The Number Concentration of Non–Volatile Particles
Design Study for an Instrument According to the PMP Recommendations

Markus Kasper
Matter Engineering, Wohlen, Switzerland

The increasing use of diesel particulate filters (DPF) as the most effective exhaust aftertreatment method to reduce particle emissions from internal combustion engines emphasizes the need for new particle measurement methods beyond gravimetric. Following a guideline of the Swiss EPA to extend particle measurement to particle size, number concentration and surface concentration, a group of European countries, joined by Japan, have initiated a large–scale investigation of particle metric and measurement methods, the "Particulate Measurement Programme" (PMP). Under the auspices of the UNECE Group of Experts on Pollution and Energy (GRPE), PMP aims at finding a particle metric that is more sensitive to the toxicologically relevant submicron particles and that is to supplement, or even replace, gravimetric as future certification standard for particle emissions.

The particle metric and corresponding measurement system recommended after phase I and II of GRPE–PMP is the number concentration of non–volatile exhaust particles, to be measured with a combination of thermo–diluter and condensation nucleus counter (CNC). This paper presents a design study for an integrated instrument according to the PMP recommendations. Thermo–dilution as particle conditioning concept is explained and compared to alternative methods such as hot diluter and thermo–desorber. Particle number as preferred metric is discussed as well as the suggested instrument, CNC, and some of its challenges. Along with issues of principal and scientific interest, the measurement system must fulfill very practical usability criteria when used as certification instrument, such as robustness, ease of use, and moderate cost.
The Number Concentration of Non-Volatile Particles

Design Study for an Instrument According to the PMP Recommendations

Markus Kasper
Matter Engineering AG

7th ETH Conference on Combustion Generated Nanoparticles,
Zürich, August 19, 2003
GRPE-PMP Phase II Report

Recommendation to measure
the number concentration of
solid (non-volatile) particles

CVS + ThermoDiluter + CPC

Ref [1]
The Scope

• Why Number?

• CPC - Commonly Preferred Consensus?

• ThDil - No Nanodroplets Allowed

• NanoMet-C - All in One
The Scope

- Why Number?
- CPC - Commonly Preferred Consensus?
- ThDil - No Nanodroplets Allowed
- NanoMet-C - All in One
Available Particle Metrics

• mass (PM, EC)
• active surface
• total aerosol length
• number
• ?
Why Prefer Number to Mass?

Particle Diameter $D_p$ [nm]
Why Prefer Number to Mass?

\[ \sim D_p^3 \]

Particle Diameter \( D_p \) [nm]
Why Prefer Number to Mass?

Ref [2]
Why Prefer Number to Mass?

decrease diameter from 100 nm to 50 nm at constant number
Why Prefer Number to Mass?

decrease diameter from 100 nm to 50 nm at constant number mass is reduced by factor 8
Why Prefer Number to Mass?

decrease diameter from 100 nm to 50 nm at constant number

mass is reduced by factor 8

deposited particle number is increased
Weighting Functions: $\text{Vol, } S_{\text{act}}, D_p, N$

Ref [2]
The Scope

• Why Number?

• CPC - Commonly Preferred Consensus?

• ThDil - No Nanodroplets Allowed

• NanoMet-C - All in One
Instruments to Measure “Number”

- CPC (Condensation Particle Counter)
- DMS, SMPS, ELPI, EDB – integrated
- ...

Matter Engineering AG
CPC Effective Count Rate

• cut-off at low diameters
• due to working principle of CPC

Ref [3, 4, 5, 6]
CPC Effective Count Rate

Number Concentration $dN/d\log D_p$

Mobility Diameter $D_p$ [nm]
CPC Effective Count Rate

- condensation problem in sampling system
- ash particles, lube oil; fuel borne catalysts

Ref [7]
CPC Effective Count Rate

measured number < actual number

- reliability of measurement?
- lack of independent control
CPC Effective Count Rate

Number Concentration $dN/d\log D_p$

Mobility Diameter $D_p$ [nm]
CPC Effective Count Rate

Number Concentration $dN/d\log D_p$

Mobility Diameter $D_p \text{ [nm]}$
CPC Effective Count Rate

measurement OK if

\[ N_{\text{CPC1}} \approx N_{\text{CPC2}} \]
CPC Effective Count Rate

Analyse Intensity of Scattered Pulses

- small light pulses
  - small condensation droplets
  - small particles
- many small pulses = critical size range
- requires white light for scattering
- homework for the CPC manufacturers

Number Concentration $dN/d\log D_p$

Mobility Diameter $D_p$ [nm]
The Scope

• Why Number?
• CPC - Commonly Preferred Consensus?
• ThDil - No Nanodroplets Allowed
• NanoMet-C - All in One
Why Separate Volatiles from Solids?

**solid particles (soot, ash)**
- insoluble
- health effect by “existence”
- limit number concentration

**volatile droplets (sulfate, HC, water)**
- soluble
- health effect by toxic components
- limit substance specific mass concentration

Ref [8]
From Vapor to Droplet to Vapor

Ref [2]
Results: Exhaust from a 2-Stroke Scooter
From Vapor to Droplet to Vapor
Results: Exhaust from a 2-Stroke Scooter

- Raw exhaust dilution 1:7'500
- ThermoDesorber after diluter (1:7'500)
From Vapor to Droplet to Vapor

Dilution

Thermo-

exhaust

failed due to cold spot

CVS

Dilution

(gas) temperature $T \, [\degree C]$
Results: Exhaust from a 2-Stroke Scooter
From Vapor to Droplet to Vapor
From Vapor to Droplet to Vapor
Results: Exhaust from a 2-Stroke Scooter

- raw exhaust dilution 1:7'500
- ThermoDesorber after diluter (1:7'500)
- ThermoConditioner before diluter (1:15'000)
- ThermoConditioner after diluter (1:15'000)

Number, dN/dlog Dp [cm^-3]

Mobility Diameter, Dp [nm]
The Scope

• Why Number?

• CPC - Commonly Preferred Consensus?

• ThDil - No Nanodroplets Allowed

• NanoMet-C - All in One
All in One: NanoMet-C

- (CVS)
- rotary diluter
- thermal conditioner
- CPC
- stand-alone DAQ unit
Conclusions

- PMP recommendation can be fulfilled, instrument likely to work
- number criterion maps health effects
- use ThermoDiluter, not ThermoDenuder
Conclusions / Still Unclear

• PMP recommendation can be fulfilled, instrument likely to work
• number criterion maps health effects
• use ThermoDiluter, not ThermoDenuder
• CPC counting efficiency?
• (size dependent) transfer function of ThDil?
• maybe use some size discrimination?
Acknowledgments

Matter Engineering
  Thomas Mosimann
  Michael Riner

ISS, University of Applied Sciences Aargau
  Martin Fierz
References


