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FUEL QUALITY CHANGES AND DRY MATTER LOSSES DURING THE STORAGE OF WOOD CHIPS - PART 2: CONTAINER TRIALS TO EXAMINE THE EFFECTS OF FUEL SCREENING

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Abstract:
Biological degradation during storage may cause high dry matter losses and a decline in fuel quality. This process might increase with a higher amount of fines in the fuel. Therefore, the aim of this study was to monitor dry matter losses and fuel quality changes of screened (particle diameter > 8 mm) and unscreened (as received) wood chips. These two variants were observed for five different raw materials of fresh wood chips. Samples were filled in containers (0.6 m³) with perforated bottoms and were stored in an outdoor shelter for five months. After 23 weeks of storage, the average decrease in moisture content was 21.5 w-% (± 4.2 w-% SD). Average dry matter losses were 8.6 w-% (± 6.1 w-% SD). Screening of wood chips led to a positive drying effect and also dry matter losses were smaller compared to unscreened samples. Accordingly, temperature difference between wood chips and ambient air increased significantly with higher amount of fines. Moreover, the results on drying and dry matter losses during the trials with container storage reached similar levels compared to field trials under practical conditions. Therefore, small scale container trials can be a simple method to assess storage behavior of wood chips on larger scales.

Keywords: wood chips, fuel quality, storage, dry matter losses, screening

1 Introduction

Wood chips quality varies largely due to different raw materials and processing techniques. However, biomass boilers and biomass heating plants require homogeneous fuel qualities to operate efficiently (Noll & Jirjis, 2012; Thörnqvist, 1984), as fuel quality influences boiler operation and emission behavior during combustion. Especially small boilers rely on homogeneous and high quality fuels (Kuptz & Hartmann, 2014). High quality wood chips are characterized e. g. by low and homogeneous moisture contents, low ash contents and a small amount of green biomass, bark and fines (Neuhof *et al*., 2012).

Storage of fresh wood chips is an important step of the biomass supply chain as it is used to compensate for temporal and spatial differences in fuel supply and demand. Moreover, wood chips are frequently stored for drying. The rate of drying however depends on numerous factors. Physical factors of wood chips such as particle size and amount of fines have an influence on drying, but also external factors like air temperature, relative humidity, wind exposure and precipitation are important for natural drying (Pettersson & Nordfjell, 2006). Drying in wood chip piles follows the principle of natural convection (Neuhof *et al*., 2012). Thereby, due to self-heating processes, cold ambient air streams into the pile take up moist and warm air and transport it to the surface of the pile.

At the same time, biological degradation processes during storage may cause high dry matter losses and a decline in fuel quality. These processes might even be enhanced by a large amount of fines. Small particles like needles, small twigs and leaves not only offer a large surface area but are also rich in macroand microelements and build an additional source for microbial colonization (Noll & Jirjis, 2012). Furthermore, free water molecules enhance the biological degradation (Scholz *et al.*, 2004; Hartmann, 2016). Optimal moisture contents for fungal growth are between 30 and 50 w-%. Below a moisture content of 20 w-% no further growth is to be expected. Air temperature is one of the most important external factors affecting not only the rate of drying but also the rate of decomposition. Mesophilic fungi show optimal growth in a range between 20 and 35 °C and tolerate temperatures up to 40 °C, whereas thermophilic fungi show optimal growth rates within a temperature range between 35 and 55 °C (Scholz *et al.*, 2004).

Storage trials to examine the effects of different wood chip properties on dry matter losses are usually done in large field trials. However, such trials consume time and labor and are very cost intensive. Thus, for the current study, container trials were conducted to determine the effect of fine particles on dry matter losses and drying effects. To test the validity of this procedure for future studies, container trials were performed in parallel to field trials (see Hofmann *et al.,* 2016, i. e. part 1 of this study).

2 Material and Methods

In total, five different raw materials of wood chips were stored, i.e. wood chips from forest residues (FRC) of deciduous and coniferous trees, wood chips from energy roundwood (ERC) of Norway spruce (*Picea abies*) and European beech (*Fagus sylvatica*) and wood chips from short rotation coppice (SRC) of European poplar (*Poplar spp.*) (Fig. 1). Each raw material was stored in two variants: screened (particle diameter > 8 mm) and unscreened (as received). Screening was done with a custom built drum screen (hole diameter = 8 mm). Wood chips were filled into 0.6 m^3 containers (Fig. 1). Container bottoms were perforated with holes (2 cm diameter) to ensure natural aeration. To prevent small particles from falling through the holes, a net was placed on top. To insure a microclimate similar to large storage piles, all side walls of the containers were insulated (Fig. 1).

Figure 1: Five raw materials of wood chips used and containers in outdoor shelter (Energy roundwood chips of Norway spruce (1) and European Beech (2), Forest residue chips from deciduous trees (3) and conifer trees (5) and wood chips from short rotation coppice of poplar (4))

Storage was performed over 23 weeks starting in May 2015. The storage took place in a rain and wind protected outdoor shelter to minimize influencing factors on the drying rate such as wind speed and precipitation. Each container was equipped with a temperature sensor in the middle of the container to constantly monitor wood chip temperature. Furthermore, air temperature and relative humidity were recorded in 30 min intervals during the storage period. Moisture content (in w-%) of each type of wood chips was determined before (n=6) and after storage (n=6) according to EN 14774-2 (DIN, 2010a). To compare the effect of particle size and, especially of the fine fraction, particle size distribution was determined according to EN 15149-1 (DIN, 2010b). To monitor mass changes during storage, containers were weighted every third week. Moisture content could only be analyzed before and after the full storage period. Otherwise, storage conditions within the containers would have been disturbed. Accordingly, dry matter losses were calculated by the dry weight before and after storage.

3 Results and discussion

3.1 Particle size distribution and wood chip temperature

Unscreened wood chips of all types could be classified as P31 according to ISO 17225-1 (DIN, 2014a). The only exception was forest residue chips from deciduous trees (P45, see Tab. 1). For three of five assortments, screening had a positive effect on particle size distribution as screened wood chips could now be classified as one of the 'S-classes' according to ISO 17225-4 (DIN, 2014b). Hence, these wood chips could now be recommended for small-scale applications after screening due to higher fuel qualities. In one case, screening had an adverse effect. Due to the loss of the fine fraction, wood chips could neither be classified according to Part 1 nor to Part 4 of the ISO standard. Table 1 shows that approximately 10 to 30 w-% of fine material (particles ≤ 3.15 mm and ≤ 8 mm) were lost due to the screening process.

Table 1: Particle size distribution of wood chips and percentage of particles < 3.15 and 8 mm

Wood chip type	Particle size class (according to ISO 17225-1/-4)	Particles < 3.15 mm [w-%]	Particles < 8 mm [w-%]
FRC coniferous trees [unscreened]	P31 / n.c.*	15.1	34.6
FRC coniferous trees [screened]	P31 / P31S	0.8	14.7
ERC spruce [unscreened]	P31 / P31S	7.5	17.8
ERC spruce [screened]	P31 / P31S	0.2	6.5
FRC deciduous trees [unscreened]	P31 / n.c.*	17.4	33.6
FRC deciduous trees [screened]	P45 / P45S	1.2	6.0
ERC beech [unscreened]	P31 / n.c.*	14.5	30.5
ERC beech [screened]	n.c.* / n.c.*	0.1	1.6
SRC poplar chips [unscreened]	P31 / n.c.*	11.5	34.5
SRC poplar chips [screened]	P31 / P31S	2.0	13.4

*n.c. = non classifiable according to ISO 17225 (Part 1 or Part 4)

Temperature measurements within the containers of unscreened wood chips showed on average higher temperatures compared to air temperature (Tab. 2). Thereby, temperature was higher compared to the respective screened variant. After two days of storage, ERC of beech reached an overall maximum of 39.1 °C. The FRC of deciduous trees also showed peak temperatures during the first days, whereas all other variants reached maximum temperatures during the hot and dry summer months. The reason for the different temperature development might be explained by the different moisture contents at the beginning of storage. The moisture content of FRC of deciduous trees and ERC of spruce had moisture contents between 33 and 40 w-% which is within the optimal range for fungal growth (Scholz *et al.*, 2004; Hartmann, 2016). Storage of all other variants started at higher moisture contents, therefore they had to dry first in order to reach optimal fungi growth rates.

Interestingly, temperature increase in the small storage containers was lower compared to temperature increase in larger storage piles (see Hofmann *et al.,* 2016, i. e. part 1 of this study). Thörnqvist (1985) made similar observations in his study. Due to their small storage volume, temperature in small piles (< 120 m³) usually follows ambient air temperature.

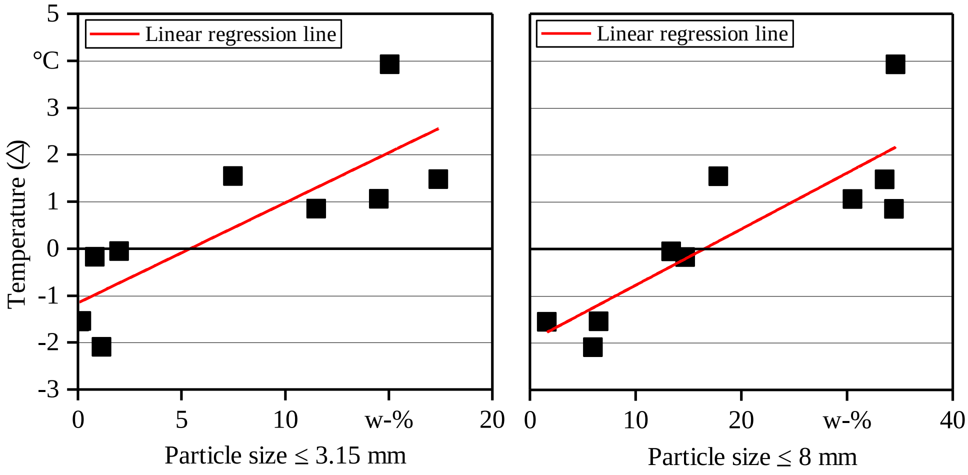

Figure 2: Correlation of the share of particles having a particle size ≤ 3.15 mm (left figure**) and a particle size ≤ 8 mm** (right figure) **and temperature** (Δ = difference in wood chip and ambient temperature) **of all wood chip types and variants**

The temperature difference (Δ) between ambient air and wood chip temperature positively correlated with the amount of fines ($p \leq 0.05$, Pearson correlation; Fig. 2). The larger the fine fraction (particles ≤ 3.15 mm), the higher was the temperature development in wood chips. A large amount of fine particles can lead to a decrease in aeration, causing a heat accumulation within storage containers. Moreover, they display a larger surface for microbial infection and usually they also provide a larger share of easily available nutrients for microbial communities enhancing their growth and thus, enhancing self-heating of storage piles. This effect was distinct for the amount of particles ≤ 8 mm.

3.2 Metereological data and weight losses

During the storage period, mean air temperature from May until October was 19.0 °C and relative humidity was 65.2 %. Temperatures during this storage period were on average 3 °C warmer than during the previous 10 years (DWD, 2016). Especially, during July and August temperatures were high (ø 24.0 °C) and relative humidity was low (ø 57.9 %). Due to a warm and dry climate, weight losses of wood chips ranged from 21 to 53 w-% after 23 weeks of storage. Weight measurements did not show significant differences between unscreened and screened variants. On average, wood chips lost approximately 1.0 w-% per week. Thereby, mean weight losses within this period negatively correlated with the average relative humidity of ambient air ($p \leq 0.05$, Pearson correlation; Fig. 3). Hence, the higher the humidity, the lower the weight losses observed. Overall, screened variants showed smaller deviations in average weight loss compared to unscreened variants. This led to the assumption that drying processes strongly depend on relative humidity.

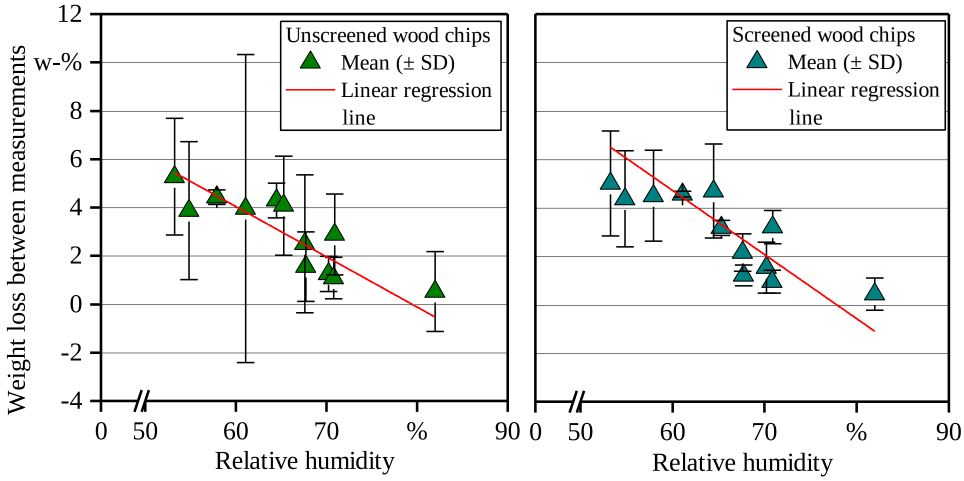

Figure 3: Relative humidity (average daily values between weight measurements) and weight losses between measurements during the storage period

3.3 Moisture content and dry matter losses

During 23 weeks of storage, moisture content on average decreased by 21.5 w-% (± 4.2 w-% SD) for all variants. Thereby, screened variants showed significantly smaller moisture contents compared to their unscreened variants (*p* ≤ 0.05, Students t-Test). With the exception of wood chips from spruce and poplar and the unscreened forest residues chips of coniferous trees, all variants reached moisture contents < 20 w-% after five months of storage (Tab. 2). Therefore, all these variants could be declared as 'stabile in storage'. In contrast, variants with moisture contents > 20 w-% could be exposed to decomposition due to microbial activity even after five month storage. Therefore, longer storage duration might have caused even higher dry matter losses for poplar and spruce chips and for the unscreened variant of FRC of coniferous trees.

Table 2: Moisture contents before and after storage (Δabs: difference absolute), average temperature increases in containers and dry matter losses

Raw material [unscreened/screened]	**Moisture content [w-%]**		**Average temperature (Δ*) [°C]**	**Dry matter losses [w-%]**
	0 weeks	**23 weeks (Δabs)**		
FRC coniferous trees [unscreened]	49.6	25.9 (-23.7)	22.9 (+3.9)	11.6
FRC coniferous trees [screened]	46.3	19.3 (-27.0)	18.8 (-0.2)	7.5
ERC spruce [unscreened]	51.2	30.4 (-20.8)	20.5 (+1.5)	8.7
ERC spruce [screened]	51.7	27.9 (-23.8)	17.4 (-1.5)	4.2
FRC deciduous trees [unscreened]	33.2	19.7 (-13.5)	20.0 (+1.1)	4.2
FRC deciduous trees [screened]	32.7	16.1 (-16.6)	17.4 (-1.6)	1.7
ERC beech [unscreened]	39.4	19.3 (-20.2)	20.4 (+1.5)	7.0
ERC beech [screened]	39.3	16.2 (-23.1)	16.9 (-2.1)	4.0
SRC poplar chips [unscreened]	68.9	49.1 (-19.8)	19.8 (+0.8)	21.7
SRC poplar chips [screened]	67.5	41.3 (-26.2)	18.9 (-0.1)	15.5

*difference between wood chip temperature and air temperature

Mean dry matter losses for the five month storage period measured 8.6 w-% (± 6.1 w-% SD). Overall, screened variants showed smaller dry matter losses compared to the respective unscreened variant (Tab. 2). Furthermore, moisture content at the beginning of the storage period strongly correlated with dry matter losses ($p \leq 0.05$, Pearson correlation; Fig. 4). This might be due to the fact that these wood chips were exposed to optimal moisture contents for fungal growth, i. e. 30 – 50 w -%, for a longer period of time.

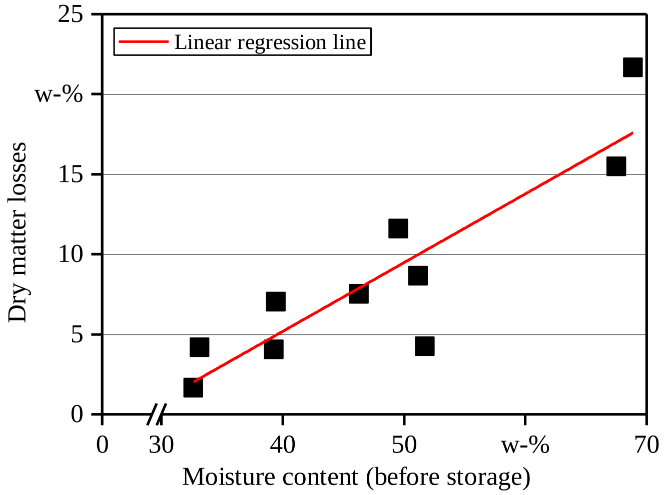

Figure 4: Correlation between moisture content before storage and dry matter losses after storage of wood chips

In large storage piles (see Hofmann *et al.,* 2016, i. e. part 1 of this study) dry matter losses were 11.1 and 6.9 w-% for forest residue chips and energy roundwood chip pile, respectively; both piles had been arranged with rain protection. Therefore, even if the temperature development in containers was substantially smaller, dry matter losses of the two assortments reached similar levels as in the field.

4 Conclusion

Screening of wood chips not only leads to better drying but also to smaller dry matter losses during storage. The study confirmed that drying and dry matter losses depend on numerous external and physical factors such as the amount of fines or ambient air humidity and that these factors are also interdependent. Thereby, screening of wood chips usually leads to higher fuel quality and a favorable classification according to ISO 17225-4. However, due to the screening process approximately 10 to 30 w-% of wood chips are separated and may be regarded as loss if no commercial use can be found. Higher fuel prices of the screened material may compensate for this loss but profitability of screening might be critical on an economic basis. Hence, there is a need for further investigation concerning the effectiveness and profitability of screening processes on fuel quality and drying of wood chips in large storage piles.

The results on drying and dry matter losses during the trials with container storage had reached similar levels compared to field trials under practical conditions. It may therefore be concluded that trials using small storage containers (0.6 m³) can be an applicable and relevant low cost method to assess storage properties of various fuel treatments and drying stages. But further validation of this finding is needed.

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