ABSTRACT: To meet the strict emission thresholds for log wood stoves foam ceramic elements (filters or catalysts) could be an alternative to electrostatic precipitators. To evaluate the potential of foam ceramic elements three differently aged foam ceramic filters and one retrofit foam ceramic catalyst were tested in a log wood stove applying a “close to real life” test cycle. Results show that foam ceramic filters without catalyst coating provide no appreciable emission improvement under practical conditions. When the foam ceramic was catalytically coated while having the same flow properties, the reduction effects were significant: -46 % for carbon monoxide (CO), -21 % for non-methane-organic gaseous carbon (non-methane OGC) and -10 % for particulate matter (PM). When operated in partial load the reductions were: -47 % for CO, -23 % for non-methane-OGC and -12 % for PM. No effect on NO\textsubscript{X} concentration was observed for any of the tested variants. Foam ceramic elements can reduce gaseous flue gas emissions (CO, OGC) from log wood stoves noticeably, if they have been catalytically activated. For general recommendation in real life applications this finding should however be verified in long term field tests.

Keywords: catalyst, ceramic material, emissions, reduction, stove
2.4 Appliance and fuel used

The appliance used for the combustion test was a state-of-the-art log wood stove with a nominal heating power output of 8 kW and a room-independent combustion air supply. In the condition as supplied to the customer, the appliance is provided with a non-catalytic foam ceramic filter. The combustion air can be controlled by a primary and a secondary air flap. Furthermore, there is a diverting flap which allows to by-pass the foam ceramic elements, however this flap was closed for all test runs. For all test runs the stove was operated with natural beech wood without bark, having a log length of 25 cm and a triangle shape.

2.5 Combustion test facility

All measurements were performed at the combustion test stand of TFZ in Straubing. Figure 4 shows the applied test rig on which all measurements were performed.

The combustion appliances were placed on a scale in order to record the mass loss continuously during combustion. Flue gas temperature was measured with a suction pyrometer in accordance to DIN EN 13240 (and with an additional centrally placed thermocouple) it was combined with the gas sampling [1]. The flue gas tunnel for dust sampling was reduced to an effective inner diameter of 64 mm in order to increase the velocity for a reliable isokinetic PM sampling. Gas temperature and velocity near the total dust sampling were continuously recorded for volume flow calculations. The particle sampling was performed following the VDI-Guideline 2066 [2]. In deviation the sampling temperature at the sampling probe was raised from 160 °C to 180 °C. The filter pre- and post-treatment happened at 180 °C.

2.6 Testing method

The objective of this research was to evaluate the reduction potential on the “real life” emissions by using foam ceramic elements in log wood stoves. Therefore a “close to real life” test cycle consisting of 8 batches per replication (5 at full load and 3 at partial load) was used for the test runs. The partial load batches were executed by refilling half of the usual full load fuel mass and reducing the secondary air by approximately 20 %. Particle sampling was performed without interruption over the each whole batch, including the ignition process for the first batch. The gaseous emissions were also sampled over the whole cycle from ignition to the end of batch 8.

The test runs regarding the long-term behavior of the non-catalytic foam ceramic elements were executed on a natural draught chimney. But for the test runs regarding the comparison of non-catalytic and the catalytic foam ceramic elements as well as the “dummy”, a controlled draught chimney was used where pressure was kept constant at -12 Pa.

2.7 Evaluation of testing data

Each test run consists 3 full testing cycles (8 batches). From these measurement data one value, declared as full load, is calculated as time weighted average value of batch one to five. The other value, declared as partial load, is calculated as time weighted average value of batch one, two, six, seven and eight (Fig. 5). The partial load value should simulate a typically heating day in the transition time, when the heat output of the stove is to high respective the smooth ambient temperatures. The failure bars in the diagrams are showing the minimum and maximum of the three repetitions.
2.8 Pretesting

To test the flow behavior in the stove and through the foam ceramic elements, pretests were executed, they were inspired by tests performed by Aigenbauer et al. [3]. The stove was set under a constant negative pressure of 12 Pa, and the flow rate through the stove as well as the pressure drop over the foam ceramic was logged. Then the leakages were tightened up in 4 steps using air tight tape: Step 1 initial state, Step 2: foam ceramic masked (Fig. 6, left), Step 3: all leakages masked and Step 4: cutting the tape from the foam ceramic (Fig. 6, right).

![Figure 6: Pretesting of the flow behavior: Step 2 (left), Step 4 (right)](image)

3 RESULTS & DISCUSSION

3.1 Flow behavior through the stove and foam ceramic

The results from the pretesting (Tab. I) show that it is not ensured that the complete flue gas is streaming through the foam ceramic while the stove is operated. By comparing Step 2 and Step 4 it appears that the flow rate and pressure drop over the uncovered foam ceramic (Fig. 6, right) is nearly the same as for the foam ceramic masked with air tight tape (Fig. 6, left). Therefore it may be assumed that the flue gas is streaming in equal parts through the foam ceramic and the gaps among the ceramic facing of the stove.

<table>
<thead>
<tr>
<th>Step</th>
<th>Draught</th>
<th>Flow rate</th>
<th>Pressure drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Initial state</td>
<td>-11.8</td>
<td>35.4</td>
<td>3.2</td>
</tr>
<tr>
<td>2: Foam ceramic masked</td>
<td>-11.9</td>
<td>33.9</td>
<td>3.8</td>
</tr>
<tr>
<td>3: All leakages masked</td>
<td>-11.8</td>
<td>21.2</td>
<td>9.1</td>
</tr>
<tr>
<td>4: Only foam ceramic cut free</td>
<td>-12.0</td>
<td>33.9</td>
<td>3.9</td>
</tr>
</tbody>
</table>

3.2 Long-term behavior and emission reduction of non-catalytic foam ceramic elements

In comparison the gaseous emissions for the three foam ceramic filters used (Fig. 7 to 8) are slightly different but are showing no clear trend relating to the operating hours, neither for full load nor for partial load. The CO emissions are in average approx. 11 % and the OGC emissions approx. 13 % higher in partial load operation.

![Figure 7: Gaseous emissions using three differently aged foam ceramic filters for full load operation](image)

![Figure 8: Gaseous emissions using three differently aged foam ceramic filters for partial load operation](image)

![Figure 9: Particle emissions using three differently aged foam ceramic filters for full load operation](image)
Generally it can be stated that gaseous and particle emissions measured with the “close to real life” testing cycle are much higher than the type testing results given on the inspection plate. Thus, the use of a non-catalytic foam ceramic element can not secure that the strict emission thresholds for type testing will also be met in practical use in the field. This is true for both, particle and gaseous emissions, and it applies particularly when the stove is operated at partial load which happens during transition times or at mild winter temperatures, particularly when the stove power does not fit to the heat demand of the room.

3.3 Catalytic foam ceramic elements

The catalytic foam ceramic reduces the CO emissions (Fig. 11 to 12) by about 46 % at full load and by about 47 % in partial load operation, in average. The non-catalytic foam ceramic shows no mentionable reduction of CO emissions.

As expected, no significant reduction of the CH$_4$ emissions could be observed because methane behaves very stable at catalyst temperatures below 650 °C [4]. The same applies for the NO$_x$ emissions, for which the catalyst manufacturer had claimed some reduction potential. For the reduction of NO$_x$ from flue gas the SNCR and the SCR (both using urea or ammonia) seems to be the best secondary measure [5].
Total particle emissions (Fig. 15 to 16) were slightly reduced by 10% for full load and by 12% for partial load operation when using the catalytic foam ceramic elements, but the differences may partly also be attributed to measurement uncertainties. This is illustrated by the distinct min-max-bars given for "Filter" and "Dummy".

**Figure 15:** Comparison of the particle emissions for the foam ceramic filter, the catalyst and the dummy at full load operation

![Graph](image1)

**Figure 16:** Comparison of the particle emissions for the foam ceramic filter, the catalyst and the dummy at partial load

![Graph](image2)

The temperatures at the catalyst surface (Fig. 17) are on average 431°C for full load and 399°C at partial load. The average maximum temperature (after refilling) is 543°C and the average minimum temperature (ignition batch or end of batch) is 264°C at the catalyst surface. For CO conversion the “light off” temperature (temperature from where a conversion becomes visible) lies between 200°C and 350°C, depending on the mixture of noble metals, the flue gas composition and the age of the catalyst [6][7][8]. These temperatures could easily be reached and they could be sustained almost over the complete measuring cycle of the 8 batches. For methane the “light off” temperature lies between 500°C and 650°C [4][8]. In the test runs these high temperatures could only be observed during a very short time frame (for only few minutes after each refilling). The “light off” temperature of total organic carbon lies approx. between 300°C and 400°C [4]. But the conversion rate rises with the surface temperature from the “light off” until 800°C and then may be higher [4]. This means that at an average temperature of 431°C for full load and 399°C for partial load the catalyst is just becomes active for OGC-reducing, but the conversion may be optimized by realizing higher temperatures at the catalyst surface.

**Figure 17:** Minimum, maximum and average temperatures at full load and partial load measured at the surface of the catalytic foam ceramic element

![Graph](image3)

4 CONCLUSIONS

To apply non-catalytic foam ceramic elements in a log wood stove has no relevant potential for reducing gaseous and particle emissions. The aging of the foam ceramic does not matter anyway. But the reduction potential of foam ceramic elements (catalytic and non-catalytic) may be optimized by ensuring that the complete flue gas will flow through the foam ceramic and not through gaps in the ceramic lining of the furnace. Therefore further tests are now conducted where a tightening of the stove’s by-pass streams is achieved using high-temperature ceramic glue.

The catalytic foam ceramic element reduces CO emissions quite well because the temperatures in the combustion chamber are sufficient to allow high CO conversion rates. To increase the OGC- and perhaps also the CH₄-reduction higher temperatures at the catalyst surface are required. This can be achieved by optimizing the combustion chamber geometry and insulation or by choosing another position for the catalyst.

5 REFERENCES


397

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7 LOGO SPACE