Development of Electrostatic Precipitator (ESP) for Small-scale Wood Furnaces

Basics and First Project (FHNW) - J. Wüest (IBRE)
Implementation and Further Development (OekoSolve) - B. Müller (Oekosolve)
Modelling and Simulation-possibility (FHNW) - D. Rubinetti (ITFE)
Objectives

- Introduction / Motivation
- Basics for electrostatic particle deposition
- Electrode design
- Feasibility study on brick-built chimneys
- Field measurements long-term tests
- Implementation and development (OekoSolve) for biomass firing
- Product range OekoSolve
- Simulation of fields, corona, space charge, particle loading and deposition
- Analytical and experimental validation
- Application to other industry application
Immissions of Particulate Matter - CH

Reference: FOEN Statistic, Particulate matter immissions
Beitrag verschiedener Quellen zum PM1-Feinstaub in Zürich im Winter während einer Smoglage

- Landwirtschaft: 15%
- Holzheizungen & offene Feuer: 12%
- Verkehr: 20%
- Industrie: 7%
- Öl- & Gasheizungen (Haushalte): 26%
- natürliche Quellen

Im ‚groben Feinstaub‘ (zwischen 1 und 10 μm Durchmesser): andere Quellen
Introduction / Motivation

1. Biomass combustion plants account for a significant proportion of total particulate emissions.

2. Both primary and secondary measures for the reduction of particulate matter are needed.

3. Electrostatic precipitation (ESP) is tried and tested means of reducing dust emissions in large facilities.

4. The use of ESP in small-scale furnaces was investigated in a first project (degree of precipitation, suitability in brick-built chimneys and durability).
OekoTube Chimney flue system

Chimney flue system

High voltage power supply

Exhaust gas

Sharp-edged
Electrical Field in Chimney

$E_{zyl}(r) = \frac{U}{r \ln(D/d)} = \frac{\lambda}{2 \pi \varepsilon_0 r \ln(D/d)}$

$d = \text{Diameter electrode} \\
D = \text{Diameter chimney} \\
r = \text{Radius} \\
U = \text{Electrode-voltage}$

Electrical field strength in cylindrical arrangements as a function of the radius (without space charge)
Electrode Design

- The larger the electrode radius (→ surface), the larger the E-field at position x between electrode and chimney
- Small radii increase the corona current
Deutsch-Anderson Equation

\[ \eta = 1 - p = 1 - e^{-w_e \frac{A}{Q}} \]
Pellet oven with brick-built chimney

- **Voltage**
- **Particles/Joule**

![Graph showing voltage and particles per joule over time from 09:00 to 14:30]

- Voltage and particles per joule are plotted over time from 09:00 to 14:30.

- The graph displays periodic spikes in particles per joule, indicating fluctuations in the system.

- The voltage remains relatively stable throughout the observed period.

- The data is visualized using blue dotted line for voltage and magenta dashed line for particles per joule.

- The chart is labeled with time intervals and corresponding voltage and particle values.
Electrical field in front of the electrode

- Field distribution in front of the electrode and its influence on the deposit location
Field-measurement long-term test

- **DiSC (Diffusion Size Classifier):** Measures particle number from 3 to 300 nm (particulate matter).

- **OPC (Optical Particle Counter):** Measures particle size and size of 0.3 - 30 µm

- Gravimetric filter method with 2 Wöhler measuring devices (before and after the ESP, extraction opening against and in flow direction).

- Gas analyzer (O\textsubscript{2}, CO\textsubscript{2}, CO, OGC) online before and after the ESP.

- Process variables of the ESP (current, voltage, etc.).

- Dust collected from the chimney sweep.
Tested Furnaces

1. Log boiler, 40 kW, combustion automatically controlled, 6 h burning time.
   Fireplace: Ø = 180 mm, L = 11.4 m. Fuel: Hardwood, approx. 50 kg.
   $T_{\text{flue gas}} = 212 \, ^\circ C$

2. Log chimney, 9 kW (mostly overloaded, ca. 15 kW). Fireplace: Ø = 250 mm, L = 8 m. Fuel: Hardwood 10-15 kg per burning cycle, $T_{\text{flue gas}} = 320 \, ^\circ C$

3. Pellet stove, 9 kW. Fireplace: $\varnothing_{\text{upper}} = 150 \, \text{mm}$, $\varnothing_{\text{lower}} = 80 \, \text{mm}$, L = 6 m, with 90° redirection
Setup field measurement
Development in time of the precipitation efficiency

Compilation of different degrees of precipitation over the entire measurement period
Results long-term tests

<table>
<thead>
<tr>
<th>Degree of Precipitation (without flocculation)</th>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chimney sweep dust mass related to field measurement (without flocculation)</td>
<td>79 %</td>
<td>81%</td>
</tr>
<tr>
<td>Gravimetric measurement Wöhler ((p_0 - p_1))</td>
<td>77 %</td>
<td>76%</td>
</tr>
<tr>
<td>DISC measurement</td>
<td>72 %</td>
<td>84%</td>
</tr>
<tr>
<td>OPC (partially not measurable)</td>
<td>(0 %)</td>
<td>55% / 62%</td>
</tr>
<tr>
<td>Expected according to the Deutsch-Anderson formula</td>
<td>73 %</td>
<td>76 %</td>
</tr>
</tbody>
</table>

Table: Compilation of the determined precipitation rates with different measuring methods at the plant at the beginning and at the end of the measurement period
OekoSolve AG

OekoSolve – Micro-dust filters and heat exchange recovery
OekoSolve AG

- 2006-2007
  - Idea of the OekoTube
  - Established OekoSolve

- 2008-2009
  - Selling of precipitator up to 40kW

- 2010-2011
  - Selling of precipitators up to 300kW (wet cleaning)

- 2012-2013
  - Move to Plons, Mels

- 2014
  - Selling of precipitators up to 500kW (Dry cleaning)

- 2015-2016
  - Precipitators up to 2 MW
  - Construction of new office and production building

- 2017
  - Selling Wood chip drying with integrated electrostatic precipitator
  - 26 employees including 3 apprentices
OekoSolve AG

- Competences
  - High voltage (development and production)
  - Insulator (development and production)
  - Electronics & Control Box (development and production)
  - Software (development)
  - Plant construction in CAD
  - Mechanical production and assembling of precipitators
  - In-house measuring technology and analysis of particulate matter
  - Test stand with different fires
  - Cooperation with various national and international universities and research institutes
  - Reliable and well-trained service team across Europe

- Its own production makes the development fast
# Portfolio Precipitators OekoSolve 2017

## Cleaning

<table>
<thead>
<tr>
<th>Cleaning Method</th>
<th>Bis 2MW</th>
<th>Bis 10MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manually</td>
<td>DE, FR, IT</td>
<td>CH, DE, FR, IT</td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanically</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood chips drying</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Market

- **DE**
- **FR, IT**
- **CH, DE, FR, IT**
- **CH**

## Power [kW]

- **OekoTube (2008)**
- **FilterBox (2011)**
- **OekoRona (2013)**
- **OekoRona M (2014)**
- **Neviro (2016)**

---

**CONTACT**

beat.mueller@oekosolve.ch  |  www.sccer-biosweet.ch  |  11.10.2017  |  20
Praxis

Wien AT:
Dual plant Herz 1’000 + 300 kW
Woodchips W30
OekoRona 5M + 2M

OekoRona M D300 for 1.4 MW

Installation filter through ceiling opening

OekoTube for 40kW, field test

Loading truck at OekoSolve
Biomass District Heating in the Settlement Area

- **Advantages**
  - Cost-effective clean heat generation, CO$_2$-neutral
  - Value added in the region (independent of foreign countries)

- **Requirement**
  - Short distances for heat distribution
  - Professional technical planning and support
  - Fuel quality, combustion quality, storage
  - Use of ESP: Good air quality for the residents

- **Example**

<table>
<thead>
<tr>
<th>Mels, CH</th>
<th>2015</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>Wood chips W50</td>
<td></td>
</tr>
<tr>
<td>Boiler Capacity [kW]</td>
<td>550</td>
<td>550 &amp; 900</td>
</tr>
<tr>
<td>Chimney Height [m]</td>
<td>6.1</td>
<td>9.1</td>
</tr>
<tr>
<td>Storage [m$^3$]</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>Type of Precipitator</td>
<td>OekoRona 4M &amp; 6M</td>
<td></td>
</tr>
<tr>
<td>PM [mg/Nm$^3$ 13% O$_2$]</td>
<td>104</td>
<td>3 &amp; 16</td>
</tr>
<tr>
<td>Neighbourhood</td>
<td>complains</td>
<td>satisfied</td>
</tr>
</tbody>
</table>
New Product: Woodchip Dryer NEVIRO

- Woodchip drying by flue gas with ESP
- Applicable for woodchip heating systems > 1 MW
- Precipitation of particulate matter by wet ESP
- Pilot plant in St.-Aubin NE, 2.2 MW
- 2 projects 2017 over 2 MW and 4MW
Modelling and Simulation-possibility
Simulation – Coupled ESP-Physics

Diagram showing the interconnections between ESP-Geometry, Flow, Electric Field, Particles, Corona-Wind, Ion-Air-Coupling, Drag Force, Electric Force, Space Charge Density, Particle-Air-Coupling, Particle Charging.

Arrows indicate the influence strength: strong, moderate, weak.
Simulation – Test case
Simulation – Multi-physics Structure

1. Turbulent Flow Analysis of Exhaust Gases
2. Corona Discharge + Particle Charging
3. Particle Tracking
Simulation Result – Particle Trajectories

0.001 μm

0.01 μm

0.1 μm

1 μm

10 μm

Inlet

z
Ongoing Investigation

Color Legend
- black – 0 C/m³ (charge free)
- yellow – 10E-4 C/m³

Optimization of emitting electrode configuration

Single needle
Double needle
Horizontal needle
Essentials of ESP Modelling

• Promote clean combustion technologies
• Predict physical behaviours and processes
• Spot optimization potential
• Reduction of development costs
• Adaptation to similar applications for particle control
Acknowledgement

- BIOSWEET, CTI and BFE for funding
- Prof. H. Burtscher (IAST) for the discussions on the dust problem
- A. Keller (IAST) for the support of particle counting devices
- W. Egli for the simulations and ideas
- the whole OekoSolve crew for the good and interesting cooperation.