IEA Task 32 Workshop: “Highly efficient clean log wood stoves"

Performance of foam ceramic elements in log wood stoves

October 29th, 2015, Berlin

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Filter material for measurement of long term feasibility

Porosity: 35 ppi

New foam ceramic

Foam ceramic after 200 batches

Foam ceramic after 2 heating seasons
Approx. 550 batches
(Filter had been washed after 1st heating season)
## Retrofit catalyst for stoves using foam ceramic filters

Product specification data as **declared by manufacturer**:

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Linder Katalysatoren GmbH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal resistance</td>
<td>&gt; 1450 °C</td>
</tr>
<tr>
<td>Carrier material</td>
<td>SiC- foam ceramic</td>
</tr>
<tr>
<td></td>
<td>(SiC – SiO₂ + 3 C → SiC + 2 CO and Al₂O₃)</td>
</tr>
<tr>
<td></td>
<td>(Al₂O₃ components fired at 2300-2500°C)</td>
</tr>
<tr>
<td>Coating</td>
<td>Platinum (Pt78), Palladium (Pa45), Rhodium (Rh46)</td>
</tr>
<tr>
<td>Reduction</td>
<td>CO, OGC, NOₓ, PM</td>
</tr>
<tr>
<td>Structure</td>
<td>&gt; 70% open porous surface</td>
</tr>
<tr>
<td>Porosity</td>
<td>PPI 8, PPI 10, PPI 20, PPI 30,</td>
</tr>
</tbody>
</table>
Construction of an equivalent flow reduction ("Dummy"-Filter)

**TFZ-Dummy:**
Material: Vermiculite (25 mm)
Drill holes: 8 and 10 mm

- Frequency converter
- Pressure measurement
- Filter
- Velocity meter
- Fan

![Graph](image)
Measurement of filter temperature

- T Flue gas [°C]
- T Filter [°C]
- O₂ % [%]
- CO₂ % [%]
- CO mg/Nm³ [mg/Nm³]
- OGC mg/Nm³ [mg/Nm³]
- Nox mg/Nm³ [mg/Nm³]
Determination of the actual flue gas flow path

Flow rate: 35.4 Nm³/h
Draught at socket: -11.8 Pa
Pressure drop, burning chamber to socket: 3.2 Pa
Determination of the actual flue gas flow path (2)

1. Masking the filter plates with air tight tape

Flow rate: 33.9 Nm³/h
Draught at socket: -11.9 Pa
Pressure drop, burning chamber to socket: 3,8 Pa
Determination of the actual flue gas flow path (3)

2. Masking all suspected leakages with air tight tape

Flow rate $= 21.2 \text{ Nm}^3/\text{h}$

Draught at socket $= -11.8 \text{ Pa}$

Pressure drop, burning chamber to socket: $9.1 \text{ Pa}$
Determination of the actual flue gas flow path (4)

3. Cutting the air tight tape from the filter plates

Similar flow rate and pressure drop to variant 1.

Flow rate = 33.9 Nm³/h
Draught at socket: -12.0 Pa
Pressure drop, burning chamber to socket: 3.9 Pa
Flowchart of the testing procedure used

PM 1  PM 2  PM 3  PM 4  PM 5  PM 6  PM 7  PM 8  Cool down

Flue gas sampling

T Flue gas [°C]
T Filter [°C]
O2 % [%]
CO2 % [%]
O2/CO2 [%]
CO mg/Nm³ [mg/Nm³]
OGC mg/Nm³ [mg/Nm³]
Nox mg/Nm³ [mg/Nm³]

Duration

PM 1  PM 2  PM 3  PM 4  PM 5  PM 6  PM 7  PM 8

0 1 2 3 4 5 6 °C

full load operation

partial load operation

X = Refilling criteria

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P 15 B Mc 011
15B Mc 060
Folie 10
Evaluation of measuring cycle (full load and part load)

Full load: time weighted average value of batch 1-5

Part load: time weighted average value of batch 1,2,6,7,8
Comparison of foam ceramic filters: **Full load cycle (1)**

**Graph 1:**
- CO, OGC, Lambda emission levels for new ceramic filter and after 200 and 550 batches.
- Details:
  - 3 testing days per filter
  - All tests at natural draught
  - One weighted average value of batch 1-5
  - Same damper settings for all tests
  - Test fuel: Beech with bark
  - PM sampling starts before refilling and ends before next refilling

**Graph 2:**
- PM emission levels for new ceramic filter and after 200 and 550 batches.
- Details:
  - 3 testing days per filter
  - All tests at natural draught
  - One weighted average value of batch 1-5
  - Same damper settings for all tests
  - Test fuel: Beech with bark
  - PM sampling starts before refilling and ends before next refilling
Comparison of foam ceramic filters: **Full load cycle (2)**

- **Graph 1:**
  - Y-axis: gaseous emission in mg/Nm³ (13% O₂)
  - X-axis: New ceramic filter, Ceramic filter after 200 Batches, Ceramic filter after 550 Batches
  - Data points: 152, 150, 153

- **Graph 2:**
  - Y-axis: thermal efficiency in %
  - X-axis: New ceramic filter, Ceramic filter after 200 Batches, Ceramic filter after 550 Batches
  - Data points: 58.0, 60.0, 61.0
Comparison of foam ceramic filters: Part load cycle (1)
CO conversion

Filter → Catalyst

Nominal load

Partial load

Nominal load

Partial load

Filter → Catalyst

Nominal load

Partial load

Dummy → Catalyst

Nominal load

Partial load

Carbon monoxide emission (mg/Nm³) with 13% O₂

Filter → Catalyst

Nominal load

Partial load

Nominal load

Partial load

Dummy → Catalyst

Nominal load

Partial load

CO Filter

CO Cat

CO Filter

CO Cat

CO Filter

CO Cat

CO Dummy

CO Cat

CO Dummy

CO Cat

38 %

43 %

46 %

47 %

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Folie 15
Non-Methane-OGC conversion

Filter $\rightarrow$ Catalyst

<table>
<thead>
<tr>
<th></th>
<th>Nominal load</th>
<th>Partial load</th>
</tr>
</thead>
<tbody>
<tr>
<td>OGC Filter</td>
<td>340 mg/Nm³</td>
<td>277 mg/Nm³</td>
</tr>
<tr>
<td>OGC Cat</td>
<td>251 mg/Nm³</td>
<td>23 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Nominal load</th>
<th>Partial load</th>
</tr>
</thead>
<tbody>
<tr>
<td>OGC Filter</td>
<td>327 mg/Nm³</td>
<td>21 %</td>
</tr>
<tr>
<td>OGC Cat</td>
<td>277 mg/Nm³</td>
<td>23 %</td>
</tr>
</tbody>
</table>

Dummy $\rightarrow$ Catalyst

<table>
<thead>
<tr>
<th></th>
<th>Nominal load</th>
<th>Partial load</th>
</tr>
</thead>
<tbody>
<tr>
<td>OGC Dummy</td>
<td>349 mg/Nm³</td>
<td>23 %</td>
</tr>
<tr>
<td>OGC Cat</td>
<td>324 mg/Nm³</td>
<td>251 mg/Nm³</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th></th>
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<th>Partial load</th>
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</thead>
<tbody>
<tr>
<td>OGC Dummy</td>
<td>21 %</td>
<td>23 %</td>
</tr>
<tr>
<td>OGC Cat</td>
<td>23 %</td>
<td></td>
</tr>
</tbody>
</table>
Methane conversion

Filter $\rightarrow$ Catalyst

<table>
<thead>
<tr>
<th></th>
<th>Nominal load</th>
<th>Partial load</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH4 Filter</td>
<td>208</td>
<td>195</td>
</tr>
<tr>
<td>CH4 Cat</td>
<td>220</td>
<td>222</td>
</tr>
</tbody>
</table>

-6% $\rightarrow$ -14%

Dummy $\rightarrow$ Catalyst

<table>
<thead>
<tr>
<th></th>
<th>Nominal load</th>
<th>Partial load</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH4 Dummy</td>
<td>245</td>
<td>227</td>
</tr>
<tr>
<td>CH4 Cat</td>
<td>220</td>
<td>222</td>
</tr>
</tbody>
</table>

10% $\rightarrow$ 2%
NO$_x$ conversion

**Filter → Catalyst**

- Nominal load: 8% NO$_x$ conversion
- Partial load: 5% NO$_x$ conversion

**Dummy → Catalyst**

- Nominal load: -12% NO$_x$ conversion
- Partial load: -11% NO$_x$ conversion

![Bar charts showing NO$_x$ emissions for filter and dummy systems under nominal and partial load conditions.](image-url)
PM reduction

Filter → Catalyst

Nominal load

Partial load

Dummy → Catalyst

Nominal load

Partial load

Particle emission

mg/Nm³ (13 % O₂)

6 %

8 %

10 %

12 %
Conclusions

- Expectations for PM reductions by foam ceramic elements were not met (particularly for non-catalytic elements).

- Catalytic foam ceramic elements can reduce gaseous flue gas emissions (CO, OGC).

- Log term monitoring of this effect is required (field tests).

- Regarding the flue gas flow through the foam ceramics there is still some potential for optimisation.

- It is desirable to achieve higher surface temperatures (< 700 °C) on catalytic elements.

- Retrofitting of catalytic foam ceramic elements may be an interesting option.
Thanks for your attention!

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