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COLD AIR VENTILATED AND SEALED STORAGE OF WOOD-CHIPS FROM WILLOW

Laboratory Experiments

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SUMMARY

Two storage methods for chipped willows (*Salix spp.*), cold air ventilation and sealed storage, were tested at laboratory scale. Fresh chips were stored in six insulated containers for 62 days in a store-room. Temperature development during storage was continuously monitored. Dry matter losses and fungal spore counts, in the central part of the containers, were determined. Two 1.7 m^3 containers were continuously ventilated with ambient air (mean temperature 2.7° C) at a rate of 175 $m^3 \cdot h^{-1} \cdot t^{-1}$ dry matter. As a control, a third unventilated identical container was used. To test sealed storage, a similar experiment was conducted using two containers of 0.63 m^3. A third, unsealed, container served as a control. These three containers were placed in a room where the average temperature during storage was 14.7° C.

In the central part of the ventilated containers, the average temperature of the chips was close to ambient temperature (average 4° C) during most of the storage period while the temperature in the unventilated container averaged at 32.4° C and a maximum of 42° C. The dry matter losses were 5.2% and 13.3% by weight in the ventilated and the control containers respectively. The total number of micro fungal spores increased by 3-5 times in the chips stored in the ventilated containers but, in the control, it increased more than 100 times.

The temperature in the central part of the sealed containers was close to ambient (14° C), while the maximum temperature of the control was 59.3° C with an average of 28.8° C. Different dry matter losses were measured in the two sealed containers, 2.7% and 6.0%. However, higher loss of dry matter (8.2%) was determined in the control. The fungal growth in the test containers was less intensive than that in the control. The total number of spores was increased by 3-4 folds in the sealed material compared to 60 times in the control.

Keywords: *storage, sealed, ventilated, cold, willow, wood-chips, bioenergy.*

1. INTRODUCTION

During the last few years, many research and development programmes on short rotation forest (SRF) for energy purposes have been carried out in Sweden. Most of the efforts have been concentrated on developing a complete system for willow (*Salix spp.*) in order to reduce the production costs. The results of these studies have led to new clones of high yields, a good knowledge of the cultivation techniques, an efficient planting machine and several types of harvesting machines. Salix plantations in Sweden in 1993 amounts to around 10,000 ha.

One of the main developed harvesting systems is the direct-chipping using a modified maize harvester. The chips are transported and burnt shortly after harvesting in a near district heating plant. In such a system, in order to secure supply and to meet variable demands, a buffer stock should be available. As the moisture content of fresh willow chips is about 50% wet basis, their storage in traditional piles produces problems related to allergy-causing micro spores, dry matter losses, self-heating and risks for spontaneous combustion. These difficulties are well documented from numerous investigations dealing with storage of forest residues (Thörnqvist, 1984) and pulpwood chips (Bergman, 1985).

Since willow cultivation for energy is rather a new concept, the storage studies are few. Rice et al., 1992, observed much higher temperatures and fungal spore development in a chip pile from SRF than from sawmill residues. Due to the high level of micro spores in the SRF pile and the health risk associated with them, they concluded that the material would be very difficult to handle. Similar results were obtained by Thörnqvist (1982), in an experiment using material from wild species of willow, where a considerable increase in temperature and fungal activity as well as high dry matter losses occurred in the chip pile. He also pointed out that intensively cultivated energy wood would presumably deteriorate still more because of its higher content of nitrogen and proportion of juvenile parts.

The problem of self-heating observed during the storage of organic material with high moisture content is attributed to metabolic activity of the plant material and microbial aerobic growth which results in the release of CO_2 and H_2O as well as energy in the form of heat. The accumulation of heat, due to the limited air movement, can continue raising the temperature to over 60° C. At this temperature, chemical oxidation of the material takes place leading to further increase of the temperature which could cause a self-ignition if oxygen is available (Springer et al., 1971).

A possible method to reduce or stop heat accumulation during storage is to ventilate the pile with cold air. Moreover, cooling the material below 15° C will reduce microbial activity too, since most of the storage moulds have their optimum growth at temperatures over 20° C (Bergman, 1985). Cold air ventilated storage could be an interesting method in Sweden since willow plantations are harvested during winter when ambient temperature is low and outdoor air can be utilized for cooling chip piles through forced ventilation.

Another alternative to reduce temperature and mould development is to create anaerobic conditions by sealing the material. Sealed preservation is widely used in agriculture, e.g. silages. However, creating complete anaerobic conditions is expensive, particularly, if large quantities are to be stored. But, if chip volumes are relatively small and utilizing thick polyethylene film, the sealed preservation of wood chips could be attractive (McKee & Daniel, 1966; Feist et al., 1971).

Studies testing these storage methods are few and deal mostly with forest wood chips (Feist et Al., 1971; Hedström, 1991; McKee & Daniel, 1966; Nilsson & Werner, 1988). Hence, a laboratory scale experiment was designed in order to obtain basic data **on Salix chip storage using cold air ventilation and sealed storage.** As financial resources were very limited, the number of replications was a minimum and did not allow a real statistical analysis of the results. Consequently, the objective of the experiment was reduced to obtaining some information for further work. As the results, however, turned out to be interesting, the authors decided to publish them at this preliminary state.

2. MATERIALS AND METHODS

2.1. Biological material

The 5 years old willow plantation, from which the chips were obtained, was grown for energy purposes in the region of Örebro, southern of Sweden. The plantation was directly chipped with a modified maize harvester on 9 February 1993. The Salix chips were transported in a container to Uppsala the following day. The chip temperature at the beginning of the experiment was the ambient temperature, about 4° C, and the average moisture content was 49.4% (±0.5) wet basis (w.b.) determined on 5 samples. The bulk density was 285 kg·m^{3} and the fraction size distribution showed that 60% of the material passed the 16 mm sieve (Fig. 1).

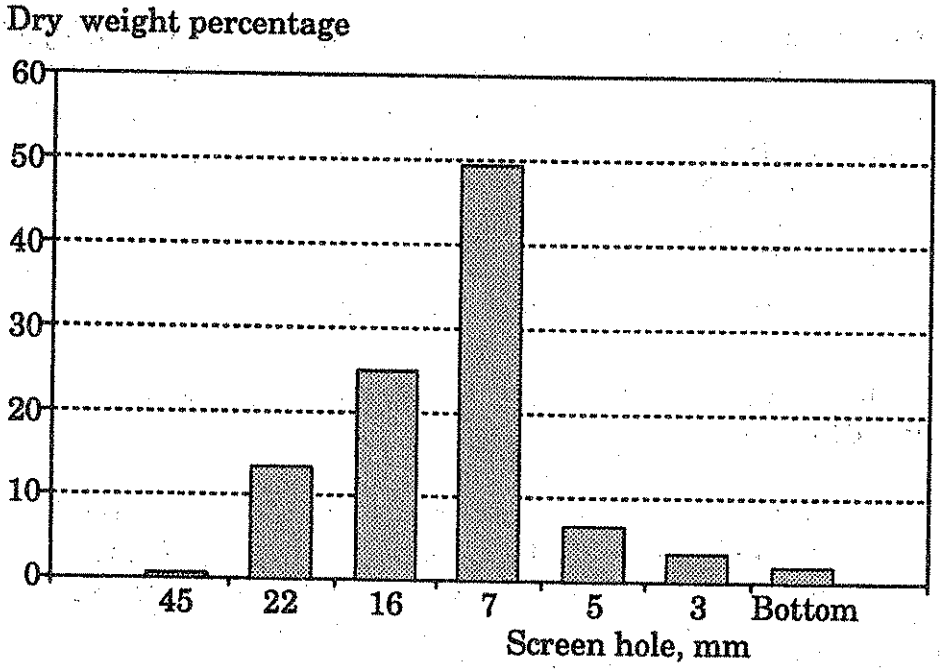

Fig. 1. *The size distribution (% of dry weight) on each screen after 10 minutes screening at the beginning of storage (mean of two samples).*

2.2. Cold air ventilated storage of Salix-chips

The material was stored in 3 steel rectangular containers of 1.7 m^{3} each for 62 days. Two of the containers had a perforated bottom to allow a forced air

ventilation. The air of the store room was sucked in through the material from top to bottom by negative pressured ventilation in order to prevent the heating which occurs when air is blown. The ventilation fan was continuously running at a rate of 175 $m^3 \cdot h^{-1} \cdot t^{-1}$ dry matter. Only the walls of the containers were insulated with 10 cm thick mineral wool in order to prevent heat losses through the walls. The top and the bottom of the containers, air inlet and outlet, respectively, were not insulated. The third container, the control, was unventilated and totally insulated, except for the top where small holes in the insulation material were made to allow air exchange. The three containers were placed in an unheated store-room with an average temperature of 2.7° C from 10 February to 11 April.

2.3. Sealed storage of Salix chips

The fresh chips were stored in insulated cylindrical steel containers of 0.63 m^3 each and placed in a store room with an average temperature of 14.7° C. Two of the containers were completely sealed but provision for pressure variation was made. A rubber tyre tube was connected to each container, acting as expansion chamber. During the experiment, the internal pressure of the two sealed containers was about 200 Pa above the atmospheric pressure, thus no air infiltration occurred. The third container, the control, was not sealed, small holes in the insulation cover were provided to allow air passage.

2.4. Determination of moisture content, dry matter losses and temperature monitoring

Moisture content was determined after weighing and drying 0.5 kg chips at 105° C (± 2) for 24 hours, and expressed on wet basis. For the dry matter measurements, 5 net bags containing about 1 kg chips were placed in the centre of each container. The moisture content was determined at the beginning and the end of the experiment and dry matter losses were calculated. Temperatures were measured and recorded three times hourly during the experiment with an AAC-2 System data acquisition, using encapsulated type-T thermocouples placed at various locations in each container.

2.5. Fungal analysis

Samples from the central part of the containers were taken before and after storage for the determination of mould spores. The total number of mould

spores was obtained using the counter chamber method and viable spores were enumerated by the viable plate count technique at two incubation temperatures: 20° and 40° C following the method described by Jirjis (1989).

3. RESULTS

3.1. Cold air ventilated storage

By the end of the storage period, the material in the control (unventilated) container was clearly deteriorated, dark colouration with zones of fungal white mycelia were visible. During the removal of chip from the container a strong odour and a cloud of spores were observed. The chips stored in the ventilated containers showed no sign of visible deterioration or mould growth.

3.1.1. Moisture content. Despite the continuous forced ventilation, most of the areas in the container were dried by about 2% units (w.b.). More drying took place at the 10 cm top layer (air inlet) which was dried from 49.4% to 36 % moisture content. In the control container the moisture content decreased in the central zones to 36% while the area adjacent to the walls showed an increase in moisture content to 59% (condensation zones).

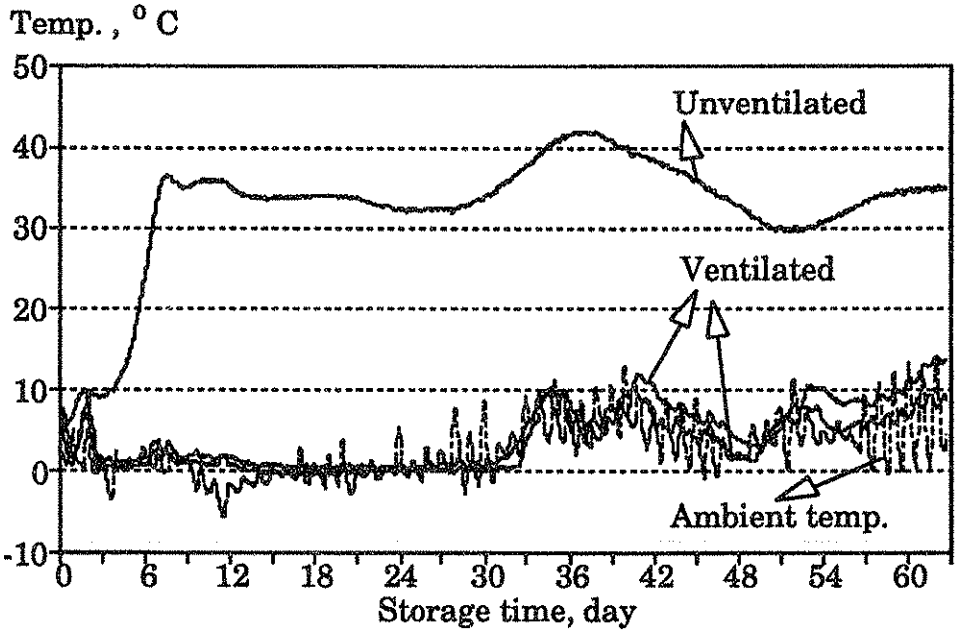

Fig. 2. *Temperature development in the centre of the ventilated containers, control and ambient temperature.*

3.1.2. Temperature. The temperature measured in the centre of the ventilated containers (average 4.0° C) showed a similar profile to that of ambient temperature (average 2.7° C) with less variation. In the unventilated container, the temperature was increased rapidly during the first 7 days,

reaching about 35° C which was maintained for the next 4 weeks. The maximum temperature (42° C) was measured after about 5 weeks of storage. A slow decline in temperature was measured in the last two weeks of storage with a minimum temperature of 30° C (Fig. 2).

3.1.3. Dry matter losses. In the central part of the ventilated containers, after two months of storage, the total dry matter losses were considerable (5.8% and 4.5%). However, much higher losses with an average of 13.3% were obtained in the unventilated container (Fig. 3).

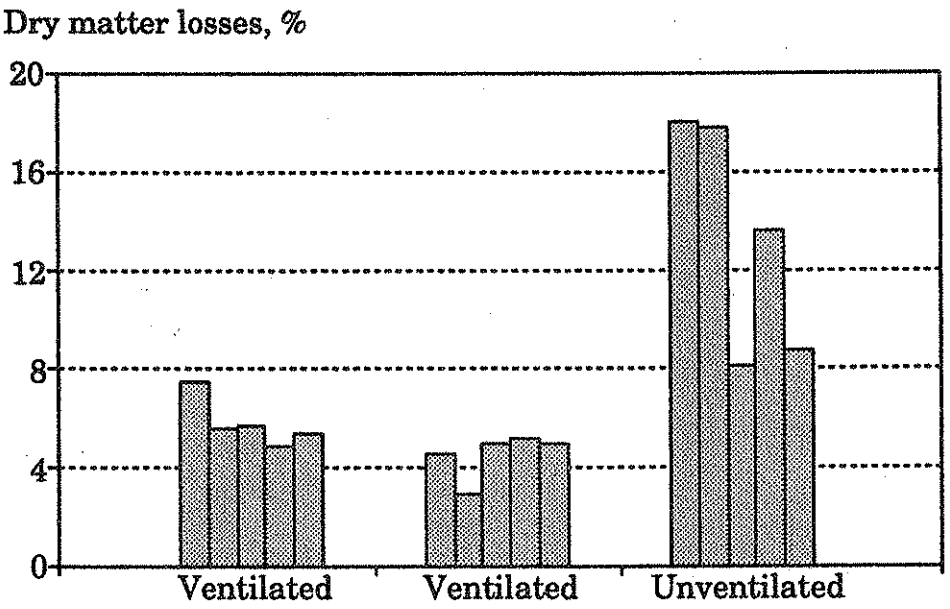

Fig. 3. *Dry matter losses of each chip sample in the two ventilated containers and the control.*

3.1.4. Fungal activity. The total number of fungal spores on the material before storage was 1 x 10^9 spore/kg dry weight (Table 1). The count of viable spores showed that the majority of the spores could grow at 22° C while the presence of thermophilic fungi was below detection limits, around 10^4 (Table 1). After 2 months storage, the total number of microspores increased by about 5 times in the ventilated stored chips. Most of the increase was observed in the mesophilic species (grown at 22° C). Relatively small number of viable spores could be grown at 40° C (Table 1). In the unventilated container, the total number of spores increased by 100 times after 2 months storage. Even more

significant increase was observed in the viable counts at both 22 & 40° C (Table 1). Many species of moulds were observed in this study amongst which *Penicillium sp., Aspergillus Niger, Aspergillus sp. and Paecilomyces variotti.*

Table 1. Number of fungal microspores per kg dry weight in the ventilated storage experiment before and after storage

Sample	Viable spores grown at 22° C	Viable spores grown at 40° C	Total spores count	Total dry matter losses; %
Fresh material	$1.5 \cdot 10^7$	n.d.*	$1.0 \cdot 10^9$	-
Stored material				
air-cold ventilated				
Container 1	$8.4 \cdot 10^7$	$4.5 \cdot 10^4$	$4.0 \cdot 10^9$	5.8
Container 2	$3.4 \cdot 10^7$	$1.7 \cdot 10^4$	$5.8 \cdot 10^9$	4.5
Control, unventilated	$3.5 \cdot 10^{10}$	$2.1 \cdot 10^8$	$1.4 \cdot 10^{11}$	13.3

*n.d. = not detected.

3.2. Sealed storage experiment

The chips stored in the sealed containers looked completely fresh with slightly sour odour. No discolouration or visible growth of fungi was detected. The material in the unsealed container was considerably deteriorated and resembled the chips of the unventilated container in the first experiment.

3.2.1. Moisture content. The initial level of moisture content (49.4%) in the material stored in the sealed containers remained unchanged after 2 months storage. The material stored in the central parts of the control container decreased in moisture content by 6% units.

3.2.2. Temperature. In the central part of the sealed containers, the temperature was very stable and slightly lower than ambient temperature of the storage room (Fig. 4). In the control container, the temperature was increased rapidly during the first 10 days reaching a peak around 60° C, followed by a continuous decline at variable rates reaching around 20° C after 6 weeks of storage (Fig. 4).

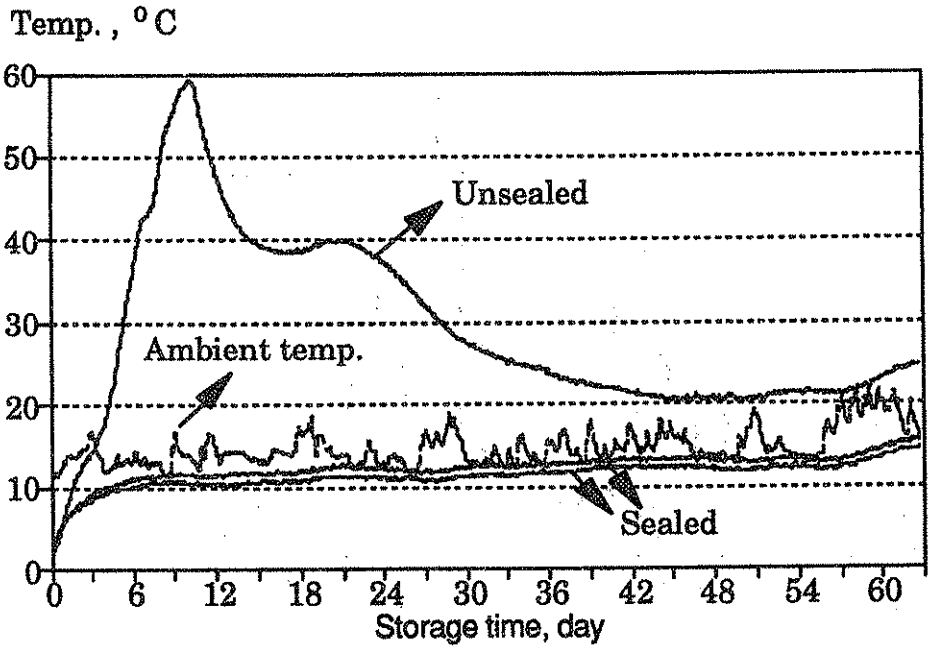

Fig. 4. *Temperature development in the centre of the sealed containers, control and ambient temperature.*

3.2.3. Dry matter losses. The losses measured in the central part of the two sealed containers showed different values. In one of them the dry matter loss was 2.7% while the chip in the other container had 6% dry matter loss. The dry matter loss in the control was 8.2% after two month storage (Fig. 5).

3.2.4. Fungal activity. After storage in sealed containers, the total spore counts were increased by 3 times compared to fresh chips (Table 2). The count of viable spores grown at 22° C was impossible due to the dominant growth of the mould *Trichoderma viride* which prevented the growth of other species. Mould fungi such as *Aspergillus niger and Penicillium sp.* were identified in the cultures incubated at 40° C. The concentration of their microspores on the chips was relatively high (Table 2). Intensive fungal growth was observed in the control container and was reflected by the high number of the viable grown at 40° C

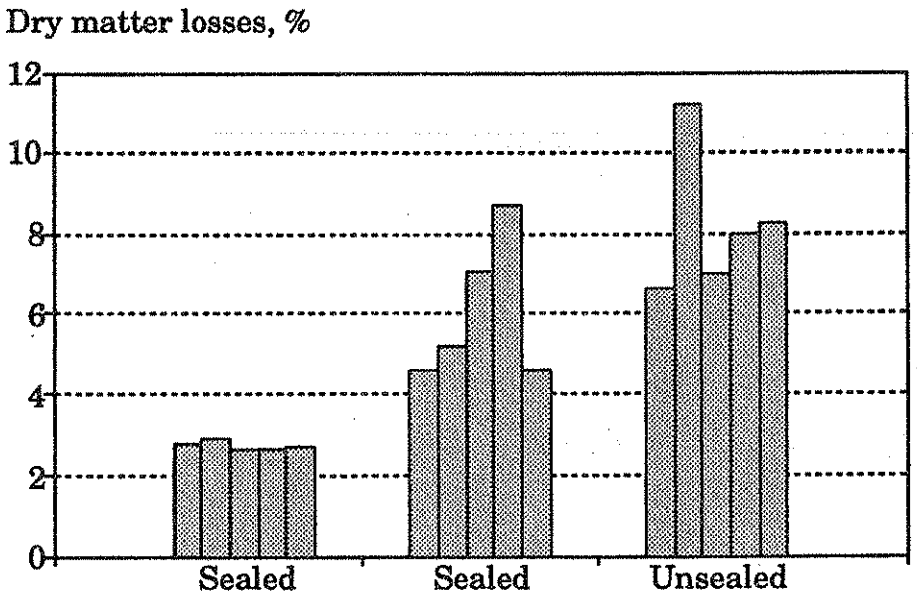

Fig. 5. *Dry matter losses of each chip sample in the two sealed containers and the control.*

Table 2. *Number of fungal microspores per kg dry weight in the sealed storage experiment before and after storage*

Sample	Viable spores grown at 22° C	Viable spores grown at 40° C	Total spores count	Total dry matter losses, %
Fresh material	$1.5 \cdot 10^7$	n.d.*	$1.0 \cdot 10^9$	-
Stored material				
Sealed storage				
Container 1	**	$6.6 \cdot 10^6$	$3.7 \cdot 10^9$	2.7
Container 2	**	$7.1 \cdot 10^7$	$2.8 \cdot 10^9$	6.0
Control, unsealed	**	$3.2 \cdot 10^9$	$6.6 \cdot 10^{10}$	8.2

* n.d. = not detected.
** Uncountable due to the growth of *Trichoderma viride* (see text).

4. DISCUSSION

The storage of Salix chips in open containers resulted in a rapid temperature build-up, considerable dry matter losses and intensive fungal growth. This increase in temperature is not unusual considering the freshness of the material, the relatively high moisture content and the availability of nutrients (nitrogen content in Salix is about 0.5 %) (SOU, 1992). In addition, the storage period extended over the time where the respiration rate of the material is high and degradation rate is at its peak, i.e. the first two months of storage (Ernstson et al., 1989). Similar observation were reported during storage of fresh chips from short rotation forest with 49% moisture content in Ireland (Rice et al., 1992).

4.1. Cold air ventilated storage

The highest dry matter losses (13.3%) and fungal activity were observed in the control container where the temperature was about 35° C for most of the storage time. This temperature favours fungal development due to the fact that most of the rot fungi have their optimal growth around temperatures between 20-35° C (Nilsson, 1965; Ernstson et al., 1989).

Despite the low temperature which was maintained through the storage period in the ventilated containers, and the relatively small increase in microspores, dry matter losses were considerable . This shows the limitation of the ventilation technique used here and indicates the difficulties of storing fresh Salix chips.

As the ventilation system was running continuously and considering the variations of outdoor temperatures, the material was, some times, heated when the ambient air temperature was higher than the chips. This was evident during the second month of storage when the outdoor temperature was clearly above 0° C and much more variable than the first month of storage, reaching a maximum of 13.9° C. Hence, this method of ventilation is not very efficient in keeping the material temperature as low as possible. Higher efficiency could be expected if ventilation is controlled by a differential temperature system. In which case, the material will be only ventilated when the wood chip temperature is higher than the ambient temperature. Utilizing such a system would also save energy.

The disadvantages of storage, i.e. dry matter losses and microbial growth, could be virtually eliminated if the material is frozen. This state is naturally achieved when the pile is build under very cold weather or ventilating the pile

when ambient temperature is clearly below 0° C. It takes relatively long period for a frozen pile to thaw out in temperate climates (Bergman, 1973; Maslov, 1974; Sampson & McBeath, 1987).

Considering the drying effect of ventilation, the applied air-flow had little effect on reducing moisture content (except for the top layer). This is due to the low air flow rate used in this experiment and the reduced drying capacity of outdoors winter air (low temperature and high relative humidity).

4.2. Sealed experiment

The dry matter loss measurements in the two sealed containers were clearly different. The temperature development and fungal spore counts indicate a low level of biological activity. In one of the sealed containers, dry matter losses were considerably higher probably due to measurement error or some other unknown factor. As there are only few reported studies on sealed storage of wood chips, the comparison possibilities of the results are limited. In one of these studies, McKee & Daniel, 1966, found no visible deterioration in a 6- and 12-month sealed drum experiment with pine chips. Feist et al., 1971, working with fresh aspen chips stored during 180 days in piles encased with polyethylene film, reported 2.3% weight loss for a pile where oxygen was excluded and 13.0% losses for a pile where the anaerobic conditions were not well preserved.

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