Field Particle Emission Measurement on Domestic Wood Firing Systems Retrofitted with Electrostatic Particle Precipitators

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Project Motivation

**Wood-combustion** contributes with about **32%** to the particulate matter (**PM2.5**) emissions in Switzerland

→ **Solution:** electrostatic precipitators (**ESP**)?

→ **BAFU/FOEN-Project**

**Goal:** Check 20 wood combustion plants equipped with ESP

- Collection efficiency in the field
- Problems / maintenance
Ideal Field-Laboratory Saas-Fee

- Car-free, no/low agriculture/industry → combustion=main PM-Source
- high density of ESPs installed on rooftops
Standard-compliant measurement...

- ... requires additional measuring section
- measurement upstream of the ESP inside the building for raw gas measurement
- Not suitable for many old chimneys
Dilution-Independent Emission Measurement (DIEM) Principle

- consisting of: flue gas collector, DiSCmini (particles), diluter, neutralizer, Licor 840A (CO\textsubscript{2} and H\textsubscript{2}O), MRU Optima 7 (CO)
Project plan

measurement-method

mobile measurement device

Measurements in Saas-Fee
Measuring principle: Diffusion Size Classifier (DiSC)

1. **Charging** the particles (as in ESP, but positively)
2. **Measurement of the current** in the diffusion stage and in the filter stage
3. Calculate **number concentration** $[100 - 10^6 \#/\text{cm}^3]$ and **mean diameter** $[20-300 \text{ nm}]$, assuming a log-normal particle size distribution with a certain geometric standard deviation $\sigma$
Particle Size Distribution: Wood Log Fireplace

Spectrum of particle size distribution in the main phase, taken with a Scanning Mobility Particle Sizer (SMPS). Yellow: Size-Range of DiSC

\[ \sigma = 1.9 \]
DiSC Characteristics and Particle Behavior

- DiSC measuring range: 20 – 300 nm; size distribution is assumed with a log normal shape and a certain standard deviation $\sigma$.

- $\sigma$ changes with the fuel (pellet: $\sigma = 1.5$, log wood $\sigma = 2$); For a specific fuel, $\sigma$ changes only slightly over the operating phases, but the mean diameter changes significantly. $\rightarrow$ Assumption of static $\sigma$ for specific fuel is ok. Error is small.

- The fractal shape of the particles (influenced by combustion quality, coagulation time etc.) must be considered for mass calculation.

$\rightarrow$ SMPS- and gravimetric measurements showed: DiSCmini is suitable for PM-Emission from combustion processes.
**CO$_2$ - Standardisation**

**Problem:** unknown, high dilution with ambient Air → O$_2$-Standardisation fails

\[ \lambda = \frac{O_{2}^{amb}}{O_{2}^{amb} - (O_{2}^{measured})} \]

\[ \lambda = \frac{21%}{21% - (20.8 \pm 0.1)\%} \]

\[ \lambda = 70...210 \]

**Solution: CO$_2$-Standardisation**

e.g. Beechwood → 
CO$_{2\text{max}}$=20.4% (λ =1 )

\[ \lambda = \frac{CO_{2\text{max}}}{CO_{i}^i} \]

\[ CO_{i}^i=5\% \]

\[ \lambda_0 \approx 4 \]

Dilution

\[ CO_{i}^i=2000 \text{ ppm} \]

\[ \lambda_1 \approx 100 \]

PM-dilution = CO$_2$-dilution

\[ CO_{i}^i = CO_{2\text{ measured}} - CO_{2\text{ ambient}} + CO + (C_x H_y) \]
DIEM vs Testo-380 in the Field Measurement
in cooperation with Team HSLU - Verenum

Pelletboiler equipped with ESP (Oekotube) switched ON and OFF (5 min interval)

High dilution → Testo-380 fails to measure low dust concentration.
Efficiency of ESP: Testo 66%, DIEM mass 83%, (DIEM number 84%)
DIEM vs gravimetric measurement (SM96 and MRU)

Measured in Saas-Fee on a storage stove
Online Measurement of ESP-Data, PM, CO (CO2)

<table>
<thead>
<tr>
<th>Time</th>
<th>Cold start</th>
<th>Burn cycle 1</th>
<th>Burn cycle 2</th>
<th>Burn cycle 3</th>
<th>Burn cycle 4</th>
<th>Burn cycle 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Interval</td>
<td>ESP OFF</td>
<td>ESP ON</td>
<td>ESP ON</td>
<td>ESP OFF</td>
<td>Interval</td>
</tr>
</tbody>
</table>

- Burn cycle 1: ESP OFF
- Burn cycle 2: ESP ON
- Burn cycle 3: ESP ON
- Burn cycle 4: ESP OFF
- Burn cycle 5: Interval

Graph showing voltage (HV [V]) over time, with intervals and burn cycles indicated.
Online-Measurement of ESP-Data, PM, CO (CO2)

Total collection efficiency 73%
→ 4 kg PM/a accumulated

(Assumptions: 4800 kg wood/a, 10m3/ kg wood @13%O2)
Conclusion

- **Good agreement** of the new DIEM method **with standard measurements** for PM and CO in laboratory and field. Even **better for measurements after ESP** and delivering **additional metrics** (d, N, LDSA).

- With the new DIEM method, **reproducible collection efficiencies** can be **measured easily in highly diluted exhaust gas**. (without additional measuring section, short measuring time).

- Due to the high dilution, **condensation is not a problem**, the measuring **devices** are not heavily loaded and **can therefore be operated continuously**. → further miniaturisation is planned.
Conclusion

- The cleaner a furnace runs, the less DIEM dilutes and the more accurate the measurement can be. PM-measurement is able to detect < 0.1 mg/m³.

- **Collection efficiencies about 60-80%** on 20 plants in Saas-Fee were measured; the ESPs (Oekotube) seem to be very robust, but must regularly checked. Final project report at the end of 2019.
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References

- BAFU (FOEN) Switzerland’s Informative Inventory Report 2018 (IIR); March 2018
- DIN SPEC 33999:2014-07
- https://oekosolve.ch/produkte/feinstaubfilter-oekotube/