Diesel Particulate Matter Measurement Methodology, DPM Emissions from Mining Equipment and Measurement of DPF Filtration Efficiency

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- Used sample conditioning and measurement equipment
- DPM emissions from mining equipment
- Effect of DPF on emissions
- Effect of DPF regeneration on emissions
- Applied Vs. standard measurement methodology and what needs to be considered when evaluating results
- Conclusions

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Introduction

- Evaluation of DPM emissions is important in mining operations
- What is the effect of vehicle activity on DPM emissions?
- What is the efffectiveness of DPF technology in reduction of emissions?
- What is the effect of measurement methodology on results?

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Used measurement instruments and sample conditioning

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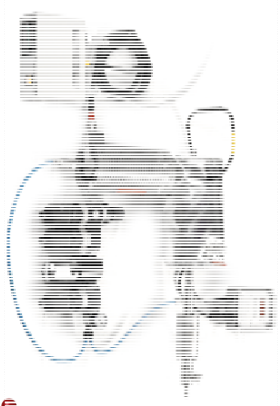
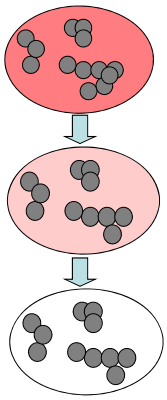
Dekati double diluter





Tailpipe:

- High concentration
- High temperature
- High vapor pressure

Hot Dilution

- Concentration decrease
- Vapor pressure decrease
- Temperature preserved

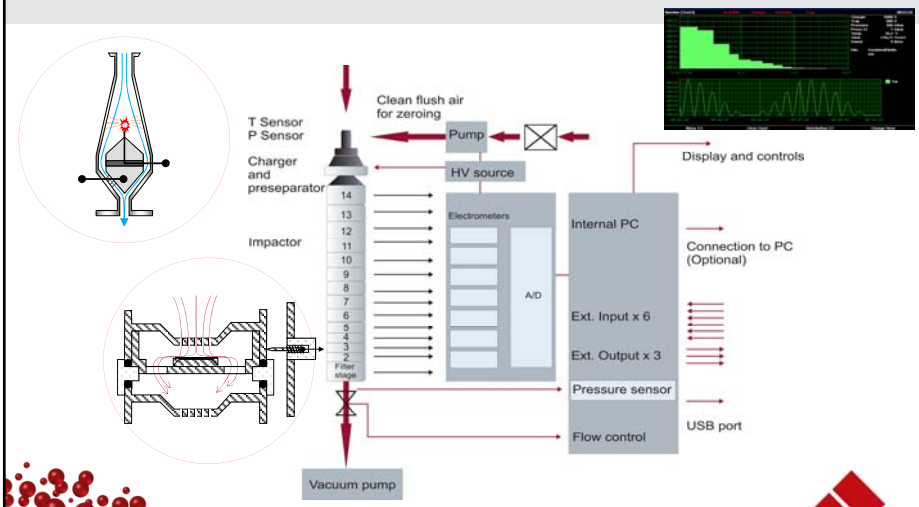
Cold Dilution:

- Concentration decrease
- Low vapor pressure => safe temperature decrease

ELPI+™: Electrical Low Pressure Impactor

- Number size distribution and concentration
  - Real-time, 10 Hz
- 6 nm - 10 µm
  - 14 size fractions
- Particles are collected
  - Enables subsequent chemical analysis on the collected samples
- Wide dynamic range
  - From outdoor air to power plant stack concentrations

ELPI+™ Operating Principle



Measured engines/vehicles

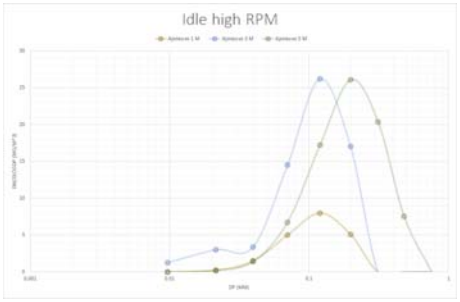
- Tier 4f 13L equipped loader
- Tier 4i 13L equipped loader
- Tier 2 13L equipped loader with DPF
- Tier 2 16L equipped loader with DPF
- Tier 2 19L equipped dumper

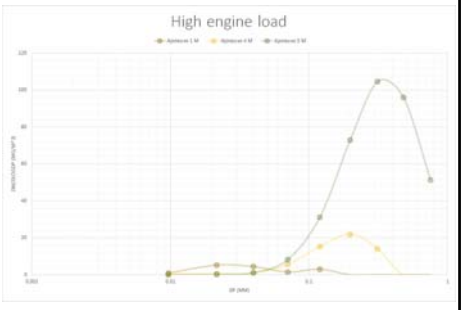
- Tier 3 7L equipped medium duty truck with DPF

Measurement cycles

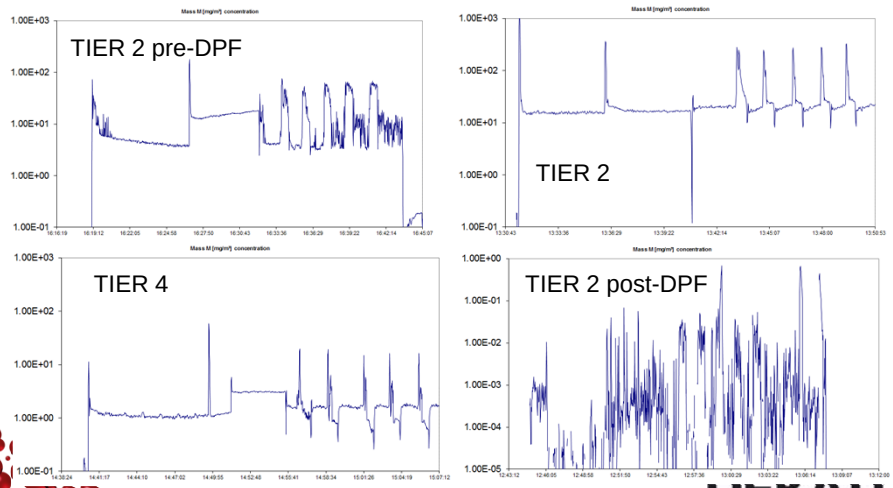
- Mining vehicles
  - 5 min idle
  - 5 min max rpm, no load
  - Max engine load against brakes, 5 repetitions
  - Pre- and post DPF for DPF equipped vehicles
- Medium duty truck
  - Delivery truck actual delivery run cycle incl.
    - Start/stop traffic light cycles
    - Uphill/downhill sections
    - Highway
  - Pre and post DPF

Mass size distributions





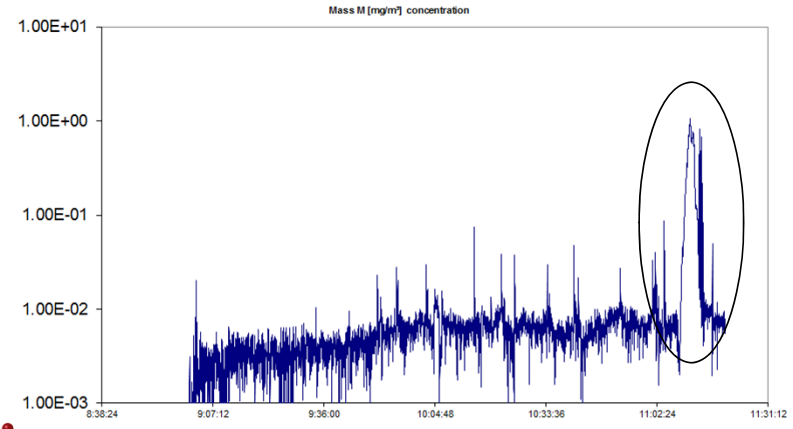
Real-time mass concentration



DPF filtration efficiency

- Very high observed efficiency for solid particles (far greater than 99%)
- Reasonably low upstream pressures also beneficial in case of a cracked filter
- What is the effect of regeneration on emissions?

DPF efficiency and regeneration

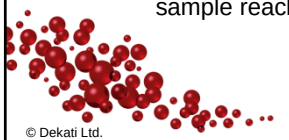


Measurement methodology

- Two main questions
  - Measurement of mass or number?
    - If number, how small particles?
    - Measurement of mass emphasizes the effect of large particles
    - Measurement of number emphasizes small particles
  - Treatment of volatiles?
    - Main reason of uncertainty in both mass and number concentration measurements
    - Can be controlled with sample conditioning
    - Measurement of ”solid” PM or ”total” PM

Legislation

- ISO 8178
- Automotive mass measurement US/Europe
- Automotive number measurement in Europe
- Measurement with filter generally considered to be ”true” or ”filterable” mass measurement
  - Sample conditioning before filter governs what is in particle form when sample reaches the filter material



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Dekati® eFilter™

- **Target**: add real-time information to standard gravimetric PM measurement without weakening usability
- **Implementation**: Parallel gravimetric and diffusion charger particle measurement, battery operation with internal pump for electrical measurement
- **Design**: Compatible with existing gravimetric PM measurement filter holders and sampling systems
- **Usability**: Fully automated operation. No cables, hoses, no additional work required compared to standard gravimetric measurement

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eFilter™ design

eFilter measurement result

- Unaffected gravimetric PM measurement result
  - Total particle mass
- Electrical current from the diffusion charger electrometer
  - Fast response second-by-second data
  - Unaffected by particle material
  - Wide operating conditions
- Real-time data benefits:
  - Repeatable
  - Sensitive
  - Real-time signal can also be used for PM measurement Q/A

Conclusions

- Engine transient operation has a profound operation on emitted particle size and concentration
- DPFs were found to be highly effective in abatement of particle emissions
- DPF regeneration causes a significant increase in emissions compared to baseline. Total emissions were nevertheless very low
- It is important to evaluate used measurement methodology when comparing results from different sources

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