BIOMASS CONDITIONING – AN INVESTIGATION OF THE DEGRADATION PROCESS OF WOODCHIPS AND FOREST RESIDUES DURING STORAGE IN WESTERN AUSTRIA

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Abstract

During the storage of woodchips for heat and energy production wood components are metabolized by fungi causing material losses of up to 5% monthly. Besides the negative economic impact a high risk of auto-ignition of woodchip piles is present. The project "Biomass conditioning" focuses on the determination of the degradation process aiming to theoretically characterize a woodchip pile. To generate a better understanding, quantify the dry matter loss and to minimize the economic damage and the risk of an auto-ignition different test set-ups and practical experiments were established.

Key words: *bioenergy, biomass, woodchip, wood decay, auto-ignition*

1. INTRODUCTION

During the storage of biogenic materials such as wood and other agrarian products, destruction and conversion processes take place inevitably. A diverse spectrum of bacteria and fungi colonize the biomass finding perfect growth conditions which leads to the degradation of the main biomass components such as sugars, cellulose, hemicellulose and lignin. These microbiological processes are for most agrarian products like grain and oilseed manageable and even negligible since they are processed immediately after harvest or stored in dry condition. Since these products are generally of higher value, costly pre-treatment processes are worthwhile. This does not apply for lignocellulose materials such as wood or straw where drying the biomass is in most cases not economic (Kaltschmitt, Hartmann, & Hofbauer, 2009). Woodchips for energy production are harvested during summer season and have to be stored until the beginning of the heating season starting in October or November. During this time especially mold fungi metabolizing cellulose, hemicellulose and lignin are responsible for an economical relevant biomass loss. Data quantizing the weight loss of woodchips differ considerably indicating fluctuations probably due to different used test set-ups, unseasonal conditions and biomass qualities.

Taking a look into literature an annually loss of dry matter of 10-40% is postulated (Scholz, Idler, Daries, & Egert, 2005) (Kaltschmitt, Hartmann, & Hofbauer, 2009) (He, 2012). These studies have demonstrated that especially moisture content, pile temperature, particle size distribution, biomass quality, air permeability and pile geometry influence the degradation process considerable. Other factors such as initial microbial infestation, oxygen availability and the ambient temperature also have to be taken into consideration. For instance woodchips with a small particle size distribution offer a higher surface for microbes to attack and their high amount of fine materials (e.g. needles and sawdust) causes limited air passage leading to higher temperatures. Gjølsjø (1994) showed that heat production in large chunk and firewood piles was relatively small and dependent on ambient conditions. The temperature of woodchips and fine chunk showed higher values (>30°C) and were less dependent on ambient conditions (Gjølsjø, 1994). In another study a maximum pile temperature of 280°C could be measured for forest residues being stored indoor thus bearing a high risk of auto-ignition of the woodchip pile (Jirjis & Theander, 1990). All studies proved a significant correlation between pile temperature and dry matter losses (Buggeln, 1999) (Jirjis, 2005) (Ferrero, Lohrer, Schmidt, Noll, & Malow, 2009) (He, 2012).

In 2011 the research project *Biomass conditioning* has been initiated in cooperation with the South Tyrolean Energy Association, alpS GmbH, Syneco Consulting and as a scientific partner the Management Center Innsbruck. This two year COMET-project aimed to quantify the biomass loss of different woodchip qualities being used in Southern-Tyrol. To generate a better understanding of the degradation process inside a woodchip pile and to minimize the economic damage for district heating plants different test set-ups and practical experiments have been established and compared. By an initial survey where operators of district heating plants have been involved, data of the most commonly used woodchip qualities, storage conditions, pre-treatment methods and storage habits have been collected and evaluated. Based on this survey different approaches to determine the biomass loss and to investigate different storage and pre-treatment methods were defined and will be discussed in subsequent chapters. A follow-up project started in November 2014 aiming to describe the degradation and auto-ignition process inside woodchip piles. This project is being conducted in cooperation with various district heating plants of Western Austria (Tyrol, Vorarlberg, Salzburg) and its subject matter will be presented in this paper.

2. DETERMINING THE BIOMASS LOSS BY DRY MATTER WEIGHT LOSS METHOD

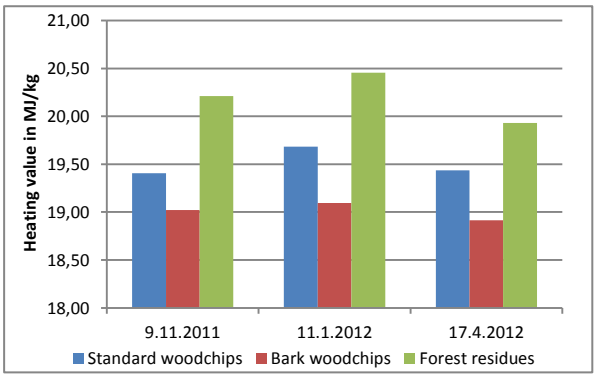
An up to now widely used method to determine the degradation of woodchips is the dry matter weight loss method. In particular sampling bags consisting of a tight meshwork are filled with the biomass of interest, closed and weighed. These bags are placed in either testing piles or real woodchip stocks and are being removed in frequent intervals. To determine the dry matter weight loss the initial water content of the woodchip material has to be measured. In the course of the project *Biomass conditioning* two test set-ups have been prepared: one winter and one summer trial. For each test set-up twelve conical piles with an estimated volume of 15 to 20m³ and a height of about two meters were erected in South Tyrol and are shown in figure 1.



Figure 1: Testing piles of different woodchip qualities in South Tyrol (left) and sampling bags (right).

Three woodchip qualities namely standard woodchips, bark woodchips and forest residues in wet and dry form have been investigated. The temperature and moisture content were measured with a moisture meter every second day. In a monthly frequency three bags out of different layers were removed and dried to determine the dry matter weight loss. As it has already been presented at the 21th European Biomass Conference (2013) the temperature of all piles followed a characteristic course where a maximum temperature of 58°C was reached for all wet bark materials. Also forest residues reached higher temperature values of 51°C which is probably due to a higher content of fine materials leading to a limited air permeability of the pile. No temperature rise could be seen for all dried materials. During this study fungal growth has been determined by streak-plate method indicating that these two materials are more susceptible to microbial degradation and the growth of thermophilic fungi. It is assumed that bark woodchips and forest residues show a higher dry matter loss than standard woodchips. Taking a look at the biomass losses determined by sampling bags a high

statistical spread with an increase of dry matter of up to 18% could be seen (Heinek, et al., 2013). The cause of this inaccuracy is the inhomogeneity of the woodchips in moisture content. Anheller (2009) and Toro (1994) faced similar problems during their studies. In his investigation Toro (1994) could determine a biomass loss of 4.5% to 5.8% for ventilated Salix chip piles and 2.7% to 6.0% for Salix chips stored in sealed containers in a two month trial but also stated methodical difficulties leading to high fluctuations (Toro, Jirjis, & Daniel, 1994). Anheller (2009) determined the biomass loss of recovered wood and bark by using nylon material with a mesh size of 2mm. Similar to our findings most of the sampling bags showed an increase of dry matter after 30 days of storage emphasizing similar methodical problems. Anheller (2009) also stated another reason for high fluctuations in biomass loss. During the drying of woodchips at >100°C volatile extractive compounds are released leading to an underestimation of the dry matter of the woodchips but as long as the initial and final moisture content of the biomass are determined in the same way these differences can be neglected (Anheller, 2009).



Month	Standard		Bark		Forest residues	
	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor
1.	-2	-3	-2	-1	0	-1
2.	-6	-1	-2	-7	0	0
5.	**11**	0	-2	-1	**2**	0
6.	**12**	-18	-6	-8	-2	-2
8.	**8**	-	-	-	**3**	0

Figure 2: Results of the heating value (left) and the dry matter weight loss (right) of the winter storage trial. The loss of biomass is given in % on dry weight basis (Heinek, et al., 2013).

Since the size of our testing piles was in no accordance to real woodchips stocks with up to 100,000Lm³ sampling bags have also been placed in woodchip stocks of three different South Tyrolean district heating plants. During storage temperature and moisture content of the stocks, as well as evolved gas such as carbon dioxide, oxygen, methane, hydrogen and hydrogen sulphide were measured. Figure 3 shows a bar chart contrasting the biomass loss of all sampling bags that could be found in two of the district heating plants after eight months of storage. The materials being used for district heating plant 1 was standard woodchips with a high amount of sawdust and a bark fraction with a water content of 55%. The material being used for district heating plant 2 was forest residues with a water content of 42%. All sampling bags were located up to three meters inside the pile. According to gas measurements all parts of the woodchip piles offered an oxygen-rich atmosphere. Seven out of ten sampling bags could be removed from the stock of district heating plant 1 showing an average biomass loss of 13.6% within eight months of storage resulting in a monthly dry matter loss of 1.7%. As indicated by different colours, the stock of district heating plant 2 could be divided into two main sections: section one (shown in orange) represents the area where the wheel loader had to pass daily leading to a compaction of the material. In this area a maximum temperature of 40°C could be measured. The average monthly dry matter loss amounted 3.3%. In contrast the average monthly dry matter loss of section two (shown in blue), where no compaction of the material occurred amounted 1.0%. These results lead to the conclusion that the temperature enhances the degradation process considerable. This assumption could also be confirmed by respirometric tests which will be presented in chapter 4 (Heinek, et al., 2013).

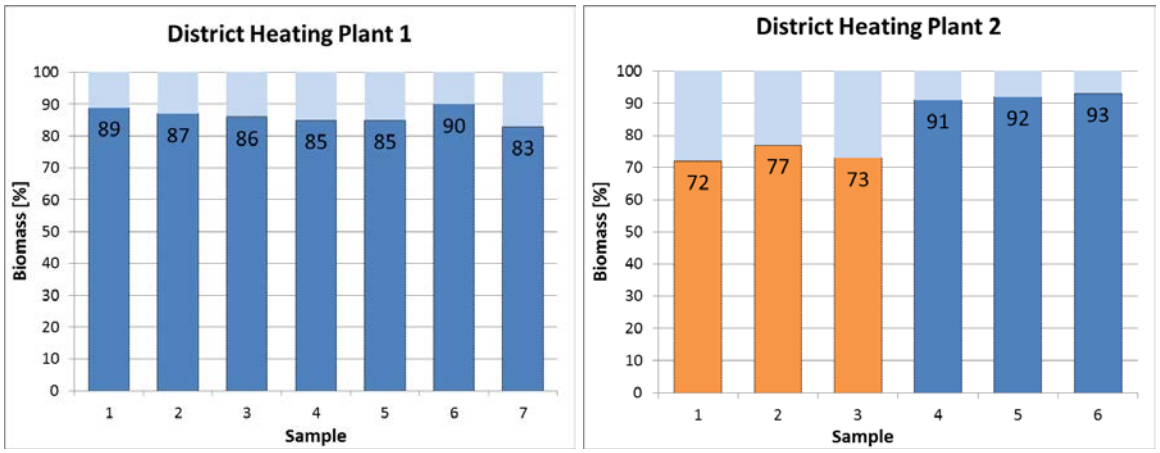


Figure 3: Dry matter losses of all sampling bags of two of the district heating plants (Heinek, et al., 2013).

Various other research groups follow another approach to gain more information about the negative effects of suboptimal storage conditions by measuring the change of the heating value over time. During storage trials several samples are taken from different spots and depth of the woodchip pile periodically and the heating value is determined according to ISO 1928:2009 or other national standards. In our work the heating value of all different woodchip qualities has been determined after two and five months of storage. Figure 2 shows the heating value of all wet woodchip qualities being stored outdoor. A downward trend of the heating value can be seen for bark woodchips and forest residues however also these values were fluctuating and more samples and measurements are necessary to draw an accurate conclusion. Jirjis (2005) described the change of the net heating value of willow chips over a period of three months showing a marginal decrease from 19.57MJ/kg to 19.48MJ/kg. Also other research groups were not able to receive significant changes in calorific value concluding that although the calorific value will slightly decrease during storage, the degradation of biomass will have a greater effect on the overall efficiency and economics of the district heating plant (Graham, Eastwick, & Snape, 2011) (Garstang, Weekes, Poulter, & Bartlett, 2002).

3. THE ASH CONTENT AS AN INDICATOR FOR WOOD DEGRADATION

Another approach to determine the biomass loss over storage time is the analysis of the ash content. During microbial degradation of wood an increase of inorganic matter can be observed which is due to the loss of organic matter (Bakker & Elbersen, 2005). Since this is a cheap and easy approach to determine the dry matter loss, the ash content of all materials has been determined after 9, 22 and 26 weeks of storage according to ASTM E1755-01. Even though the ash content of all standard woodchip materials fluctuated around its initial value no increase of inorganic components could be verified. All bark woodchip piles showed an increase in ash content. The ash content of both dried bark woodchip piles increased from 3.4% to 3.9% indicating a monthly biomass loss of 2.2%. The ash content of both wet bark woodchip piles increased from 3.9% to 5.5% indicating a monthly biomass loss of 5.0%. Determining the ash content of forest residues showed difficulties due to the high inhomogeneity of the material consisting of three different main components such as heartwood, bark and needles (Heinek, et al., 2013).

During this study it could be shown, that the ash content provides a good indicator for determining the biomass loss, however, it is very sensitive and error-prone to inhomogeneous materials such as forest residues.

4. RESPIRATORY TESTS AS A NEW APPROACH

The biodegradability of organic compounds is generally testes by respirometric tests, where evolved carbon dioxide is quantified. During our studies the microbial activity and therefore the wood degradation is determined by a modification of ISO-14852 (1999). Sealed glass reactors were filled with approximately 500g of woodchips and incubated at different temperatures and moisture contents. In order to keep aerobic conditions air is flushed every second day into the reactor at a flow rate of 0.006m3/h. Atmospheric carbon dioxide is removed by soda lime and carbon dioxide evolved during the degradation process is flushed through three washing bottles containing 0.05M sodium hydroxide solution forming sodium hydrogen carbonate. By titration of the solution with 0.02M hydrochloride acid the concentration of sodium carbonate is determined and the concentration of CO_2 can easily be calculated. The set-up of the respirometric tests is shown in figure 4.

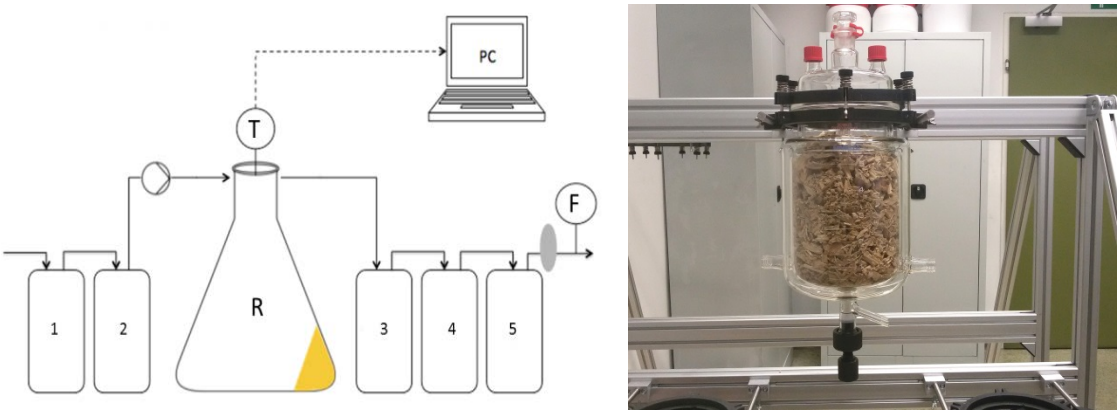


Figure 4: Experimental set-up of the respirometric test (left) and a reactor filled with standard woodchips (right). (1) soda lime, (2) distilled water or silica gel, (3, 4, 5) 0.05M sodium hydroxide solution, (R) reactor, (T) temperature measure, (F) flow measure.

As seen in figure 5 the production rate of CO_2 of all bark woodchips peaks within the first three days reflecting a high metabolic activity and an intense growth rate. Fengel and Wegener (1984) reported that during the first day's microorganism metabolize the easiest-biodegradable wood components such as sugars and amino acids leading to a high release of temperature (Fengel & Wegener, 1984). This temperature increase could be verified at the testing piles in South-Tyrol (see above chapter 2) but not during respirometric tests since produced heat had been transported out of the reactor while measuring carbon dioxide. However, this initial increase in temperature and CO_2 production rate is also a result of the respiration of freshly chipped parenchyma cells trying to rebuild themselves. Comparing bark woodchips with varying water content an average CO_2 production rate of 0.02g/h could be demonstrated. In contrast the CO_2 production of dry woodchips stayed below 0.05g/h during the whole experiment excluding the initial peak. These experiments have been conducted at 20°C. CO_2 production rate of bark woodchips incubated at 40°C fluctuated enormously until the end of the test but always stayed above 0.01g/h leading to 0.04g/h in average. Similar results were obtained for standard woodchips and forest residues (data not shown). This higher metabolic activity of the microbes leads to a higher degradation rate and corresponds to our previous findings by ash analysis and dry-matter weight loss. Ferrero (2009) incubated woodchips at 30°C and 40°C showing a higher carbon dioxide production at higher temperature. They also reported a second CO_2 production maximum after 60 days which is probably due to the sudden available easy-biodegradable fractions being produced by habitat-specific microorganisms (Ferrero, Lohrer, Schmidt, Noll, & Malow, 2009). A monthly biomass loss of 1.7% for wet bark woodchips at 20°C and 4.4% at 40°C could be calculated and correspond to our previous findings by dry matter loss analysis. Drying bark woodchips to a water content of below 25% showed a considerable decrease of CO_2 production leading to a biomass loss of 0.3% per month. No differences could be noticed between w=18% and w=25%.

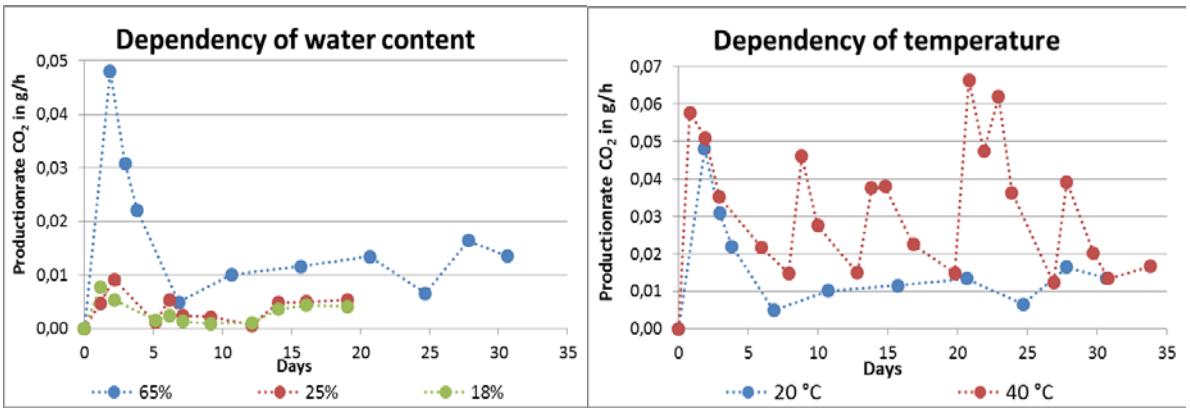


Figure 5: Production rate of CO_2 in g/h over incubation time of bark woodchips in dependency on water content (18%, 25% and 65%) and temperature (20°C, 40°C).

4. CONCLUSION AND OUTLOOK

Summarizing all findings, standard woodchips showed lowest biomass losses and a low microbiological activity. Bark woodchips and forest residues tend to be more susceptible to fungal growth and highest biomass losses could be proved for bark woodchips. Temperature and water availability perform a significant high influence on the degradation process. Increasing the incubation temperature from 20°C to 40°C almost tripled the monthly biomass loss which had already been proved by other research groups (Ferrero, Lohrer, Schmidt, Noll, & Malow, 2009). Drying the biomass to a water content below 25% led to a remarkable reduction of fungal growth and in turn of biomass loss which could be confirmed by field and laboratory tests. However, drying the biomass leads to high costs which have to be considered and calculated.

Taking a deeper look into the different used techniques to determine the biomass loss, difficulties for the dry matter weight loss method and ash analysis method are inevitable. Due to the inhomogeneity of some woodchip materials (i.e. forest residues) problems with determining the water content or inorganic fraction by glowing loss analysis occur, leading to fluctuating and non-reproducible results. A high amount of samples should be withdrawn and also the sampling and homogenisation technique should be carried out carefully. However dry matter weight-loss method is complicated by the structure of a woodchip pile consisting of different layers. Each layer offers varying growth conditions for microbes leading to differences in biomass loss within one woodchip pile. Our findings indicate that the piles consist of three main layers:

- weather layer
- aerobic layer
- anaerobic layer

The outer weather layer is interacting with the atmosphere and its temperature and moisture content depend on ambient weather conditions. This part is assumed to be between 0,2-1,0m deep depending on the woodchip quality and pile shape. The inner aerobic layer incorporates the biggest part of the woodchip pile and offers optimal growth conditions for fungi. The temperature in this area stays mesophilic but also reaches up to 60°C if air permeability is inhibited by compaction or a high fine material content of the woodchips. Due to vaporization and condensation of the water, wet and dry parts alternate in this area. If woodchip piles are high enough the most central part can develop an anaerobic environment. Other factors such as compaction, fine material content and moisture content are triggering the development of an anaerobic zone. Even though it can be assumed, that the biomass degradation is much higher if oxygen is present this zone bears the highest risk for auto-ignition. In the course of the project *Biomass conditioning* gas analysis was conducted at different woodchip stocks in South-Tyrol and in at least two cases methane could be detected. At various locations where steam escaped (“chimney”) methane, carbon dioxide, hydrogen and hydrogen sulphur could be measured.

Processes taking place in this area and their assumed potential for auto-ignition are up to now not well documented and investigated. Further studies have to be conducted to verify this assumption.

Respirometric tests provided accurate and reproducible results showing a high potential to better understand wood degradation processes. In order to further investigate the wood degradation process as well as the auto-ignition of woodchips the follow-up project *Biomass conditioning II* has started in November 2014 in cooperation with Bioenergie Tirol, Syneco-tec GmbH and Management Center Innsbruck. Respirometric tests will be conducted at varying parameters such as temperature (20, 40 and 60°C), moisture content (influence of rewetting of pre-treated woodchips), oxygen availability (aerobic, anaerobic) and particle size distribution. Additionally, laboratory tests will be established for investigating the auto-ignition behaviour. As a second approach, district heating plants of Western Austria will be visited to conduct measurements and visual inspections of the woodchip stocks to further investigate the layer model. By conducting a survey data of currently implemented storage techniques and the occurrence of auto-ignition or pre-stages such as pyrolysis are collected and further used for economical consideration. A catalogue of countermeasures for operators of district heating plants will be elaborated supporting an efficient and economical storage concept.

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