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Low-cost instrumentation for on-board real-time diesel PM measurement

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Introduction

- Internal combustion engines = major source of fine particulates, bad effects on health!
- To know the effect of various measures on PM emissions, we need to measure!
- New vehicles on NEDC mastered; real-world operation over the entire vehicle lives less so.
- Emissions problem is shifting to the "third world" (influx of used vehicles, growth in traffic).
- Portable, on-board monitoring systems for real-world emissions measurements – should be simple, robust, reasonable size and weight; for third world also inexpensive and easy to repair.

Goal

To evaluate simple instruments based on detection methods used in mass-produced smoke alarms - light scattering and ionization detectors – for their potential use for on-board, real-time measurements of PM emissions.

Experimental

- Two instruments built: a light scattering detector and a measuring ionization chamber
- Sampling: Undiluted sample + moderately heated line to avoid condensation; diluted sample from improvised CVS (laboratory exhaust duct system).
- Test mix: Laboratory and on-board tests, vehicular and off-road engines, diesel and biofuels.
- Test-to-test repeatability on-road and in the lab; lab comparison with gravimetric method.

Results

- Examples and results of repeatability and comparison tests shown throughout the poster.

Discussion

- **Good test-to-test repeatability** – can be used for relative / comparative measurements (comparing different fuels, engine settings, emissions at different rpm and loads, etc.).
- **Absolute calibration** (such as to PM mass – this is also to be determined) is **problematic** and may or may not be resolved, depending on the accuracy requirements.
- **Ionization chamber measurement** should be approximately proportional to the total particulate length (more extensive comparison to be done).
- **Optical measurement** can be proportional to the particle count (when operating as a condensation counter) or to the 6th power of the particle diameter (Mie scattering, if no nucleation or coagulation occurs); the reality is somewhere in between, notably with undiluted exhaust; the instrument has been "tuned" to the particulate mass.
- **Total measurement error.** Making the instrument small, simple, versatile and practical for installation on a variety of vehicles and other moving machinery was not well compatible with the standard sampling and sample handling procedures. Many liberties were taken, and, as a result, the measurement accuracy was likely compromised. On the other hand, substantial errors can be committed by inferring the overall emissions from a fleet from a small number of laboratory tests (or no tests).
- **Economics**: "Garage-grade" units similar to today's multi-gas analyzers and opacity meters can likely be mass-produced for hundreds to thousands of Euros, for preliminary and exploratory measurements, diagnostics of problematic operating regimes, engine/emissions diagnostics, possibly for emissions inspections.
- With on-board measurements, instrument and test design should go hand-in-hand.

Conclusions

Preliminary work with two simple, portable instruments – a measuring ionization chamber and a light scattering detector – shows a good test-to-test repeatability when sampling both diluted and raw (undiluted) diesel exhaust; absolute calibration remains to be resolved. Work demonstrates a potential for low-cost instrumentation for at least qualitative on-board real-time measurement of PM emissions.

Acknowledgements

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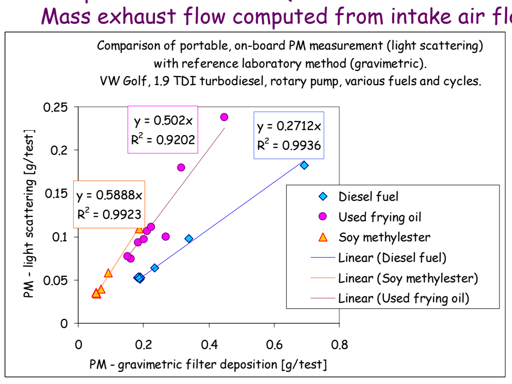
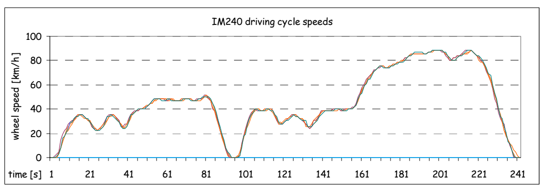
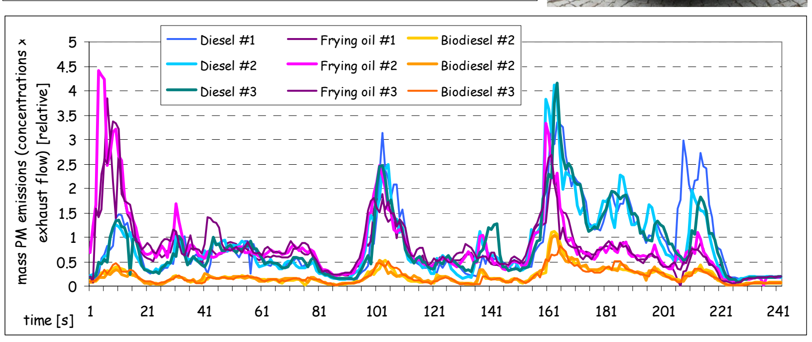
Comparative measurements - VW Golf - chassis dynamometer tests

cycles: US EPA FTP, I/M 240, US EPA Highway Fuel Economy Test
Fuels: Highway diesel, soy methylester (biodiesel), used frying oil (canola)
Optical measurement (forward side-scattering) in undiluted exhaust
Mass exhaust flow computed from intake air flow and CO_2 concentrations

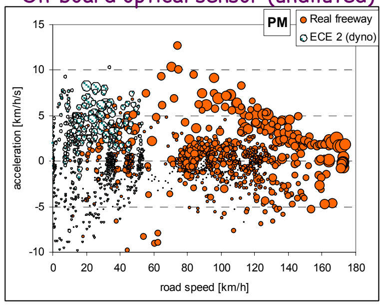


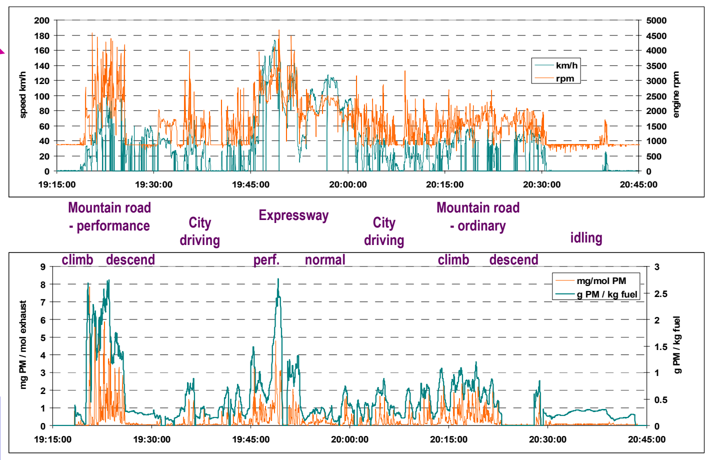


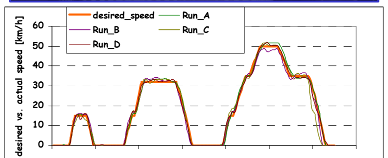


Example: On-road emissions

Škoda Octavia 2,0 TDI PD
On-board optical sensor (undiluted)

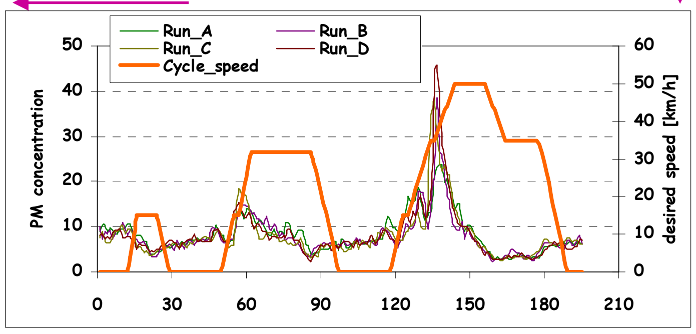






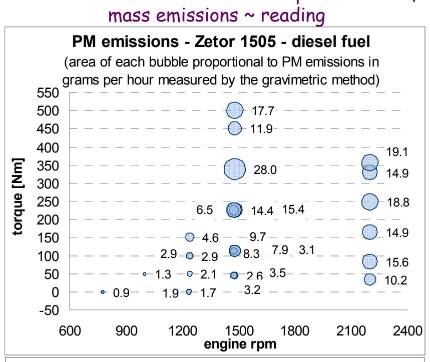
Test-to-test repeatability - optical method, undiluted exhaust

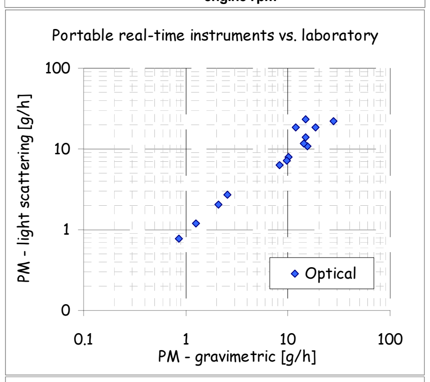
4 repetitions of ECE cycle driven with a diesel van on a test track

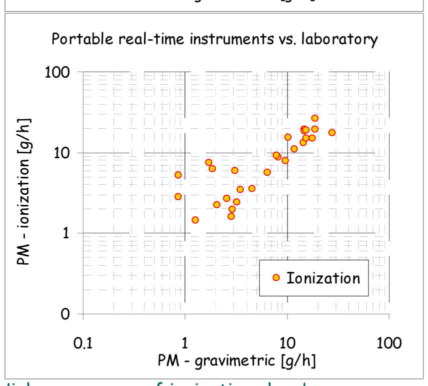


Comparative measurements - Stationary engine dynamometer tests

Zetor 1505 tractor engine
gravmetric: one filter pair per regime
Optical: Undiluted exhaust, measured emissions = measured concentrations x intake air flow
Ionization: Mild dilution in an improvised CVS, mass emissions ~ reading



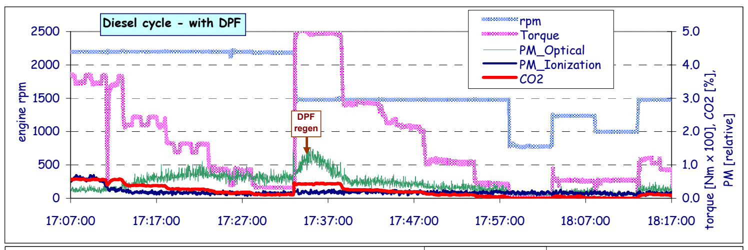


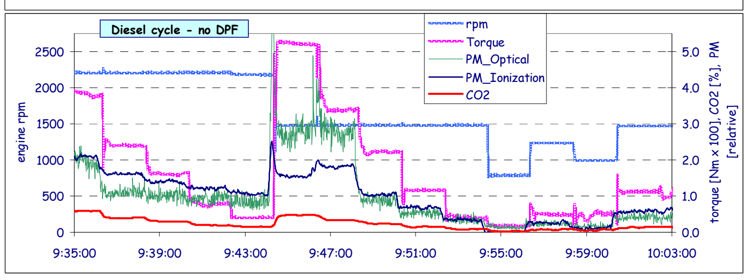


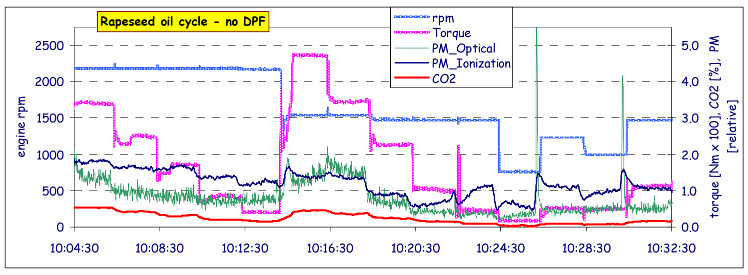
Higher response of ionization chamber correspond to low rpm, no or low load conditions, where strong nanoparticle peaks were observed with SMPS-CPC measurements; same conditions led to slightly lower reading on the optical detector.
Higher readings on the optical detector correspond to full load (high water content?).

Example measurements - Stationary engine dyno tests

Zetor 1505 tractor engine – diesel fuel and heated rapeseed oil
Optical and ionization measurements on diluted sample from CVS







Example measurements - Stationary engine dyno tests

Zetor 1505 tractor engine – diesel fuel and three biodiesel blends
Optical and ionization measurements on diluted sample from CVS