Storage of spruce pulpwood for mechanical pulping

Part 1.
Effects on wood properties and industrially produced pulp

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Preface

This report contains the results from the first part of a storage experiment carried out at Stora Enso Kvarnsveden Paper Mill in 2001. This first report deals with the set-up of the storage experiment, the properties of the wood and the results from the industrial pulping experiments. Part two of the report will present and discuss the results from the laboratory pulping and bleaching experiments, which were part of the project.

The project was conducted as a joint project involving Stora Enso Kvarnsveden, Stora Enso Forest, Åbo Akademi University and SLU. The project was funded by Stora Enso Kvarnsveden and Stora Enso Forest.

During the experiments numerous individuals have been involved in the operations, from felling and transports to the pulping experiments and laboratory analyses. The authors wish to thank all involved for their enthusiasm, commitment and professional skills, which made the project successful.

Sammanfattning

Rapporten redovisar första delen av resultaten från det lagringsförsök som genomfördes på Stora Enso Kvarnsvedens pappersbruk under sommaren 2001. Syftet med försöket var att undersöka förändringarna i ved- och massaegenskaper vid lagring. Fyra lagringsalternativ undersöktes: bevattnad och obevattnad lagring samt lagring av barkad respektive obarkad massaved. Försöket genomfördes med två upprepningar. Den första påbörjades i maj och den andra i juni.

Bevattningen av veden gjordes med en klimatstyrd bevattningsanläggning och bevattningsvattnet recirkulerades. Bevattningsgiva och beräknad avdunstning registrerades under försöket. Ved- och massaegenskaper utvärderades vid försökens start samt efter fyra och åtta veckors lagring. Bestämning av fukthalt och barkbindningsstyrka gjordes på borrprover ur splintveden. För bestämning av veddensitet, årsringsbredd och fiberlängdfördelning i veden samt för framställning av massor i laboratorieskala togs prover i form av trissor.

Vid massaförsöken som redovisas i denna rapport användes en metod utvecklad vid Kvarnsveden som gjorde det möjligt att blanda in försöksveden i det normala vedflödet före renseriet och därefter sortera ut den före slipverken. Därigenom kunde försöksveden utsättas för samma behandling som ordinär ved i renseriet, samtidigt som massaförsöken kunde genomföras med små mängder försöksved. Slipningarna utfördes på samma slipverk med samma sten under hela försöksperioden.

Resultaten från försöken visar att bevattningen effektivt förhindrade uttorkning, försämrad barkbarhet och uppkomsten av blånad. Detta skedde dock till priset av en viss nedgång i massans ljushet. Styrkeegenskaperna hos massorna som tillverkades av bevattnad ved var dock jämförbara med de hos massor tillverkade av färsk ved.

Torrlagring av ved gav upphov till inhomogen fukthalt och vissa angrepp av blånad. Massorna som tillverkades av torrlagrad ved hade en lägre andel långfiber och lägre rivstyrka, och sämre ljushet än massor tillverkade av färsk eller bevattnad ved.

Bevattningsparametrarna var de samma som normalt används på vedgården. Dessa visade sig ge en vattengiva som var betydligt större än den kalkylerade avdunstningen. Missfärgningarna av bevattnad ved, som bl. a orsakas av tanninskador, har tidigare visat sig vara beroende av bevattningsintensiteten. Effekterna av en minskad bevattningsintensitet kunde därför vara värda att undersökas med hänsyn till ved- och massaljushet.

Summary

This report contains the first part of the results from a storage experiment carried out at Stora Enso Kvarnsveden Papermill in the summer of 2001. The experiment aimed to investigate the changes in wood and pulp properties during storage of pulpwood. Four different storage alternatives were evaluated: sprinkled and unsprinkled storage of debarked and undebarked pulpwood. The experiment was made both on wood felled in May and wood felled in June. The same stand was used for both fellings.

The sprinkling of the wood was done in accordance with the principles of climate adaptation and the water was recycled. The sprinkling intensity and the calculated evaporation were registered on a daily basis during the experiment. The wood and pulp properties were measured at the start of the experiment and after four and eight weeks, respectively. The samples for MC and debarking resistance were drilled out while samples for laboratory pulping experiments, and measurement of density, fibre lengths and ring width consisted of disks.

The pulping experiments shown in this report were performed in accordance with a method developed at Kvarnsveden. The method makes it possible to handle experimental wood mixed with the ordinary wood in the woodroom and thereafter to collect the experimental logs. This makes it possible to perform realistic pulping experiments using small quantities of wood. The grindings were made on the same pulpstone during the whole experiment.

Results from the experiment show that the sprinkling efficiently prevented drying-out, debarking problems and the occurrence of fungal blue stain. However, this was achieved with one major drawback; decreased brightness. The strength properties of the pulps made from sprinkled wood were comparable with those of pulps made from fresh wood.

Unsprinkled storage of pulpwood gave wood with inhomogeneous MC and some blue stain infections. The pulps made from unsprinkled wood had a smaller long fibre fraction, a higher content of fines and lower brightness than pulps made of fresh or sprinkled wood.

The settings of the sprinkling system were the same as those normally used at the woodyard. They were found to give a much higher sprinkling intensity than the calculated evaporation, especially on days with low evaporation. Tannin discoloration of pulpwood is known to be related to the sprinkling intensity. Therefore it is of interest to evaluate the possibilities to decrease the sprinkling intensity.

Contents

Introduction

BACKGROUND

Production of high-grade newsprint and SC-paper is largely based on mechanical pulps, with addition of chemical reinforcement pulp when necessary. The most important quality parameters of the final paper are related to strength and optical properties. Mechanical pulps are generally cheaper to produce than chemical pulps, primarily due to the higher yield. Since almost all of the wood raw material becomes pulp the pulp properties are closely related to the properties of the wood.

The raw material for mechanical pulping in the Nordic countries is basically Norway spruce. During the spring and summer the wood supply from the forests is restrained by a number of factors. The consumption of pulpwood does not vary to the same extent, Which is why the difference between fellings and consumption has to be handled by storage of wood.

There are a number of factors negatively affecting the fellings and supply of pulpwood during the spring and summer. The climatic conditions cause transport problems, affecting both terrain transports and road transports, primarily during the spring but occasionally also in the autumn. There are also fewer fellings during the summer, both due to economic and biological reasons. The sawmills usually have a one-month production stop in the summer. From the forest owner's point of view, pulpwood is more or less a by-product from the production of saw logs due to its comparably low value. This means that when the production of saw logs stops due to the holiday at the sawmills, the production of pulpwood also ceases to a large extent. Not only the supply of pulpwood decreases but also the supply of chips, since about one-third of the volume of the saw logs becomes chips that are used in the pulpmills. The biological reasons to avoid fellings of spruce during the summer are related to the risk of butt-rot (Heterobasidium annosum) infections in the remaining or future stand. The risk of infections could be reduced if the butts are sprayed with *Phlebiopsis gigantea* or urea (Bendz-Hellgren, 1997; Thor and Stenlid, 1997), which is an established and practiced method.

The seasonal variations in fellings could probably be levelled-out to some extent, depending on willingness to pay for a more evenly distributed pulpwood supply. The cost of levelling-out the fellings has to be compared with the alternatives, i.e. storage of wood. The costs for storage can be sub-divided into three groups:

1. Costs related to handling, woodyard and transports
2. Capital costs for the stored wood
3. Costs due to changes in wood properties during storage

The first two groups of costs are often rather easily calculated while the third is more difficult to estimate.

During storage of pulpwood for mechanical pulping at the industry or terminal, protection against drying-out and insect infestations is often done using water sprinkling. Traditionally, the sprinkling intensity has been more or less fixed without adaptation to the actual need. During the 90´s a method to adapt the sprinkling to the calculated evaporation from the piles was developed. The method has been found to prevent drying-out and damage related to the drying-out and also reduces the wastewater loads significantly. The method was initially developed for saw logs, but has also been implemented at pulpmills and primarily mechanical pulpmills.

During the warm season, mechanical pulpmills often experience that the resulting pulp has a lower brightness than during the rest of the year. There are probably several factors involved, both related to the original properties of the used wood and changes related to the handling and storage.

Bark

Bark that has not been removed prior to defibrization is known to have a detrimental effect on the brightness of mechanical pulp (Fig.1) (Lorås, 1976; Hartler, 1986; Pulkki, 1992).

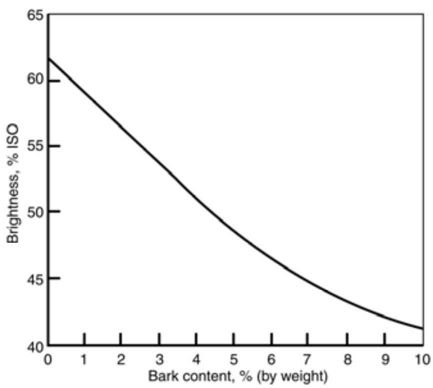

Fig. 1. The effect of bark in the wood on brightness of mechanical pulp (Pulkki, 1992).

The result of drum debarking is dependent on the geometry of the logs and the bond strength between bark and wood (Berlyn, 1966). The latter is strongly affected by early stages of the wood handling system. During the spring and early summer the natural wood-bark bond strength is low (Hägg, 1997). The harvester´s feeding wheels and delimbing knives therefore often tear off a high proportion of the bark. In combination with the often-favourable conditions for drying-out, this means than the wood rapidly dries. The bark-wood bonding strength is correlated to the MC in the sapwood (Duchesne and Nylinder, 1996). The combination of damaged bark and weather favourable for drying therefore negatively affects the possibilities to remove the remaining bark on the logs in the debarking drum.

The brightness of the pulp is affected by the occurrence of blue stain in the used wood. Blue stain in pulpwood is caused by the melanin coloured (Zink and Fengel, 1988) hyphae of blue stain fungi, e.g. *Ophistoma*. These fungi prefer sapwood with a MC below about 50% and above about 25%, and thus the risk of infection is related to the drying-out of logs. Earlier experiments with climate-adapted sprinkling of spruce pulpwood has shown that low-intensity sprinkling, corresponding to the calculated evaporation, does not completely prevent the formation of blue stain, while a higher intensity is sufficient to prevent infection (Persson and Elowson, 2001).

The effect of blue-stained wood on groundwood has been evaluated in laboratory grinder experiments. Pulp made from wood where about 50% of the volume suffered from visible blue stain gave a pulp with 2-3 ISO- units lower brightness than pulp made from corresponding unstained wood (Persson, Bergquist, Elowson, Jäkärä and Lönnberg, 2001). After bleaching using an alkaline hydrogen peroxide process, the difference between blue-stained and unstained wood almost disappeared (Persson et al., 2001).

In order to protect pulpwood and timber from drying-out and related damage, sprinkling is often used. Wet storage in general is known to facilitate bacterial degradation of, e.g. intercellular pits, which causes increased permeability. Wet storage also causes tannin migration from the bark into the wood (Tydén, 1956; Alhojärvi and Alm, 1957; Wilhelmsen, 1968; Soila and Avela, 1971). The tannin damage is related to the water temperature and storage time (Tydén, 1956). If the water temperature is below about 13 °C the damage develops very slowly (Soila and Avela, 1971). Experiments with traditional sprinkling and ponding of pulpwood used in mechanical pulping has shown that the pulp suffers from decreased brightness, poorer bleach response and poorer brightness stability than pulp made from unstored wood (Lorås and Wilhelmsen, 1974a-b). The occurrence of tannin damage is dependent on the occurrence of bark on the log surface (Tydén, 1956).

Groundwood made from spruce pulpwood stored under climate-adapted sprinkling showed similar tendencies. The sprinkling intensity was an important factor for the degree of damage. Sprinkling corresponding to the evaporation did not completely prevent blue stain but caused only limited tannin damage. A higher sprinkling intensity gave severe tannin damage after 3 months of storage even if blue stain was efficiently prevented (Persson and Elowson, 2001; Persson et al., 2001).

The difference in brightness between tannin-damaged and unstored wood was about 3-4 ISO-units after 3 months of storage. After bleaching the difference decreased but was still 2-4 ISO-units (Persson et al., 2001).

The use of climate-adapted sprinkling and the effects on mechanical pulp has so far only been evaluated in laboratory pulping experiments. The critical storage time is one important factor in ranking the different methods to handle the lack of pulpwood during the summer.

The reported close correlation between the occurrence of tannin damage and bark implies that sprinkled storage of debarked pulpwood might be of interest if other problems do not occur.

Objectives

The overall objective of the project was to contribute to the efforts to improve pulp properties during the summer by improved wood handling practices. The primary objective of the present experiment was to estimate the critical storage time with respect to brightness and strength properties. The secondary objective was to evaluate two storage alternatives, climate-adapted sprinkling and unprotected storage, and two alternative pre-treatments of the logs, debarked logs and logs with bark.

Materials and Methods

WOOD RAW MATERIAL

Origin

The pulpwood used in the experiment was taken from a clearfelling not far from the pulpmill. The registry data of the stand are presented in Table 1. The stand was divided in two parts in order to get experimental wood from the same stand for both experiments. Therefore, half the stand was felled in May and the other half was felled in June.

Table 1. Stand data for the clear felling where the experimental logs were collected

Area, ha	Volume, m^3sub/ha	No of stems/ha	Species, % P	S	Hw	Volume, m^3sub	Average stem volume, m^3sub/tree	Site index	Age, years
2,7	283	570	3	7	0	764	0,50	G 25	120

Preparation

The stand was felled using a Caterpillar grapple harvester (Fig. 2). The experimental logs were bucked to a standard length of 4.6 m. Saw logs were bucked up to a diameter of 16 cm. The experimental logs were transported by forwarder and piled at the roadside and finally transported by truck to Kvarnsveden. Half of the logs were transported to Brossfors sawmill for debarking before they were transported to Kvarnsveden. The debarking was done using a ring debarker.

Due to the natural variation in bark-wood bonding strength over the year (Hägg, 1997), more of the bark was torn-off the logs felled in June than the logs felled in May during harvesting (Figs. 3-4).

Fig. 2. Harvester working in the stand.

Fig. 3. Experimental logs felled in May.

Fig. 4. Experimental logs felled in June.

Storage

There were two storage alternatives: sprinkled and unsprinkled storage. The sprinkling was done using the method for climate adaptation (Elowson and Liukko, 1995; Liukko, 1997; Liukko and Elowson, 1997) in combination with recycling of the sprinkling water. The experimental wood was stored in a separate pile with a buffering pile at the south side (Fig. 5). The experimental pile consisted of about a 1.5 m layer of ordinary wood on the ground, on which the experimental wood was piled. On top of the experimental logs there was another 1.5 m-thick layer of ordinary logs as buffer (Figs. 6-7). All experimental logs were located in the same pile. Half of the pile was sprinkled while the other half was unsprinkled. The sprinkling and evaporation data during the period are presented in Fig. 12.

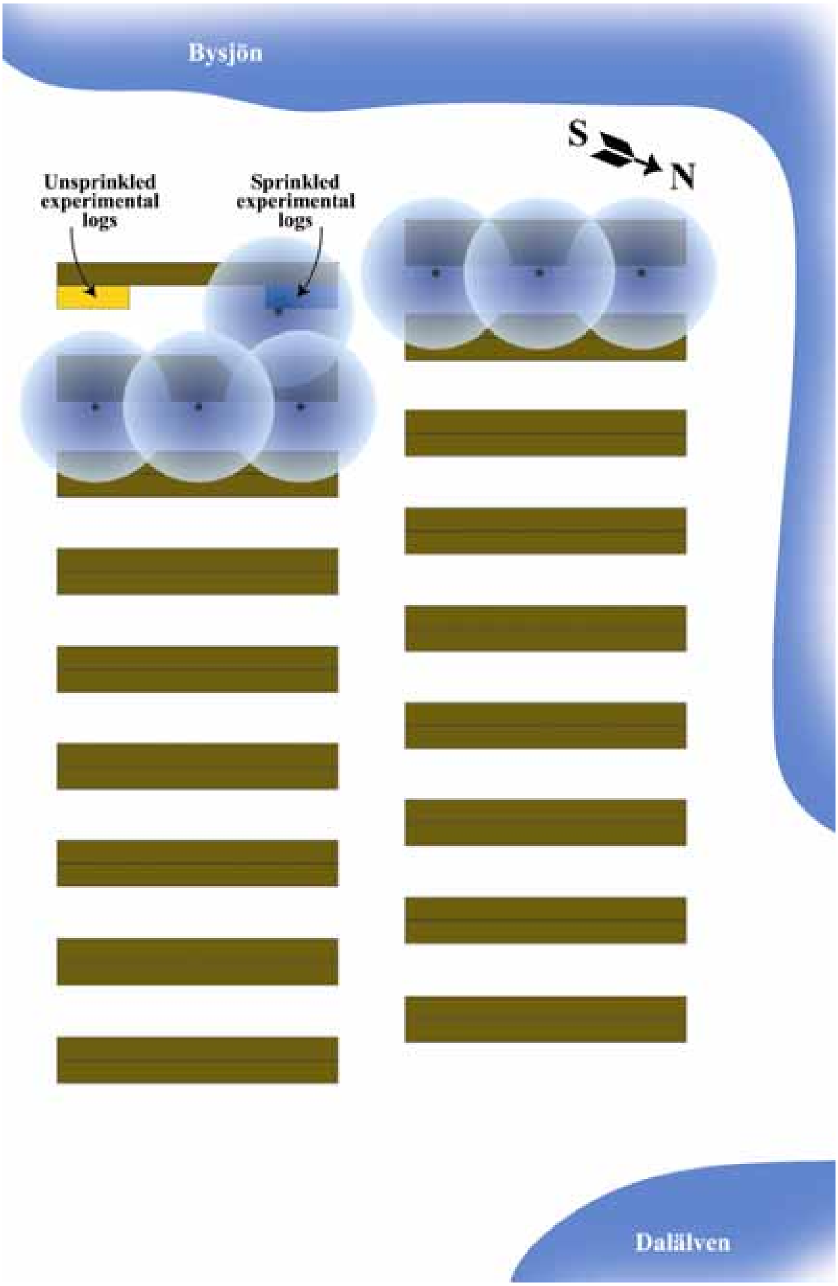

Fig. 5. The woodyard at Tägten.

Fig. 6. The logs felled in June are just about to be covered with buffering wood.

Fig. 7. The experimental logs (the upper layer marked with red) in the experimental pile after 8 weeks of sprinkled storage.

MEASUREMENTS ON WOOD

Wood samples

Two types of wood samples were collected: 50 mm-discs for laboratory pulping experiments and measurement of density and annual ring width and bore cores ∅ 12 × 20 mm for MC determinations and measurement of the wood-bark bond strength. Both the discs and the bore cores were taken about 20 cm from the end of the logs. The cores were drilled-out radial to the log using an electrical drill.

Bark-wood bonding strength

The wood-bark bonding strength was measured using an instrument for measurement of the required force to shear off the bark from a circular wood sample (Duchesne and Nylinder, 1996) (Fig. 8). The result is presented in N/area unit, where one area unit corresponds to the area of a 12 mm sample.

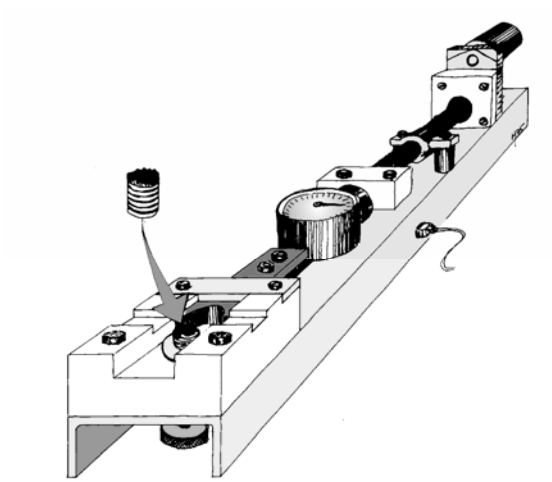

Fig. 8. Instrument for bark-wood shear strength measurements.

Moisture content

The moisture content was measured on bore cores. The green weight of the cores was measured, then they were dried at 103 °C, whereafter the dry weight was determined. The moisture content is presented as MC wet-base, i.e., the weight of the water in the wood divided by the weight of the green sample.

Blue stain

The occurrence of blue stain was roughly estimated using the bore cores. The number of cores visibly infected by blue stain was identified and counted. No other quantification of the occurrence of blue stain was made at this stage.

Density

The density was measured on 30 randomly selected discs from each of the two start sample sets. The measurements were made in accordance with the Tappi standard Basic density and moisture content of pulpwood, T 258 os-76.

Ring width

The annual ring width was measured on the same 30 randomly selected discs as used for the density measurements. The measurements were made using a WinDendro image analysis system, specially developed for ring width measurements. The arithmetic mean value of the ring width was calculated for the two groups.

Fibre properties

The fibre properties of the wood were measured on a sub sample from the 30 discs used for measurement of density and ring width. A wedge-shaped wood sample was prepared from each disc ensuring a representative distribution of sapwood-heartwood and juvenile wood. The sample was dissolved using peracetic acid and hydrogen peroxide and the resulting fibre suspension was analysed using a Kajaani FiberLab instrument.

METHOD FOR HANDLING, IDENTIFICATION AND RECLAIMING OF SAMPLE LOGS IN THE INDUSTRIAL PROCESS

A method to mark, identify and reclaim logs after the debarking drum was developed at Kvarnsveden prior to this project. The method makes it possible to make pulp from small consignments of logs that have been fed through the wood room system as a part of the normal wood flow.

Marking of logs

The sample logs were marked with diagonally oriented, about 10 mm deep scars made by chainsaw. The scars were made at every ½ meter along the log.

Fig. 9. Collection of wood samples and preparation of sample logs.

Debarking

The sample logs were fed into the process as ordinary pulpwood. The logs first passed over a slashing deck where they were cut to 1.5 m long bolts using a Kone KMW cross cutter. Thereafter the bolts were debarked in a Rauma Repola debarking drum (length 25m, diameter 3.8m). Wood from all storage alternatives was debarked in the debarking drum; also the wood debarked prior to storage.

Identification and extraction of sample logs after debarking

After the debarking drum the bolts were transported on a belt conveyor to the wood feeding system for the grinders. The marked logs were manually collected at the belt conveyer, and transported by an overhead travelling crane to the grinder used for the experiments (Fig. 10). To fill the two pockets of the grinder, about 80 bolts were required.

Fig. 10. Wood bolts collected after debarking and prepared for transport by crane.

GRINDING

The grinding was done using one of the Tampella grinders at Kvarnsveden Papermill. The same grinder was used during the whole experiment. The Tampella 18-15 grinder is a two-pocket grinder built for 1.5 m bolts with a maximum effect of 5.9 MW. The stone used was a Norton A605N7V21 with the sharpening pattern #8/45°. The stone was not sharpened during the experiment.

Average SEC	1600kWh/t
Effect during experiment	4.8 MW (exception: the start samples in June, 4.3 MW)
Peripheral speed	34 m/s
Shower water temperature	67 °C
Target freeness (in pit)	75 ml
Pulp conc. prior to screening	1-1.4%

Before the experiments, the normal supply of wood to the grinder was stopped. The grinding continued until there were bolts left for two portions in each pocket. The grinder was then set aside with filled pockets and with another portion in the waiting stage (Fig. 11). Thereafter one portion of ordinary bolts, one portion of experimental bolts and finally one portion of ordinary bolts were prepared for each grinder pocket.

The following grinding sequence was used for all treatments except the start samples (0 weeks) where two pockets of experimental wood were used.

1. 2 × 2 pockets of ordinary pulpwood
2. 1 × 2 pockets of ordinary pulpwood as reference
3. 1 × 2 pockets of experimental wood
4. 1 × 2 pockets of ordinary pulpwood as reference

Pulp samples were only collected from grindings 2-4. The first stage was aimed to make the process conditions and temperature stable.

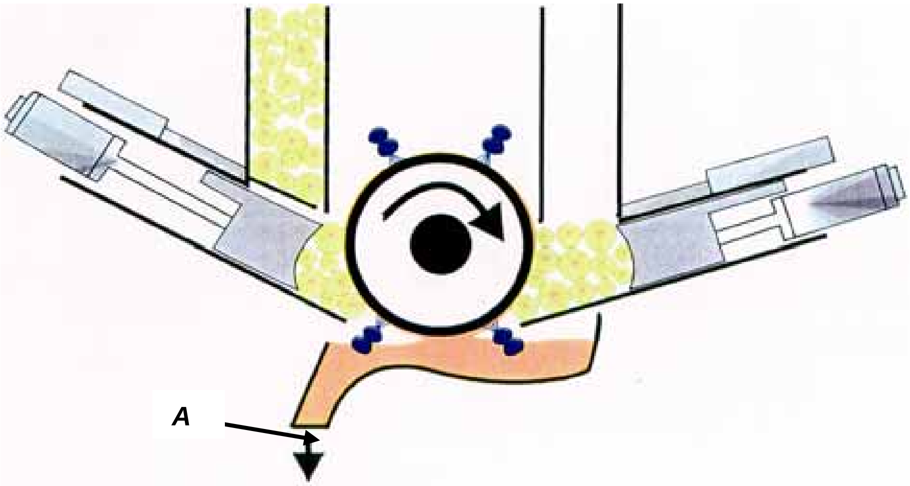

Fig. 11. Principal grinder design.

The grinding was then started by simultaneously starting the two pockets. The first two portions of bolts were used to reach working temperature and stable grinding conditions in general. When the two portions of reference bolts and the experimental logs were about to be ground, the pockets are manually manoeuvred to start simultaneously.

Pulp samples were collected immediately under the pulpstone (Fig. 11, *litt. A*) four times during each grinding cycle. About 2 l of pulp was collected on each sampling occasion. The temperature of the pulp was measured on each sampling occasion. The four samples from each portion of bolts were thereafter mixed together and screened prior to further analyses.

PULP TESTING

Immediately after grinding, the pulps were pre-screened using a vibrating screen with ∅ 4mm holes. The average freeness (CSF) of the pre-screened pulps was 64 ml. The content of shives was analysed using the *Sommerville* method (0.15 mm slit width) and the fibre fraction composition was analysed using the *Bauer-McNett* method.

Handsheets with a grammage of 60g/m^2 were prepared using a 100-mesh wire without recirculation of the whitewater. The following pulp properties were tested: brightness, light scattering, light absorption, density tear index and tensile index. The tests were performed using Stora Enso standard, which basically follows the corresponding SCAN standard.

Results and Discussion

ORIGINAL WOOD PROPERTIES

Wood density and mean annual ring width

The density and mean ring width was measured on the logs used as reference samples, i.e. the logs processed to pulp immediately after felling. There were only small differences in ring width and density between the two fellings (Table 2).

Table 2. Density and mean ring width of the experimental logs used as references

	Felling	
Wood property	May	June
mean density(g/cm3)	0.42	0.41
standard dev. density	0.03	0.04
mean ring width (mm)	0.96	1.04
standard dev. ring width	0.32	0.34

Fibre properties of the experimental wood

The fibre length and fibre width were measured on wood taken from the samples used for the density measurements. The wood felled in June had shorter fibres than the wood felled in May. The difference in length weighted fibre length (L(l)) was about 0.5 mm (Table 3).

Table 3. Fibre dimensions of the used wood

	May			June		
	1	2	3	1	2	3
Fibre length L(n) (mm)	1.3	1.26	1.22	1.04	1.05	1.09
Fibre length L(l) (mm)	2.94	2.93	2.92	2.46	2.44	2.47
Fibre length L(w) (mm)	3.63	3.63	3.65	3.13	3.11	3.13
Fibre width (my)	31.1	30.8	30.5	29.5	28.5	29.7

SPRINKLING

The sprinkling was done in accordance with the principles of climate adaptation. The actual sprinkling intensity was higher than the calculated evaporation, especially when the evaporation was low (Fig. 12). There seems to be a minimal daily sprinkling intensity of about 15 mm. The difference between sprinkling intensity and calculated evaporation is therefore smaller at higher levels of evaporation.

It might be worth evaluating the possibilities to reduce the sprinkling intensity in order to decrease the degree of tannin damage. The decreased sprinkling intensity has to be balanced against the increased risk of blue stain and less homogeneous moisture distribution. Earlier findings imply that the degree of tannin damage is dependent on the sprinkling intensity (Persson and Elowson, 2001; Persson et al., 2001), water temperature, and bark on the logs (Adler, 1951).

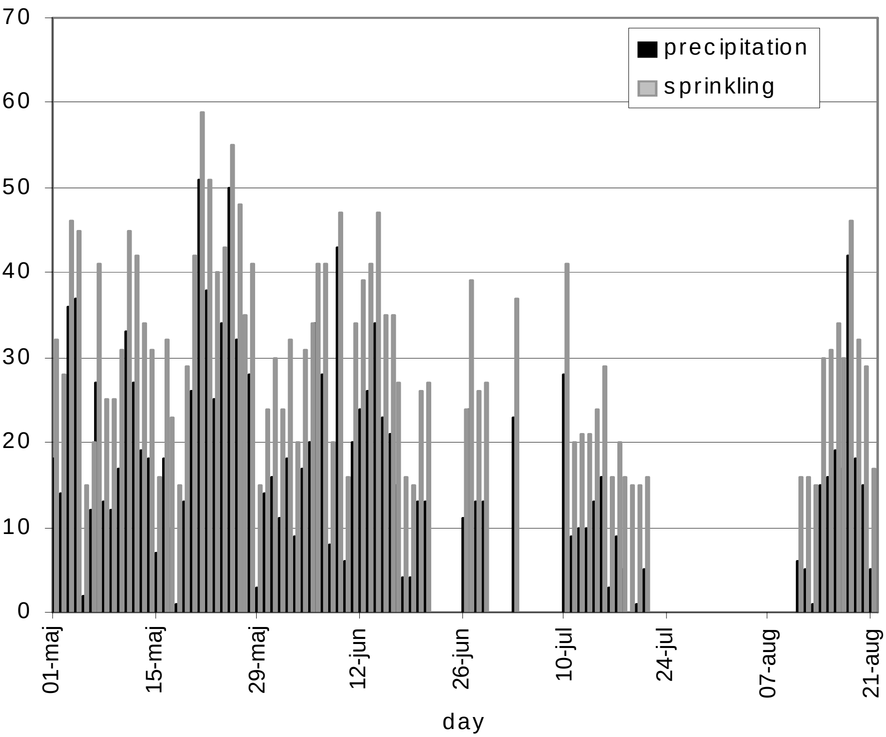

Fig. 12. Sprinkling intensity and calculated evaporation.

CHANGES IN WOOD PROPERTIES DURING STORAGE

Moisture content

The sapwood MC showed a small increase from 57% to 59% after 4 weeks of sprinkling (Tables 4-5). This applied both to debarked and unbarked logs felled in May and unbarked logs felled in June. In the debarked logs felled in June, the MC was unaffected after 4 weeks of sprinkling. In general, the difference between the debarked and unbarked logs stored under sprinkling was negligible. No further increase in MC was observed during the last 4 weeks in the storage alternatives where the MC increased during the first 4 weeks. A similar small increase in MC during the first weeks in logs stored under climate-adapted sprinkling and not dried-out prior to storage, has earlier been observed (Liukko and Elowson, 1999; Persson and Elowson, 2001).

In logs stored without sprinkling the MC decreased during the storage period (Tables 4-5). The debarked logs felled in June dried-out most rapidly, and the debarked logs felled in May also dried faster than the unbarked logs. The drying rate was generally higher in June than in May, which probably is a result of the severe damage to the bark combined with favourable weather for drying-out.

The logs stored without sprinkling also showed greater variation in MC than sprinkled logs (Tables 4-5, Figs. 13-18). This implies that even if the mean MC might be acceptable there are individual logs that have an unacceptably low MC (Figs. 15,18). The MC distribution in a consignment of wood is of importance since only a small share of the logs causes the majority of the bark contamination in the wood raw material (Öman, 2000).

In general, an unprotected pile at the roadside probably dries faster than the unsprinkled pile in this experiment, the reason being that the sprinkling at the woodyard probably affects the drying rate also in nearby unsprinkled piles by increasing the humidity at the site and by wind-spread droplets.

Table 4. Sapwood moisture content in experimental logs felled in May

May	start		4 weeks		8 weeks	
MC	mean	st dev.	mean	st dev.	mean	st dev.
unsprinkled, w bark	57	4.5	51	8	46	9.8
unsprinkled, debarked	57	4.5	47	10	42	9.5
sprinkled, w bark	57	4.5	60	4	59	4.4
sprinkled, debarked	57	4.5	59	5	59	3.8

Table 5. Sapwood moisture content in experimental logs felled in June

June	start		4 weeks		8 weeks	
MC	mean	st dev.	mean	st dev.	mean	st dev.
unsprinkled, w bark	54.2	7.3	49.2	6.4	45.2	9.6
unsprinkled, debarked	54.2	7.3	39.8	9.7	30.3	8.4
sprinkled, w bark	54.2	7.3	59.6	4.2	58.9	5.3
sprinkled, debarked	54.2	7.3	54.6	7.3	57.5	4.4

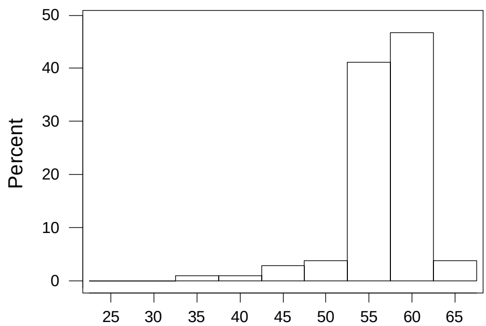

Fig. 13. MC distribution in start samples felled in May.

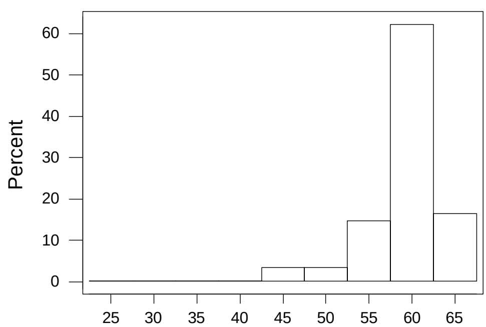

Fig. 14. MC distribution in sprinkled samples with bark felled in May after 8 weeks of storage.

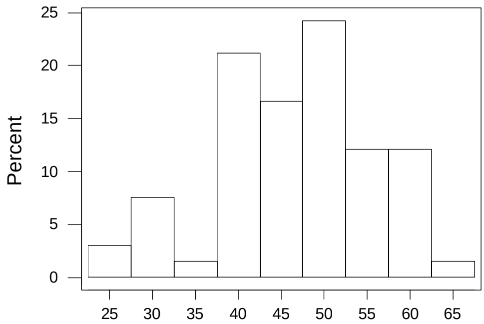

Fig. 15. MC distribution in unsprinkled samples with bark felled in May after 8 weeks of storage.

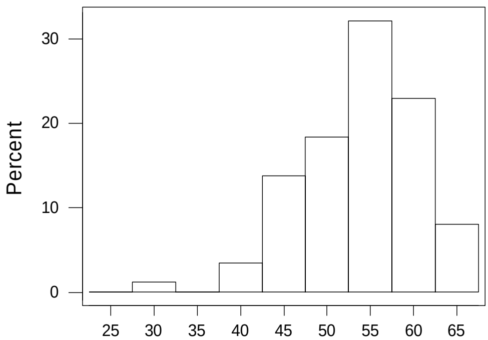

Fig. 16. MC distribution in start samples felled in June.

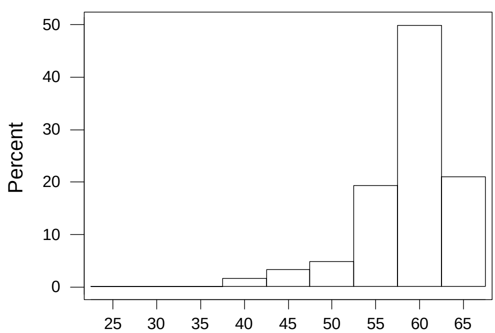

Fig. 17. MC distribution in sprinkled samples with bark felled in June after 8 weeks of storage.

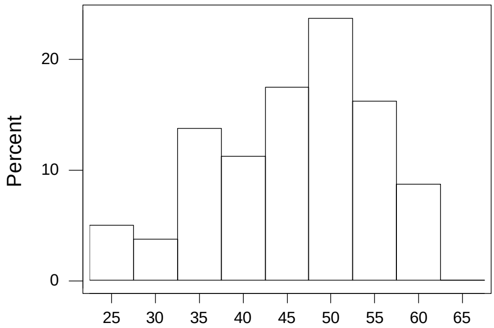

Fig. 18. MC distribution in unsprinkled samples with bark felled in June after 8 weeks of storage.

Bark-wood bonding strength

The bark-wood bond strength did not increase to the extent expected prior to the experiment (Table 6). There were difficulties in drilling-out samples from logs with very low bark-wood bond strength since the drill shears off the bark from the wood. This implies that the true bark-wood bond strength is lower than the observed for logs with very low bond strength. The high humidity in unsprinkled piles discussed above might also have affected the decomposition of the cambial zone and there by decreased the wood-bark bond strength.

Table 6. Bark-wood bond strength

		Start	4 weeks		8 weeks	
			sprinkled	dry	sprinkled	dry
May	mean	3.04	3.36	3.94	3.12	3.20
	stdev	0.92	0.95	1.03	0.99	0.90
June	mean	2.48	3.04	3.06	3.73	3.71
	stdev	0.94	0.89	1.23	1.25	1.22

Blue stain

The blue-stained samples noted were concentrated to the samples from logs stored for 8 weeks without sprinkling and especially the logs felled in June. This rough estimation of the occurrence of blue stain in the logs showed very limited infections. In the worst-case 7 samples of 81, i.e. less than 10% of the samples were affected by blue stain. The results show that the sprinkling intensity used was sufficient to prevent growth of blue stain fungi during the storage conditions in this experiment.

Table 7. Number of blue-stained samples in sapwood bore cores of the total number of sample cores

		4 weeks		8 weeks	
Felling	Pre-treatment	sprinkled	dry stored	sprinkled	dry stored
May	w bark	-	-	-	-
	Debarked	-	-	-	1 of 74
June	w bark	1 of 54	-	-	7 of 81
	Debarked	-	-	-	3 of 64

PULP PROPERTIES

Fibre dimensions

The fibre dimension composition of the pulps made of stored wood were analysed using Bauer-McNett fractioning of all pulps. There are small differences between the storage methods. There were more fines in pulp made from unsprinkled wood and more long fibres in pulp made from sprinkled wood (Tables 8-9, Figs. 19-20). This result generally corresponds to earlier findings (Brandal and Johannessen, 1958; de Montmorency, 1962, 1964; Eriksen, Hauan, Gaure and Mattans, 1981; Kärenlampi, 1992). There is a close relationship between long fibre content and pulp strength.

The long fibre content in the experiment might also be affected by the tendency for increased long fibre content in the pulps produced by the grinder used (Fig. 21).

Table 8. Fibre length distribution in pulp made from wood felled in May

Fibre fraction	Start	4 weeks storage				8 weeks storage			
		Sprinkled		Unsprinkled		Sprinkled		Unsprinkled	
		w bark	debarked	w bark	debarked	w bark	debarked	w bark	debarked
+ 16, %	19.4	17.3	13.6	16.2	13.7	18.7	16.5	16.0	16.1
16-30, %	11.1	11.4	13.5	11.3	11.5	11.2	11.9	11.8	12.4
30,%	30.5	28.7	27.1	27.5	25.2	29.9	28.4	27.8	28.5
30-200, %	38.0	38.4	41.3	39.3	40.2	38.4	40.3	38.5	38.4
-200%	31.6	32.9	31.6	33.2	34.6	31.7	31.3	33.7	33.1

Table 9. Fibre length distribution in pulp made from wood felled in June

Fibre fraction	Start	4 weeks storage				8 weeks storage			
		Sprinkled		Unsprinkled		Sprinkled		Unsprinkled	
		w bark	debarked	w bark	debarked	w bark	debarked	w bark	debarked
+ 16, %	18.5	17.0	19.4	15.8	16.5	18.3	17.3	16.1	16.0
16-30, %	10.8	11.6	13.3	11.7	12.8	13.1	13.0	11.8	11.1
+ 30, %	29.3	28.6	32.7	27.5	29.3	31.4	30.3	27.9	27.1
30-200, %	37.7	37.7	37.8	39.9	39.2	38.6	38.9	38.1	38.6
- 200, %	33.1	33.7	29.5	32.6	31.5	30.0	30.8	34.0	34.3

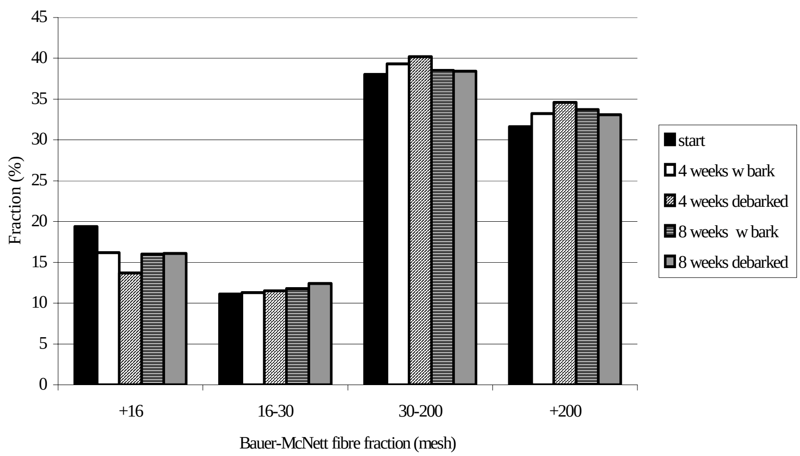

Fig. 19. Fibre fractions in dry stored wood felled in May.

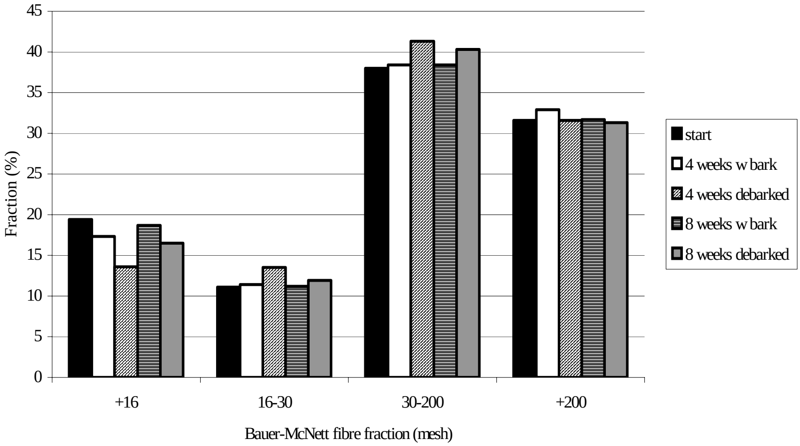

Fig. 20. Fibre fractions in sprinkled wood felled in May.

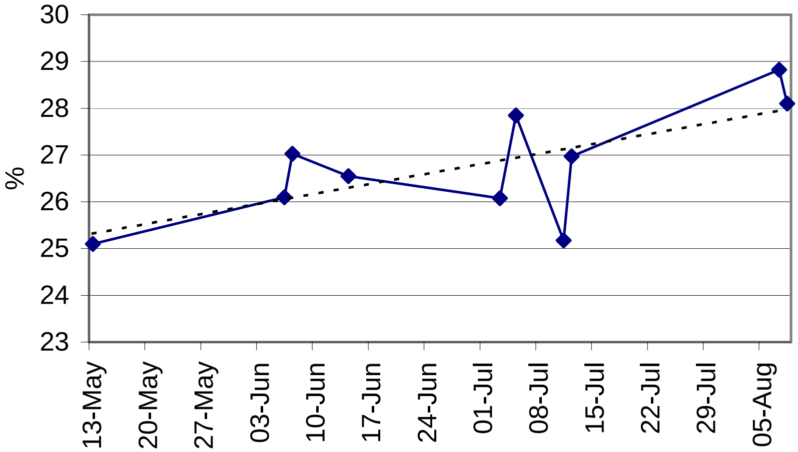

Fig. 21. Long fibre content (+30) reference pulps.

Tear index and tensile index

In general, the strength properties of the pulps were better for the sprinkled wood than the dry stored wood (Figs. 22-23). The tear index of the start sample from wood felled in June is exceptionally high and might be the result of problems with the instrument and sample preparation equipment. The unbarked unsprinkled wood stored for 8 weeks gave the worst tear index (Figs. 22-23). The debarked wood seems in general to have a slightly higher tear index than the wood stored with bark. That is somewhat contradictory to the generally prevailing opinion that the higher wood MC during grinding the better the pulp strength, since the debarked logs had a lower sapwood MC than the logs stored with bark (Tables 4-5).

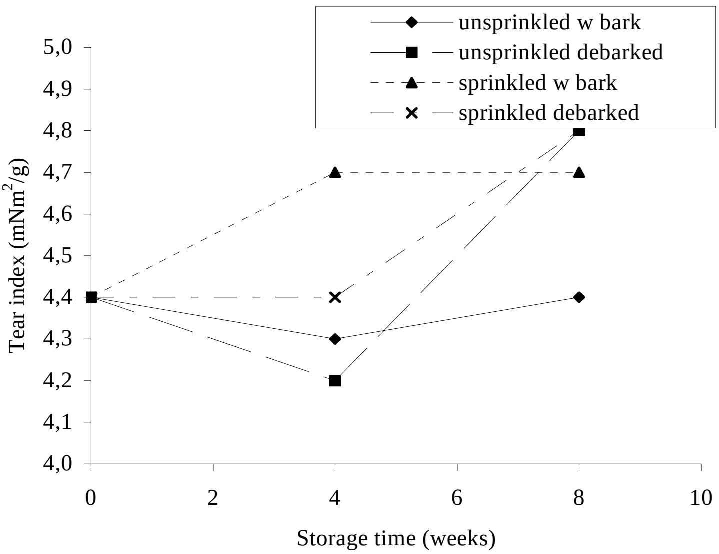

Fig. 22. Tear index versus storage time for wood felled in May.

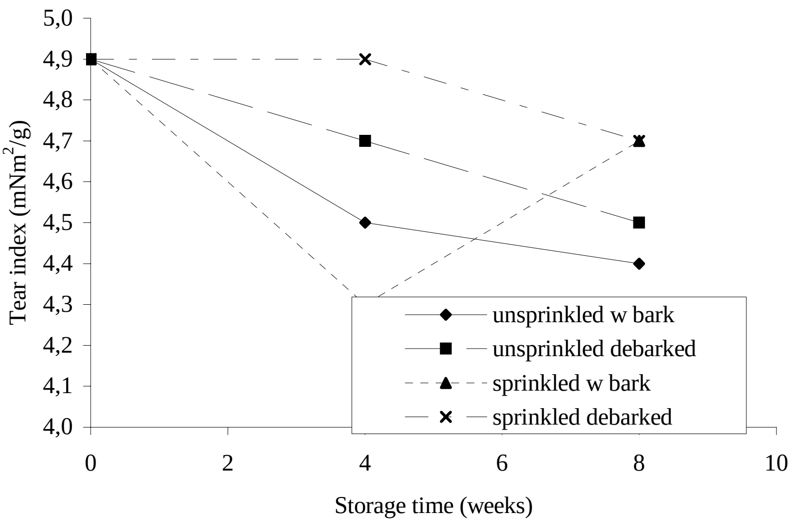

Fig. 23. Tear index versus storage time for wood felled in June.

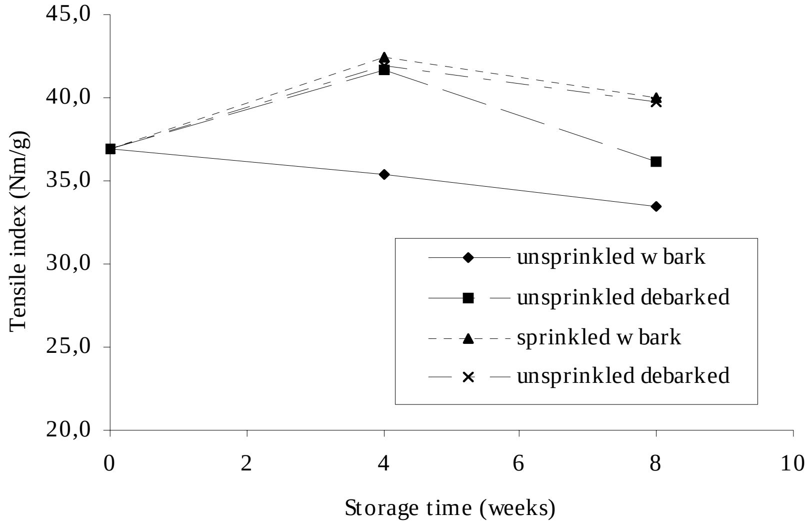

Fig. 24. Tensile index versus storage time for wood felled in May.

The tensile index of the pulp made from wood felled in May was higher, or in one case unaffected, after 4 weeks of storage (Figs. 24-25). The wood felled in June shows the opposite trend, i.e. the tensile index was lower, or in one case unaffected, after 4 weeks of storage. The contradictory result might be a result of differences in the density of the handsheets. The handsheets made

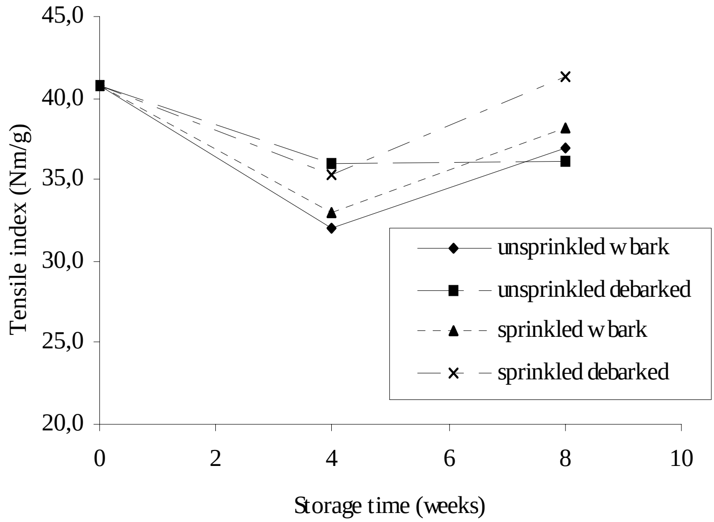

Fig. 25. Tensile index versus storage time for wood felled in June.

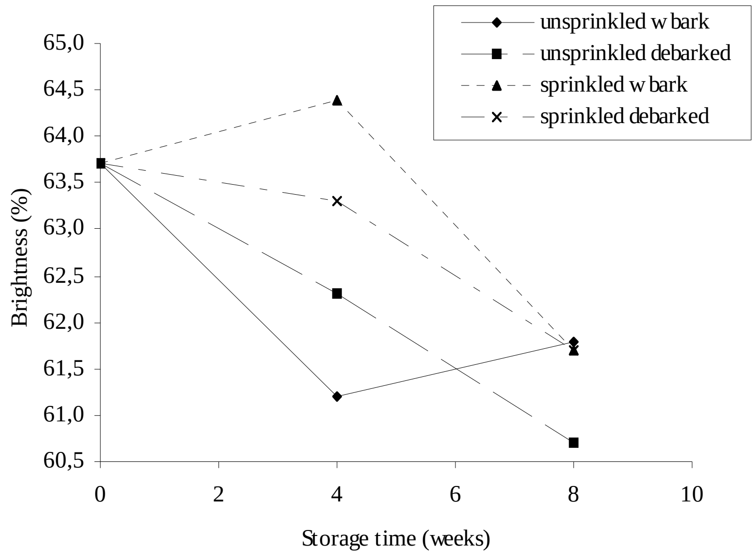

Fig. 26. Brightness of pulp made from wood felled in May.

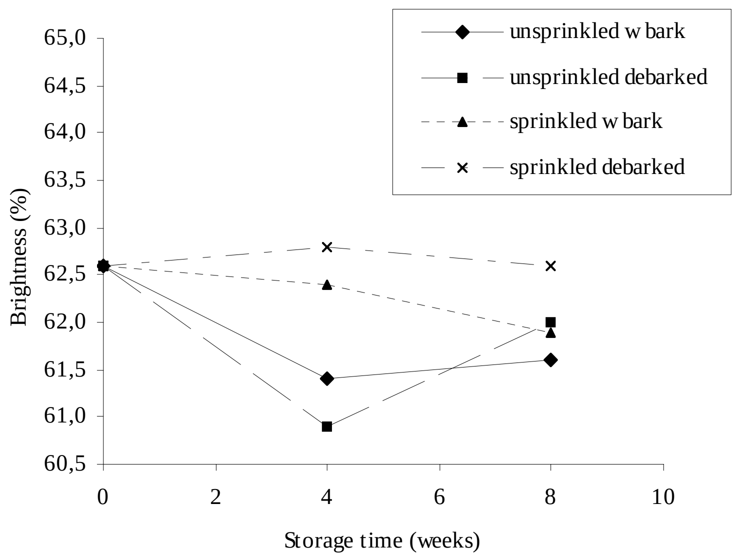

Fig. 27. Brightness of pulp made from wood felled in June.

from the felling in May had a higher density, which causes more fibre-fibre bonds on the surface and thereby better tensile index. The correlation between density and tear index was 0.65 in this experiment.

The tensile index of the unsprinkled assortments was somewhat lower than of the sprinkled wood after 8 weeks of storage (Figs. 24-25). This applies both to wood felled in May and to wood felled in June. The debarking of logs prior to storage does not seem to affect the tensile index.

Brightness

The general trend is decreasing brightness during storage. The decrease is greatest for pulp made of wood stored without sprinkling (Figs. 26-27). The occurrence of blue stain caused by fungal infection was also largest in these storage alternatives (Table 7). The negative effect on brightness caused by blue stain has earlier been described (Persson et al., 2001).

The brightness losses were less evident in pulp made from sprinkled wood. The damage seems to be small during the first four weeks of storage and increases more rapidly during weeks 5-8. The wood debarked prior to storage does not show an evidently smaller decrease in brightness, as expected. There is more than one possible reason for this. The debarking was far from perfect, the debarked logs are more sensitive for fungal infections, and the sprinkling water is coloured in itself due to the recirculation.

Conclusions

- The sprinkling intensity used in the experiment was the same as the used intensity for the normal sprinkling of pulpwood at Kvarnsveden. The used intensity efficiently prevented drying-out of the wood and also prevented the occurrence of blue stain caused by fungal infections.

- The pulp made from sprinkled wood had properties similar to pulp made from fresh wood with one important exception: lower brightness. The brightness losses were greatest in wood stored without sprinkling, but the brightness also decreased in the sprinkled wood.

- The settings of the sprinkling system gave a sprinkling intensity that is considerably higher than the calculated evaporation. In order to reduce the brightness losses caused by tannin migration in the sprinkled wood it would be interesting to evaluate the possibilities to reduce the sprinkling intensity. The use of recycled water might also increase the tannin discolorations both directly due to the coloured water and indirectly by facilitating bacterial degradation of the wood during storage.

- Unsprinkled storage of pulpwood caused inhomogeneous MC and thereby a significant share of logs with an MC lower than acceptable with respect both to debarking and pulping properties. The un-sprinkled storage used in this experiment was probably subject to a lower drying-rate than the average pile at the roadside or even worse, logs spread out at the felling site.

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Tables and Figures