

CONTAMINATION OF WOOD PELLETS WITH SELECTED MINERAL SOILS – FUEL QUALITY AND COMBUSTION BEHAVIOUR

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ABSTRACT: Due to careless operation during fuel production, considerable shares of mineral soil might be added to wood chips and wood pellets leading to contamination of the biofuels. This can result in high gaseous and particle emissions, corrosion or slag formation during combustion. To investigate this effect, four pellet fuels were produced at TFZ using coniferous wood of Norwegian spruce, i. e. a pure sample as reference and three pellets that were contaminated with different mineral soils (2 w-%). The contaminated pellets had significantly higher ash contents (2.47 to 2.63 w-%, d.b.) compared to the reference fuel (0.83 w-%, d.b.). The reference sample fulfilled the specifications for A2 according to DIN EN ISO 17225-2, while the contaminated pellets only met the I3 quality criteria. A visual differentiation between contaminated and uncontaminated fuels was not possible. The pellets were combusted in a pellet boiler with a nominal heat output of 15 kW. During combustion of the contaminated pellets, the boiler shut down because of to severe slag and ash formation after 118, 120 and 278 minutes of full load operation. Particle emissions and NO_x decreased for the soil contaminated pellets compared to the reference fuel while SO_x increased. Carbon monoxide was on a very low level for all fuel assortments. A final interpretation of the correlation between soil contamination of wood pellets and their respective emission behaviour is not possible yet as analysis of chemical element concentration is still ongoing. Overall, the contamination of woody biomass had a noticeable effect on emissions and on the continuous, undisturbed operation of the pellet boiler and should be avoided.

Keywords: wood pellet, combustion, production, emissions, sintering, solid biofuels.

1 INTRODUCTION

The contamination of woody biomass with mineral soil might have a substantial impact on the combustion behaviour of the fuels due to an unsuitable chemical fuel composition. Chemical elements that are considered critical for combustion of woody biomass are, for example, nitrogen (N), sulphur (S) and chlorine (Cl). These elements can cause increased emissions of NO_x, SO_x or HCl. Other elements such as potassium (K), sodium (Na), lead (Pb), zinc (Zn) and to a certain degree S and Cl influence the amount of aerosols formed during the combustion process. Chemical elements are also critical in terms of high temperature corrosion (S, Cl) or slagging (K, silicon (Si)) [17, 26, 28, 29]. The concentration of these elements is typically low in wood as they mainly occur in other organic (e. g. needles, bark) or inorganic sources (e. g. mineral soil) [17].

Due to careless operation during fuel production, high levels of mineral soil may be added to the fuels, e. g. during the logging process, transportation, storage or fuel processing after storage [24]. Current studies reported up to 10 w-% of mineral soil in woody biomass [17]. This may lead to unwanted effects during combustion which can even result in a boiler shut down. Mineral soils in woody biomass could also be an economic disadvantage for the combustion plant operator, if the accounting of the delivered fuels is based on fuel mass.

The aim of this study was to evaluate the combustion behaviour of coniferous wood pellets, which were contaminated with 2 w-% of mineral soil (dry basis, d.b.). The study included the identification and evaluation of potential damage to boilers (e. g. corrosion, slagging) and of the environmental impact (e. g. emissions).

2 MATERIAL & METHODS

2.1 Selection of mineral soils and wood

The project focused on the state Bavaria in Germany. Three different types of mineral soil (soil A, B and C) were selected in order to represent big forest growing regions of coniferous tress, in Bavaria with high timber production (Figure 1).

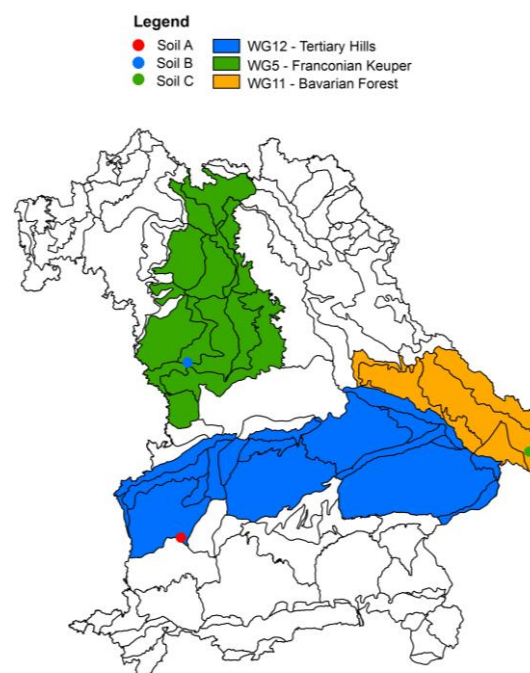


Figure 1: Location of three different soil types. Each soil is representative for the considerable parts of the marked region [Zimmermann]

Regions with a high amount of rocks were excluded, because contamination with mineral soil is not very likely at these areas. The following soils / regions were selected:

- Soil A: waterlogged loess/clay from tertiary Hills
- Soil B: podsol brown soil above sandy-loam Frankonian Keuper from northwest Bavaria
- Soil C: brown earth from weathered granite and gneiss substrates from the Bavarian Forest

The mineral soils were manually taken from the upper 30 cm, excluding the layer of humus.

To decrease possible damages of the pellet mill (see section 2.2), the soil was prepared before pelletization. First, each soil was air-dried indoor at room temperature. After drying, each soil was homogenized and by sample reduction, a representative sample of every soil was obtained. The respective samples were crushed manually by a concrete drum (Figure 2 left top). The drum was wrapped in cling film and rolling was done on a tarpaulin. Each soil was then screened mechanically to a grain size of 2 mm using a self-made vibrating screen (Figure 2 right top). This diameter corresponds with the geological fraction-limit between fine soil and coarse soil fraction [27, 31]. The screened and dried soils can be seen in the bottom of Figure 2.



Figure 2: Preparation of soil; left top: crushing with a concrete drum; right top: screening at 2 mm with a self-constructed vibration screen; bottom, from left to right: soil A, B and C

2.2 Pellet production

Wood of Norwegian spruce (*Picea abies*) was used as energy stemwood (Figure 3 left top). Stems were chipped with a stationary drum chipper (VecoPlan) at TFZ using a 40 × 40 mm screen (Figure 3 right top). The wood chips were milled in an Amandus Kahl 33-390 pellet mill (Figure 3 left middle). Afterwards, the grinded biomass was contaminated with soil material (2 w-% d.b.) for pellets P - A to P - C and moistened to a moisture content of 11 w-% using an extract mixer for 20 minutes (Figure 3 right middle). As it was determined by pre-tests at TFZ, this procedure provides for a homogenous moistening and contamination. After a resting phase of 12 h, the grinded biomass was pelletized using a die with a press-channel diameter of 6 mm in the Amandus Kahl 33-390 pellet press (Figure 3 bottom).

In addition to the contaminated fuels, untreated pure reference sample was produced without soil addition.

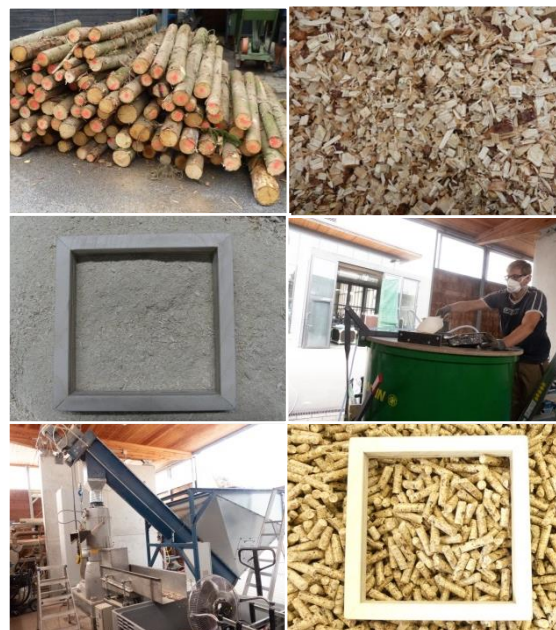


Figure 3: Manufacturing process of pellets; left top: spruce energy stemwood; right top: wood chips; left middle: grinded spruce; right middle: contamination and moistening of the grinded wood with a extract mixer; left bottom: Amandus Kahl 33-390 pellet mill; right bottom: produced pellets (wooden frame = 10 × 10 cm)

2.3 Fuel property analysis

Before combustion, fuel quality parameters of the pellets were determined according to international standards for solid biofuels. The moisture content ($n = 2$) was determined gravimetrically according to DIN EN ISO 18134-2 using a drying cabinet (FED 720, Binder GmbH) immediately prior to the combustion tests [7]. Determination of length and diameter was done according to DIN EN ISO 17829 [15]. The ash content ($n = 3$) was determined according to DIN EN ISO 18122 in a muffle furnace (Nabertherm GmbH) [6]. The bulk density ($n = 3$) was determined according to DIN EN ISO 17828 prior to storage [10]. The net calorific value was determined using a calorimeter (C 2000 basic, IKA) according to DIN EN ISO 18125 [5]. All chemical analyses were done according to current standards at an external laboratory [8, 11 to 14].

The samples for moisture content, pellet length and diameter, ash content, chemical analysis and net calorific value were taken with a sampling lance after the production process to get a representative sample over the cross section in the storage container (Figure 4). Samples for bulk density determination were taken in regular intervals during pellet production.



Figure 4: Sampling with a sampling lance

2.4 Combustion trials and test stand

In total, four different pellet fuels were tested (Table I) during 6 h full load operation trials after a 2 h preheating phase. In case of boiler shut down (e.g. due to too much ash or slagging), the 6 h operation time was split in shorter aligned full load operation sections with manually triggered grate cleaning processes in between.

Table I: Pellet assortments from Norwegian spruce

No	Description of the pellet batch
P	Pure reference sample
P - A	Sample with 2 w-% soil A
P - B	Sample with 2 w-% soil B
P - C	Sample with 2 w-% soil C

All measurements were performed on the combustion test stand at TFZ using the setup as shown in Figure 5. The dimensions of the scheme follow the current instructions given in the European standard for type testing (DIN EN 303-5) [16].

The pellet boiler for the combustion trials was with a special dumping grate and a nominal heat output of 15 kW. The fuel is fed into the boiler by lateral insertion controlled by a fill level sensor. Ash is removed using a dumping grate to a screw conveyor that transports the ashes into the ash box.

To determine fuel consumption during combustion tests, the boiler was placed on a platform scale (Mettler-Toledo GmbH, MT KD600) with a resolution of ± 5 g. The heat consumption was permanently regulated to a nominal load of 15 kW following DIN EN 303-5 [16]. The gaseous components CO , CO_2 , and O_2 were determined using a single component analyser (ABB Automation GmbH ABB AO2020), NO_x by a chemiluminescence detector (Eco Physics GmbH CLD 822 Mhr Analysator) and for the volume fraction of water vapor in the flue gas, SO_x , HCl and CH_4 an FTIR-analyser (Ansyco GmbH FTIR DX4000N) was used. The recording interval during the continuous measurement was set to 10 s. Total particulate matter (TPM) was measured according to VDI 2066-1 applying a filtration temperature during sampling [32]. The filter pre-

treatment temperature was done at 180°C , the post treatment as well as the filtration temperature during sampling were uniformly at 160°C . The boiler was operated at a constant flue gas draught of 12 ± 2 Pa as it is suggested by the boiler manufacturer. The diameter of the flue gas duct and the connection pipe was 10 mm. The TPM-, gas sampling and velocity measurement (v) via a vane anemometer (Höntzsch GmbH, ZS25/25-ZG4) were performed in a narrowed measurement section with a diameter of 80 mm. The temperatures ($T_1 - T_5$) were measured using centrally placed thermocouples to calculate all test results at standard testing conditions (0°C , 1.013 hPa).

Chimney

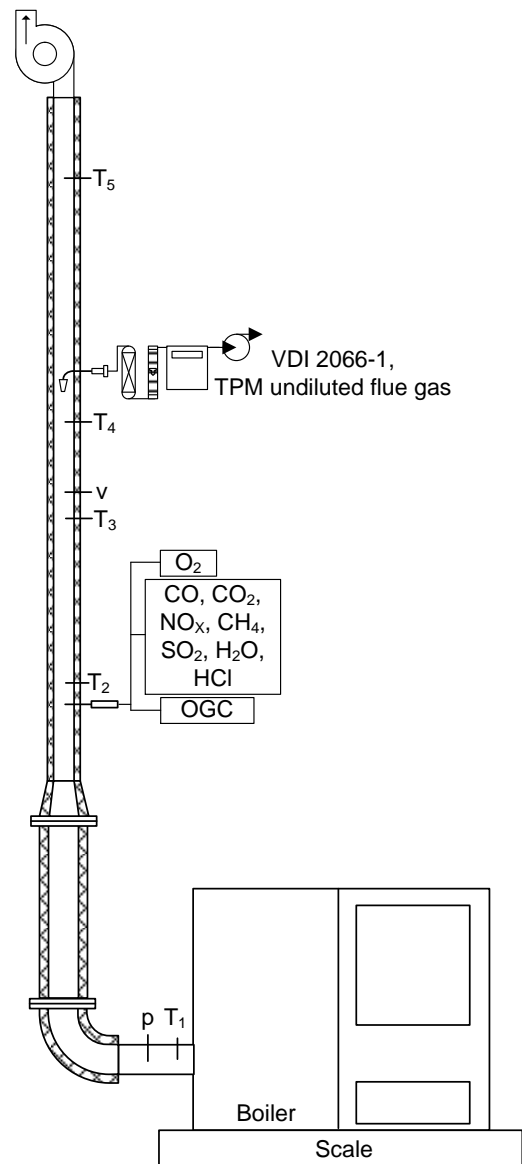


Figure 5: Experimental setup at the TFZ combustion test stand

Table II: Physical and chemical fuel parameters of the produced pellets (mean value \pm standard deviation, d.b. = dry basis, a.r. = as received)

Parameter	Unit	Pure pellets (P)	Pellets A (P - A)	Pellets B (P - B)	Pellets C (P - C)
Contamination		No contamination	Soil A. 2 w-%	Soil B. 2 w-%	Soil C. 2 w-%
Moisture content	w-% (n = 2)	7.21	6.65	7.25	6.24
Diameter D;	mm	D = 5.69 (\pm 0.04)	D = 5.94 (\pm 0.05)	D = 5.97 (\pm 0.04)	D = 5.94 (\pm 0.02)
Length L		L = 14.96 (\pm 5.43)	L = 15.58 (\pm 6.2)	L = 15.88 (\pm 5.78)	L = 15.45 (\pm 5.68)
Ash content (d.b.)	w-% #(n = 11) *(n = 3)	0.83 (\pm 0.06) [#]	2.47 (\pm 0.05) [*]	2.63 (\pm 0.07) [*]	2.45 (\pm 0.06) [*]
Bulk density (a.r.)	kg/m ³ (n = 3)	720	740	740	740
Net calorific value (d.b.)	MJ/kg (n = 1)	18.88	18.42	18.66	18.64
Mechanical durability (a.r.)	w-% (n = 3)	98.6	98.3	98.4	98.8
Fines mass fraction (a.r.)	w-% (n = 3)	0.08	0.16	0.04	0.02
Sulphur (d.b.)	w-% (n = 1)	0.009	0.011	0.009	0.006
Nitrogen (d.b.)	w-% (n = 1)	0.12	0.13	0.09	0.08

2.5 Measurement procedure

Prior to each trial, combustion chamber, heat exchanger and fuel feeding system were completely cleaned using a vacuum cleaner, a brush and compressed air. The storage tank was filled with a sufficient amount of the respective fuel and the boiler was started and heated up to steady state operation at nominal load (15 kW) within approx. 2 h. Then the measurement was performed for 6 h at nominal load operation. During this time, the gaseous emissions were continuously recorded but were evaluated only for the time frames were TPM sampling takes place. Five TPM measurements lasting 30 minutes each were performed and evenly spread over the whole 6 h operation at full load. All reported emissions refer to standard testing conditions (STC = dry flue gas at 0 °C and 1.013 hPa) and are based on a volume fraction of 13% O₂.

3 RESULTS AND DISCUSSION

3.1 Fuel quality

According to the specifications of DIN EN ISO 17225-2 and without considering the chemical analyses, the reference sample was categorized as fuel class A2 [9]. Contaminated batches P - A, P - B and P - C met specifications of fuel class I3 because of the overall increased ash contents. The physical parameters are summarized in Table II.

A visual differentiation of the pellets with soil contamination and the pure pellets was not possible (Figure 6).

**Figure 6:** Experimental pellets; from left to right: P, P - A, P - B and P - C

The moisture content was between 6.24 w-% (P - C) and 7.25 w-% (P - B). Diameter and length of the pellets were similar. The pelletisation of the fuels was performed with the same die (press ratio 1:5).

The samples differed in ash content. For the reference fuel, ash content was 0.83 w-% (d.b.). Due to the maximal diameter of stems suitable for the stationary drum chipper, only stems with a diameter of less than 12 cm could be chipped. The high ash content of the reference sample was assumed to be relatively high compared to typical ash contents of wood pellets from coniferous wood due to the high proportion of bark compared to stem wood. The value of the reference sample was significantly lower compared to the contaminated pellets ($p \leq 0.05$, Student's T-Test). Ash content of contaminated fuels was in the range of 2.45 to 2.63 w-% (d.b.).

The bulk density of the samples P - A and P - C were significantly higher compared to the reference sample ($p \leq 0.05$, Student's T-Test). All values met the requirements of the DIN EN ISO 17225-2 fuel class A1, as well as specifications according to ENplus A1 and DINplus (> 600 kg/m³, a.r.). According to a European pellet screening with 42 samples, the average bulk density of wood pellets is 662 kg/m³ (a.r.). Thus, bulk density of the test fuels was relatively high [2].

The net calorific value for the reference sample (18.88 MJ/kg, d.b.) was higher than the batch P - A to P - C (18.42 to 18.66 MJ/kg, d.b.) due to soil contamination. All values comply with the specifications according to

DIN EN ISO 17225-2 (i.e. A1 > 16.5 MJ/kg), ENplus A1 and DINplus.

So far only sulphur (S) and nitrogen (N) are evaluated. The S content complies with the specifications of DIN EN ISO 17225-2 (A1 < 0.04 w-%, d.b.), DINplus and ENplus A1 specifications (i.e. < 0.03 w-%, d.b.). For N, the standards give a threshold of 0.3 w-% (d.b.). Thus, the reference sample and the contaminated pellets comply with the international and national standards (Table II).

Overall, with exception of the ash content, all physical and chemical fuel parameters that are analysed so far complied with values reported in the literature [2] and met the specifications of fuel class A1 according to DIN EN ISO 17225-2.

3.2 Combustion trials

All fuels were combusted in the 15 kW boiler for 6 h full load operations. During the combustion of the reference sample (P), only three valid measurements were conducted.

The combustion trials with contaminated (P - A, P - B, P - C) had to be interrupted after the second TPM measurement due to severe slagging and high ash content (Figure 7).



Figure 7: Combusting chamber; left: clean and empty; right: after shutdown combusting contaminated pellets filled with ash and slag

The high ash content of the fuels combined with severe slagging due to the mineral soil blocked the fuel level sensor. Thereby, the boiler reduced the fuel feeding into the combustion chamber. As a consequence, the heat output steadily decreased to below 11 kW, i.e. the pre-defined shut down criteria for the trials using contaminated pellets. The duration until breakdown was different for the respective soil contamination:

- Soil A: 118 min (full load operation)
- Soil B: 120 min (full load operation)
- Soil C: 278 min (full load operation)

Without cleaning the grate, a steady state performance of the boiler was not possible. After the second TPM measurements the cleaning mode of the boiler was triggered manually. After cleaning, the boiler was preheated again and two more TPM measurements were operated. After the overall fourth TPM measurement, the manual cleaning mode was triggered a second time and the fifth and last TPM measurement was executed after preheating.

3.2.1 CO emissions

The CO emissions from the reference sample were very low at about 2.6 mg/m³ (Figure 8). Due to the overall low level of the CO emissions and due to the high deviation between individual measurements, an interpretation of a potential effect of the contamination

on CO emissions cannot be made. All CO emissions complied with the current national emission thresholds of the German Federal Emission Control Act (1. BImSchV) [3].

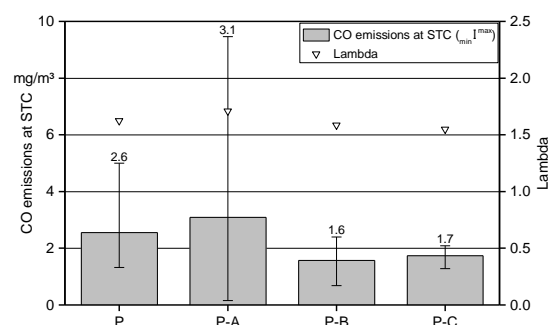


Figure 8: Mean CO emissions and lambda measured for the wood pellets (P) and the contaminated pellets (P - A to P - C). Whiskers indicate the range of minimal and maximal values for the measurements

3.2.2 OGC and NO_x emissions

For the organic gaseous carbon (OGC) emissions no clear trend was observed between pure and contaminated pellets (data not shown). The highest OGC emissions were detected for P - B (0.80 mg/m³). The lowest value was measured for pellets contaminated with soil C (P - C, 0.54 mg/m³).

NO_x emissions were between 179 mg/m³ and 211 mg/m³ (Figure 9). The highest NO_x emissions were measured for the reference sample (P) and the emissions of the contaminated pellets were significantly lower ($p \leq 0.05$, Mann-Whitney-U-Test).

The emissions decreased with the contamination of every soil compared to the reference fuel. The highest nitrogen content in the fuel was found in P - A (0.13 w-%) and in the reference sample (P). The mechanism behind the results is still unknown, because the remaining chemical analyses of the reference sample, the contaminated pellet samples and the soils are still ongoing. Further considerations are needed to get a detailed explanation about the positive effect of the soil on the NO_x emissions. One explanation may be the dilution of the fuel due to the contamination with soil.

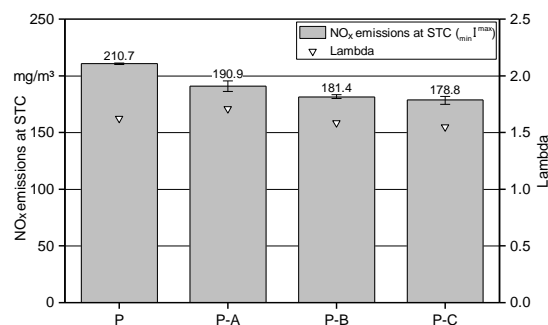


Figure 9: NO_x emissions and lambda measured for the pure pellets (P) and the contaminated pellets (P - A to P - C). Whiskers indicate the range of minimal and maximal values for the measurements

3.2.3 HCl and SO_x emissions

For the HCl emissions (data not shown) no clear trend was observed between pure and contaminated fuels.

The highest HCl emissions were detected for pellets with soil A (P - A, 1.64 mg/m³). The lowest value was detected for P - B and P - C (< 1 mg/m³). The HCl values complied with the emissions values of the current national thresholds of the German Federal Emission Control Act (1. BImSchV) (HCl < 20 mg/m³) [3].

The SO_x emissions increased significantly ($p \leq 0.05$, Student's T-Test) due to contamination with mineral soil compared to the pure fuel (Figure 10). The S content of P - B and P - C was lower than the reference sample (Table II). A final interpretation of the SO_x emission values also requires data on other chemical elements in fuels (e. g. Al or Si, see section 3.2.3). However, this calculation is still ongoing.

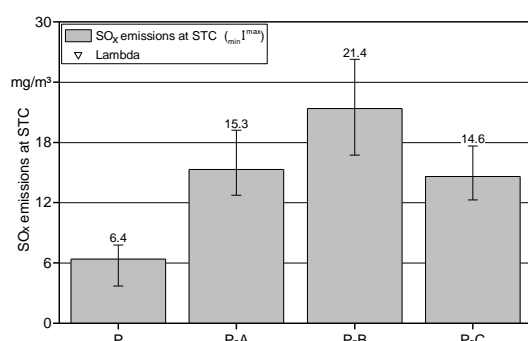


Figure 10: Mean SO_x emissions measured for the wood pellets (P) and the contaminated pellets (P - A to P - C). Whiskers indicate the range of minimal and maximal values for the measurements

3.2.4 Total particulate matter emissions

Total particulate matter (TPM) emissions are summarized in Figure 11. The reference sample emitted 33 mg/m³ of TPM during full load operation. This value is close to the German TPM emission threshold of 20 mg/m³, i. e. the TPM emission limit of the 1. BImSchV [3]. Contaminated pellets with soil A to C significantly reduced TPM emissions compared to the reference sample (Figure 11) ($p \leq 0.05$, Mann-Whitney-U-Test). The lowest TPM emissions were measured for the pellets with soil A (P - A).

One explanation for lower TPM emissions might be the abundance of clay minerals in the soils. This effect was also shown by addition of woody and agricultural fuels with the clay mineral Kaolin [14,19-23,30]. For further interpretation of the data, the chemical analyses of the samples are needed. However, the co-occurring increase in SO_x emissions suggest the same effect as for TPM, as Al-silicates in clay minerals tend to fix K that would otherwise form aerosols with S. When K is fixed into the ash, more S can be emitted as SO_x [25]. Another reason for the reduction of TPM may be the slag formation which might impede the release of particles with the flue gas.

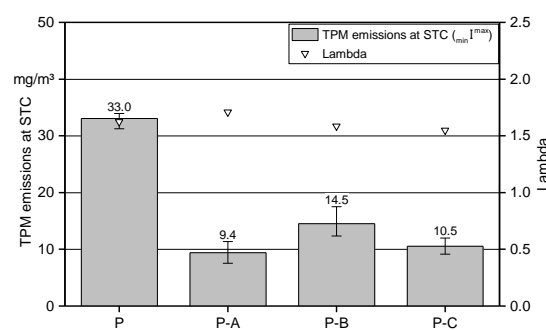


Figure 11: Mean TPM emissions and lambda measured for the wood pellets (P) and the contaminated pellets (P - A to P - C). Whiskers indicate the range of minimal and maximal values for the measurements

4 CONCLUSION

The following conclusions can be drawn from this investigation:

- Soil contamination in pellets (2 w-%, d.b.) cannot be seen visually. The pure reference sample distinguished significantly from the contaminated pellets in ash content (lower). Other differences are expected within the concentration of chemical elements in the fuels due to mixing of wood with mineral soil, especially in values for silicon, aluminium and potassium.
- Careless operation during fuel production, e.g. during logging, chipping or transportation might lead to contamination of wood pellets and, thus, to problems during combustion. All trials with pellets that were contaminated with mineral soil resulted in a shutdown of the pellet boiler within two to four hours of full load operation. Slagging and too high shares of ash in the combustor chamber prohibited constant full load operations. More frequent cleaning of the boiler made an operation possible, but this is unsuitable for practical application.
- No clear trend could be identified regarding CO and HCl emissions but for both parameters, the legal requirements of the current national emission thresholds of the German Federal Emission Control Act (1. BImSchV) [3] were met.
- The NO_x and the TPM emissions decreased with soil contamination, while SO_x emissions increased. This is most likely due to changes in chemical fuel properties and slag formation in the pellet burner. For the final interpretation, the still ongoing chemical analyses are required.

5 OUTLOOK

Some analyses and trials are still ongoing. Following specific cases and open points will be analysed and published in a scientific paper:

- Chemical analyses and interpretation of chemical reactions of the soil in relation to the emissions, including a stoichiometric

calculating of the mass fraction.

- Quantification of the ash of the combusting trials, including a qualitative comparison of the slag index calculated by the PASSA method with the boiler ashes.
- Comparison of slagging, sintering and the emissions with fuel indices.
- Comparison of mineral soil with existing fuel indices to identify contamination [18].
- Combustion trials with beech pellets according to the same experimental design.
- In the course of the project, combustion trials with soil contamination of forest wood chips and wood chips from energy round wood will be performed, as well.

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8 LOGOS

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