Influence of pulping conditions on eucalyptus kraft pulp yield, quality, and bleachability

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ABSTRACT: This study evaluated the effect of cooking temperature and residual alkali on kraft pulp yield, bleachability, and quality. We cooked *Eucalyptus grandis* wood chips to kappa number 16-17 using high and low residual alkali (14-18 g/L and 3-4 g/L) and high and low temperatures (170°C and 160°C). We then quantified process yield and evaluated pulp quality through measurement of strength properties, carbohydrate composition, hexenuronic acid content, alkali-leachable lignin content, and residual lignin nature. After oxygen delignifying the pulps and bleaching them to full brightness with the sequences D(EOP)DD and D(EOP)(ZE)D, we determined their bleachability and brightness stability. Low temperature and low residual alkali during pulping resulted in the highest screened yield (54.2%) and viscosity (64.6 mPa•s). Pulps cooked at low residual alkali showed about 1.7%-2.1% higher yield, 20%-30% higher viscosity, and higher strength properties (except for tear index) than those cooked at high residual alkali both at 160°C and 170°C. Lower temperature and/or residual alkali during pulping favored pulp refining. Pulps produced at high residual alkali showed slightly lower oxygen delignification efficiency (2%-3%), but significantly higher (10%-15%) bleachability, as measured by active chlorine consumption, regardless of cooking temperature. Pulps cooked at high residual alkali showed higher initial brightness (6-8% ISO) for a fixed kappa, which carried on across oxygen delignification and ECF bleaching processes. Oxygen delignification filtrates of pulps cooked at low residual alkali contain substantially more COD and color than those cooked at high residual alkali because the former pulps are richer in alkali-leachable lignin. Pulping conditions did not affect pulp brightness stability. Pulps produced at high residual alkali showed lower contents of xylans and of hexenuronic acids and higher quantities of lignin containing carboxyl and aliphatic hydroxyl groups. Pulps cooked at 160°C presented higher xylan and hexenuronic acid content in relation to those cooked at 170°C.

Application: These findings may give mills tools to adjust their pulping process conditions in order to improve their pulp yields or to improve the bleachability of their pulps, according to their needs and desires.

Significant changes in kraft pulping technology in the last decade have been sparked by the need to reduce pulp kappa number and bleaching chemical consumption. Such modifications have sometimes penalized pulp yield and decreased pulp bleachability. The anticipated bleaching chemical savings derived from a lower kappa number have even been offset by poorer pulp bleachability. On the other hand, extending the cook to low kappa numbers has resulted in substantial yield losses depending upon the cooking protocol and wood used.

At a given optimum kappa number (e.g. 16-18), hardwood kraft pulps may also show significant variability in pulp yield, bleachability, and quality. Many of these differences result from wood variability itself, but others depend upon pulping process (1) and conditions (2). Pulping conditions affect pulp residual lignin and pulp carbohydrate composition, including variations in hemicellulose and hexenuronic acid contents.

Studies have shown that pulps cooked with low effective alkali present poorer bleachability (2,3). This trend has been attributed to the high content of condensed phenolic lignin structures present in these pulps (3). Research has also shown that kraft lignin carboxylic content increases with increasing effective alkali concentration (4). The content of the highly reactive phenolic hydroxyl groups in residual lignin is also affected by the effective alkali used in pulping (4). These groups have been shown to represent about 50% of the residual lignin present in kraft pulps (5). Pulping conditions that favor the formation of such functional groups may positively influence pulp bleachability.

Studies with hardwoods have demonstrated that higher cooking liquor alkalinity has the potential of increasing digester throughput without any negative effect on pulp yield and viscosity and with improved bleachability (6). On the other hand, it has been shown that pulping with lower alkalinity results in pulps of higher hemicellulose content, which leads to less energy requirement during refining (3). Cooking with excess effective alkali has been shown to cause extensive degradation and dissolution of xylan chains (7).

Eucalyptus wood contains about 13% of 4-O-methylglucuronoxylan, which represents 18% of its carbohydrate fraction and 71% of its hemicelluloses content (8). Therefore, pulping conditions that increase dissolution of these hemicelluloses have a significant impact on process yield. These hemicelluloses also contain an unusually low xylose-to-glucuronic acid ratio, about 6:1 (8). This means that they are richer in uronic acids than other hardwood xylans. Uronic acids can be converted into hexenuronic acids (HexA) during pulping via β-elimination of methanol (9). The formation of these acids depends upon pulping conditions such as temperature, cooking time, and effective alkali (10). Pulping at high effective alkali results in lower amounts of HexA in the pulp (6, 10, 11). The degree of HexA retention in the pulp

COOK #	TEMP., °C	ACTIVE ALKALI % (AS NaOH)	TIME AT TEMP., MIN	H FACTOR
E1	170	24.0	30	584
E2	170	16.0	150	2460
E3	160	22.5	80	584
E4	160	15.5	360	2460

*time to maximum temperature = 90 min, liquor/wood ratio = 4/1 and sulfidity = 25%.

I. Cooking conditions*

STAGE	BLEACHING CONDITIONS TIME, MIN	TEMP., °C	CONSISTENCY, %	PRESSURE, kPa	FINAL pH
O	60	100	10	500	11.5
D_0	45	65	10	-	3.0
(EO)	60	90	10	200	11.5
D_1	180	70	10	-	3.5
D_2	180	70	10	-	4.5
Z	1-2	30	10	-	2.5
E	30	60	10	-	9.0

II.General bleaching conditions

affects process yield only slightly. However, it can have a significant effect on pulp bleachability because the acids do not react with oxygen and hydrogen peroxide (12) and they react only slowly with "pure chlorine dioxide" (ClO_2) during bleaching (13).

Process control in pulp mill operation is sometimes difficult because upsets in pulping conditions, triggered by wood supply heterogeneity, can substantially affect pulp bleachability, yield, and quality. Although many studies substantiate these facts, their understanding at a molecular level is not complete, particularly for eucalyptus wood. Pulping conditions can affect residual lignin nature, pulp carbohydrate composition, and the contents of alkali-leachable lignin, lignin-carbohydrate complexes, and HexA present in hardwood kraft pulps. These are likely the underlying factors affecting bleachability and brightness stability of bleached pulps, but their relative importance is not clearly understood for eucalyptus kraft pulp. A better understanding of the effect of pulping conditions on pulp chemistry may lead to better ways to produce bleached eucalyptus kraft pulp—the main objective of this study.

EXPERIMENTAL

Industrial eucalyptus chips classified according to SCAN-CM 40:94 standard method were cooked in a M&K lab digester to a kappa number of 16-17 using the general conditions shown in **Table I**. Cooking liquors were prepared from commercial-grade sodium hydroxide and sodium sulfide. Four different types of kappa 16-17 pulps were prepared by varying process conditions, including two temperatures (160°C and 170°C) and two active alkali charges (15%-16% and 22%-24%). These alkali charges were established experimentally by varying the time at temperature in such a way to also have two levels of H-factor (2460, 584). After pulping, we drew samples of black liquor for residual NaOH and Na_2S analyses. The cooked chips were disintegrated by vigorous agitation in a 25 L lab hydrapulper and the resulting pulp screened in a Valley flat screen having 0.008 inch slots. We replicated these experiments 12 times.

Table II presents the general bleaching conditions. Pressurized bleaching stages were carried out with 280g oven-dry samples in a Quantum Mark V mixer/reactor. The medium consistency ozone stage was carried out using the Ozone Cart system, also made by Quantum Technologies. Conventional bleaching stages were carried out with 150g oven-dry samples in polyethylene bags. We used excess distilled water for pulp washing between stages and replicated these experiments three times.

We performed pulp analyses, including physical strength tests, according to TAPPI standard procedures. Pulp beating was carried out on never-dried, unbleached samples in a PFI mill. Heat reversion was measured on hand sheets heated for one hour at 105±3 °C and 0% RH. We measured pulp metals content by atomic absorption spectroscopy after pulp wet ashing according to the CPPA standard. Carbohydrate analysis was performed by HPLC using a refractive index detector. HexA were determined on unbleached pulp samples according to a method described elsewhere (14). We indirectly measured alkali-leachable lignin through evaluation of the kappa number before and after pulp alkali soaking at pH 12.5 (initial), 100 ºC, for 60 min at 10% consistency.

Pulp residual lignin was isolated by mild enzyme hydrolysis with cellulase and subsequent acid hydrolysis as described elsewhere (15). We acquired quantitative ^{31}P NMR spectra of residual lignins using a Mercury 200 spectrometer as described by Granata (16). Cholesterol was used as an internal standard and 128 transients were acquired to ensure a high signal to noise ratio. The lignin spectra were integrated and the contents of different functional groups were calculated as described elsewhere (17).

RESULTS AND DISCUSSION

Pulping

Table III shows pulping results obtained at variable conditions of temperature, time, and active alkali. The interplay among these conditions allowed for the achievement of pulps with similar kappa numbers at much different yields and residual alkali at the end of the cook. Note that for each condition the cooks were replicated 12 times and the standard deviation (SD) for total yield was only 0.1%. At a given active alkali charge, pulps cooked at 170°C (samples E1 and E2), presented lower yield and viscosity values than those cooked at 160°C (samples E3 and E4). Cooking at higher alkali charges (samples E1 and E3) also resulted in lower yield and viscosity. The use of high temperature (170°C) and alkali charge (24%) simultaneously (sample E1) resulted in the lowest pulp yield and viscosity and the highest rejects content (likely caused by the short cooking time and insufficient chip impregnation). Based on yield and viscosity alone, we inferred that optimum conditions to cook eucalyptus wood include lower temperature (160°C) and low residual alkali (3-4 g/L), i.e., the conditions used for sample E4. However, the largest impact on pulp yield and viscosity is caused by the residual alkali, suggesting that this parameter is the most significant in controlling eucalyptus kraft pulping.

From Tables 1 and 3 it is possible to separate four different pulp types: those produced at 170°C with 18 g/L and 3.5 g/L residual alkali and those produced at 160°C with 14.3 g/L and 3 g/L residual alkali. The different H-factors and active alkali charges used to make these pulps were merely vehicles to achieve similar kappa numbers at the end of the cook. We analyzed these four different pulp types for pentosans, total carbohydrate

COOK #	KAPPA NUMBER	VISCOSITY, mPa•s	BRIGHTNESS, % ISO	YIELD, % TOTAL ± SD	YIELD, % REJECTS	RESIDUAL BLACK LIQUOR pH	NaOH, g/L	Na_2S, g/L	TOTAL, g/L AS NaOH
E1	16.5	40.9	33.9	51.6±0.1	0.3	13.4	10.4	7.6	18.0
E2	16.5	53.5	25.7	53.5±0.1	0.1	11.6	0.1	3.5	3.5
E3	16.8	51.8	32.1	52.7±0.1	0.1	13.4	8.1	6.2	14.3
E4	16.3	67.3	26.5	54.3±0.1	0.0	11.5	0.1	2.9	3.0

III. Pulping results and black liquor characteristics

PULP ANALYSIS	E1 (170°C, 18.0 g/L RESIDUAL)	E2 (170°C, 3.6g/L RESIDUAL)	E3 (160°C, 14.3g/L RESIDUAL)	E4 (160°C, 3g/L RESIDUAL)
Pentosans, %	12.8	14.80	14.50	15.10
Carbohydrate Content (% on pulp):				
Glucose	75.50	74.50	75.00	74.10
Xylose	11.30	12.50	12.60	13.20
Mannose	1.30	0.80	1.00	0.80
Galactose	0.70	0.60	0.50	0.70
Arabinose	0.40	0.60	0.50	0.40
Rhamnose	0.60	0.50	0.50	0.50
Xylose/Glucose	0.15	0.17	0.17	0.17
Hexenuronic acid, mmol/kg pulp	24.80	35.80	31.70	33.60

IV. Pulp carbohydrate composition and hexenuronic acid content

FUNCTIONAL GROUPS	E1 (170°C, 18g/L RESIDUAL)	E2 (170°C, 3.6g/L RESIDUAL)	E3 (160°C, 14.3g/L RESIDUAL)	E4 (160°C, 3g/L RESIDUAL)
Aliphatic OH, mmol/g	3.08	2.52	2.13	2.13
Phenolic OH, mmol/g	2.08	2.36	2.13	2.17
Acid COOH, mmol/g	0.39	0.34	0.35	0.27

V. Pulp residule lignin characteristics

METALS, mg/kg PULP	E1 (170°C, 18g/L RESIDUAL)	E2 (170°C, 3.6g/L RESIDUAL)	E3 (160°C, 14.3g/L RESIDUAL)	E4 (160°C, 3g/L RESIDUAL)
Mg	423	496	441	525
Ca	2444	3200	2736	3303
Cu	8.3	8.5	6.7	6.8
Mn	2.7	3.6	4.1	3.4
Fe	10.9	8.3	10.6	10.8

VI. Pulp metals content

content, and hexenuronic acid content (**Table IV**). A combination of high residual alkali and high temperature (pulp E1) produced pulp of lower xylan content measured both *via* regular pentosan and HPLC analyses. The ratio of xylose-to-glucose for this sample was about 12% lower than that of the other three samples. Consequently, we found lower amounts of HexA in this pulp sample as well, in agreement with other research (10). Other pulping conditions did not show a consistent pattern for pulp carbohydrate composition and hexenuronic acid content, except for the mannan content, which tended to be higher in pulps cooked at a higher residual alkali.

Lignins isolated from the four pulp types showed significant differences in their contents of phenolic/aliphatic hydroxyl groups and carboxylic groups (**Table V**). The content of lignin aliphatic OH groups was higher for the pulps cooked at higher temperature and residual alkali. For a similar residual alkali, increasing the temperature from 160°C to 170°C increased the content of these groups by 18%-45%. Furthermore, increasing residual alkali from 3.6 g/L to 18 g/L at 170°C increased aliphatic OH by about 22%. It is worth noting that aliphatic OH groups tend to increase lignin reactivity and thus should improve pulp bleachability. At the same pulping temperature, the amount of residual phenolic lignin tends to be lower for a higher residual alkali. We observed the opposite for the acid groups, which were less frequent in the samples cooked at lower residual alkali. At a 160°C cooking temperature, increasing residual alkali from 3 g/L to 14 g/L increased the acid groups content by about 29%. Again, a higher content of carboxylic groups in the lignin should improve pulp bleachability.

Pulp metals

Pulp metals significantly affect bleachability, especially when bleaching is carried out with oxygen derived chemicals. Pulp metals also play important roles in water minimization programs since they

O-STAGE RESULTS	E1 (170°C, 18g/L RESIDUAL)	E2 (170°C, 3.6g/L RESIDUAL)	E3 (160°C, 14.3g/L RESIDUAL)	E4 (160°C, 3g/L RESIDUAL)
Kappa Drop Across Stage, % (A)	38.3	41.8	36.8	40.0
Viscosity Drop Across Stage, % (B)	36.7	38.0	40.6	39.4
Bright. Gain Across Stage, % ISO	19.5	23.3	20.2	22.5
Selectivity (A/B)	1.04	1.10	0.91	1.01
Yield ± SD, % on unbleached pulp	98.3±0.21	97.4±0.25	98.1±0.19	97.3±0.26
Alkali-leachable Lignin, k units	1.0	1.7	0.5	2.2
Filtrate COD, kg O_2/odt pulp	28.4	46.2	25.2	35.8
Filtrate Color, kg Pt/odt pulp	28.1	53.6	26.8	47.1

[1]O-stage: 10% consistency, 60 min, 100 ºC, 600 kPa, 18 kg/t NaOH, 20 kg/t O_2, 0.2kg/t Mg.

VII. Oxygen delignification results

BLEACHING RESULTS	E1 (170°C, 18g/L RESIDUAL)	E2 (170°C, 3.6g/L RESIDUAL)	E3 (160°C, 14.3g/L RESIDUAL)	E4 (160°C, 3g/L RESIDUAL)
D(EO)DD Sequence:				
Total ClO_2, kg/odt pulp	13.3	14.8	13.5	14.9
kg ClO_2/ k unit O-stage	1.40	1.67	1.38	1.66
Viscosity, mPa•s	19.8	24.4	23.5	27.0
Brightness Reversion, % ISO	2.1	1.6	2.0	1.7
Yield ± SD, % of O-stage pulp	98.5±0.30	98.2±0.31	98.3±0.30	98.4±0.29
Combined Filtrate COD, kg O_2/odt pulp	17.3	16.7	17.0	18.8
Combined Filtrate Color, kg Pt/odt pulp	7.66	7.75	7.25	6.95
D(EO)(ZE)D Sequence:				
Total ClO_2, kg/odt pulp	8.1	9.5	8.4	9.5
kg ClO_2/ k unit O-stage	0.85	1.07	0.86	1.05
kg ClO_2/kg O_3	1.73	1.77	1.70	1.80
Viscosity, mPa•s	19.4	25.1	22.9	28.0
Brightness Reversion, % ISO	2.1	2.1	2.3	2.3
Yield ± SD, % of O-stage pulp	98.6±0.29	98.4±0.28	98.5±0.29	98.6±0.26
Combined Filtrate COD, kg O_2/odt pulp	18.7	17.3	17.5	18.3
Combined Filtrate Color, kg Pt/odt pulp	9.1	9.5	9.3	9.5

VIII. Bleaching results to 90% ISO with the sequences D(EO)DD and D(EO)(ZE)D:O_2 delignified pulps

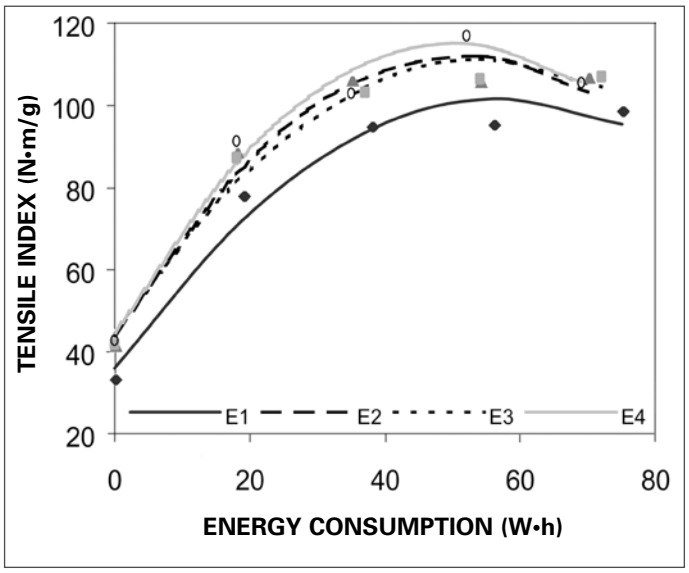
PULP STRENGTH AT 40W.h REFINING ENERGY	E1 (170°C, 18g/L RESIDUAL)	E2 (170°C, 3.6g/L RESIDUAL)	E3 (160°C, 14.3g/L RESIDUAL)	E4 (160°C, 3g/L RESIDUAL)
Tensile Index, N•m/g	95.6	108.8	106.4	112.1
Burst Index, kPa•m²/g	6.1	7.9	6.9	7.9
Tear Index, mN•m²/g	11.2	9.8	10.9	9.2
Tensile Energy Absorption, J/m²	128.8	173.8	158.5	189.2

IX. Pulp strength obtained at a refining energy consumption of 40 W.h

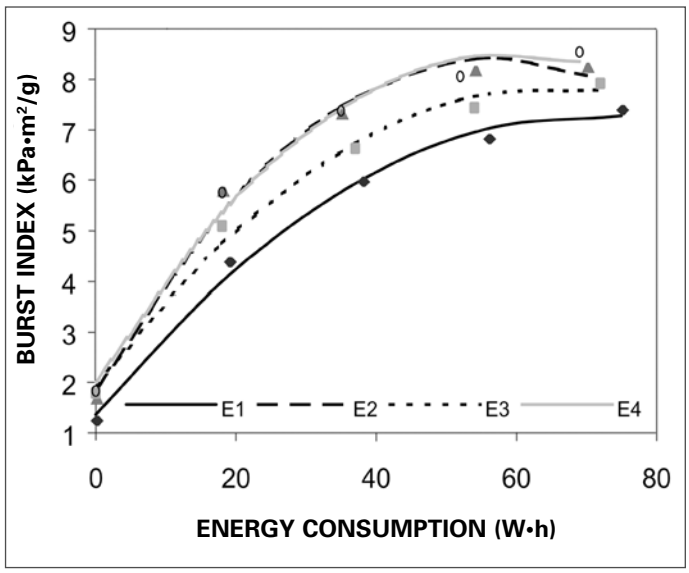
are non-process elements that accumulate in the loop, thus affecting water circuits closure. The transition metal content of the pulps produced by the different cooking protocols showed no clear trend as far as the impact of the temperature and residual alkali (**Table VI**). However, it is clear that pulps cooked at high residual alkali present less calcium (Ca) and magnesium (Mg) than their counterparts. Pulps produced at lower temperature showed higher contents of the alkaline earth metals for a given residual alkali. At 170°C, increasing cooking residual alkali decreased Ca and Mg contents by 24% and 15% respectively, while at 160°C the decrease in Ca and Mg was 17% and 16%, respectively (Table VI). These differences in alkaline metals content are not anticipated to have had any significant impact on pulp yield, bleachability, and other properties among the various pulps. The contents of the transition metals that usually have a higher impact on pulp bleachability were not significantly different among the various pulps.

Oxygen delignification

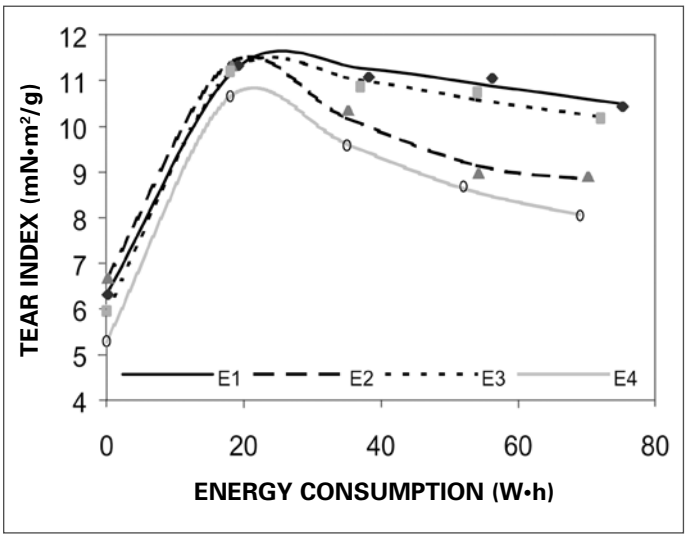
Cooking conditions only slightly affected oxygen delignification performance. Pulps cooked at low residual alkali showed 3%-4% higher kappa drop and 2%-3% ISO higher brightness gain in relation to those cooked to high residual alkali (**Table VII**). This improved O-stage performance may be traced to the higher content of alkali-leachable lignin present in the pulps cooked at low residual alkali (Table VII). The lower end pH of the cooks conducted to a low residual alkali may not have been sufficient to extract all the lignin fragments cleaved during the bulk delignification phase. These lignin fragments were removed in the subsequent O-stage, thus increasing the overall kappa drop. Conversely, when the cook ended at a high residual alkali, most of the lignin fragments were removed from the fibers during the pulping operation itself,



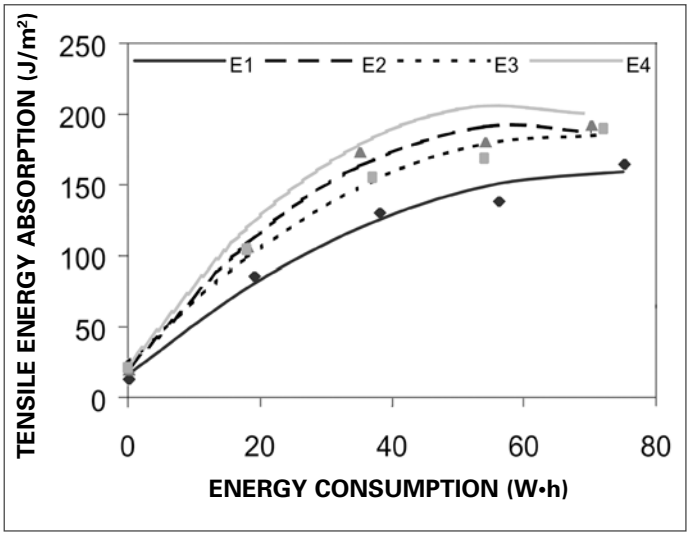
1. Tensile strength as a function of energy consumption



2. Burst strength as a function of energy consumption



3. Tensile energy absorption as a function of energy consumption



4. Tear strength as a function of energy consumption

with only a small fraction remaining to be alkali-leached in the oxygen delignification stage.The pulps containing a high content of alkali-leachable lignin also showed lower yield across the oxygen delignification.

The pulp viscosity drop across the O-stage varied only slightly, in the range of 36%-40%, with the lower shrinkage for the pulps cooked at 170°C, which had lower viscosities to begin with.The selectivity values were in the range of 0.9-1.1 and reflected the kappa and viscosity drop values (Table VII).

Pulps cooked at high residual alkali had higher initial brightness (6%-8.5% ISO), which carried through across the O-stage and ECF bleaching. This is explained by their lower content of highly colored low molecular weight alkali-leachable lignin (Table VII). We define alkali-leachable lignin here as the total amount of lignin that can be extracted solely by alkali under the conditions prevailing in an oxygen delignification stage. The higher amounts of alkali-leachable lignin present in the pulps cooked at low residual alkali resulted in a substantially higher content of COD and color in their O-stage filtrates (Table VII).

Bleaching

The results in **Table VIII** indicate that the ECF bleachability of pulps cooked at high residual alkali, measured by the amount of ClO_2 consumed per kappa unit removed, is higher than those cooked to low residual alkali. These pulps consumed 15%-20% less ClO_2 when bleached with both DEoDD and DEo(ZE)D sequences. Other researchers have observed this trend (2), explained on the basis of the residual lignin nature. In fact, these pulps showed higher contents of aliphatic hydroxyl and carboxyl groups (Table V) which are hydrophilic and thus have a positive impact on pulp bleachability. One factor that may also have improved bleachability of the pulps cooked at high residual alkali is their lower content of hexenuronic acid (Table IV).

The final bleached viscosity of the pulps cooked at high residual alkali were in general lower than those cooked at

low residual alkali, reflecting their lower initial viscosities. Note that the total viscosity loss across O-stage and ECF bleaching was much more significant for the pulps cooked at low residual alkali. This occurred because these pulps had much higher initial viscosities (Table VIII).

Pulp brightness reversion (1 h, 105ºC, 0% RH) varied in the range of 1.6%-2.3% ISO. The pulping conditions had no significant effect on reversion. Pulps bleached with the DEoDD sequence tended to show slightly lower reversion values in relation to those bleached with the sequence DEo(ZE)D. The bleaching yield (excluding oxygen delignification), and the color and COD loads of the combined bleaching filtrates were not significantly affected by the pulping conditions. The combined filtrates of the sequence DEo(ZE)D showed slightly higher color in relation to those of the sequence DEoDD (Table VIII).

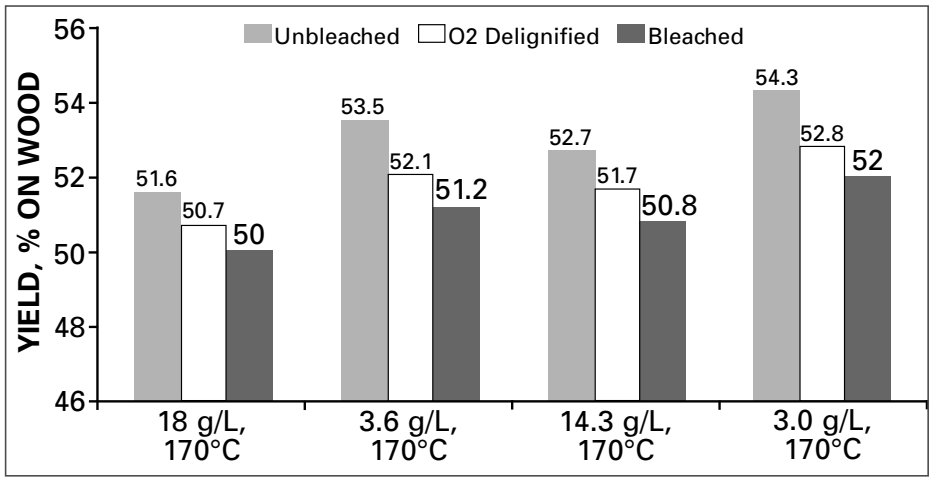
Pulp quality

Figures 1, 2 and 3 show that pulps cooked at lower temperature or lower alkali charge and, consequently, at lower residual alkali present higher tensile, burst and tensile energy absorption (TEA), and are also easier to refine. At a refining energy consumption of 40 W·h pulps cooked at high residual alkali show lower tensile, burst, and TEA properties (**Table IX**). Pulps produced at high residual alkali showed 5% and 12% lower tensile, respectively, for the temperatures of 160°C and 170°C, while showing 13% and 22% lower burst and 16% and 26% lower TEA. These three properties correlate strongly with fiber bonding capacity and suggest that pulps produced at milder cooking conditions can more easily form bonds and thus present better conformability. The better inter-fiber bonding ability of these pulps can be traced to their higher xylan content (Table IV). Pulp tear strength, however, presented an opposite trend (**Fig. 4**), i.e., higher values were obtained for the pulps cooked at high temperature and high residual alkali. At a refining energy consumption of 40 W·h, the pulps produced at high residual alkali presented, respectively, 15% and 12.5% higher tear index for 160°C and 170°C (Table IX). We can not easily explain this result. Tear index is certainly affected by individual fiber strength, which may have been improved by the higher residual alkali because of extensive xylan removal. However, removal of these hemicelluloses also penalizes inter-fiber bonding that has a positive effect on tear strength.

PULPS	YIELD LOSS, % ON WOOD	ClO_2 SAVINGS, kg/t	COST INCREASE, US$/TON PULP
E1 (170°C, 18g/L residual)	2.0	1.6	+1.72
E2 (170°C, 3.6g/L residual)	0.8	0.1	+1.24
E3 (160°C, 14.3g/L residual)	1.2	1.4	+0.40
E4 (160°C, 3g/L residual)	Ref.	Ref.	Ref.

*Wood = US$40/ton; **ClO2 = US$1,000/ton, NaOH = US$300/ton

X. Summary of wood* and bleaching chemical** costs



5. Yield based on wood after pulping, oxygen delignification and ECF bleaching with the sequence D(EO)DD.

Overall economics

Wood cost is certainly the most significant component of the overall bleached pulp production cost, followed by bleaching chemicals cost. In **Table X,** we have attempted to quantify the impact of pulping conditions on wood and bleaching chemical costs. We assumed a wood cost of US$ 40/ton, chlorine dioxide at US$ 1000/ton, sodium hydroxide at US$ 300/ton, and the fiber line yields shown in **Figure 5**. Cooking at high temperature and to high residual alkali increases wood and chemical costs by US$ 1.72/ton of pulp in relation to the reference case which used milder pulping conditions. Note that wood and bleaching chemical costs were the only parameters taken into account in this economic analysis. Other factors such as energy (power and steam), pulping chemicals (chemical recovery costs), pulp refining energy, mill through-put, recovery load, causticizing load, and effluent load must also be taken into account. We anticipate that pulping at higher alkalinity and temperature will decrease energy costs (lower H-factor, Table I), increase pulping chemical costs, increase pulp refining energy (**Table XI**), increase through-put (existing mills), and increase recovery and causticizing loads. These costs are mill specific and have to be calculated on a case-to-case basis depending upon pulp mill objectives.

CONCLUSIONS

This study addressed the influence of pulping conditions on eucalyptus kraft pulp yield, quality, and bleachability. The main conclusion was that pulps of highest bleachability are obtained by cooking at high residual alkali and temperature, whereas low residual alkali and temperature favors process yield and pulp quality, except for tear strength. The implication of this work is that conditions that favor pulping yield and pulp quality decrease pulp bleachability and *vice versa*. Proper manipulation of pulping conditions allows for the achievement of the most suitable process economics and pulp quality. **TJ**

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PULP STRENGTH AT 40 °SR DRAINAGE DEGREE	E1 (170°C, 18g/L RESIDUAL)	E2 (170°C, 3.6g/L RESIDUAL)	E3 (160°C, 14.3g/L RESIDUAL)	E4 (160°C, 3g/L RESIDUAL)
Tensile Index, N•m/g	96	105	105	114
Burst Index, kPa•m²/g	7.0	8.1	7.2	7.9
Tear Index, mN•m²/g	10.5	9.7	10.3	9.6
PFI Revolutions	4675	3884	4347	3705

XI. Pulp strength and refinability at a drainage degree of 40 °SR

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INSIGHTS FROM THE AUTHORS

This research complements previous research done by our own group. We have been looking at the factors affecting pulp bleachability. We have investigated the influence of wood quality, type of cooking process, and now the effect of pulping parameters. Of course our focus has been on eucalyptus. There have been other studies on this area mostly with softwoods.

We chose this topic because improved yield is one of the characteristics the pulp industry is seeking most these days. Wood is the principal component of the final pulp price. Any alternative that leads to increased yield is greatly welcomed by the industry because it saves wood and decrease recovery loads.

The most difficult aspect of the study was to identify the causes of poorer pulp bleachability when the pulping process is conducted to low residual effective alkali. We managed to understand the problem by evaluating the nature of the pulp residual lignin and also evaluating a new variable called "alkali leachable lignin," which allowed us do identify the causes of poorer bleachability.

We discovered that cooking at drastic conditions of alkali and temperature penalizes process yield because it decreases pulp low molecular weight carbohydrate contents and, consequently, improves pulp bleachability, and vice versa. We also concluded that gains in bleachability never pay for yield losses. Yield is the most important thing to search for in pulp manufacturing.

The next step is to determine the factors affecting pulp brightness reversion in elemental chlorine free (ECF) bleaching of eucalyptus kraft pulps.

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