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# Traping Efficiency of Several Diesel Particle Filters from the VERT-Building Machinery Field Test

# Traping Efficiency of Several Diesel Particle Filters from the VERT – Building Machinery Field Test

by

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## Workshop „Nanoparticle Measurement"

## ETH-Zurich, August 7, 1998

- Engine, test procedure and PM-measuring apparatus
- VERT – objectives and filed test
- Comparison of results with different particulate traps
  - limited emissions
  - particles size distribution and integrated particles numbers
  - coulometry
  - free acceleration
  - formation of sulphates at certain conditions
  - traping efficiency for: mass, number, elemental carbon
- Summary

## Engine Liebherr I:

Manufacturer: Liebherr

Type: 941 T

Displaced volume: 6.11 liters

Rated RPM: 2000

Rated power: 105 kW

Combustion: Direct injection

Super-charging: Without intercooling

## Test procedure

### operating conditions:

| Test point | RPM | Torque in % |
|---|---|---|
| 1 | 2000 (100%) | 100 |
| 2 | 1400 (50%) | 100 |
| 5 | 2000 | 50 |
| 6 | 1400 | 50 |

### measurements:

- exhaust gases and PM gravimetric
- PM size distribution

] 4 points (VERT) stationary

- free acceleration – opacity
- coulometry – EC, OC

# VERT - Project

Verbesserung der Emissionen von Realmaschinen in Tunnelbau

Improvement of emissions of the real machines in tunnel construction.

## Objectives

- **to diminish the emissions at the source**
- **to define the new limit values of emissions**
- **to find the methods and apparatus to control the machines in the field**
- **to confirm the feasibility of the particulate traps (PT) and regeneration systems in the field tests**
- **to give support to the users by introducing the PT-systems**

# VERT FIELD TESTS

A field test with 10 engines was run between October 1995 and June 1997.

4 different filter media and 4 regeneration systems were tested.

Over 23000 hours were accumulated.

## Filter systems selected for VERT filed test

| | Manufacturer |
|---|---|
| 5 ceramic monoliths | Corning, NGK |
| 2 metal sinter filters | HJS (SHW) |
| 2 knitted fiber filters | TSP BUCK |
| 1 Braided fiber filter | HUG |

## Regeneration systems

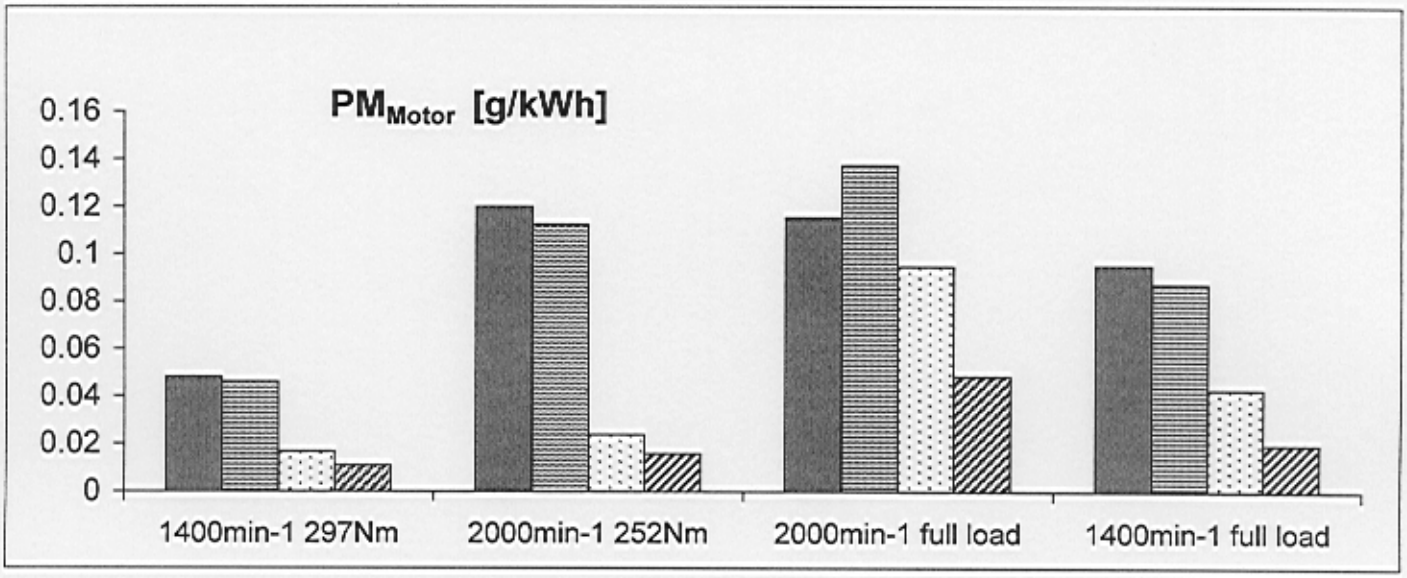
| |
|---|
| 2 systems with periodic electrical regeneration |
| 2 systems with full flow Diesel burner |
| 4 systems with fuel additives |
| 2 systems with catalytic coating |

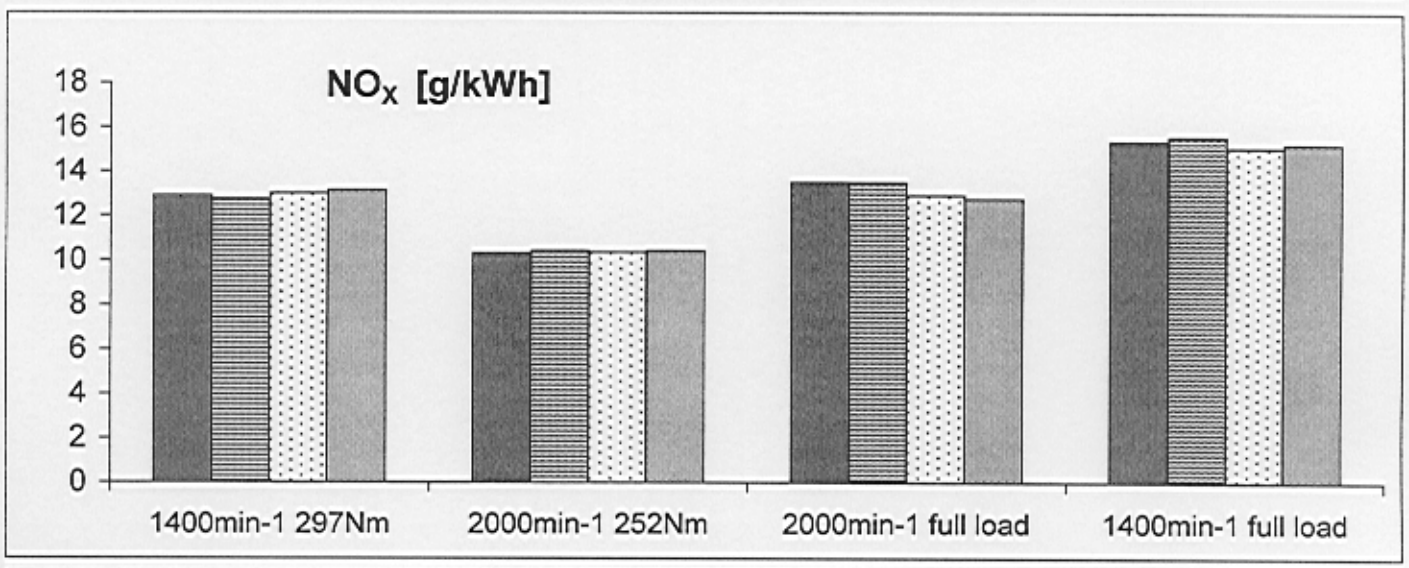
# Particle Filters in the VERT field test

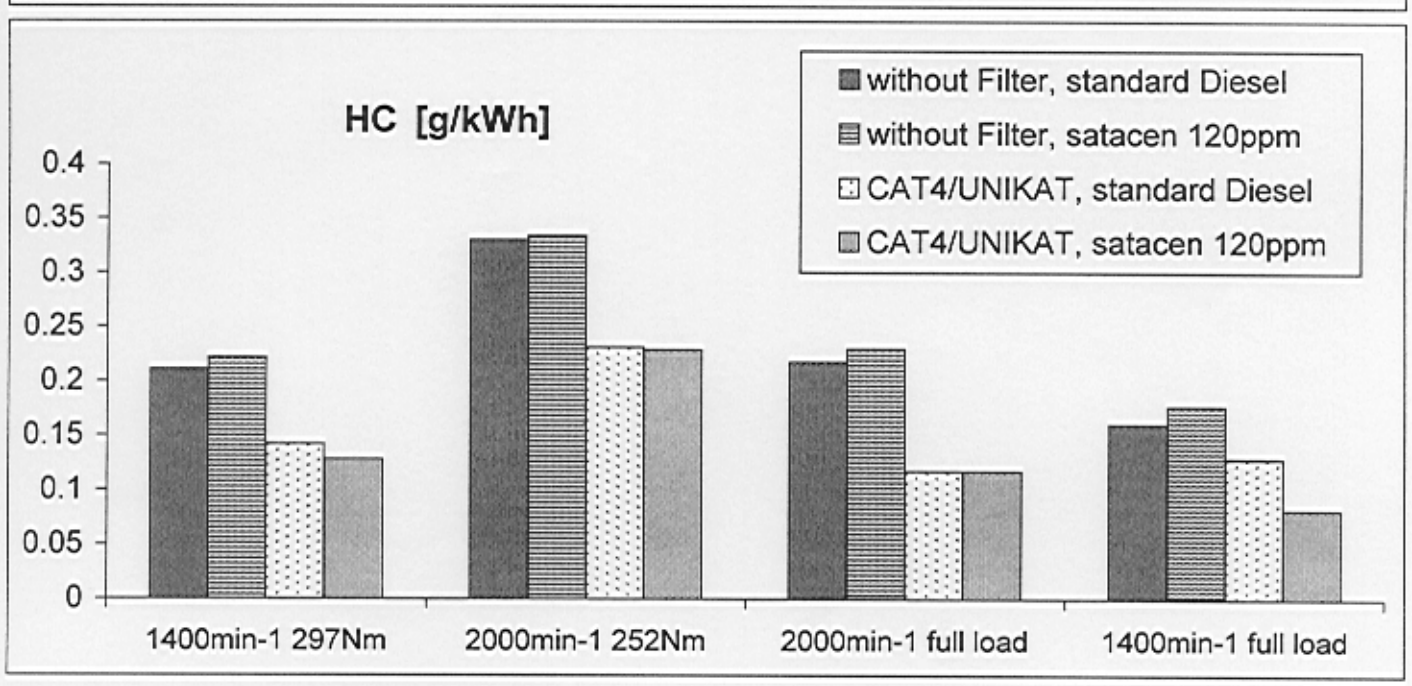
| Engine Type | Manufacturer of Filter | Regeneration | Time of use [h] | Symbol |
|---|---|---|---|---|
| Liebherr 1 | SHW (HJS) | Eolys (Ce) satacen (Fe) | 1846 | LIB1/SHW |
| 2 | BUCK | Catalytic coating | 1270 | LIB2/BUCK |
| 3 | ECS | Lubrizol (Cu) | 2061 | LIB3/ECS |
| 4 | DSI | full flow Diesel burner | 1705 | LIB4/DSI |
| Catapillar 1 | SHW | satacen (Fe) | 1534 | CAT1/SHW |
| 2 | DSI | full flow Diesel burner | 1724 | CAT2/DSI |
| 3 | BUCK | satacen (Fe) | 2189 | CAT3/BUCK |
| 4 | UNIKAT | electrical off-line | 6933 | CAT4/UNIKAT |
| 5 | UNIKAT | electrical off-line | 2775 | CAT5/UNIKAT |
| 6 | HUG | catalytic coating | 1707 | CAT6/HUG |

... not analysed after the field test

# Limited emissions with CAT4/UNIKAT-Filter, Engine: Liebherr D914T

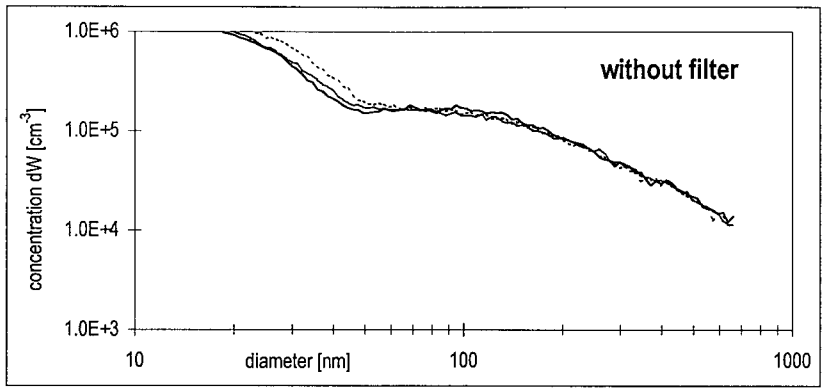


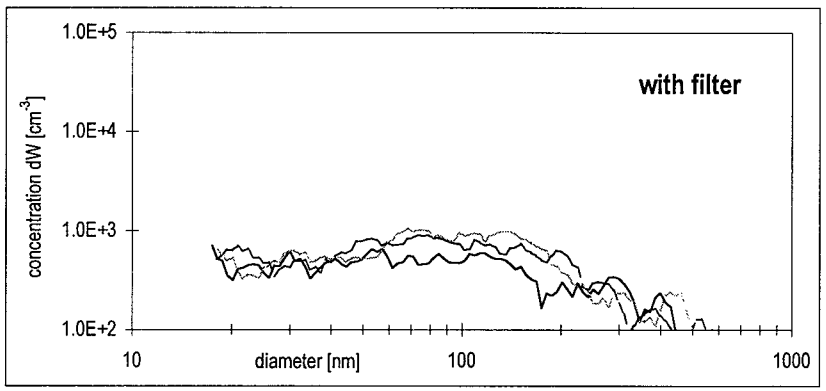



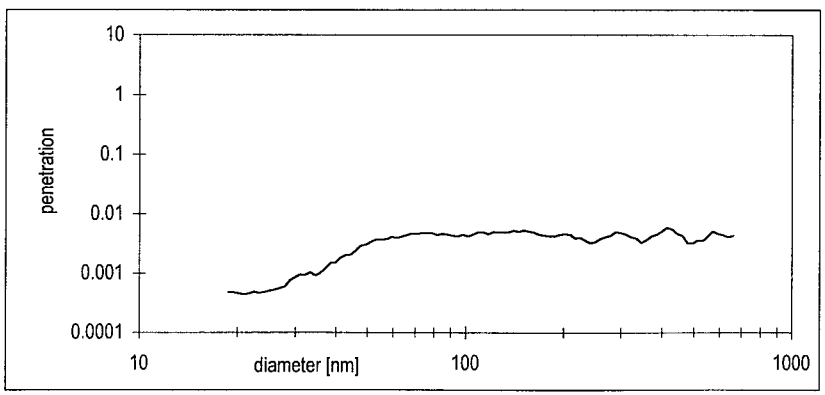



# Size distributions with / without CAT4/UNIKAT-Filter, Liebherr D914 T, 2000 rpm/full load, HC-Trap

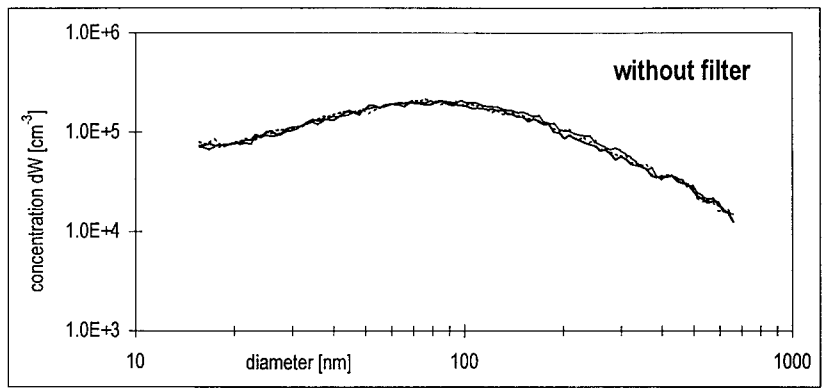
## satacen 120ppm (36ppm Fe)

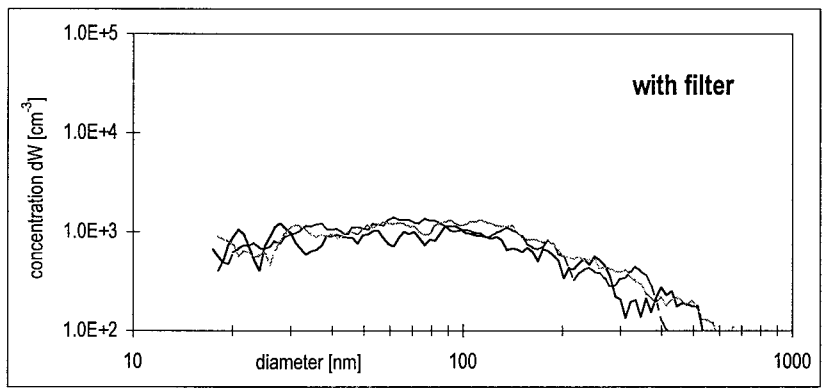


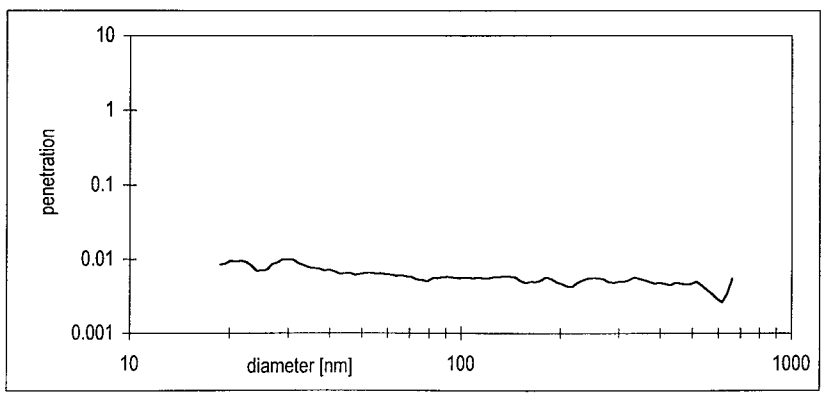




## standard Diesel

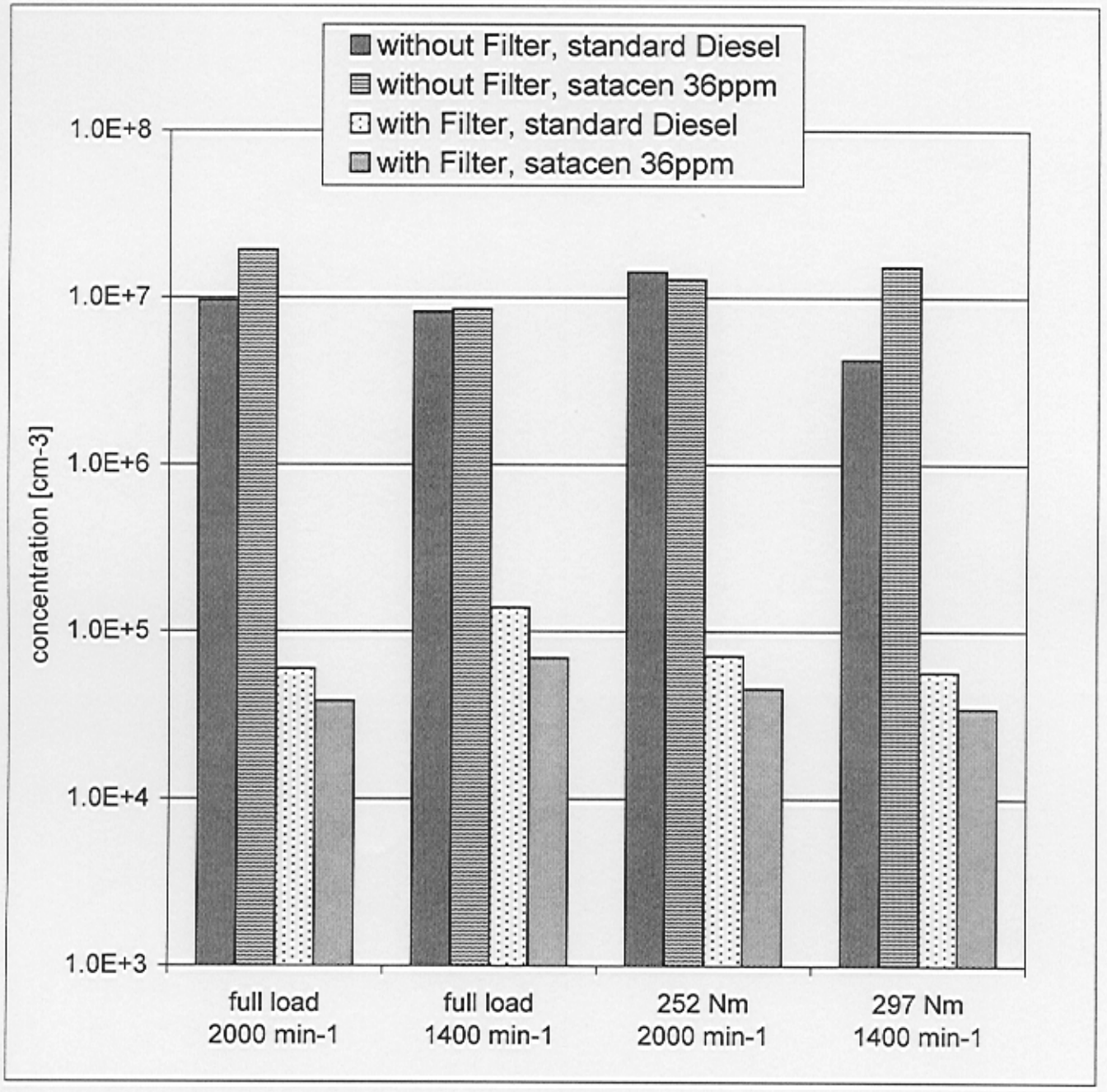


**Integrated numbers of particles in the size spectrum 20-200 nm**

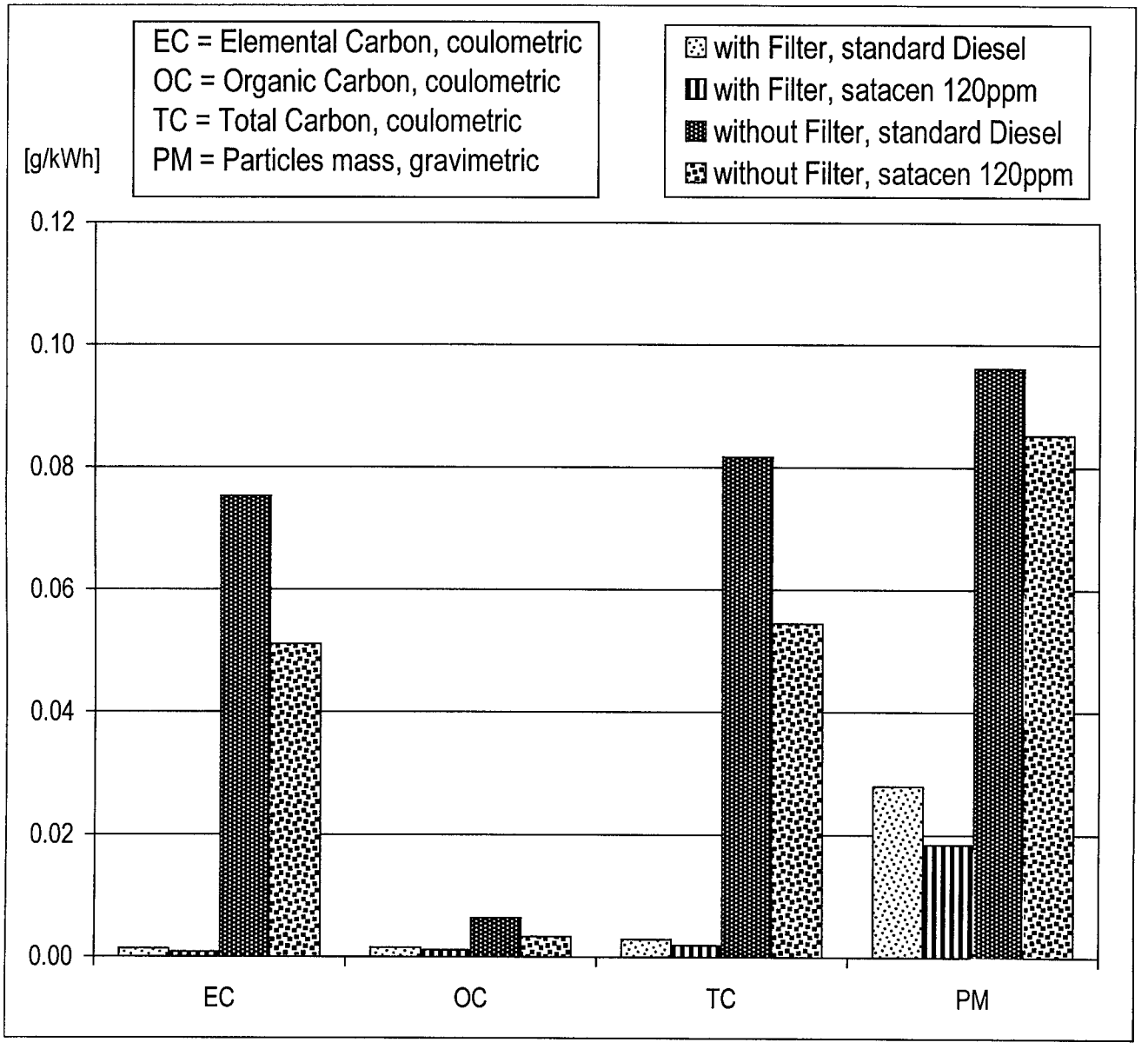
## CAT4/UNIKAT-Filter, with thermodenuder



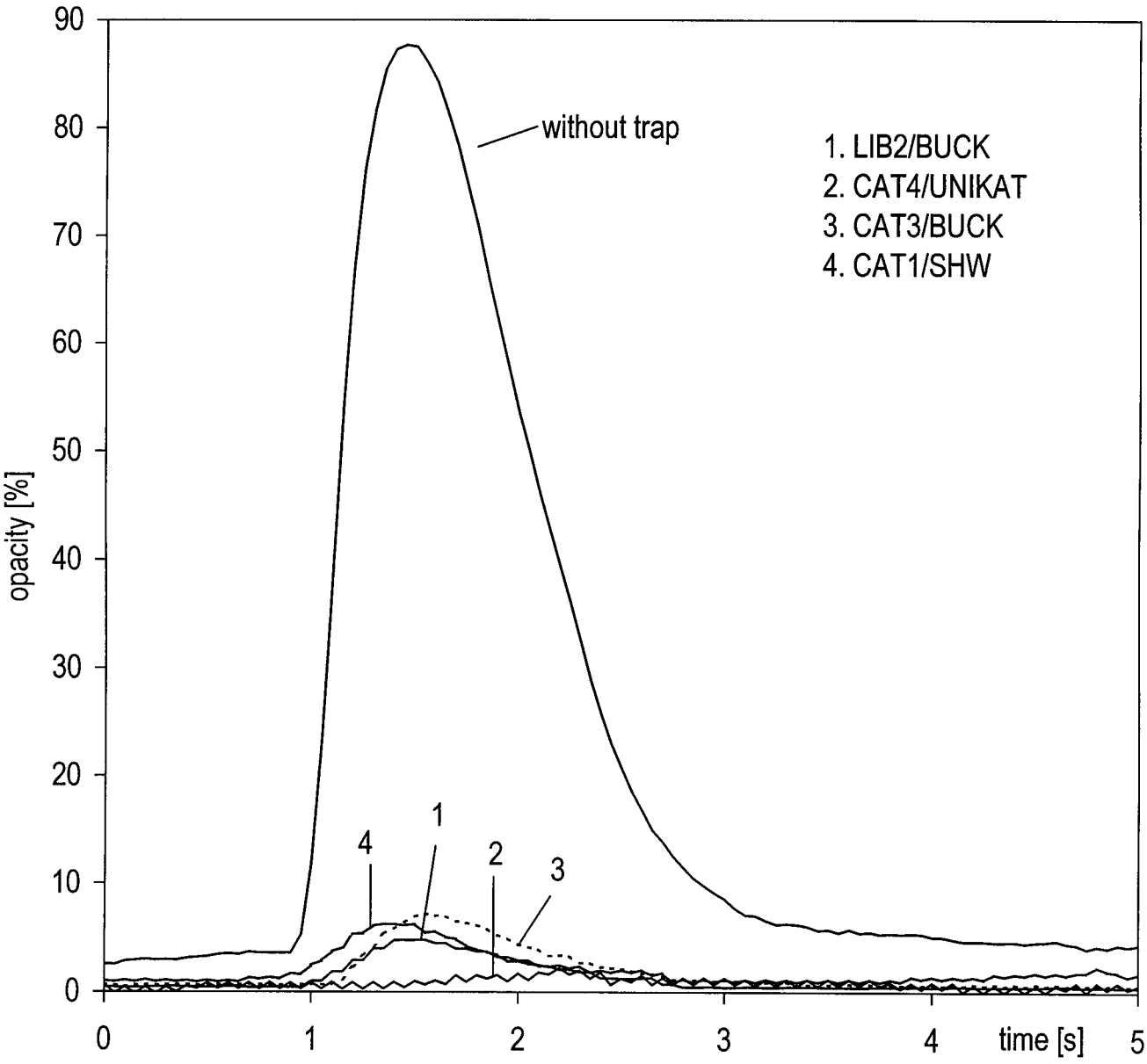
## Comparison Coulometry / Gravimetry

# with/without CAT4/UNIKAT-Filter

## Liebherr D914T at 1400min-1 / full load



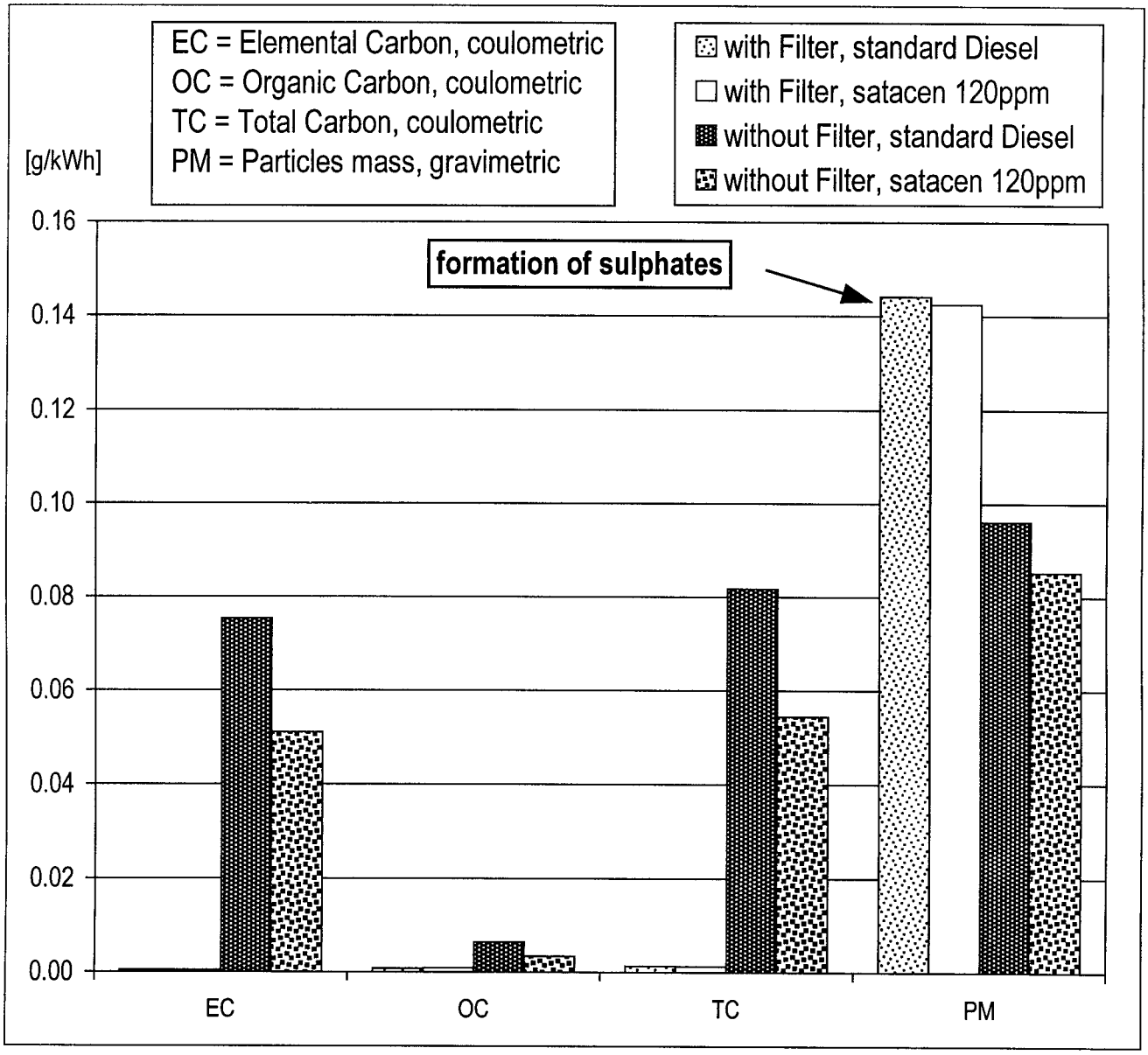
# Opacity during the free acceleration with different traps from the VERT-field test



# Comparison Coulometry / Gravimetry

# with/without LIB3/ECS-Filter

## Liebherr D914T at 1400min-1 / full load



# Comparison of traping efficiencies of
## mass (PMAG) and counts 20-200nm (PZAG)

| | | standard Diesel | | satacen 120ppm | |
|---|---|---|---|---|---|
| Filter | measure point | mass PMAG [%] | counts PZAG [%] | mass PMAG [%] | counts PZAG [%] |
| **LIB4/DSI** | 2 | 74.9 | 85.3 | 78.9 | 86.0 |
| | 6 | 48.5 | 84.3 | 77.5 | 98.6 |
| | 5 | 79.2 | 88.9 | 75.4 | 87.5 |
| | 1 | 73.4 | 88.1 | 72.5 | 94.4 |
| | 2 | 76.3 | | | |
| **LIB2/BUCK** | 2 | 87.2 | 96.7 | 90.3 | 95.5 |
| | 6 | 57.3 | 96.2 | 57.5 | 99.6 |
| | 5 | 65.6 | 93.8 | 73.9 | 97.6 |
| | 1 | 84.4 | 94.8 | 92.0 | 98.5 |
| | 2 | 88.1 | | 91.3 | |
| **LIB3/ECS** | 2 | -52.7 | | -59.2 | |
| | 6 | 89.3 | | 86.9 | |
| | 5 | 93.0 | | 90.1 | |
| | 1 | -80.1 | | -64.2 | |
| | 2 | | | | |
| **LIB1/SHW** | 2 | 21.6 | 97.1 | -18.5 | 94.1 |
| | 6 | 86.1 | 96.7 | 85.6 | 99.3 |
| | 5 | 87.2 | 97.6 | 89.7 | 98.0 |
| | 1 | -182.0 | 93.7 | -67.8 | 97.1 |
| | 2 | -17.8 | | 27.2 | |
| **CAT4/ UNIKAT** | 2 | 39.8 | 98.3 | 77.1 | 99.2 |
| | 6 | 65.4 | 98.7 | 76.5 | 99.8 |
| | 5 | 80.2 | 99.5 | 86.0 | 99.6 |
| | 1 | 17.8 | 99.4 | 64.8 | 99.8 |
| | 2 | 70.6 | | 78.3 | |
| **CAT3/BUCK** | 2 | 60.9 | 90.2 | 84.3 | 94.2 |
| | 6 | 47.6 | 95.1 | 57.7 | 99.2 |
| | 5 | 62.6 | 95.3 | 68.0 | 97.0 |
| | 1 | 69.6 | 83.5 | 83.1 | 96.7 |
| | 2 | 80.3 | | 90.6 | |
| **CAT1/SHW** | 2 | 72.6 | 97.3 | 85.9 | 97.5 |
| | 6 | 69.9 | 97.7 | 87.4 | 99.7 |
| | 5 | 79.4 | 98.4 | 90.3 | 98.7 |
| | 1 | 80.1 | 97.7 | 86.7 | 99.3 |
| | 2 | 85.7 | | 87.9 | |

## Arithmetic averages of trapping efficiencies: mass (PMAG) - counts (PZAG) for the traps without problems

| | PMAG | | PZAG | |
|---|---|---|---|---|
| | standard Diesel | satacen 120 ppm | standard Diesel | satacen 120 ppm |
| LIB4 / DSI | 70.46 | 76.08 | 86.65 | 91.63 |
| LIB2 / BUCK | 76.52 | 81.00 | 95.38 | 97.80 |
| CAT4 / UNIKAT | 54.76 | 76.54 | 98.98 | 99.60 |
| CAT3 / BUCK | 64.20 | 76.74 | 91.03 | 96.78 |
| CAT1 / SHW | 77.54 | 87.64 | 97.79 | 98.80 |
| mean values | 68.7 | 79.6 | 94.0 | 96.9 |
| total mean values | 74.15 | | 95.44 | |

## Correlation between trapping efficiencies of: mass (PMAG) and elemental carbon (ECAG) at 1400 rpm/full load

| LIB4/DSI | | LIB2/BUCK | | LIB3/ECS | | LIB1/SHW | |
|---|---|---|---|---|---|---|---|
| PMAG [%] | ECAG [%] | PMAG [%] | ECAG [%] | PMAG [%] | ECAG [%] | PMAG [%] | ECAG [%] |
| standard Diesel | | | | | | | |
| 74.9 | 84.2 | 88.1 | 93.9 | -52.7 | 99.3 | -17.8 | |
| satacen 120ppm (36ppm Fe) | | | | | | | |
| 72.5 | | 91.3 | 95.5 | -59.2 | 99.2 | 27.2 | 93.1 |

| CAT4/UNIKAT | | CAT3/BUCK | | CAT1/SHW | |
|---|---|---|---|---|---|
| PMAG [%] | ECAG [%] | PMAG [%] | ECAG [%] | PMAG [%] | ECAG [%] |
| standard Diesel | | | | | |
| 70.6 | 98.2 | 80.3 | 86.9 | 85.7 | 97.2 |
| satacen 120ppm (36ppm Fe) | | | | | |
| 78.3 | 98.4 | 90.6 | 95.3 | 87.9 | 96.6 |

# Summary

- the average traping efficiencies are:
  (without traps with clear appearance of sulphates formation)
  - mass 74%
  - counts (20 – 200 nm) 95%
  - elemental carbon 94% (only 1400 rpm / full load)

- there is a catalytic influence of additive residue in the filter on the volatile components - oxidation of CO & HC

- the additive increases the number of smallest particles which are efficiently traped by the filter

- there is a very good filtering at transient conditions (free acceleration)

- at certain conditions – with catalytic residue in the trap and with higher temperatures – there is an intensive formation of sulphates. The PM gravimetric emission may increase strongly at full load points, similarly as with ox-cat.

- after in average 2375 hours of service the particulate traps were found to be in excellent condition