Design and operation characteristics for electrostatic precipitators for wood combustion particles as function of combustion conditions

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1. Introduction
2. Theory
3. Experimental Setup
4. Results
5. Conclusions
In Switzerland, biomass combustion contributes significantly to PM10 in the ambient air.

[BAFU, 2005]
ESP for Wood Combustion

- Electrostatic precipitation (ESP) is commonly applied for particle separation in large scale utility boilers. Design parameters are well known for coal, e.g. [White, 1963]

- Today, ESP’s are applied for small and medium-scale applications for heating purposes:

  for wood boilers > 500 kW
  for wood stoves < 70 kW

[Scheuch]  [Oekotube]
1. Introduction
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Particle Formation

Solid Particles & Condens.
- Salts
- Soot
- COC

Gas phase emissions
- VOC
- CO
- CO₂
- H₂O

Wood

CₙHₘOₙ + w(H₂O)

PM₁₀

PM₁₀ + hv → SOA

COC = Condensable Organic Compounds
VOC = Volatile Organic Compounds

KCl
CO₃

nucleation
K + Cl evaporation
CaCO₃ release

PAH

T > 850°C [1]

prim. Tar

sec. Tar

T = 700-850°C [1]

O₂ = 0; (local) lack of O₂

τ <

τ >

CₘHₙ

CO

C

[1]: Evans and Milne, 1987
[2]: Jess, 1996
Solid Particles & Condens.
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Gas phase emissions
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- CO₂
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Particle Sources

[Hochschule Luzern
Engineering and Architecture]
### Particle Properties

<table>
<thead>
<tr>
<th>Gas phase emissions</th>
<th>Salts</th>
<th>Soot</th>
<th>COC</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H2O</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Solid Particles & Condens.**

<table>
<thead>
<tr>
<th>C/H</th>
<th>&gt; 6 – 8 [5]</th>
<th>≈1 (&lt; 2)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Electrical conductivity</th>
<th>medium</th>
<th>high</th>
<th>low (isolating)*</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>ESP [3]</th>
<th>ideal</th>
<th>re-entrainment</th>
<th>back-corona</th>
</tr>
</thead>
</table>

* primary tar: isolating, Secondary tar and PAH: semiconductive [4]

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[3]: Parker, 1997
[4]: Roempp, 1989
[5]: Leuckel and Römer, 1979
Particle Types

Soot  Salt  COC ('Tar')

[mg/Nm$^3$] (11% O$_2$)

Excess Air Ratio $\lambda$

CO

[Nussbaumer, Energy & Fuels 2003, 17]

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Engineering and Architecture
ESP Operation with Automatic Wood Boiler

- After 20 days of operation
- After boiler cleaning
- ESP on at 140°C
- ESP on at 120°C

CO [mg/m³]

T_{gas} [°C]

ESP

Salt

Soot or COC
1. Introduction
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Experimental Setup

ESP:
- L 1000 [mm]
- D 100 [mm]
- U 1 [m/s]
- SCA 45 [s/m]
- U_{\text{max}} -65kV

Particle generator:
- Pellet boiler
- modified
- Q 15kW

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Experimental Setup

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Calculated ESP efficiency depending on electric field strength

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Gas and Chemical Analysis

- CO, HC, CH₄ concentrations vs. λ
- TOC [%] vs. fuel type (Ref, Salt, Soot, COC)
- Tc [°C] vs. λ
- C/H [mol/mol] vs. fuel type

*Ref: 1MW AWC
Specific Dust Resistivity

**Electrical conductivity [3]**
- High
- Medium
- Low

**Dry flue gas**
- Back-corona
- Re-entrainment

**Salt**

**COC**

**Soot**

**Wet flue gas**

---

*Dry: 5 vol.-% H$_2$O e.g. excess air ratio 3 & wood moisture content 5%*

*Wet: 20 vol.-% H$_2$O e.g. excess air ratio 1.2 & wood moisture content 50%*

*Ref: 13 vol.-% H$_2$O: excess air ratio 1.5 & wood moisture content around 30%*

[3]: Parker, 1997

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IU Characteristic / ESP efficiency

- Flue gas at ~150°C
- Back-corona onset

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Dust Layer Build-up

Conductive particles:
→ 'dendritic' build-up

Soot
weak adhesion / re-entrainment

Normal or isolating particles:
→ homogeneous build-up

Salt
stable layer

COC
sticky layer

[Blanchard et al., 2002]
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Conclusions 1/2

1. Three different particle types from wood combustion have been identified which correspond to different combustion regimes

2. The three particle types exhibit completely different physical and chemical properties, among which the electrical conductivity is most relevant for ESP operation

3. Particles from good combustion (mainly salts) exhibit ideal conductivity for ESP

4. Soot reveals high conductivity thus enabling high precipitation efficiency but severe re-entrainment of agglomerated particles

5. COC exhibit low conductivity thus leading to back-corona which limits ESP operation
Conclusions 2/2

6. ESP operation for good and stationary conditions during wood combustion with mainly inorganic particles causes no operation problems, while it may be critical e.g.

- during start-up due to COC from low temperatures or

- during throttled air, either due to COC at low temp. or due to soot from lack of oxygen.

Both conditions are common for heating applications.
Outlook

ESP availability is crucial and needs to be improved by three measures:

1. **Stationary combustion** operation and plant design with two boilers and two ESP for variable load

2. **Process integrated control** of ESP with specific information as indicators for the particle properties:
   - flue gas temperature (as today) plus:
     - excess air ratio
     - combustion temperature
     - water content of the fuel
   This increases the operation regime of the ESP

3. **Measures to avoid re-entrainment**:
   - Limitation of gas velocity to < 1.5 m/s
   - optimised shape of collecting plates
   - shorter dedusting interval during re-entrainment regimes

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Acknowledgments

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