Particle precipitation in medium- and large-scale biomass combustion plants

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Content

- Characterisation of particles to be precipitated
- Technological description of different dust precipitation technologies
- Evaluation of the aerosol precipitation efficiencies of different dust precipitation technologies
- Recommendations concerning the application of different dust precipitation technologies in biomass combustion plants
Typical particle size distributions of fly ashes formed during biomass combustion
Dust precipitation technologies – overview

- Cyclones
- Multi-cyclones
- Flue gas condensation units
- Electrostatic precipitators (ESP)
  - dry ESP
  - wet ESP
- Baghouse filters
Precipitation efficiencies of different dust precipitation technologies

- Bag filter
- Wet ESP
- Dry ESP
- Scrubber condenser
- Cyclone

Separation efficiencies $T(x_e)$ [%]

Particle Size $x_p$ [μm] ($ρ_p=2.600kg/m^3$)
Cyclones and multi-cyclones

**Principle:** precipitation by centrifugal forces

**Cut diameters:**
~ 5 µm

**Operation temperature:**
- up to 1,300 °C
- usually 150 - 250°C

**Operation pressure:**
- up to 100 bar
- usually atmospheric

*Only suitable for coarse fly ash precipitation*
Scheme of a multi-cyclone

- **脏气体**: dirty gas
- **清洁气体**: clean gas
- **收集的灰尘**: collected dust out
- **出口管**: outlet tube
- **旋翼**: spin vanes
Multi-cyclones – aerosol separation

Measured particle size distributions of aerosols upstream and downstream a multi-cyclone
(coarse fly ashes are not considered)

Almost no separation of aerosol particles

Explanations: all data related to dry flue gas and 13 vol.% O₂
ae.d.: aerodynamic particle diameter
underfeed stoker, full load
fuel: hardwood (wood chips and sawdust)
Flue gas condensation units

- Combined dust precipitation and recovery of sensible and latent heat
- Not applicable in all biomass combustion units.

Constraints for application are:
- low temperature of return
- high moisture content of fuel

- Particle separation efficiency
  coarse fly ashes: almost 100%
  aerosols: depends on amount of condensed water vapour

- Pre-separation of coarse fly ash particles is recommended to avoid plugging of tube pipes
- Sludge/water separation is necessary
- Heat exchanger tubes can be cleaned by water injection
Flue gas condensation units – aerosol precipitation

Measured particle size distributions of aerosols upstream and downstream a flue gas condensation unit

Aerosol precipitation efficiency: test 1: 39%, test 2: 60%

Explanations: all data related to dry flue gas and 13 vol.% O₂; ae.d.: aerodynamic particle diameter; grate-fired combustion unit, 70% load; fuel: bark
Electrostatic precipitators - principle of dry ESP

**Principle:**
(1) Particles are charged and
(2) precipitated at collection electrodes (plates)
(3) particles are removed from electrodes by rapping

**Required properties of dust:**
Specific electric resistivity between $10^7$ and $10^{11}$ Ohm*cm

**Operation temperature**
up to 480°C, usually <250°C

**Operation pressure**
up to 20 bar, usually atmospheric
Electrostatic precipitators - plate and tube-type ESP

(a) Plate-type ESP
(b) Tube-type ESP
Dry electrostatic precipitators – aerosol precipitation vs. voltage

Explanations: results from impactor measurements; only particles <1µm considered
all data related to dry flue gas and 13 vol.% O₂
grate-fired combustion unit; filter current: <2 mA
Electrostatic precipitators - principle of wet ESP (I)

**Principle:**

- The flue gas flows vertically through honeycomb-shaped collection surfaces.
- An emission electrode is located in the centre of the honeycombs.
- Before entering the wet ESP, the flue gas is cooled by a quenching process and saturated with water.
- Increasing the amount of moisture in the flue gas reduces the electrical resistance of the dust, making it easier to charge and remove the particles.
Electrostatic precipitators - principle of wet ESP (II)

Principle:

- Collection surfaces are configured as circular pipes
- These collection surfaces are cooled on the outside by a surrounding flow of ambient air, which causes a layer of condensed vapour on the inside of the pipes
- Disadvantage: larger overall size
- Advantage: enhanced self-cleaning effect (as the condensate drains off, it creates a film of water that carries away the separated particles)
Wet ESP – aerosol precipitation vs. filter current

Explanations: results from impactor measurements; <1µm ... particles collected on impactor stages with a cut diameter <1µm; total ... total amount of particles collected with the impactor; all data related to dry flue gas and 13 vol.% O₂; grate-fired combustion unit; fuel: mixture of bark, wood chips and sawdust; filter voltage: <60 kV
**Baghouse filters**

**Principle:**
- Flue gas is filtered on the surface of filter media by cake generation
- The cake is periodically removed from the surface by pressurised air

**Operation temperature**
- up to 850°C (depending on filter material)
- usually in the range between 160 and 220°C

**Operation pressure**
- up to 50 bar
- usually atmospheric

**Additional advantage**
- Combination with dry sorption in order to decrease HCl, SO$_x$, Hg and PCDD/F emissions
Baghouse filters – scheme

- Flue gas inlet
- Filter bags
- Valves
- Pressurised air (3-6 bar)
- Flue gas outlet
- Dust
Baghouse filters – filter bag cleaning

**Filtration**

- Dirty gas
- Clean gas

**Cleaning**

- Pressurised air
Baghouse filters – aerosol precipitation

Aerosol precipitation efficiency:  >99%

Explanations: results from impactor measurements; all data related to dry flue gas and 13 vol.% O₂; grate-fired combustion unit; fuel: waste wood
### Particle separation in biomass combustion units – results from measurements

<table>
<thead>
<tr>
<th>combustion technology</th>
<th>multi-cyclone</th>
<th>flue gas cond. unit</th>
<th>ESP 1</th>
<th>ESP 2</th>
<th>baghouse filter</th>
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<tbody>
<tr>
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Explanation: all data in mg/Nm³ related to dry flue gas and 13 vol.% O₂
Conclusions and recommendations

Best applicable precipitation technology with respect to the capacity range and fuel used

- Emission limit: >150 mg/Nm³, multi-cyclone
- Emission limit: 50 mg/Nm³, flue gas condensation units, dry ESP
- Emission limit: 20 mg/Nm³, dry or wet ESP
- Emission limit: 10 mg/Nm³, baghouse filters, wet ESP
- Waste wood fired plants, highly efficient baghouse filters

Generally, a cyclone or multi-cyclone should be implemented upstream an ESP, baghouse filter or flue gas condensation unit in order to remove the coarse fly ash particles.