LOG WOOD COMBUSTION IN STOVES – INFLUENCE ON EMISSIONS AND EFFICIENCY

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ABSTRACT: Variable wood log sizes and different fuel masses loaded per fuel batch were applied in three different residential stoves in order to evaluate user behaviour influences on operation, which are believed to be largely responsible for a great deal of pollutant emissions and efficiency variation. Pollutant emissions carbon monoxide(CO-) and organic gaseous carbon (OGC)-emissions as well as total particulate matter were determined from both undiluted and diluted flue gas which were released from two chimney stoves and one tiled stove insert. The results show, that too small logs (here wood pieces of 5 x 5 cm cross section) should not be used for the normal operation of a stove as CO and OGC emissions were about two to three times higher than for medium log sizes (i.e. 7 x 7 cm). In the same order these pollutant emissions increased when only one single log was charged per batch (low load operation). But stove overloading should also be avoided, here also the particle emissions increased by the order of two to three. Thermal efficiency is also greatly influenced by the loaded fuel mass with the low load (one single log) causing a decline of about 10 percentage points compared to the designated fuel mass per batch in both tested chimney stoves.
Keywords: chimney stove, tiled stove insert, log size, fuel amount loaded, emission, thermal efficiency

1 INTRODUCTION AND OBJECTIVES

In log wood stove operation the user behaviour is believed to be largely responsible for a great deal of pollutant emissions and efficiency variation. Such user influences are for example the loaded fuel mass, log size, time of reloading, fuel type differences and variable fuel moisture contents. But these impacts have so far only rarely been investigated systematically. The aim of this research was therefore to evaluate several of the mentioned operational practices. Here, the focus was set on the log size and the loaded fuel mass per batch. Several of the other mentioned influences had previously been investigated and separately reported (e.g. fuel moisture impacts see [1], briquette type and wood species impacts see [2]).

The research goal was to choose typical stoves representing the state of the art in Germany and to apply practise related testing procedures for highly reproducible results. The findings are to be used to derive recommendations for stove operation guidelines.

2 MATERIAL AND METHODS

2.1 Wood stove appliances used

For the trials two different chimney stoves (i. e. light stove with usually large window) as well as a tiled stove insert were chosen, Figure 1.

Figure 1: Applied wood stoves (left: chimney stove 1, middle: chimney stove 2, right: tiled stove insert)

Chimney stove 1 was a Buderus blueline No. 12 with a nominal heat power output of 8 kW and a combustion chamber of 37 litres. Chimney stove 2 was a Fireplace Santa Fe with a lower nominal heat power output of 6 kW and a combustion chamber of 25 litres; it represents the low-cost segment. The third furnace was a tiled stove insert Brunner KKE 33 with a nominal heat power output of 8 kW and a combustion chamber of 35 litres. Both chimney stoves were equipped with a grate, while the tiled stove insert had no grate. Chimney stove 2 was equipped with additional secondary air inlets from the backside of the combustion chamber.

2.2 Combustion test facility

All measurements were performed at the combustion test stand of the TFZ in Straubing. Figure 2 shows the applied test rig with flue gas and dilution tunnel on which all measurements were performed.

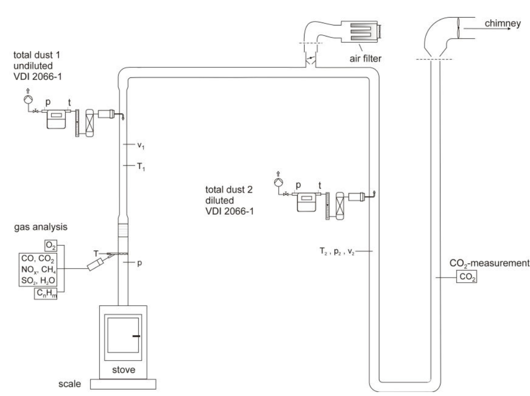

Figure 2: Test stand with flue gas tract and dilution tunnel for flue gas emission measurements

The stoves were placed on a scale in order to record the mass loss during combustion. Flue gas temperature was measured with a suction pyrometer in accordance to DIN EN 13240, it was combined with the gas sampling

[1]. The flue gas tunnel for dust sampling was reduced to an effective inner diameter of 64.4 mm in order to increase the velocity for a reliable isokinetic dust 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 consistently kept below 50 °C throughout all tests. CO_2 was determined in the diluted flue gas for the calculation of the dilution ratio.

2.3 Procedure of performing combustion trials

The stoves were heated up over one or two initial batches using beech wood without bark. Then always three combustion batches were performed. For each batch the measuring started right after loading when the door was closed. The measurement of a batch was terminated when only 4 wt.-% of the original mass of the fuel was reached.

The determination of total dust 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 Figure 2). 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 and conditioning in a desiccator. 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. This was done by washing the sampling tract with desalinated water (two to three times) and with acetone and desalinated water again.

For all three batches the undiluted flue gas was always analysed for gaseous compounds and for total dust. In the diluted flue gas dust was only determined for the first and third batch.

3 FUELS USED

3.1 Fuel type and fuel properties

For the combustion trials beech wood without bark was used. The fuel originated from the same location so that high variability of chemical composition can be excluded. Beech wood was applied in the shape of the test fuels in accordance to the Norwegian test standard for wood heaters (NS 3058-1 [5]), see Figure 3. The test fuel logs usually had a cross section of 7 x 7 cm.

Figure 3: Beech wood logs without bark in test fuel shape

Beech wood without bark contains only a relatively small amount of ash (here: 0.65 wt.-%). The main elements of this fuel are summarized in Table 1. The total concentration of all aerosol forming elements (S, Cl, K, Na, Zn and Pb) is 1,654 mg/kg (dry basis).

Table 1: Main components, other relevant elements, aerosol forming elements and net calorific value for beech wood without bark

Parameter	C	H	O	N	Ash	Net calorific value
	wt.-% (dry basis)					kJ/kg
beech without bark	50.0	6.4	42.9	0.13	0.65	17,963
Parameter	Ca	Mg	Si	Cd	Cr	Cu
	mg/kg					
beech without bark	955	408	1,580	0.2	3.6	2.7
Parameter	S	Cl	K	Na	Zn	Pb
	mg/kg					
beech without bark	60	40	1,530	18	3.9	1.8

3.2 Log size

Three different log sizes in the test fuel shape were used. The cross section varied between 5 x 5 cm, 7 x 7 cm and 9 x 9 cm. The mass per batch was kept constant depending on the furnace nominal fuel load requirement. This was achieved by adjusting the length of the logs as well as the number of logs per batch. The different sizes are shown in Figure 4.

Figure 4: Beech wood with different log sizes in cuboid “test-fuel” shape at a constant mass

3.3 Fuel mass loaded per batch

For the impact analysis of the fuel load per batch three different masses were selected for combustion in all three stoves, Figure 5. The low load was realized using one single log per batch while the nominal load was based on the maximum fuel mass recommended by the manufacturer, it was achieved by using three logs. An overloading of the stove was achieved by charging five logs in one batch. The cross section of the logs was kept constant at 7 x 7 cm with a length of 25 cm. The lower charging mass per batch was chosen at 30 % of the nominal fuel load and the stove overloading was achieved by using a fuel mass of 160 %.

Figure 5: Beech wood without bark using different fuel masses per batch.

4 RESULTS OF COMBUSTION TRIALS

4.1 Influence of log size

The use of different log sizes (as described in chapter 3.2) leads to varying emission from all three stoves. The smallest logs with a cross section of 5 x 5cm cause an intensive combustion during the initial phase of the batch with rapid release of volatiles followed by short residence time of the flue gases in the hot combustion chamber. This causes high CO emission which range between 3,864 mg/Nm³ (at 13 % O_2) for chimney stove 2 and 5,026 mg/Nm³ for chimney stove 1, Figure 6. The lowest CO concentration for chimney stove 1 was achieved when using the medium size logs (7 x 7 cm), whereas for chimney stove 2 and the tiled stove insert the lowest CO emissions could be measured using the largest logs. In all cases at least two logs per batch had been used and the mass per batch was kept constant at nominal level using about 1.6 kg of beech wood (in chimney stove 2) or 2.5 kg (in the other two stoves), according to the manufacturers requirements.

Unexpectedly the CO emissions from chimney stove 1 are higher than from the low-cost chimney stove 2. The improved performance can probably be attributed to the additional secondary air inlet at the backside of the firebox in chimney stove 2.

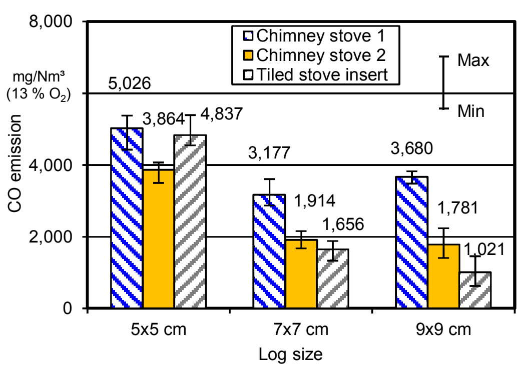

Figure 6: Influence of log size on CO emission using beech wood in the shape of the test fuel with varying edge lengths in three stoves but applying uniform fuel masses

A similar log size impact pattern is observed for the organic gaseous carbon (OGC) emission, Figure 7. The highest OGC emission is achieved with the smallest log size. Between the two chimney stoves quite significant differences occur, as the low cost stove (2) performs much better. Thus, the purchase price can obviously not serve as a suitable estimate for gaseous emission prevention. The best performance concerning OGC is given for the tiled stove insert, but this stove is sensitive towards the use of too small wood pieces, too.

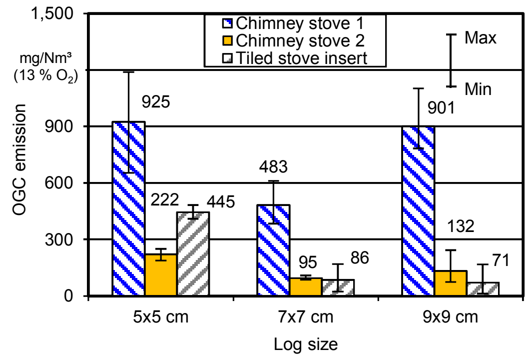

Figure 7: Influence of log size on OGC emission using beech wood in the shape of the test fuel with varying edge lengths in three stoves but applying uniform fuel masses

For particle emissions the same tendencies regarding fuel size selection are observed for both sampling modes, undiluted and diluted flue gas, Figure 8 and Figure 9. The only difference is that now the particle emissions of the low cost chimney stove 2 exceed the values from chimney stove 1. The lowest values for particle emission were detected using the tiled stove insert. This furnace was connected to a heating box which can act as a precipitator due to the high surface area.

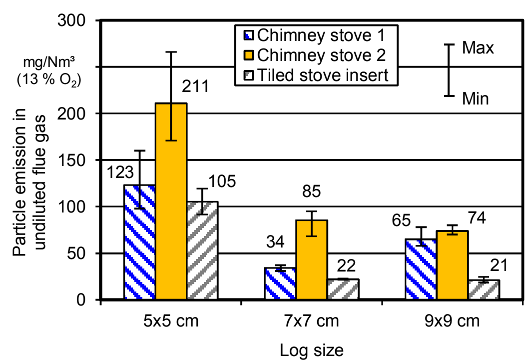

Figure 8: Influence of log size on particle emission in the undiluted flue gas using beech wood in the shape of the test fuel with varying edge lengths but applying uniform fuel masses

Due to the dilution of the flue gases an increase of PM emission especially for chimney stove 1 with high OGC emissions is shown in Figure 9. The additional mass from condensables raised the total PM emission by the factor of two (for small log combustion) and by the factor of almost three for large logs. But only a slight increase in PM emission was observed for chimney stove 2 and the tiled stove insert.

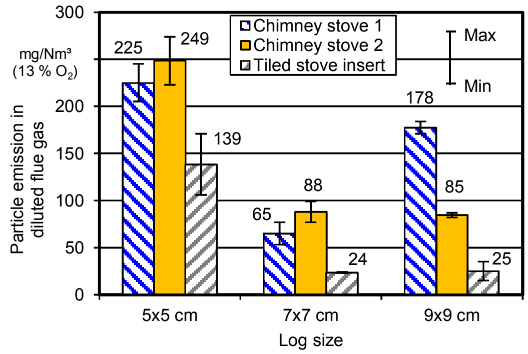

Figure 9: Influence of log size on particle emission in the diluted flue gas using beech wood in the shape of the test fuel with varying edge lengths but applying uniform fuel masses

The choice of log size does not only influence the emission behaviour but also the thermal efficiency, which was generally higher for the tiled stove insert due to the extra heat yields from the attached heating box. For the tiled stove the log size had no influence on thermal efficiency. Only a slight decrease of about 3 percentage-points was observed when the largest log size was chosen for the chimney stoves, Figure 10.

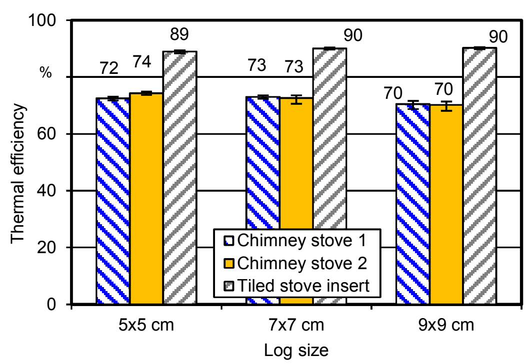

Figure 10: Influence of log size on thermal efficiency using beech wood in the shape of the test fuel with varying edge lengths in three stoves but applying uniform fuel masses

4.2 Influence of fuel mass loaded per batch

The second parameter of interest was the influence of the fuel mass loaded per batch on emission and thermal efficiency. This mass was varied between 30 % (low load) to 160 % (overload) of the nominal fuel mass recommended by the manufacturer. The results show, that the loading of only a single logs (low load) causes the highest CO emissions in chimney stove 1 and also in tiled stove insert, Figure 11. Lowest CO values are achieved using the nominal load for all stoves.

Overloading is generally also an unfavourable operational mode, e. g. there was a considerable increase in CO emission from chimney stove 2 because the high wood layer had covered the opening of the additional secondary air nozzles at the backside of the firebox so that the air distribution was disturbed. Similar disturbance may have occurred in the tiled stove during overloading, but for chimney stove 1 the CO increase was only small since the flame combustion space remains still large enough to ensure stabile burnout conditions.

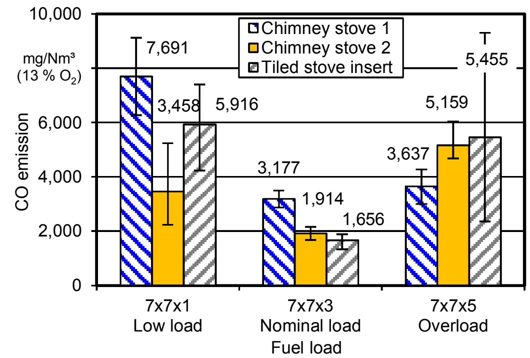

Figure 11: Influence of fuel amount loaded on CO emission using beech wood in the shape of the test fuel with an edge length of 7 x 7 cm in three stoves

A similar emission pattern for the different fuel masses applied was also found for the OGC release, Figure 12.

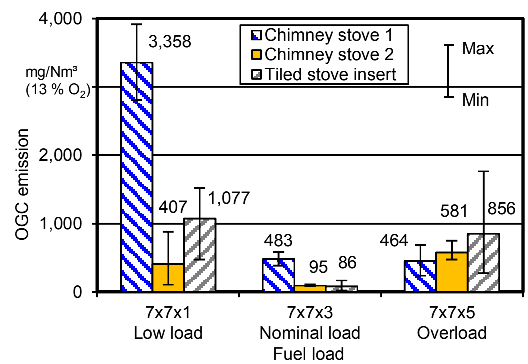

Figure 12: Influence of fuel amount loaded on OGC emission using beech wood in the shape of the test fuel with an edge length of 7 x 7 cm in three stoves

A negative combustion performance by overloading (i. e. 160 % of nominal mass) was also observed when regarding particle emissions, which had been sampled from either undiluted (Figure 13) or diluted flue gas (Figure 14). For PM emissions also a low charging mass (here 30% of nominal value) was mostly harmful, as it was particularly pronounced with chimney stove 1 when measuring in diluted flue gas, Figure 14. This stove operation also caused a fivefold increase of measured PM emissions due to the dilution step compared to undiluted sampling. With chimney stove 2 and tiled stove insert this increase was lower or even not at all observed.

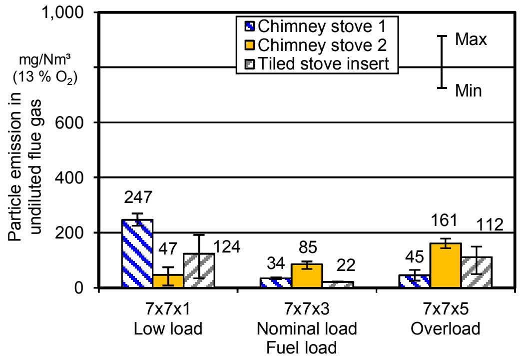

Figure 13: Influence of fuel amount loaded on particle emission in the undiluted flue gas using beech wood in the shape of the test fuel with an edge length of 7 x 7 cm in three stoves

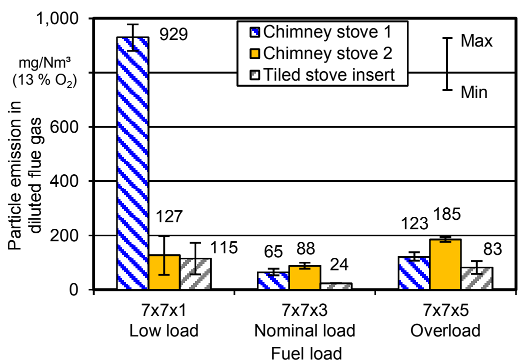

Figure 14: Influence of fuel amount loaded on particle emission in the diluted flue gas using beech wood in the shape of the test fuel with an edge length of 7 x 7 cm in three stoves

Concerning the thermal efficiency the loaded fuel mass is of great importance. Particularly a low load operation is associated with lowest efficiencies of here only around 63 % (chimney stoves) or 84 % (tiled stove insert). The thermal efficiency increases by about 10 percentage points if the designated fuel mass per batch is applied in the chimney stoves, Figure 15.

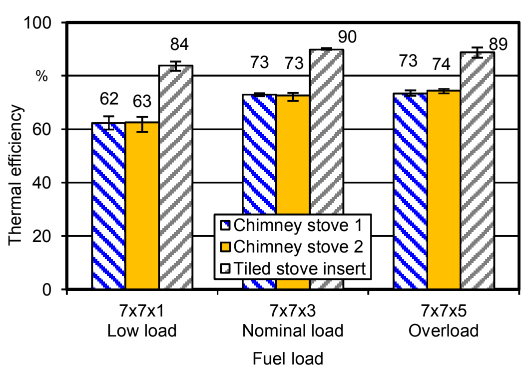

Figure 15: Influence of fuel charging load on particle emission in the undiluted flue gas using beech wood in the shape of the test fuel with an edge length of 7 x 7 cm in three stoves

5 CONCLUSIONS

The following recommendations regarding a proper stove operation can be derived from the here presented results.

- Small logs should not be used for the normal operation of a stove; they should rather be selected and saved for the ignition batch. During combustion of medium and larger logs lower pollutant emissions are usually released. Nevertheless, the log size has only minor effects on thermal efficiency.
- A reloading of only one single log per batch should be avoided in the here applied stove types. This will lead to high emissions and low thermal efficiency.
- Stove overloading should also be avoided, it causes a drastic increase of pollutant emissions, depending on the geometry of the combustion chamber and on achieved air staging. Any additional air inlets in the furnace shall never be blocked by the loaded logs.
- The best combustion behaviour is achieved when applying the maximum fuel mass in accordance with the manufacturer's instructions.

Generally it can be stated, that combustion performance and emission behaviour are as much depending on operational influences as they are also influenced by the stove construction and the technological design. The latter is not simply related to investment costs, as for the low-cost chimney stove which did not cause higher emissions compared to the high value stove. The tiled stove insert performed almost consistently better than both chimney stoves while at the same time providing highest thermal efficiencies of around 90 %.

Also the test setup plays an important role for correct evaluation of stove emissions, particularly concerning particle emissions. Differences in operational concepts become highly visible when the particle sampling is performed after a flue gas dilution. The dilution and cooling step is obviously responsible for condensation of organic gaseous compounds which add up to the measured total dust. Thus, the sensitivity towards operational and fuel quality variation is enhanced. These interactions are also in good conformity with correlations found in previous studies concerning dilution practises (see [8]).

The here presented conclusions are used for the preparation of stove operation guidelines for the instruction of stove operators by chimney sweeps, as it has recently become obligatory in Germany.

6 REFERENCES

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7 ACKNOWLEDGEMENT

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