# FACTORS AFFECTING BRIGHTNESS REVERSION OF HARDWOOD KRAFT PULPS

Vanessa L. Silva,[a,]* Alessandro G. Lino,[a] Robisnéa A. Ribeiro,[a] Jorge L. Colodette,[a] Annbritt Forsström,[b] and Eva Wackerberg [b]

Ten industrial fully bleached hardwood pulps representing very different brightness reversion profiles were evaluated. The pulps were characterized before and after brightness reversion. The aging method (dry, wet, high/low RH, high/low temperature, short/long time) had, in most cases, no effect on overall brightness reversion trends, but affected the absolute reversion values significantly. Relative humidity in the range of 50 to 90% influenced reversion much more than temperatures in the range from 30 to 45°C. Dry and wet heat-induced brightness reversion correlated positively and significantly with hexenuronic acid (HexA) content in the pulp. The brightness reversion causes a significant decrease in pulp viscosity values, and HexA thus causing decrease of kappa number. Modern pulps produced by TCF and light ECF bleaching technologies were more prone to brightness reversion than regular ECF pulps, partly due to the higher content of HexA. At a pH level above 8, the brightness reversion process was strongly retarded for pulps with a very high HexA content.

*Keywords: Bleached kraft pulps; Brightness reversion; Humidity; pH; Temperature*

*Contact information: a: Federal University of Viçosa, Viçosa, 36570-000, Brazil; b: Eka Chemicals AB, SE-445 80 Bohus, Sweden; * Corresponding author: vanessa.silva@ufv.br*

## INTRODUCTION

Brightness reversion is of importance for high brightness hardwood kraft pulp producers, particularly for those operating with low chemical charges in the bleach plant. Low kappa numbers and high brightness values in modern hardwood kraft pulps do not necessarily imply high brightness stability.

A number of researchers have investigated heat-induced brightness reversion in both dry and humid atmospheres using different wood raw materials as well as different elemental chlorine free (ECF) and totally chlorine free (TCF) bleaching sequences (Colodette et al. 2003; Ganström et al. 2002). It has been suggested that hexenuronic acid (HexA) groups, carbonyl groups, and lignin residues are involved in the brightness reversion reactions (Sevastyanova 2005). Transition metal ions such as $Fe^{2+}$, $Fe^{3+}$, $Cu^{2+}$ or $Mn^{2+}$, present in bleached pulps in trace amounts, have been associated with a faster brightness loss (Forsskåhl 2000; Gellerstedt et al. 2003; Frosström et al. 2007), but their exact role in the color formation is not yet known.

Hexenuronic acids are formed during kraft pulp cooking when 4-O-methyl-glucuronic acid groups in glucuronoxylan are converted to 4-deoxy-4-hexenuronic acid groups. In most cases, the HexA groups survive TCF and ECF light bleaching operations

operations (Eiras et al. 2008, 2009). Bleaching sequences with reduced chlorine dioxide consumption are termed ECF light bleaching.

This paper describes the brightness reversion characteristics of ECF- and TCF-bleached industrial hardwood kraft pulps produced from different wood raw materials. The influence of aging conditions, HexA and carbonyl groups, copper number, and metal ion content of the pulp will also be discussed.

## EXPERIMENTAL

### Pulp and Paper Analyses

The experiments were carried out on industrial bleached hardwood kraft pulps produced from eucalyptus, birch, and acacia, obtained from South American, European, and Asian pulp mills. The pulps were thoroughly washed with distilled water (4 liters of water to 25 grams of pulp) and then characterized according to measurements of conventional kappa number, viscosity, brightness, organically-bound chlorine, reducing groups, carboxyl groups, hexenuronic acids, dicloromethane (DCM) extractives, glucans, and xylans.

Next, these pulps were used to form handsheets at two pH levels (4.5 and 8.0). The pH-value of the pulp suspension was adjusted with sulfuric acid and sodium hydroxide at 0.3% consistency before sheet-making. The handsheets were then formed according to TAPPI standard T218 sp-97 and dried for 12 hours to a moisture content of 10-11% in an environmentally controlled room, (50±2% relative humidity and 23±1 °C) before aging according to conditions I -VI described below.

### Aging Conditions

The extent of reversion, evaluated as brightness loss and post color (PC) number (Giertz, 1945), was determined using the following conditions:

(I) 105°C for 4 h and ~0% relative humidity (RH),
(II) 70°C for 64 h and 10% pulp moisture content,
(III) 45°C for 720, 1080, 1440h and 50% RH,
(IV) 30°C for 720, 1080, 1440 h and 50% RH,
(V) 45°C for 720, 1080, 1440 h and 90% RH,
(VI) 30°C for 720, 1080, 1440 h and 90% RH.

The aging of the handsheets according to Condition I was performed by placing the sheets in an oven, and aging according to Condition II was performed by placing the sheets in a sealed plastic bag in a water bath. Conditions III-VI were obtained by placing the sheets in an acclimatizing chamber, which allowed for temperature (± 1°C) and relative humidity (± 1%) control. The acclimatizing chamber was also used for determining the moisture content (TAPPI standard T 412 om-94) of handsheets as a function of temperature (30, 45, and 60°C) and relative humidity (30, 50, and 90%). Table 1 summarizes the standard methods used for determining the chemical composition, optical properties, viscosity, and kappa number before and after aging. The metal ion content of the pulps was determined after wet combustion with nitric acid, using a microwave system with an Inductively Coupled Plasma instrument (Iris Radiell, Thermo ICP).

**Table 1.** Methods Used in this Study

| Analysis | Method |
|---|---|
| Kappa number | TAPPI T 236 om-85 |
| Viscosity | TAPPI T 230 om-85 |
| Brightness | TAPPI T 452 om-86 |
| Carbohydrates | TAPPI T 249 cm-85 |
| Extractives (dichloromethane) | TAPPI T 204 cm-97 |
| Hexenuronic acid (HexA) | Vuorinen et al. 1999 |
| Copper number | TAPPI T 430 om-94 |
| Organically bound chlorine (OX) | SCAN W 9:89 ECS 1600 |
| Carboxyl groups | TAPPI T 237 om-93 |

### Principal Component Analysis (PCA)

PCA is frequently used to reduce the dimensionality of data in chemical problems. The objective of PCA is to compress data within a group of new variables, which is a linear combination of the original variables, maximizing the description of data variance (Correia and Ferreira 2007). The PCA was performed by assigning the sample data from the different initial pulps characteristics. The principal component was carried out using the Unscrambler (version 7.0, Camo (Norway), USA).

## RESULTS AND DISCUSSION

The objective of this study was to establish proper laboratory conditions to assess brightness reversion, relevant to the reality during pulp transportation. The purpose was also to further understand in what way the chemical composition of commercial pulps influences the heat-induced aging process. The accelerated aging conditions I and II (Granström et al. 2001) and the more natural aging conditions III through V were used for evaluation of brightness reversion. The metal and extractive contents of the bleached pulps were evaluated and considered to be on a low level and are therefore not discussed further in this work. The metals report limits (mg/kg) were: Cu, 0.1; Fe, 0.5; and Mn, 0.1.

### Pulp Characterization

The ten pulp samples used in this study were obtained from nine different companies, from three wood species. Two pulps were produced from birch, one from acacia, and the remaining pulps were produced from eucalyptus (Table 2). Two pulps were bleached with TCF technology, and eight pulps with ECF technology, except that one of them employed an ECF light treatment with low dosage of chlorine dioxide. The other pulps were bleached with modified ECF bleaching sequences; four with a final P stage and three with a final D stage. The initial brightness of the pulps was 89 to 92% ISO, and the kappa number was between 0.2 and 5.8. It is noteworthy that the viscosity of the bleached acacia pulp was very low (Table 2).

**Table 2.** Properties of the Industrial Hardwood Kraft Pulps Prior to Aging

| Pulp Number | Wood species | Bleaching sequence* | Brightness, %ISO | Kappa Number | Viscosity, $dm^3/kg$ |
|---|---|---|---|---|---|
| 1 | Euca. | ECF *D* | 90.8 | 0.8 | 866 |
| 2 | Euca. | ECF *P* | 92.2 | 0.2 | 876 |
| 3 | Euca. | ECF *P* | 89.6 | 0.4 | 842 |
| 4 | Euca. | ECF *P* | 90.6 | 3.7 | 674 |
| 5 | Euca. | ECF *P* | 89.6 | 4.5 | 734 |
| 6 | Euca. | ECF light *P* | 90.9 | 1.9 | 829 |
| 7 | Euca. | TCF *P* | 89.0 | 5.8 | 813 |
| 8 | Birch | ECF *D* | 89.6 | 0.2 | 1150 |
| 9 | Birch | TCF *P* | 90.2 | 4.8 | 811 |
| 10 | Acacia | ECF *D* | 90.9 | 0.4 | 487 |

*The final bleaching stage for the ECF pulps is given in italics.

The copper number (reducing groups), carboxylic groups, hexenuronic acid (HexA) content, organically bound chlorine (OX), carbohydrate, and extractive (dichloromethane) contents of the pulps before aging are given in Table 3. Pulps with a high HexA content also had high carboxyl group content and a high kappa number. The ECF birch pulp (no. 8) had high organically-bound chlorine content, likely caused by usage of chlorine dioxide in the bleaching sequence. The xylan content of the birch pulps (pulps 8 and 9, Table 3) was, as expected (Sjöström 1981), significantly higher compared to the other hardwood pulps.

**Table 3.** Properties of Industrial Hardwood Kraft Pulps Prior to Aging

| No. | Copper number, $gCu_2O/100g$ | Carboxyl groups, meq/100g | HexA groups, mmol/kg | OX, mgCl/kg | Glucans, % | Xylans, % | Extractives (DCM), % |
|---|---|---|---|---|---|---|---|
| 1 | 0.04 | 6.2 | 6.2 | 103 | 83.4 | 15.7 | 0.08 |
| 2 | 0.27 | 5.9 | 1.8 | 87 | 83.3 | 16.0 | 0.10 |
| 3 | 0.11 | 6.2 | 4.1 | 74 | 84.6 | 14.7 | 0.10 |
| 4 | 0.37 | 10.4 | 25.8 | 80 | 83.6 | 15.8 | 0.10 |
| 5 | 0.19 | 11.1 | 29.9 | 103 | 83.2 | 16.4 | 0.10 |
| 6 | 0.23 | 6.2 | 10.7 | 28 | 83.2 | 16.0 | 0.11 |
| 7 | 0.06 | 10.4 | 47.7 | 7 | 81.8 | 15.5 | 0.06 |
| 8 | 0.38 | 5.4 | 2.1 | 171 | 72.7 | 24.7 | 0.10 |
| 9 | 0.05 | 9.2 | 37.1 | 6 | 74.5 | 23.2 | 0.08 |
| 10 | 0.40 | 2.3 | 1.2 | 119 | 83.8 | 13.7 | 0.10 |

The PCA showed that 99% of the information contained in Table 2 and 3 can be represented in two main components. In Fig. 1, PC1 scores explain 94% and PC2 explains 5% of the total variance. PC1 mainly represents the OX content, while the PC2 represents the HexA content (see the loadings in Fig. 1).

In Fig. 1, it can be noted that PC1 seems to separate the pulps according to the type of bleaching technology, in which those with TCF and ECF light technologies have negative scores, and ECF has positive scores and scores close to zero. The distribution along PC1 is quite reasonable; the pulps with high OX content are positioned at more positive score values than the those with low OX content (Pulps 6, 7 e 9). On the other hand, PC2 is mainly dominated by the effects of HexA.

With respect to the loadings that define PC1 and PC2, it is interesting to note that the contributions of kappa number, xylan, glucan, extractives, copper number, and carboxyl groups are negligible.

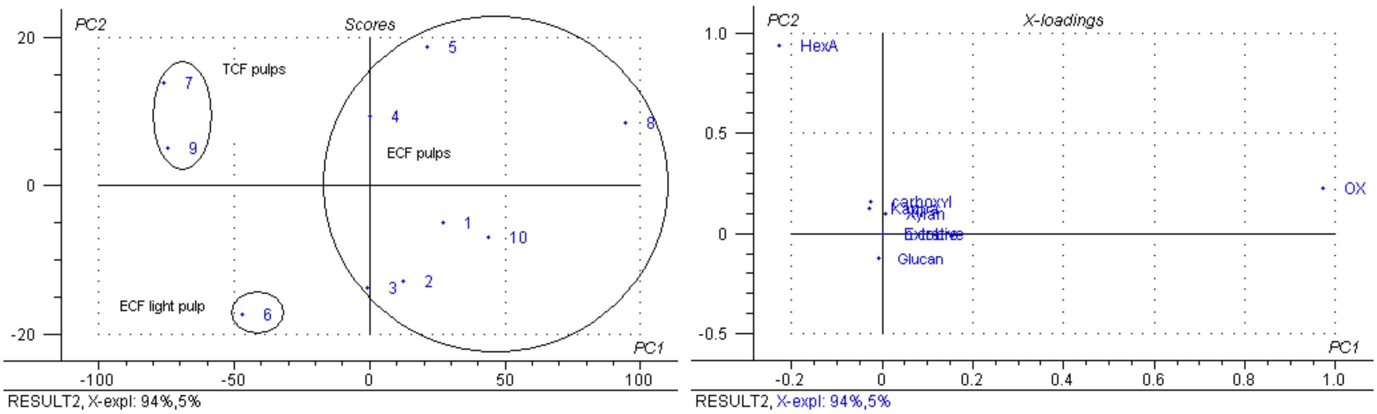


**Fig. 1.** PC1 against PC2 scores and loadings plots from Principal Component Analysis (PCA)

## Brightness Reversion

*Accelerated aging according to Condition I*

Pulp handsheets of the various samples were prepared at two pulp slurry pH values: 4.5 and 8.0. The handsheets were then submitted to the accelerated dry brightness reversion test (Condition I). The properties of the industrial hardwood kraft pulps after aging were determined and are given in Table 4.

When aging under dry conditions, the moisture content decreased from 10% to 0% within 7 minutes and remained at that level for the whole aging period. To isolate the effect of moisture, pulp handsheets were prepared at a pH of 4.5 and 8.0, then dried in an acclimatizing room to 10% moisture and further dried to 0% moisture in desiccators under vacuum in the presence of phosphorous pentoxide ($P_2O_5$) at room temperature. The treatment did not affect brightness reversion to any significant extent, indicating that the level of moisture present during aging according to Condition I was of minor importance. Figure 2 shows the brightness reversion for the different pulps, aged according to Condition I.

The results indicate that brightness reversion varies significantly (as anticipated) among the different pulp samples, which is explained by the type of pulp and bleaching technology used in the various cases. The TCF pulp samples (7 and 9) showed very high brightness reversion, as did the ECF light sample (6). Pulps 4 and 5 had similar post color number (PCN) to pulp 6, probably because of the high HexA content in these pulps. This may be due to the different bleaching sequences used. The ECF samples presented the lowest brightness reversion values.

**Table 4.** Properties of Industrial Hardwood Kraft Pulps after Aging According to Condition I

| No. | Bleaching Sequence* | pH | Bright. loss, %ISO | Kappa No. | HexA Groups, mmol/kg | Reacted HexA, mmol/kg | Copper number, $gCu_2O/100g$ | Carboxyl Groups, meq/100g | OX, $mgCl^-/kg$ | Visc., $dm^3/kg$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ECF *D* | 4.5 | 2.4 | 0.5 | 4.8 | 1,4 | 0.05 | 7.0 | 102 | 809 |
| | | 8.0 | 1.3 | 0.7 | 5.8 | 0,4 | 0.04 | 7.9 | 103 | 831 |
| 2 | ECF *P* | 4.5 | 2.1 | 0.1 | 1.6 | 0,2 | 0.40 | 6.1 | 86 | 813 |
| | | 8.0 | 1.1 | 0.2 | 1.7 | 0,1 | 0.30 | 6.4 | 87 | 838 |
| 3 | ECF *P* | 4.5 | 1.9 | 0.2 | 3.1 | 1,0 | 0.31 | 7.1 | 73 | 820 |
| | | 8.0 | 1.0 | 0.3 | 3.9 | 0,2 | 0.20 | 7.3 | 73 | 832 |
| 4 | ECF *P* | 4.5 | 3.9 | 2.6 | 24.1 | 1,7 | 0.42 | 10.5 | 79 | 602 |
| | | 8.0 | 2.0 | 3.0 | 25.2 | 0,6 | 0.36 | 10.9 | 79 | 621 |
| 5 | ECF *P* | 4.5 | 4.1 | 2.5 | 22.5 | 7,4 | 0.40 | 12.1 | 101 | 697 |
| | | 8.0 | 2.1 | 3.8 | 29.6 | 0,3 | 0.30 | 12.6 | 103 | 714 |
| 6 | ECF *light P* | 4.5 | 3.8 | 0.9 | 8.5 | 2,2 | 0.29 | 6.5 | 26 | 790 |
| | | 8.0 | 2.9 | 1.5 | 10.0 | 0,7 | 0.24 | 7.3 | 27 | 824 |
| 7 | TCF *P* | 4.5 | 5.9 | 4.7 | 45.9 | 1,8 | 0.22 | 10.5 | 7.0 | 743 |
| | | 8.0 | 3.4 | 5.3 | 47.2 | 0,5 | 0.15 | 11.3 | 7.0 | 757 |
| 8 | ECF *D* | 4.5 | 2.3 | 0.1 | 1.7 | 0,4 | 0.42 | 5.4 | 168 | 1001 |
| | | 8.0 | 1.5 | 0.2 | 1.9 | 0,2 | 0.40 | 5.6 | 169 | 1066 |
| 9 | TCF *P* | 4.5 | 5.4 | 3.8 | 36.2 | 0,9 | 0.15 | 9.2 | 6.0 | 746 |
| | | 8.0 | 3.2 | 4.2 | 36.9 | 0,2 | 0.08 | 10.0 | 6.0 | 778 |
| 10 | ECF *D* | 4.5 | 1.7 | 0.2 | 1.1 | 0,1 | 0.45 | 2.4 | 118 | 437 |
| | | 8.0 | 0.9 | 0.4 | 1.2 | 0 | 0.42 | 2.5 | 118 | 463 |

*1The final bleaching stage for the ECF pulps is given in italics.

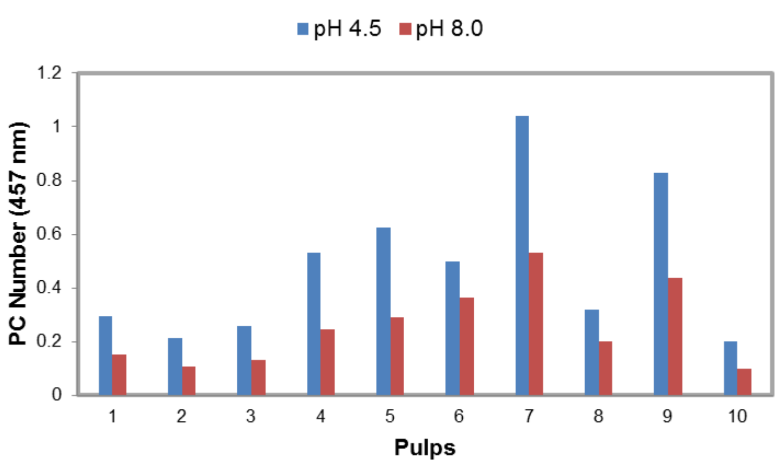


**Fig. 2.** Post color number (457 nm) of Pulps 1-10 aged according to Condition I

The hypothesis that a final P-stage (Pulps 2-7, 9; Table 4) in the bleaching sequence of hardwood pulps is beneficial for brightness stability (Eiras and Colodette 2005) was not proven in this study. The correlation between post color number (PCN) and pulp HexA content is shown in Fig. 3. The original pulp HexA content correlated positively and significantly with brightness reversion for all pulps in this study. Also, kappa number had the same tendency as hexenuronic acid.

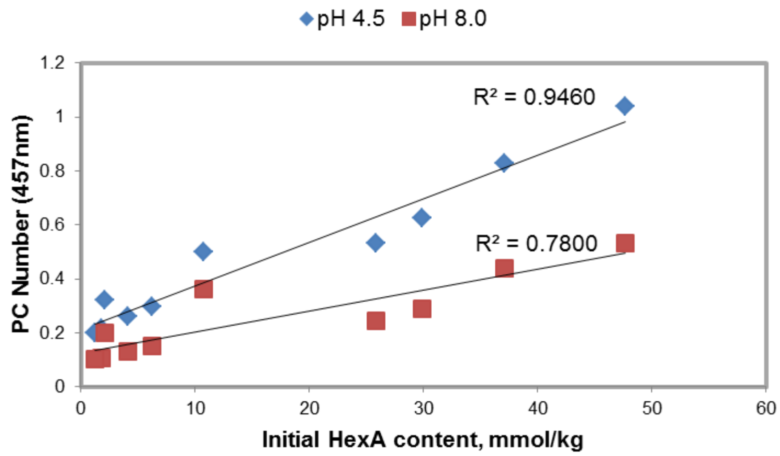


**Fig. 3.** Correlation between Post color number (457 nm) and hexenuronic acid (HexA) content for pulps aged according to Condition I

An increase in pulp slurry pH from 4.5 and 8.0 during sheet formation decreased the dry brightness reversion substantially for all pulp samples. This is in agreement with previously reported results (Frosström et al. 2007a, b).

The post color number was plotted versus the decrease in HexA content (Reacted HexA) in Fig. 4. The fact that degradation of hexenuronic acids was higher at pH 4.5 than pH 8.0 can be explained by the occurrence of an acid hydrolysis reaction of HexA.

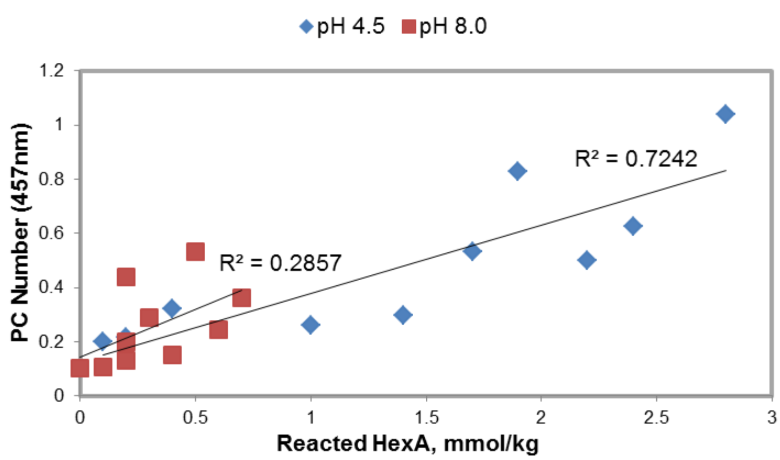


**Fig. 4.** Correlation between post color (PC) number (457 nm) and reacted hexenuronic acid (HexA) groups for pulps aged according to Condition I

Additional pulp chemical characteristics after accelerated dry aging are given in Table 4, and an increase in both copper number and carboxylic groups is observed as well as a decrease in viscosity. Zhou et al. (2011) studied the effect of carbonyl groups on brightness reversion and concluded that the carbonyl content correlated linearly with the PCN of pulp aging, but this is not proved in the present study. A good example is the fact that pulp 10 with higher cooper number (0.40 $gCu_2O/100g$ in the initial pulp) had the lowest PC number 0.2 at pH 4.5 and 0.1 at pH 8.0.

*Accelerated aging according to Condition II*

Brightness reversion Condition II is significantly different from Condition I with respect to aging time, temperature, and moisture content. Based on earlier studies, the brightness reversion values were expected to be substantially higher in the humid condition (Björklund et al. 2005). The effect on brightness reversion of kappa number, HexA content, viscosity, copper number, OX, and carboxylic groups was evaluated. The results are shown in Table 5 and Figs. 5 to 7 below.

**Table 5.** Properties of the Industrial Hardwood Kraft Pulps after Aging According to Condition II

| No. | Bleaching Sequence* | pH | Bright. loss, %ISO | Kappa No. | HexA Groups, mmol/kg | Reacted HexA, mmol/kg | Copper Number, gCu2O/100g | Carboxyl Groups, meq/100 g | OX, mgCl⁻/kg | Visc., dm³/kg |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ECF *D* | 4.5 | 13.2 | 0.4 | 4.5 | 1.7 | 0.06 | 7.2 | 100 | 732 |
| | | 8.0 | 5.6 | 0.7 | 5.6 | 0.6 | 0.05 | 8.1 | 102 | 783 |
| 2 | ECF *P* | 4.5 | 8.7 | 0.1 | 1.4 | 0.4 | 0.50 | 6.3 | 86 | 720 |
| | | 8.0 | 5 | 0.1 | 1.7 | 0.1 | 0.40 | 6.8 | 86 | 802 |
| 3 | ECF *P* | 4.5 | 12.1 | 0.2 | 2.7 | 1.4 | 0.40 | 7.4 | 71 | 702 |
| | | 8.0 | 5.4 | 0.3 | 3.6 | 0.5 | 0.30 | 8.1 | 72 | 791 |
| 4 | ECF *P* | 4.5 | 29.8 | 2.1 | 16.8 | 9 | 0.54 | 8.1 | 78 | 528 |
| | | 8.0 | 7.1 | 2.9 | 25.3 | 0.5 | 0.39 | 10.5 | 78 | 580 |
| 5 | ECF *P* | 4.5 | 32.4 | 2.3 | 18.4 | 11.5 | 0.56 | 10.4 | 101 | 587 |
| | | 8.0 | 7.9 | 3.5 | 29.4 | 0.5 | 0.40 | 11.4 | 101 | 659 |
| 6 | ECF light *P* | 4.5 | 17.5 | 0.9 | 7.6 | 3.1 | 0.05 | 6.9 | 23 | 707 |
| | | 8.0 | 5.6 | 1.6 | 9.7 | 1 | 0.04 | 7.8 | 25 | 743 |
| 7 | TCF *P* | 4.5 | 45.6 | 4.1 | 20.9 | 26.8 | 0.29 | 5.7 | 7.1 | 462 |
| | | 8.0 | 23.5 | 4.9 | 43 | 4.7 | 0.20 | 9.4 | 7.2 | 624 |
| 8 | ECF *D* | 4.5 | 15.8 | 0.1 | 1.4 | 0.7 | 0.58 | 5.4 | 165 | 829 |
| | | 8.0 | 10.4 | 0.2 | 2 | 0.1 | 0.47 | 5.6 | 167 | 941 |
| 9 | TCF *P* | 4.5 | 43.2 | 3.4 | 22.3 | 14.8 | 0.25 | 5.1 | 6.X | 525 |
| | | 8.0 | 10.8 | 4.3 | 36.6 | 0.5 | 0.15 | 9.3 | 5.9 | 711 |
| 10 | ECF *D* | 4.5 | 8.2 | 0.2 | 0.9 | 0.3 | 0.6 | 2.2 | 110 | 381 |
| | | 8.0 | 7 | 0.3 | 1.1 | 0.1 | 0.52 | 2.6 | 111 | 415 |

*The final bleaching stage for the ECF pulps is given in italics.

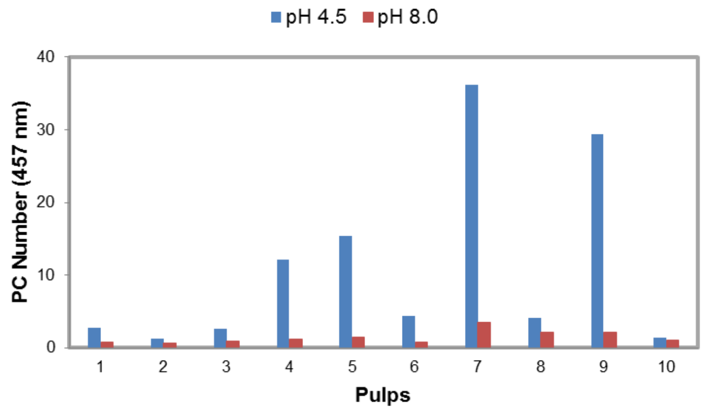


**Fig. 5.** Post color number (457 nm) of Pulps 1-10 aged according to Condition II

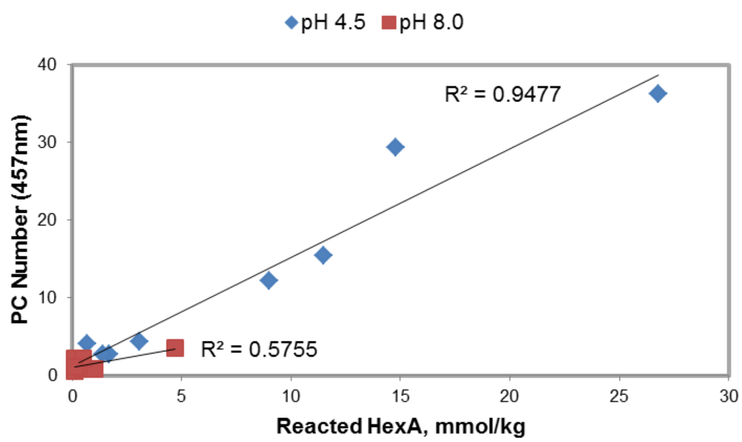


**Fig. 6.** Correlation between post color (PC) number (457 nm) and reacted hexenuronic acid (HexA) groups for pulps aged according to Condition II

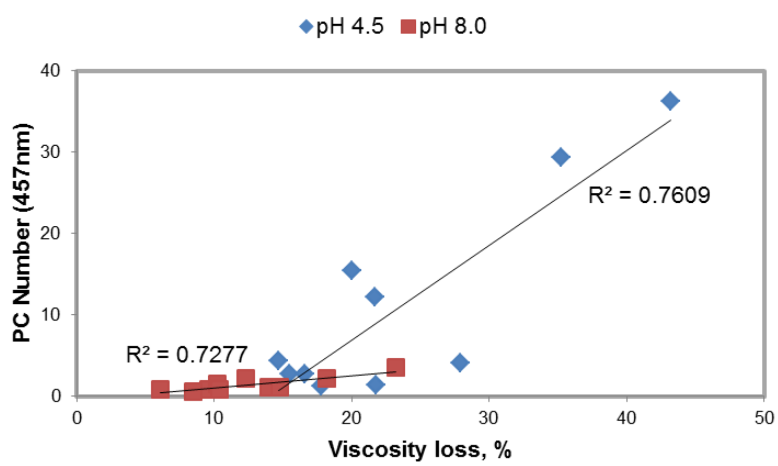


**Fig. 7.** Correlation between post color (PC) number (457 nm) and viscosity loss for pulps aged according to Condition II

The correlation between the PC number and the amount of reacted HexA groups was very high for aging Condition II. The degradation of pulp HexA was very significant for pulps prepared at a pH of 4.5, e.g. more than half of the HexA content was degraded during aging of the ECF Pulp 5 (Table 5). At pH 8.0, the degradation was much lower, which can be explained by a lower degree of hydrolysis of HexA (Vuorinen et al. 1999).

A significant reduction in pulp viscosity was also observed during aging of all pulp samples. As anticipated, viscosity loss was much more significant for reversion Condition II compared to Condition I, and the effect was more pronounced for most pulps at pH 4.5 than at pH 8.0 (Tables 4 to 5). The TCF pulps (no. 7 and 9) showed high viscosity losses, as did the birch ECF pulp (no. 8). The kappa number tended to decrease during aging, mainly at pH 4.5. This result was anticipated, since the major hardwood kappa number components, e.g. lignin and HexA, are known to cause reversion. Jääskeläinen et al. (2009) studied the reactions of aromatic structures in brightness reversion of bleached kraft pulps and concluded that lignin participates in brightness reversion of chemical pulps; however, it is evident that when pulp contains hexenuronic acid groups, they also have great participation in chromophore formation.

The pulp carboxylic acid content tended to increase during aging for the majority of the pulp samples at pH 8.0. At pH 4.5, where the degradation of HexA is at the highest, the pulp samples 4, 5, 7, and 9 showed a decrease in carboxylic acid groups. This result may be explained by the rather sharp decrease in HexA content of these pulps during aging at Condition II. In other words, the creation of carboxylic acid groups that occurred during aging was more than counter-balanced by the loss of HexA groups. It is worth noting that more carboxylic acids were formed at pH 8.0 than at pH 4.5. It is also true that less HexA was destroyed during aging at pH 8.0 than at 4.5.

Organically-bound chlorine (OX) content showed no significant correlation with brightness reversion. As demonstrated under Condition I, no significant changes in pulp OX content occurred during pulp aging, even in the more humid environment of Condition II.

*Natural aging testing according to Conditions III-VI*

Bleached pulp baling is usually done at temperatures in the range of 30 to 45°C. Average relative humidity around the globe tends to be in the range of 50 to 90%. Thus, an attempt was made to simulate brightness reversion under these conditions, which would be more likely to occur in a real-life situation. The preliminary results indicated very long necessary aging times in order to obtain meaningful reversion results. Aging times of 720 to 1440 hours (30 to 60 days) were therefore investigated.

In order to better visualize the effect of temperature and relative humidity on the reversion rate, the results of aging under Conditions III through VI are shown only for pulp number 4 (ECF, eucalyptus). The PC number versus aging time is presented in Fig. 8. It is evident that reversion is much more severe at 90% RH than at 50% RH at pH 4.5. The impact of moisture is drastically enhanced at pH 4.5, compared to pH 8.0 (Fig. 8).

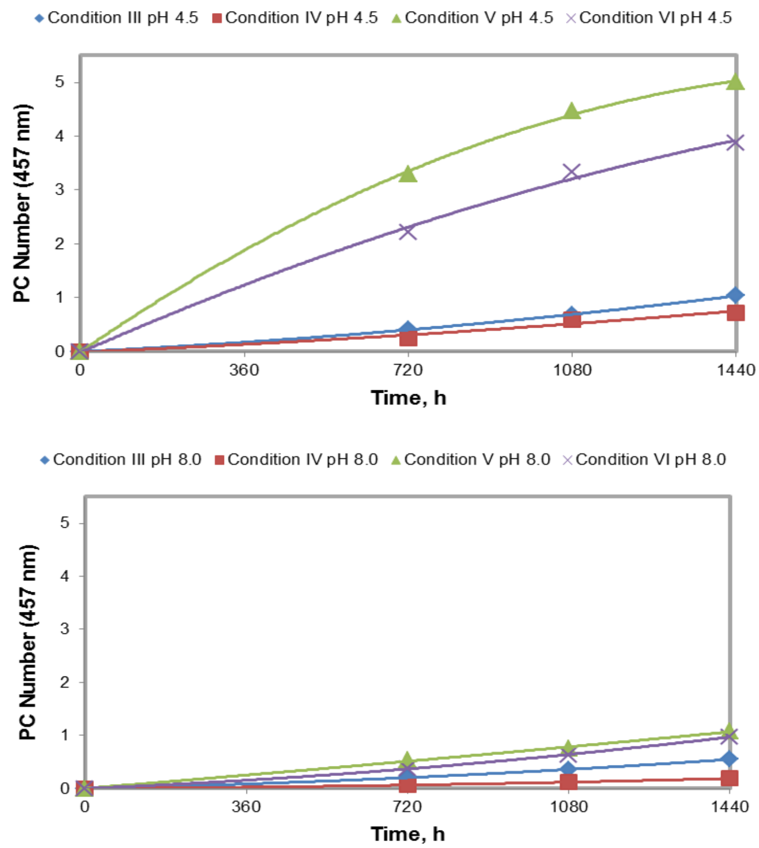


**Fig. 8.** Post color (PC) number (457 nm) as a function of aging time for Pulp no. 4, aged according to Conditions III-VI at pH 4.5 and 8.0

For all aging conditions, it is apparent that low reversion can be achieved by increasing the pH of the pulp slurry prior to baling and keeping the pulp at the lowest temperature and relative humidity possible. A pulp slurry pH of 8.0 may be too high for practical applications, and further studies are therefore needed to find the best compromise between brightness stability and drainability on the drying machine. The introduction of retention aids can improve the drainability in the pulp drying process, if negatively affected by the higher pH of the pulp suspension.

*Relative humidity versus handsheet moisture content*

Considering that various temperatures and relative humidity were evaluated in this investigation, it was deemed useful to determine the handsheets equilibrium moisture content at such conditions. The plot shown in Fig. 9 indicates that pulp moisture increases with increasing relative humidity and decreases with increasing temperature, as expected. The effect of relative humidity was much more significant than that of temperature, in the ranges studied. Therefore, for the aging conditions evaluated in this study, the following were the moisture contents of the handsheets: Condition III (45°C, 50% RH) = 8.5%; Condition IV (30°C, 50% RH) = 9.9%; Condition V (45°C, 90% RH) = 17%; and Condition VI (30°C, 90% RH) =17.8%. One significant consequence of the quantity of water held by the pulp handsheet is that the presence of water accelerated hydrolytic degradation in the pulp.

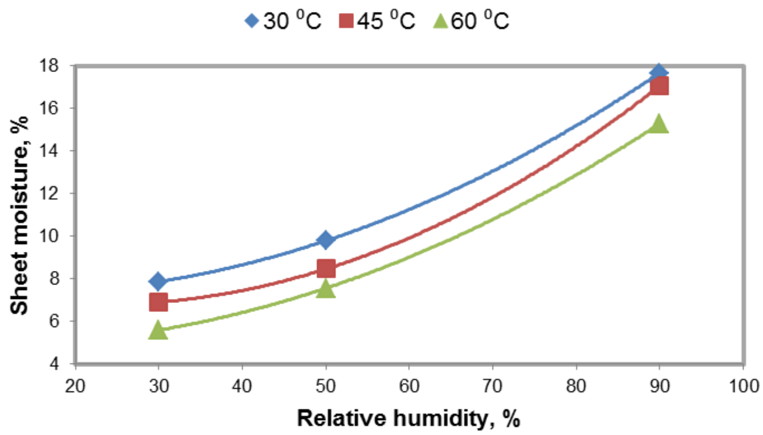


**Fig. 9.** Sheet moisture content as a function of surrounding conditions (temperature, relative humidity).

## CONCLUSIONS

1. The method of aging (dry, wet, high/low RH, high/low temperature, short/long time) has, in most cases, no effect on overall brightness reversion trends, but significantly influences the absolute reversion values.
2. Dry and wet heat-induced brightness reversion correlates positively and significantly with pulp hexenuronic acid content.
3. Pulps produced by TCF bleaching sequences are more prone to reversion than regular ECF pulps
4. Brightness reversion correlates with a significant decrease in pulp viscosity values, and HexA thus coinciding with a decrease of kappa number, especially for aging at pH 4.5.
5. In general, pulp reducing groups (copper number) increase during aging.
6. Pulp carboxyl group content increases during aging, but this tendency is not as clear when the pulps had high carboxylic acid groups during wet aging. This may be explained by the rather sharp decrease in HexA content of these pulps during wet aging.
7. Pulp brightness stability is substantially improved by raising pulp slurry pH from 4.5 to 8.0.
8. Pulp organically-bound chlorine content has no significant effect on the extent of brightness reversion and shows little variation in the course of aging.
9. Relative humidity in the range of 50 to 90% influences reversion much more strongly than temperature in the interval 30 to 45°C.
10. Handsheet moisture content decreases from 9.9% to 8.5% by raising surrounding temperature from 30°C to 45°C at 50% RH, and increases from 9.9% to 17.8% by increasing RH from 50% to 90% at 30°C.

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