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Pre-normative research on solid biofuels for improved European standards

SPECIFIC TARGETED RESEARCH OR INNOVATION PROJECT

PRIORITY [6-1] – Sustainable energy systems

Task IV – Supply chain based properties

Fuel quality effects in wood log combustion

Results from trials with a log wood boiler

Deliverable DIV.7 – Part 4

Report of partner TFZ
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Involved Participants

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CONTENTS

List of Abbreviations

P	Particle size of fuel, D and L, mm
D	Diameter, mm
L	Length, mm
M	M_{ar} =Moisture content, ar = as received, w-%
A	ash content, dry basis, w-%
$q_{,net, d}$	Net calorific value, dry basis
Q	$q_{,net, ar}$ =Net calorific value, as received, MJ/kg or kWh/kg (1 kWh/kg = 3.6 MJ/kg) used in quality tables of prEN 14961
BD	Bulk density, kg/m^3
DU	Mechanical durability of pellets, w-%
E_{ar}	Energy density, kWh/m^3 E used in the quality tables of prEN 14961
F	Fines (< 3.15 mm)
S	Sulphur, dry basis, w-%
N	Nitrogen, dry basis, w-%
Cl	Chlorine, dry basis, w-%
CO	carbon monoxide, reported at 10% oxygen content, mg/Nm^3
OGC	organic gaseous compounds, reported at 10% oxygen content, mg/Nm^3
Total dust	Total mass of particles, reported at 10% oxygen content, mg/Nm^3
NO_x	nitrogen monoxide and nitrogen dioxide, reported at 10% oxygen content, mg/Nm^3

1 The aim of the combustion tests

The aim of the research was to identify and assess suitable class boundaries of wood log fuel properties in view of the respective impact on the performance of suitable combustion appliances. In particular the effects of two variable fuel parameters were regarded, the fuel moisture content and the wood log dimensions. This was done by performing specific combustion trials under the repeatable and controlled furnace conditions which were arranged on the combustion test stand of TFZ. Table 1 shows the respective test plan.

Table 1: Test plan for combustion trials

Influence / variant	Beech wood	Spruce wood	Explanation
Moisture, w-%			
M10	1	1	M=5-<10
M15		1	M=10-<15
M20	1	1	M=15-<20
M25	***1***	1	M=20-<25
M30	1	1	M=25-<30
M35		1	M=30-<35
M40	***1***		M=35-<40
Log dimensions			
Log diameter, mm			all logs: L=500 mm, M15
D60-100		1	each log is weighed and measured (L, D)
D100-150		1	each log is weighed and measured (L, D)
D150-250		1	each log is weighed and measured (L, D)
Total variants:			
planned	3	9	
measured	5	9	

2 The appliance used in the tests

A downdraft log wood boiler by Fröling (Grießkirchen, Austria) of the type "FHG Turbo 3000 (Lambda)" with 30 kW nominal heat power output was used (Figure 1). As it is common for wood boilers in Germany and Austria the boiler was equipped with turbulence spirals in the heat exchanger pipes. Their use leads to an increased combustion efficiency and through a mechanical moving system a de-ashing and cleaning of the heat exchanger pipes is achieved. The boiler applies a lambda controlled air flow and it represents the actual state of technology in Germany and Austria. Furthermore, due to the high market share of this boiler it is highly representative for the described regions.

The boiler has a large feeding hopper which is fitting to the use of half metre logs. This enables a long burning duration. The combustion chamber and the heat exchangers are spatially separated. The high temperature turbulence chamber and the electronically controlled suction fan allow an adaptation to variable fuels, while the combustion air flow is optimized via lambda signals and via an adjustable flue gas temperature. The range of heat output is between 9 and 30 kW, which is typically for rural single house heating demands. The features and the technical data of the furnaces are compiled in Table 1.

Figure 1: Wood log boiler FHG Turbo 3000-30 (Fröling)

Table 1: Technical features and characteristics of the wood log boiler Fröling FHG Turbo 3000-30

Component	Realisation/characteristic
Furnace	
Type	wood log boiler
Variation	furnace integrated in boiler
Nominal heat power output	30 kW
Minimum power output	9 kW
Combustion principle	downdraft
Fuel supply	manually, with large feeding hopper
Ignition source	manually
Ash removal	manually
Heat exchanger	
Type	tube heat exchanger, upright
Cleaning	manually
Combustion air supply	
Primary air	laterally fed into into the fire bed
Secondary air	secondary air injection nozzle below the fire bed
Fan	suction ventilator
Air volume control	adjustable rotation speed of fan
Power control	
Control parameters	boiler water temperature and flue gas temperature
Adjusted parameter	combustion air flow
Combustion control	
Control parameters	flue gas temperature, lambda
Adjusted parameter	combustion air flow
Operational data	
Operational pressure	3,0 bar
Operational temperature	100 °C
Water volume in boiler	120 l
Diameter of flue gas hitch	150 mm
Electrical power input	max. 160 W

3 Test procedure

3.1 Combustion test stand

The measurements were performed at the combustion test stand of the Technology and Support Centre (TFZ) in Straubing. The applied equipment and the test setup were selected and designed as required for the measuring task. Figure 2 shows the setup with the boiler, the flue gas tract and the flue gas sampling system.

The flue gas tract comprises the section of the flue gas pipe where all necessary openings were arranged. It was in a vertical position and had a diameter of 150 mm. Three sampling positions were used for

- determination of gaseous components,
- determination of temperature and pressure,
- determination of the total dust concentration.

Prior to the sampling section a calm flow section of minimum 450 mm length was given, this length represents 3-times the diameter of the flue gas tract. Figure 2 shows the setup.

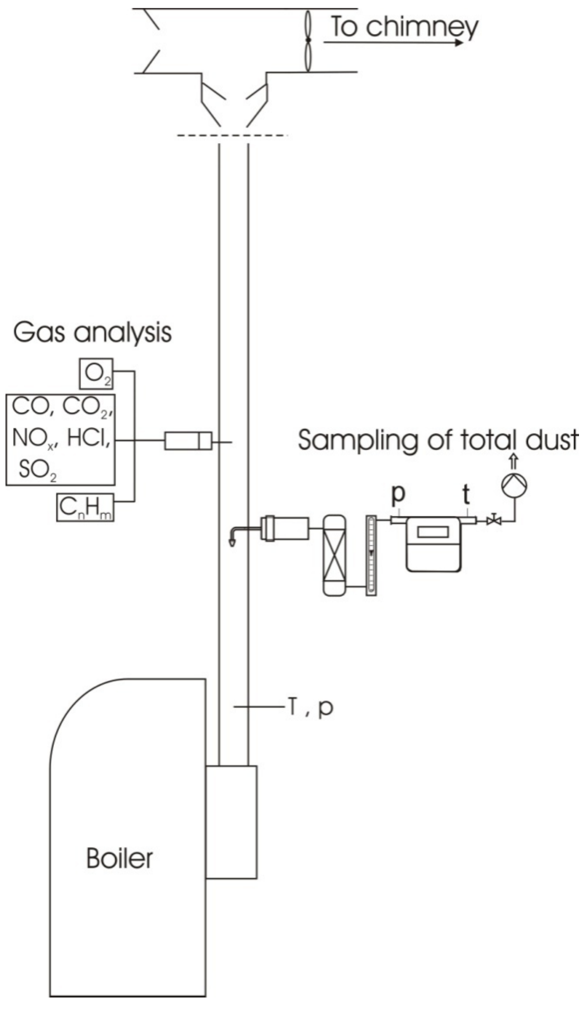


Figure 2: Scheme of gas and dust sampling for the wood log boiler FHG Turbo

The boiler was connected to a special water cooling circuit with direct determination of the useful heat provided. The hydraulic parameters fulfilled the requirements of DIN EN 304. Heat power output was determined by measuring the temperature differences between outflow and reverse flow and by measuring the volume flow. The volume flow was kept constant while the temperature of the reverse flow was adjusted via a 3-way mixing valve. Two heat exchangers transferred the heat to the cooling water which was mostly rain water from a reservoir.

3.2 Procedure of testing

Several pre-tests with the furnace were performed in order to optimize the boiler and to determine the required time until constant operational conditions were reached. During these pre-tests also the expected level of total dust in the flue gas was determined and comparative tests at different measuring positions were made. The actual trials were performed between May and August 2008. The procedure is described in the following.

Starting phase and constant operational stage. In the start-up phase the cooling water was kept circulating, then the heat release phase started at a boiler temperature of 50 °C. The cold water flow was here adjusted to the flow as required for the power output at the constant operational phase. The outflow temperature was at 70 °C and the temperature difference was usually 15 K. Constant operational conditions were reached when heat power and the relevant flue gas parameters were more or less in a steady state.

Measurement phase. The recording of measured parameters was started after calibration of the gas analysers. Prior to the sampling for total dust the sampling rate was determined. For each trial (replication) 3 dust samplings were performed. Each trial was repeated once (total of two full fuel chargings).

4 Measuring equipment

During the measuring programme the following parameters were recorded and evaluated:

– Flue gas consituents: CO, OGC, NO_x, total dust.

– Furnace parameters (flue gas): O_2, CO_2, H_2O, heat power output, fuel consumption, flue gas temperature, out- and reverse flow temperatures, chimney draught, dynamic pressure,

– Environmental conditions: air temperature, relative humidity, air pressure.

All continuously measured parameters are compiled in Table 2. All methods comply with German and international measuring standards. Data signals were recorded as analogous or digital signals via the modular I/O-system “FieldPoint” by National Instruments and recorded by a PC for further evaluation. The data logging was done by a software which was developed by TFZ and programmed with the use of the developing environment of LabView 6.1. Data signals were recorded in increments of 1 s and saved as mean values of 60 s. For each interval the gas speed was calculated from the mean values per minute for the dynamic pressure, the flue gas components and the flue gas temperature.

Table 1: Continuously recorded measuring parameters – technical data of instruments

Parameter measured	Manufacturer/type	Measuring principle/method	Active measuring range
Environmental conditions and operational parameters			
Air pressure	Toss combi-sensor, type 20500	Piezoresistive effect	900 – 1100 hPa
Air temperature	Toss combi-sensor, type 20500	Temperature depending changes of resistance (Pt 1000)	-40 – 60°C
Air humidity	Toss combi-sensor, type 20500	Multi layer sensor	0 – 100%
Flue gas temperature	Thermocouple (type K), by Philips-Thermocoax	Thermoelectricity	0 – 1.000°C
Static pressure	Differential pressure transmitter, GE LPX 5000	Induction	-200 Pa - 200 Pa
Dynamic pressure	Differential pressure transmitter, GE LPX 9000	Induction	0 – 50 Pa
Flue gas components			
CO_2	Gasmet CX 4000 FTIR by Ansyco	Fourier-transformed infrared-absorption	0 – 25 Vol.-%
H_2O	Gasmet CX 4000 FTIR by Ansyco	Fourier-transformed infrared-absorption	0 – 30 Vol.-%
CO	Gasmet CX 4000 FTIR by Ansyco	Fourier-transformed infrared-absorption	0 - 15000 ppm
NO_x	Gasmet CX 4000 FTIR by Ansyco	Fourier-transformed infrared-absorption	0 – 2000 ppm 0 – 1500 ppm
O_2	PMA 100-L by M&C Products	Paramagnetism	0 – 25 Vol.-%
OGC	Thermo-FID by Mess-&Analysentechnik GmbH	Flame-ionisation	0 – 10000 ppm[1)] C_3H_8-Äquivalent
Heat power output and efficiency			
Temperature	Resistance thermometer calibrated in pairs, by Thermokon	Temperature depending changes of resistance (Pt 100)	0 – 100 °C
Cooling water volume flow	Promag 53 P by Endress+Hauser	Magnetic-inductive flow measuring system	240 – 6000 l/h
Fuel consumption	Platform balance Mettler Toledo KD 600g	electromagnetic power compensation	0 – 600 kg

The determination of total dust was made discontinuously by sampling according to the VDI Guideline 2066 (method with filtering head device and method with plane filter [3]). In this method the dust load of an isokinetically sampled partial flue gas stream is retained in a dust collection system. For retention a stuffed quartz wool cartridge with a subsequent glass plane filter (retention 99.998 % according to DOP (0.3 µm), diameter 45 mm) was used. Both media were combined in a filter head device which was located outside of the flue gas tract. The sampling system outside of the flue gas tract was heated in order to avoid any condensation. Behind the filter the sampled gas was conveyed into a gas drying unit and the volume flow was determined. With the help of a sinker flow metering device the isocinetical flow was monitored and adjusted via a bypass at the sample gas pump. The sampling was performed over 30 minutes time, as described in the VDI Guideline 2066 [3]. Exceptions from this requirement were only made when the filters' dust loading became too big and the maximum flow of the sample gas pump was exceeded. Dust was then determined gravimetrically after the conditioning of the used filter media. For this the conditioned unloaded and loaded filters were weighed on a precision balance (Mettler Toledo XP 56, maximum load 56 g, resolution: 1 µg).

5 Fuels

The fuels which were used for the trials were procured from a local fire wood trader. For the trials concerning the log wood size effects they were selected by hand and for each log the weight, the length and the diameter was individually determined. The diameter was measured as described in prEN/TS 14961-1 (2008) (working document N164). Figure 3 shows the three size classes of the spruce wood logs used.

60 – 100 mm | 100 – 150 mm | 150 – 250 mm

Figure 3: Hand sorted wood log diameters as used in the trials concerning the size effects

A compilation of the recorded data for the respective wood log assortments as used in the combustion trials is given in Table 3.

Table 3: Characteristics of wood logs used in the combustion trials (results from individual determinations)

Diameter of logs		Minimum	Maximum	Mean	Std.-dev.	CV
D10 L500	Diameter	60 mm	100 mm	81 mm	10.6	13%
	Length	470 mm	530 mm	499 mm	9.5	2%
	Mass	0.26 kg	1.22 kg	0.81 kg	0.20	25%
D15 L500	Diameter	100 mm	150 mm	126 mm	15.6	12%
	Length	465 mm	535 mm	499 mm	11.7	2%
	Mass	1.17 kg	2.94 kg	1.83 kg	0.38	21%
D25 L500	Diameter	150 mm	215 mm	180 mm	19.8	11%
	Length	480 mm	535 mm	509 mm	15.0	3%
	Mass	2.20 kg	3.83 kg	3.12 kg	0.50	16%

In Table 4 an allocation of the determined wood log properties according to the classification system of CEN/TS 14961-1 (2008) (working document N164) is presented.

Table 4: Measurement and reporting of fuel properties according to prEN/TS 14961-1 (2008) (working document N164) (Table 7)

Property	Standard for measurement	prEN 14961 category	Actual measured value (min-max)
Moisture (Origin: 1.1.2.1, deciduous)	CEN/TS 14774-2	M20	7.9 and 18.3%
Moisture (Origin: 1.1.2.1, deciduous)	CEN/TS 14774-2	M30	23.4 and 28.9%
Moisture (Origin: 1.1.2.1, deciduous)	CEN/TS 14774-2	M40	36.4%
Moisture (Origin: 1.1.2.1, deciduous)	CEN/TS 14774-2	M20	7.9; 12.5 and 16.5%
Moisture (Origin: 1.1.2.2, coniferous)	CEN/TS 14774-2	M30	22.7 and 29.0%
Moisture (Origin: 1.1.2.2, coniferous)	CEN/TS 14774-2	M40	33.5%
Length and diameter	CEN/TS14961-1 (2008) Table7	L500 D10 D15 D25	L: 465-535 mm (min/max) 3 diameter classes: D60-100 D100-150 D150-250 (see table 3)

The combustion trials were performed with the wood masses per charging as presented in Table 5.

Table 5: Applied wood log numbers and masses per charging for each assortment of fuel tested in the combustion trials

Diameter of logs	Number of logs			Fuel mass		
	1st charging	2nd charging	Total	1st charging	2nd charging	Total
D = 60 – 100 mm (Class D10)	42	36	78	31.05 kg	31.83 kg	62.88 kg
D = 100 – 150 mm (Class D15)	19	16	35	34.72 kg	29.40 kg	64.12 kg
D = 150 – 250 mm (Class D25)	11	7	28	32.91 kg	23.33 kg	56.24 kg

6 Results from combustion tests

In the combustion trials performed at TFZ the influences of variable wood log moisture contents and of the log's diameters were systematically assessed. The results are presented in the following chapters.

6.1 Influence of high fuel moisture contents

Moisture content effects were recorded on the CO-emission and on further flue gas components as total dust, NO_x and OGC. Additionally the effects on combustion efficiency and on the achievable power output at steady furnace settings were determined. The results are presented in the following.

CO-emission. The CO-emission can be regarded as the key parameter characterising the quality of combustion and the completeness of the flue gas burnout. Therefore the results were evaluated separately for this parameter. They are given in Figure 4.

Th results show a clearly visible trend towards higher CO-emissions when the moisture content is rising above a critical level of around 25 to 30%. With spruce wood this effect already became evident at a level of 29%, while for beech wood logs the effect started above this moisture level. However, in wood log combustion such observations are often overlayed by effects of occasionally occurring bridge-build-up effects in the combustion zone. This may have been the reason for the CO-peak at the moisture level of 29% in Figure 5. The subsequent decline at an even increased moisture content can however not easily be explained, particularly in view of other result obtained in a separate research performed by TFZ using the same boiler. In these trials a severe CO-increase was also monitored at the 31% moisture content, accompanied by a vast decline in the maximum possible heat power output (see [1]).

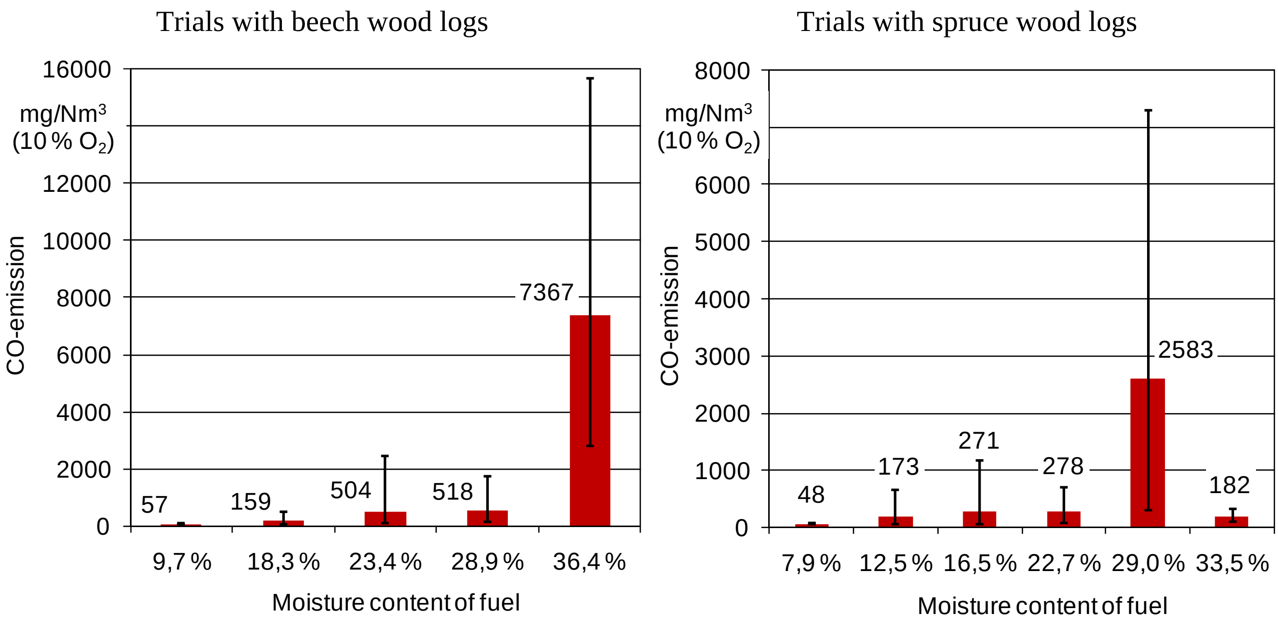


Figure 4: CO emissions from a log wood boiler at five (beech wood) and six (spruce wood) different moisture content levels in wood fuel logs (length: 500 mm, boiler: Fröling FHG 3000 turbo). Tests at maximum power output, data given as mean values of two consecutive trials (i.e. two fuel charges)

Total dust, NO_x and OGC-emissions. Apart from the CO-emissions several other flue gas parameters were recorded and evaluated. The results are presented in Figure 5 (for beech wood logs) and in Figure 6 (for spruce wood logs). They show that for NO_x-emission there is no sensitivity towards fuel moisture content. However, the total particle mass is significantly increasing when fuel moisture content rises above a level of around 23%. This was observed for both test series with either beech or spruce wood.

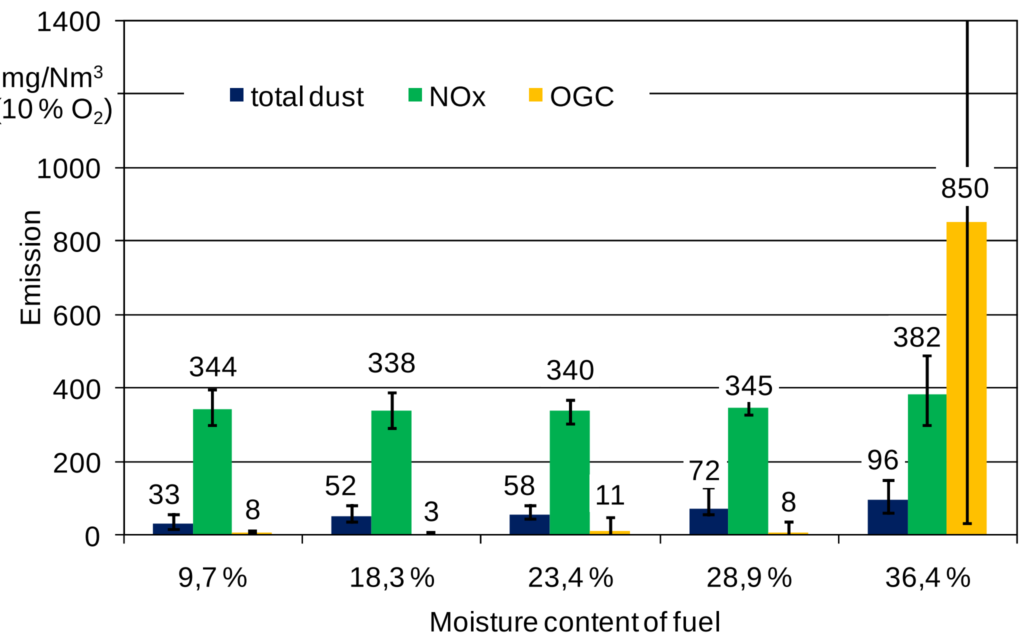


Figure 5: Emissions of total dust, NO_x and organic gaseous compounds (OGC) from a log wood boiler at five different moisture content levels in beech fuel logs (length: 500 mm, boiler: Fröling FHG 3000 turbo). Tests performed at maximum power output, data given as mean values of two consecutive trials (i.e. two full fuel charges)

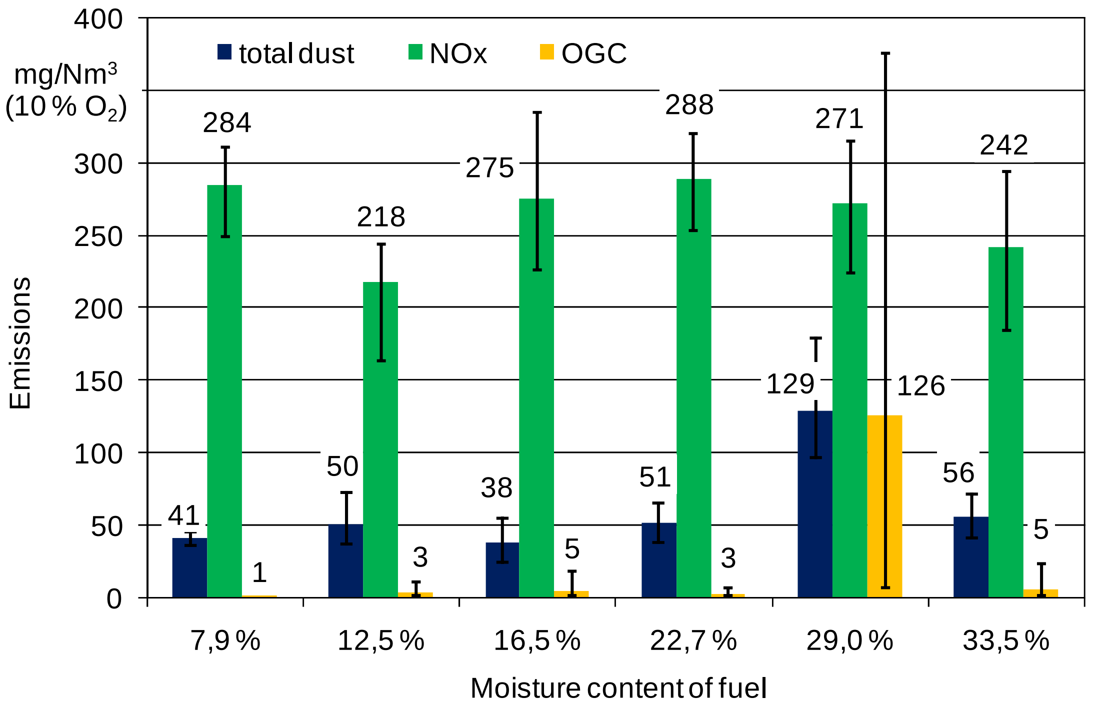


Figure 6: Emissions of total dust, NO_x and organic gaseous compounds (OGC) from a log wood boiler at five different moisture content levels in spruce fuel logs (length: 500 mm, boiler: Fröling FHG 3000 turbo). Tests performed at maximum power output, data given as mean values of two consecutive trials (i.e. two full fuel charges)

In about the same moisture range the organic gaseous compounds are also responding towards increased fuel moisture. The results from other research trials at performed in 2007 at TFZ (using the same log wood boiler) suggest that the moisture content threshold should rather be fixed at around 20%, even for modern downdraft wood log boilers (Figure 7).

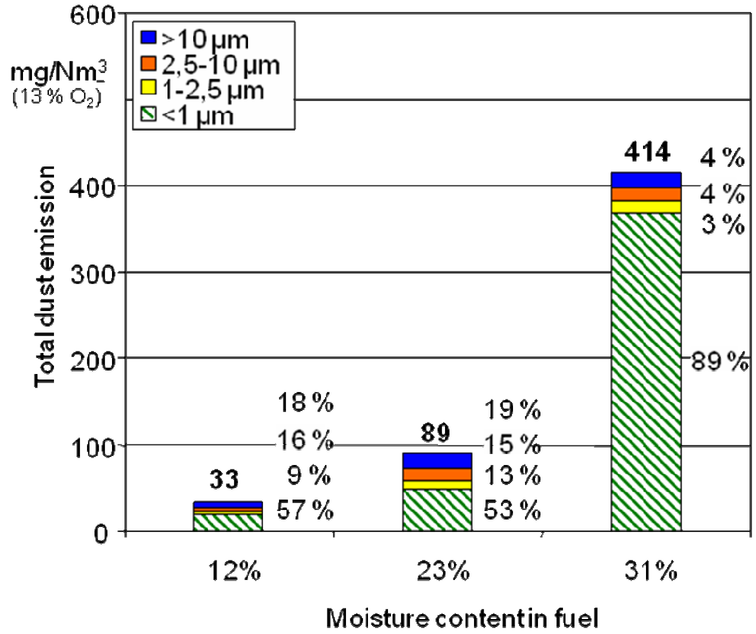


Figure 7: Effect of moisture content of wood logs (spruce wood, 500 mm length) on total dust emissions from emissions from 30 kW wood log boiler (Fröling FHG 3000, n = number of trials). Results from a parallel research project [1].

It is evident that modern downdraft boilers have a higher flexibility towards fuel moisture variation than other log wood furnaces. Therefore the sometimes observed low respond towards exceeding moisture contents above 20% can to a much lesser degree be expected with other log wood boiler types (e.g. updraft boilers or natural downdraft boilers) or with wood stoves. Chimney stoves and tiled stoves, for example, are much more depending on a proper fuel moisture content. This was shown in another research project conducted by TFZ. In the chimney stove the moisture effect becomes particularly obvious during diluted (and cooled) flue gas sampling. The cooling of the flue gas enables any organic gaseous compounds (OGC) to condensate and thus to form additional particle mass (Figure 8). Such a full stream dilution causes a flue gas temperature decline to a range between 50 and 60 °C (see [1], [2]). Here any particle increase due to unfavourable combustion conditions becomes strongly enhanced and the true dust emissions as observed at the outlet of the chimney are thus recorded in a more realistic way (Figure 8).

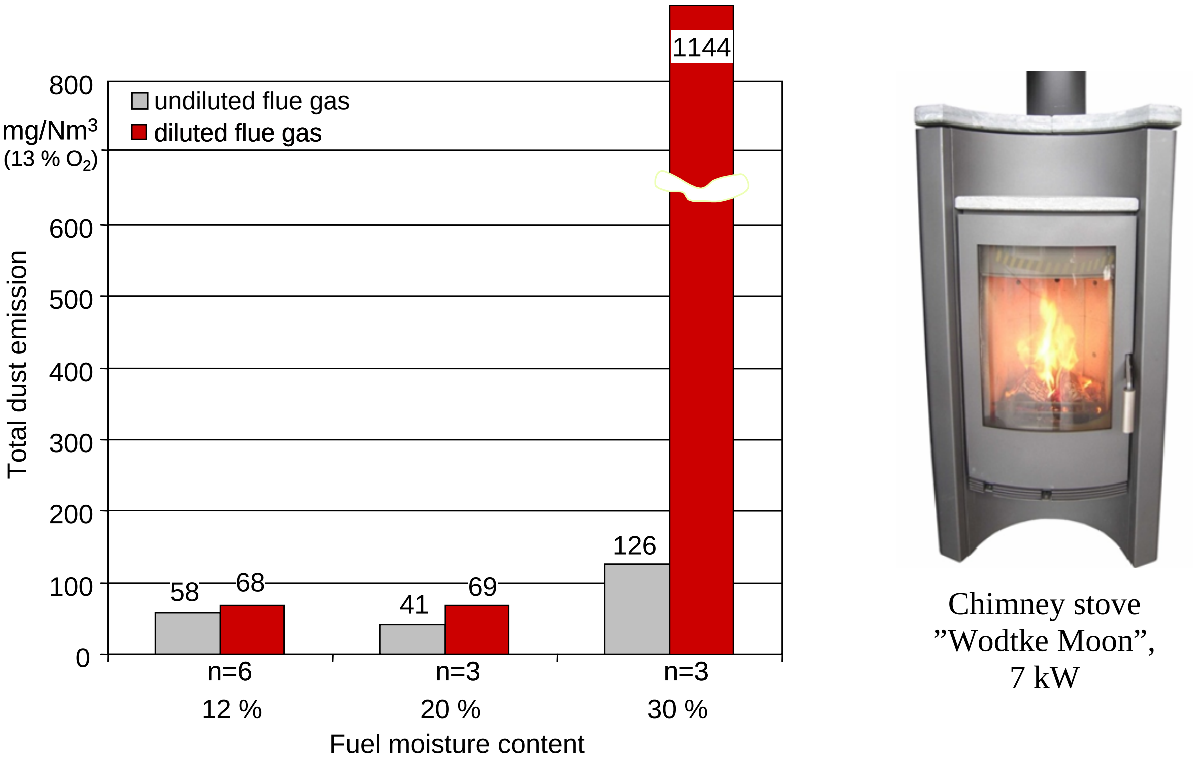


Figure 8: Effect of moisture content of wood logs (beech wood, 330 mm length) on total dust emissions from emissions from a 7 kW chimney stove (“Wodtke Moon”) (n number of trials). Results from a parallel research project [1], [2]. (Flue gas dilution was performed in a full stream dilution tunnel at a mean dilution ratio of 5.7 and a mean particle sampling temperature of 56°C.)

Efficiency and power output. More moisture induced effects can also be observed when the combustion efficiency and the maximum achievable power are regarded. The results are presented in Figure 9.

Power output was determined at fixed optimised settings which had been chosen after the performance of pre-tests using regular suitable wood fuels. It was then kept constant in order to enable quality related effects to become visible. The results show, that power output is usually affected by the moisture content, but not in all cases a clear threshold value can be defined. The heat power output gradually declines in the trials with beech wood (Figure 9, left side) while with spruce wood a steeper decline is only observed at a moisture content above 17% (Figure 9, right side).

For the combustion efficiency the trend is not clear but a decline is possible when moisture content rises above 29% (Figure 9, left side).

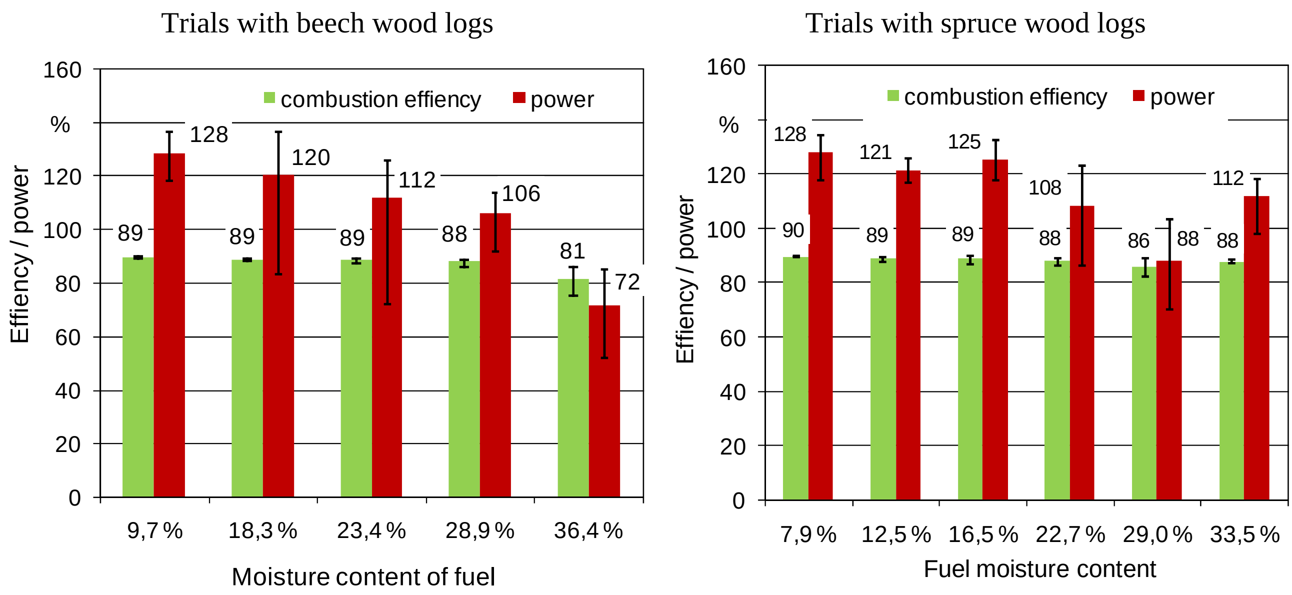


Figure 9: Maximum power output and combustion efficiency of a log wood boiler at five different moisture content levels in beech and spruce fuel logs (length: 500 mm, boiler: Fröling FHG 3000 turbo). Tests performed at fixed power output settings, data given as mean values of two consecutive trials (i.e. two full fuel charges)

6.2 Influence of extremely low fuel moisture contents

From the results shown in Chapter 6.1 no evidence could be derived that low fuel moisture contents could lead to unfavourable combustion conditions. This was either due to the fact that the furnace chosen for the trials (a downdraft log wood boiler with forced ventilation) was not sensitive towards any extreme low fuel moisture, or – in the case of the also presented wood stove results – the moisture content had in the tests not fallen below a critical value.

However, along with a growing log wood market the demands for a continuous fuel supply throughout the year is likely to increase and market actors want to be able to react flexible to a changing demand. Therefore in Germany, for example, there is a growing tendency to apply artificial drying by the use of waste heat from biogas plants. If necessary this allows an expansion of the fuel production within a shorter term than the usual one year of natural drying by conventional storage. Figure 10 gives an example of such a wood log dying concept based on waste heat from a biogas plant. The figure shows an exchangeable drying container with insertion of hot air via several plastic pipes which feed into a porous effuse canal at the container bottom.

Figure 10: Simple container based appliance for artificial drying of wood logs using waste heat from biogas plants (Photo: TFZ)

As a result of such artificial drying operations the fuel moisture content is mostly well below 10%, sometimes even values of only 5% are achieved. During onward storage the moisture content will usually then only slowly increase and adapt to equilibrium with the atmosphere. This was found in long term storage trials of wood logs [4]. If such fuel is immediately delivered as “oven ready” fuel to an end consumer and is there stored in tempered rooms (e.g. heating room) the moisture is likely to remain low.

In several trials which were performed in a project parallel to “BioNormII” it was found that the fuel moisture content can for some applications be too low, too. Figure 11 shows the effect of very low moisture content of wood logs in a simple chimney stove purchased from a local building centre. The presented results suggest that fuel moistures of below 8% shall be avoided in order to prevent the furnace from a too rapid pyrolysis due to the reduced cooling by moisture evaporation. Furnaces with natural draft are believed to be particularly disadvantageous in this context as an excessive primary combustion air flow is consequently stimulated by a use of too dry wood. Therefore the retention time of the surplus fuel gases produced in the combustion zone is not optimal. For furnaces with controlled combustion air insertion such effects are not expected (see results for modern wood boiler in Chapter 6.1).

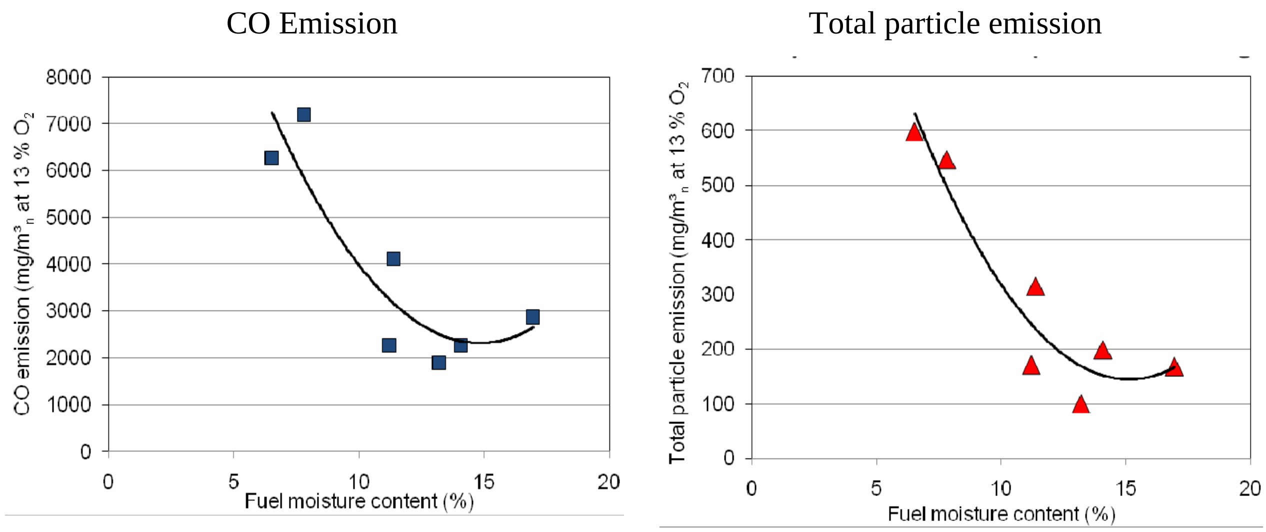


Figure 11: Low fuel moisture content effects in a simple wood stove (chimney stove, 7 kW): impacts on CO and total particle emission (unpublished results from ongoing research project at TFZ, March 2009)

6.3 Influence of log diameters

Apart from the fuel moisture content the impact of variable log sizes were also assessed in the combustion trials. Three different log diameter classes were applied (for their main size characteristics see Chapter 5).

Pollutant emissions. The results for the effects on flue gas pollutants are given in Figure 12. No significant impact can here be observed. The slight trend towards higher CO-emissions for the largest log diameter class should here carefully be interpreted, as such deviations reflect the usual range of repeatability for such measurements. The CO-emissions are anyway quite low. Also the low level of the other pollutant emissions (total dust, NO_x, OGC) shows, that in such modern wood log boilers only little sensitivity towards variable fuel log geometries and sizes is given.

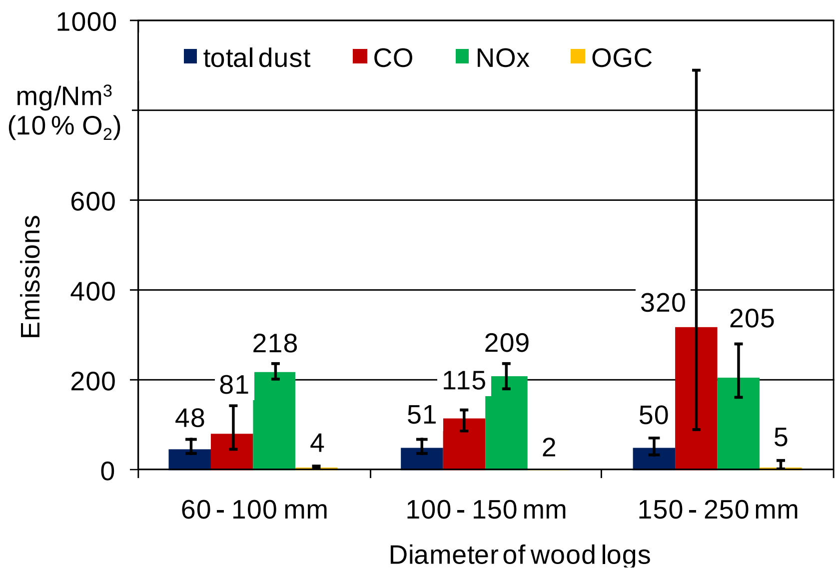
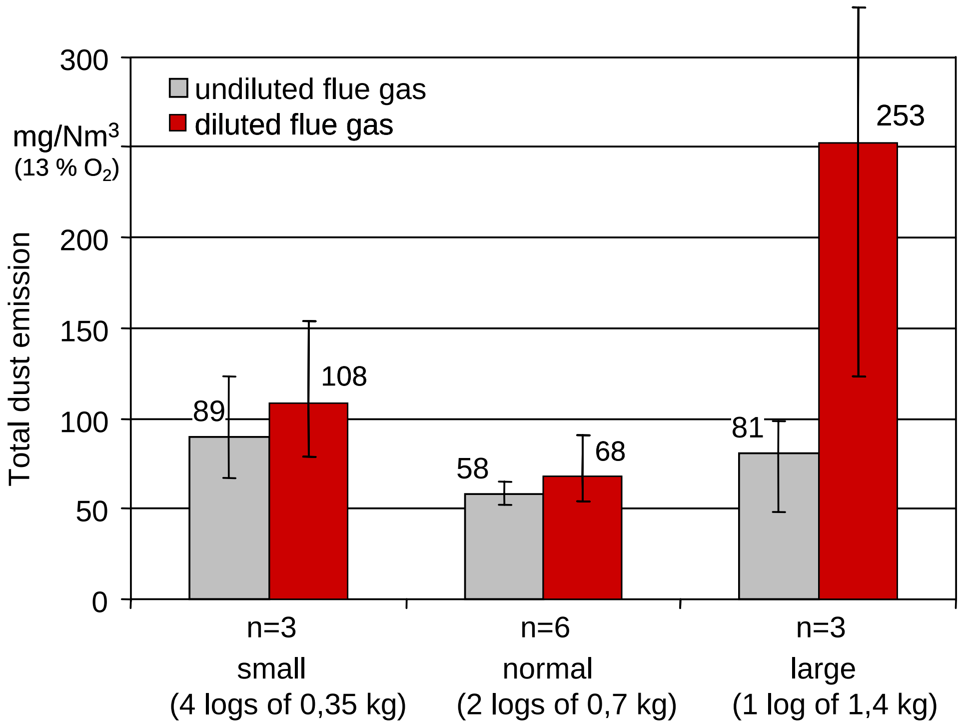


Figure 12: Emissions of CO, total dust, NO_x and organic gaseous compounds (OGC) from a log wood boiler using three different log diameters of spruce wood (length: 500 mm, fuel moisture: 11%, boiler: Fröling FHG 3000 turbo). Tests performed at maximum power output, data given as mean values of two consecutive trials (i.e. two full fuel charges)

However, for other log wood boiler types (e.g. updraft boilers or natural downdraft boilers) and for wood stoves such assumptions can not generally be made. Chimney stoves and tiled stoves, for example, are depending on proper and suitable wood log diameters, this was shown in another research project conducted by TFZ (Figure 13).



Chimney stove ”Wodtke Moon”, 7 kW

Figure 13: Effect of wood log size (beech wood) on total dust emissions from the 7 kW chimney stove “Wodtke Moon” (n number of trials). Results from a parallel non-BioNorm research project [1], [2] where flue gas dilution was performed in a full stream dilution tunnel at a mean dilution ratio of 5.7 and a particle sampling temperature of 56°C.

For the heat power output a slight benefit for the smaller and more reactive log diameters was observed. This was in line with expectations because the higher specific wood surface leads to an enforced heat transfer to the fuel and thus to a higher production of pyrolysis gases. On the other hand the combustion efficiency was not significantly affected (Figure 14).

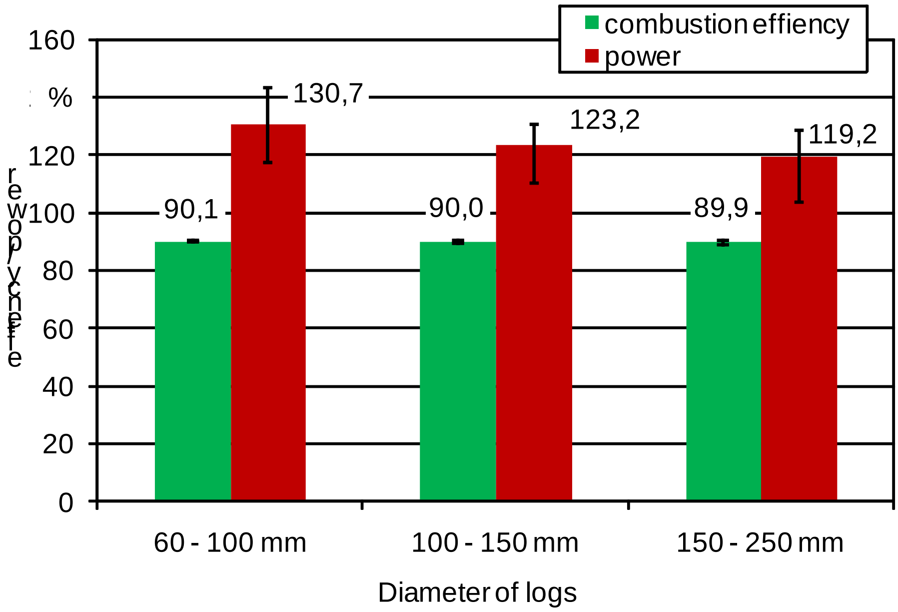


Figure 14: Maximum power output and combustion efficiency of a log wood boiler using three different log diameters of spruce wood (length: 500 mm, fuel moisture: 11%, boiler: Fröling FHG 3000 turbo). Tests performed at fixed power output settings, data given as mean values of two consecutive trials (i.e. two full fuel charges)

7 Conclusions

From the here presented results the following conclusions can be made concerning the moisture content of wood logs:

- For modern wood log boilers an increased risk of rising CO and particle emissions is given at moisture levels higher than M = 25%.
- Power output of the boiler is gradually declining with higher fuel moisture content between 10 and 35%, associated with a slight loss of efficiency.
- These conclusions can not be applied for stoves where experiments performed in other similar projects show a larger response of pollutant emissions towards moisture contents above 20%.
- In updraft furnaces (e.g. stoves) fuel moisture content below M=10% can also cause problems by high pollutant emissions.

Concerning the log dimension the following conclusions can be drawn:

- Modern downdraft wood log boilers (with ventilation and lambda control) are largely tolerant towards variable log diameters between 60 and 250 mm, this means that
  - no influence on efficiency is expected,
  - a slight decline in power output may be possible for larger log diameters
  - no significant effect on pollutant emissions can be expected if the moisture content of the fuel is in the required range.
- These conclusions do not apply for older boiler types (e. g. updraft combustion) and for stoves, where experiments performed in similar projects by TFZ show that a clear optimum is given for medium log sizes (this applies for chimney stoves and tiled stove inserts [2],[3]).

8 Recommendations to the prEN14961

From the here presented results and with reference to other similar or relevant experimental trials performed at TFZ the following recommendations can be made to future definitions and to fuel product requirements in the frame of EN14961 (part 5: non industrial fire wood).

Maximum fuel moisture. For wood log combustion the use of fuels with higher moisture content than 20% implies an increased risk of poor combustion quality. This risk is lower for modern lambda controlled downdraft boilers, but such technology cannot be compared to updraft furnaces such as wood stoves. In order to avoid any excessive pollutant emissions and to prevent a decline in combustion efficiency and power output the fuel moisture content should be limited to a maximum of 20% at the time of energetic use but also already at the time of delivery, because such users often buy their fuels for immediate use.

Minimum moisture content. An extremely low moisture content of wood logs, as achievable by technical drying with hot air, may also be problematic, although no advantage or disadvantage was shown in the here performed tests using a modern lambda controlled log wood boiler. However, from ongoing research at TFZ recently some evidence arose, that such low moisture contents may be highly problematic for single stoves (e.g. with fuel moisture around 7%). For the definition of log wood quality requirements it should therefore be considered to establish a minimum fuel moisture limit (e.g. at 9%). Additionally there should be a normative indication, which informs the customer whether the drying to oven ready fuel was achieved under atmospheric conditions (by ambient air during long term storage) or by ventilation with hot air. Hot air drying becomes more and more popular in Germany due to the necessity to make use of the residual heat from agricultural biogas plants and due to the requirement to increase the flexibility towards unexpected market developments.

In order to allow a differentiation between stoves (updraft) and modern downdraft boilers it should be considered to define the minimum (M_{min}) and maximum M_{max}) fuel moisture requirements as follows:

P1000 and 500:	M_{min}: no limitations, M_{max}: 25% (at delivery to customer) to be stated: method of drying (ambient air / hot air)
P250 and P330:	M_{min}: 9%, M_{max}: 20% (at delivery to customer) to be stated: method of drying (ambient air / hot air)

Log diameters. For modern wood log boilers which commonly use logs of 500 or 1000 mm length the diameter limitations as given in prEN14961 are suitable, as these boilers are largely insensitive towards variable wood log diameters. But there is a difference between split and unsplit (round) wood, which however was not tested here, but it was observed during experiments performed by TFZ in similar other project [1]: Round wood is associated with a higher risk of forming a bridge over the fire bed (so-called "hollow fire") which consequently increases the pollutant emissions. Round wood should therefore be treated as a separate fuel quality class.

For individual stoves, where the updraft combustion principle is commonly applied, a more narrow range of diameters seems useful. Previous research by TFZ shows, that benefits are given for medium size wood logs of the 330 and 250 mm length [1]. The highest quality class should therefore be defined by a slightly stricter diameter range than the one mentioned in prEN14961 (Table 7).

9 Literature

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