Combustion particle size distribution measurements in real-scale power plants

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Aerosol particles

- Visibility and air quality
- Climate
- Health effects

Effects of aerosol particles

Natural aerosols

Anthropogenic aerosols

Origin of aerosol particles
Why to study combustion aerosols:

- Increased use of waste and biomass in energy production
- Increased corrosion in superheaters
- Different fuel mixtures and fuel additives
- Differences in characteristics of emissions
- Effects on air quality and climate: role of particles
- Need to study aerosols in/from combustion processes
Results presented here are from:


Experimental 1

BFB boiler at Anjala Paper Mill

Measurement locations:
- Superheater
- 2nd pass

<table>
<thead>
<tr>
<th></th>
<th>SRF (%)</th>
<th>Bark (%)</th>
<th>Sludge (%)</th>
<th>Peat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel 1</td>
<td>50</td>
<td>44</td>
<td>6</td>
<td>–</td>
</tr>
<tr>
<td>Fuel 2</td>
<td>70</td>
<td>24</td>
<td>6</td>
<td>–</td>
</tr>
<tr>
<td>Fuel 3</td>
<td>50</td>
<td>10</td>
<td>6</td>
<td>34</td>
</tr>
<tr>
<td>Fuel 4</td>
<td>60</td>
<td>–</td>
<td>6</td>
<td>34</td>
</tr>
</tbody>
</table>

- Flue gas particles existing in the boiler
- Particles formed in the dilution from the gas phase components
- Mobility size distributions (SMPS)
- Effective density (DMA+ELPI)
- Net charge (ELPI, charger on/off)
Size distributions

- Number size distributions of fine particles (below 500 nm)
- Logarithmic scales
- Multiplied by dilution ratio (DR ~ 200)
- Two modes
  - Mode 2 more stable
  - Mode 1 dominates the number concentration in most of the cases
Size distributions

- Fuels 3 and 4 containing peat (34%)
- Huge decrease in the concentration of Mode 1 while moving from SH to 2nd pass (Fuels 1 and 2)

Ferric sulfate additive
- Decreases the concentration of Mode 1
- Increases the mean particle size of Mode 2
Effective density is the factor combining the aerodynamic size and mobility size – For spherical particles same as bulk density

\[ \rho_{\text{eff}} C C(d_p) d_p^2 = \rho_0 C C(d_a) d_a^2 \]
Net charge

- Particles have clearly measurable net charge
- Both positive and negative charge seen as a function of particle size
- Negative net charge can be connected to Mode 1 and the larger particles of Mode 2
- The core of Mode 2 has positive net charge
Conclusions 1

- Particles formed in the dilution or grown by condensation
- Alkali chlorides (KCl, NaCl) with some other compounds slightly lowering the density
- Negative net charge

- Particles most likely existing in the boiler
- High density (> 3g/cm³)
- Zn and Pb compounds found
- Positive net charge

In future, applications using aerosol measurement technology for monitoring combustion processes?

Experimental 2

Combined heat and power plant
Base-load power station with two 365 MW\textsubscript{th} boilers
12 pulverized fuel low-NO\textsubscript{x} burners (6 with coal, 6 with fuel mixture)

\[ N_{\text{tot}}, \frac{dN}{d\log D_p}, \text{CO}_2, \text{SO}_2.. \]
Instrumentation: particles in boiler

Dilution
- Porous tube type primary dilution, DR ~11
- Ejector diluter, DR_{tot}~300

Concentration of gaseous compounds

Particle number size distribution
- ELPI+ (6 nm - 10 μm)
- SPMS (10.8 - 410 nm)

Particle mass size distribution

1-SMPS

Diluting sampling probe

FTIR in raw gas

FTIR in diluted gas

Super heater area 900-1000 °C

Instrumentation: particles in boiler

ESP on/off

PM10

PM10

PM10

DLPI

DLPI

CO2 analyzer

ELPI

E1

F

E2
Instrumentation: flue gas in stack

Dilution
- Porous tube type primary dilution
- Ejector diluter DR~21-27

Concentration of gaseous compounds

Particle number size distribution
- ELPI+ (6 nm - 10 μm)
- SPMS (10.8 - 410 nm)

Particle number concentration
Concentration of gaseous compounds

Particle number size distribution
- EEPs (5.6 nm – 560 nm)
- SPMS (10.8 - 410 nm)

Particle number concentration

Instrumentation: flue gas plume in atmosphere

- Vent
- Inlet
- RH, T
- GPS
- 0.8 m SO₂ analyzer 1.0 slpm
- 0.8 m CO₂ analyzer 1.0 slpm
- 2.16 m CPC 1.5 slpm
- 0.81 m EEPS 10.0 slpm

Flue gas plume in atmosphere
Boiler: Effect of dilution ratio

Particle number size distribution does not change

- Geometric mean diameter 25 nm
- Geometric standard deviation 1.4

No low-vapour pressure gases

Particles have formed before sampling
Boiler: effective density of particles

\[ \rho_p = \left( \frac{D_a}{D_p} \right)^2 \frac{C_c(D_a)}{C_c(D_p)} \rho_0 \]

- \( D_p \): electrical mobility diameter
- \( D_a \): aerodynamic diameter
- \( C_c \): Cunningham slip correction factor
- \( \rho_p \): particle (effective) density
- \( \rho_0 \): unit density (1 g cm\(^{-3}\))

\( \rho_p = 2.86 \) g cm\(^{-3}\)
Slightly different total particle number concentrations, GMD 25 nm

“c+ip10.4%” changes the size distribution “significantly”
  - Second particle mode, GMD 120 nm
After ESP, FLUE GAS DESULPHURIZATION AND FABRIC FILTERS

- $N_{tot} 420 \text{ cm}^{-3} (\text{CPC})$
- $N_{tot} 354 \text{ cm}^{-3} (\text{CPC})$
- $N_{tot} 1.8 \cdot 10^6 \text{ cm}^{-3} (\text{CPC})$
- $N_{tot} 0.74 \cdot 10^6 \text{ cm}^{-3} (\text{CPC})$

Stack: particle number concentration and size distribution
In-plume particle number concentrations, coal

BYPASSING FLUE GAS DESULPHURIZATION AND FABRIC FILTERS IN ONE DUCT
Conclusions 2

Particle number concentration (cm$^{-3}$)

- $\sim 10^9$
- $\sim 10^6$
- $\sim 10^3$

City center (Lähde et al. 2014, AAQR)

Urban background (Pirjola et al. 2012, AE)

Boiler [3]

Effect of electrostatic precipitator

Effect of desulphurization and fabric filters

Atmospheric dilution

Time

$\sim 1$ s

$\sim 100$ s
Conclusions 3

Aerosol measurements are essential when aiming to understand:
- Combustion processes
- Corrosion
- Filtration
- Emissions
- Effects on air quality and human health
- Effects on climate

... and thus in technology development regarding these issues
Thank you!

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