Flue Gas Particle Characterization at Different Parts of the Power Plant

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Introduction

Fine particles are one of the main pollutants in urban environment. Especially in developing countries one of the main sources is energy production at power plants[1].

In order to better understand and reduce the emissions it is important to characterize these combustion-generated particles and study their formation and transformation at power plants. This allows also optimization of combustion process and flue gas cleaning system.

The problem is that normal particle measuring equipment can only measure close to ambient temperature sample. Therefore sampling of combustion-generated particles in a controlled way requires sample temperature and concentration decrease and prevention of unwanted sample transformations and VOC and water condensation at the same time.

In this work we present a system for advanced particle characterization at power plant, capable of measuring particle size and concentration at different parts of the power plant, all the way from the flame up to the flue gas exit from the chimney.

Methods

Particle detection

Instrument used for particle measurements was the Electrical Low Pressure Impactor ELPI, manufactured by Dekati Ltd. in Tampere, Finland. ELPI is an aerosol spectrometer measuring particle size and concentration in real-time and its wide size range (0.007 – 10 microns aerodynamic diameter) allows characterization of all normal combustion aerosols, both nanoparticles (<100 nm in diameter) and coarse mode particles.

ELPI operation principle is based on combining particle charging in an unipolar diffusion charger, particle size classification in a 13-stage low pressure cascade impactor and electrical detection of charged particles. Particles carrying a known charge after the corona charger are size classified in an impactor with electrically isolated stages and current carried by these particles are is measured with electrometers connected to all impactor stages. This measured current signal is directly proportional to particle number concentration on corresponding impactor size class. By using 12 parallel electrometers the size distribution is measured in real with one second time resolution[2]. Operation principle is presented in figure 1:

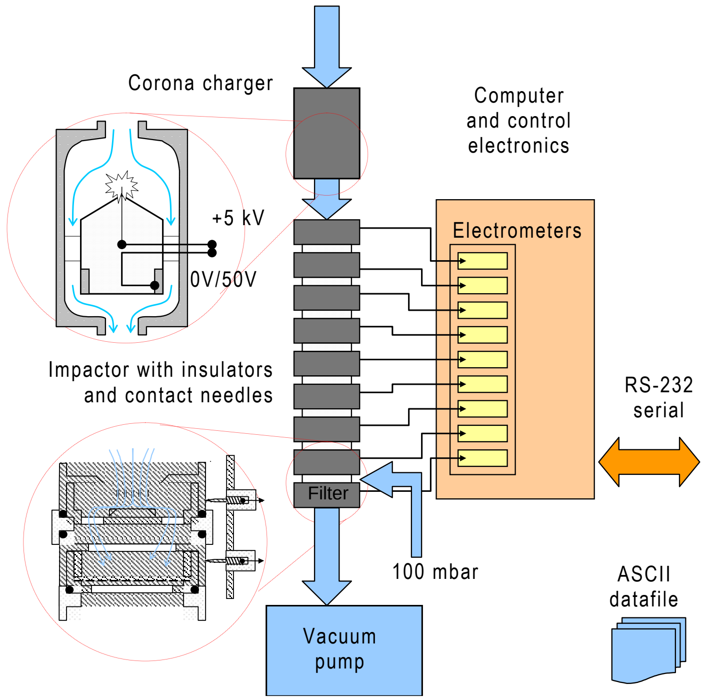

Figure 1: ELPI operation principle

Particle sampling

Sample temperature varies significantly in different parts of the plant. In all cases the sample temperature must be decreased to ambient temperature and pressure to be suitable for the measuring instrument.

When decreasing the sample temperature one must take into account the possibility of volatile material (VOC and water) condensation and nucleation, sample transformation and thermophoretic losses. Different sampling and dilution parameters (dilution temperature, dilution ratio) can change measured particle size distribution and concentration.

Sampling system developed for this study consists of two parts: 1) temperature controlled sampling probe designed for high temperatures and 2) DEED, Dekati Engine Exhaust Diluter, a two-stage dilution system with low losses and volatile particle removal.

Heated probe consisted of two austenitic high-temperature stainless steel tubes, larger tube having outer diameter 12mm, inner diameter 10 mm and the inner tube ID/OD 6/8mm located inside the larger one (figure 2). A pressurized air heater was used to feed heated (200°C) air between the tubes. This air was used to maintain the inner probe temperature; in high-temperature measurement the probe cools down the sample to about 200°C, at lower temperature measurements it is used for sample heating. This air flow was not used for dilution but only for probe temperature control, air flow was approximately 60 lpm.

After the probe there is sample temperature and pressure measurement and a heated stainless steel line (200°C) to Dekati DEED, two-stage ejector diluter system. The first dilution stage of the DEED is heated to 200°C (dilution ratio about 1:10), followed by an evaporation tube (350°C) and finally a secondary (ambient temperature) diluter, DR 1:10. The principle is adopted from the automotive industry solid particle measurements where EURO V / EURO VI legislation requires VOC removal in number count measurements. First hot dilution stage prevents volatile material condensation, evaporation tube evaporates all remaining VOCs having evaporation temperature of 350°C or less, after that 1st dilution the VOC partial pressure is so low that the sample can be cooled in the 2nd dilution stage without condensation or nucleation[3].

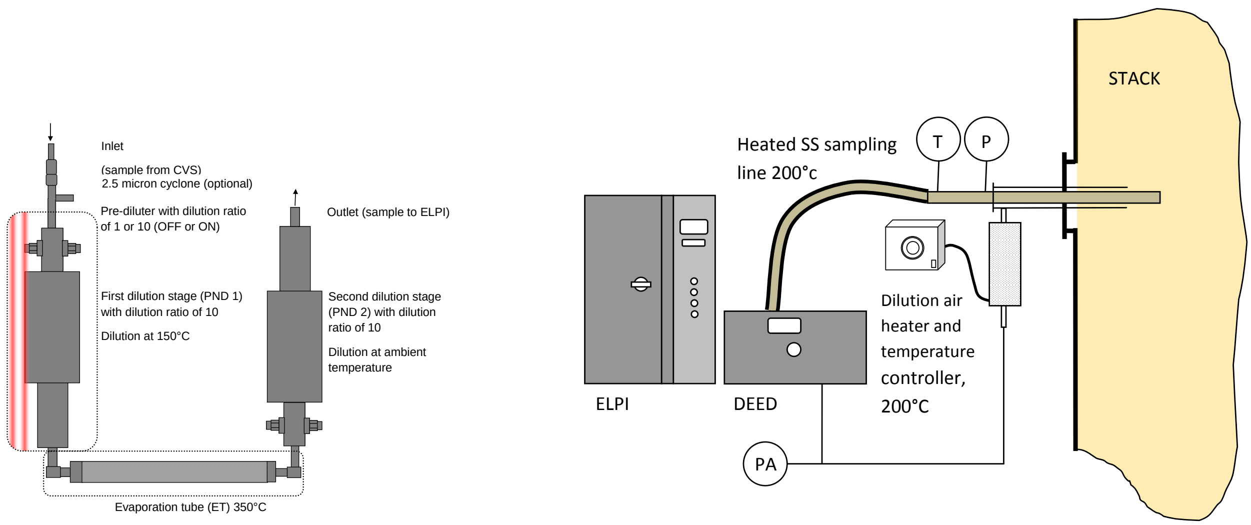

Figure 2: DEED operation principle (left) and sampling and measurement setup (right)

High-temperature probe combined with DEED resulted to a known, constant and controlled sample temperature decrease in all measurement locations.

Results

Particle size distribution and concentration measurements were conducted at 4 MW CFD (Circulating Fluidised Bed) pilot plant in Finland using wood pellets as fuel. Flue gas cleaning was done with a baghouse filter. Other details of the plant are classified.

First measurement location ("hot") was located just above the flame where the flue gas temperature was approximately 800°C. Second location ("cool") was after the heat exchangers where the temperature was approximately 200 degrees C.

Particle concentrations in both locations are seen in figure 3, left is number-based concentration and right is mass-weighed. Note that the ELPI calibration is based on number concentration, mass is calculated simply by assuming a spherical particle size and unit density; there is some uncertainty in the mass result but it gives some estimation about the mass emission. .

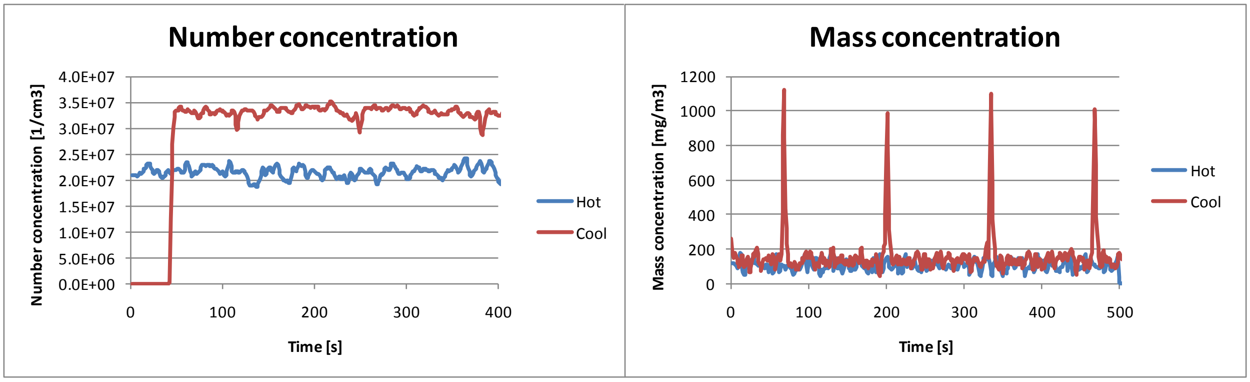

Figure 3: Number and mass concentrations before and after heat exchangers

Total number concentration is approximately 30% lower in the flame than after the heat exchangers while the mass remains the same. Soot blowing spikes are clearly seen in "cool" measurement location mass concentration but not in number data except a very slight decrease during soot blowing.

Particle size distributions in figure 4 show how particles change in the stack and how soot blowing increases the large particle fraction:

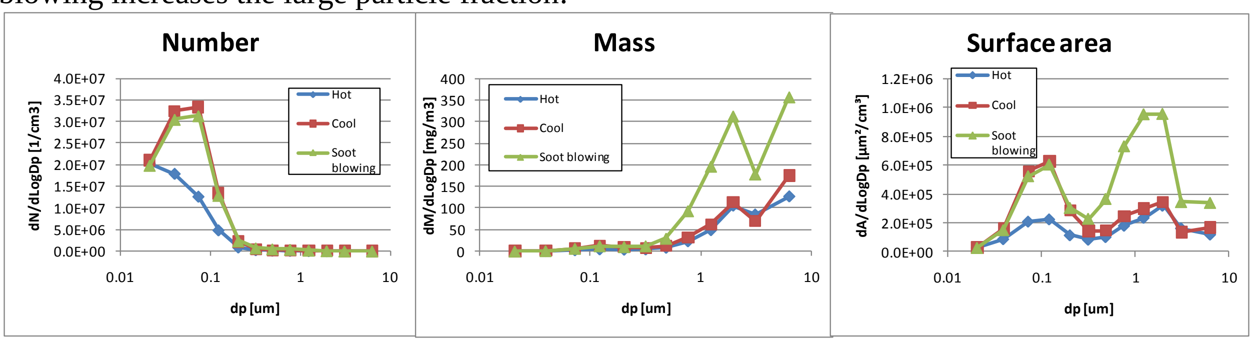

Figure 4: Size distributions beforee and after the het exchangers and during soot blowing

In the flame the number-based size distribution, dominated by small particles, is clearly smaller than after the heat exchangers while mass based size distribution (large particles) remain unchanged. Lower number concentration is caused by a large number of particles smaller than ELPI detection limit of 7 nm but it is also possible that some of the material in the hot measurement is still in gas phase. Submicron particle size shifts to larger particles when temperature drops; this is caused by both coagulation and condensation[4].

The effect of soot blowing to the size distribution is also clear; it increases large particle fraction and mass concentration but number based size and emission is not affected. The most right-hand side figure presents surface-area weighed size distribution showing clearly bi-modal distribution.

Last measurement location was after the plant flue gas cleaning system. A baghouse filter efficiency was measured by conducting the last measurement after the filter.

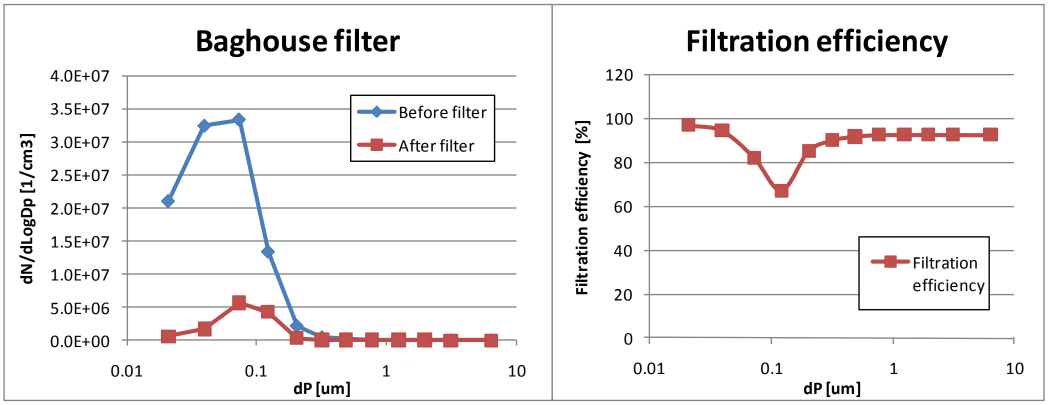

Figure 5: Size distributions before and after the baghouse filter and filtration efficiency

Overall filtration efficiency was 90% in terms of number and 92% in terms of mass. Filtration efficiency curve shows a minimum at around 100 nm. Emission level after the baghouse filter was approximately 3.2e6 #/cm3 and 24 mg/m3.

Conclusions

In this work we developed a new sampling and dilution system for power plant particle size measurements. A novel design of the probe allows particle size distribution measurements in different parts of the power plant stack, including the flame itself, with low losses and without volatile material condensation or nucleation.

Electrical Low Pressure Impactor ELPI was combined with this sampling system and was used for particle size distribution measurements in the size range of 0.007-10 microns. Data collected from three different locations in power plant indicates that particle size distribution is clearly bi-modal, number weighed size distribution is dominated by nanoparticles (<100 nm in diameter) while the mass is in the large particles. Submicron particle size changes significantly after the flame and in heat exchangers while large particles and total mass of particles remain constant. Nanoparticle size shift is most likely caused by condensation of and coagulation of solid particles. Real-time data shows how soot blowing affects the concentration and size distribution. Upstream and downstream baghouse filter measurement show size-dependent filtration efficiency and overall efficiency of approximately 90%.

Acknowledgments

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3) ECE/TRANS/WP.29/2008/62, World Forum for Harmonization of Vehicle Regulations, One-hundred-and-forty-fifth session, Geneva, 24-27 June 2008. Item 4.2.8 of the provisional agenda

4) Lind, T. (1999) Ash formation in circulating fluidized bed combustion of coal and solid biomass. Ph D Thesis. Technical Research Centre of Finland (VTT). VTT Publications 378, Espoo, Finland, 1999

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Introduction

- Characterization of power plant PM emissions is important
  - Ambient PM
  - Wood combustion is a new variable

- Measurement at stack good for determining emissions but not sufficient for process developement

- Particle characterization at plant allows
  - Understanding particle formation and transformation
  - Optimization of combustion process
  - Optimization and control of cleaning systems

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In this work we present:

- Conditioning and measurement system for power plant flue gas PM measurements
  - Sample dilution in different locations of the plant
  - Controlled sample cooling and VOC control
  - Particle size distribution and concentration measurement
- Results for
  - Particle concentration and size distribution in the flame, after heat exchangers and after baghouse filter
    - Size distribution change
    - Effect of baghouse filter cleaning system
- Discussion
  - About PM transformation

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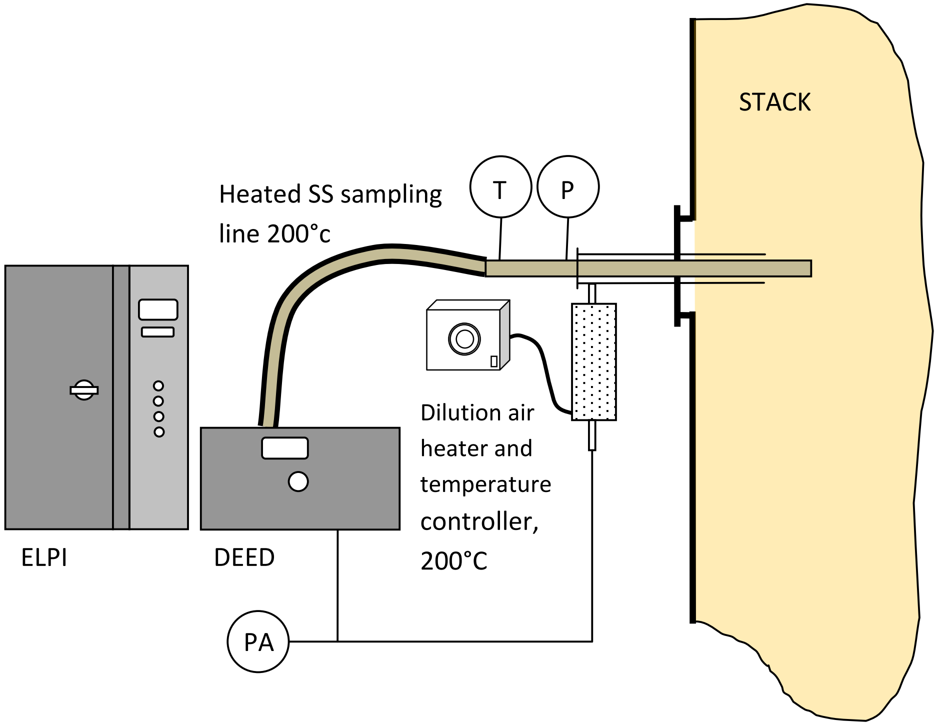
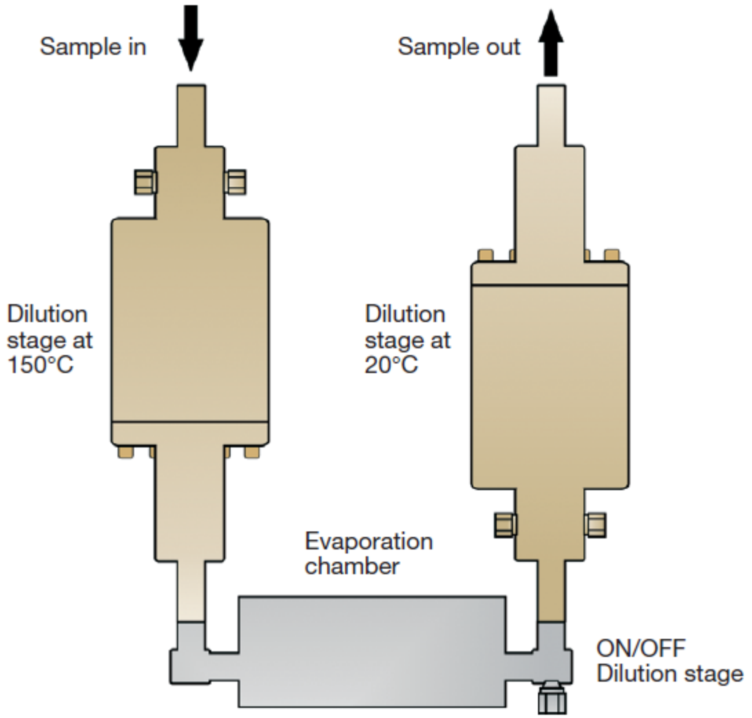
Method : Sample conditioning

- Temperature controlled probe
  - Heated with pressurised air, 200 C
  - Austenitic stainless steel for high temp measurement
- P and T measurement after probe
- Heated sampling line, 200 C
- DEED
  - Three-stage dilution system
  - Removal of VOC and water



Method : Dilution with DEED

- Three-stage dilution:
  - Heated dilution stage 1:10
  - Evaporation tube at 350°C evaporates already condensed VOCs
  - Cold dilution stage 1:10 cools down the sample without condensation
  - (Extra 1:10 dilution stage on/off)



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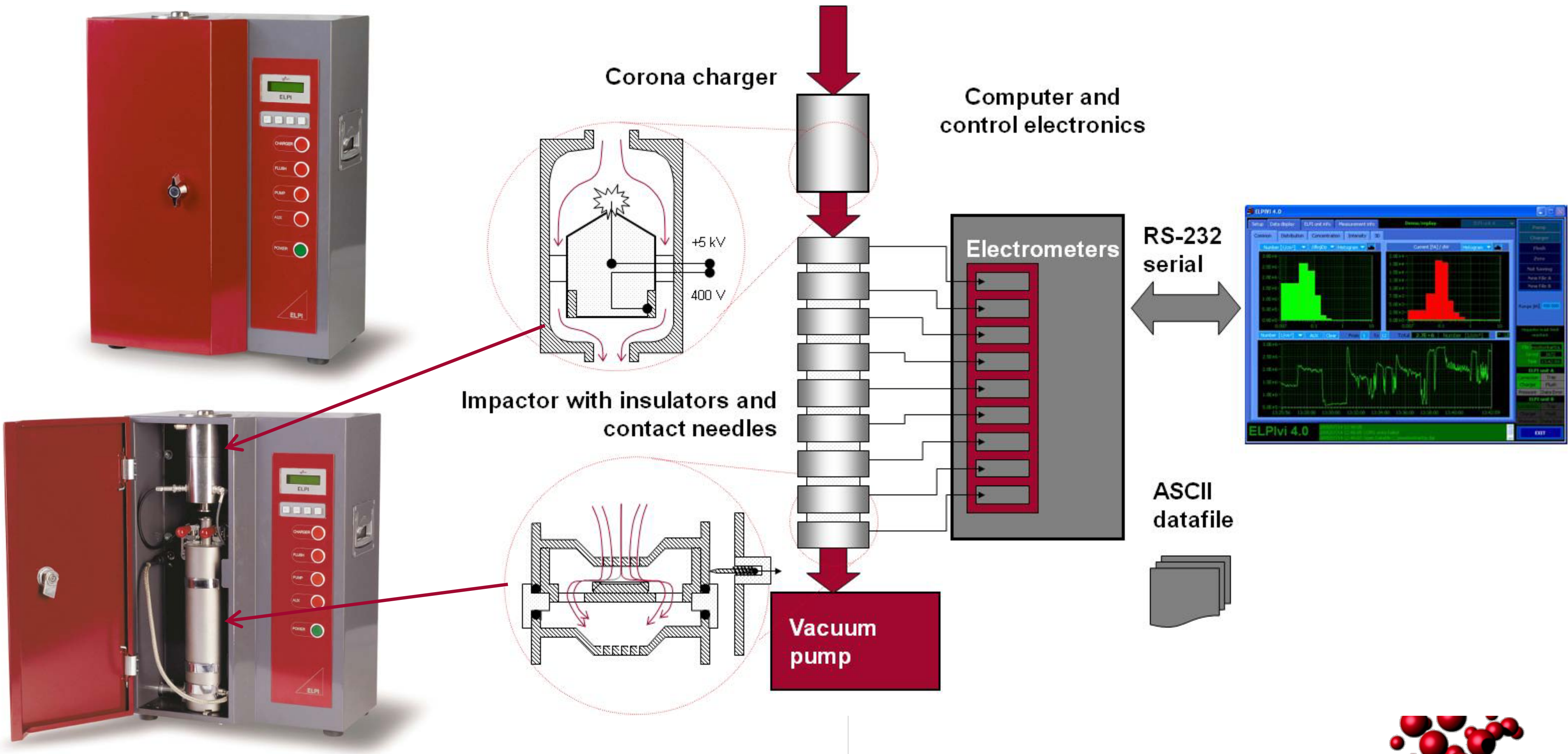
Method : PM characterization with ELPI



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ELPI offers

- Real-time particle size distribution 0.007 – 10 µm
- Real-time number concentration, calculation for mass
- Wide dynamic range
- Particles are collected - option for size-selected chemical /physical analysis
- Option for particle charge level measurements (ESP studies)

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Measurements:

- 4 MW pilot power plant in Finland
- Circulating Fluidised Bed combustion
- Wood pellets
- Baghouse filter
- Measurement locations:
  - After flame, before heat exchangers, T=800 °C
  - After heat exchangers, T=200 °C
  - After baghouse filter

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Measurements

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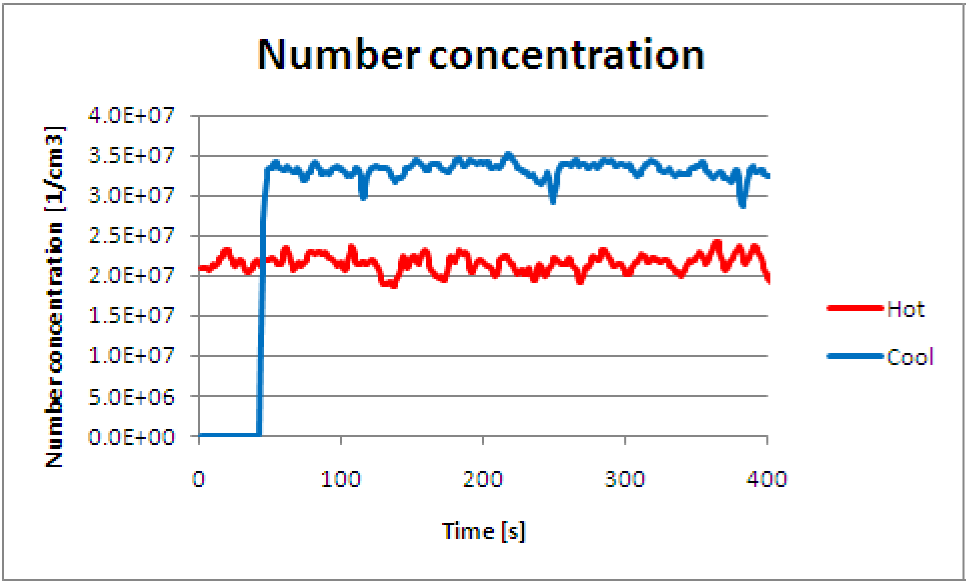
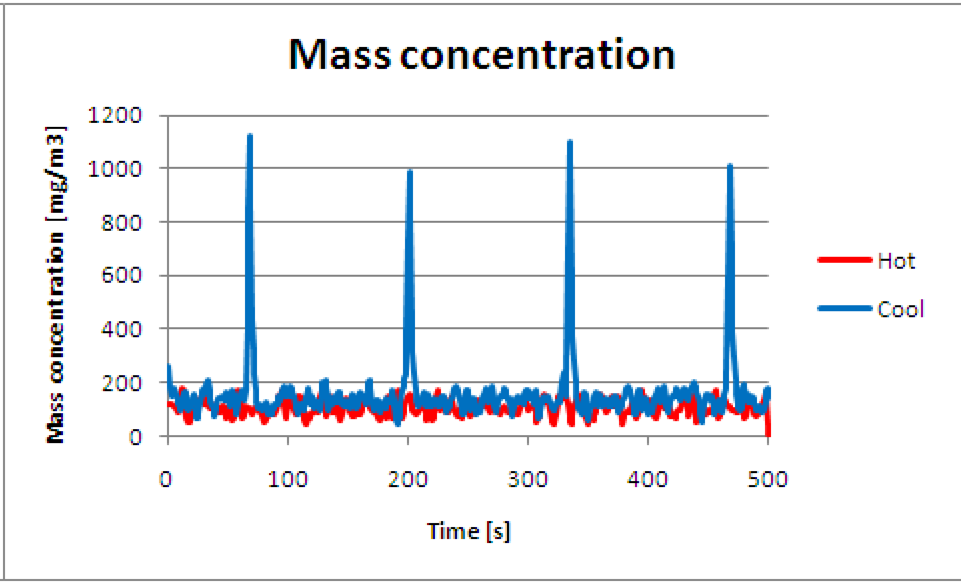
Results 1: PM concentration





- Flame has lower number concentration than after heat exchangers
- Mass concentration is the same
- Effect of soot blowing – decrease number, increase in mass (fine particle washout)

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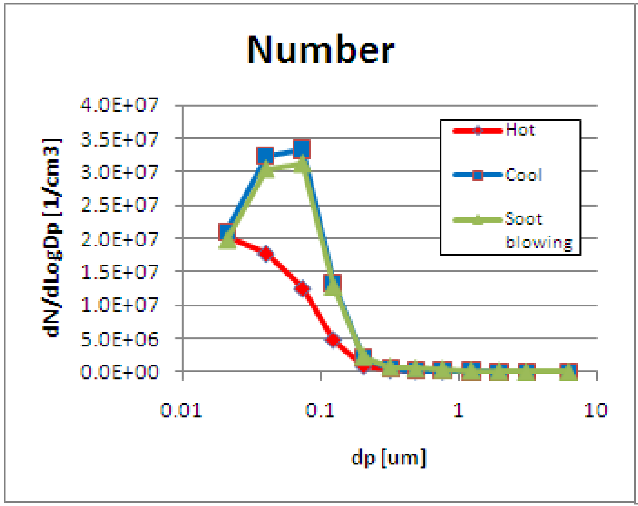
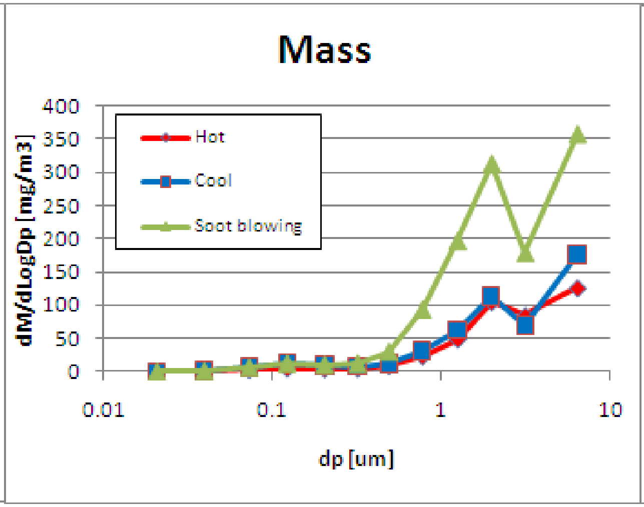
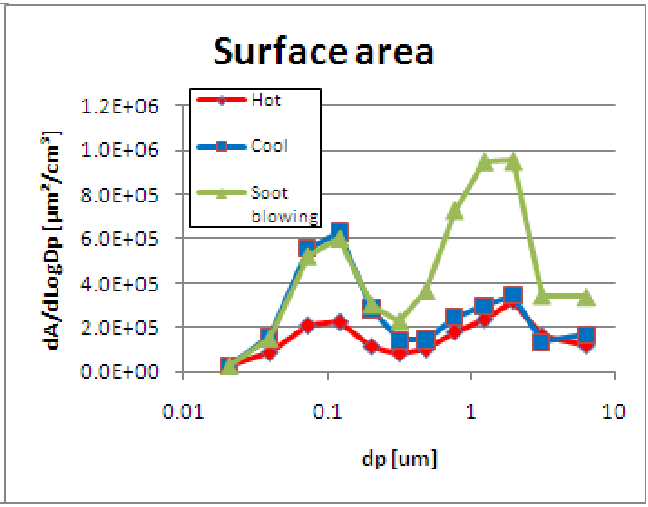
Results 2: PM size distribution







- Increase in number-based size (and concentration) when T decreases – dominated by small particles
- Mass distribution remains the same except during soot blowing
- Bi-modal distribution (seen in surface area)

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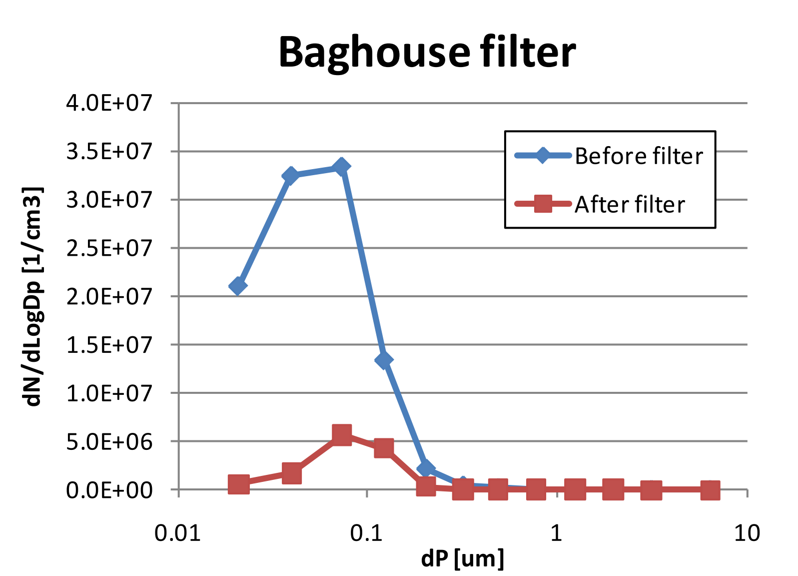
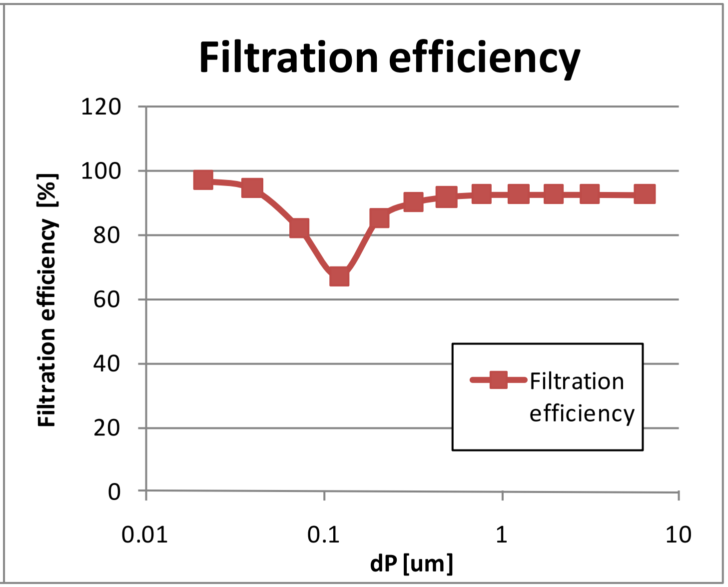
Results 3: Baghouse filter





- Efficiency 90% for number, 92% for mass
- Drop in efficiency at about 100 nm
- Concentration after the filter 10.8 mg/m^3

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Discussion

- Reason for small particle size change
  - Condensation and agglomeration?
  - Further chemical and SEM analysis possible

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Conclusions

- Measurement shows clear change in particle size distribution when flue gas temperature decreases
- Effect seen in number concentration, mass unchanged
- Size-resolved filtration efficiency for flue gas cleaning system
- DEED succesfully applied for stack measurements

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Thank you for your attention!

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