Electrical particle number measurement for automotive applications

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Motivation

- **Particle number** limit value for vehicles in EU
- **Complex** lab setup necessary (PMP)
- Particle detector: **automotive CPC**
- Legislation is moving towards **real driving emissions (RDE)** – think of Volkswagen scandal

Image: https://wwwavl.com/real-driving-emissions-rde-

**PN-PEMS**
Particle Number Portable Emissions Measurement System
Motivation

• What options are there to replace the automotive CPC with a simpler, more robust device based on electrical charging?
• How well can such a replacement device work?
The problem with charging

• Standard setup for charging (very simple):

Charging is linear in particle diameter $d$, $Q \sim N \cdot <d>$

$\Rightarrow$ Unless $d$ is known, $N$ cannot be measured
Options: Dual-stage detection

Size-selective detection in two stages \(\Rightarrow\) diameter \(\Rightarrow\) number

More options: two devices

- 2 Pegasor devices operating at different ion trap voltages
Challenges

• These (and similar) schemes use sensible assumptions to determine average particle diameter, and with that also particle number (so they offer more information than a CPC)

• But they have drawbacks too...
Options: Dual-stage detection

For rapidly changing aerosols:
- Induced currents on diffusion stage
- Different response time of the two stages
More options: two devices

- 2 Pegasor devices operating at different ion trap voltages
  - Added complexity + cost
  - Long-term stability? (two devices must age identically)
Use induced currents (pulsed charging)

Alternating charged and uncharged clouds

High Voltage

Pulsed, on-off

Charging current measurement

Faraday cage
Electrometer

Instrument response

Electrometer zero offset (and its drift!) is irrelevant 😊

But it's not a particle number counter 😞
After unipolar diffusion charging, the conductivity of an aerosol is proportional to the particle number concentration.
The idea

Alternating charged and less charged clouds

Pulsed, high-low

Faraday cage Electrometer

High Voltage

Always on

Charging current measurement

Single detection stage! All issues of other schemes solved!
The implementation

- Limits of detection: \(~500 – 1.5 \cdot 10^6\) pt/cm³
- Particle size range: 15-200 nm
- Size: 16.5 x 8.8 x 3.2 cm
- Weight: 500g
- Power: \(~2W\)
- Response time: 1 second
- Flow rate: 2.0 lpm
- Operating temperature up to 55°C
New instrument response (NaCl)

![Graph showing the relationship between Signal/Particle and Particle Diameter. The graph indicates a linear increase with increasing particle diameter.]
Normalized instrument response (@ 70nm), NaCl
Comparability for multiple instruments (initial calibration only! NaCl)

24 AP devices calibrated with NaCl

Scatter $\sim \pm 5\%$
Aging

- 2 devices were contaminated for 18 hours with undiluted CAST soot ($2 \cdot 10^7$ Pt/ccm)
- Shaded area = $\pm 10\%$ deviation of initial calibration

18h at $2 \cdot 10^7$ Pt/ccm = 3600h @ $1 \cdot 10^5$ Pt/ccm
Soot

- NaCl produces cubic particles, soot consists of agglomerates – how does this affect the device?
Soot: Morphology is relevant
Real world example

Cycle average:
APC Tailpipe $1.09 \cdot 10^{12}$ Pt/km
PN-PEMS Tailpipe $1.26 \cdot 10^{12}$ Pt/km (+16%)
Conclusions

• New all-electrical "particle number" counter demonstrated (in PMP sense)

• Single-stage design avoids all drawbacks of similar attempts to measure particle number (but doesn't measure diameter!)

• Fits PMP curve very nicely for NaCl particles, a bit less nicely for (CAST) soot

• Interesting technology for future applications outside of the lab environment
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