EVALUATION OF SCREENIG AND DRYING AS PROCESS STEPS TO IMPROVE FUEL PROPERTIES OF LOW QUALITY WOOD CHIPS FOR THE USE IN SMALL-SCALE GASIFIER-CHP PLANTS

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ABSTRACT: Small-scale wood gas CHP plants might strongly contribute to the energy transition from fossil fuels to renewable energies. Currently, raw material assortments of high quality such as stemwood are usually combusted in these plants. In the future, increasing shares of low quality fuels from circular or cascade use will have to be gasified. These fuels can cause problems for failure-free plant operation due to their high fuel heterogeneity and their lower chemical and physical fuel properties. In this study, three different supply chains for processing low quality wood chips by screening and drying were investigated. Processing was tested with wood chips from forest calamities and from road side maintenance. Without processing, fuels were unsuitable for combustion in small-scale wood gas CHP plants due to high moisture contents (> 42 w-%) and exceeding particle length. After processing, moisture content, ash content and the fine and coarse particle fractions were reduced. Upgraded fuels were applied in three commercially installed wood gas CHP plants. Thereby, results indicate that a decrease of moisture content, ash content and the fine particle fraction can lead to an increase in electrical efficiency.
Key words: wood chip, upgrading, gasification, combined heat and power generation (CHP), fuel quality.

1 PURPOSE

The share of renewable energies in power generation will increase in the future. In addition to fluctuating power sources such as solar and wind energy, the contribution of decentral small-scale wood gas CHP plants will be important as they help to balance volatile energy production and are therefore needed for the stabilization of the electricity grid. These plants require wood fuels with high physical and chemical fuel properties for energy efficient and failure-free plant operation.

Considering a growing competition for high quality wood for material use (e.g. for biorefinery processes), biomass residues from circulatory and cascade use might increasingly be applied in small-scale wood gas CHP plants [1]. Due to the high heterogeneity of such low quality wood fuels and their overall higher shares of fuel properties that are considered critical for combustion and gasification compared to stemwood, failure-free plant operation is a challenge. Flexible, energy efficient and cost-effective secondary fuel processing steps such as screening and drying are necessary to increase fuel properties of low quality fuels and make them suitable for the use in small-scale CHP plants.

2 MATERIAL & METHODS

During this study, two wood chip assortments were processed by screening and drying, i.e. wood chips from forest calamities (windthrow and bark beetle attacks) and from road side maintenance while a third trial with chemically untreated scrap wood is still ongoing. Dried and screened wood chips from stemwood of Norway spruce (*Picea abies*) were gasified as a reference.

All raw materials were chipped using the same self-propelled chipper (Albach Diamant 2000). New sharp knives were installed before each hacking process. The machine was always operated by the same driver to avoid an influence of the chipping process on the fuel quality (Figure 1).

Figure 1: Chipping with the self-propelled Albach Diamant 2000 (left) was carried out with new and sharp knifes (right)

The wood chips from calamity wood and from roadside maintenance were upgraded by screening and drying in three supply chains while the reference wood chips were only upgraded in supply chain I (Figure 2):

I. Continuous drying in a walking floor dryer (Spanner Re²) with a subsequent continuous screening in a self-constructed, small-scale drum screen with round holes (48 mm) and rectangle holes (3 × 20 mm)
II. Continuous drying in a walking floor dryer (Spanner Re²) which represent at the same time the bunker of the gasification plant (see below) with a continuous sieving in the screw conveyer of the plant (round holes: 4.5 mm and rectangle holes: 50 × 85 mm)
III. Batch drying in a self-constructed container dryer (15 m^3) and screening in a self-constructed drum screen (rectangle holes, 10 mm and 40 mm)

All drying techniques use heated air for drying (i. e. excess heat from small-scale wood gas CHP plants, see below).

Fuel property analysis was performed before, in between and after processing according to international standards for solid biofuels listed in Table I (particle size distribution (n = 5), ash content (n = 5), moisture content (n = 10), net calorific value (n = 5) and elemental composition (n = 1)). The analysis of chemical elements and some net calorific values are still ongoing.

Figure 2: Screening in supply chain I (up) and in supply chain III (down)

Table I: International standards to determine the physical fuel properties of solid biofuels (d.b. = dry basis)

Parameter	Unit	ISO Standard
Moisture content	w-%	18134-2
Ash content (d.b.)	w-%	18122
Net calorific value (d.b.)	MJ kg^{-1}	18125
Particle size distribution	w-%, mm	17827-1

After processing, fuels were employed in three different commercially installed wood gas CHP plants (Figure 3). Thereby, fuels from each supply chain were gasified in at least two of the three plants.

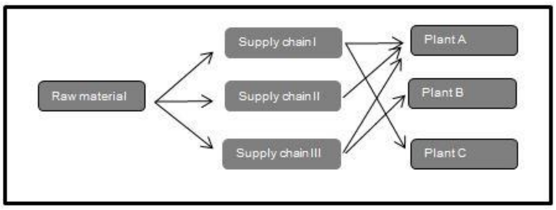

Figure 3: Simplified flowchart in the experiment

The plants used in the project were constructed by Spanner Re^2 GmbH (Neufahrn i. NB., Germany). The gasifiers produce wood gas according to the direct current principle with a fixed bed. The plants generate both electricity and heat. The overall generated power depends on the individual system components that are applied. Figure 4 shows an example for a Spanner Re^2 wood gas CHP plant as it is used in this project. The three plants A to C differ only in their engine and their cooling systems.

Figure 4: Gasification unit (HKA 35/45/49 Spanner Re^2) [2]

Plant A is a HKA 45 which is installed on the manufacturer's premises, Spanner Re^2. It supplies 45 kW of electrical power as well as 100 kW of thermal power. Plant A was used as a reference. Processed materials from all supply chains were gasified in this plant to ensure a high comparability between fuels (Figure 3). Thereby, plant A comprises supply chain II, i.e. the bunker of plant A is the walking floor dryer of supply chain II and the screw conveyor system between bunker and CHP plant allows for screening of the fuels. Fuel processing was not applied on already processed fuels (i.e. coming from supply chain I and III).

Plant B is located on an agricultural farm that is also the location of supply chain III (Figure 3). It is a HKA 35 that was upgraded with a more powerful engine. It currently delivers about 50 kW electric power and 110 kW of thermal power.

Plant C is also located on an agricultural farm and uses the materials that are processed in supply chain I. It is a HKA 35 with its original engine that provides 35 kW of electrical power and 80 kW of thermal power.

According to the manufacturer Spanner Re^2, moisture content, particle size distribution and ash content are the most important fuel properties in order to ensure energy efficient and failure-free plant operation [3]. The moisture content of the wood chips should not exceed 13 w-% for ideal reactions in the gasifier unit. Particle size distribution should be low in fines (i.e. particles $\leq$ 3.15 mm) and oversized particles (> 45 mm), with a maximal length shorter than 150 mm, since these can lead to blockages in the feeding system and to increased shares of tar in the product gas [3]. Increased ash contents and individual chemical elements also have negative effects on failure-free plant operation as they influence ash melting temperature (slagging) [4].

During fuel processing and gasification, energy balances (electrical and thermal) and throughput rate were recorded.

3 RESULTS

Gasification trials with the reference material, the calamity wood (i.e. forest residues derived from bark beetle attacks) and the wood from road side maintenance were already performed while trials with scrap wood are still ongoing.

3.1 Moisture content before and after drying

Before drying, raw materials had typical moisture contents of recently harvested wood of 43 w-% (calamity wood) and 50 w-% (road side maintenance wood, Figure 5) [6]. Thus, moisture contents strongly exceeded 13 w-% as it is recommended by the plant manufacturer.

Within every supply chain, the moisture content strongly decreased due to the used drying systems (Figure 5). In all cases, the recommendations regarding the maximal moisture content of 13 w-% could be met. The individual drying systems differ in moisture content homogeneity after drying. Thereby, the batch processes (supply chain III) provided moisture contents with a higher standard deviation compared to continuous drying systems (supply chain I and II).

Concerning the time required for drying, no direct comparison between supply chains is possible because the thermal power used for the drying process differed significantly. For instance, wood chips in supply chain I were dried with a maximum thermal power of more than 300 kW, while in supply chain III only a maximum power of about 100 kW was available for the drying process. In addition, ambient air temperatures that also affect the drying process strongly differed in between individual drying periods of the same supply chains.

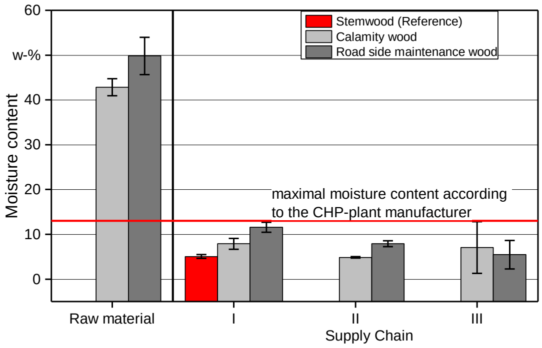

Figure 5: Moisture content (in w-%) for the raw materials and after processing with the three supply chains and maximal moisture content (mean values ± standard deviations)

Considering the overall drying success, the three applied drying systems differ also in terms of disturbance and workload for the operator. Drying in supply chain I facilitate continuous drying but the dryer is not included into the CHP plant. Thus, the same workload for transferring wood chips as in supply chain III is necessary. In contrast, supply chain II is integrated directly into the storage bunker of the CHP plant and, thus, requires no additional work after processing. Supply chain III requires a high level of manpower to operate. After the screening step, the batch dryer has to be filled manually. After drying, the material has to be transported into the bunker of the CHP plant.

3.2 Ash content and particle size distribution

Ash content (on dry basis) of the reference material was significantly ($p<0.05$, t-test) lower than that of the calamity wood and the wood from road side maintenance (Figure 6) The ash content of the unprocessed calamity wood was 0.8 w-% (dry basis (d.b.)) and therefore lower than the usual ash values for this assortment. [6] This indicates that the used assortment consists to high shares of stemwood and has only low amounts of bark or needles [6].

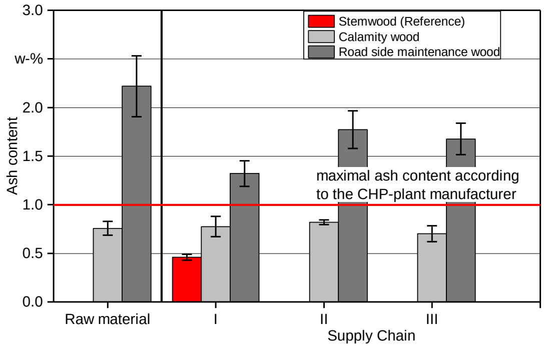

Figure 6: Ash content (in w-%, dry basis) for the raw materials and after processing with the three supply chains (mean values ± standard deviations) and the maximal ash content

In the case of the calamity wood, no difference in ash content was measured before and after screening (Figure 6). This was rather unexpected as the ash content of the fine particle fraction was much higher (e.g. 3.61 w-% (d.b.) in supply chain I). As the mass fraction of the screened fines was 12 w-% of the whole raw material, ash content of the processed calamity wood chips should be much lower (i.e. 0.37 w-% instead of 0.76 w-% in supply chain I). As ash content of calamity wood after processing was on a similar level in all 3 supply chains, the value for the unprocessed raw material might be too low, probably due to sampling of the material in the field. This is consistent with the findings from previous studies that found a reduction in ash content through screening [5].

In case of the road side maintenance wood, the ash content of 2.2 w-% (d.b.) decreased by the treatment in every supply chain (Figure 6). Thereby, supply chain II reached the lowest ash content of approx. 1.3 w-% (d.b.). Only reference stemwood and calamity wood met the maximal ash content of 1.0 w-%.

Table II: Fuel-related disorders in the respective CHP plant in relation to the supply chain and the raw material

Raw Material	Supply chain	Disorders per CHP plant		
		A	B	C
Reference	I	1	0	0
Calamity wood	I	6	/	8
	II	1	/	/
	III	3	0	/
Road side maintenance wood	I	4	/	2
	II	7	/	/
	III	0	1	/

No clear correlation could be observed between the ash content and the functional stability of the CHP plants (Table II). For example, ash contents of the road side maintenance wood in supply chain II and III had similar values after processing. Both materials were gasified in the CHP plant A. In the case of the material from supply chain II, a total of 7 fuel-related disorders appeared in the system. The material from supply chain III, on the other hand, could be gasified without a fuel-related disturbance (Table 2). Plant malfunction was recorded by the individual plant operators and no qualitative assessment was provided on the type of disturbance. Thus, plant malfunction might also be due to other parameters such as particle size distribution or the concentration of chemical elements. At the current moment, without knowledge about the concentration of chemical elements in the fuels, no final conclusion is possible on whether plant malfunction is related to ash content, particle size distribution or the formation of slag.

Regarding particle size distribution, the reference material (stemwood of Norway spruce) contained significant lower masses of very fine particles (≤ 3.15 mm) and oversized particles (> 45 mm) compared to the other fuels (Figure 9 and Figure 10). These differences were also visible by optical assessment of the processed wood chips (see Figure 7 and Figure 8).

In the case of the wood chips from calamity wood, processing by screening resulted in a reduction of both the coarse and the fine fraction (Figure 9 and Figure 10). In case of the wood chips from road side maintenance, no reduction of fines was recorded for supply chain II. This was most probably due to water vapor condensing on the screen within the screw conveyor. Due to the very low outside temperatures at the time of the experiment (December 2018), the condensation water froze and, thus, restricted the functional capability of the sieving unit. This explanation is supported by the results from previous projects which show a clear correlation between fines reduction and functional screening [5].

Figure 7: Reference wood chips (stemwood of Norway spruce) after processing in supply chain I (size of the rectangle frame = DIN A5)

Figure 8: Road side maintenance wood chips upgraded in supply chain I (size of the rectangle frame = DIN A5)

The most effective way to reduce the amount of fines was screening in supply chain I. The continuous screening using rectangle holes (3 × 20 mm) (Figure 2) provided the highest degree of separation in the tested materials. In case of oversized particles, the screening method of supply chain III, i. e. the drum screen with 50 mm round holes gave the best results (Figure 2).

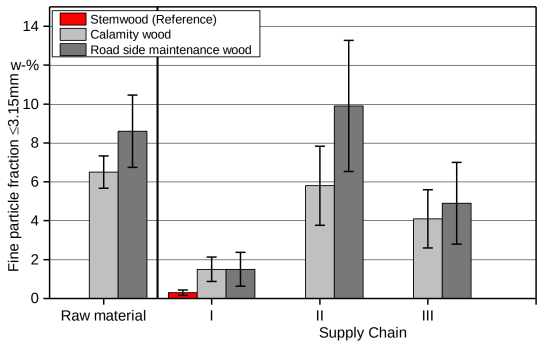

Figure 9: Fine particle fraction (≤ 3.15 mm) in w-% for the raw materials and after processing with the three supply chains (mean values ± standard deviations)

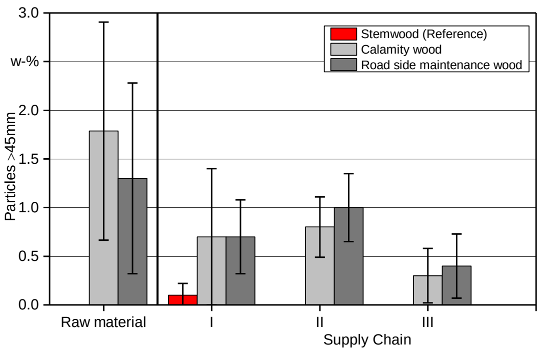

Figure 10: Coarse particle fraction (> 45 mm) in w-% for the raw materials and after processing with the three supply chains (mean values ± standard deviations)

3.3 Gasification suitability and efficiency

The calculation on energy efficiency of the gasification process in the individual power plants is still ongoing. For the final calculation, the results on the concentration of chemical elements (and the net calorific value) in the fuels are necessary. These were not yet completed at the time of the conference. For this reason, the results on electrical efficiency of an example system that is discussed below are preliminary and database values on element concentration in fuels were used to calculate the net calorific values.

In Figure 11, the preliminary electrical efficiency of plant A that was linked to supply chain II is displayed together with the content of fines (particles ≤ 3.15 mm) in the fuels. Electrical efficiency decreased with increasing fines. Although this effect was rather small, the findings coincide with the manufacturer's fuel recommendations that identify low fines as one of the most important parameters for efficient operation.

Comparing the influence of the fine fraction on the electrical efficiency with the influence of the moisture content (Figure 13), it can be seen that the influence of the moisture content is less pronounced. Still, the electrical efficiency tends to decrease with increasing moisture content.

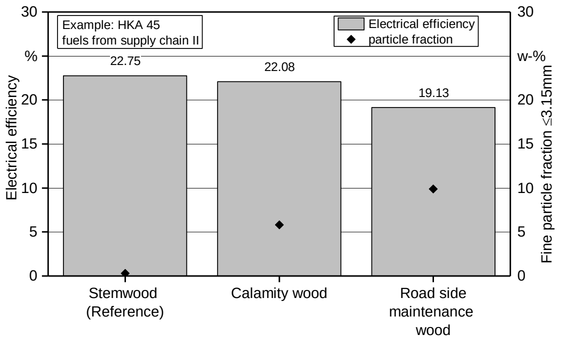

Figure 11: Electrical efficiency (in %) of plant A compared to the fine fraction (≤ 3,15 mm in w-%) for fuels processed with supply chain II

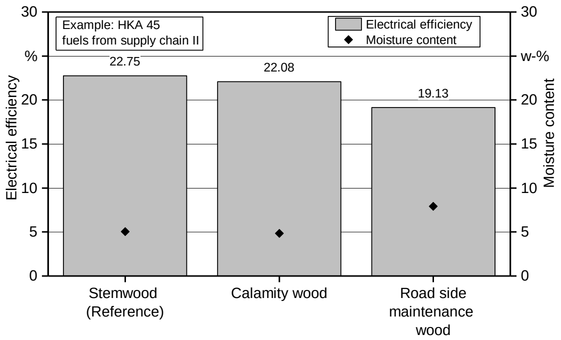

Figure 12: Electrical efficiency (in %) of plant A compared to the moisture content (w-%) for fuels processed with supply chain II

4 CONCLUSION

Results on fuel quality indicate that none of the unprocessed raw materials would be effectively usable at the CHP plants without secondary fuel treatment due to high moisture contents or unsuitable particle size distributions. After upgrading in the supply chains, low quality wood chips were suitable for the combustion in the investigated small-scale CHP plants. This assessment coincides with the experiences of the involved plant operators. Still, even with the processed fuels, more plant disturbances were recorded compared with the combustion of stemwood. Thus, using these fuels requires trained plant operators.

Individual processing techniques differed in terms of final fuel quality, but also in investment costs and required manpower. Final calculations and the trial with scrap wood are still ongoing. However, the results already confirm that operation of wood gas CHP plants with processed wood chips from low quality raw materials is possible and might contribute to future energy systems.

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7 LOGOS

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