Effect of cooking conditions on ECF bleaching and brightness reversion of birch kraft pulps

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ABSTRACT: Cooks with high and low levels of hydroxide ions and hydrosulfide ions were carried out to two different kappa number levels. The pulps were bleached by two difference ECF sequences, OD(EOP)DnD and OD(EOP)DP. A higher concentration of hydroxide ion was found to give a brighter unbleached pulp and a somewhat higher final brightness after each bleaching sequence. A higher level of hydrosulfide ion did not give a higher unbleached brightness, but it led to better brightness development during bleaching. The final kappa number was not critical for the final bleached brightness, but an increase in cooking kappa number from 16 to 22 gave a 17% increase in chlorine dioxide consumption in the OD(EOP)DnD sequence. The humid brightness reversion correlated with the HexA content after bleaching, but the dry brightness reversion did not correlate with any of the studied parameters. For the humid atmosphere, a final D stage gave less brightness reversion than a final P stage gave, but the reverse was true for the dry atmosphere.

Application: The concentrations of hydroxide ion and hydrogen sulfide ion in a birch kraft cook have an impact on the results of ECF bleaching.

How do the conditions in the kraft cooking of birch pulp influence bleachability in two different ECF sequences, OD(EOP)DnD and OD(EOP)DP? Only a few studies have been carried out on this subject, and the results are somewhat inconclusive.

Previous studies have shown that a high level of hydroxide ion in the cooking liquor gives a brighter unbleached pulp and often leads to better bleachability in standard ECF sequences [1–7]. Most of these studies used a given concentration of sulfidity, and the hydrosulfide ion level therefore followed the hydroxide ion level. The effect of the hydrosulfide ion level in the cooking liquor has seldom been studied separately.

According to the few studies that have isolated the effects of hydrosulfide, a higher level of hydrosulfide ion has a slightly positive effect on the unbleached brightness [3, 8] and has a positive effect on ECF bleachability [3, 9]. The cooking kappa number is obviously important for the bleaching result, and earlier studies have shown that a higher kappa number gives better bleachability [4, 9–11] and higher reactivity [10].

In studies on birch, pulps of kappa no. 19 bleached with D(EO)DED showed 20–30% better bleachability when the effective alkali (EA) charge (as Na_2O) was 20% than when it was 14% [2]. However, for a pulp of kappa no. 18 bleached with ODEDED, there was little difference in bleachability between active alkali (AA) levels of 20% and 16% (as Na_2O) in the cook [1].

With cooks of constant composition (very high liquor-to-wood ratio), Axelsson showed that pulps with kappa numbers of approximately 16 had better bleachability in an OD(EOP)DD sequence when higher hydroxide levels, higher hydrosulfide levels, or lower sodium ion levels were used in the cooking liquor [3]. The concentration ranges in the study were: $[OH^-]$ = 0.2–0.8 mol/L, $[HS^-]$ = 0.1–0.3 mol/L, and $[Na^+]$ = 1–3 mol/L.

Although these studies give good information about the ECF bleachability of birch, there were some contradictions, and some aspects were not covered. In our study, the cooks were performed with industry-like conditions to different kappa numbers. The hydroxide and hydrosulfide ion levels in the cook were varied at the same time but independently of each other. The bleachability was evaluated in both OD(EOP)DnD and OD(EOP)DP sequences.

The heat-induced brightness reversion in humid and dry atmospheres was also included in this study since it is an important parameter, especially for hardwood pulps. Both dry and humid conditions were included because the moisture content of the sheet is important for the heat-induced brightness reversion [12]. No procedure has been standardized, and little is known about the relationship between the actual brightness reversion during storage and transport and the results of different laboratory tests.

EXPERIMENTAL

Industrial birch chips were air dried, screened, and sorted by hand to remove bark and knots. In each experiment, we cooked 2000 g of o.d. chips in a laboratory circulation digester.

Prior to cooking, the chips were presteamed for 5 min at a pressure of 0.1 MPa and a temperature of 110°C. The cooks were divided into three zones: impregnation, Cooking Zone 1, and Cooking Zone 2. In the impregnation zone, the temperature was 130°C, the pressure was 1.0 MPa, the time was 45 min, and the liquor-to-wood ratio was 3.5:1. At the end of the impregnation stage and the start of Zone 1, the temperature was increased, the pressure was lowered to the corresponding vapor pressure, and white liquor was added. In Cooking Zone 1, the liquor-to-wood ratio was 4:1. After 120 min, white liquor was again added, and cooking was continued in Cooking Zone 2 for 150 min with a liquor-to-wood ratio of 4.5:1.

We cooked the chips to different kappa numbers by adjusting the temperature and the chemical charges as detailed in **Table I**. Three different levels of both hydroxide ions and hydrosulfide ions in the cooking liquor were applied, as shown in **Fig. 1**. The high, medium, and low hydroxide ion levels were denoted HA, MA, and LA, and the high, medium, and low hydrosulfide ion levels were denoted HS, MS, and LS. An extra cook with an addition of 35 g of tall oil per kg of pulp was also included. The tall oil was charged at the beginning of the impreg-

nation stage.The pulps were screened on a 0.2-mm-slot screen and washed before the subsequent analyses, oxygen delignification, and bleaching.

All pulps were oxygen delignified. In the oxygen stages, the time, temperature, and oxygen pressure were kept constant at 60 min, 107°C, and 0.5 MPa, respectively. The sodium hydroxide charge was adjusted to give residual pH levels between 10.4 and 11.8, and we added 0.05% $MgSO_4$. The pulp and chemicals were mixed at 10% consistency. They were distributed evenly in polypropylene bags, and the atmosphere in the bags was saturated with oxygen. The plastic bags were closed and placed in autoclaves, which were pressurized with oxygen. This oxygen delignification procedure has been thoroughly investigated and used for a long time at the Eka Chemicals AB laboratory, and it gives the same results as oxygen delignification where the pulp is under direct oxygen pressure.

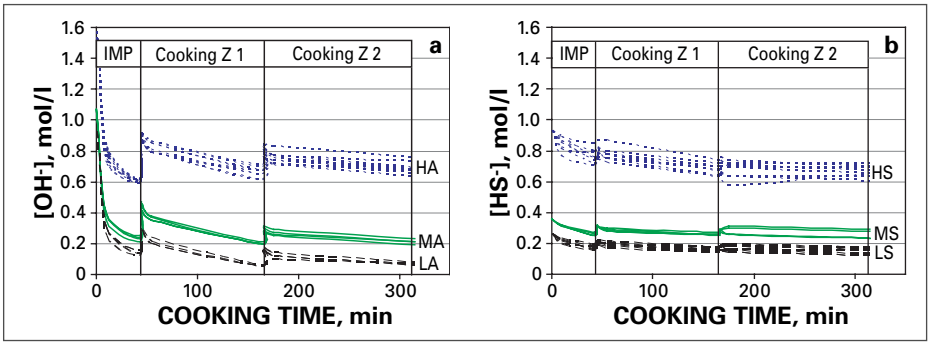
Samples of each of the oxygen-delignified pulps were bleached in both D(EOP)DnD and D(EOP)DP sequences. At least two bleachings were performed for each pulp and bleaching sequence. The consistency was 10% in all the bleaching stages, and all nonpressurized stages were performed in plastic polyethylene bags. In the D_0 stage in each case, the kappa factor was 0.2 (expressed as % Active chlorine [aCl] on pulp/kappa no.), the temperature was 50°C, the time was 50 min, and the final pH was between 2.7 and 3.4.

The EOP stages were performed in an oxygen-saturated atmosphere at a pressure of 0.22 MPa, as already described for the oxygen delignification, and the hydrogen peroxide charge was 0.1% on pulp. In the EOP stages, the time was 60 min, the temperature was 90°C, and the final pH was between 11.3 and 11.8.The conditions in the D_1 stage were 0.8% aCl, 70°C, 75 min, and a final pH between 3.0 and 4.0. The conditions in the D_2 stage were 0.5% aCl, 70°C, 150 min, and a pH of 3.1–4.3.The conditions in the P stages were 0.2% H_2O_2, 90°C, 120 min, and a pH of 10.7–11.6. After each bleaching stage, the pulp was washed with distilled water. In the wash stage between D_1 and D_2, the washing liquid was neutralized to pH 7.

Cook	H-factor	Kappa no.	EA charge, %	OH^- charge, mol/kg	OH^- consumed, mol/kg	HS^- charge, mol/kg	HS^- consumed, mol/kg
HAHS	352	10.9	31	7.75	5.00	4.00	0.95
HAHS	287	12.0	31	7.75	4.90	4.00	1.24
HAHS	205	12.6	31	7.75	4.80	4.00	1.01
HAHS*	145	17.3	31	7.75	4.52	4.00	1.15
HAHS*	118	22.9	30	7.50	4.61	4.00	1.24
HAHS	104	24.6	31	7.75	4.55	4.00	1.10
HALS*	249	15.8	31	7.75	4.86	1.20	0.50
HALS	207	18.6	31	7.75	4.65	1.20	0.52
HALS*	190	23.8	30	7.50	4.70	1.20	0.48
MAMS*	415	16.1	21	5.25	4.35	1.75	0.52
MAMS,T*	415	16.2	21	5.25	4.25	1.75	0.52
MAMS*	296	21.6	20	5.00	4.20	1.75	0.77
MAMS	270	23.7	20	5.00	4.11	1.75	0.76
LAHS*	594	16.4	18	4.50	4.16	4.00	1.34
LAHS*	402	21.8	17.3	4.33	4.10	4.00	1.34
LALS*	853	15.9	18	4.50	4.20	1.20	0.70
LALS	603	20.0	17.3	4.33	4.07	1.20	0.65
LALS*	576	22.0	17.3	4.33	4.07	1.20	0.56
LALS	549	25.4	17.3	4.33	4.04	1.20	0.70

*Pulps used for oxygen delignification and bleaching. A=hydroxide. S=hydrosulfide. T=tall oil. H=high. M=medium. L=low.

I. Cooking conditions.



1. The [OH^-] and [HS^-] profiles in the cooking liquor for the different cooks.

The kappa number and ISO brightness were determined according to SCAN-C 1:00 and SCAN P3:93, respectively. The [HS^-] and the [OH^-] in the liquors used for cooking were determined according to SCAN-N 30:85, and the residual levels in the cooking liquors were determined according to SCAN-N 31:94 and SCAN-N 33:94, respectively. The HexA was determined by acidic hydrolysis of pulp in a formate buffer, followed by UV analysis of the 2-furoic acid formed in the hydrolysate, based on the work of Vuorinen *et al.* [13].

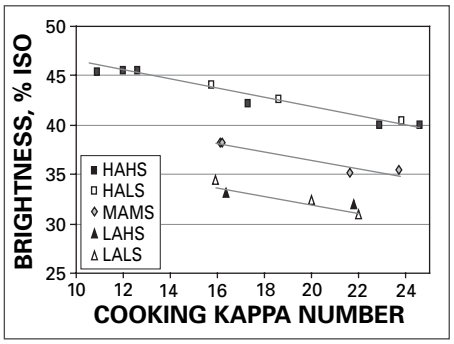
The heat-induced brightness reversion was evaluated by two different methods, one in a dry atmosphere and the other in a humid atmosphere. We evaluated the dry brightness reversion by measuring the brightness loss after drying the sheet in an oven at 105°C for 4 h and then allowing the sheet to stand at room temperature for at least 30 min. For the humid brightness reversion, we measured the brightness loss after the sheet was conditioned at 23°C and 50% RH, was sealed in a polyethylene bag and kept at 70°C for 64 h, and was finally removed from the bag and allowed to stand at room temperature for at least 1 h.

We also investigated whether the color caused by brightness reversion was stable or soluble in water, as performed by Granström [14]. This phenomenon is important to consider when one is trying to understand the brightness reversion

Cook	H-factor	Kappa no.	Brightness, % ISO	Yield, %	Viscosity, dm³/kg	Shives, % of pulp
HAHS	352	10.9	45.3	47.2	1249	0.1
HAHS	287	12.0	45.5	48.1	1328	0.0
HAHS	205	12.6	45.5	48.2	1401	0.0
HAHS*	145	17.3	42.2	49.0	1552	0.4
HAHS*	118	22.9	40.0	49.4	1572	1.9
HAHS	104	24.6	40.0	48.3	1596	2.7
HALS*	249	15.8	44.0	49.0	1411	0.3
HALS	207	18.6	42.6	49.0	1478	0.6
HALS*	190	23.8	40.4	49.3	1420	4.0
MAMS*	415	16.1	38.2	52.4	1450	0.1
MAMS,T*	415	16.2	38.2	52.5	1493	0.1
MAMS*	296	21.6	35.2	53.6	1571	0.9
MAMS	270	23.7	35.4	53.1	1575	2.0
LAHS*	594	16.4	33.2	51.9	1530	0.1
LAHS*	402	21.8	32.0	53.7	1541	1.1
LALS*	853	15.9	34.5	53.0	1419	0.1
LALS	603	20.0	32.4	54.0	1460	0.7
LALS*	576	22.0	30.9	53.7	1474	2.0
LALS	549	25.4	30.2	53.4	1342	3.7

*Pulps used for subsequent oxygen delignification and bleaching. A=hydroxide. S=hydrosulfide. T=tall oil. H=high. M=medium. L=low.

II. Cooking results.



2. Unbleached brightness of all the cooked pulps.

mechanisms, and it is interesting to evaluate what happens when the pulps are disintegrated. After brightness reversion, the sheets were disintegrated in water again, and new handsheets were made. The brightness of the new sheet was then measured, and the difference between this value and the value prior to disintegration was called the "water-soluble" brightness reversion. The residual brightness reversion is referred to here as "water-stable" brightness reversion.

RESULTS AND DISCUSSION

Cooking

The kraft cooking variables studied were the kappa number after cooking and the concentrations of hydroxide and hydrosulfide ions in the cooking liquor. The hydroxide and the hydrosulfide ion levels were varied at the same time but independently of each other, as shown in Fig. 1. For all the cooks, the high, medium, and low concentrations of residual hydroxide ion were approximately 0.69 mol/L, 0.21 mol/L, and 0.06 mol/L, respectively. Similarly, the high, medium, and low concentrations of residual hydrosulfide were approximately 0.65 mol/L, 0.25 mol/L, and 0.15 mol/L, respectively. Five different types of cooks were performed with these concentration profiles: HAHS, HALS, MAMS, LAHS, and LALS.

Within each type of cook, we produced pulps at two different kappa numbers, at least, by adjusting the cooking temperature. The results of these cooks are shown in **Table II**. One cook with an addition of tall oil was included. Tall oil is commonly used as a dispersant in the industry to reduce pitch problems when birch is cooked, but it is seldom used in laboratory studies.

The results showed that the brightness of the pulp after cooking was influenced mostly by the hydroxide ion concentration and the kappa number. A high concentration of hydroxide ion increased the brightness by 10 brightness units compared with a low concentration and by 5 brightness units compared with a medium concentration, as **Fig. 2** shows. The influence of the kappa number was smaller. A pulp at kappa no. 16 was about 3% units brighter than a pulp at kappa no. 22.

The hydrosulfide ion concentration in the cooking liquor did not influence the unbleached brightness, but it changed the H-factor needed to reach a given kappa number, as Table II reflects. In other words, at a given kappa number, a pulp produced with a given hydroxide ion level, a high level of hydrosulfide ions, and a relatively low H-factor had the same brightness as a pulp cooked with a low level of sulfide ions and a high H-factor. These results show that the direct correlation between H-factor and unbleached pulp brightness reported for birch by Axelsson [3] may not be valid when large changes are made in the hydrosulfide ion concentration.

As the results in Table II also show, a high level of hydroxide ion gave a cooking yield that was approximately 4 units (% ISO) lower than that obtained for the medium and low levels of hydroxide ion. A lower kappa number also gave a somewhat lower yield. At kappa numbers above 22, the screened yield decreased as a result of an increase in shives (>1% of pulp). The pulp cooked with tall oil contained 0.85% dichloromethane extract, and the reference pulp contained 0.68% dichloromethane extract, but no other differences in the pulp parameters were noted.

Oxygen delignification

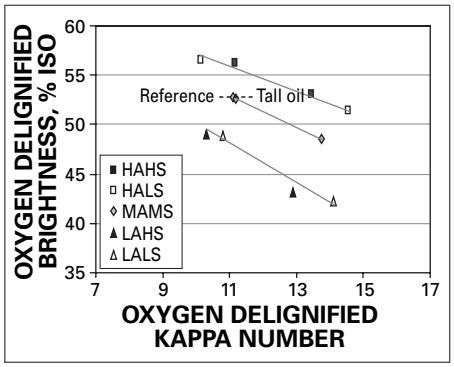
Pulps from two different kappa number ranges, 15.8–17.3 and 21.6–23.8, were chosen for oxygen delignification and further bleaching (denoted by asterisks in Tables I and II). At each kappa number level, one pulp from each of the cooking types was included; at the low kappa number level, the extra pulp cooked in tall oil was also included. The results after oxygen delignification and after the D_0(EOP) pre-bleaching are shown in **Table III**.

The kappa number reduction in the oxygen stage was 31–37% for the pulps of low cooking kappa number (upper part of Table III) and 36–41% for the pulps of high cooking kappa number (lower part of Table III). The pulps of high cooking kappa number probably exhibited a better kappa number reduc-

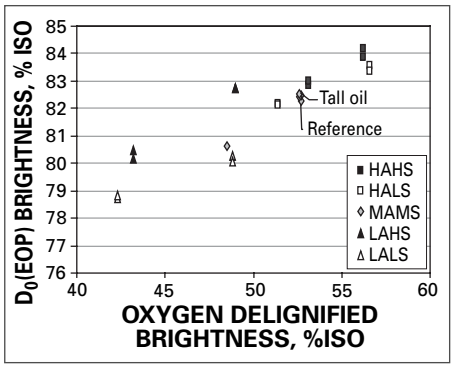
Pulp	Cooking kappa no.	O-stage Kappa no.	O-stage Brightness, % ISO	O-stage HexA, mmol/kg	O-stage Kappa no. red.,* %	EOP Kappa no.	EOP Brightness, % ISO
HAHS	17.3	11.2	56.2	40	36	4.4	84.0
HALS	15.8	10.2	56.6	35	36	3.9	83.5
MAMS	16.1	11.1	52.7	48	31	4.6	82.4
MAMS,T	16.2	11.2	52.6	50	31	4.6	82.5
LAHS	16.4	10.3	49.0	39	37	4.4	82.7
LALS	15.9	10.8	48.8	44	32	4.3	80.2
HAHS	22.9	13.5	53.1	48	41	4.1	82.9
HALS	23.8	14.6	51.4	52	39	3.7	82.1
MAMS	21.6	13.8	48.5	48	36	3.9	80.6
LAHS	21.8	12.9	43.2	44	41	3.6	80.3
LALS	22.0	14.1	42.3	43	36	3.1	78.8

*Kappa number reduction. A=hydroxide. S=hydrosulfide. T=tall oil. H=high. M=medium. L=low.

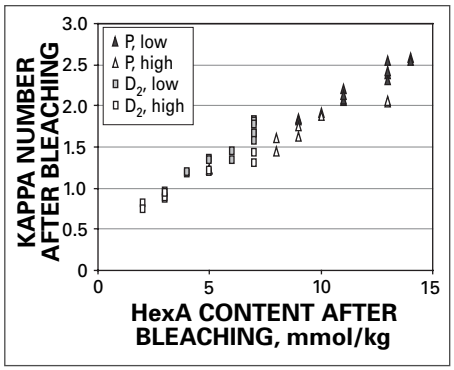
III. Results after oxygen delignification and D_0(EOP) prebleaching.



3. Brightness after oxygen delignification.



4. Brightness after D_0(EOP) bleaching vs. brightness after oxygen delignification.



5. HexA content and kappa number after bleaching. (In the labels, "low" and "high" indicate low and high cooking kappa numbers. "P" indicates a final hydrogen peroxide stage, and "D" denotes a final chlorine dioxide stage.)

tion since they had a higher lignin content than the pulps of low cooking kappa number. Within the pulps of low cooking kappa number, it was not possible to see any direct effect that the different cooking conditions had on the kappa number reduction. For the pulps of high cooking kappa number, the differences in kappa reduction were even lower, and no effects could be linked to the different cooking conditions.

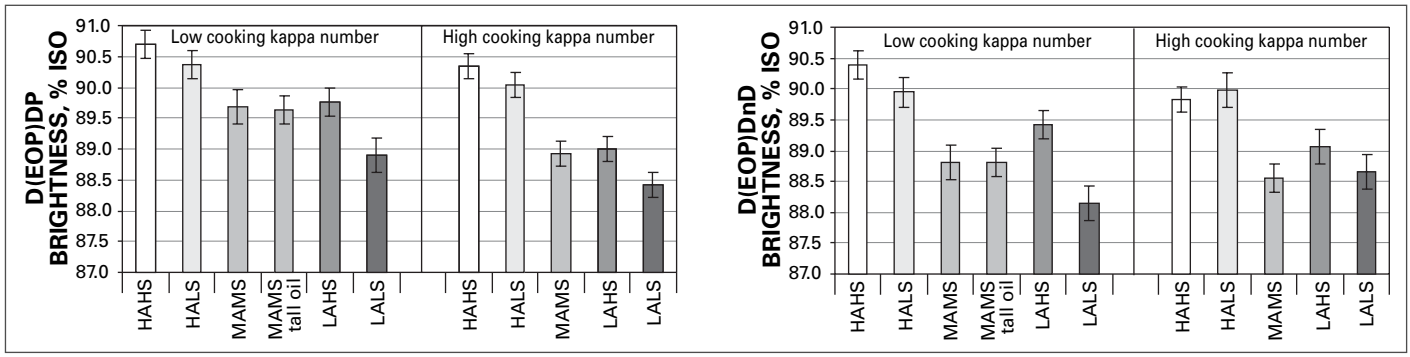
After oxygen delignification, almost the same brightness differences were seen between the different cooking types as were seen after cooking. (Compare **Fig. 3** and Fig. 2.) The brightness difference between high and low levels of hydroxide ion in the cook was still 10 ISO brightness units for the pulps of high cooking kappa numbers and only slightly lower, 8 ISO brightness units, for the pulps of low cooking kappa numbers. This difference was not the case for softwood pulp in our earlier study where oxygen delignification substantially reduced the brightness differences between pulps cooked with high and low alkali [4]. The hydrosulfide ion level in the cook had no effect on the brightness after oxygen delignification.

The HexA values in Table III were obtained after oxygen delignification, but the values after cooking are the same, since oxygen delignification does not reduce the HexA content. As the results show, the variations in cooking conditions gave only small differences in HexA content. The different cooks had similar HexA content at both kappa numbers, indicating that the HexA peak level was within or close to the studied kappa number range. This outcome means that the HexA content peaks in this study were slightly higher than those reported for similar birch cooks [3] and much higher than those reported for birch cooks with a high temperature (170°C) and a shorter cooking time [15].

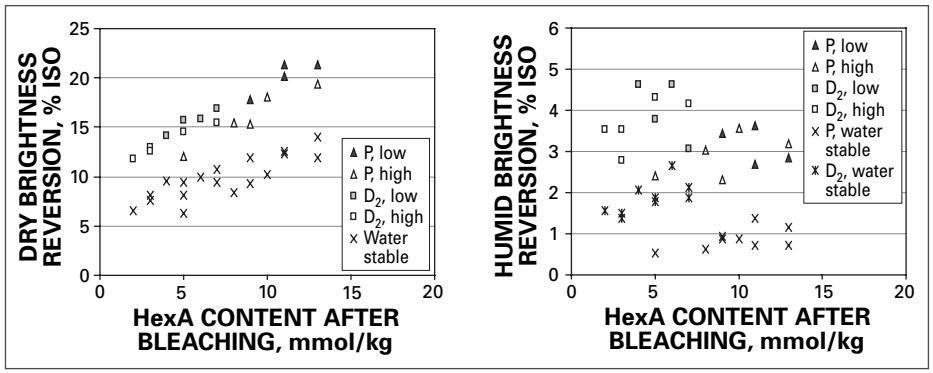
D_0(EPO) prebleaching

After the oxygen delignification stage, the pulps were prebleached in a D_0(EOP) sequence with a kappa factor of 0.2 (% aCl on pulp/kappa no.) in the D_0 stage (Table III). Interestingly, when the brightness after the D_0(EOP) stages is compared with the brightness after the oxygen delignification (**Fig. 4**), the positive effect that a high level of hydroxide ion had on brightness still persisted. However, a positive effect of the high hydrosulfide level was also detected, which was not seen with unbleached and oxygen-delignified pulps. Pulps cooked with a high level of hydrosulfide ion showed a better brightness gain in the D_0(EOP) stages. The LAHS pulps had especially good brightness development and showed a final brightness similar to that of MAMS pulps despite substantial differences in brightness after the oxygen delignification stage.

In Fig. 4, the data points furthest to the right in each category represent the pulps of low cooking kappa numbers. The use of a kappa factor in the D_0 stage did not even out the brightness differences between the pulps of high and low kappa number. The pulps from the low kappa numbers reached an ISO brightness that was 1–2 units higher than that of the pulps of high kappa number. However, Table III shows that after D_0(EOP) the pulps of high cooking kappa number reached lower final kappa number values than did the pulps of low cooking kappa number. No correlation



6. Final brightness of pulps bleached by the OD(EOP)DP and OD(EOP)DnD sequences.



7. Total and water-stable brightness reversion in humid and dry atmospheres.

between kappa number and brightness was apparent after D_0(EOP). Adding tall oil to the cook had no effect on the D_0(EOP) bleaching performance.

Final brightness

As **Fig. 5** shows, the final kappa number was highly dependent on the HexA content of the final bleached pulp. Although there are some variations, pulps bleached in a final chlorine dioxide stage have lower kappa numbers than pulps bleached in a final hydrogen peroxide stage. The pulps of high cooking kappa number also end up with a slightly lower kappa number and a slightly lower HexA content than the pulps of low cooking kappa number. There were small variations between the pulps cooked with different chemical profiles, for which no specific effect could be found in terms of the kappa number or HexA content after bleaching.

The graphs in **Fig. 6** show the results for the final bleached pulps after the OD(EOP)DP sequence and the OD(EOP)DnD sequence.

The final brightness of the pulps after D_1P bleaching showed exactly the same trends as after D_0(EOP) bleaching (first graph). A high level of hydroxide ion and a high hydrosulfide level were both beneficial for bleachability. In general, the hydroxide ion level had a more pronounced effect than produced by the hydrosulfide ion level. However, for the LAHS pulps, the high hydrosulfide ion level was important, and these pulps reached the same final brightness as obtained with the medium reference cooks.

As after the D_0(EOP) stages, the D_1P final bleached pulps with high cooking kappa numbers did not reach the same brightness as the pulps with low cooking kappa numbers reached. The increase in chemical charge achieved by the constant kappa factor in the D_0 stage was evidently not sufficient for the pulps of high cooking kappa number to reach the same final brightness as attained by the pulps of low cooking kappa number in the OD(EOP)DP sequence.

With D_1nD_2 instead of D_1P as the final bleaching stages, the pulps cooked with a high hydroxide ion level again showed the best bleachability (second graph). A high level of hydrosulfide ion seemed important for bleachability at the low kappa number level and especially at a low level of hydroxide ion. At the higher kappa number level, the differences were smaller. There was no noticeable effect caused by different hydrosulfide ion levels and no noticeable difference between medium or low levels of hydroxide ion. Interestingly, the LAHS pulps reached a higher brightness than did the MAMS pulps at both levels of kappa number.

For these D_1nD_2 bleached pulps, the differences in final brightness attributable to differences in cooking kappa number were smaller, and the pulps of high cooking kappa number reached almost the same final brightness as the pulps of low cooking kappa number reached. Tall oil addition had no effect on the bleaching result in either of the bleaching sequences.

Brightness stability

As the first graph in **Fig. 7** shows, the humid brightness reversion was very high, and it increased with increasing HexA content of the bleached pulp. The correlation with HexA has been shown before for TCF-bleached pulps, and it was suggested that this outcome came about because HexA was reduced during the heat treatment and because the degradation product released from the pulp had formed colored complexes with metals [14]. Our data support this hypothesis and show that there is a kappa number decrease during the heat treatment, indicating a decrease in HexA content. However, it seems that a large part of the brightness reversion cannot be linked to the HexA content since the brightness reversion is still fairly high even at low HexA contents.

The heat-treated sheets were disintegrated, and fresh sheets were made to allow us to measure the water-soluble and water-stable brightness reversion. A large part of the brightness reversion was water-soluble for these

ECF-bleached pulps, as shown before for TCF-bleached pulps [14]. The percentage of the brightness reversion fraction that was stable in water was approximately the same (between 52% and 67%) for all the different pulps with different HexA contents.

The general trend was thus that better humid heat brightness stability was achieved with cooking and bleaching conditions that gave low HexA content in the final pulp. This stability was better achieved with a final chlorine dioxide stage than with a hydrogen peroxide stage and was also better achieved with a higher kappa number after cooking.

The dry brightness reversion was much less than the reversion in a humid atmosphere. In this case (second graph), the pulps bleached with a final P stage showed less brightness reversion than did the pulps bleached with a final D stage, even though the peroxide-bleached pulps had a higher HexA content. The hydrogen-peroxide-bleached pulp also had a smaller portion of water-stable brightness reversion (20–38%) than the pulps bleached with a final chlorine dioxide stage (42–62%). No direct correlation was found between the dry brightness reversion and the final kappa number, HexA content, or cooking conditions.

Some of the pulps were also tested with the dry method for longer periods to see if the results would then be more like the results obtained under humid conditions. The longer dry treatment (3 days) gave about 2.4 times as high a brightness loss as the shorter dry treatment (4 h). However, the general conclusions were the same, and no correlation was found between the dry and humid brightness reversions.

A good correlation (with the exception of one data point) between dry and humid brightness reversion has been reported for eucalyptus pulps from different bleaching sequences [16]. However, our findings suggest that the correlation between dry and humid brightness reversion is probably limited to certain pulp variations and that no general relationship exists. These findings emphasize the need to study in more depth the different methods and their correlation with natural yellowing.

CONCLUSIONS

A higher level of hydroxide ion during kraft cooking gave a brighter unbleached pulp and a somewhat higher final brightness in both the OD(EOP)DnD and OD(EOP)DP sequences. A higher level of hydrosulfide ion during kraft cooking did not give a higher unbleached brightness, but it gave a better brightness development during the ECF bleaching sequences.

The effects of the variables in the kraft cook were smallest when pulps were cooked to a high kappa number and bleached in an OD(EOP)DnD sequence. The kappa number reduction during bleaching was not influenced by the cooking variables studied, and the final kappa number was not critical for the final brightness reached after bleaching. A cooking kappa number increase from 16 to 22 gave a 17% increase in chlorine dioxide consumption in the OD(EOP)DnD sequence.

The humid brightness reversion correlated with the HexA content after bleaching. A higher cooking kappa number and a final chlorine dioxide stage gave a lower HexA content after bleaching, and these conditions were therefore beneficial for humid brightness stability. The dry brightness reversion did not correlate with the humid brightness reversion or HexA content after bleaching. In this case, a final hydrogen peroxide stage gave a lower brightness reversion. Thus, totally different conclusions were drawn depending on the brightness reversion method used. **TJ**

ACKNOWLEDGEMENT

The authors thank the personnel at Kvaerner Pulping AB, the project reference group, and Dr. Anthony Bristow. The authors also thank the Swedish Knowledge Foundation for financial support.

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Received: September 21, 2004
Revised: February 21, 2005
Accepted: February 23, 2005

This paper is also published on TAPPI's web site <www.tappi.org> and summarized in the July *Solutions! for People, Processes and Paper* magazine (Vol. 88 No. 7).

INSIGHTS FROM THE AUTHORS

The link between cooking and bleaching is important in controlling the whole process. Although a lot of research on kraft cooking has been done, it is important to include the effects on pulp bleaching and on the final bleached pulp quality. Since the cooking conditions may influence the achievable brightness and the HexA content of the pulp after cooking, the cooking conditions probably affect the final pulp brightness and brightness reversion.

This study of birch kraft pulp complements earlier studies by including cooking at different kappa number levels and by including multivariate changes of the hydroxide and hydrosulfide ion concentration in the cook. The ECF bleaching was also evaluated with both D and P as final stages, and brightness reversion was evaluated in both dry and humid atmospheres.

The most difficult aspect of the work was to measure brightness reversion, since no evaluation procedure has been standardized and because there is limited knowledge about the correlation between laboratory methods and the actual yellowing of paper and market pulp. To contend with this problem, we included measurements of brightness reversion in both humid and dry atmospheres.

It was interesting to discover that a higher concentration of hydrogen sulfide ion in the cook does not affect the brightness of the pulp after the cook but still gives a better bleachability. Another surprising finding was the difference in results obtained when brightness reversion was evaluated in a humid atmosphere as opposed to a dry atmosphere.

With regard to what is most relevant to the mill, brightness reversion in a dry atmosphere has no general correlation with brightness reversion in a humid atmosphere. In a birch kraft cook, the concentrations of both the hydroxide ion and the hydrogen sulfide ion have an impact on the subsequent ECF bleaching results.

Our research in this area will continue. We plan to look at brightness reversion of other types of hardwood and the role of HexA in brightness reversion.

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