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Abstract

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Title:

"Meeting EU 4/5 PM emission standards: Comparison of different particulate filter types"

Abstract:

The Diesel engine is an essential part of the strategy to fulfill the CO_2 reduction commitment made by ACEA and other automobile manufacturers' associations. Over the last years, Diesel engine powered passenger cars have gained a market share of more than 50% in some European countries.
Negative aspects of Diesel engines are the emission of particulates and higher NO_x emissions compared to gasoline engines. Political pressure especially drives the further reduction of particulate emissions.
The proposal of the Euro 5 emission standard for particulate matter, as defined in COM(2005)683 final in December 2005, limits the particulate mass to 5 mg/km, which is expected to require the use of Diesel particulate traps to fulfill this limit. Additionally, a PM number limit is under discussion and the retrofit of older Diesel engine powered vehicles is desired in order to reduce PM 10 immission levels (environmental and health issues).
Hyundai Motor Europe and Darmstadt University of Technology conducted a study with various PM reduction devices to check their reduction performances with regard to achieving the EU 4/5 PM limits for passenger cars. Measurements were done at two different engine generations. Apart from several wall flow filter systems, open filter systems as well as slightly damaged wall flow filters were investigated.
All measurements were carried out with respect to particle mass, particle number and opacity for steady-state tests as well as NEDC tests.

Meeting EU4 / 5 PM emission standards:

Comparison of different particulate filter types

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"10th ETH Conference on Combustion Generated Nanoparticles"
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Motivation

Open particulate filter systems

Validation of CPF systems

Summary & Conclusion

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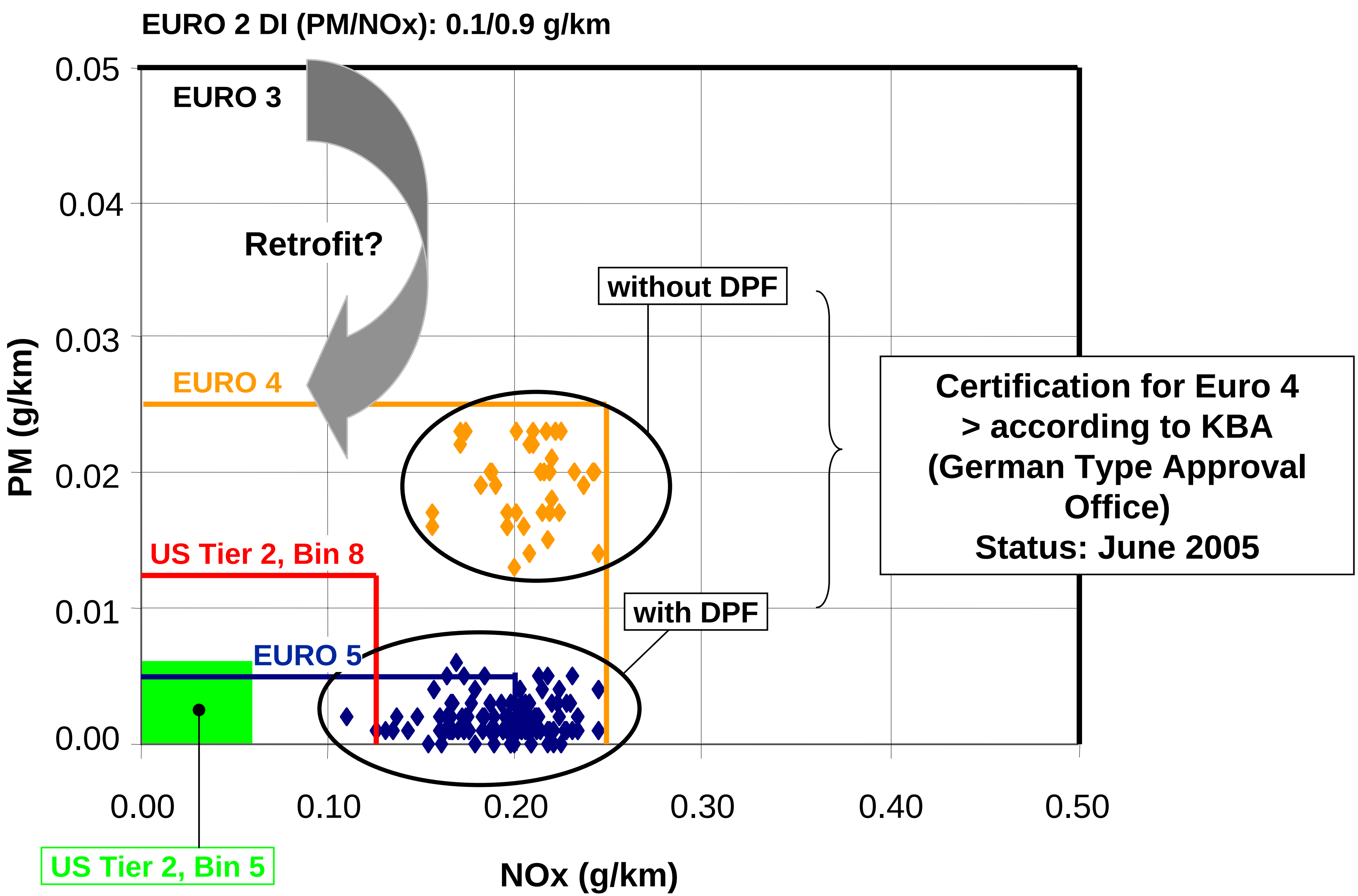
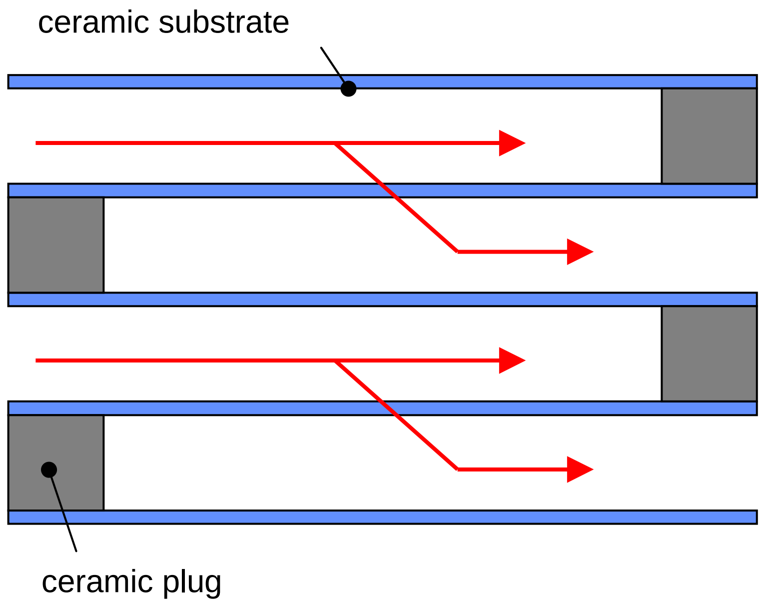
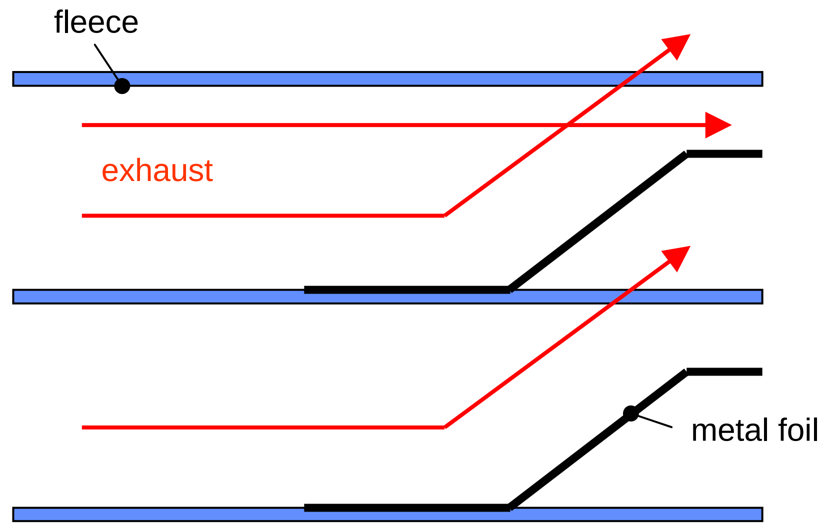
Summary & Conclusion

- Due to the increased population of **Diesel engine powered passenger cars** in Europe (market share of about 50%), the application of Diesel particulate filter systems (DPFs) becomes more and more important:
  - ⇨ The Euro 4 emission standard can be met with and without Diesel particulate filters
  - ⇨ The Euro 5 emission standard proposal (5 mg/km) is expected to require the use of DPFs
  - ⇨ PM number limit is under discussion
- **Retrofit** of older Diesel engine powered vehicles is desired in order to reduce PM10 immission levels
- Tests of **various PM reduction devices** were done on EU3 & EU4 engine generations under steady-state and dynamic conditions (NEDC)
  - ⇨ Open filter systems (catalytically coated and uncoated)
  - ⇨ CPF (catalytically coated particulate wall flow filters) including slightly damaged filters
- Measurement of **particle mass, particle number and opacity**
  - ⇨ gravimetry with conventional & mobile CVS system
  - ⇨ particle size/number with SMPS after 2-stage ejector dilution
  - ⇨ opacity with AVL 439

Past, current and future emission standards







- **ceramic substrate** (e.g. silicon carbide, cordierite, alumina titanate) as wall flow monolith, possibly coated
- soot is stored inside the channels
- regeneration is necessary in regular intervals, depending on e.g. exhaust gas backpressure, exhaust gas temperature, soot loading of DPF
- **particulate reduction: > 90%**

- corrugated, helical **metal foils** with open channels, catalytically coated
- should the fleece be plugged with soot, exhaust flows through open channels (particulate reduction is then zero)
- **thermal regeneration** is not necessary
- typ. average **particulate reduction: 30%**
- Manufacturers: e.g. Emitec, Oberland Mangold, Ecocat

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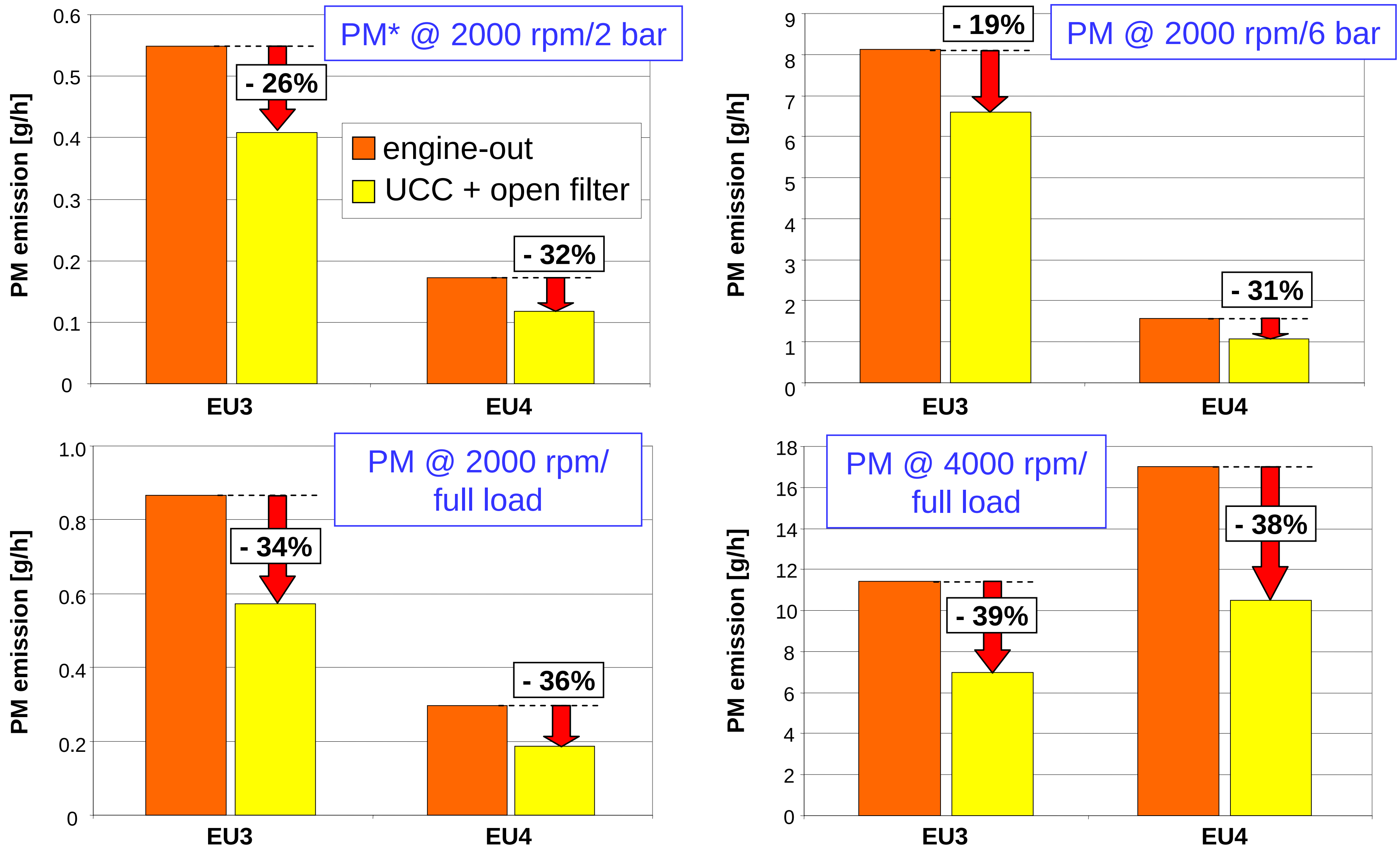
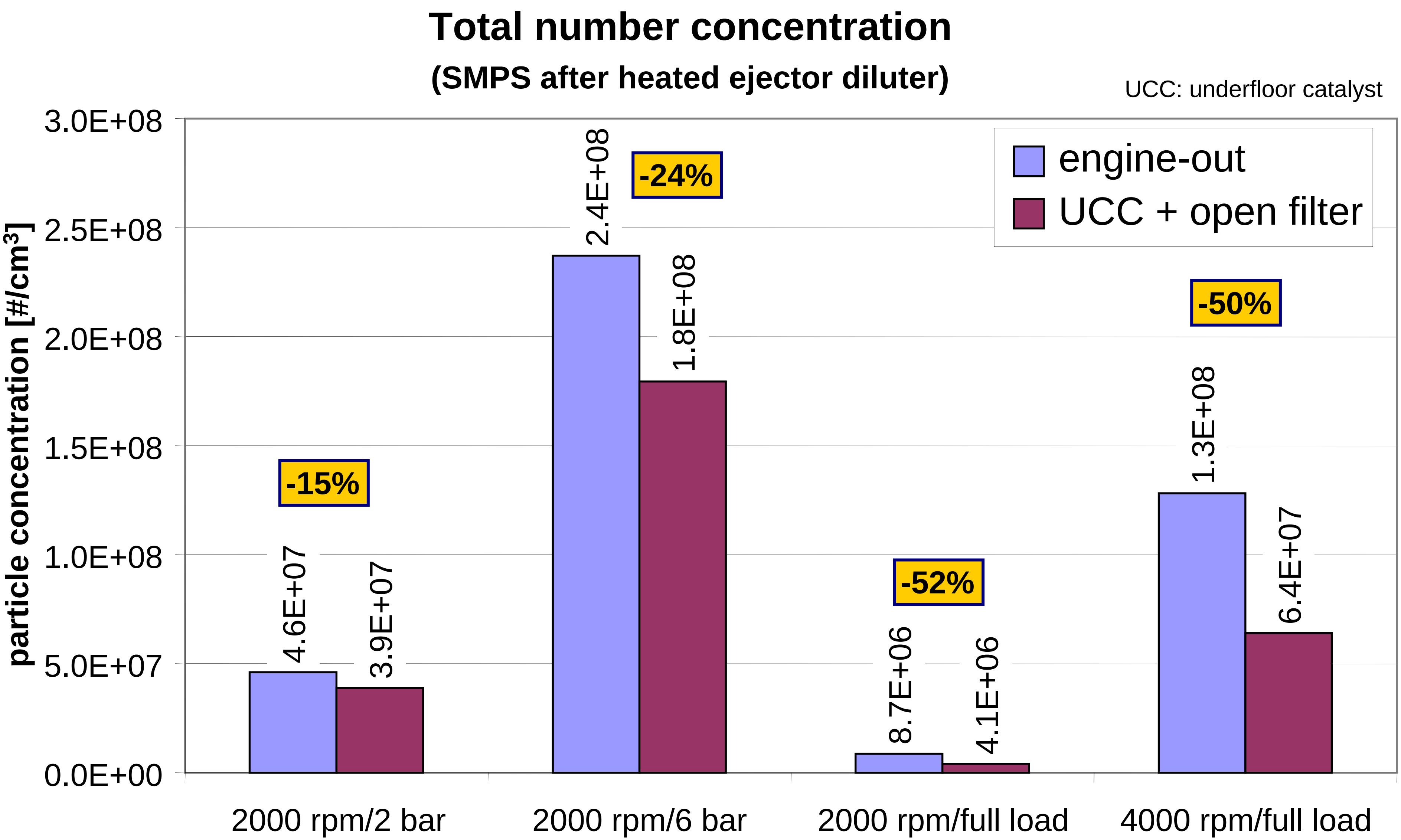
PM emission

UCC: underfloor catalyst

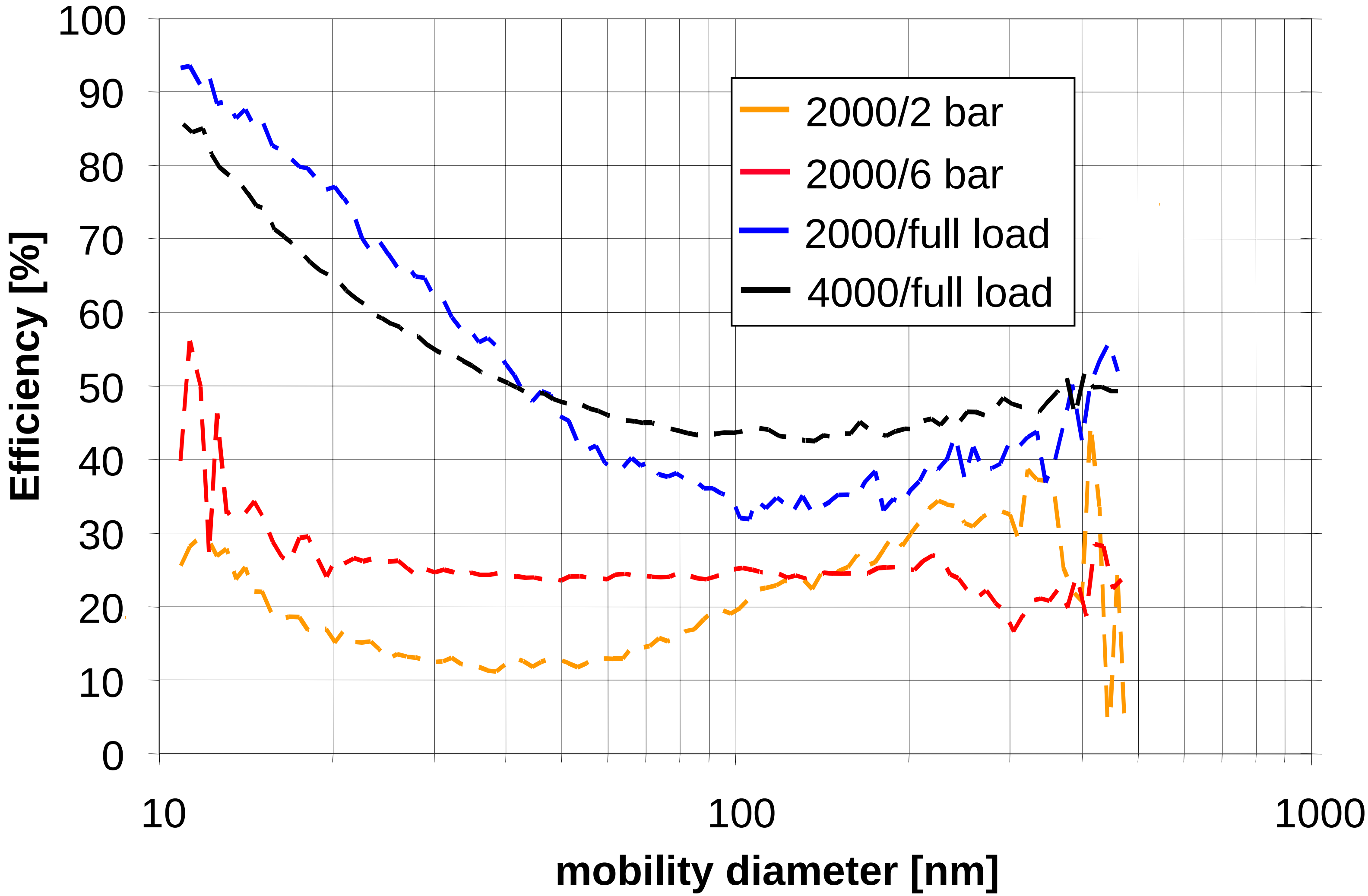


*: Particulate emission (PM) was recalculated here from AVL Smoke Meter 415S measurement


Total number concentration
(SMPS after heated ejector diluter)
UCC: underfloor catalyst
particle concentration [#/cm³]
3.0E+08
2.5E+08
2.0E+08
1.5E+08
1.0E+08
5.0E+07
0.0E+00
engine-out
UCC + open filter
-15%
4.6E+07
3.9E+07
-24%
2.4E+08
1.8E+08
-52%
8.7E+06
4.1E+06
-50%
1.3E+08
6.4E+07
2000 rpm/2 bar
2000 rpm/6 bar
2000 rpm/full load
4000 rpm/full load

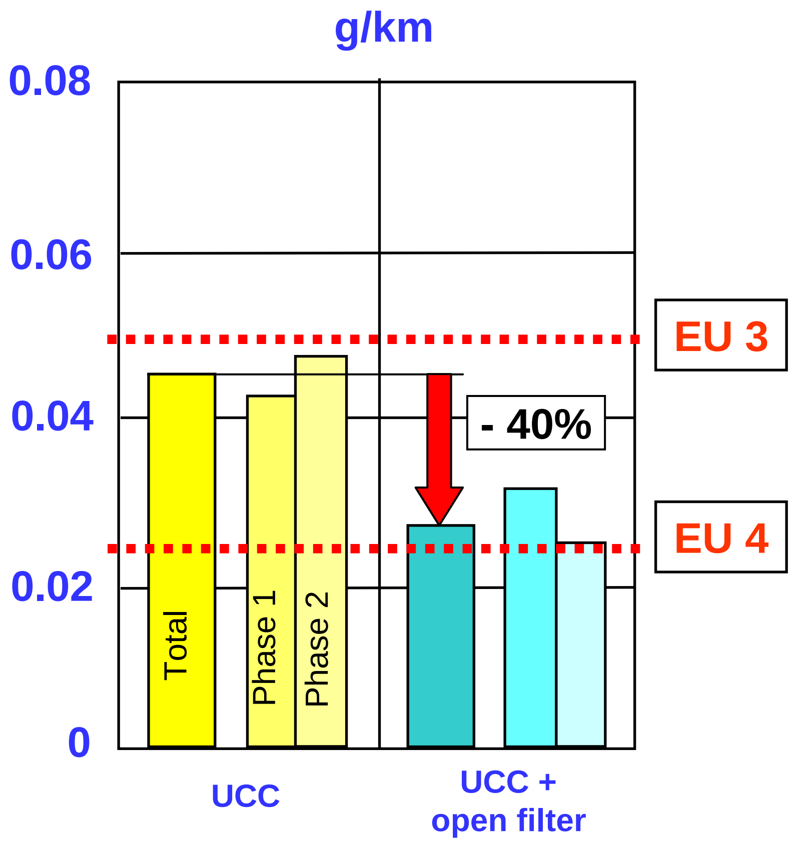
Efficiency from particle size distribution

(SMPS after heated ejector diluter)

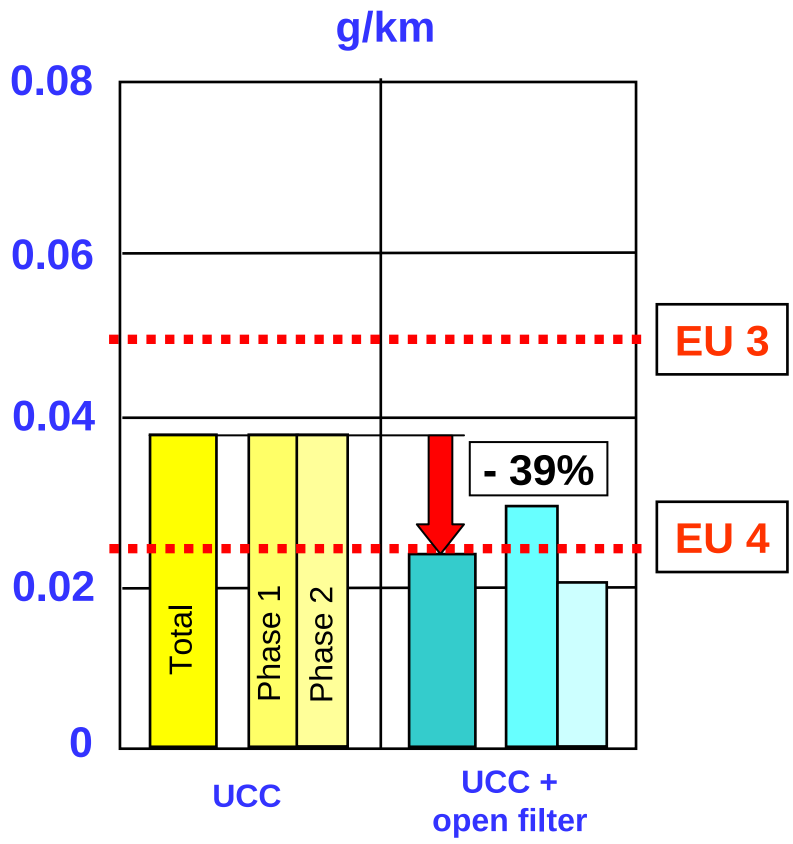


PM emission

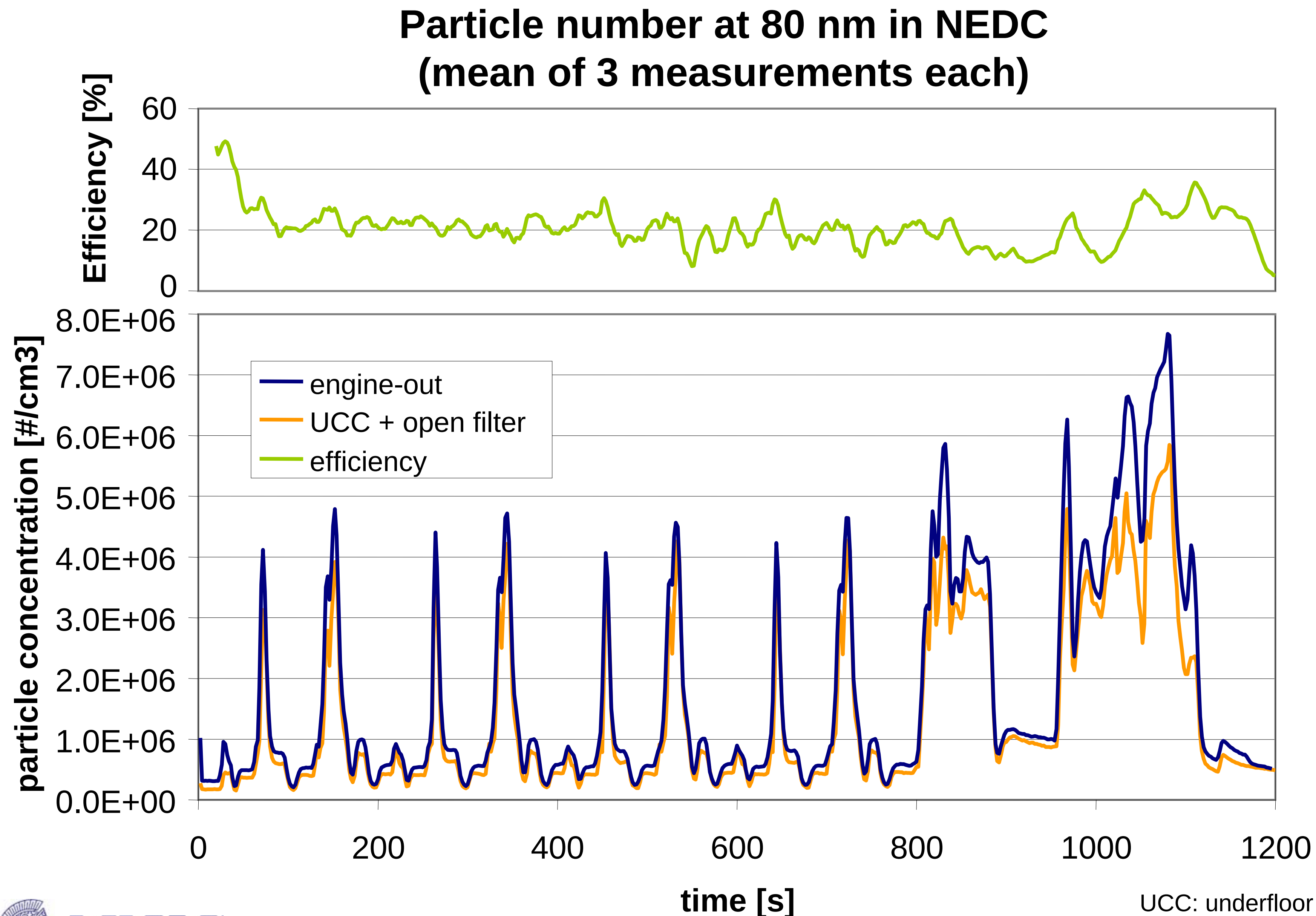
NEDC (cold)



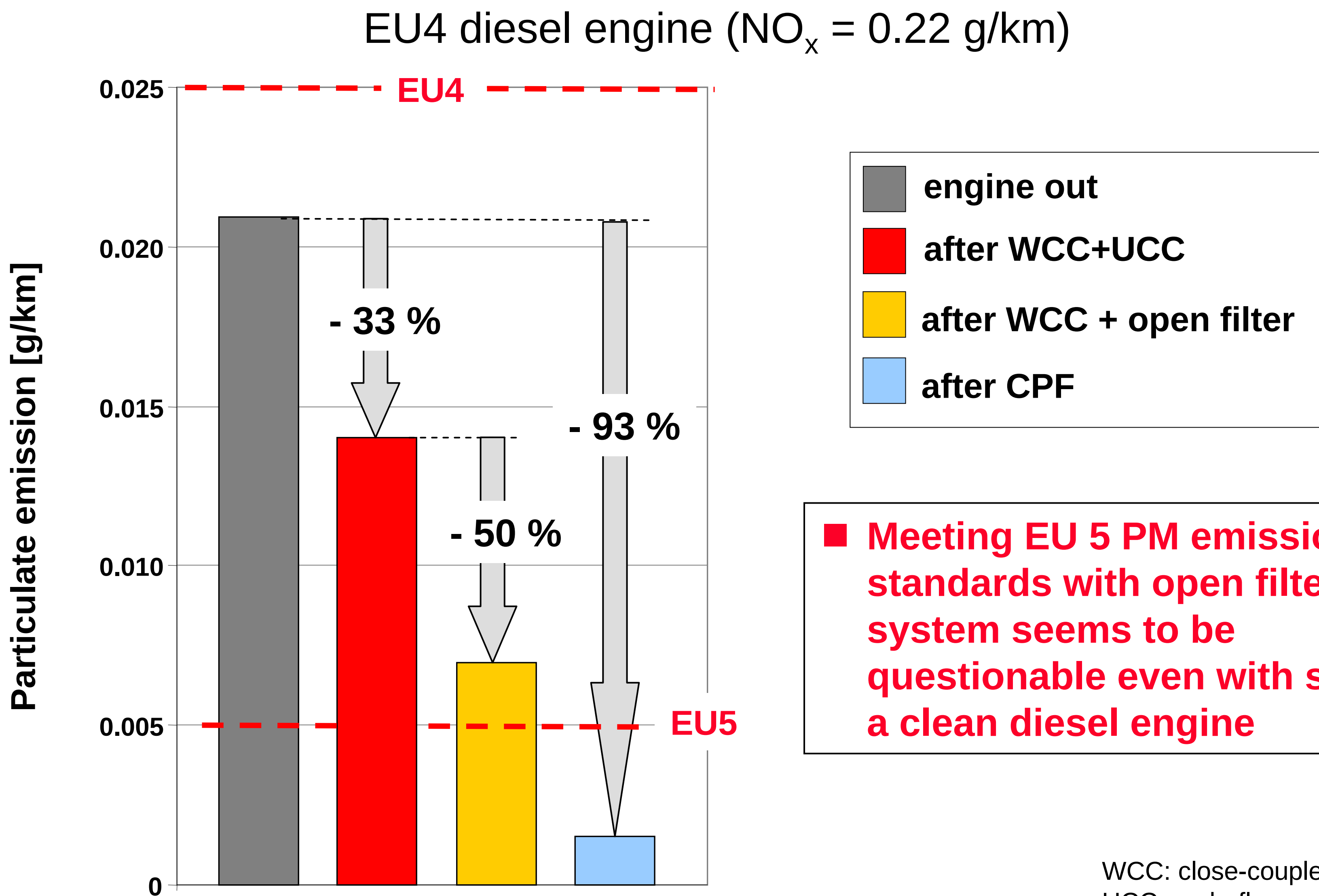
NEDC (hot)



UCC: underfloor catalyst



UCC: underfloor catalyst

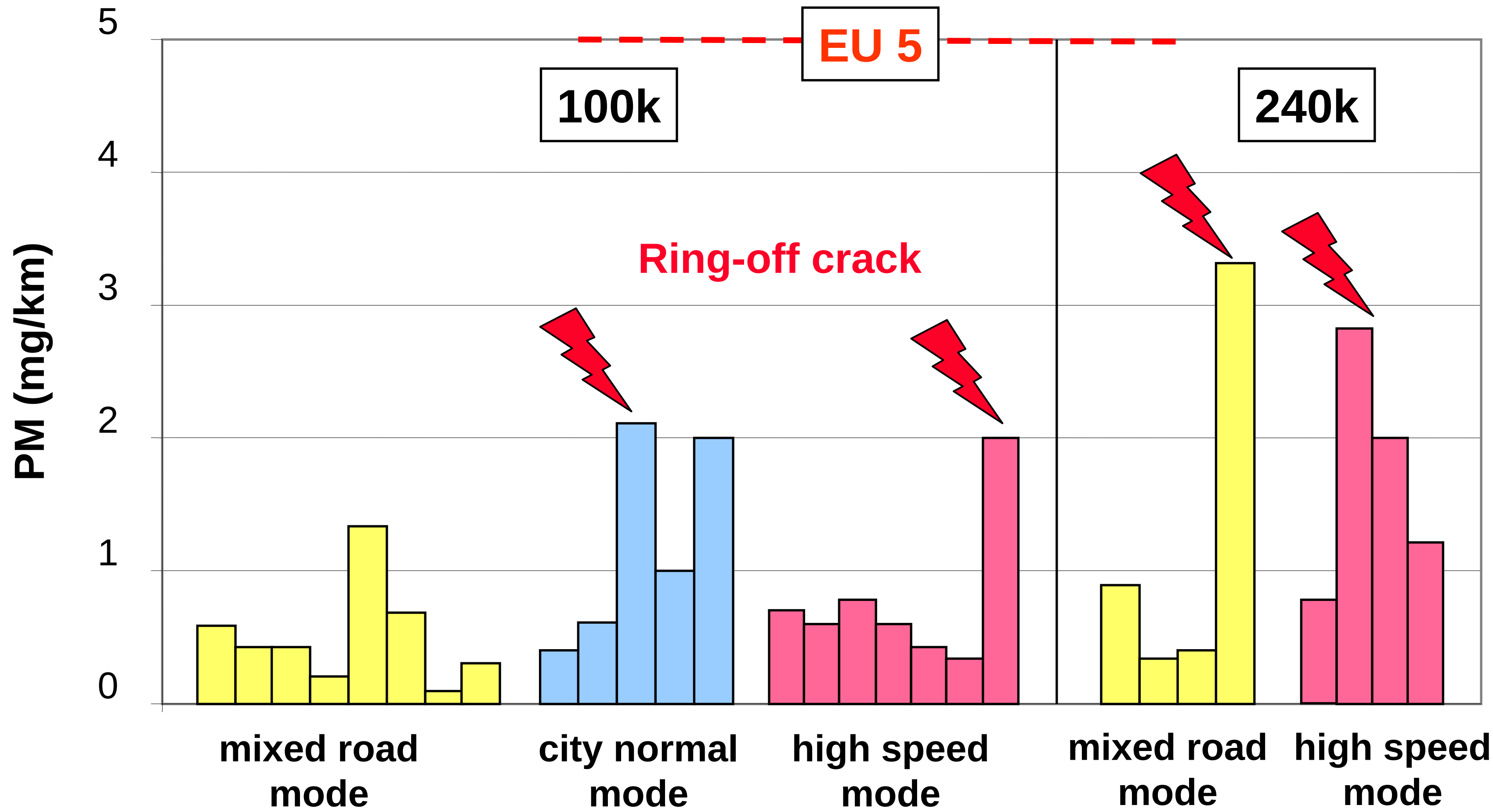


- **Meeting EU 5 PM emissions standards with open filter system seems to be questionable even with such a clean diesel engine**

WCC: close-coupled catalyst
UCC: underfloor catalyst
CPF: coated particulate filter

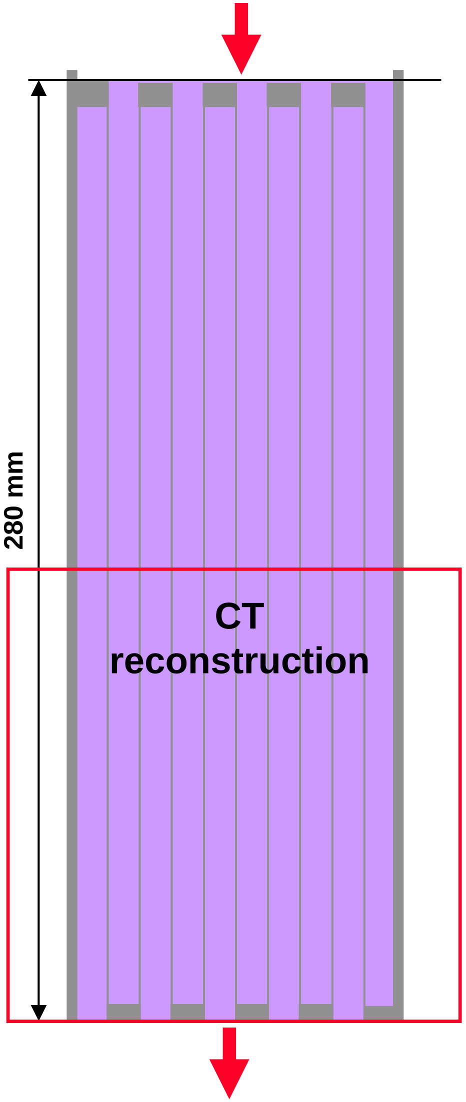
- Motivation
- Open particulate filter systems
- **Validation of CPF systems**
- Summary & Conclusion

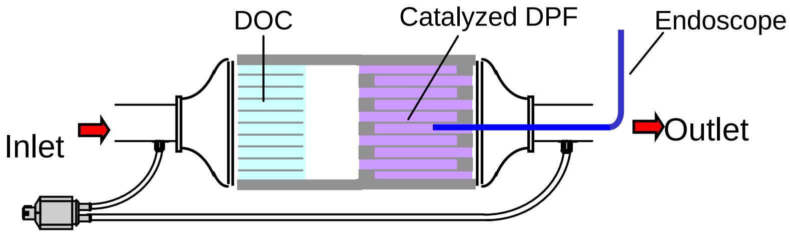
HMC/Kia vehicles with CPF



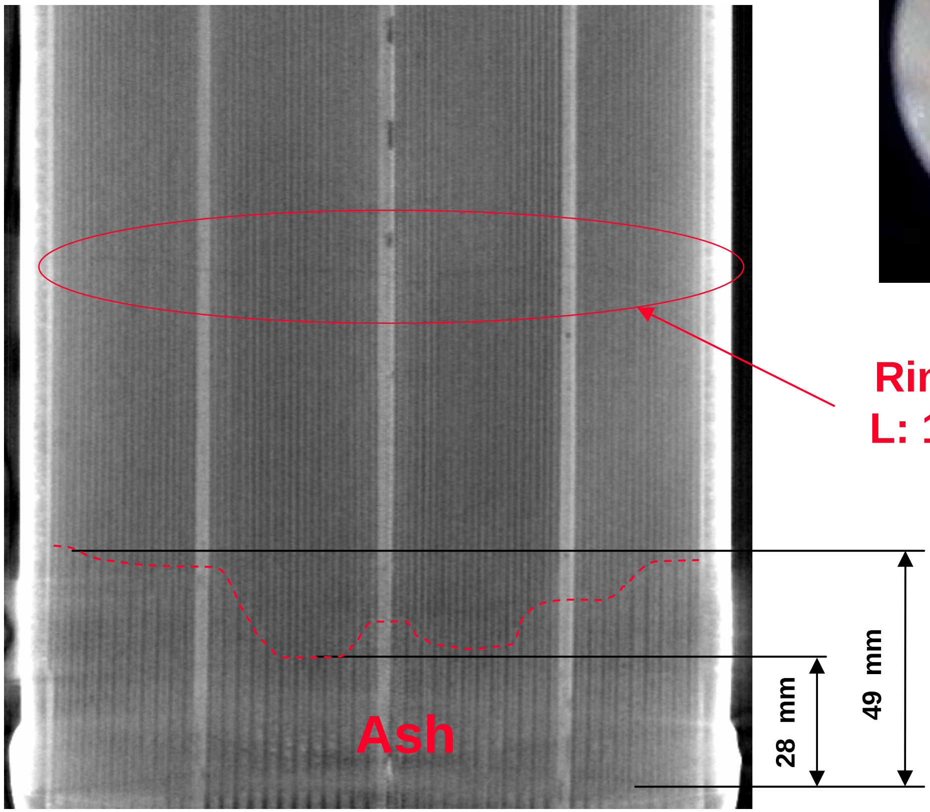
Although some particulate filters were slightly damaged (ring-off crack), PM emission standards (even for EU5) can still be met!

CT imaging & endoscopy of cracked CPF (after 100k)



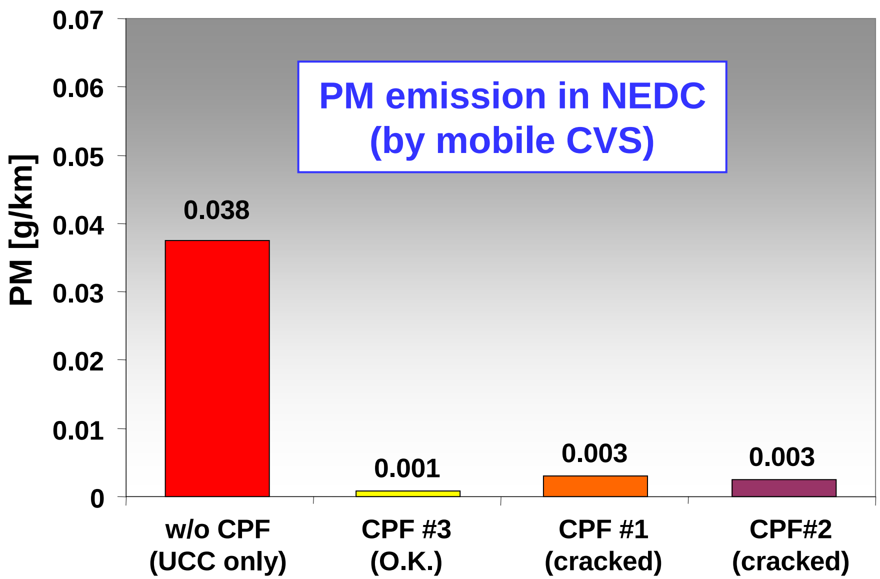


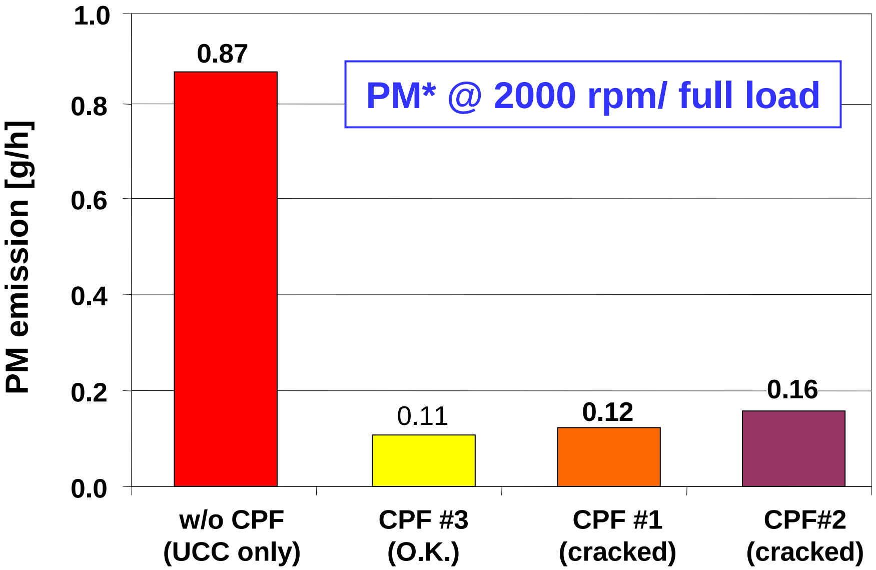
CN#006

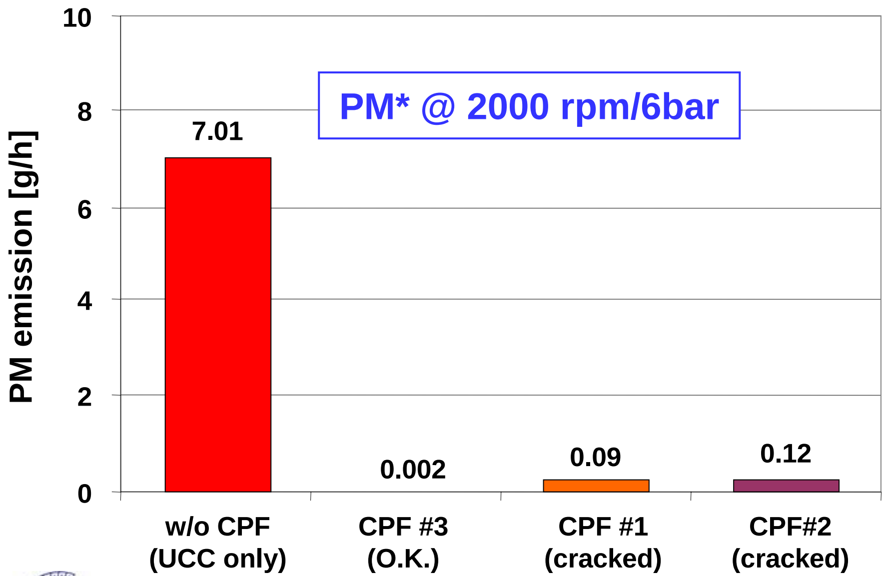


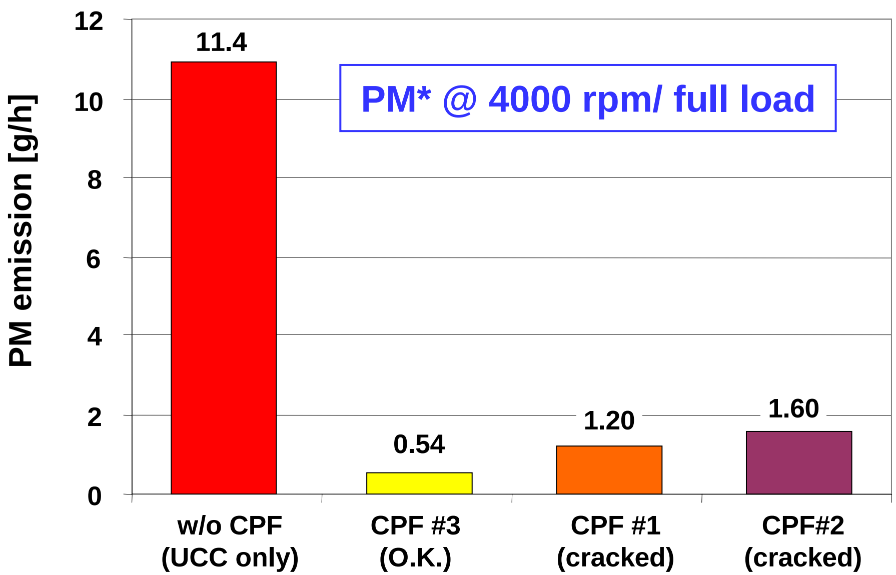
Ring-off crack
L: 100-105 mm

Comparison of PM measurement results in NEDC and steady-state tests



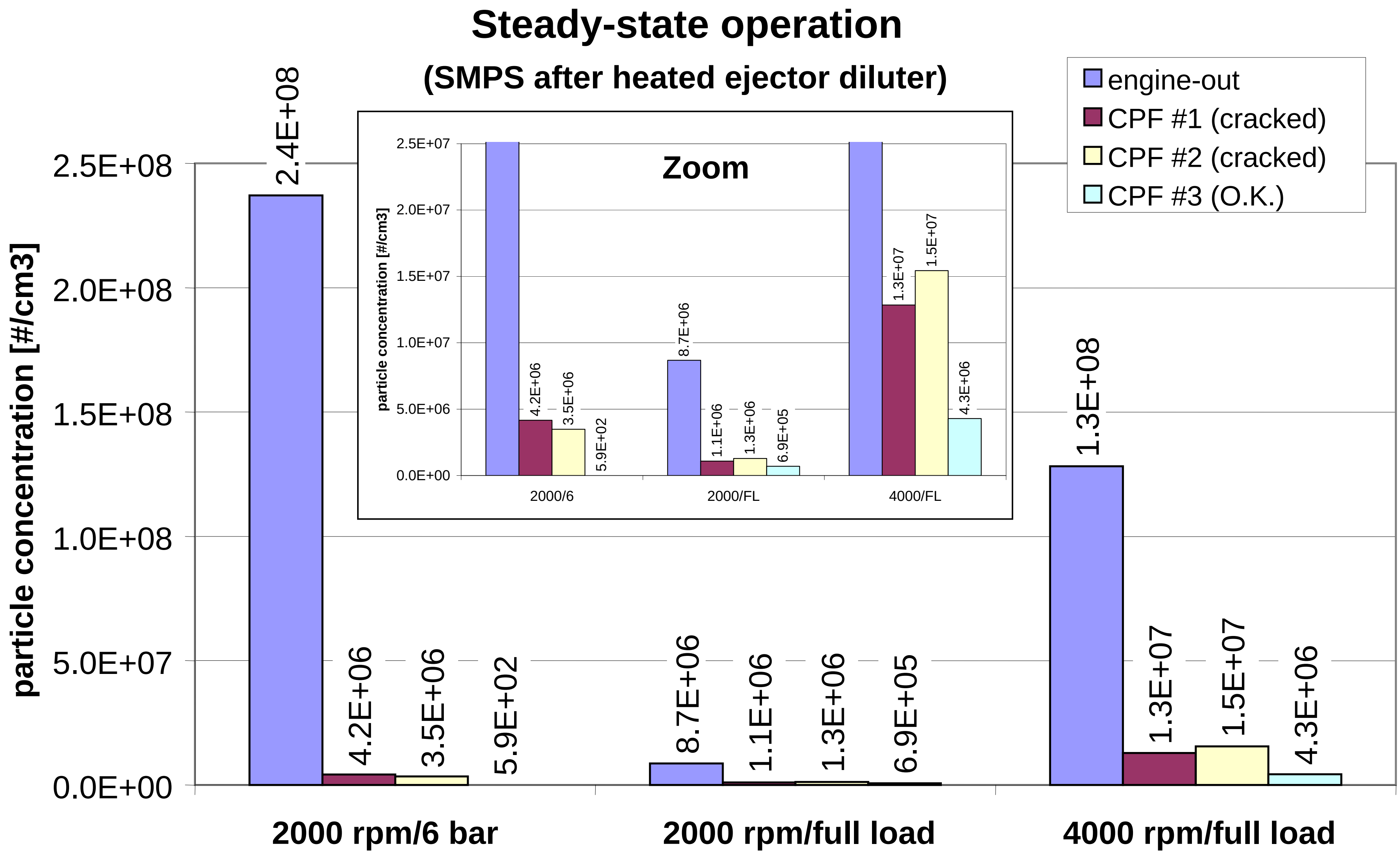




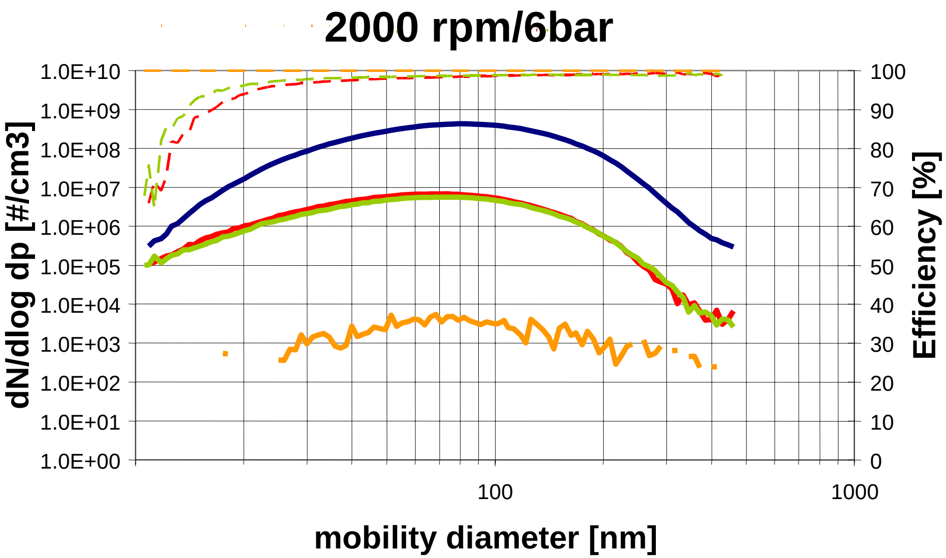


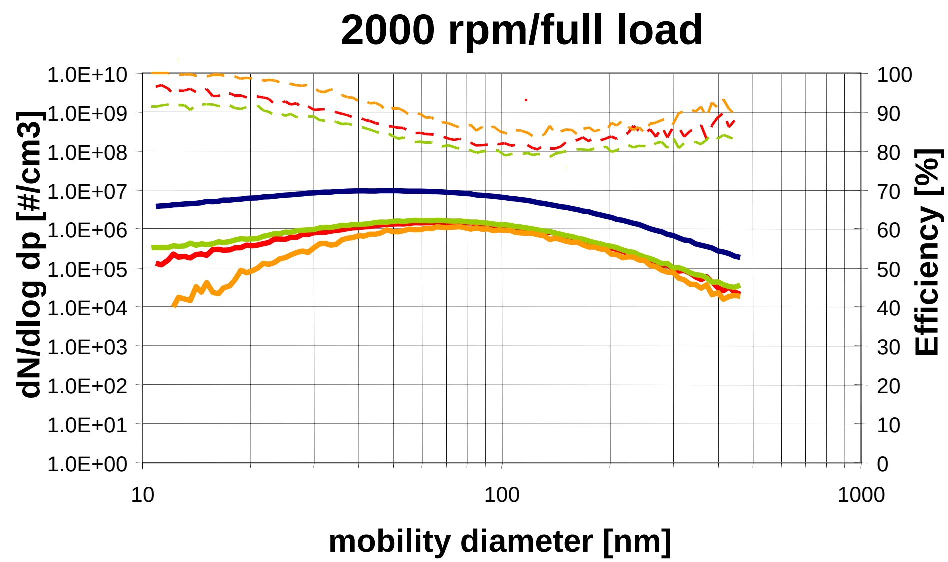
*: Particulate emission (PM) was recalculated here from AVL Smoke Meter 415S measurement

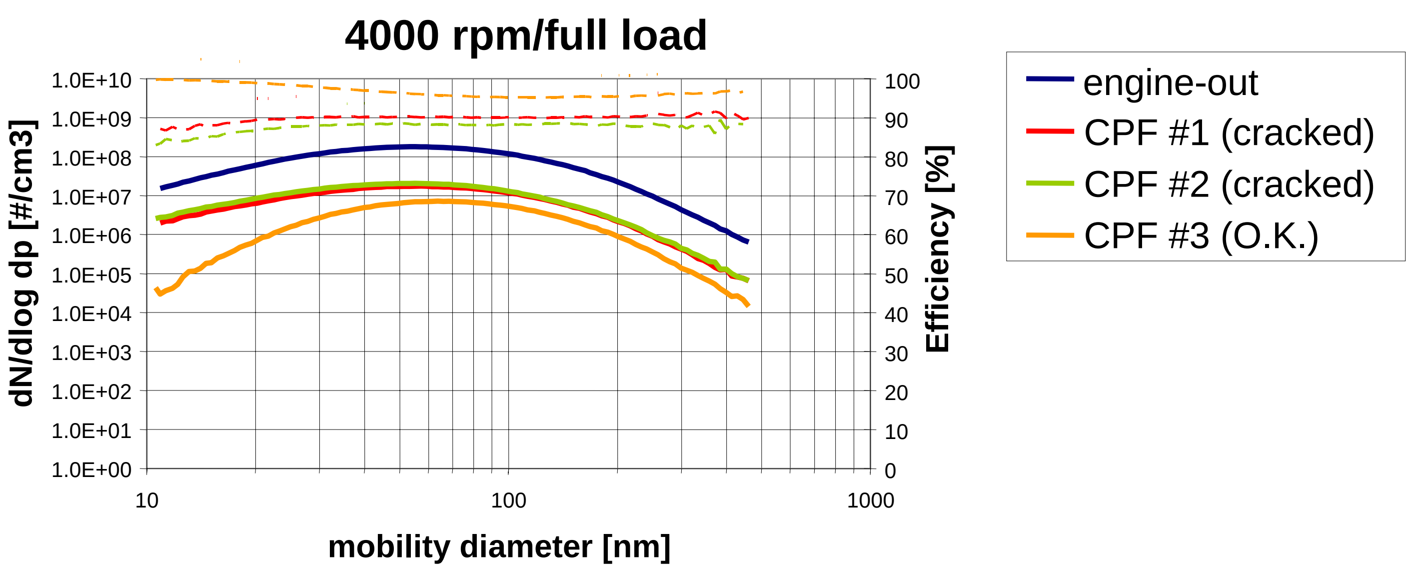
Steady-state total number concentrations for engine-out vs. various CPFs



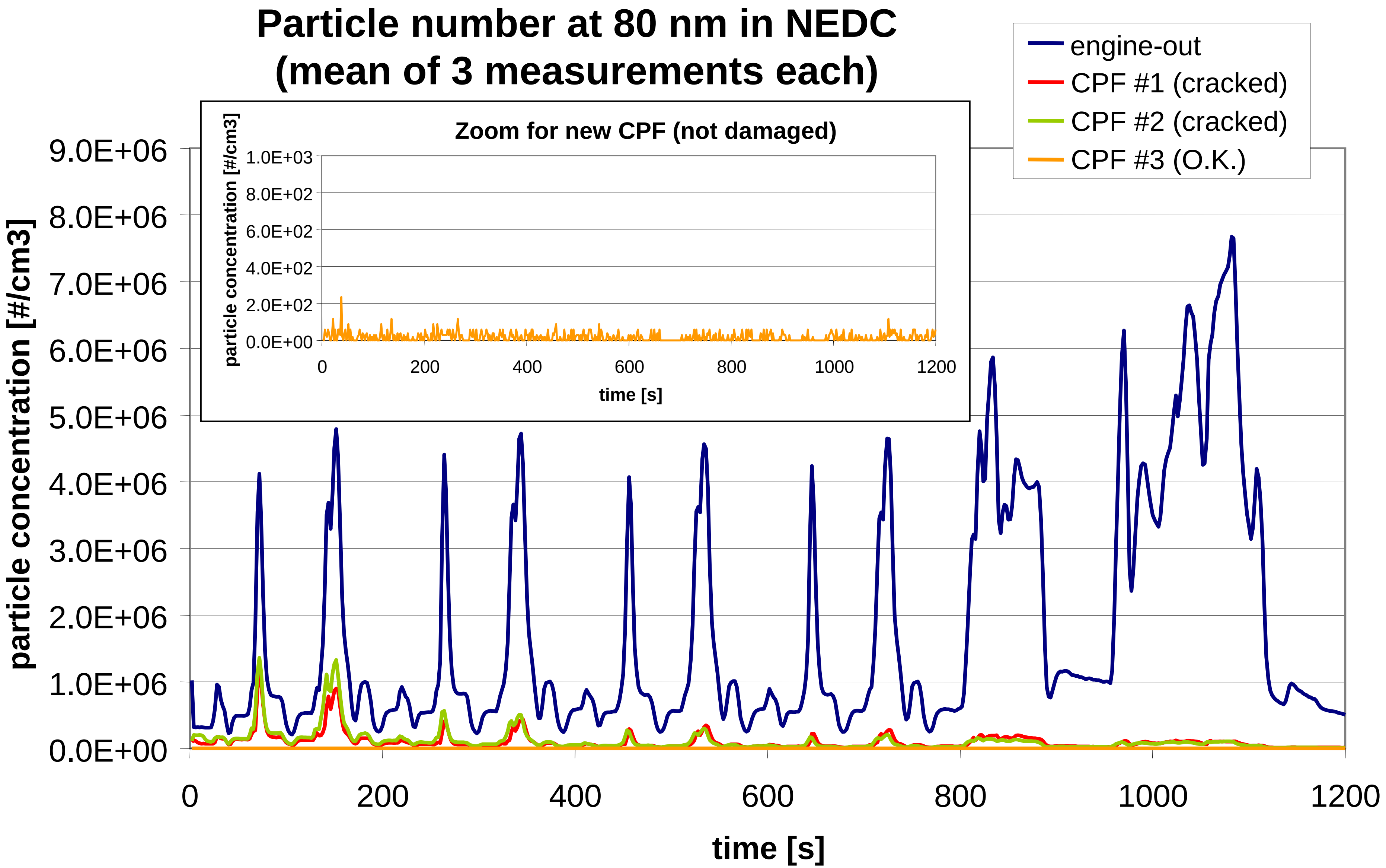
(SMPS after heated ejector diluter)

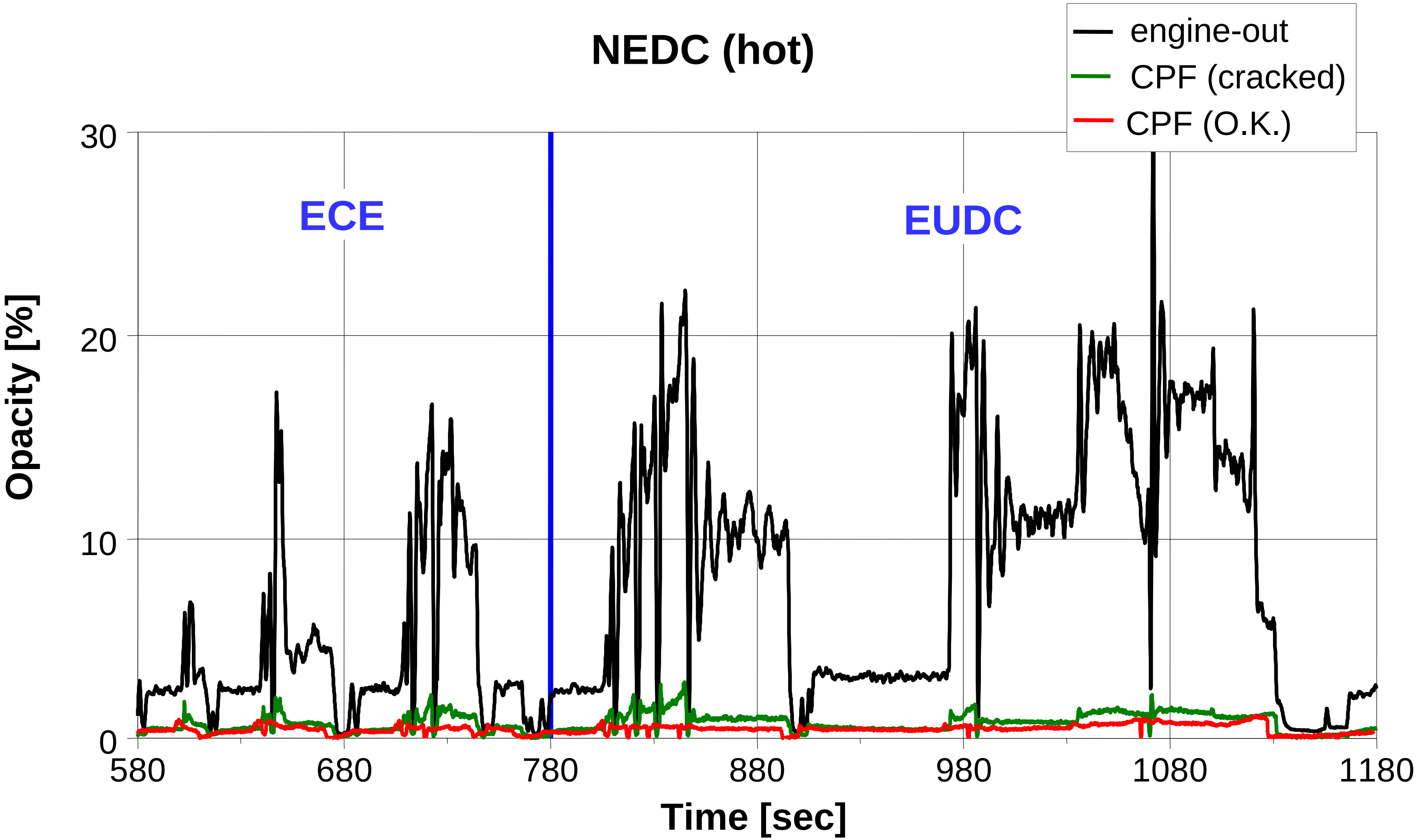






NEDC particle number concentrations for engine-out vs. various CPFs




NEDC (hot)
engine-out
CPF (cracked)
CPF (O.K.)
ECE
EUDC
Opacity [%]
30
20
10
0
580
680
780
880
980
1080
1180
Time [sec]

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- **Summary & Conclusion**

- An **open filter system** is a cost efficient PM reduction device to retrofit diesel engines without any engine H/W changes and additional regeneration calibration application:
  - ⇨ PM mass emission results at steady state conditions show an efficiency between 20 and 40% for the **open filter system**. However, under dynamic conditions such as in the NEDC test, the PM efficiencies observed are slightly higher (~40%).
  - ⇨ The SMPS measurements behind the **open filter system** showed a high variability in efficiency depending on the operating point of the engine. Highest efficiency of total number concentration was measured at 2000 rpm/full load with an efficiency of 52%, lowest particle retention was measured for 2000 rpm/2 bar with 15%.
  - ⇨ For the operating points at full load (2000 and 4000 rpm) a particle retention efficiency of >70% could be measured for small particles with a diameter <20 nm.
  - ⇨ Mean efficiency for a particle diameter of 80 nm in the NEDC measurements was 20% only. However, it should be taken into account, that only one size range was measured. Referring to steady-state results, the efficiency increased with particles getting smaller.
- However, even with very clean diesel engine, meeting EU 5 PM emissions standards with **open filter system** seems to be questionable

- Results of an extended fleet with various vehicles equipped with standard **wall flow filters** show very low numbers even after 240k. Though some of them have been slightly damaged (ring-off cracks) EU4 and even EU5 PM standards can still be met with safety margin.
  - ⇨ CPFs with ring-off cracks showed very low particle numbers compared to engine-out. At 2000 rpm/6 bar, the total particle concentration of both CPFs with ring-off cracks was approx. 2 orders of magnitude lower than engine-out. At 2000 rpm/full load and 4000 rpm/full load engine-out emission still showed 8 times higher particle concentrations than the damaged CPFs.
  - ⇨ Especially in the NEDC at a mobility diameter of 80 nm, the CPF without damage showed extremely low particle numbers. The CPFs with ring-off cracks had slightly higher numbers, but were still far below engine-out. The same applies to opacity measurements. PM mass emissions with damaged CPFs were only slightly higher than with new CPF.

Thank you for your attention!

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