PERFORMANCE OF CATALYTIC AND NON-CATALYTIC FOAM CERAMIC ELEMENTS IN LOG WOOD STOVES

Robert Mack, Hans Hartmann
Technology and Support Centre in the Centre of Excellence for Renewable Resources (TFZ),
Schulgasse 18, D-94315 Straubing, Germany
Phone: +49-9421-300154, Fax: +49-9421-300211
Email: Robert.Mack@tfz.bayern.de

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_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

1 INTRODUCTION

Log wood stoves are still representing the most common biomass heating appliance in Europe. Certainly, log wood stoves are causing the highest gaseous and particle emissions compared to automatic biomass heating appliances such as pellet boilers. To meet the new strict emission limitations not only at the test stands but also in practice, primary measures are usually not sufficient. Particulate matter (PM) emissions are not the only reason for regional combustion bans for log wood stoves. Many residents are more concerned about the gaseous emissions which cause bad smell, this is mainly due to organic gaseous carbon (OGC). To reduce the flue gas emission from log wood stoves, secondary measures like filters or catalysts can be alternative to electrostatic precipitators, since they can also reduce gaseous emissions such as carbon monoxide (CO) and OGC.

2 MATERIAL & METHODS

2.1 Non-catalytic foam ceramic elements

To verify if the operation time of foam ceramic filters in stoves has a significant influence on the emissions, three foam ceramic filters (Fig. 1) with a different amount of passed batches (0, 200 and 550) have been provided. The three filters are made of the same raw material and showing a porosity of 35 ppi.

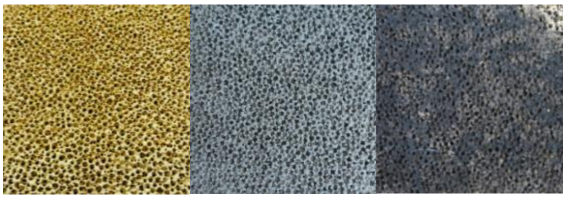

Figure 1: Foam ceramic filters applied: unused element (left), 200 batches (middle), 550 batches (right)

2.2 Catalytic foam ceramic element

The tested foam ceramic catalyst (Fig. 2) was provided by Linder Katalysatoren GmbH, Germany. The carrier material is a open porous (30 ppi) foam ceramic ($SiC – SIO_2 + 3C \rightarrow SiC + 2\ CO$ and Al_2O_3). The manufacturer declares the catalytic coating as a mixture of platinum, rhodium and palladium. The exact ratio of the catalytic components is kept secret.

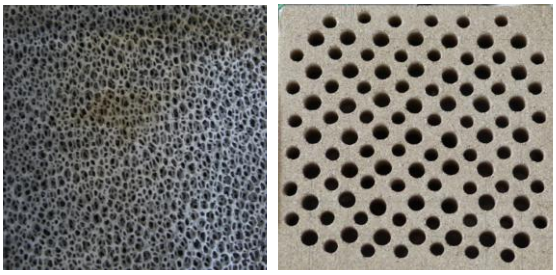

Figure 2: Catalytic foam ceramic (left), “Dummy”-element for achieving equal flow conditions (right)

2.3 “Dummy”-element resp. equivalent flow reduction

To compare the influence of a foam ceramic filter resp. a foam ceramic catalyst on the emissions a “dummy”-element (Fig. 2) causing a similar pressure drop was manufactured from a 30 mm vermiculite plate. Therefore, a test rig was built to determine the pressure drop over the foam ceramic elements and the vermiculite plate was then drilled with 8 mm and 10 mm holes until the pressure drop was equal to the foam ceramic elements (Fig. 3).

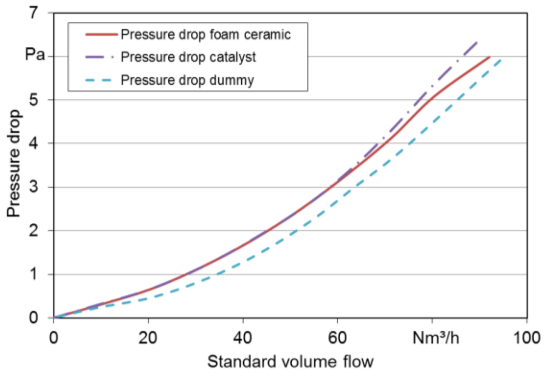

Figure 3: Validation of similar pressure drop achieved with all build-in components used

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.

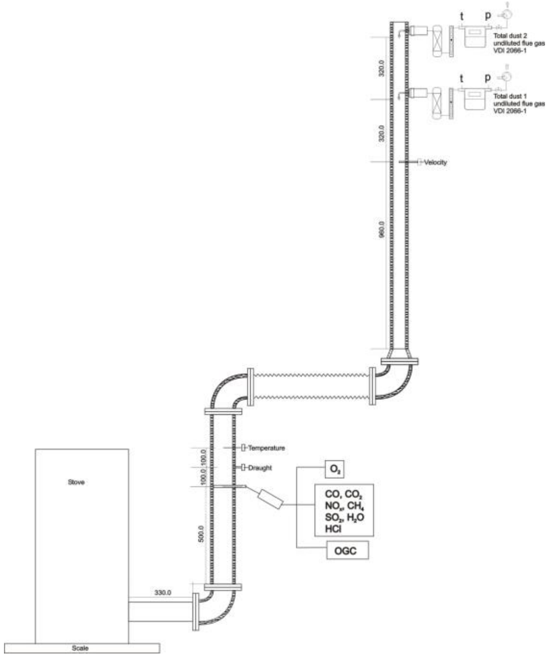

Figure 4: Test stand with flue gas tract for flue gas emission measurements

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 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.

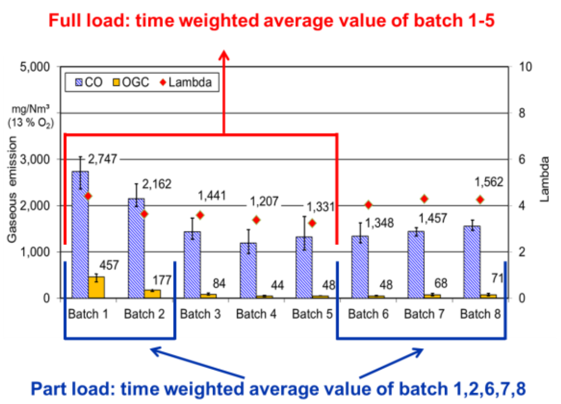

Figure 5: Evaluation scheme of the “close to real life” testing cycle

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)

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 I: Results from pretesting

Step	Draught	Flow rate	Pressure drop
	Pa	Nm³/h	Pa
1: Initial state	-11.8	35.4	3.2
2: Foam ceramic masked	**-11.9**	**33.9**	**3.8**
3: All leakages masked	-11.8	21.2	9.1
4: Only foam ceramic cut free	**-12.0**	**33.9**	**3.9**

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.

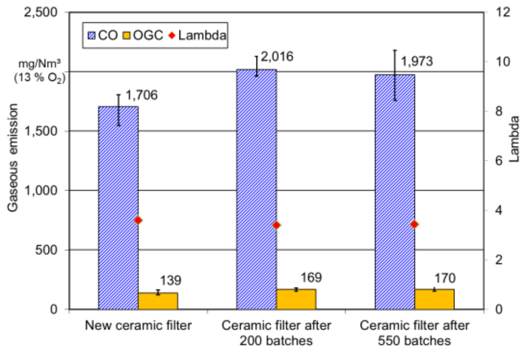

Figure 7: Gaseous emissions using three differently aged foam ceramic filters for full load operation

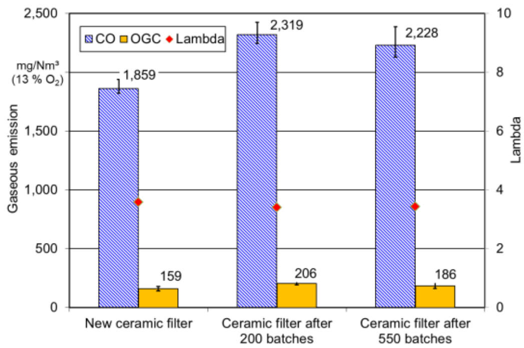

Figure 8: Gaseous emissions using three differently aged foam ceramic filters for partial load operation

The particle emissions (Fig. 9 to 10) are slightly different but are showing no clear trend relating the operating hours just as for the gaseous emissions. The particle emissions are in average approx. 6 % higher in partial load operation.

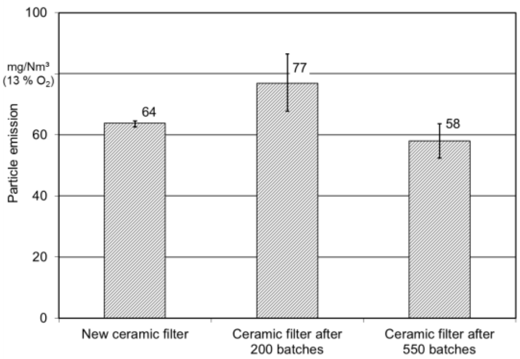

Figure 9: Particle emissions using three differently aged foam ceramic filters for full load operation

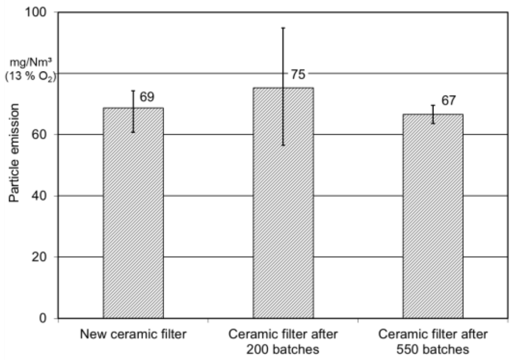

Figure 10: Particle emissions using three differently aged foam ceramic filters for partial load operation

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.

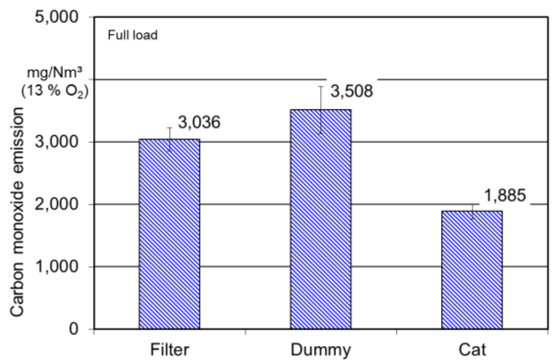

Figure 11: Comparison of the CO emissions for the foam ceramic filter, the catalyst and the dummy at full load operation

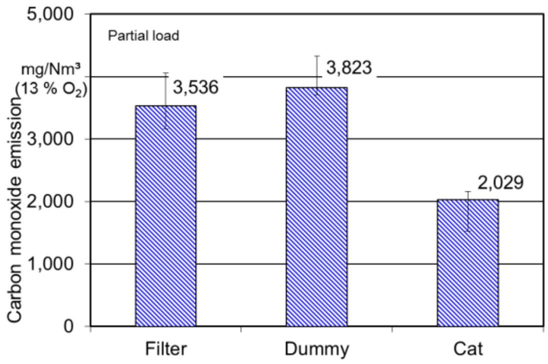

Figure 12: Comparison of the CO emissions for the foam ceramic filter, the catalyst and the dummy at partial load operation

When using the catalytic foam ceramic the non-methane OGC (FID signal minus CH_4 from FTIR) emissions are reduced by 21 % at full load and by 23 % at partial load (Fig. 13 to 14). The non-catalytic foam ceramic filter shows no significant reduction of non-methane OGC emissions.

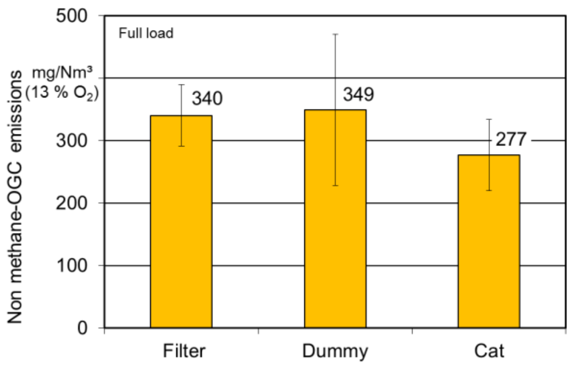

Figure 13: Comparison of the non-methane OGC emissions for the foam ceramic filter, the catalyst and the dummy at full load

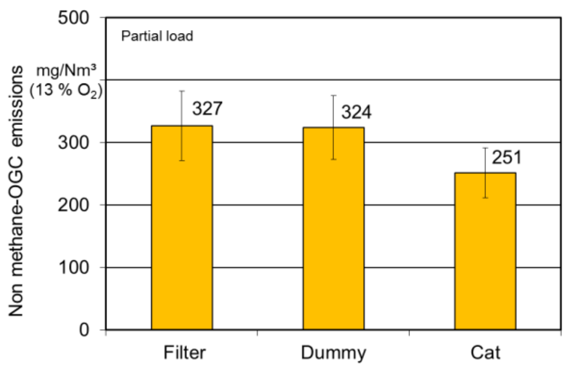

Figure 14: Comparison of the non-methane OGC emissions for the foam ceramic filter, the catalyst and the dummy at partial load operation

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".

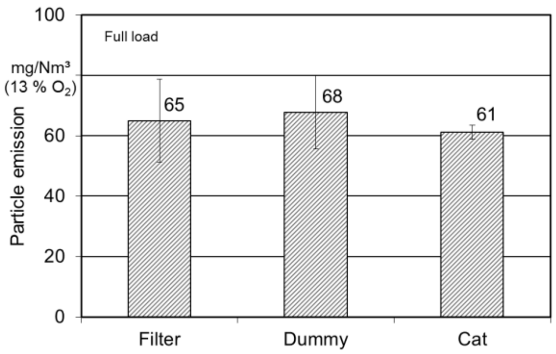

Figure 15: Comparison of the particle emissions for the foam ceramic filter, the catalyst and the dummy at full load operation

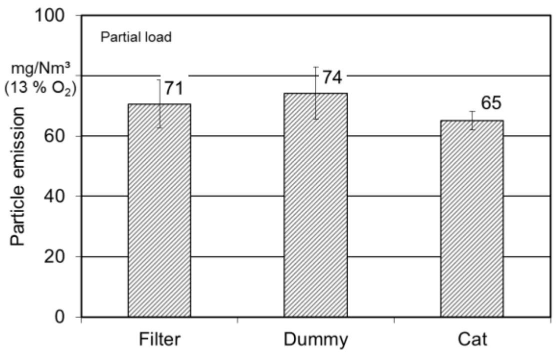

Figure 16: Comparison of the particle emissions for the foam ceramic filter, the catalyst and the dummy at partial load

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.

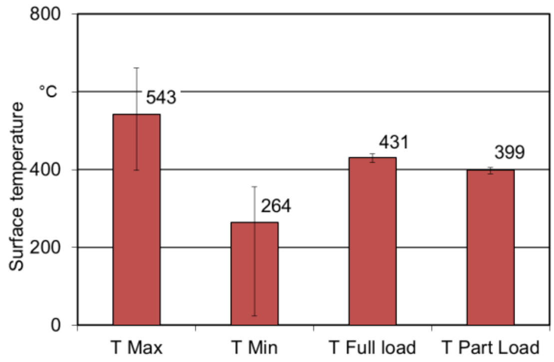

Figure 17: Minimum, maximum and average temperatures at full load and partial load measured at the surface of the catalytic foam ceramic element

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 conversation rates. To increase the OGC- and perhaps also the CH_4-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

[1] DIN EN 13 240 (2005): Roomheaters fired by solid fuel – Requirements and test methods.
[2] VDI 2066, Part 1 (2006): Particulate matter measurement, Dust measurement in flowing gases – Gravimetric determination of dust load. Verein Deutscher Ingenieure (VDI), Beuth Verlag, Berlin 2006.
[3] Stefan Aigenbauer et al. Endbericht Neue Öfen 2020, (2011), pag.63
[4] Johanna Carnö et al., Catalytic abatement of emissions from small-scale combustion of wood, Fuel Vol 75 No. 8, (1996), pag.964
[5] Thomas Nussbaumer, Combustion and Co-combustion of Biomass: Fundamentals, Technologies, and Primary Measures for Emission Reduction, Energy & Fuels Vol. 17 No. 8 (2003) pag.1514
[6] Johanna Carnö et al., Mixed manganese oxide/platinum catalysts for total oxidation of model gas from wood boilers, Applied Catalysis A: General 155, (1997), pag.265-281
[7] Magali Ferrandon et al., Deactivation in a wood-stove of catalysts for total oxidation, Catalyst Deactivation 1st Edition (1999), pag.423-426

[8] Magali Ferrandon et al., Thermal stability of metal supported catalysts for reduction of cold-start emissions in a wood-fired domestic boiler, Catalysis Today Vol. 53 (1999), pag.647–659

6 ACKNOWLEDGMENTS

- This research was funded by Federal Ministry of Agriculture by decision of the German Bundestag with the Fachagentur Nachwachsende Rohstoffe e. V. (FNR) as project executing organization.

- We thank our colleagues Benedikt Haas and Elisabeth Rist for their support during this study.

7 LOGO SPACE

Gefördert durch:

Bundesministerium
für Ernährung
und Landwirtschaft

aufgrund eines Beschlusses
des Deutschen Bundestages

Technologie- und Förderzentrum
im Kompetenzzentrum
für Nachwachsende Rohstoffe

www.tfz.bayern.de