INVESTIGATION OF NON-EXHAUST PARTICLE EMISSIONS UNDER REAL WORLD CONDITIONS FROM A LIGHT DUTY VEHICLE

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OUTLINE

- Introduction

- Potential occurrence of ultrafine particles from the tire/road interface

- Trailer based measurement method to estimate resuspended road dust emissions

- Summary
Sources of non-exhaust particle emissions:

- Resuspension of road dust
- Tire wear
- Brake wear
- Road wear
- Clutch wear (?)

The German Federal Environmental Agency expect an increasing share of PM10 non-exhaust emissions to the Transport sector for Germany from 58% to 93% (2005-2030). Similarly for PM2.5 from 24% to 74% (2005-2030).

However, in case of Resuspension: Little knowledge for Central European conditions

How can we quantify fugitive emission under real world conditions directly at the vehicle?
Dahl et al. (2006) studied particle emissions from the road-tire interface on a road simulator.

Reported particle emission factors between $4 \times 10^{11} - 3 \times 10^{12} \#/\text{vkm}$ at 50 and 70 km/h (comparable to exhaust particle number emissions post particulate Filter).

Mean particle diameter between 15-50 nm depending on tire type.

A newer study (Sjödin, 2010) found no ultrafine particles for unstuddied tires.

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Gustafsson et al. (2010)

Measurement of particle size distribution with TSI EEPS (5.6 nm – 562.3 nm)
NDIR CO₂-Measurement
GPS data via Racelogic VBOX
Up to 10 Hz Resolution

4 Measurement positions in wheel housing
1 Measurement position in driving direction in front of the car
1 Measurement position near brake disc + Pyrometer (IR-Temp)
Steady (straight) driving:

- for 4 different velocities: 50, 70, 100 & 120 km/h

Cornering (circle diameter ca. 48 m)

- at constant velocity: 30 km/h ($a_{\text{lateral}}=2.9 \text{ ms}^{-2}$), 40 km/h ($a_{\text{lateral}}=5.1 \text{ ms}^{-2}$)
- with increasing velocity until activation of stability control

Acceleration

- Normal accelerations (up to 2.4 m/s²)
- „Racing start“ (Activation of traction control)

Braking

- Normal Braking
- Full Stop Braking for different starting velocities $\rightarrow$ Activation of ABS ($a_{\text{Brake}} = 9 \text{ ms}^{-2}$)
RESULTS – STEADY (STRAIGHT) DRIVING

- Particle concentration in the order of $3 - 5 \times 10^3 \#/\text{cm}^3$ (background-level)
- No particle concentration enhancement measurable while driving
- Tracer (10% NO in N₂) released in Front of / behind the Tire
- Estimated EF is based on the average of these measurements
EMISSION FACTOR STEADY STRAIGHT DRIVING

Assumption: Equal emissions for all four tires

Estimated maximal EF: $< 1 \times 10^{11} \text{#/vkm}$ (30 times smaller than reported by Dahl et al.)
- No enhanced concentrations for normal cornering
- Extreme cornering: Screeching tires and activation of stability control.
- Tire slip results in enhanced particle concentrations up to $3.5 \times 10^6 \#$/cm$^3$.

- No enhanced particle concentrations for normal accelerations
- Enhanced particle concentrations measurable for racing start maneuvers
- No enhanced ultrafine particle concentrations for normal braking
- Harsh braking maneuvers result in particle formation
- Different particle size distribution for 100 km/h and 30 km/h full stop braking.
- 10 nm particle mode during 100 km/h braking maneuvers originate from brakes
Particles due to resuspension are generally found in the coarse mode.

Different particle physics.

New measurement setup needed!
Estimation of total non-exhaust emissions:

\[ E = \sum_{t} c_{AV} \cdot A \cdot v_{vehicle} \]

Characterization of particle dispersion in vehicle wake needed
- Isoaxial alignment of measurement device
- Investigations on optimal measurement position in vehicle wake
- Tracer gas experiment for emission factor estimation
UNPAVED ROADS

- Average emission factor at 30 km/h: 24000 mg/vkm ± 19000 mg/vkm PM$_{10}$
- Emission factor clearly velocity dependent
- No further investigations after DustTrak contamination
Average emission factor for 30 km/h ($PM_{10}$): 155 mg/vkm ± 53 mg/vkm

Each measurement will change the emission potential of a road
• High local variability of emission potential:

10 % of a real world measurement is responsible for 63 % of the total emissions

• Repeatability (covariance): 10-30 %

\[ Cov = \frac{\sigma}{\mu} \cdot 100\% \]

• Lowest emission on the autobahn
PAVED ROADS – EMISSION FACTOR

- Average PM$_{10}$ emission factor: $26 \pm 18$ mg/vkm
- Euro 5 PM$_{10}$ limit for diesel cars: 4.5 mg/km
SUMMARY

- Experimental setup capable of measuring non-exhaust particle emissions under real world conditions.
- Estimation of emission factors based on tracer gas dispersion measurements

UF particles from the Tire/road interface:
- Under normal driving conditions no substantial ultrafine particle concentration enhancement measurable.
- Upper limit of emission factor for steady straight driving estimated to be $< 1 \times 10^{11} \text{#/km}$
- Under extreme conditions only (full stop braking, extreme cornering, racing start) ultrafine particles measurable with mean particle sizes between 30 nm - 80 nm.
- Particle formation related to significant tire slip.

Resuspension of road dust:
- Diffuser inlet to sample isokinetically; Characterization of vehicle wake
- Estimated emission factors:
  - Unpaved roads (30km/h): $24000 \text{ mg/vkm} \pm 19000 \text{ mg/vkm}$
  - Agricultural paved roads (30km/h): $155 \text{ mg/vkm} \pm 53 \text{ mg/vkm}$
  - Real world roads: $26 \text{ mg/vkm} \pm 18 \text{ mg/vkm}$
- High local variability of emission potential.
Thank you for your kind attention!

VEHICLE BASED DIRECT MEASUREMENTS

TRAKER
Kuhns et al. (2001), Etyemezian et al. (2003)

SNIFFER
Pirjola et al. (2009)

SCAMPER
Fitz et al. (2002)

SCAMPER
Fitz et al. (2005)
Isokinetic sampling (U=U₀)

Super-isokinetic sampling (U>U₀)

Sub-isokinetic sampling (U<U₀)

- Isokinetic (isoaxial) sampling
  ▶ Representative sampling

- Diffuser inlet for isokinetic sampling
MEASURING LOCATION - LOMMEL PROVING GROUND

~ 2 km
- Isoaxial alignment of measurement device
- Investigations on optimal measurement position in vehicle wake
Wake characterization:

- Release of tracer gas (10% NO in N\textsubscript{2}) at 6 different probes
- Assumption: Particles and tracer gas are dispersed equally
- 2 Velocities (30 km/h, 100 km/h)
- 3 Repetitions
- 6 different tracer gas release points
- 22 measurement points
- + partial wake characterization for longer vehicle-trailer distance

- Further characterization: Local wind speed