

Exhaust Particle Sensor for OBD Application

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2. Operation principle and prototype
3. Signal relevance
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Background

- Need for OBD on diesel passenger cars and heavy duty vehicles, in view of wide application of DPFs
- NOx sensor(s) available
- PM sensor technically more demanding:
 - e.g. Euro VI thresholds:
 - NOx 1200 mg/kWh⁻¹
 - PM ~25 mg/kWh⁻¹
 - Variable chemical and physical nature

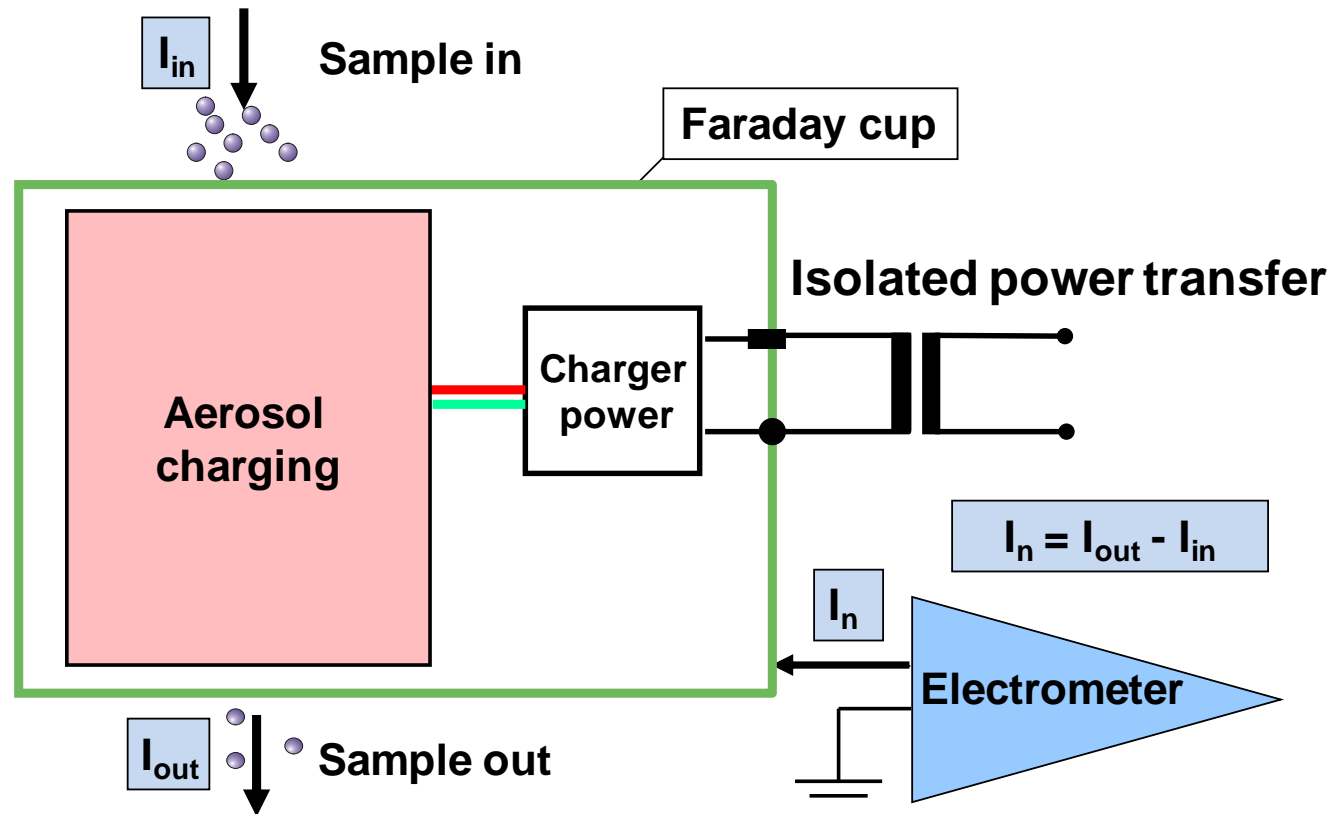
Objectives

1. Present new particle sensor (PPS) to be used for OBD downstream of DPF
2. Describe the relevance of its signal for particle mass and number determination
3. Apply prototype to test efficiency of compromised DPFs
4. Compare with lab instruments over driving cycle

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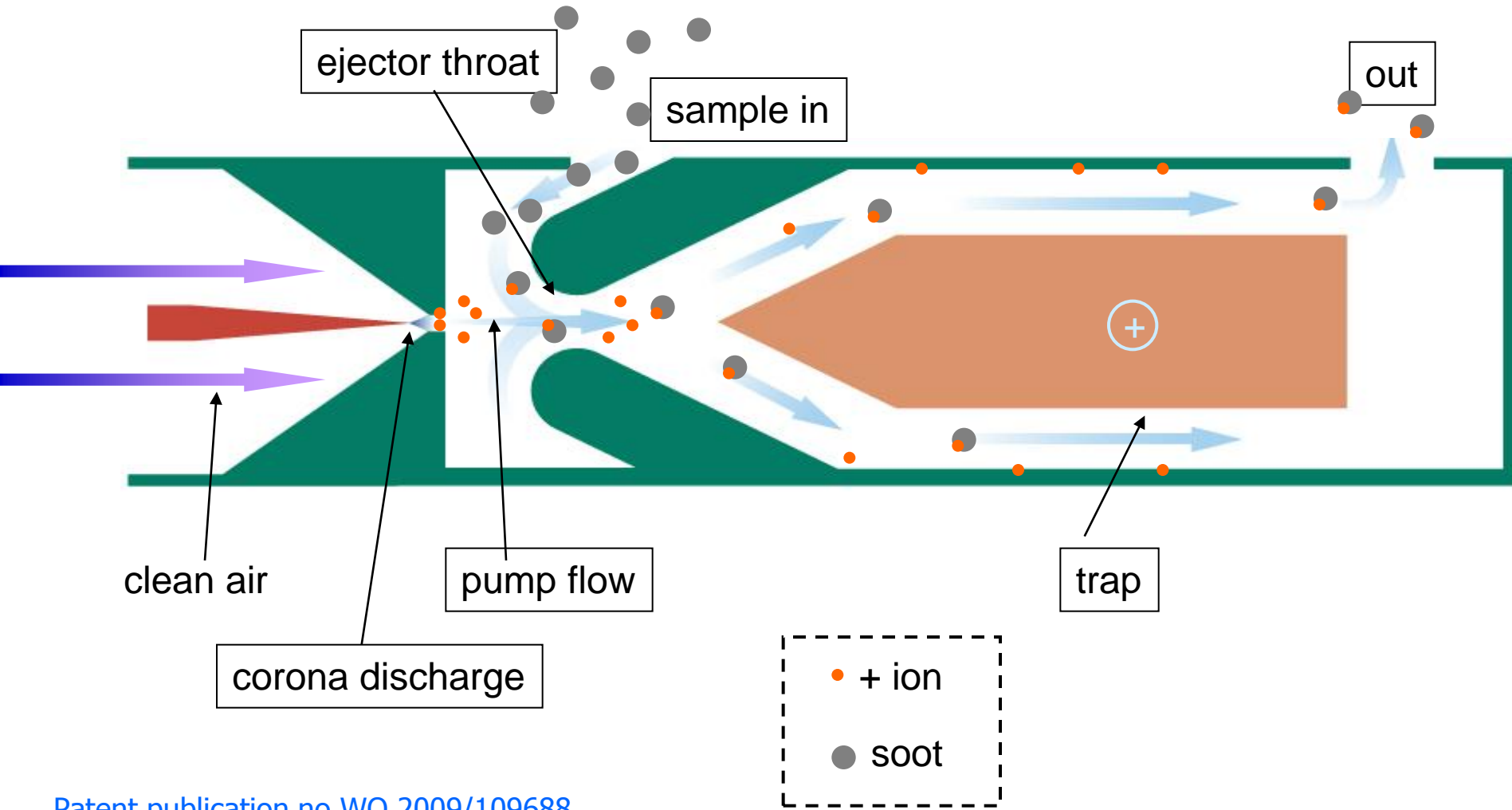
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Operation Principle



Technique referred to as "escaping current"

Configuration



Patent publication no WO 2009/109688

Characteristics

Benefits

- Particles are not collected
- Sensitive parts protected from exhaust flow
- Turbulent mixing increases sensitivity

Requirements

- On-board pumping flow

Prototype



Prototype Specifications

- Carrier flow: 3 lpm @ 0.5bar overpressure
- Communication protocol: RS485
- Sampling rate: 10 Hz
- Response time: 0.3 s

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Relevance of signal

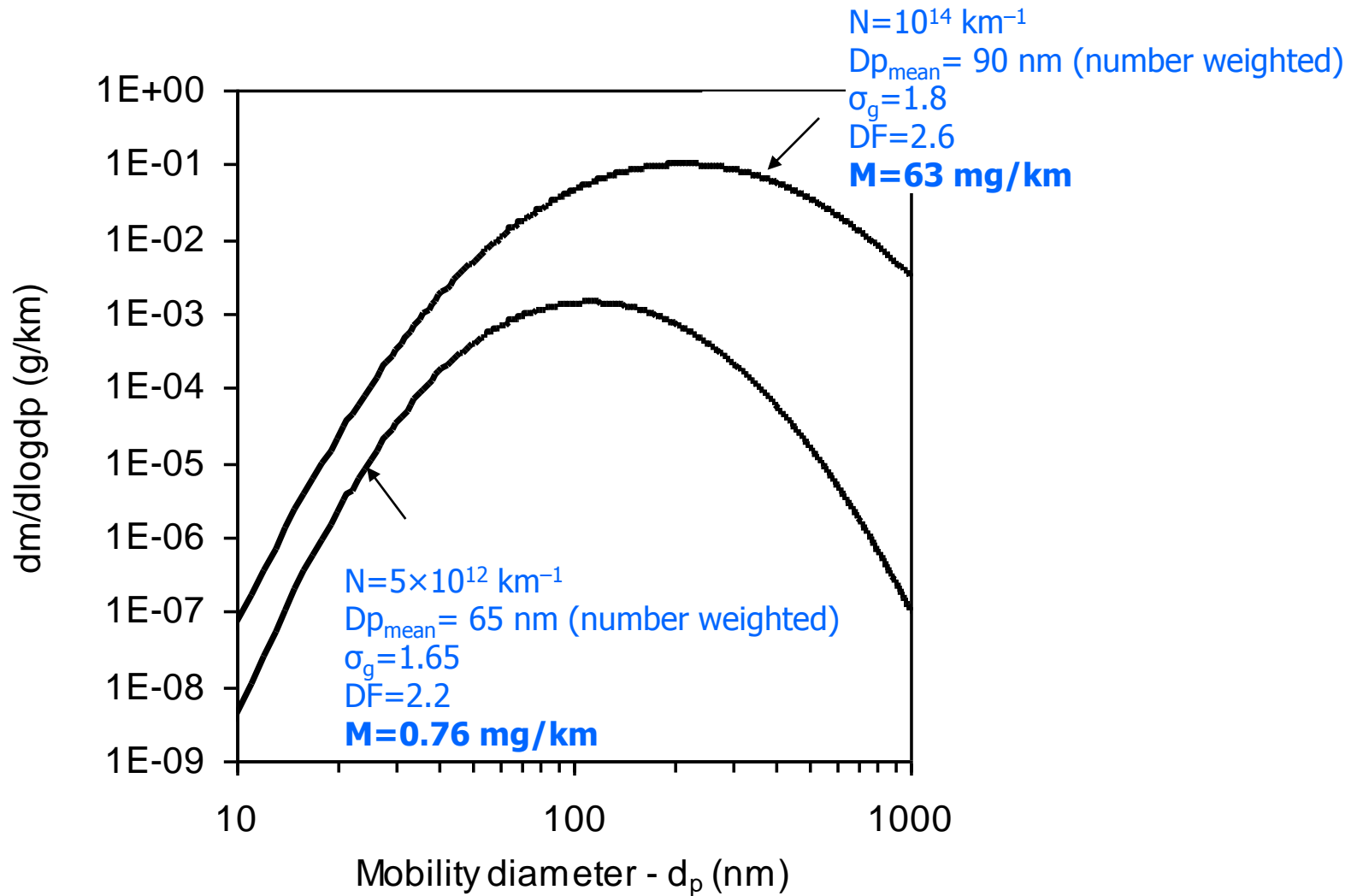
Number	d_p^0
('Active') Surface	$d_p^{1.1-1.4}$
Mass	$d_p^{2.2-2.5}$

⇒ Signal is proxy for either number or mass of particles through calibration

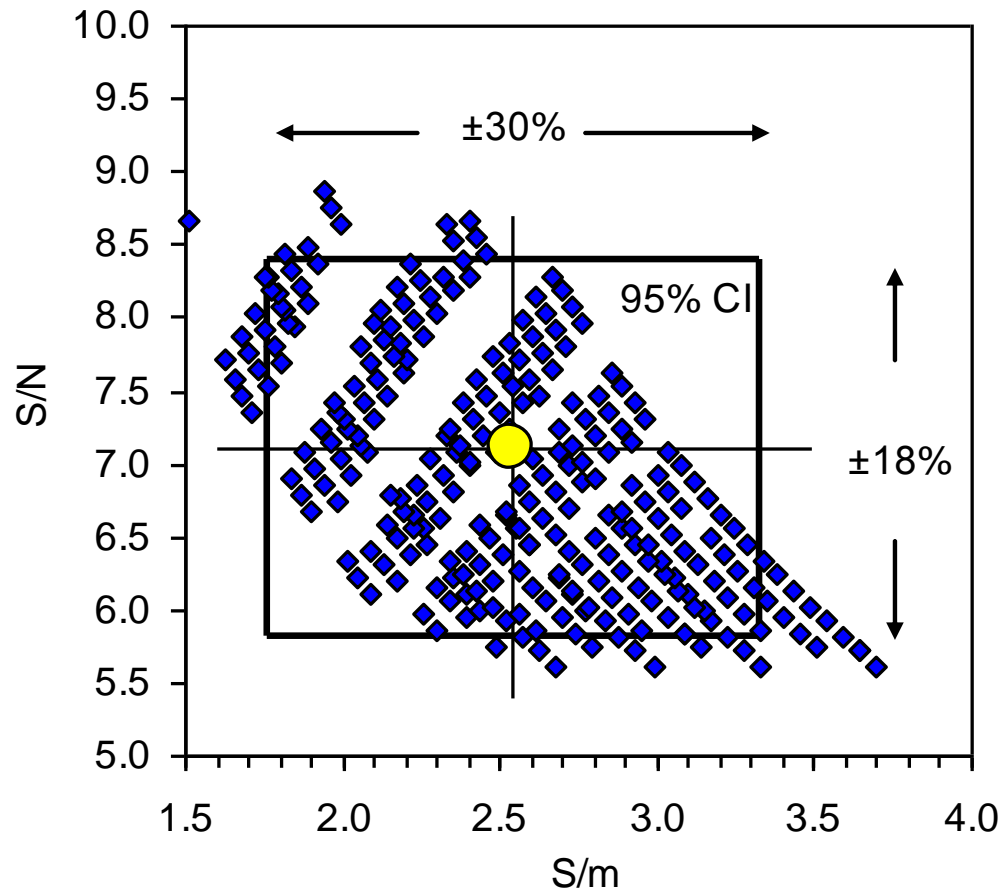
Simulation of signal relevance

Property	Range/Calculation
Distribution shape	Lognormal
Number count – N (km ⁻¹)	5×10 ¹² – 10 ¹⁴
Mean geom. diameter – d _g (nm)	65–90
Geometric st. deviation – σ _g	1.65–1.80
Fractal-like dimension – DF	2.2–2.5
Effective density (g/cm ³) for d _{p,i} >40 nm	$\rho_i = 0.85 \left(\frac{d_{p,i}}{d_{p,ref}} \right)^{DF-3}$
Mass concentration (g km ⁻¹)	$m = \frac{\pi}{6} \sum_1^{1000} N_i \rho_i d_{p,i}^3$
Sensor signal – S (km ⁻¹)	$S = \frac{\pi}{4} \sum_1^{1000} N_i d_{p,i}^{1.3}$

Boundary size distributions



Signal response over N and M



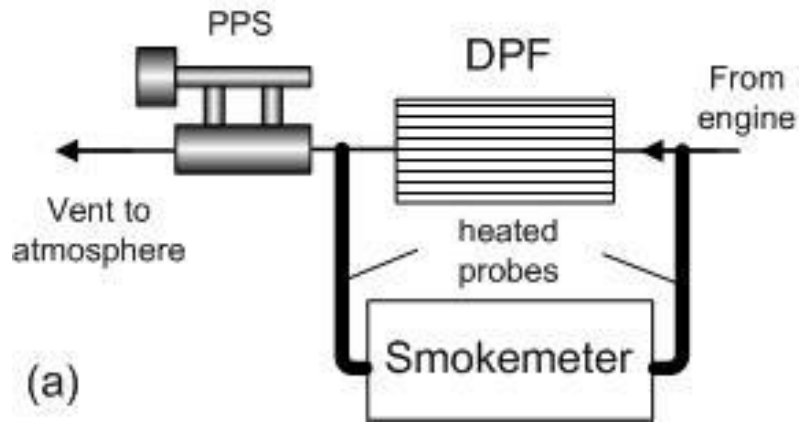
Max theoretical error (not engine specific)

Reducing the error requires engine-specific calibration

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Engine tests



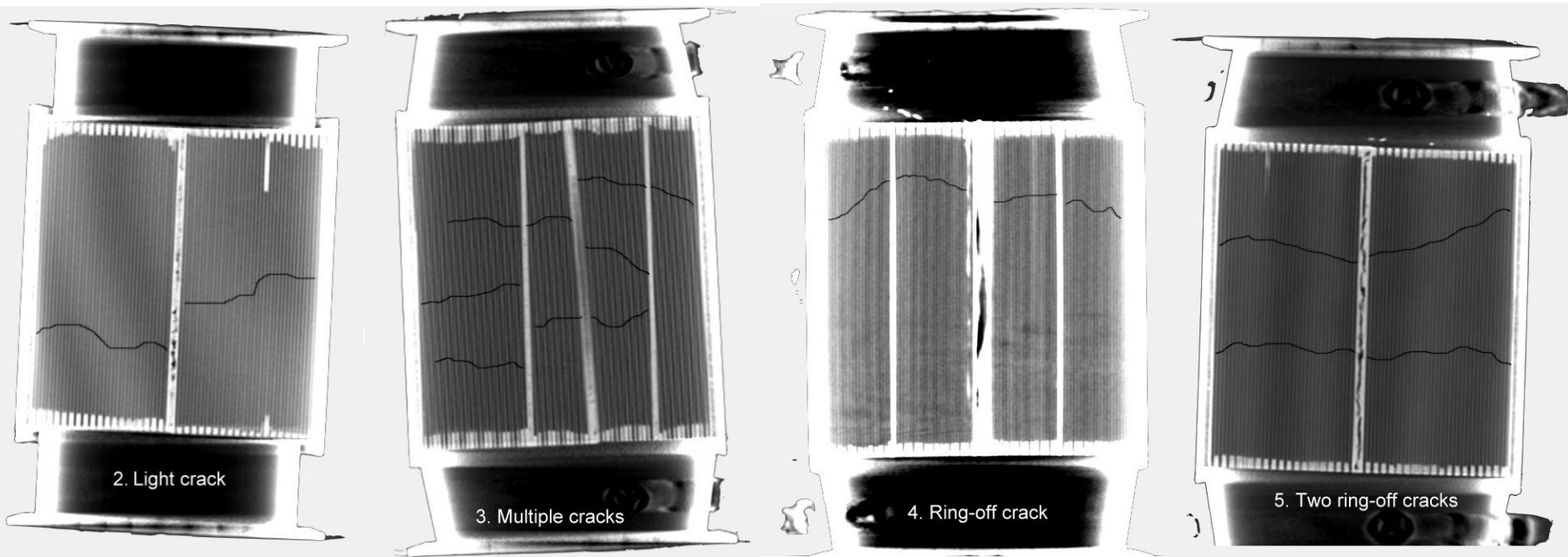
Engine type	Daimler OM646 DE22 LA
Displacement (cm ³)	2148
Fuel injection system	Common rail
Maximum power (kW/rpm)	110/4200
Maximum torque (Nm/rpm)	340/2000
Emission standard	Euro 4
Operation mode	50 Nm @ 1500 rpm



Particle filters used

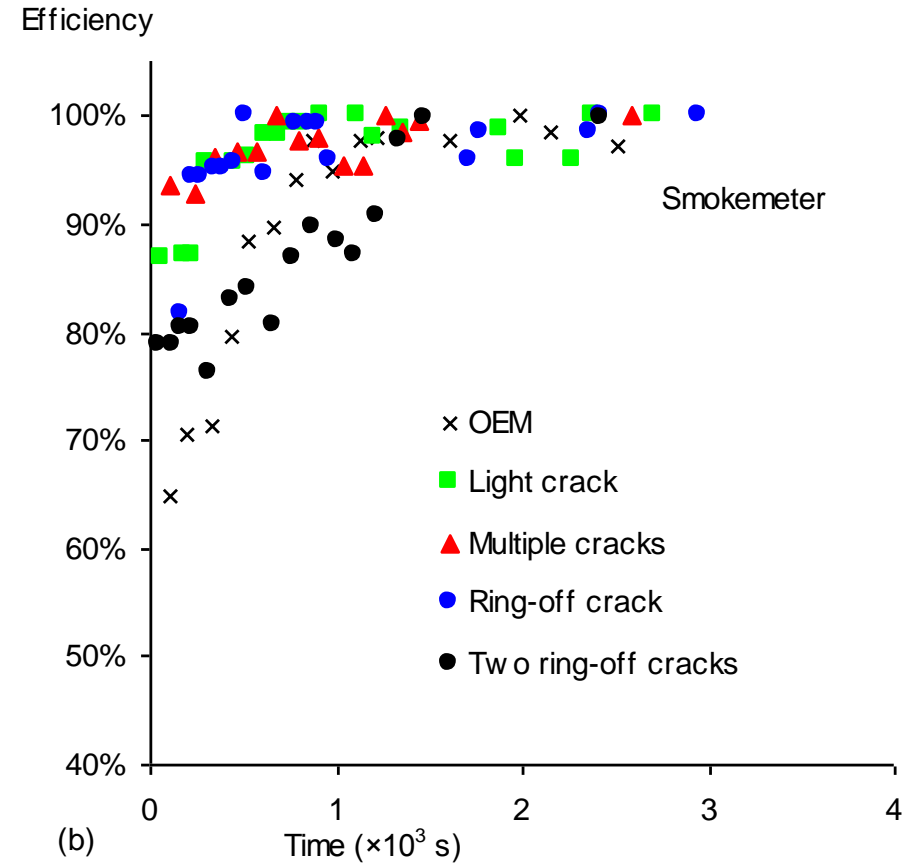
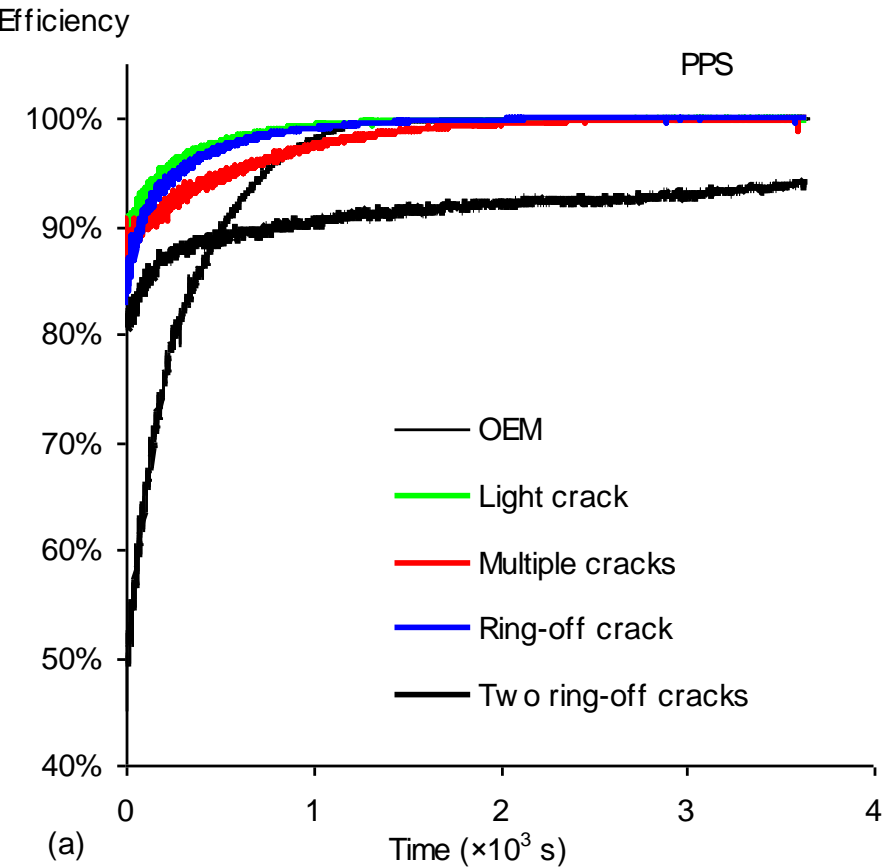
DPF Index	1	2	3	4	5
Substrate material	SiC	SiC	SiC	SiC	SiC
Segments	16	4	9	16	4
Cell density (in ⁻²)	279	200	300	300	200
Sub. thickness [mil]	10	15	12	12	15
Volume (l)	2.5	2.5	2.5	4	2.5
Length (mm)	150	154	152	254	152
Diameter (mm)	144	144	144	144	145
Condition	Good	Damaged	Damaged	Damaged	Damaged

XCT Scans of DPFs



- Cracks produced due to thermal shocks prior to testing
- All filters regenerated for 3.5 h @ 650°C before testing

Efficiency evolution



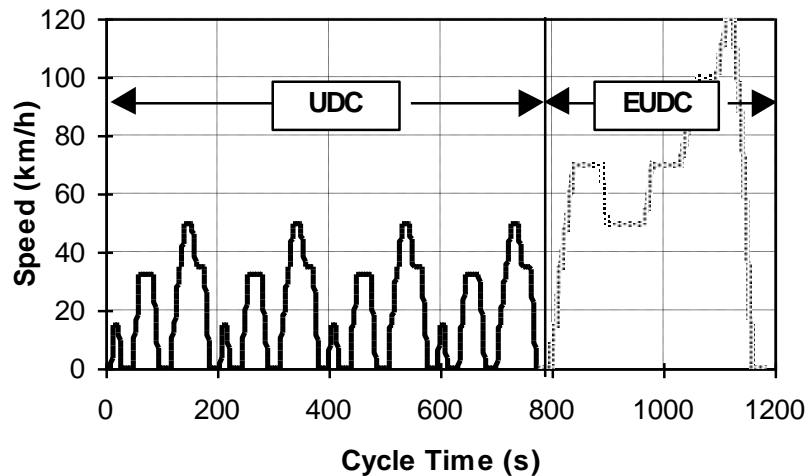
Observations

- PPS offers robust measurement of efficiency of compromised filters at high time resolution
- All but one DPFs are more than 95% efficient 1000s after regeneration
- Compromised DPF with two ring-off cracks <95% efficient when measured with PPS
- Further to OBD, PPS signal useful to optimize regeneration frequency

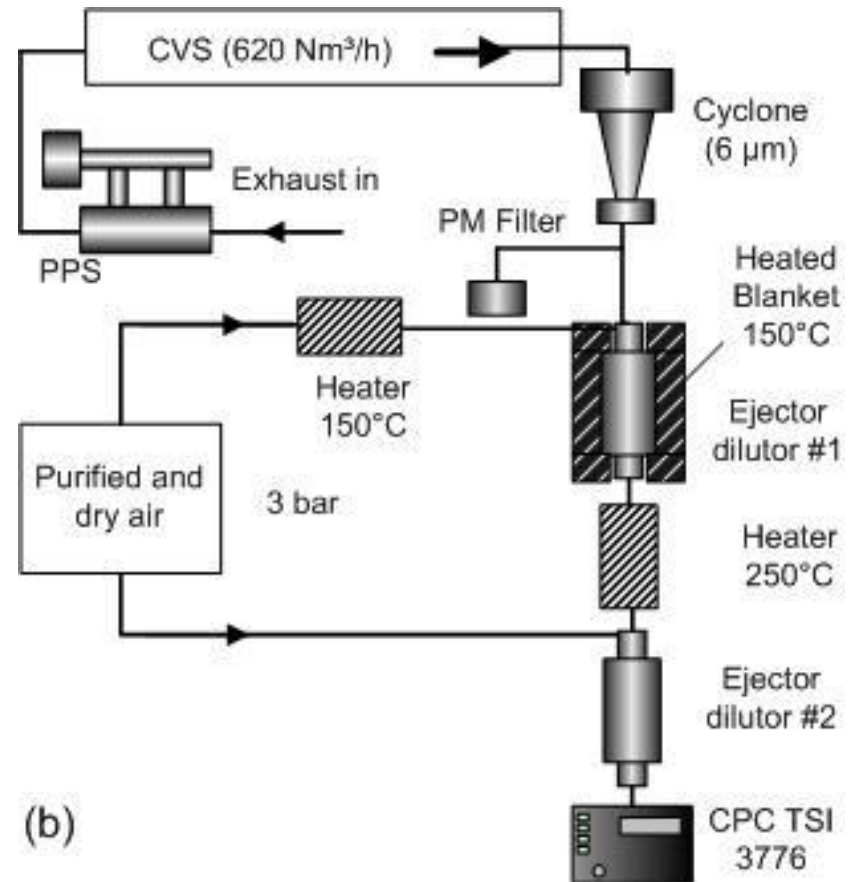
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Vehicle tests



Car model	Honda Accord 2.2
FI system	Common rail
Pmax (kW/rpm)	103/4000
Nmax (Nm/rpm)	340/2000
CR P (bar)	1600
Emission standard	Euro 4
Aftertreatment	Close-coupled and underfloor DOCs

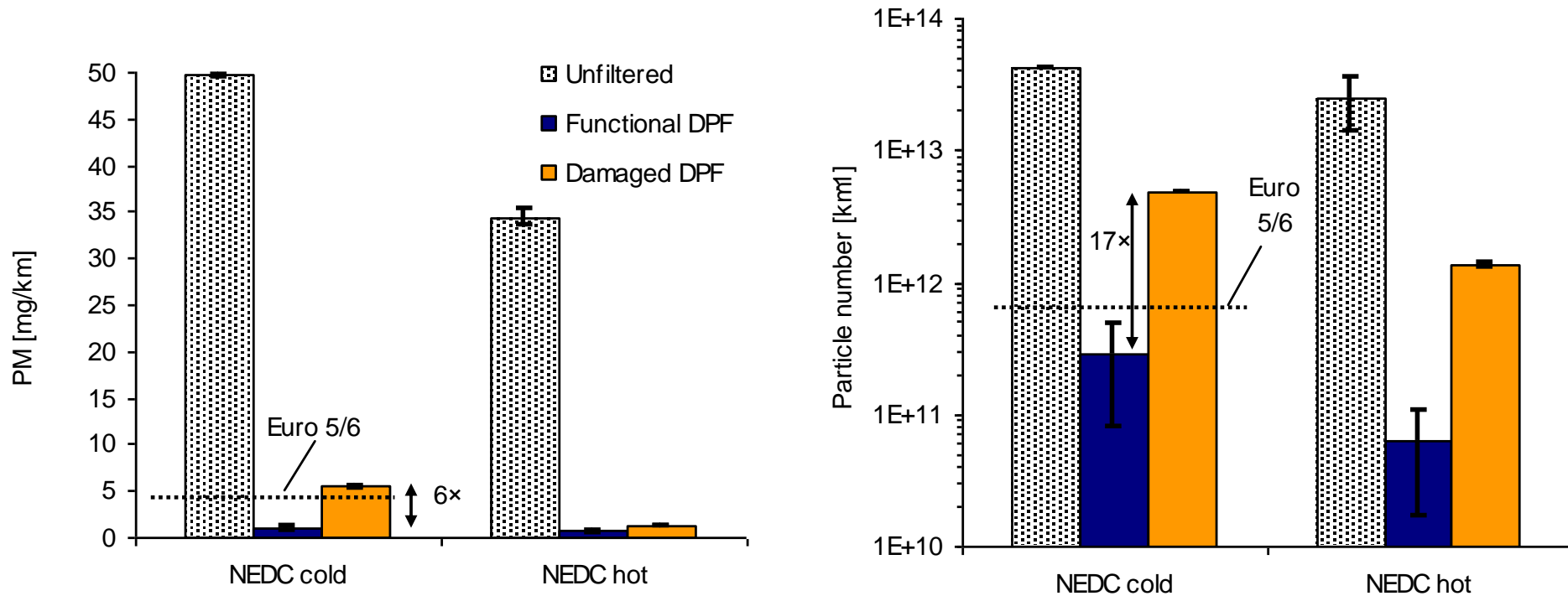


PMP compatible, except of CPC (>2.5 nm)

Particle filters used

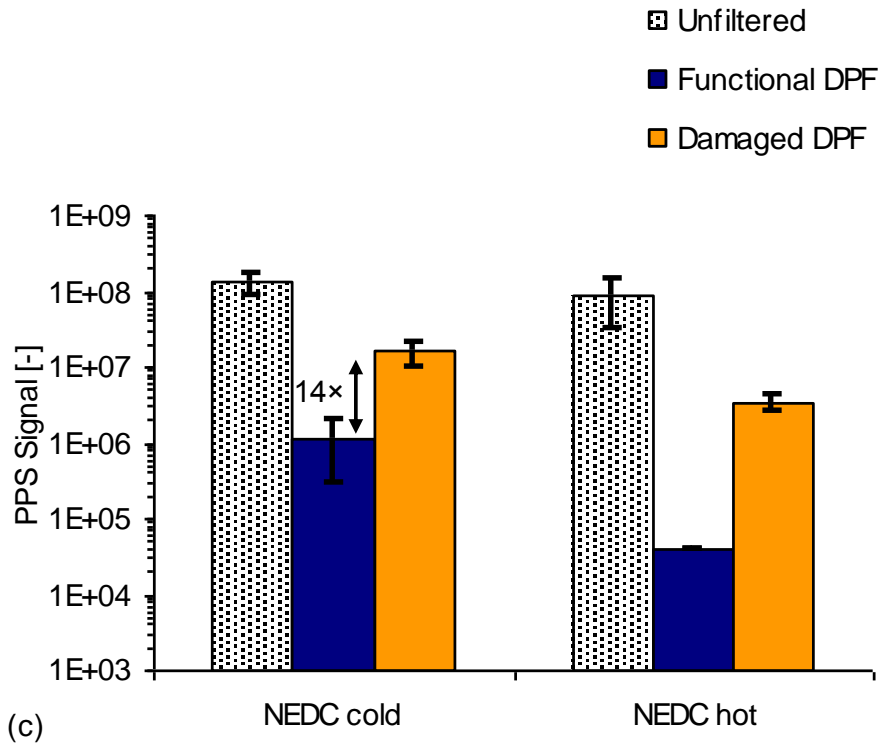
DPF Index	5	6
Substrate material	SiC	SiC
Segments	4	16
Cell density (in ⁻²)	200	300
Substrate thickness [mil]	15	12
Volume (l)	2.5	4
Length (mm)	152	254
Diameter (mm)	145	144
Condition	Two-ring off cracks	Good

Vehicle/DPF performance



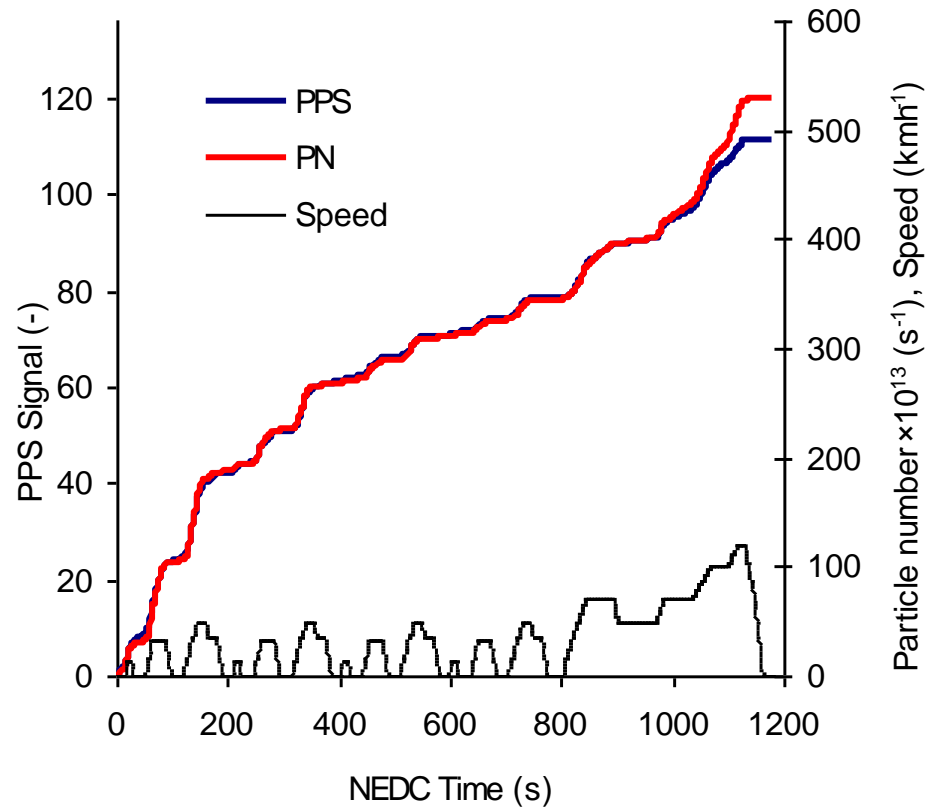
With the functional DPF, the vehicle complies with the Euro 5 limit with some margin, despite the wider range CPC used

PPS Performance



	PN (%)	PPS (%)	PM (%)
Functional DPF			
NEDC cold	99	99	98
NEDC hot	100	100	98
Damaged DPF			
NEDC cold	89	91	89
NEDC hot	96	98	97

Real-time recordings



Note: PPS signal not corrected for exhaust flowrate

Observations

- Response: between PM and PN expression
- Sensitivity
 - PM: higher than 1 mg/km (Euro 5: 4.5 mg/km)
 - PN: can distinguish $<6 \times 10^{11}$ km⁻¹
- OBD threshold: $1.5 \times ES$ (6 mg/km) possible
- Time resolution: Real-time monitoring possible

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Conclusions & outlook

1. PM OBD sensor concept based on contactless particle detection
2. Signal can be a proxy for either particle mass or number
3. Sensitivity demonstrated with tests on malfunctioning DPFs of various degree
4. Time resolution superseding potential OBD requirements
5. Next steps include downsizing and durability tests

Thank you for your attention!