SAMPLING AUTOMOTIVE EXHAUST WITH DILUTION AND/OR ADSORPTION OF VOLATILE SPECIES

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Presentation outline

- Objectives
- Measurement setup
- Result of instrument testing
- Corrections for instruments
- Final results
- Conclusions
Objectives

- Searching for nucleation tendency
- Comparison of instrument performance with soot and volatile hydrocarbon laden exhaust
- Validation of loss correction methods
Professor David Kittelson, Minnesota University: Truck exhaust plume measurement

The open symbols show runs made at 11 C

The closed symbols show runs made at 21 C

Average plume minus background SMPS size distributions normalized to 1 $\mu$m/cm$^3$ volume concentration are shown here
Effect of dilution ratio

Nucleation mode caused by sulphur compounds and volatile hydrocarbons

Accumulation mode caused by carbonaceous matter, i.e. soot and condensed hydrocarbons

- **Diesel exhaust**
- **Dilution air 22°C, residence time 1.5s**
Effect of sample residence time

Presented by Professor Kittelson / University of Minnesota
The effect of dilution air temperature

![Graph showing the effect of dilution air temperature on particle distribution.](image)

Courtesy of J. Ristimäki / Tampere University of Technology
DG TREN Particulates-programme
Instruments tested

Dekati Double Diluter (DD)

Dekati Thermodenuder (TD)

Dekati Fine Particle Sampler (FPS)
Dekati double diluter setup DI-2000

Pressurized air heater

Insulated diluter heater

Temperature controllers

Ejector type diluters

Tailpipe

To measurement device
Dekati Thermodenuder

\[ V_{\text{diff, vapour}} \gg V_{\text{diff, particle}} \]
\[ V_{\text{diff}} \gg V_{\text{th}} \]

**Heated Sample In**

*Activated char coal*

*Adsorbed vapour*

*Hydrocarbon vapours*

*Particles*

**’Dried’ Cool Sample Out**
Dekati Fine Particle Sampler

- **Porous tube:**
  - Less losses
  - Controlled mixing
  - Hot/cold dilution

- **Ejector**
  - Pump
  - Further dilution

- **Combined**
  - Possibility for continuous DR adjustment
  - Less losses to ejector
Testing setup

FD Flow divider  PD Primary Diluter (FPS)
AC Ageing Chamber  ED Ejector Diluter (FPS)
TD Thermodenunder  P,T Pressure, Temperature recording
DD Double Diluter

Diagram:
- FD (Flow divider)
- PD (Primary Diluter)
- AC (Ageing Chamber)
- ED (Ejector Diluter)
- TD (Thermodenunder)
- P,T (Pressure, Temperature)
- Control Unit
- Sample in
- Cooling

Diagram shows the flow and connections between the different units.
## Sampling parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DD</th>
<th>TD</th>
<th>FPS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary dilution ratio</strong></td>
<td>-</td>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td><strong>Secondary dilution ratio</strong></td>
<td>-</td>
<td>16</td>
<td>-</td>
</tr>
<tr>
<td><strong>Primary dilution air temperature</strong></td>
<td>°C</td>
<td>250</td>
<td>-</td>
</tr>
<tr>
<td><strong>Secondary dilution air temperature</strong></td>
<td>°C</td>
<td>ambient</td>
<td>-</td>
</tr>
<tr>
<td><strong>Heater temperature</strong></td>
<td>°C</td>
<td>-</td>
<td>250</td>
</tr>
<tr>
<td><strong>Ageing chamber</strong></td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><strong>Residence time</strong></td>
<td>s</td>
<td>4.5</td>
<td>1</td>
</tr>
</tbody>
</table>

*estimated dilution ratio
Temperature gradients

- Measured or Approximated temperature gradients within instruments (solid lines)
- Amount of dilution air added (dashed lines)
Corrections for results

- **DD correction**
  - depends on particle size, but can be approximated with 5% for particles < 1 µm

- **TD particle penetration**
  - depends on particle size according to equation:
    \[
    1 - \eta = -9.7 \cdot \ln(D_p) - 0.5 \cdot Q + 68, \quad D_p < 70 \text{ nm}
    \]
    \[
    1 - \eta = -0.5 \cdot Q + 28, \quad 70 \text{ nm} \leq D_p \leq 500 \text{ nm}
    \]
  - for mass correction 21% at 15 lpm applied

- **FPS correction under determination**
Mass concentration results

- DD and TD results corrected for losses
- Effect of volatiles clearly seen
Number concentration results

- ELPI and CPC concentrations agree
- Cooled FPS shows high nucleation at low load
Thermodenuder losses

Particle losses, %

Particle size, nm

10 100 1000

10 lpm

15 lpm

20 lpm
Thermodenuder temperature profile and residence time

- Temperature profile
- Residence time
- Heater temperature gradient, measured
- Adsorber temperature gradient, measured
- Calculated residence time
Typical number size distributions

- Low load
- Minimum 15 repetitions

- Soot mode repeatable
- Nucleation mode tendency can be studied
- Results not corrected for losses

[Graphs showing typical number size distributions for DD, TD, and FPS cooled]
Typical size distributions

- Low load, less volatile in exhaust
Effect of dilution ratio

ELPI current

Current [fA]

Ch1
Ch2
Ch3
Ch4
Ch5
Ch6
Ch7
Ch8
Ch9
Ch10
Ch11
Ch12

Distribution

Number dN/dlogDp [1/cm³]

Dp [um]

0.01 0.1 1 10

0.01 0.1 1 10

0.01 0.1 1 10

0.01 0.1 1 10
Conclusions

- Successfully applied to diesel exhaust measurements
- Repeatable particle number concentrations for soot particles
- Repeatable particle size distributions
- Effect of volatiles on nucleation and total mass concentration clearly indicated