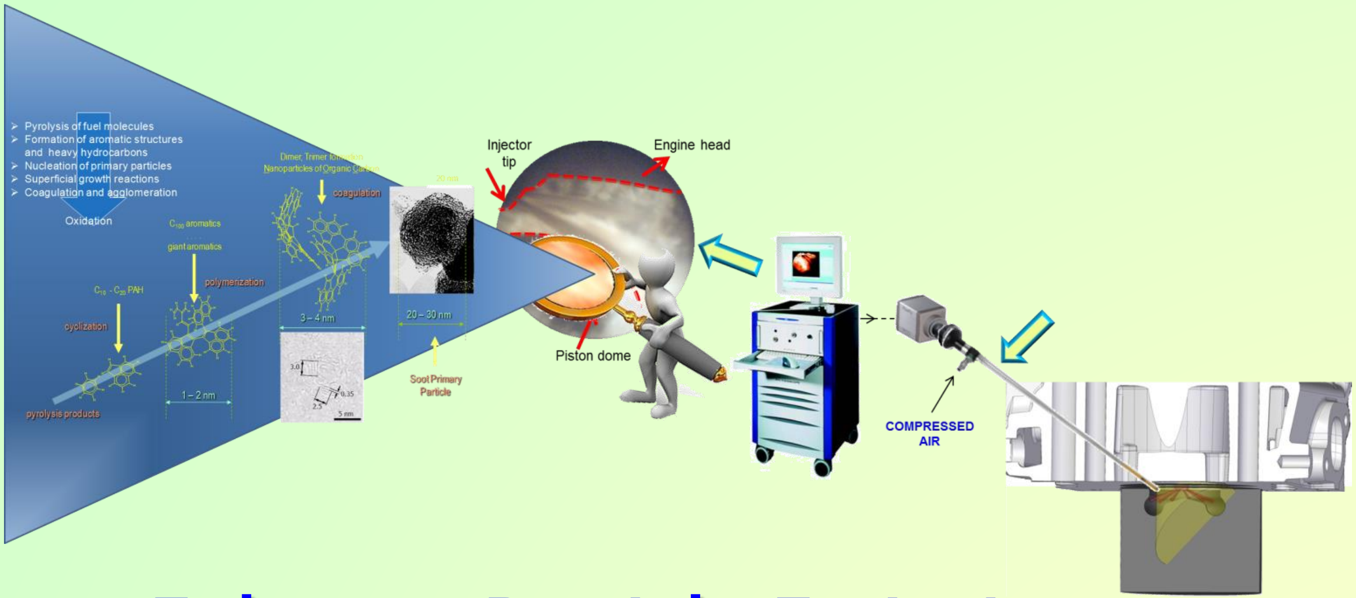




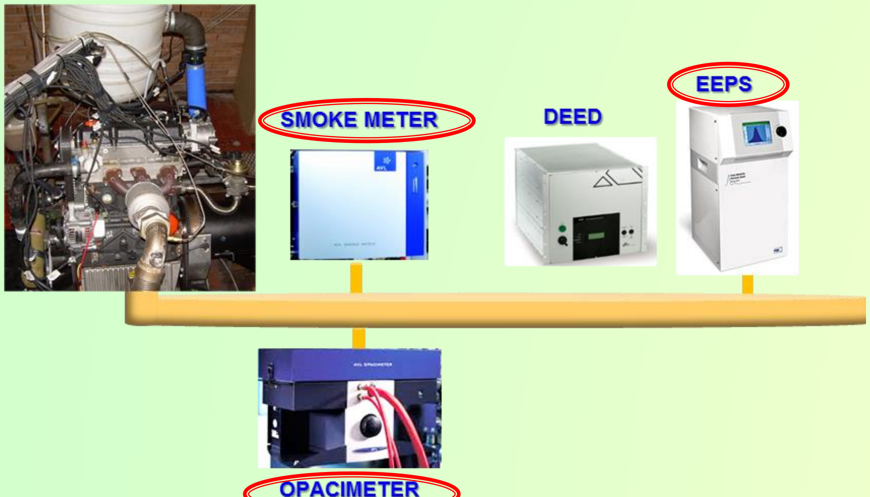
PN regulation

6.0×10^{11} 1/km of particles larger than 23 nm

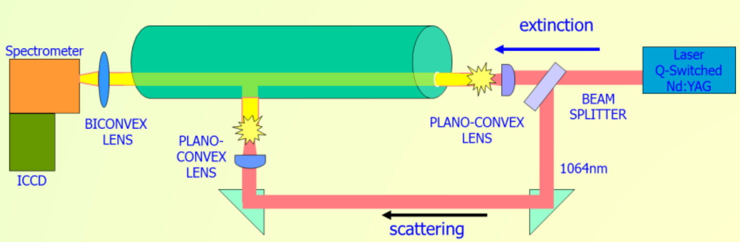
In-cylinder: Particle Formation



Exhaust: Particle Emissions

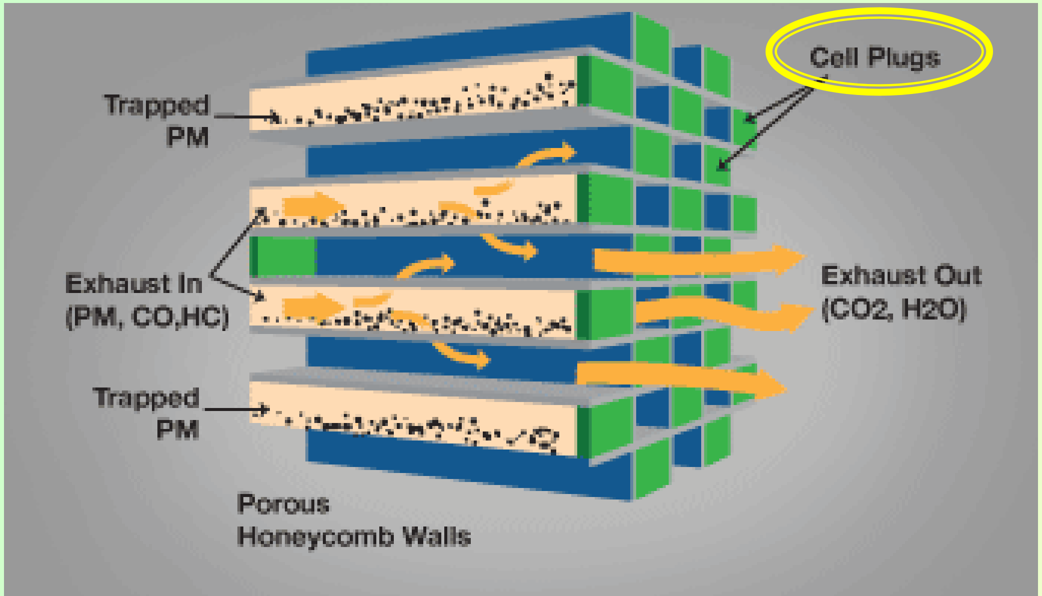


BUVESS



Chemical Information

PM emissions reduction: DPF



Structure of a typical Diesel Particulate Filter.

Monolithic structure *honeycomb* of porous ceramic material with high mechanical and thermal strength (cordierite, carbide silicon, SiC) or metal sintered.

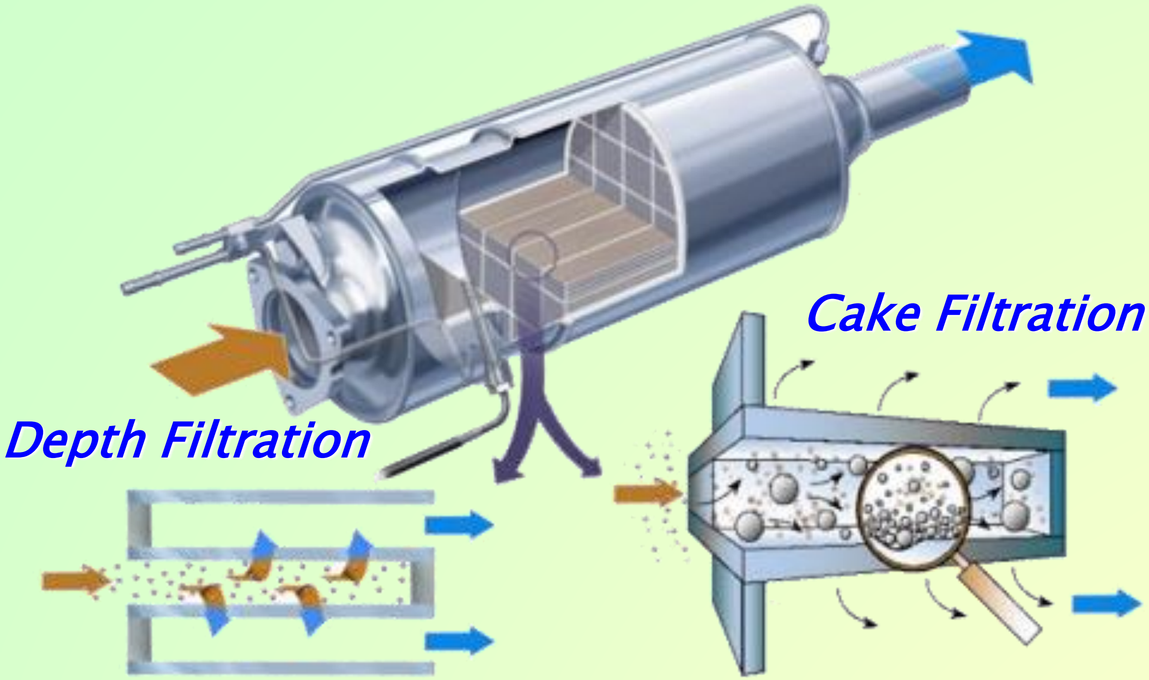
The cells are closed either by a side and the other in order to filter continuous gas discharge retain the particles

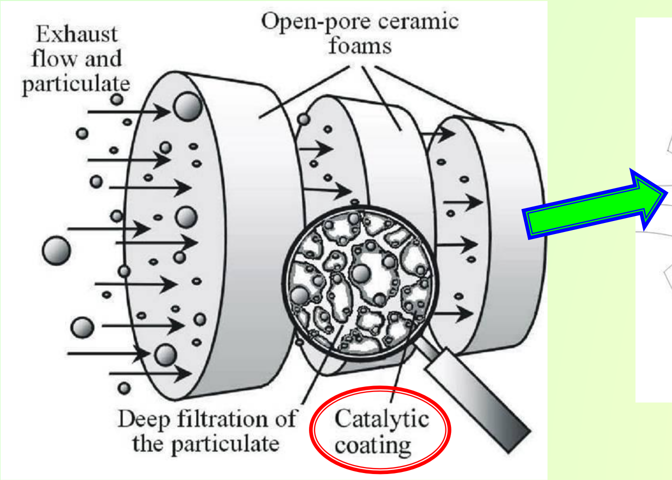
Filtration Efficiency

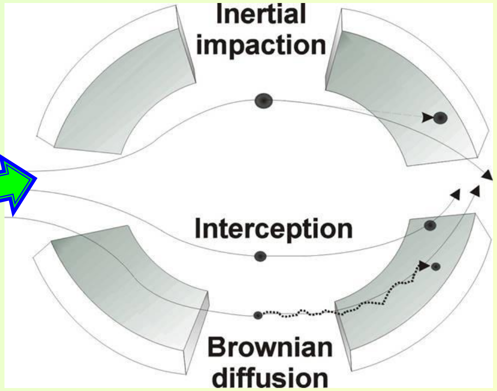
Filter Regeneration

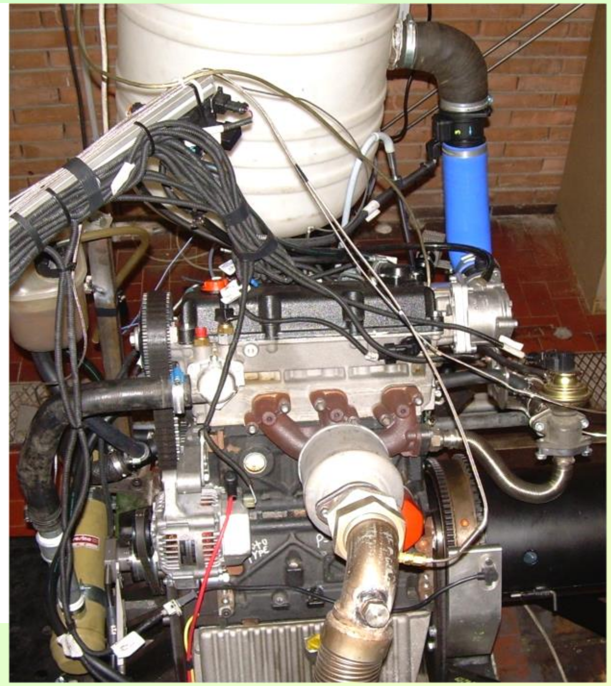
Particles<23nm

Ways of Filtration



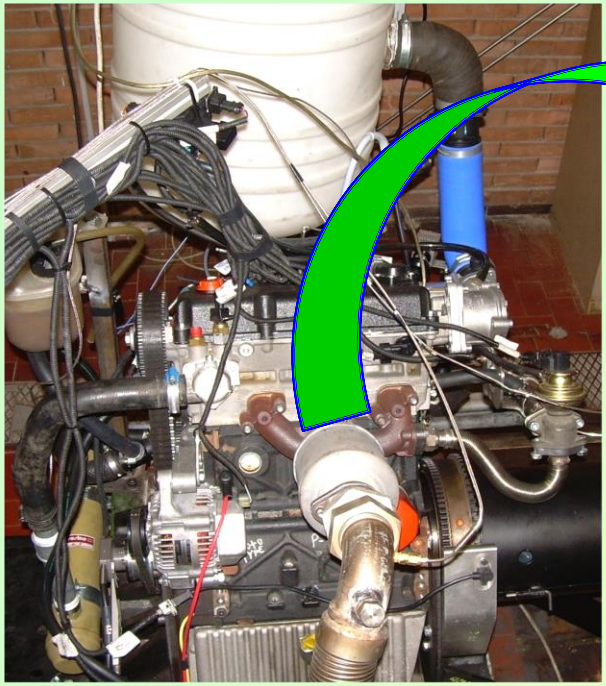


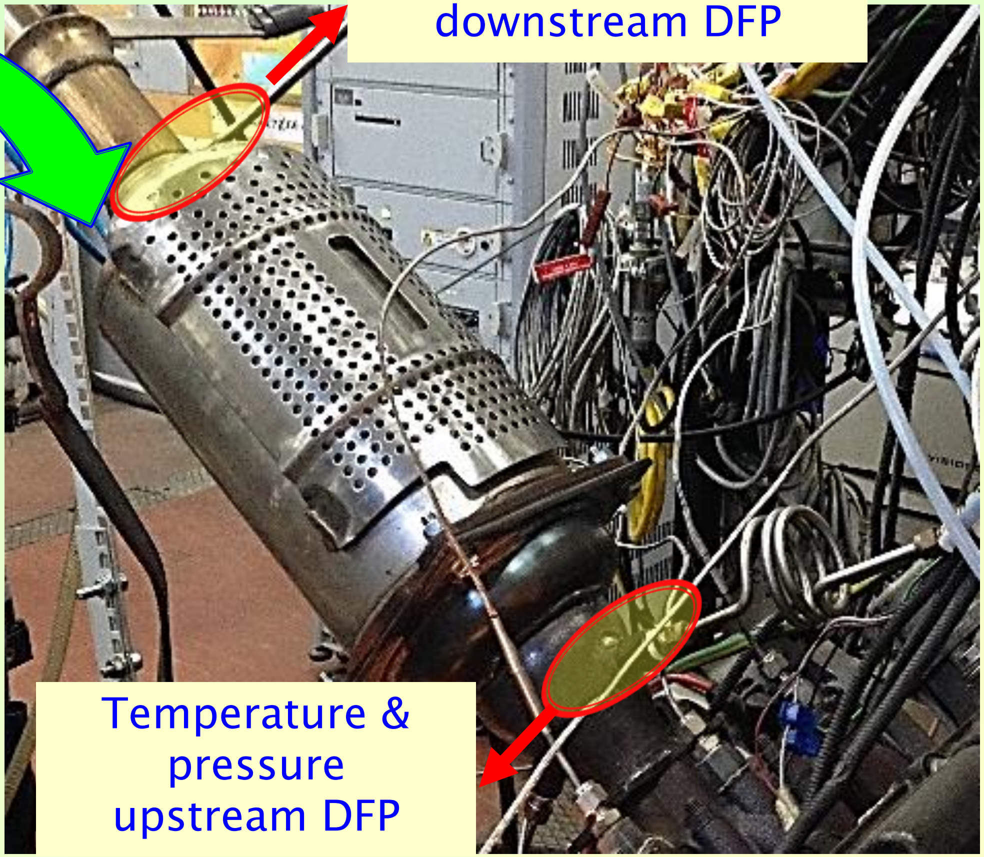




Engine	Compression Ignition
Number of Cylinders	3, in-line
Bore [mm]	75.0
Stroke [mm]	77.6
Displacement [cm^3]	1028
Compression Ratio	17.5:1
Max. Power [kW]	15 @ 3600 rpm
Max. Torque [Nm]	60 @ 2000 rpm
Injection System	Direct, Common Rail
Max injection pressure [bar]	1400
Aspiration	Naturally Aspirated

TEST ENGINE





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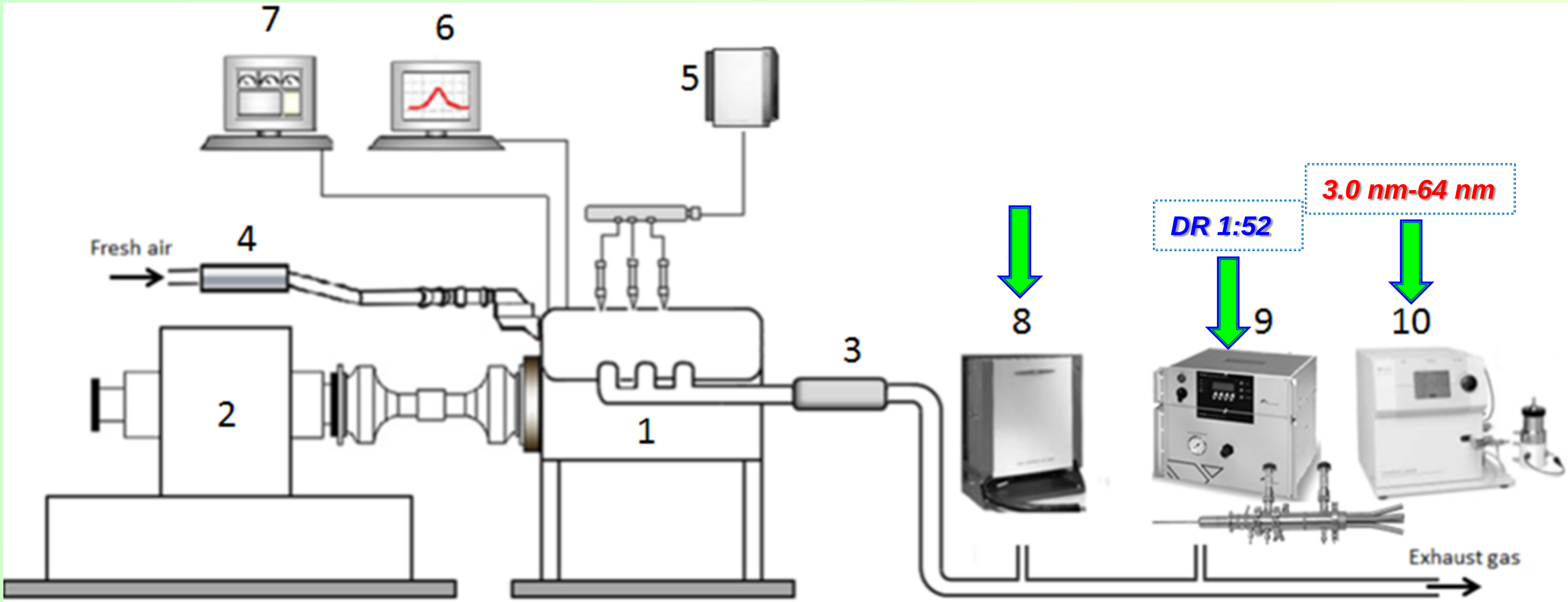
EXPERIMENTAL LAYOUT



1. Test engine
2. Dynamometer
3. DPF
4. Air flow meter
5. Fuel balance
6. High speed data acquisition
7. Low speed data acquisition
8. Smoke Meter
9. FPS
10. SMPS

Operating conditions

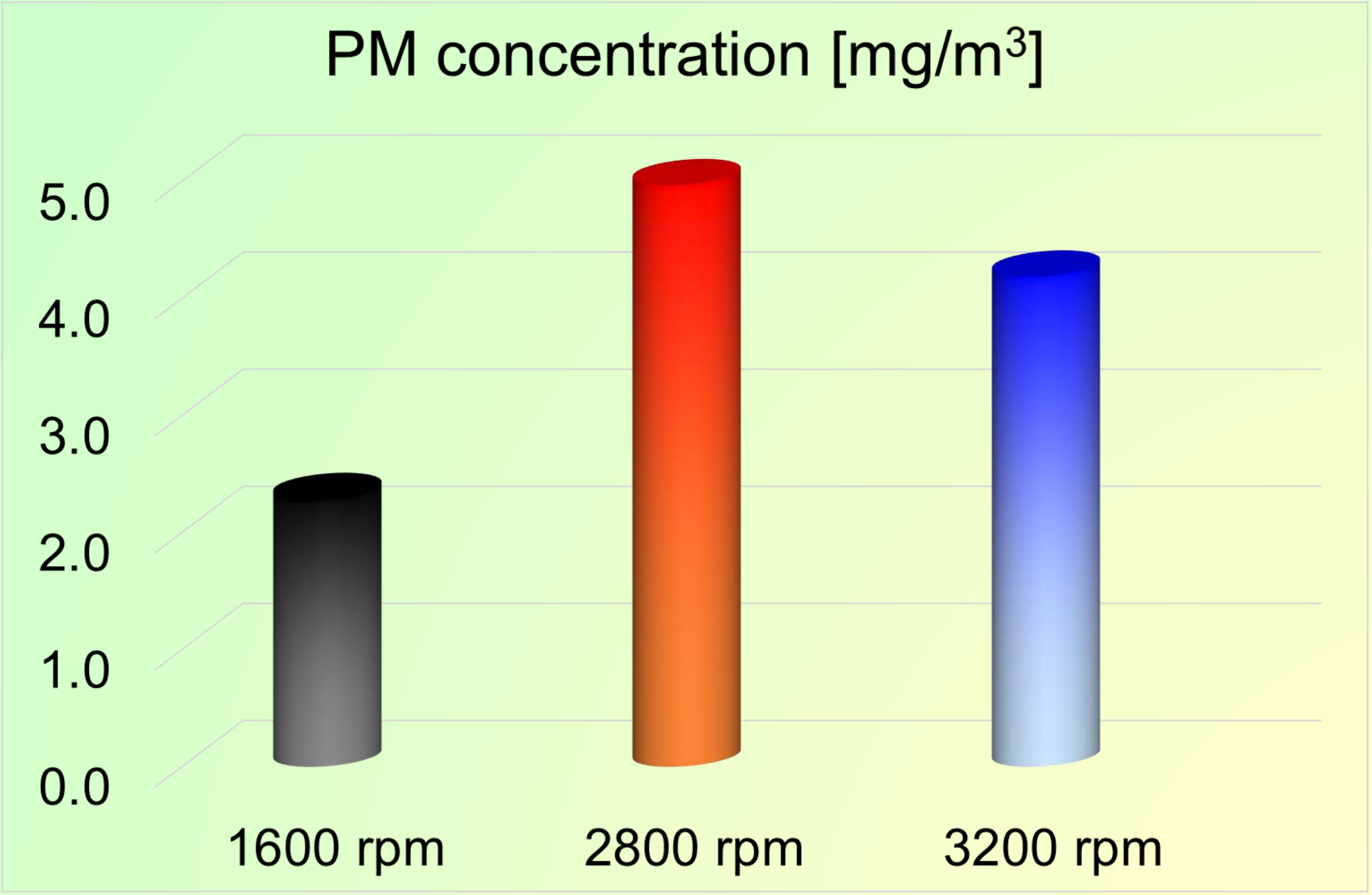
1600 rpm

2800 rpm @ 70% ***full load: 34 Nm***

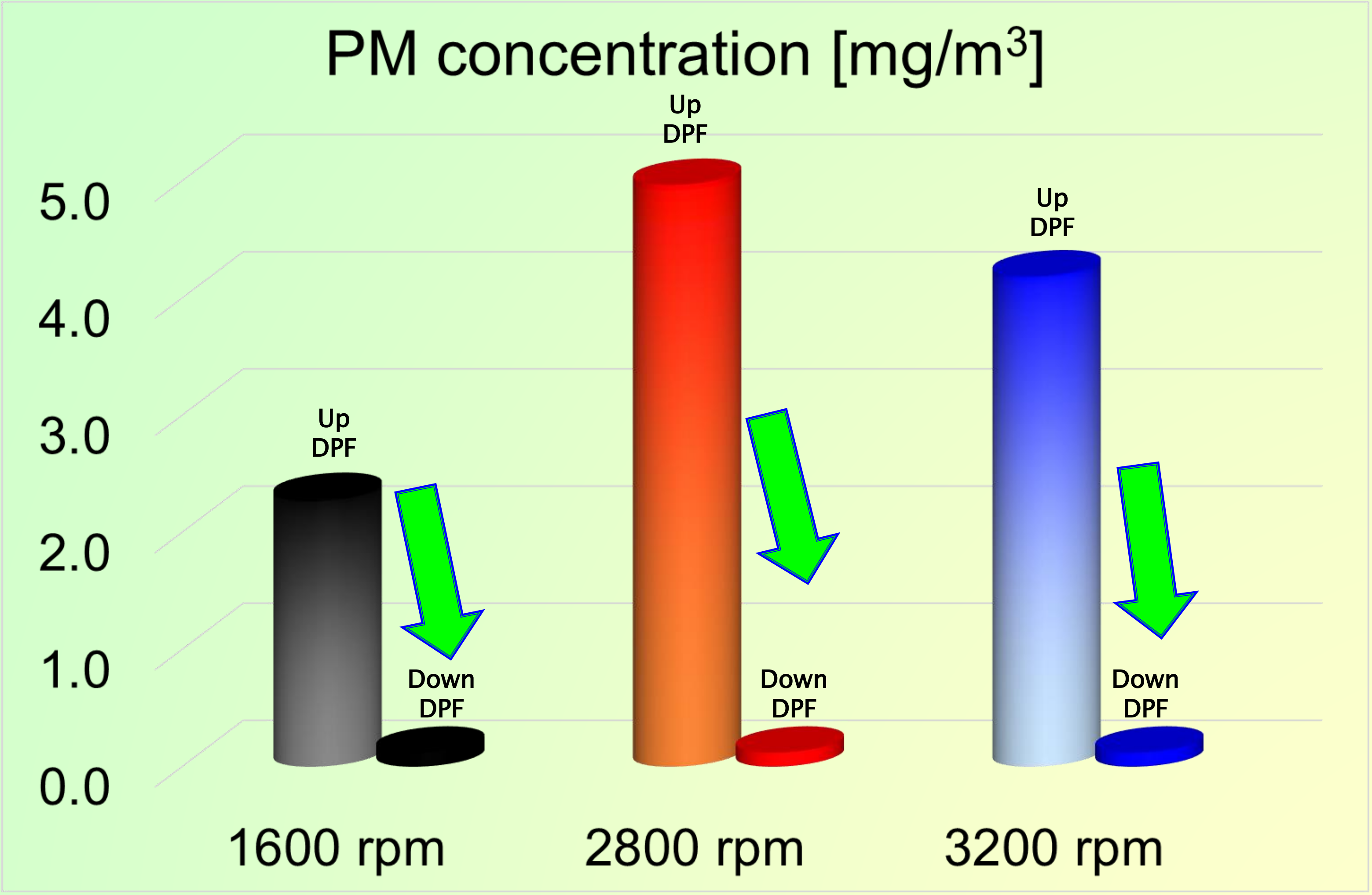
3200 rpm

Speed [rpm]	T_b [Nm]	SOI_{pilot} [cad]	DOI_{pilot} [μs]	SOI_{main} [cad]	DOI_{main} [μs]	p_{inj} [bar]	$\dot{m}_{diesel}$ [kg/h]	$\dot{m}_{air}$ [kg/h]	$T_{up\ DPF}$ [°C]	$T_{down\ DPF}$ [°C]
1600	36	−10.4	354	2.4	479	758	1.51	39.8	290	278
2800	35	−22.2	321	−4.4	464	923	2.59	82.3	349	315
3200	33	−33	344	−10.4	510	1045	2.90	101.5	363	310

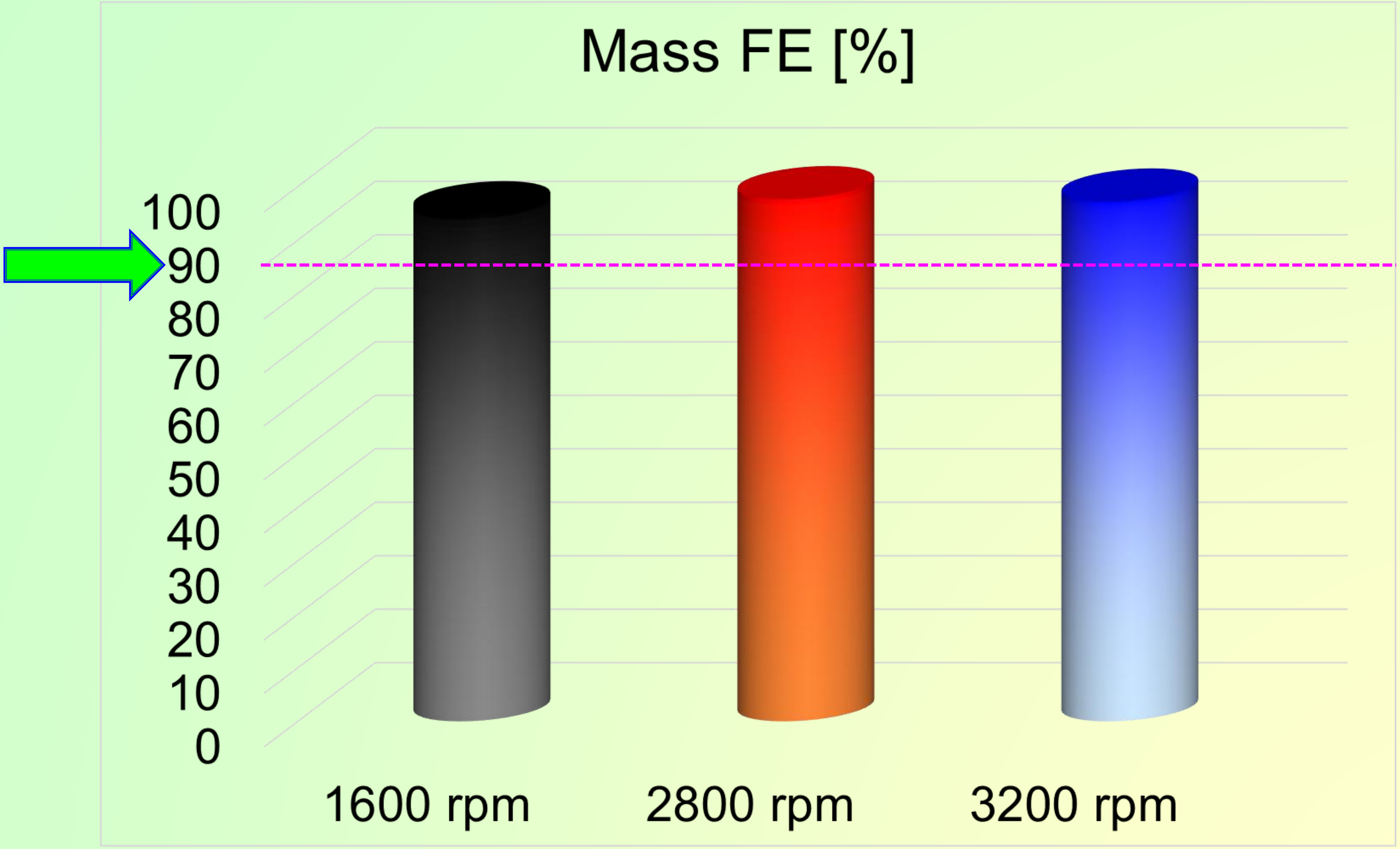
PM: Up vs Dwn DPF



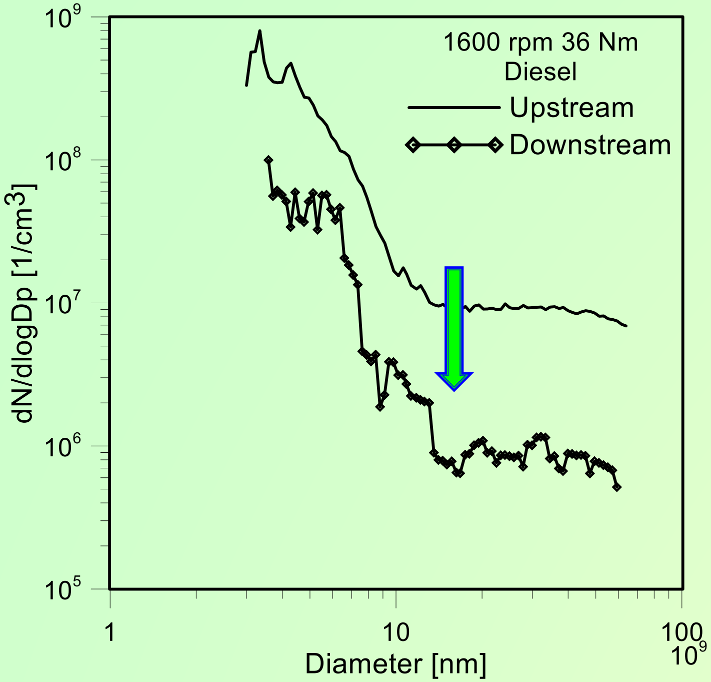
PM: Up vs Down DPF

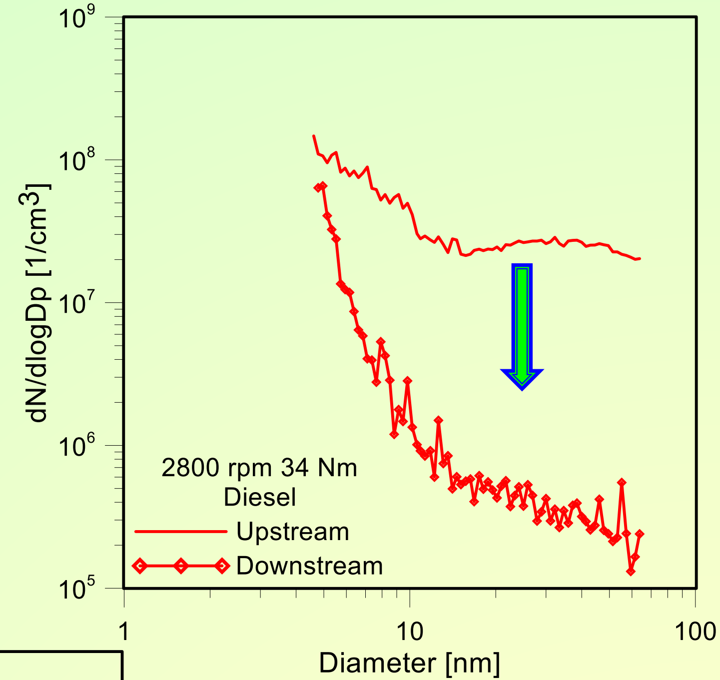


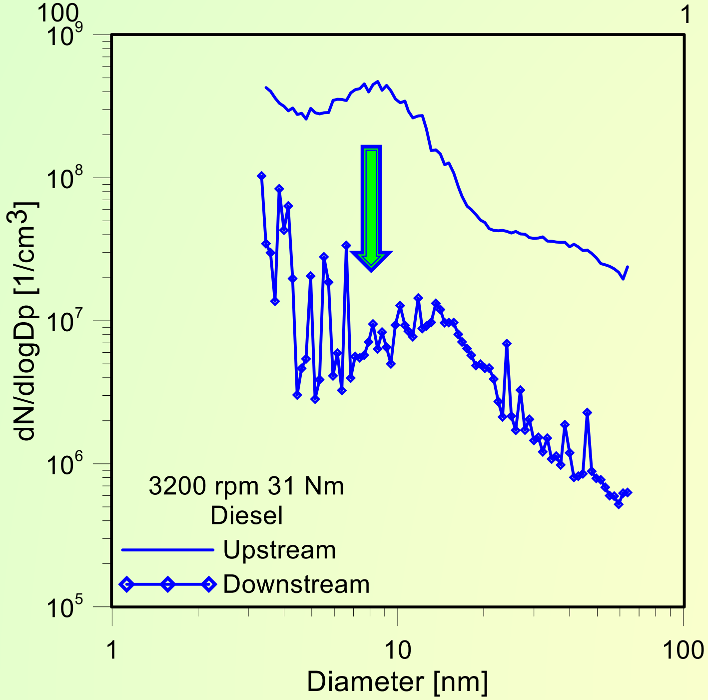
PM Filtration Efficiency



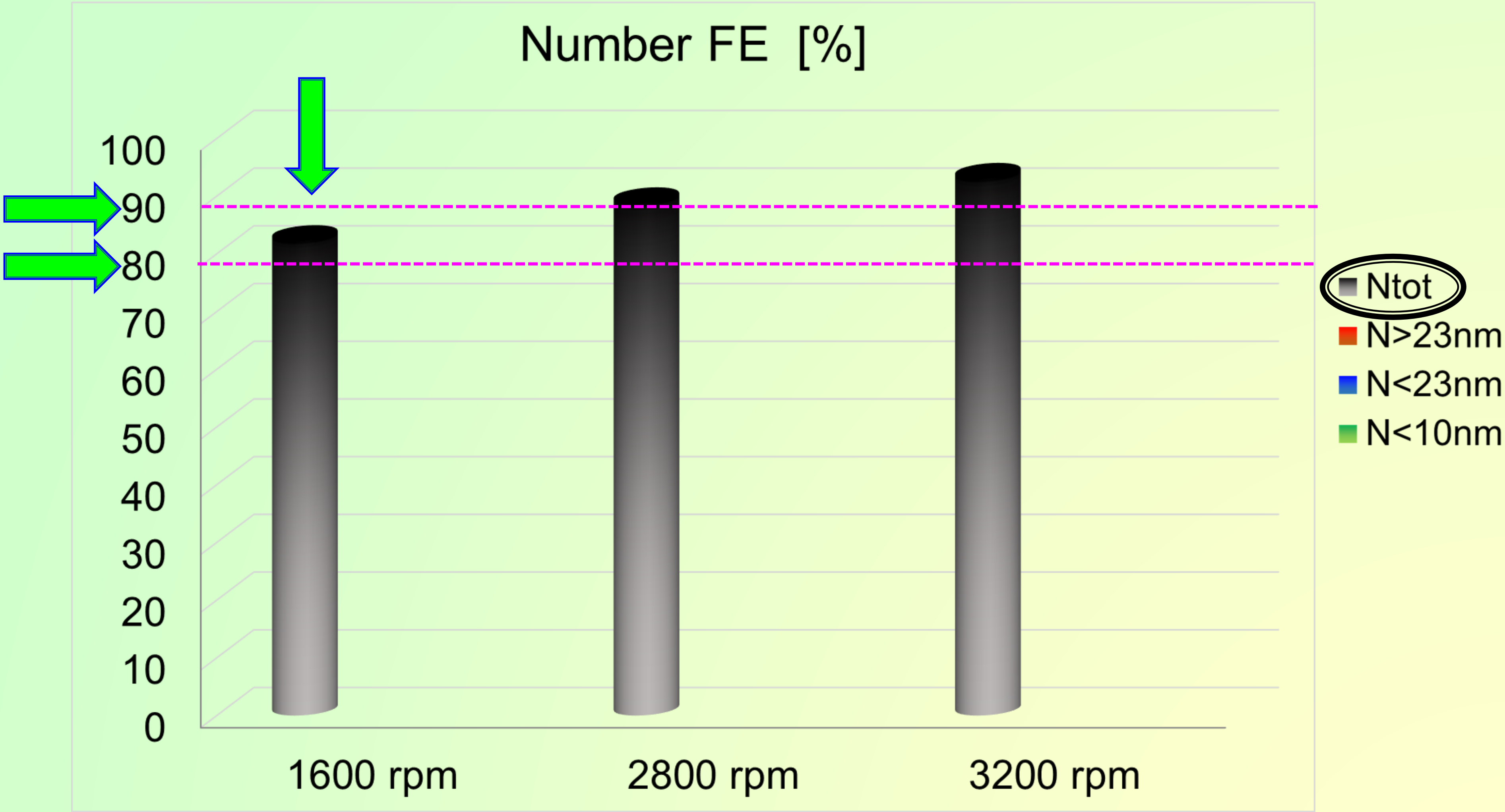
PSDF: Up vs Down DPF







PN Filtration Efficiency



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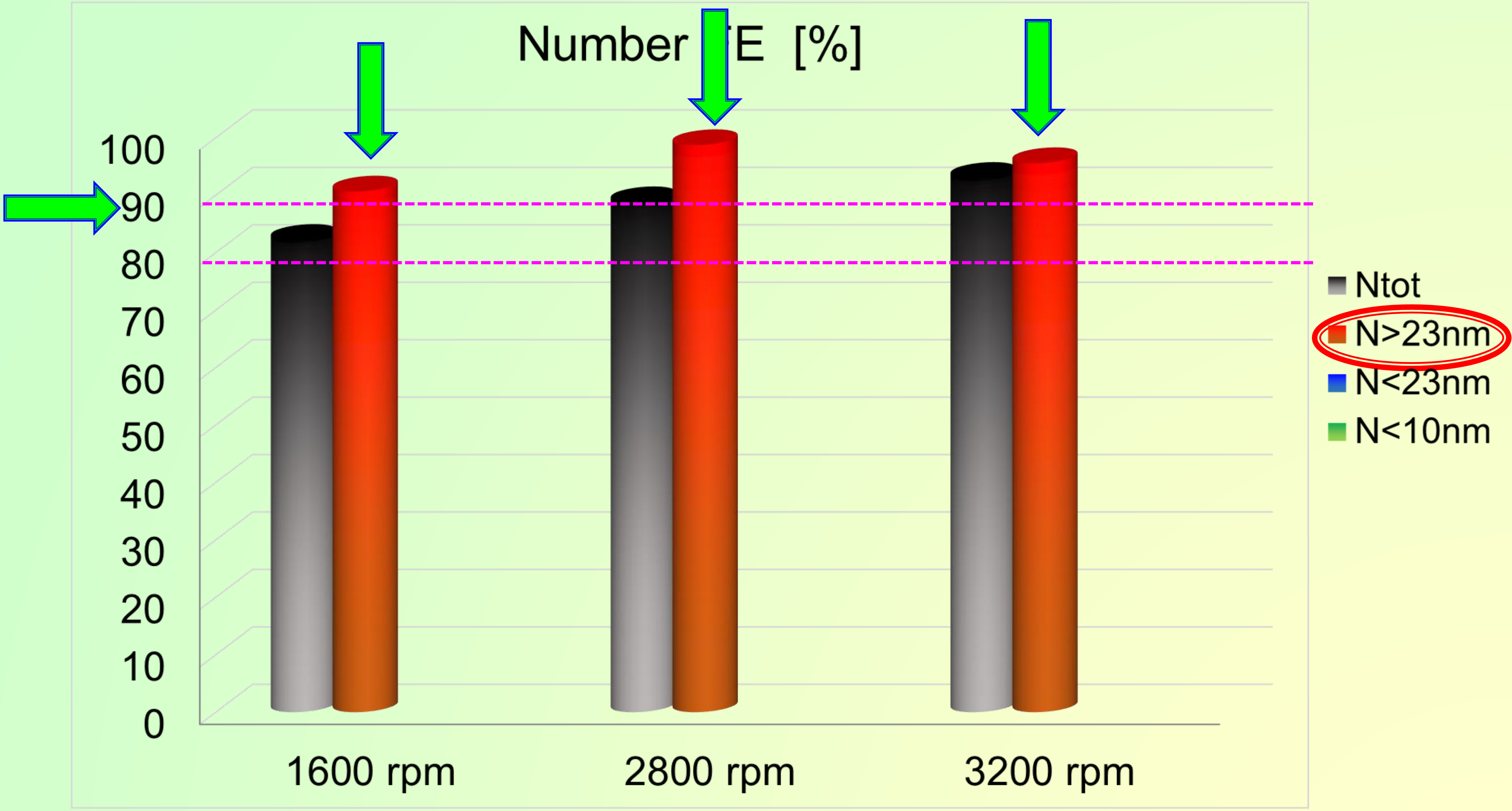

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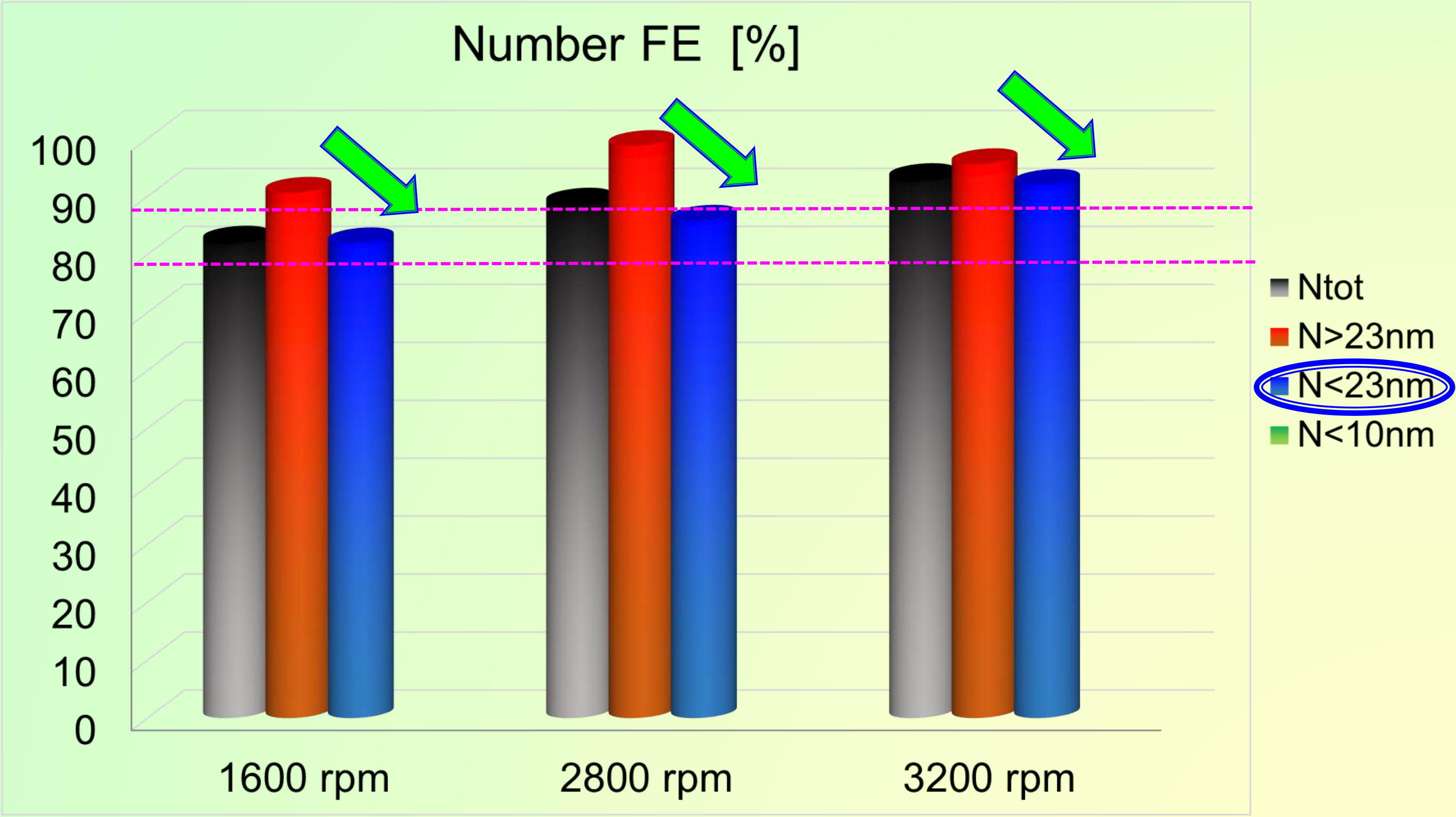

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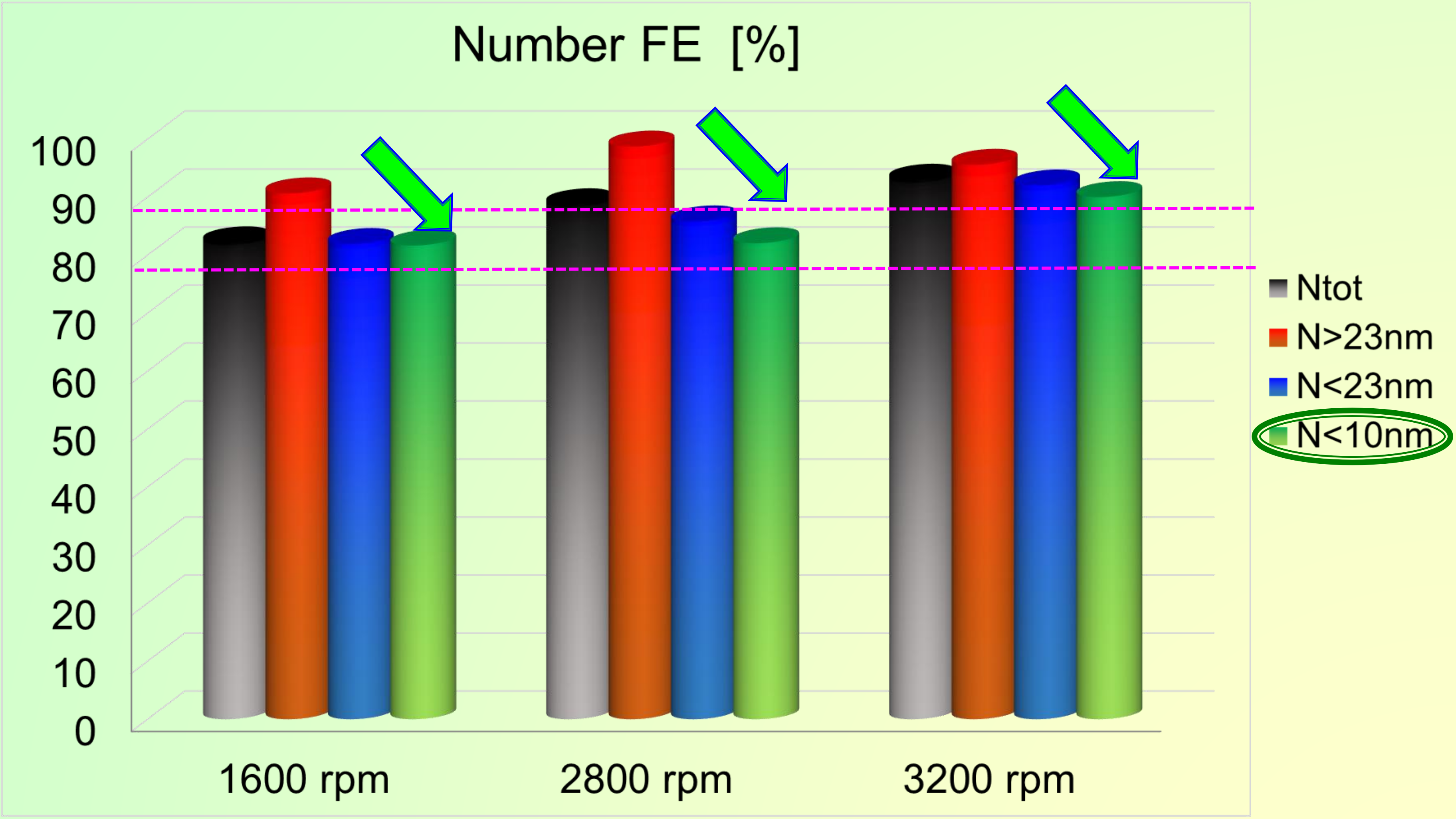
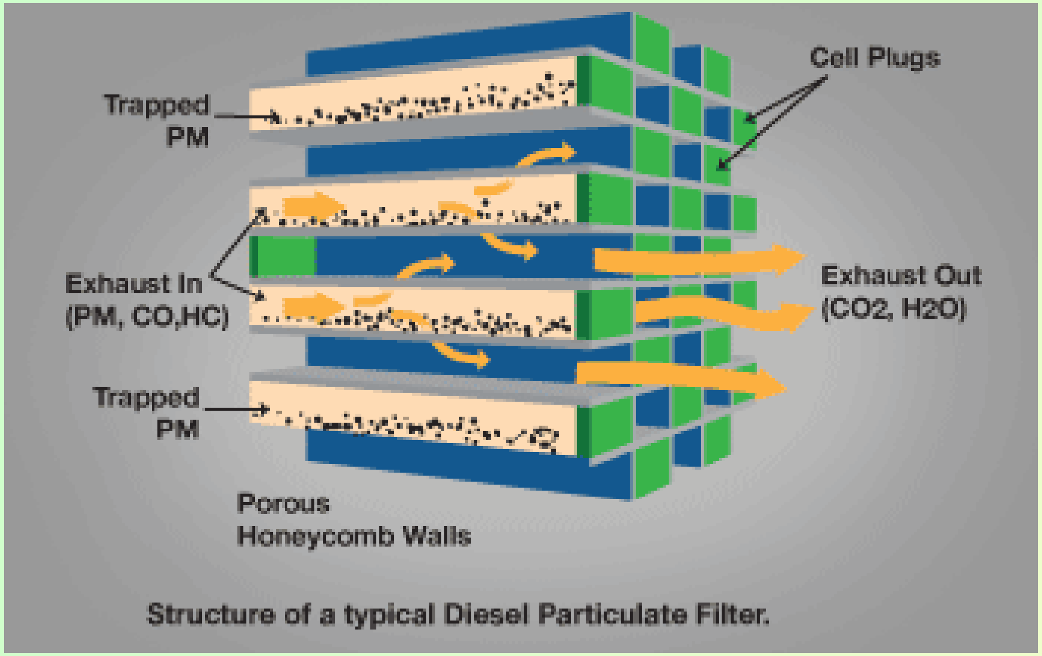


PM emissions reduction: DPF



Monolithic structure ***honeycomb*** of porous ceramic material with high mechanical and thermal strength (cordierite, carbide silicon, SiC) or metal sintered.

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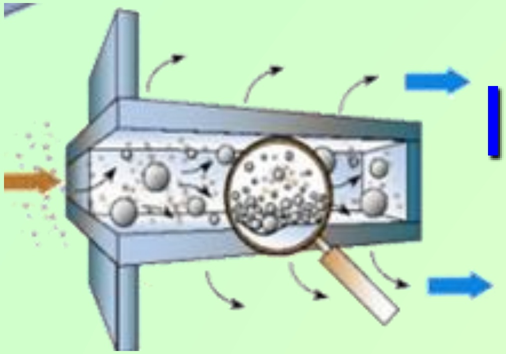
Filtration Efficiency

Filter Regeneration

Particles<23nm



Increase of soot cake:

Backpressure increases

Filtration efficiency increases

Engine efficiency decreases

Fuel consumption (CO_2) increases

DPF: Regeneration

Particle Oxidation

Passive

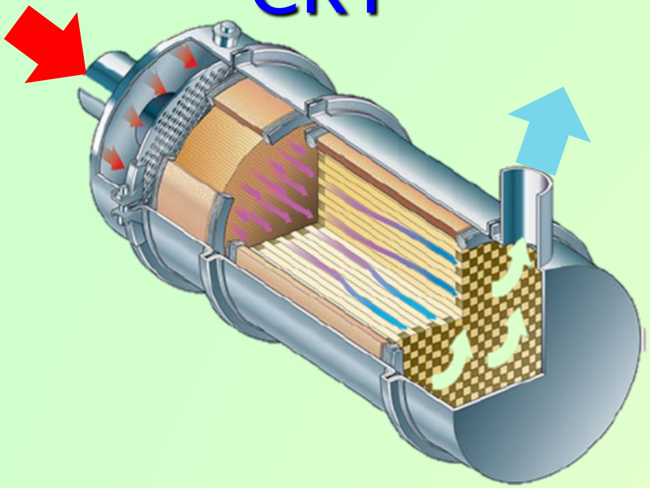
Soot oxidation temperature is lowered for autoregeneration.

Oxidation catalyst are added to the system to promote oxidation:

-Oxygen
-Nitrogen dioxide

DPF: Passive Regeneration

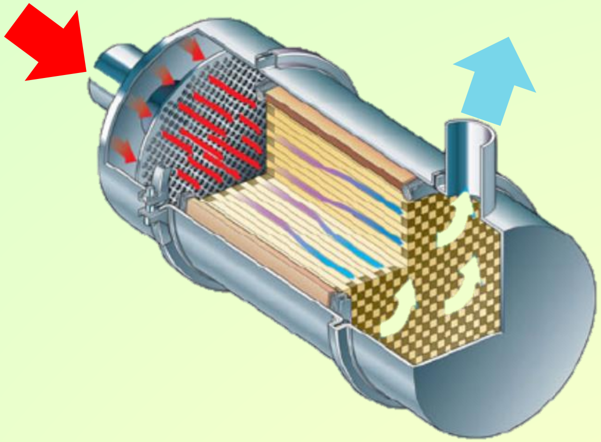
CRT



$NO + 1/2\ O_2 \longrightarrow NO_2$
$2NO_2 + 2C \longrightarrow N_2 + 2CO_2$

250°C @ NO_2

CDPF



Catalyst are on the filter surface

400°C @ O2

DPF: Regeneration

Particle Oxidation

Passive

Soot oxidation temperature is lowered for autoregeneration.

Oxidation catalyst are added to the system to promote oxidation:

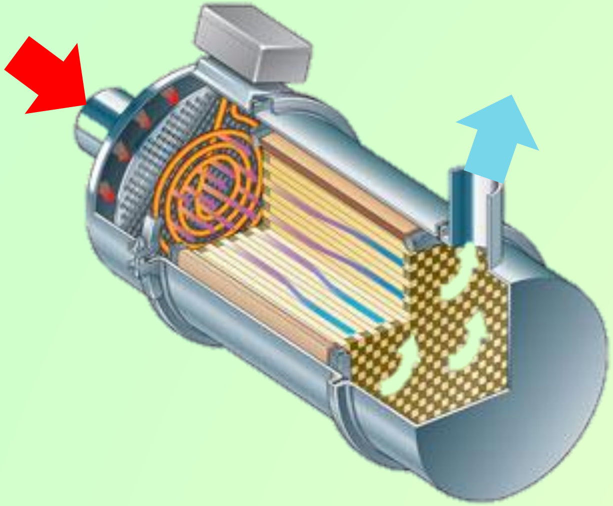
-Oxygen
-Nitrogen dioxide

Active

The temperature was increased by the use of an outside energy source

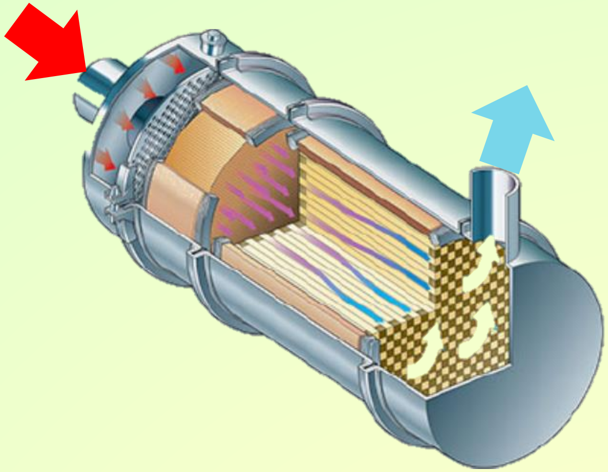
DPF: Active Regeneration

Burner

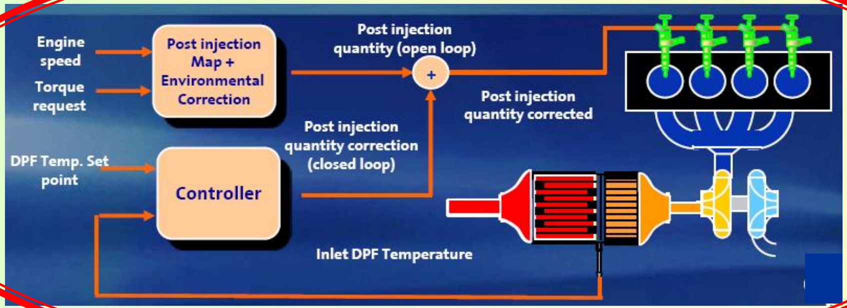


Fuel is burned in a fuel burner

Fuel Injection

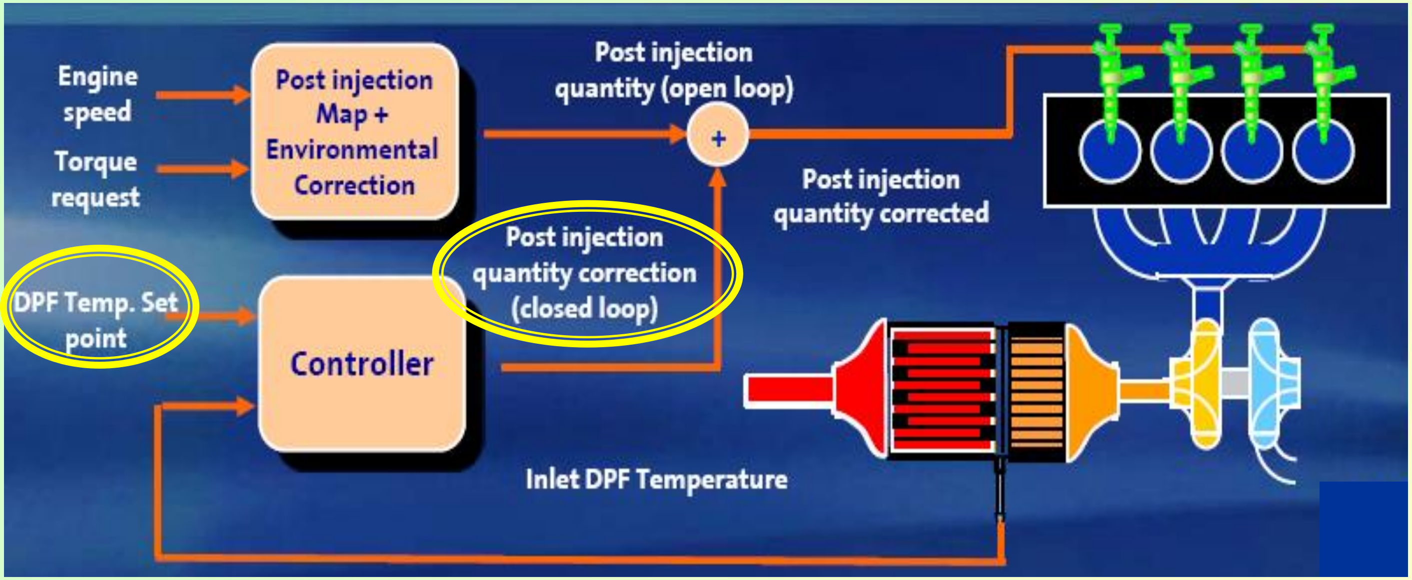


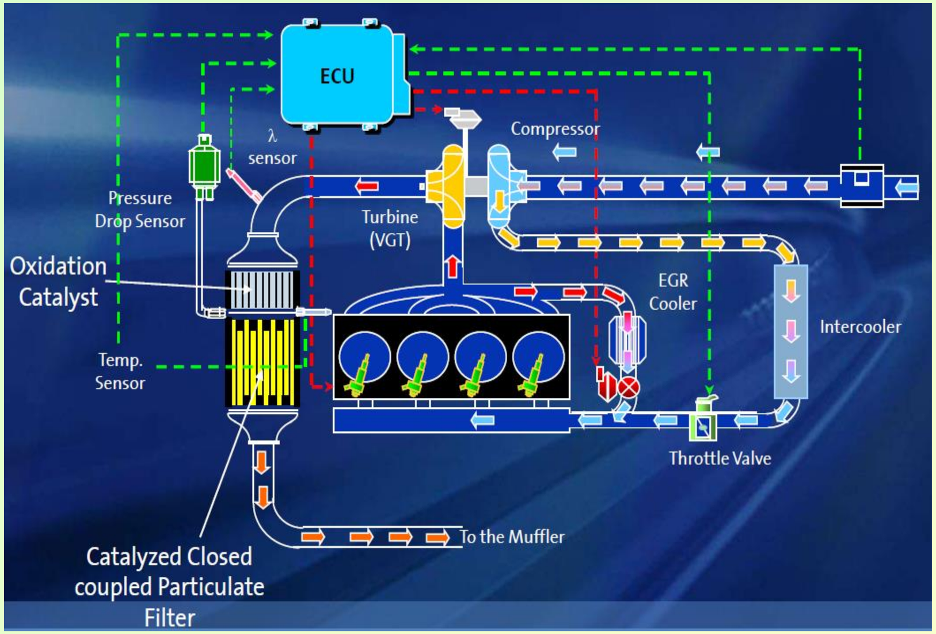
oxidized over an oxidation catalyst



DPF: Active Regeneration

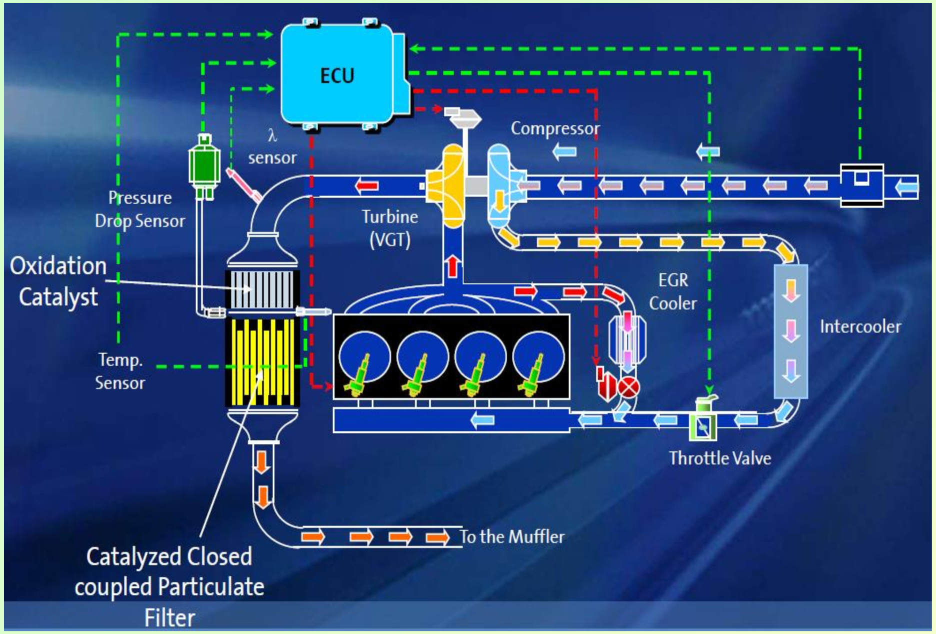
Engine Management





Detailed characterization of particulate emissions of an automotive catalyzed DPF using actual regeneration strategies, C. Beatrice, S. Di Iorio, C. Guido, P. Napolitano, Experimental Thermal and Fluid Science 39, 45-53.

Engine Layout



Engine type	4 cylinders in-line
Bore x Stroke [mm]	83.0 x 90.4
Displacement [cm^3]	1956
Compression Ratio	16.5
Rated power and torque	118kW @ 4000rpm 380Nm @ 2000rpm
After-treatment device	Integrated closed-coupled DOC & DPF

Detailed characterization of particulate emissions of an automotive catalyzed DPF using actual regeneration strategies, C. Beatrice, S. Di Iorio, C. Guido, P. Napolitano, Experimental Thermal and Fluid Science 39, 45-53.

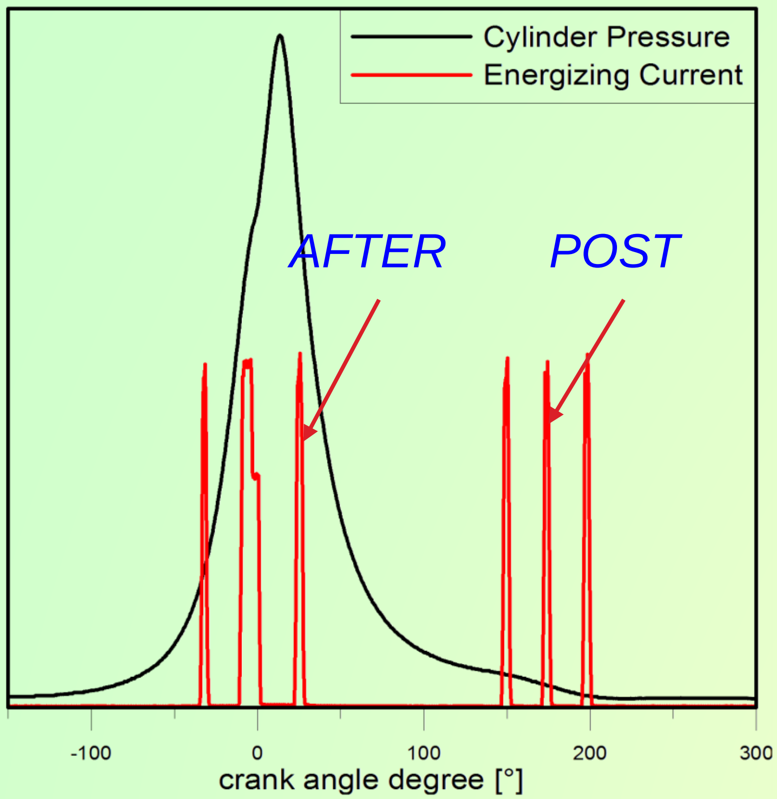
Exhaust Layout

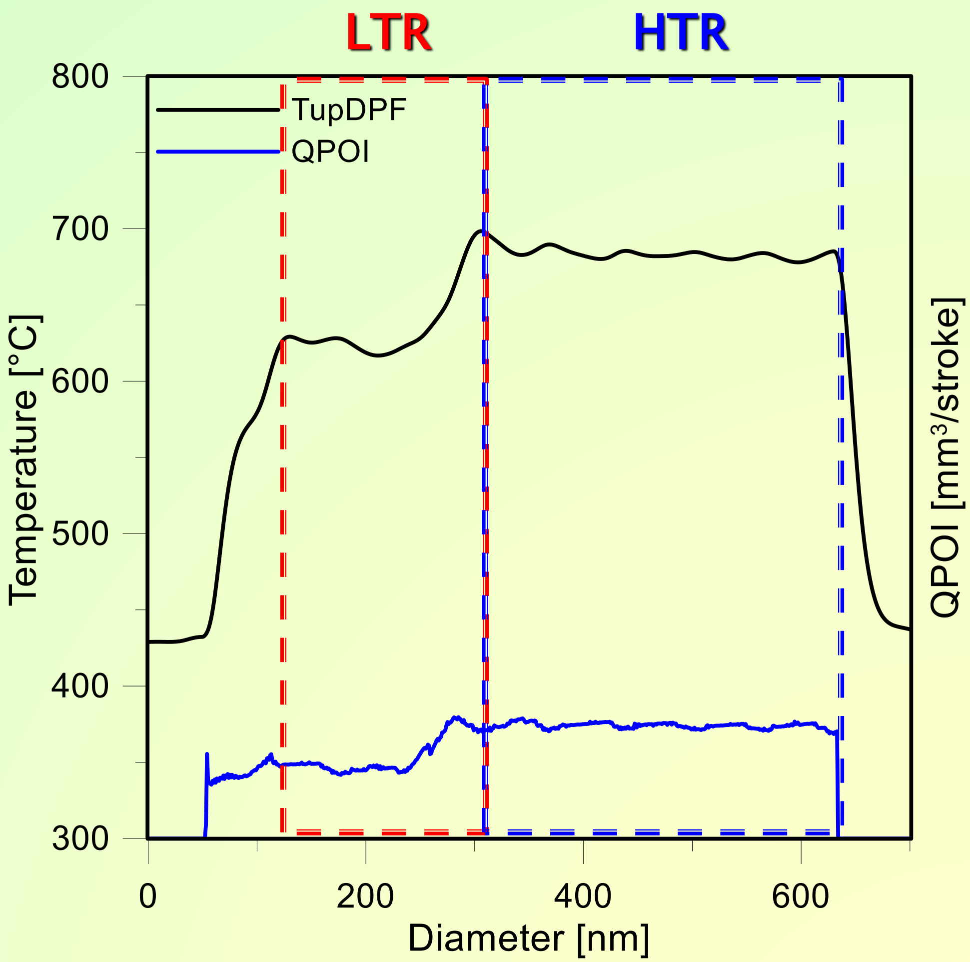
Differential Mobility Spectrometer

5-1000nm
10 Hz

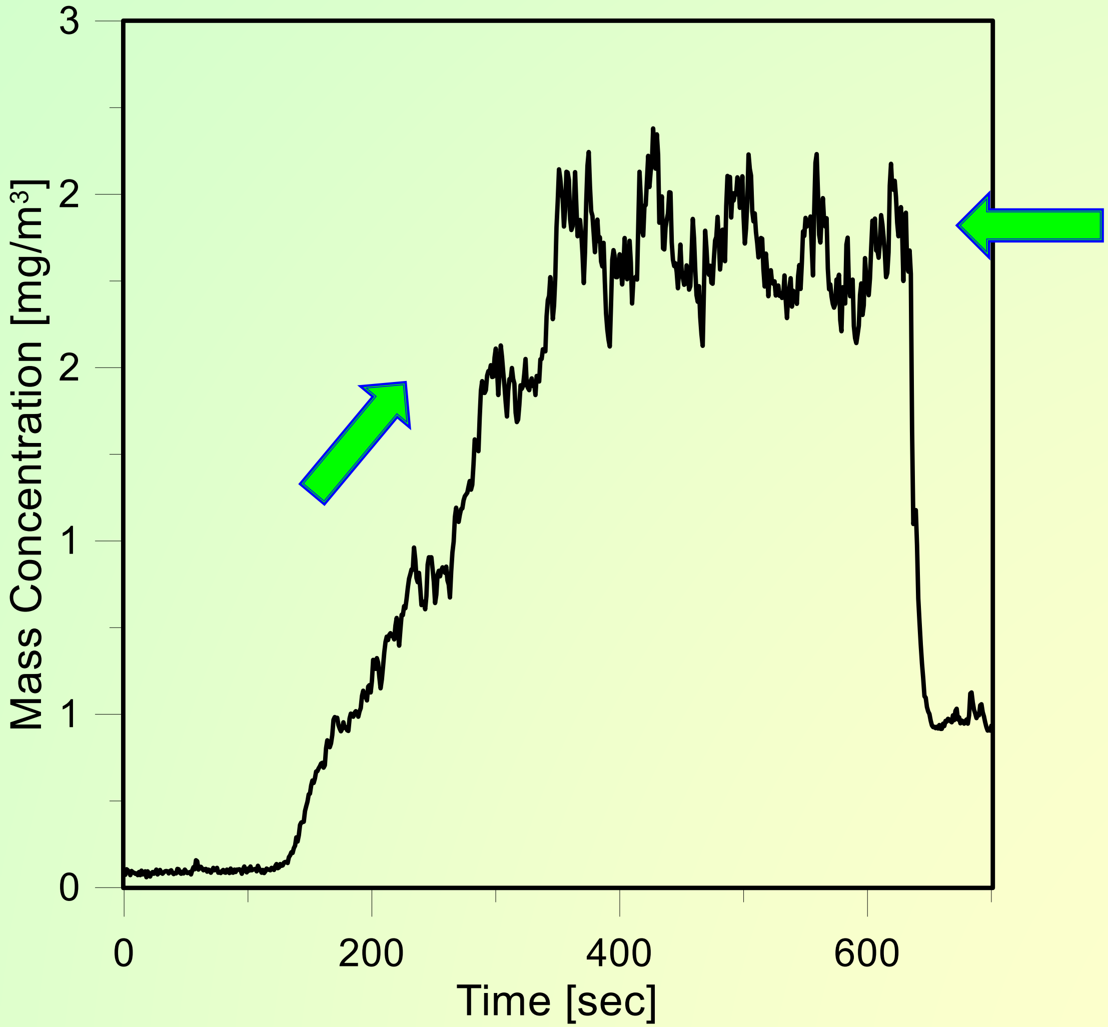
Micro Soot Sensor

Injection Calibration

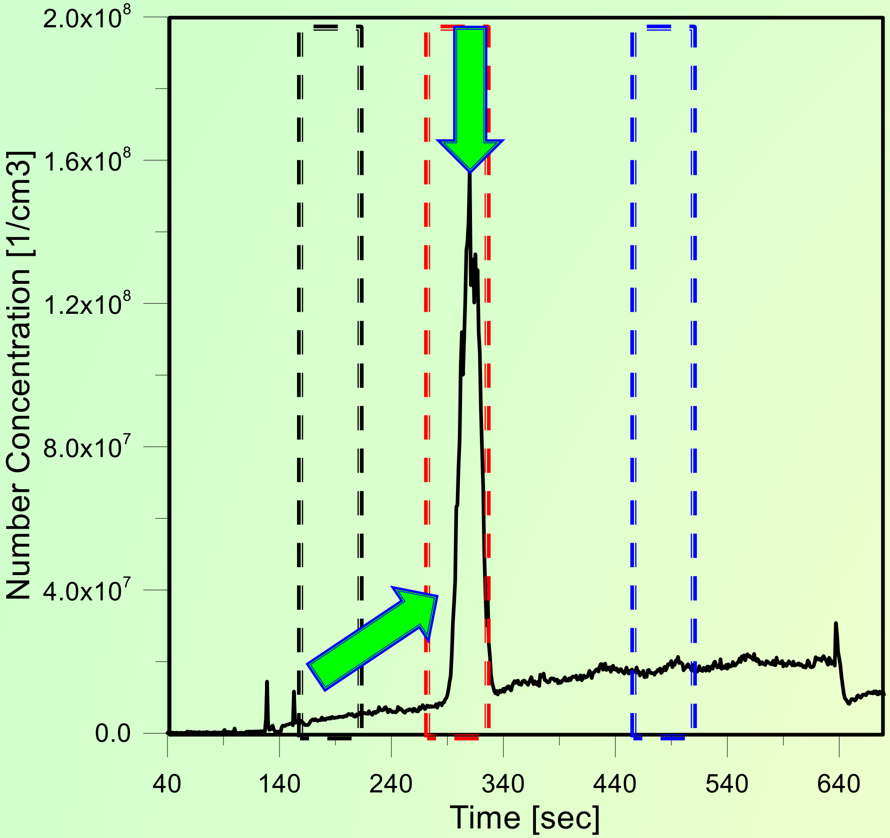


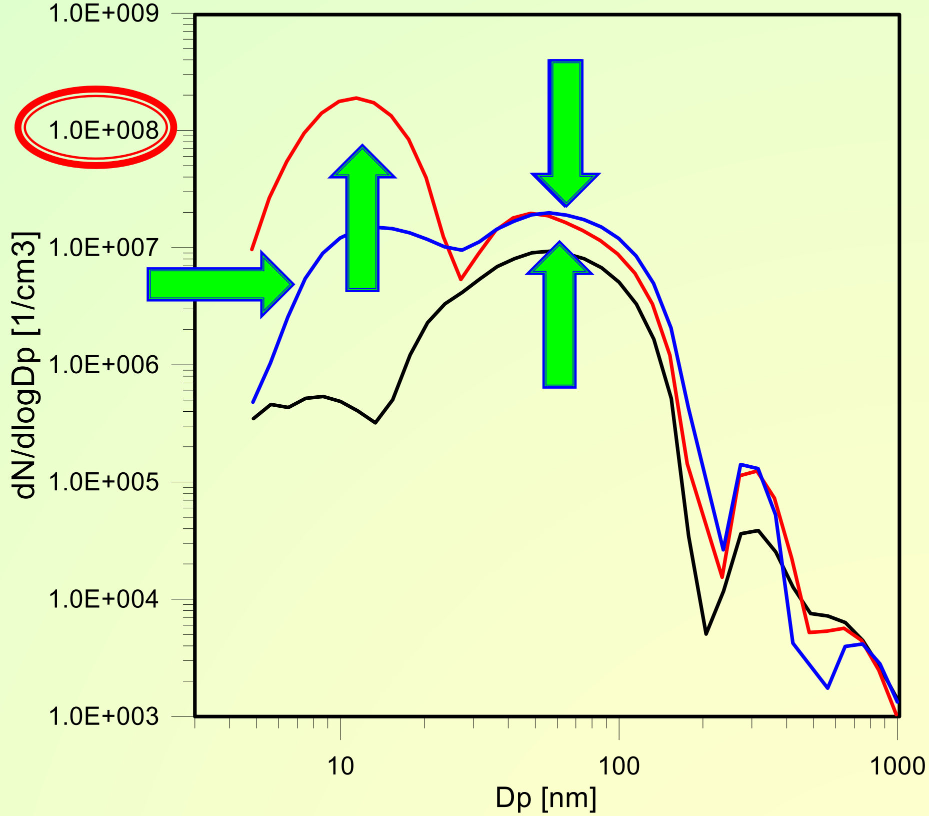


PM Emissions



PN Emissions



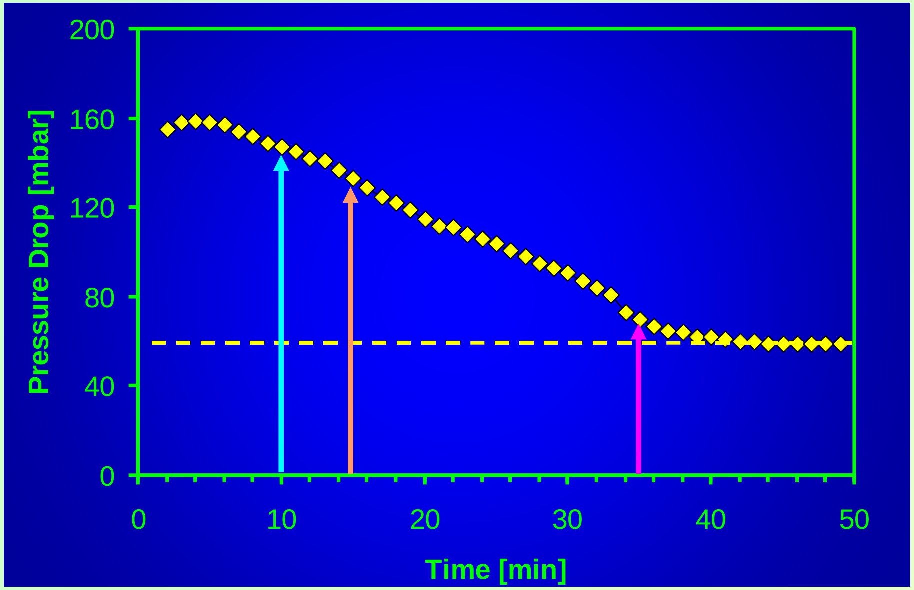


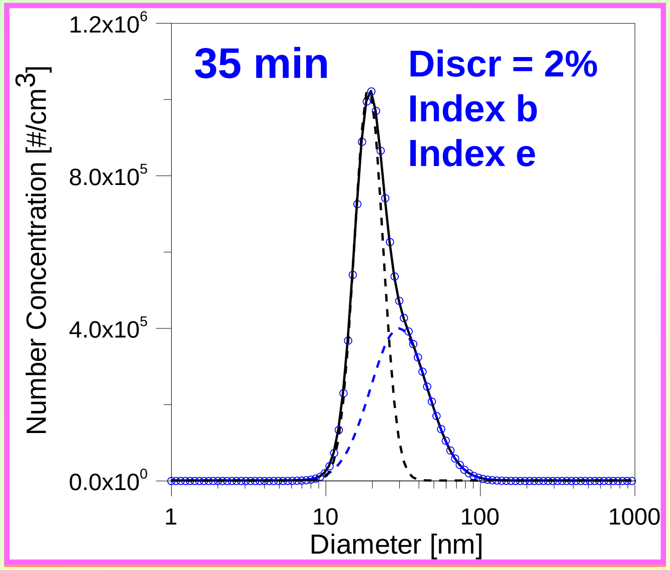
57 nm

18 nm

45 nm

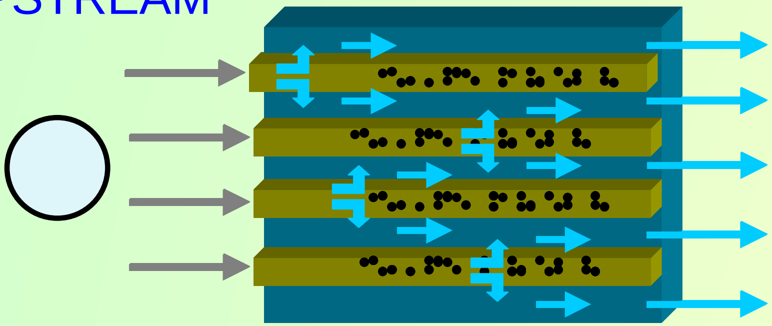
Particle Chemical Properties



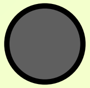


DOWNSTREAM

UPSTREAM

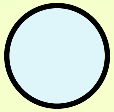


t = 10 min



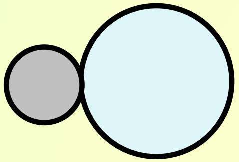
- ❖D= 15 nm
- ❖Index b

t = 15 min



- ❖D= 20 nm
- ❖Index b

t = 35 min



- ❖D_1= 30 nm
- ❖Index b
- ❖D_2= 15 nm
- ❖50% Index b
- \- 50% Index e

Conclusions (1/2)

The filtration efficiency of DPF was investigated on an engine representative of an off-road Diesel engine.

The investigation was carried out at urban driving conditions where regeneration typically does not occur.

The mass concentration, the number and the size were measured both upstream and downstream the DPF.

The size range: 3-64 nm was investigated .

↓

PM filtration efficiency is higher than 90%.
PN filtration efficiency decreases with the particle size.

Conclusions (2/2)

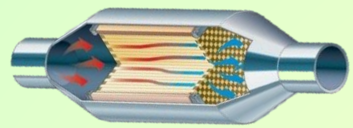
The regeneration of DPF was investigated on an engine representative of a light duty Diesel engine.

The investigation was carried out at typical driving conditions where regeneration occurs.

The mass concentration, the number and the size were measured downstream the DPF.

It was investigated the size range: 5-1000 nm.

PM and PN increase as the regeneration goes on.
Larger number of particles smaller than 23 nm was emitted during the regeneration process.
The organic and carbonaceous component of the particles varies during the regeneration process.



Thank you for the attention

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