PM MEASUREMENTS

Investigation and Results from HORIBA

29.04.2021, Greg Filer, Dr.rer.nat Dmytro Lugovyy, Dr.-Ing. Sebastian Gramstat

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Agenda

1	Background Information and Test Setup
2	Measurement Results
3	Suggestions and Points for Discussion

Particulate Number (PN) & Mass (PM)

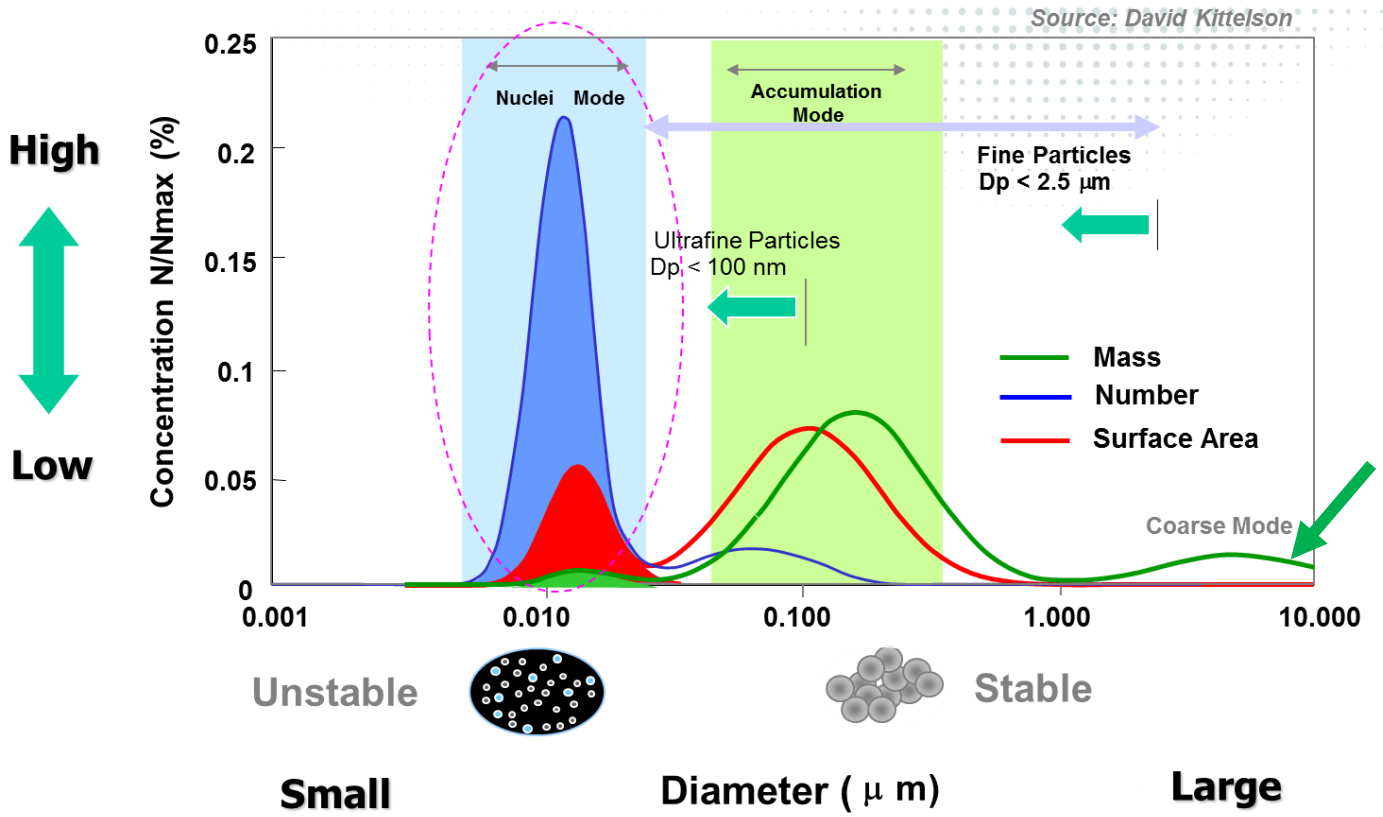
Two Different Metrics Regulated by EU Legislations

Particle Generation from Brake Systems:

1. Abrasion effects
2. Combustion-like effects at higher temperatures (<170°C)
   - Generation of VOC **(additional gaseous compounds as well?)**
   - Nano-Particle generation

PM standard underestimates smallest nanoparticles representing the largest health hazard

Introduction of **Particulate number (PN)** counting as new metric for nanoparticles emitted by combustion engines



Definition of Particulate Matter

Defined by the filter weighing method – Vehicle Emissions Experience

- Exhaust gas is diluted by ambient air in dilution tunnel -> **exhaust duct of brake dyno**
- PM is regarded as the sum of the solid and volatile components filtrated on the PM filter.
- PM is generally regarded as the mass which is weighed, after PM filter is allowed to soak / be conditioned

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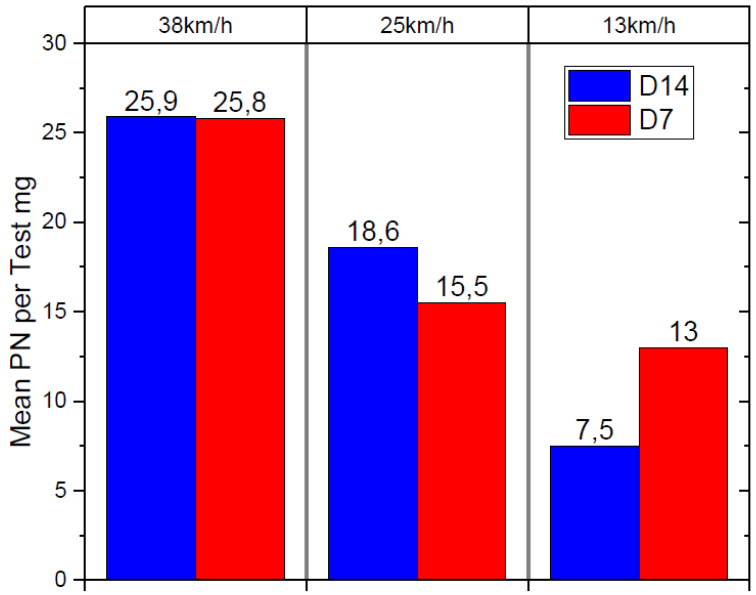
PM Findings from Measurements Performed in 2018

- In a presentation from Dr. Lugovvy (HORIBA) and Dr. Gramstat (AUDI) from the PMP50 Meeting, a relationship between PM Measurements and air-cooling speed was found and presented

Findings from 2018

WLTP class 3 cycle: Influence of sampling point and air flow



- *No big difference for sampling point*
- *PM decreases as air velocity/air flow rate decreases*
- *Settling problems are expected by theory for D14 sampling point but not observed in experiment*

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Test Setup

Brake Dynamometer

- HEPA H13 Filter installed in supply air duct
- Vertical supply/exhaust air routing (top to bottom)
- Temperature measured through embedded thermocouples in the brake disc
- Brake fixture type: L0
- Stainless Steel enclosure
- Distance from disc assembly to sampling point ~ 4,5 m -> 13D (equivalent diameter of exhaust duct 0,350m)
- Air conditions:
  - Volume flow rate range: 500 - 4000 m^3/h, @ 20°C, 50% r.H

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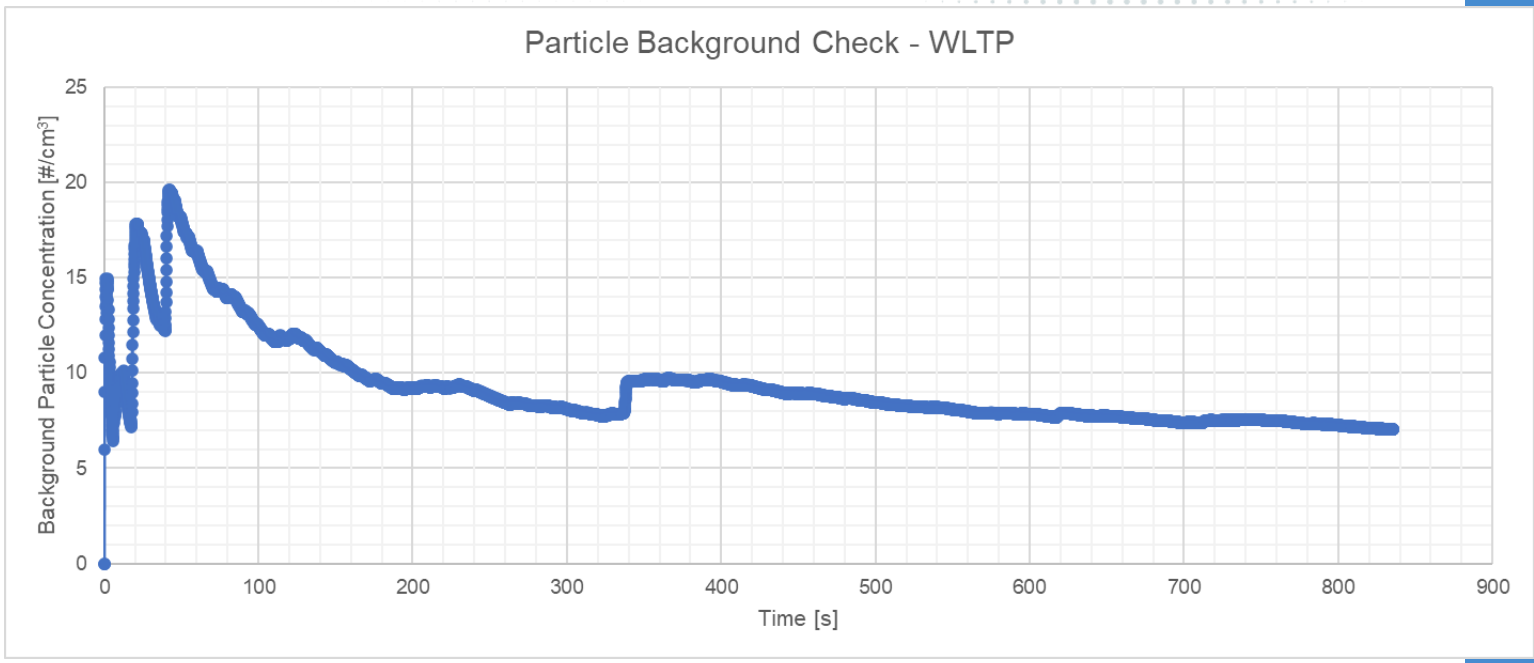
Installation of a HEPA filter upstream of the brake cabinet

- The installation of a HEPA filter into the cooling air duct
  - reduce the particle background concentration
  - minimize the related falsifying effect on the measurement results!
- Above is an example of a PN background check carried out before the WLTP Procedure was started
- The installation of the HEPA filter also improves the reproducibility of the brake dust measurements
- **PM background? A PM background concentration can not be measured gravimetrically due to low loadings…**



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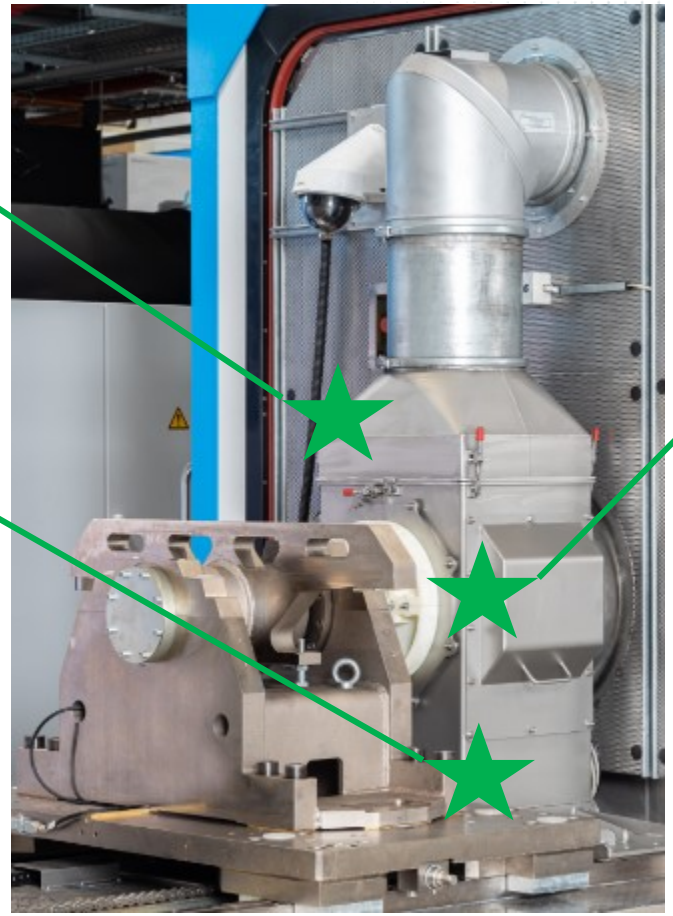
Brake System Enclosure

Installation of a brake enclosure (vertical cooling approach)

Smooth transition angles to minimize the possibility of particle losses

Stainless steel enclosure

- Stability against chemical reactions
- Static / magnetic effect minimization



Brake assembly installed in the center of the incoming cooling air

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Test Setup

Measurement Equipment

- **PM Measurements under Isokinetic Conditions:** HORIBA DLS-ONE (gravimetric collection method)
  - $PM_{2.5}$ and PM_{10} Filters
- **PN Measurements:** HORIBA MEXA2110SPCS (not focus of this presentation)
  - Particle Counting Size Range: 10nm to 2,5 µm

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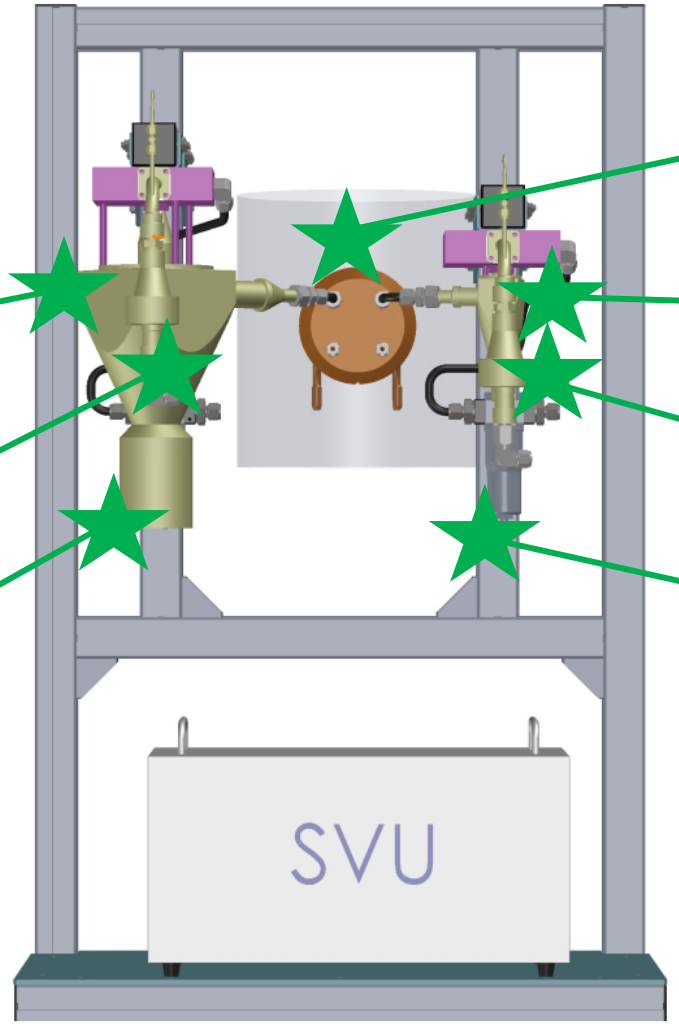
HORIBA DLS-ONE

Cyclone/ filter-holder rack

Cyclone
(10µm)

PM10 filter holder

Bypass filter



2 x sampling
(PM10 + PM2,5)

Cyclone
(2,5µm)

PM2,5 filter holder

Bypass filter

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Working principle: Gravimetric filter

Particle mass measurement by the gravimetric filter method in HORIBA´s DLS-ONE[1]

- The DLS-ONE is a combination of two cyclones (10µm and 2,5µm), two sample filters (+ bypass filters for soak times etc.) and a high-precision venturi-flow-meter to ensure a stable flow through the filter medium with a **defined filter face velocity**
- Isokinetic sampling is realized by means of different sampling probes
- Different filter materials can be used in this device
  - Standard used: Teflon coated glass fiber
  - Filter material has an influence on pressure drops, ensure same filter material in both bypass and sampling lines

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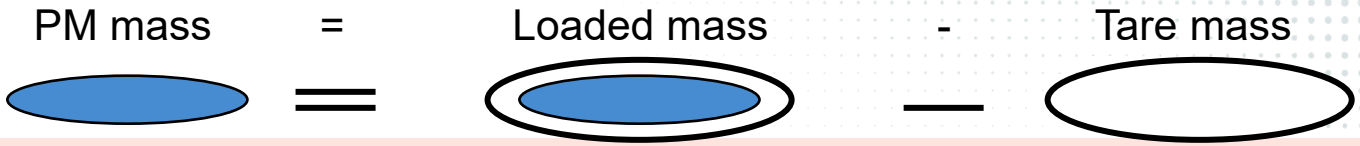
[1]DLS= Dilution system

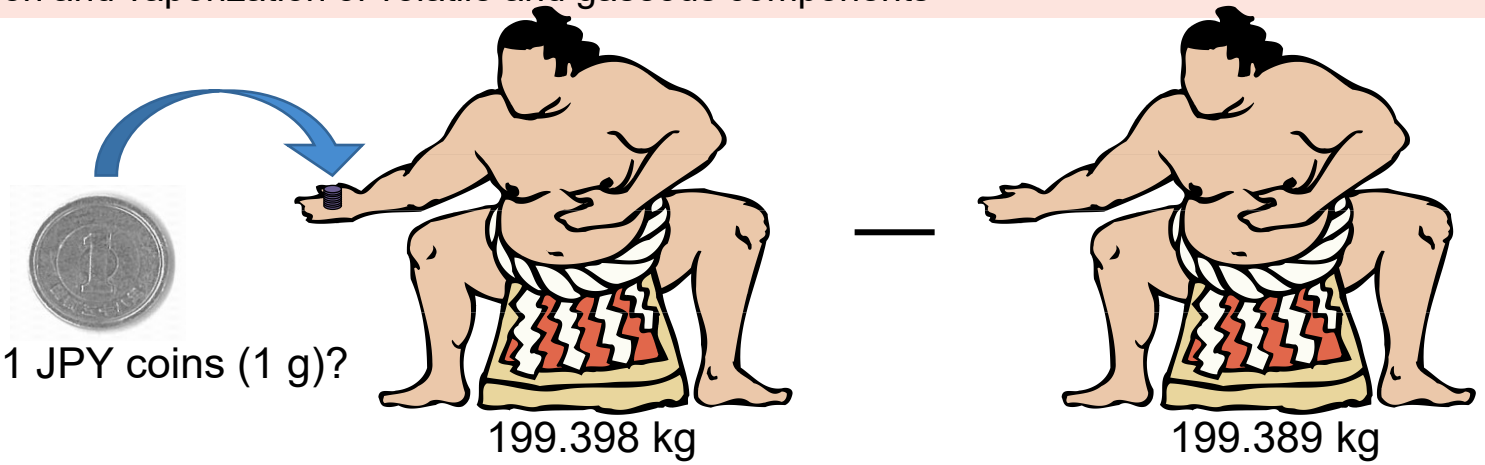
Challenges in Particulate Determination

Mass determination by the subtraction method is approaching its detection limit



- Light PM on a Heavy Filter
  - 47 mm Filter Mass： ~ 100 mg
  - Particulate Mass： 0,5 ~ 1,5 mg per brake dust test

- Error factors
  - Filtration: Dilution ratio, D.air temp., absorption of gaseous components
  - Weighing: Vibration, static electric charge, airflow, buoyancy
  - Filter stabilization: Absorption and vaporization of volatile and gaseous components



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PM Weighing Procedure

- Scale used: XPR2U Micro Scale with anti-static accessory
  - Measurement range: 0 - 2g
  - Resolution: 0,1 ug
  - Filter weight (empty): 90 mg
- Located in climatic controlled weighing closet
  - Air Temperature: 20°C
  - Air Humidity: 50% r.H
- Filters are allowed to condition for at least 12h before test

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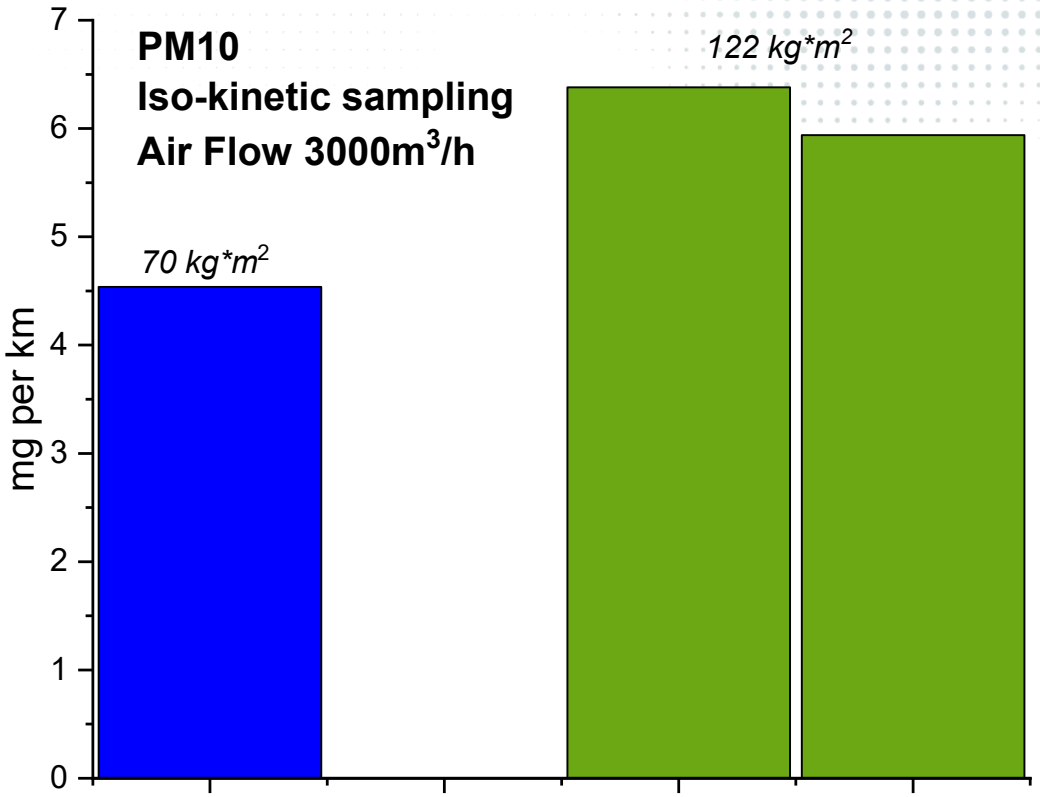
PM Measurement Results

PM10

- Vehicle: VW Transporter Flatbed
  - Front axle unloaded (70 kgm^2)
  - Front axle fully loaded (122 kgm^2)
- Brake pad material: ECE
- Air flow rate: 3000 m^3/h
- Isokinetic sampling performed



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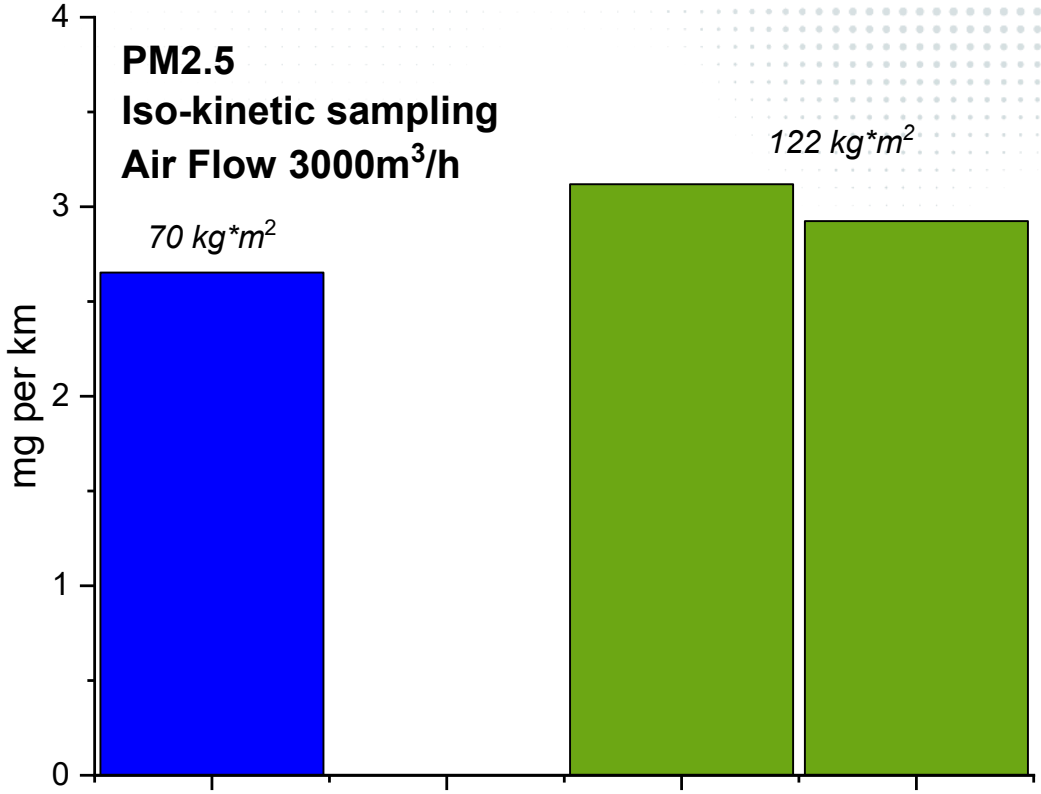
PM Measurement Results

PM2.5

- Vehicle: VW Transporter Flatbed
  - Front axle unloaded (70 kgm^2)
  - Front axle fully loaded (122 kgm^2)
- Brake pad material: ECE
- Air flow rate: 3000 m^3/h
- Isokinetic sampling performed



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Points for Further Discussion / Recommendations

- The effect on Flow drift (gradual changes in the and flow pulsations)
- Filter Face Velocity effects?
- Proper flow control and adjustment (filter face velocity remains constant)
- Particle bounce -> what is the effect on the shifting of the cut-point
- Filter material:
  - Teflon Coated
  - Pure teflon membrane

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Omoshiro-okashiku

Joy and Fun

Thank you

Cảm ơn

감사합니다

ありがとうございました

Dziękuję

धन्यवाद

Grazie

Merci

谢谢

நன்றி

ขอบคุณครับ

Gracias

Obrigado

Σας ευχαριστούμε

Děkuji

Teşekkürler

شكرا

Tack ska ni ha

Danke

Большое спасибо