MEASUREMENT STATEGIES INFLUENCING THE RESULTS OF TOTAL PARTICLE EMISSION FROM BIOMASS COMBUSTION

Claudia Schön, Hans Hartmann, Peter Turowski
Technology and Support Centre in the Centre of Excellence for Renewable Resources (TFZ),
Schulgasse 18, D-94315 Straubing, Germany
Phone: +49-9421-300112, Fax: +49-9421-300211
Email: Claudia.Schoen@tfz.bayern.de

ABSTRACT: Particle emissions from small scale wood combustion are usually measured in the hot flue gas. In order to create conditions which are closer to the situation at the chimney top, the flue gas is sometimes diluted. This, however, causes a considerable increase in measured particle emission due to partial condensation of organic gaseous compounds (OGC). In this investigation 357 parallel PM measurements in the undiluted and diluted flue gas were performed, reflecting flue gases from eight different wood furnaces. In average a percentage of 47 % of the OGC-emission is methane, which cannot condense after flue gas cooling. But about 24 % of the OGC can condense and lead to an increase of measured particle emission if it is determined in the diluted flue gas. In addition, the thermal treatment of the filter media after PM sampling is also crucial. Particle mass losses of up to 50 % are determined if the sample, which was taken from diluted flue gas at about 50 °C, is thermally treated at 120 °C instead of lower drying temperature or using a desiccator. Furthermore, the need of combining filter cartridges with subsequent plane filters is demonstrated by the results. They also show that for high pollution levels a need to also rinse the flue gas sampling tract to collect any deposited particles is given. This is particularly true if sampling is performed from undiluted flue gases and at high OGC concentrations.
Keywords: solid biofuel combustion, chimney stove, log wood boiler, PM emission, filter media treatment

1 INTRODUCTION AND OBJECTIVES

In log wood stove and boiler operation the user behaviour and fuel properties but also the technology itself are largely responsible for a great deal of pollutant emissions. But apart from such influences, also the accurate determination of particle and gaseous emissions has an impact on the results. Flue gas emission determination is a difficult task, particularly if the results shall reflect the "true" conditions at the chimney outlet, as it is sometimes required. Many method and setup-based influences on the results can be seen, among them the flue gas sampling temperature and the sample treatment temperatures as well as any dilution steps with ambient air are the major influencing factors.

It was therefore the objective to evaluate such influences systematically in order to provide input for further harmonisation of methods and to be able to interpret deviations of results from different measuring condition.

2 MATERIAL AND METHODS

2.1 Appliances used

For the combustion trials eight different biomass applications were used to ensure variable flue gas conditions and compositions: five different chimney stoves (plant 1 to plant 5), two tiled stove inserts (plant 6 and plant 7) and one log wood boiler (plant 8) were applied. The nominal heat output of the chimney stoves varied between 6 and 8 kW, for the tiled stove inserts the nominal heat power output ranged between 7 and 10 kW and the log wood boiler had a nominal heat output of 25 kW. All appliances were fired with different fuel types of different shapes, varying log size, moisture contents as well as different loads per batch in order to investigate the emission behaviour influenced by the user as well as by the selected fuel quality. A brief summary of the dependencies can be found in [1] and [2]. Tab. I gives an overview of the appliances with average temperatures in undiluted as well as diluted flue gas and the applied dilution ratios. Most of the combustion trials were performed using plant 1 (chimney stove). In total 357 parallel measurements were evaluated.

Table I: Comparison of average temperatures in the undiluted and diluted flue gas as well as dilution ratio for all eight combustion appliances. The measuring range is given in brackets.

Furnace	Number of values -	Temperature undiluted flue gas °C	Temperature diluted flue gas °C	Dilution ratio -
Plant 1	135	190 (124-265)	43 (37-54)	4.5 (2.2-8.0)
Plant 2	30	232 (174-314)	45 (38-51)	6.2 (2.6-12.6)
Plant 3	6	203 (170-229)	45 (41-48)	4.7 (3.4-5.1)
Plant 4	9	237 (175-267)	48 (42-55)	5.0 (3.5-6.2)
Plant 5	43	251 (115-338)	52 (37-66)	6.0 (3.7-10.7)
Plant 6	42	110 (83-139)	41 (36-48)	1.7 (1.2-2.0)
Plant 7	48	258 (185-311)	64 (50-81)	5.5 (4.2-6.7)
Plant 8	44	139 (124-167)	46 (41-53)	4.4 (3.5-4.9)

2.2 Combustion test facility

All measurements were performed at the combustion test stand of TFZ in Straubing. Fig. 1 shows the applied test rig with flue gas and full flow dilution tunnel on which all measurements were performed.

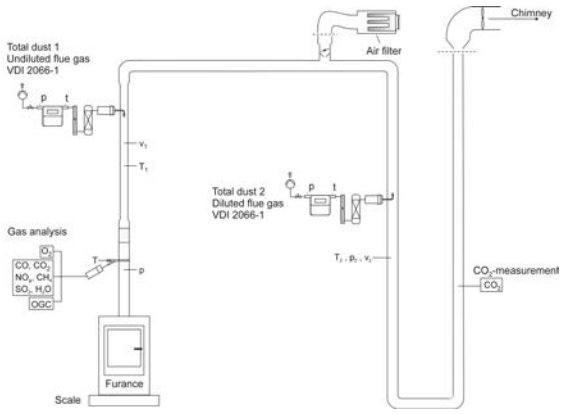

Figure 1: Test stand with flue gas tract and full flow dilution tunnel for flue gas emission measurements

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, it was combined with the gas sampling [3]. The flue gas tunnel for dust sampling was reduced to an effective inner diameter between 64 and 80 mm in order to increase the velocity for a reliable isokinetic PM sampling. Gas temperature and velocity near the undiluted total dust sampling were continuously recorded for volume flow calculations. Downstream of the dust sampling the inner diameter was widened to 150 mm again before the flue gas was diluted with filtered air. In the dilution tunnel having a diameter of 150 mm the second total dust sampling was performed in parallel, following the VDI-Guideline 2066 [4]. The temperature in the dilution tunnel was almost consistently kept below 52 °C throughout all tests. CO_2 was determined in the diluted flue gas for the calculation of the dilution ratio. Therefore, a proper calibration of the CO_2 analysers was essential and it was done depending on the expected CO_2 concentration.

2.3 Procedure of performing combustion trials

All chimney stoves as well as both tiled stove inserts were heated up using one or two initial batches. Then the actual combustion tests were performed. For each batch the measurement started right after loading as soon as the door was closed. The measurement of a batch was then usually terminated when only 4 wt.-% of the original mass of the fuel was reached; this was measured by the online recordings from the scale on which the furnace was placed. The log wood boiler was also heated up before one-hour measurements were conducted.

The determination of particulate matter was made discontinuously by sampling according to the VDI-Guideline 2066 [4] (method with filtering head device and method with plane filter). In this method the dust load of a partial flue gas stream is retained in a dust collection system. For retention a stuffed quartz wool cartridge with a subsequent quartz fibre plane filter (retention 99.998 % according to DOP (0.3 µm), diameter 45 mm) was used. Both media were combined in an out-stack filter head device (see Fig. 1). The sampling system outside of the flue gas tract was heated in order to avoid any additional condensation. Behind the filter the sampled gas was conveyed into a gas drying unit and the volume flow was determined. Dust was determined gravimetrically after thermal treatment at 120°C for one hour and conditioning in a desiccator for at least 12 hours. The unloaded and loaded filters were then weighed on a precision balance (Mettler Toledo XP 56, maximum load 56 g, resolution: 1 µg). Apart from the dust collected on the plane filter and the stuffed quartz wool cartridge, the particle deposition in the sampling tract was also accounted for in most cases (plant 1-4, 6 and 8). This was done by washing the sampling tract with desalinated water and with acetone (two to three times). There was no possibility to consider the particle deposition in the flue gas tunnel itself.

For 357 trials considered in this investigation parallel measurements in the undiluted as well as in the diluted flue gas were conducted. In all cases, the flue gas composition in the undiluted flue gas tract was analysed using FTIR, FID (at 180 °C) as well as single component analysers, e. g. for oxygen. All concentration data shown here refer to 13 vol.-% O_2.

3 RESULTS

In the following chapter different correlations and influencing parameters mainly on particle emission will be discussed.

3.1 Influence of flue gas dilution on particle emission

For the investigation of the effect of full stream dilution on particle emission 357 parallel measurements in the undiluted and diluted flue gas were evaluated. Due to the cooling of the hot flue gases also condensable fractions of particles can be accounted for in a dilution tunnel. Depending on the combustion appliance different dilution ratios were necessary in order to achieve temperatures usually below 50 °C in the dilution tunnel (except for plant 5 and 7 from earlier investigations, Table I). The temperature range in the undiluted and diluted flue gas is also given in Table I. As it can be seen an average dilution ratio of 4.5 to 6.2 was necessary for all chimney stoves, while only an average dilution ratio of 1.7 was necessary for one of the tiled stove inserts due to the high temperature decrease in the connected heating box. In average a temperature of 48 °C was applied for particle measurement in the diluted flue gas.

A clear increase in particle emission is evident if the collected PM emission in the diluted flue gas is compared to the measurements in the undiluted (hot) flue gas. The increase of particle emission over OGC is shown in Fig. 2. There is an increase in particle emission of about 24 % if the flue gas is diluted to temperatures below 50 °C with a correlation coefficient of 0.89. However, at OGC concentrations below 500 mg/Nm³ no clear correlation regarding the increase in particle emission is observed, Fig 3.

It has to be pointed out that the particle increase as it was measured here, is systematically underestimated since all filter media was thermally treated at 120 °C after particle sampling, and this has caused mass losses due to evaporation of easy volatile organic particulate matter collected in the diluted flue gas. These mass losses by thermal filter treatment are analysed and discussed in chapter 3.3.

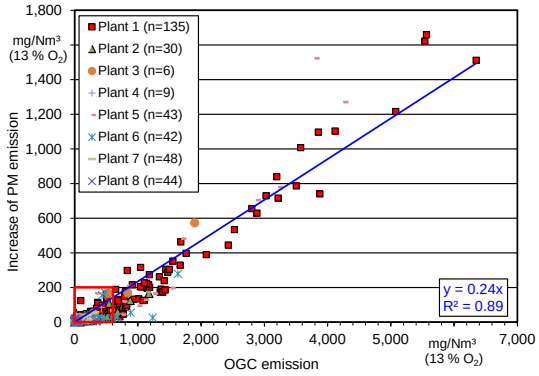

Figure 2: Increase of PM emission over OGC emission for 357 data sets using 8 different combustion appliances

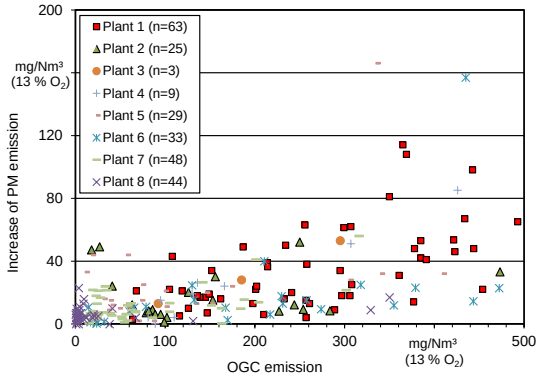

Figure 3: Increase of PM emissions over OGC emission for 254 data sets using 8 different combustion appliances with OGC concentrations below 500 mg/Nm³

Not all components of OGC can condense during the dilution step. This applies for methane. Therefore the methane concentration as detected by the use of an FTIR gas analyser was subtracted from the OGC concentration so that only the remaining 53 % of the OGC has the potential to contribute to the increase in particle emission, see Fig. 4.

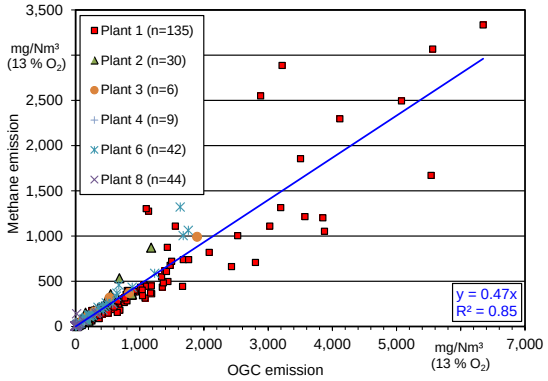

Figure 4: Methane fraction of the determined OGC emission for 266 data sets using six different combustion appliances

3.2 Particle fractions collected in stuffed cartridge, plane filter and rinsing liquid

For all presented values of particle emissions a combination of stuffed quartz wool cartridge and quartz plane filter was used. The rinsing of the sampling line was only considered for combustion trials performed on plant 1 to 4, 6 and 8. Fig. 5 and Fig. 6 show the distribution of PM emission determined in the undiluted flue gas tunnel depending on OGC emission and PM emission, respectively. It can clearly be seen that the use of a plane filter behind the stuffed quartz wool cartridge is essential since the particle fraction on the filter varies between 0 and 50 %. Also the rinsing of the sampling line is of great importance especially at high OGC concentrations in the undiluted flue gas (e. g. above 2,000 mg/Nm³), where it can account for 10 to more than 30 % of the total PM).

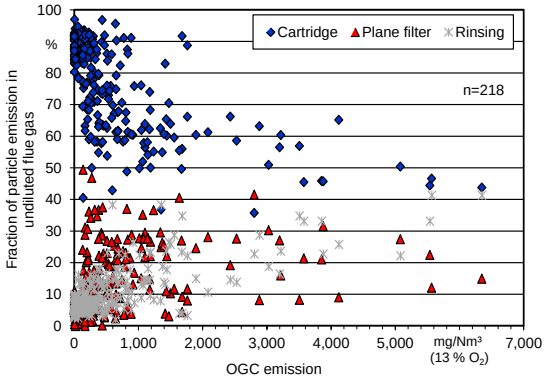

Figure 5: Fraction of particle emissions determined in the undiluted flue gas depending on OGC emission

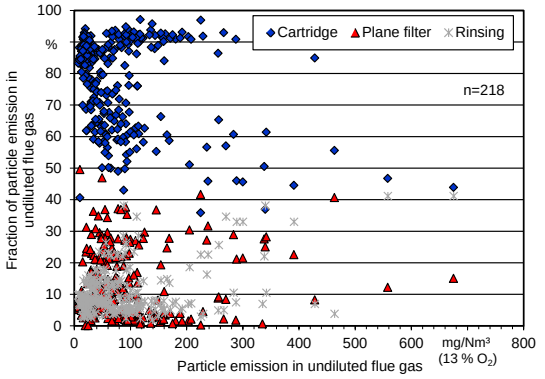

Figure 6: Fraction of particle emissions determined in the undiluted flue gas depending on PM emission

Similar partitioning of the particles in the diluted flue gas is presented in Fig. 7. In contrast to the measurements in the undiluted flue gas the rinsing fraction was lower or usually below 5 % at OGC concentrations above 1,000 mg/Nm³. This can be explained by the fact that most of the condensable particles do not deposit in the sampling line anymore.

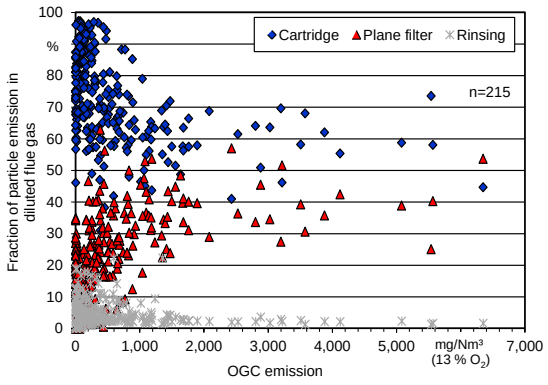

Figure 7: Fraction of particle emissions determined in the diluted flue gas depending on OGC emission

3.3 Influence of thermal treatment of filter media after particle sampling

For the results presented in the previous chapters all filter media had been thermally pre- and after-treated at 120 °C for one hour before they were stored in a desiccator for at least 12 hours. Since most of the here collected particle mass contains organic carbon and other volatile components the sample treatment after the dust collection was identified as a crucial step and its influence was therefore also assessed.

As a first step the influence of the drying temperature on the particle emission was studied using two large quartz plane filters with a diameter of 150 mm in the dilution tunnel. The temperature of after-treatment of the filter media varied between room temperature and 120 °C. A filter case made of PTFE (Fig. 8) for the use of large plane filters was used allowing particle sampling without stuffed cartridge for complete combustion cycles in order to achieve an even dust distribution on the filter media.

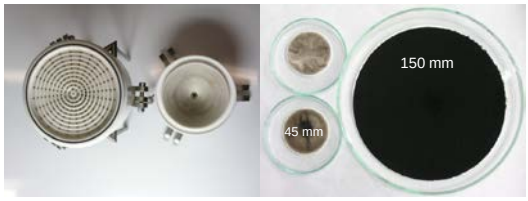

Figure 8: Filter case for plane filters having a diameter of 150 mm, made of PTFE, developed by TFZ

For this investigation a chimney stove was fired with beech wood leading to rather high emissions of 4,230 mg/Nm³ of CO and 1,063 mg/Nm³ of OGC in average for the entire combustion batch. The sampling temperature in the dilution tunnel was 44 °C with an average dilution ration of 5.2 while particle sampling was carried out twice using two large filters in parallel. After sampling the large quartz fibre filter was folded in the middle and six pieces of the same size were punched out of the filter before all filter pieces were weighed immediately after sampling. Then each piece was thermally treated at different temperatures for one hour and conditioned in a desiccator for at least 12 hours before weighing (Fig. 9).

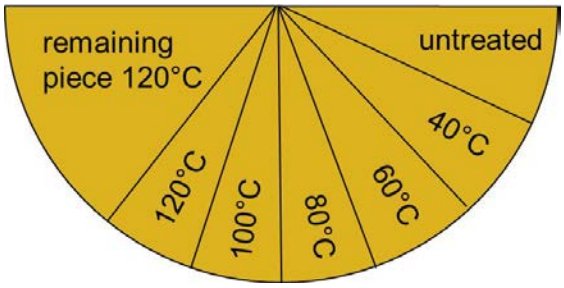

Figure 9: Pieces of the large quartz plane filter with a diameter of 150 mm for the investigation of the selected temperatures for drying the filter media after sampling

The absolute particle mass of each filter piece just after particle sampling (without any further treatment) is shown in Fig. 10 in the orange bars. It becomes obvious that the particle mass on the filter pieces considerably decreases with increasing temperature (Fig. 10, see grey striped bars). For both filter pieces treated at 120 °C a mass loss of 50 % was determined. Also at 100 °C a particle mass loss of about 30 % was recognized; which can be partly explained by water evaporation. Assuming, that all water is evaporated at 100 °C an increased loss as high as 50 % at 120 °C cannot be caused by further water evaporation compared to the value at 100 °C; in this case also other organic compounds must have become volatile. From this simple comparison it can therefore be concluded that the particle emission determined from the diluted flue gas (see chapters 3.1 and 3.2) were mostly underestimated and that the filter treatment temperatures are crucial information which should always be stated. Therefore, it can be recommended that PM samples collected in the diluted flue gas should only be stored in a desiccator before weight determination.

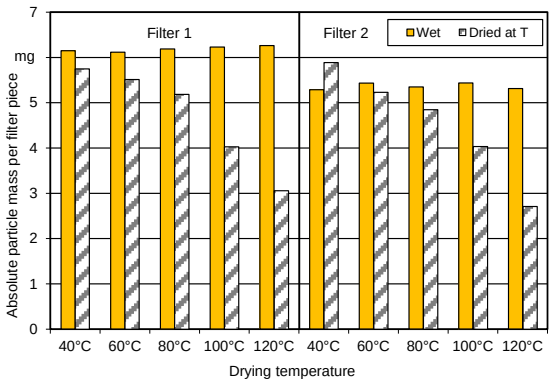

Figure 10: Changes in particle mass per filter piece depending on the selected drying temperature of the filter piece. Both particle samplings were done in the diluted flue gas at 44 °C

For an extended evaluation of the influence on thermal treatment at 120 °C of the filter media additional combustion trials were conducted using the same chimney stove. Nine parallel measurements in the undiluted and diluted flue gas using the combination of stuffed quartz wool cartridges with quartz plane filter were performed. An additional particle measurement was included in the diluted flue gas using the large plane filter with 150 mm in diameter without any stuffed quartz wool cartridge. All filter media were weighted right after the

particle measurement in wet conditions (values on y-axis in Fig. 11). After that all filter media were stored in a desiccator for more than 72 hours before second weighing in dry condition. Finally all filter media were thermally treated at 120 °C for one hour and stored in a desiccator for at least 12 hours, before being weighed a third time.

The treatment of the loaded filter media used in the undiluted flue gas shows negligible influences as indicated by the red dots in Fig. 11 and Fig. 12. No difference between weighing the filter media immediately after particle sampling and storage in a desiccator was determined, Fig. 11**,** while thermal treatment at 120 °C caused a mass loss of only 10 % for the samples from the undiluted flue gas, Fig. 12. The filtration temperature and the flue gas temperature in the hot flue gas were at about 170 °C, thus being well above the temperature during thermal filter treatment. Therefore, the low losses of particle mass are within expectations.

In contrast to that the post treatment of the filter media used in the diluted flue gas at 45 °C is crucial regarding particle emission. A decrease by the factor of about 1.9 was shown for the combination of stuffed quartz wool cartridge and plane filter after thermal treatment at 120 °C, see green line in Fig. 12. An even higher mass loss was observed if only the large 150 mm quartz plane filter was used resulting in a mass loss by the factor of 2.6, Fig. 12.

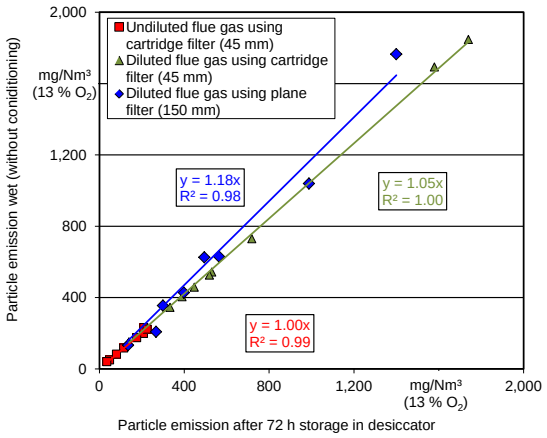

Figure 11: Influence of filter media treatment on particle emissions after sampling in undiluted and diluted flue gas using plant 1 (chimney stove) compared to storage in desiccator

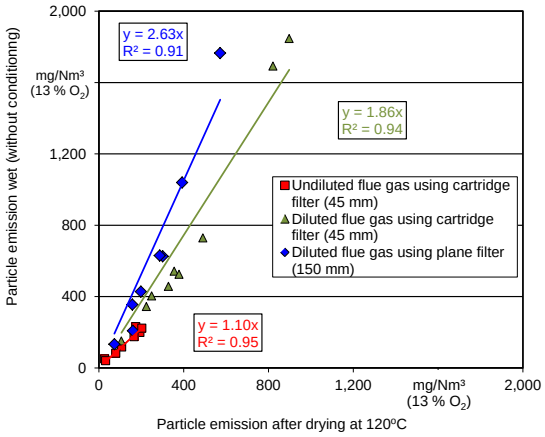

Figure 12: Influence of filter media treatment on particle emissions after sampling in undiluted and diluted flue gas using plant 1 (chimney stove) compared to dried filter

Therefore it should always be stated what kind of filter media was used. Also the sampling conditions (i. e. temperatures and dilution) and the treatment procedure after particle sampling need to be described to allow comparison with other results.

4 CONCLUSIONS

Different measurement strategies and their influence on the results on PM emission were investigated and discussed. It became obvious that the results on particle emissions are clearly higher if full flow dilution is performed before sampling. This is due to the transformation of gaseous components into particles, thus an average increase of about 24 % in particle mass was detected. Moreover, plane filters should always be added to the sampling line if stuffed cartridges are required for sampling at higher dust concentrations. The rinsing of the sampling line may contribute of up to 40 % at poor combustion conditions if the sampling is done in undiluted flue gas. In addition, the treatment of filter media after particle collection is crucial and should always be stated in reports. This makes it impossible to compare results from different researchers if no common measurement procedure for PM emission was agreed upon. Therefore, it can be recommended that PM samples collected in the diluted flue gas should only be stored in a desiccator before weight determination.

5 REFERENCES

[1] C. Schön, H. Hartmann, (2012): Log wood combustion – Emissions and efficiency, In: J. Schmid, H.-P. Grimm, P. Helm; A. Grassi (eds.): 20th European Biomass Conference & Exhibition - from Research to Industry and Markets. Proceedings of the International Conference held in Milano, Italy; ETA-Florence Renewable Energies Florence, Italy, pp 1293-1298.

[2] C. Schön, H. Hartmann (2012): Combustion of wood briquettes in stoves. In: J. Schmid, H.-P. Grimm, P. Helm; A. Grassi (eds.): 20th European Biomass Conference & Exhibition - from Research to Industry and Markets. Proceedings of the International

Conference held in Milano, Italy; ETA-Florence Renewable Energies Florence, Italy, pp 1286-1292.
[3] DIN EN 13 240 (2005): Roomheaters fired by solid fuel – Requirements and test methods.
[4] 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.

6 ACKNOWLEDGEMENT

The research was funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Fachagentur Nachwachsende Rohstoffe (FNR).

7 LOGO SPACE

Technologie- und Förderzentrum
im Kompetenzzentrum für Nachwachsende Rohstoffe
TFZ

www.tfz.bayern.de