

# Quality loss of refined softwood bleached kraft pulp during agitated storage

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**KEYWORDS:** Fiber curl, Paper properties, Pulp storage, Refining, Runnability

**SUMMARY:** The effect of agitated storage of refined pulp was studied for a never-dried bleached softwood kraft pulp. The effect on sheet properties as well as on paper machine forming conditions was evaluated on a pilot scale.

A considerable increase in fibre curl was obtained as a result of the agitated storage. The effect was time-dependant and most sheet properties were affected. In many respects the action was opposite to that of LC-refining. Both sheet-structure-related properties and mechanical properties were influenced. After 1 hour storage about 5 % of the tensile index was lost and after storage overnight about 15 % of the tensile index was lost. This loss was due both to a decrease in density and to a less efficient activation of the fibres during drying. The dewatering characteristics on the paper machine were improved in relation to the lower density. To reach the same tensile index, 60 Nm/g, if agitated storage were a part of the stock approach system, the refining energy would need to be increased from 45 kWh/t to 85 kWh/t to compensate for 1 hour storage and to 185 kWh/t to compensate for storage overnight. At the same time, the dryness after wet pressing would be reduced from 42,7 % to 39,5 %. The tear-tensile relationship was not affected, neither was the sheet uniformity.

Classification of fibre shape using a light microscope indicated that the increase in fibre curl was due to a development of fibre twist to include a change in the direction of the fibre axis, which reduced the effective fibre length in the sheet and opened up the fibre network. The mechanism is believed to be that the modest mechanical treatment activates the inherent potential of the fibres to twist.

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In spite of the extensive theoretical and practical experience of refining of chemical pulps, there are still many questions to be answered about how to refine and the benefits to be obtained from refining.

A possible explanation for the lack of consistent practical observations linking refining action to paper properties in industrial scale investigations may be that there can be considerable changes in fibre properties, particularly with regard to fibre curl, after the pulp has left the refiner and is on its way to the headbox. The straightening introduced in the fibres by refining is not

stable, and the strength gained can be lost if the suspension is stored under agitation. To the knowledge of the author this effect is not previously discussed in the literature.

Fig 1 shows results from on-line testing with the STFI FiberMaster in a fine paper mill. For the samples taken immediately after the refiner, the shape factor for the long fibre fraction 1,5 – 3,0 mm is about 88 and the variation is in the same range as the experimental accuracy. For the fibres in the machine chest, however, the shape factor was lower and the variation was considerable, from 85 – 88. The fibres entering the headbox thus contained considerably more curl than expected based on the testing done directly after the refiner. The shape factor observed for the fibres in the broke can be expected to be representative of the shape factor of the fibres in the paper.

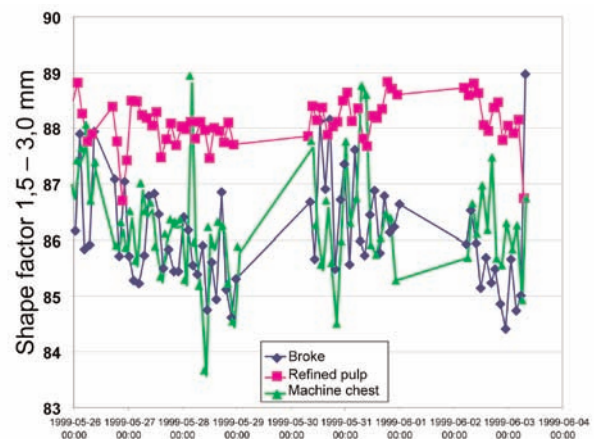


Fig 1. In the mill (fine paper), fibre properties are changed considerably from the refiner to the headbox, probably as a result of pumping and storing/stirring. The results obtained with the STFI FiberMaster in the fibre length interval 1,5 – 3,0 mm are believed to be representative for the softwood fibres in the furnish.

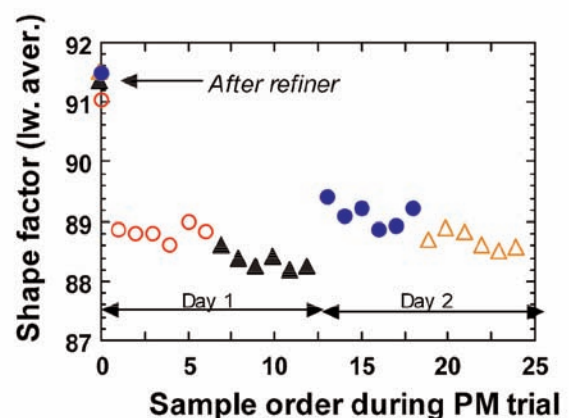


Fig 2. Change in shape factor as a result of agitated storage for a bleached birch market pulp. A large drop in shape factor occurred overnight. During the trial on the paper machine a further reduction was observed. The different symbols represent different refining batches.

Interest in the effects of pulp storage on fibre and paper properties was aroused when considerable discrepancies were found when results from sampling directly after the refiner were compared with those from sampling in the storage tower in connection with pilot scale papermaking trials. Common practice in a pilot paper machine trial is to refine the pulp batch-wise the day before the run on the paper machine. Fig 2 shows an example for a birch pulp. Refining led to an increase in the shape factor, from 90.5 as unrefined to 91.5, but when the pulp was run on the paper machine the next day the whole of this gain had been lost and some additional curling had occurred. A further reduction in fibre straightness during the trial was also noticed.

In the case of market SBK pulps, a difference in curl was observed between pulps run in the morning and in the afternoon when the refining was done the day before (Mohlin 2005). The effect was less for softwood than for hardwood pulps, but it is still extremely important since the increased fibre curl may have a considerable effect on process stability and process efficiency.

This report deals with the effect of storage time for a refined never-dried bleached softwood kraft pulp on the paper properties and paper machine runnability. The results show that the agitated storage is a factor that has to be taken into account when evaluating the effects of activities in stock preparation on paper quality. If the suspension is not agitated, the effect of storage is negligible.

## Experimental

The unrefined pulp was delivered from a Swedish mill at 4 % consistency. Sheets were produced on the EuroFEX pilot scale roll former from 100 % never-dried bleached softwood kraft pulp and the storage time after refining before papermaking was varied at three levels; zero, 1 h and overnight storage. Different batches were used for the different storage conditions but the properties were very similar.

### Refining

Refining was done in a 24" Beloit Jones Double disc refiner to two levels of refining, 80 kWh/t and 135 kWh/t. Refiner plates with an edge length of 124 km/s were used. Constant refining conditions were used, flow rate 350 l/min, temperature 37 °C, consistency 3,5 %. The two energy levels corresponded to refining intensities (SEL) (Brecht, Siewert, 1966) of 0,48 Ws/m and 0,80 Ws/m. A low throughput, 0,74 t/h, was used to fit the level of production on the paper machine. Properties of

the unrefined pulp and the refined pulp sampled directly after the refiner are shown in Table 1. The pulp was stored at the refining consistency until used for papermaking.

### Papermaking

Papermaking was carried out in the roll former unit in the EuroFEX pilot paper machine. Special care was taken to control the storage time of the fibre suspension before it was run on the paper machine. Sheets were produced from 100 % softwood kraft pulp with a target grammage of 60 g/m<sup>2</sup>. The machine speed was 600 m/min and two slice openings were used, 15 mm and 10 mm, corresponding to forming consistencies of 4,3 and 6,3 g/l. The system temperature was 22°C.

Three different storage times for the refined pulps were studied, no storage, 1 hour storage and storage overnight. 1 hour storage was obtained by refining directly to the storage chest and the PM-trial started when refining had been in progress for 1 hour and new refined fibre was then added during the trial. For the overnight storage, the pulp was stored in the chest and the agitation was maintained throughout the night.

Wet pressing was done using one short nip and two extended nips, with nip loads 60, 400 and 900 N/m. The paper was rolled wet to be dried separately. Drying was done on a separate one-cylinder-drier under restrained conditions in both MD and CD. For samples from the thick stock, handsheets were produced using standard conditions, ISO 5269-1:1998.

### Testing

The refining action was characterized by measuring WRV (SCAN-C 62:00), SR-number (ISO 5267-1:99) and fibre dimensions, fibre curl and kink using the STFI FiberMaster (Karlsson et al 1999). The machine-made paper and handsheets was tested according to SCAN and ISO methods when applicable.

Formation number and formation spectra were determined for the machine-made sheets as the coefficient of variation for the grammage using  $\beta$ -radiograms (Norman 1986).

## Results and discussion

### Storage effects on sheet properties

Most paper properties were affected by the agitated storage, although to different degrees. Similar trends were observed for handsheets as for the machine-made sheets. Test results for handsheets made from the refined pulps, sampled in the thick stock flow to the PM are compiled in Table 2. Tensile index, tensile stiffness index and tear index were the strength properties most affected. The tensile index was reduced by about 5 % after 1 hour's agitated storage and by 10 - 16 % after overnight agitated storage. The tear index increased by about 7 % after 1 hour's storage and about 20 % after overnight' storage. The tear-tensile relationship was not affected. Sheet structure was also affected, density and Scott Bond strength were reduced and the

Table 1. Properties of unrefined pulp and refined pulp sampled directly after refiner.

Trial	Unrefined	Batch A (used immediately)		Batch B (used after 1 hour storage)		Batch C (used after overnight storage)	
		80	135	80	135	80	135
Refining energy, kWh/t	0	80	135	80	135	80	135
WRV, g/g	1,46	1,66	1,76	1,65	1,73	1,67	1,81
Fibre length (l.w.), mm	2,27	2,34	2,31	2,29	2,23	2,27	2,21
Shape factor (1,5 – 3 mm)	84,1	88,1	88,2	87,8	87,8	88,1	88,2
Kink/mm	0,75	0,41	0,42	0,44	0,43	0,43	0,40

light scattering coefficient was increased.

The tensile index of the machine-made sheets was affected in a manner similar to that of the handsheets. Fig 3 shows the geometric mean for MD and CD strength, the strength reduction was similar in MD and CD. It is interesting to note that the effect of storage overnight was of the same magnitude as that associated with a 50 % increase in forming consistency, from 4 g/l to 6 g/l as indicated in Fig 3.

A linear regression analysis of the data set for the machine-made papers showed that the variations in number of kinks, forming consistency and WRV were able to explain all the differences in tensile index observed between the samples. The coefficient of determination ( $R^2$ ) was 0,96. Of the different measures for fibre curl the kink/mm gave the best fit.

### Storage and fibre properties

The examination of the fibre properties showed that the shape of the fibres was changed by the agitated storage. Fibre straightness was reduced and the number of kinks increased. No other significant changes in fibre properties were evident. A slight drop in SR number and WRV may have occurred, but the changes were within the experimental uncertainty. Fig 4 shows the very different levels of kink that were observed as a result of storage and that the WRV was not affected within the experimental uncertainty.

A considerable part of the fibre straightening achieved by refining was thus lost during storage. The kink for the unrefined pulp was 0,75 kink/mm and refining improved it to 0,42 kink/mm. After storage overnight, about half of this gain in straightness had been lost. The same trends were observed for the shape factor, however in this case the value for the stored pulp was back to the level for the unrefined pulp after storage overnight for the higher refining level.

In order to better understand the effect of the storage, a separate study was carried out where the fibre shape was classified using light microscopy. Three characteristic measures of fibre shape were followed, fibre twist, angle fold, i.e. a collapsed fibre folded over itself, and the fibre bent as a knee, Fig 5. The twist and angle fold are in principle the same type of deformation; but a twist does not include a change in the direction of the fibre axis

Table 2. Properties of pulps delivered to the paper machine, averages for each combination of refining and storage.

Storage	direct		1 h		16h	
	85 kW	135 kW	85 kW	135 kW	85 kW	135 kW
Refining						
SR	21,1	30,4	19,7	33,8	19,5	28,7
WRV, g/g	1,63	1,75	1,60	1,74	1,59	1,72
Density, kg/m <sup>3</sup>	697	726	692	714	681	717
Tensile index, Nm/g	74,1	82,8	69,3	78,5	63,5	69,9
TEA, mJ/g	1850	2080	1830	1990	1780	2090
Tensile stiffness index, kNm/g	7,64	8,20	7,20	7,90	6,69	7,20
Tear index, mNm <sup>2</sup> /g	13,4	11,4	14,3	12,4	16,0	13,7
Scott Bond, J/m <sup>2</sup>	306	388	309	365	280	382
Light scattering coeff., m <sup>2</sup> /kg	22,3	20,6	23,0	21,8	24,3	22,4
Zero-span tensile rewet, Nm/g	119	118	120	120	118	114
Zero-span tensile dried, Nm/g	144	147	145	149	143	143

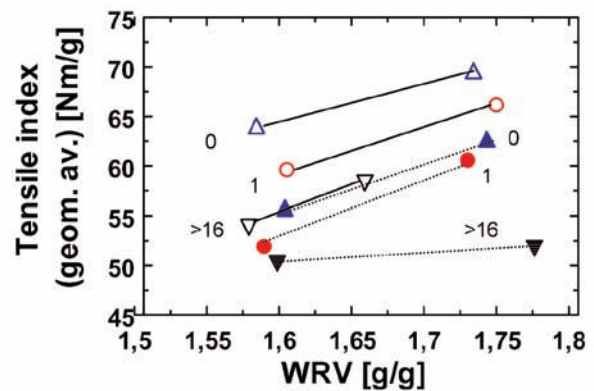


Fig 3. Tensile index for machine-made papers made directly after refining, after 1 hour agitated storage and after storage overnight (>16h) The study was made at two levels of refining (different WRV) and two forming consistencies (4 and 6 g/l; open and filled symbols respectively). The x-axis shows WRV at the time of papermaking.

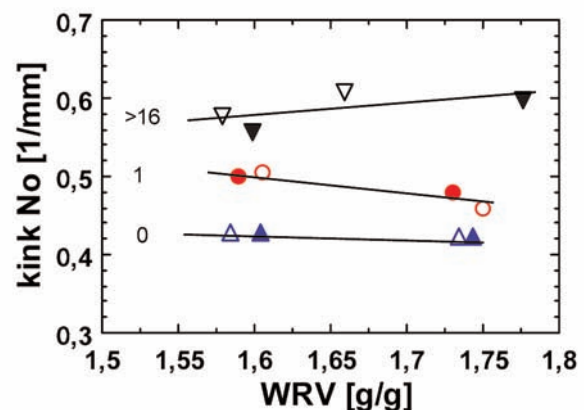


Fig 4. Kink number as a function of WRV at different storage times. Sampling in the thick stock approach flow. Open and filled symbols represent the pulps used at the two forming consistencies.

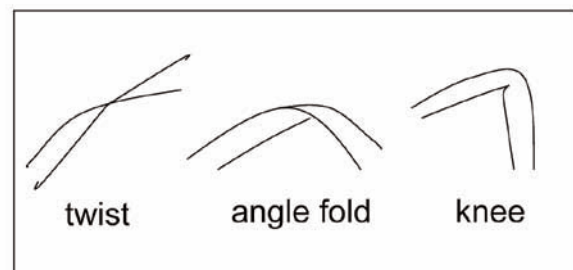


Fig 5. Different fibre defects used in microscopy classification.

Table 3. Fibre deformations as a result of storage for a bleached softwood kraft pulp.

	After refiner	1 hour	Overnight
Kink/fibre (STFI FiberMaster)	0,68	0,73	0,95
Shape factor	87,4	86,8	84,7
Zero-span (rewet), Nm/g	124	125	123
Angle fold, No/fibre	0,57	0,51	0,91
"Knee", No/fibre	0,73	0,76	0,89
Twist, No/fibre	0,45	0,35	0,24

while an angle fold does. As shown in Table 3, the twist decreased and the angle fold increased with storage. The less severe twist was thus changed into the more severe angle fold. The "knee" number also increased somewhat, but not to the same extent as the angle fold.

In Table 2 and in Table 3 it can also be seen that zero-span tensile strength was not changed in spite of the

change in fibre shape. In previous studies in pulp mills, the zero-span and the shape factor correlated strongly (Mohlin et al, Mohlin 2005). Also the curling by high consistency refining as in sack paper production affects both zero-span tensile strength and fibre kink (Mohlin, Hornatowska 2009). The reason why the zero-span strength is not affected by agitated storage is not clear. One possibility is that the twist itself reduces the zero-span so that the change from twist to angle fold has no effect and another possibility is that it is the “knee”-deformation that is more critical for the zero-span. The “knee”-deformation changed very little with agitated storage.

The increase in fibre curl due to agitation may seem rather unexpected, as this treatment is milder than that used in the disintegration applied in every laboratory preparation of samples before testing. A possible explanation is that the less intensive stirring in a storage chest interacts with the inherent potential of the fibres to twist and thus results in a more deformed fibre (Gillis, Mark, 1973).

Other fibre dimensions were not changed by the storage, nor was it possible to detect any systematic changes in WRV or SR-number. There was however a considerable variability in WRV that could have been a combination of experimental uncertainties and storage effects. In well-controlled laboratory scale experiments, minor reductions in WRV have been observed on agitation. As will be discussed later, drainage characteristics on the paper machine were affected by the storage.

If these results are compared with results from on-line testing in the mill, *Fig 1*, it can be concluded that the changes occurring in the mill cover the same range of reduction in shape factor as this pilot-scale trial. The changes were, however, larger in this trial using never-dried pulps than in the trial using market SBK pulps (Mohlin 2005).

### Fibre properties and sheet properties

From the results presented so far, it is evident that the increase in fibre kink was responsible for the change in sheet properties. From a paper mechanics point of view, the effect may, however, be two-fold, firstly the more deformed fibre will pack less densely than the straight fibre and will give a sheet with a more open structure and less bonding; secondly, the shorter straight segments of the fibres will reduce the activation of fibre segments during drying which has been shown to be an essential stage in the development of tensile strength in paper (Vainio, Paulapuro, 2005).

Evidence that both of these effects are involved is presented in *Fig 6*. There was a unique relationship between Scott Bond and sheet density, i.e. both properties were influenced by storage in the same way. The lowest density and

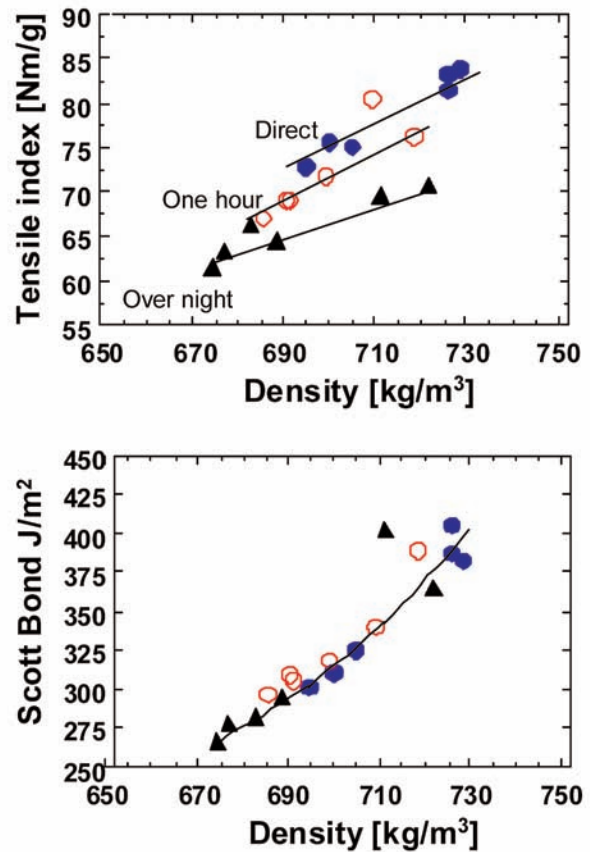


Fig 6. The tensile index vs. density relationship was affected by storage of the refined pulps while the Scott Bond density relationship was not. Results for handsheets prepared from the thick stock to the paper machine. At a given storage time, the different sample points represent the different paper machine running conditions and the two levels of refining.

the lowest Scott Bond were observed for the pulp that had been stored overnight. In this case, only the effect of kink on the packing of the fibres played a role. The tensile index, on the other hand, was also affected by the lower ability of the kinked fibres to activate the fibre network and the tensile index was lower at a given density when the pulp had been stored.

This effect of fibre kink is also very well illustrated by SEM micrographs of the paper surface, *Fig 7*. In the sheets prepared from the pulp directly from the refiner, the fibres are without kinks and very straight, whereas the fibres in the sheets made from the stored pulp contain kinks and also give a much less straight impres-

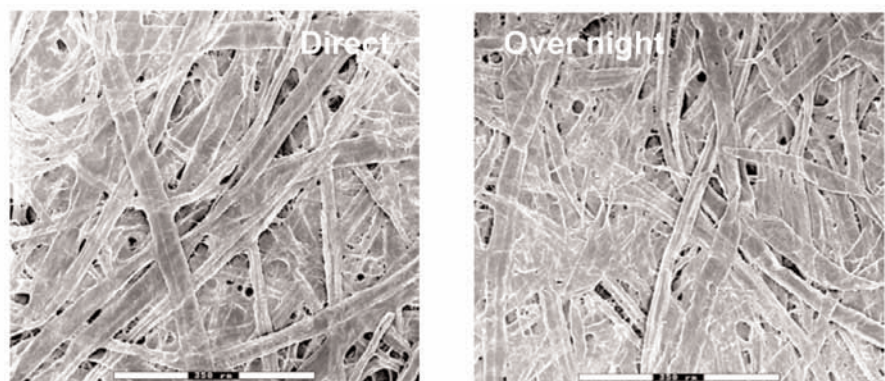


Fig 7. SEM micrographs of the surface of handsheets made from samples taken directly after refiner and after agitated storage overnight.

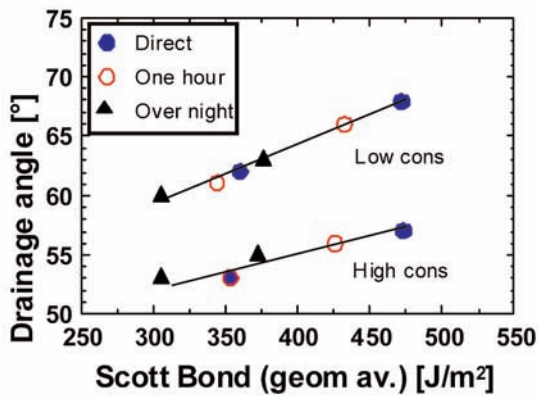


Fig 8. The drainage on the wire was improved (drainage angle was reduced) to the same extent as the bonding in the sheet was reduced by the kink introduction due to agitated storage. Different levels were obtained for the two forming consistencies

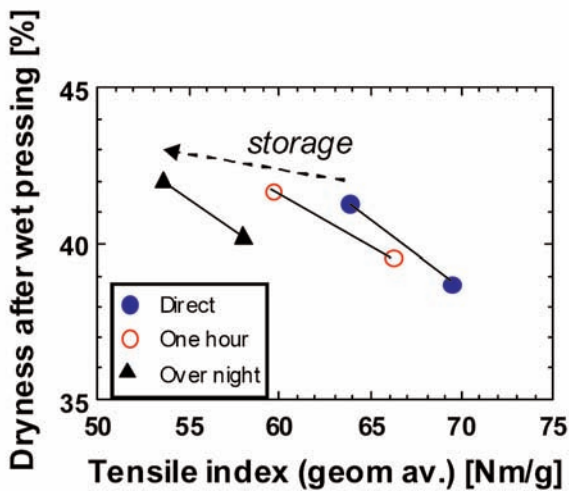


Fig 9. The dryness after wet pressing was improved to a lesser extent than the tensile index was reduced by the agitated storage. Results for the lower forming consistency. The two points represents different levels of refining.

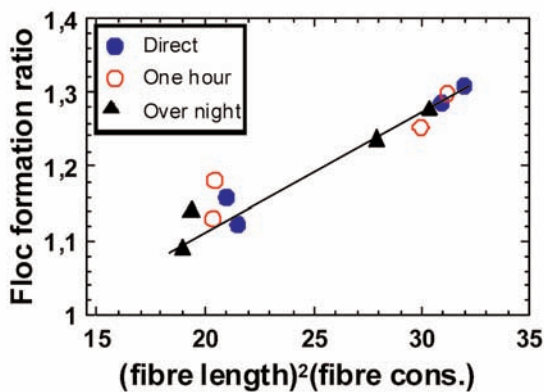


Fig 10. Floc formation ratio (ratio of formation number 3,0 – 30 mm to formation number 0,3-3,0 mm) as a function of flocculation tendency. Flocculation tendency is calculated from fibre length and forming fibre consistency (Head box consistency – white water consistency) as suggested by the Kerekes crowding factor. The two groups of data represent the two forming consistencies and within each group there are two levels of refining.

sion, implying that the activation of the segments by drying has been less efficient.

### Effect of pulp storage on sheet forming and wet pressing

The effect of agitated storage on sheet properties can thus

be seen as the opposite of refining. This was to some degree also the case when the effects of refining on paper machine runnability were studied. The more open sheet, as shown by the lower bonding level in the dried sheet, improved drainage. Both the drainage rate on the wire and the dryness after wet pressing responded in a manner similar to that of Scott Bond. Fig 8 shows the unique relationship between drainage angle on the wire and Scott Bond. A unique relationship was also observed for dryness after wet pressing and Scott Bond (not shown). However, if the comparison were made at the same tensile strength, the agitated stored pulps would have worse drainage characteristics as the tensile strength was reduced not only by the change in sheet structure but also by the less efficient activation of fibre segments. Fig 9 shows the dryness after wet pressing at the lower forming consistency. Similar trends were observed for drainage angle and at the higher forming consistency.

The wire retention of the pulps was very high, as the pulps contained little fines material. For the lower forming consistency the retention decreased by about 1 unit from about 91% to 90% when the pulps were stored overnight due to the more open network. At the higher forming consistency, it was not possible to see any significant differences.

No effect of fibre curl changes on sheet formation could be detected. Fibre flocculation has earlier been shown to be influenced by fibre length and by the number of fibres in suspension (fibre consistency and fibre coarseness) (Kerekes, Schell 1992, Mohlin 2001). It has also been shown that the effect of fibre flocculation on sheet uniformity (Mohlin 2001) is reflected in the ratio between the long and short wave length formation numbers according to the STFI method (Norman 1986)

In this trial, the same fibre was used, and the fibre coarseness can thus be assumed to be the same for all the trials. Fig 10 shows that fibre length and the fibre consistency very well explain the differences in sheet uniformity. The results thus indicate that differences in fibre curl did not affect the fibre flocculation.

## Concluding discussion

Storage under agitation had a considerable effect on sheet properties for softwood pulps, both for handsheets and for machine-made sheets. Changes in sheet structure and in strength properties could be associated with the increase in fibre curl. In many respects, the effect of agitated storage was opposite to that of pulp refining.

There are two practical considerations from this study that should be emphasized. It is important to take into account storage effects both in industrial papermaking in mills, as indicated by Fig 1, and in pilot-scale trials.

If agitated storage is a part of the stock approach system, this leads to a considerable increase in the energy consumption during refining. The following calculation is based on the present study. To reach the same tensile index, 60 Nm/g, the refining energy would need to be increased from 45 kWh/t to 85 kWh/t to compensate for 1 hour storage and to 185 kWh/t to compensate for

storage overnight. At the same time the dryness after wet pressing would be reduced from 42,7 % to 41.8 for 1 hour storage and to 39,5 % for storage overnight.

In pilot-scale studies considerable storage times for refined pulps may be necessary if the refiner capacity does not fit the throughput on the paper machine. For studies of papermaking parameters, the reproducibility of the results will probably be best if pulps are used when the change in properties has subsided. As shown in the introduction this can be difficult to achieve especially for hardwood pulps. In fibre furnish optimization studies, the most relevant results will be obtained if the fibres can be run directly on the paper machine. If this is not possible the change in pulp properties should be carefully monitored during the trial so that any storage effects can be taken into account.

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