Optimizing alkaline extraction for eucalyptus kraft pulp bleaching

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ABSTRACT: This paper evaluates different approaches for the (E*) stage of the D_{HT}(E*)D sequence for eucalyptus kraft pulp bleaching to 90%–91% ISO brightness, considering kappa factors 0.12, 0.16, and 0.20 in the first stage. These (E*) approaches included E, (EO), (EP), (EOP), (PO), P_{HT}, O, and (O/O) stages run at two temperatures. Results were compared on the basis of total active chlorine demand, chemical cost, pulp brightness stability and viscosity, and effluent load. We concluded that a D_{HT} kappa factor of 0.12 and a (PO) stage run at 85°C–95°C appeared to be the most attractive approach for bleaching eucalyptus pulp with the D_{HT}(E*)D sequence, considering cost-effectiveness, pulp quality, and effluent load; however, when the steam cost is taken into consideration, the cost advantage was lost.

Application: By optimizing alkaline extraction, pulp producers can improve eucalyptus kraft pulp bleaching efficiency, cost-effectiveness, pulp quality, and effluent load.

Environmental and market pressures have been driving the development of new pulp bleaching technologies. These include oxygen delignification, acid hydrolysis, hot chlorine dioxide, pressurized peroxide, high temperature peroxide, and ozone bleaching, among others.

ECF bleaching is the dominant bleaching technology in the industry. In 2004, approximately 90% of bleached pulp production included chlorine dioxide as the main bleaching agent. In ECF bleaching, alkaline extractions are generally used after the chlorine dioxide oxidative stage.

The alkaline extraction stage, which is the main focus of this paper, was introduced as part of the development of multistage bleaching processes, in which the stages of oxidation, dissolution, and reactivation of residual lignin were separated. The function of alkaline extraction is removing soluble lignin which has been oxidized in previous bleaching stages and reactivating residual lignin for the following oxidative stages.

After pulp oxidation with chlorine dioxide, a significant fraction of lignin remains in the pulp because of lignin's limited solubility at acid pH. Therefore, acid and alkaline stages are applied alternately to promote better dissolution of the oxidized lignin [1]. However, acid oxidative treatments are not efficient in removing all lignin from pulp because they promote lignin structure modifications, creating groups that are not labile to new oxidations. These groups can be activated in a following alkaline extraction [2].

Alkaline extraction efficiency can be improved by dosing more alkali to the pulp, but there is a concentration limit above which additional alkali provides minimal benefit. Therefore, there has been a trend toward using oxidative agents in the extraction stage to improve its efficiency. Use of oxidants is not a requirement; but without them, bleaching cost and effluent load increase significantly [1].

Carmichael et al. [2] showed the benefits of oxidative alkaline extraction for softwood kraft pulp. For a kappa factor of 0.18, the use of oxygen and hydrogen peroxide in the extraction stage (EOP) results in a reduction of kappa number after extraction from 3.5 to 2.5. Other advantages of alkaline extraction with oxidants include improvement of environmental parameters such as color COD, BOD, and AOX [3]. Strunk [4] considers significant effluent color reduction to be the greatest benefit of H_2O_2 addition in the extraction stage. Other authors indicate a reduction of 50% of alkaline effluent color [5].

A conventional alkaline extraction stage is operated at a pH value between 10 and 11, a consistency between 8% and 12%, a retention time between 60 and 90 minutes, and alkaline charge between 8 and 25 kg of NaOH per ton of pulp. The caustic soda demand is directly influenced by conditions in the previous bleaching stage. Alkaline bleaching extraction reinforced with oxygen often uses the same conditions as a regular extraction stage, except for the application of oxygen (0.3%–0.4%). Oxygen-reinforced extraction reduces pulp kappa number compared with simple alkaline extraction without significantly affecting pulp viscosity. The extraction process reinforced with atmospheric peroxide is noteworthy because of its effectiveness and low capital requirement for implementation. However, peroxide reinforcement can be more effective when pressurized in the so-called P_{HT}-stage technology [6].

The most common alkaline extractions nowadays are those reinforced with oxygen and peroxide, which are either partially pressurized (EOP) or completely pressurized (PO). The use of oxygen in these stages has been questioned for eucalyptus pulps since very little lignin is actually available in the pulp after oxygen delignification and the first chlorine dioxide stage, with hexenuronic acid (HexA) being the main oxidizable component in pulp. HexA is not degraded with oxygen [7]. However, according to Schwanninger [8], the

(EOP) stage can decrease the D(EOP) kappa number to levels that could be achieved only by a significant increase of the kappa factor in the D(EO) stages for both softwood and hardwood pulps.

Several reactions occur between wood components and oxygen and hydrogen peroxide in the presence of alkali. Some of the most important are the dissolution of chlorinated lignin, pulp delignification, pulp bleaching, pulp degradation, and peroxide decomposition. While the first three are desirable reactions and should be maximized, the others reduce peroxide efficiency and lead to unacceptable pulp viscosity losses [9].

It is common to use alkaline extraction reinforced with oxygen (EO), hydrogen peroxide (EP, P_{HT}), or both (EOP, PO) to compensate for lower chlorine dioxide availability and also to make bleaching in short sequences possible [10,11]. Bleach plants that have a low availability of chlorine dioxide and require high peroxide dosages (0.8%–1.0%) need more severe conditions for peroxide consumption. In these cases, pressurized peroxide stages such as (PO) or P_{HT} are recommended, because they allow the use of high temperatures.

A very significant increase in brightness is achieved when peroxide is applied to alkaline extraction with eucalyptus kraft pulp [12]. Another positive effect is the effectiveness of peroxide in bleaching shives. When shives were mixed with pulp and fully bleached to the same brightness in a TCF sequence, the shives after the (PO) stage appeared to be as white as the fibers in the same stage [13].

Bleaching sequences for hardwood pulps where the first stage is hot chlorine dioxide (A/D or D_{HT}) should maintain high temperatures in the extraction stage to maximize the benefits from high pulp temperature. The choice of temperature for extraction is determined not only by steam demand, but also by stage performance. Therefore, the extraction temperature should be optimized, and the peroxide dosage and pulp metal content should also be considered. Excessively high temperatures may accelerate peroxide decomposition if the pulp contains large amounts of transition metals [7].

The objective of this study is to compare different types of oxidative extractions for an oxygen-delignified eucalyptus kraft pulp, using kappa factors of 0.12, 0.16, and 0.20 in the first stage of a $D_{HT}(E^*)D$ sequence.

EXPERIMENTAL

An industrial oxygen-delignified eucalyptus kraft pulp was used throughout this study. **Table I** shows the characteristics of the pulp at the beginning of the experiment.

Researchers carried out laboratory bleaching tests using standard procedures. The following experimental approach was used for optimization of the extraction stage (E*) of the $D_{HT}(E^*)D$ sequence:

• In the hot D stage (D_{HT}): end pH 2.7, 90°C, 120 min, 12% consistency, kappa factors: 0.12, 0.16, and 0.20;

• In the (E*) stage: 90 min, 12% consistency, 5.7 kg/t NaOH for (E) and (EO) stages; 10 kg/t NaOH for (EP) or (EOP) or (PO) or P_{HT} stages and variable temperature: 85°C for (E) stage; 85°C or 95°C for (EO) or (EP) or (EOP) or (PO) or P_{HT} stages; 95°C for (O) stage; and 95°C /105°C (O/O) stage;

• In the final D stage: 180 min, 12% consistency, 75°C, variable NaOH dose to adjust final pH to 3.5–4.5, and variable ClO_2 dose to achieve 91% ISO brightness.

Brightness, % ISO	54.8
Kappa no.	9.4
Viscosity, dm^3/kg	1005.3
HexA, mmol/kg	58.1
COD, kg O_2/ODT	13.0
Metals, mg/kg pulp	
Ca	519.4
Mg	216.1
Fe	36.1
Mn	5.0
Cu	1.2

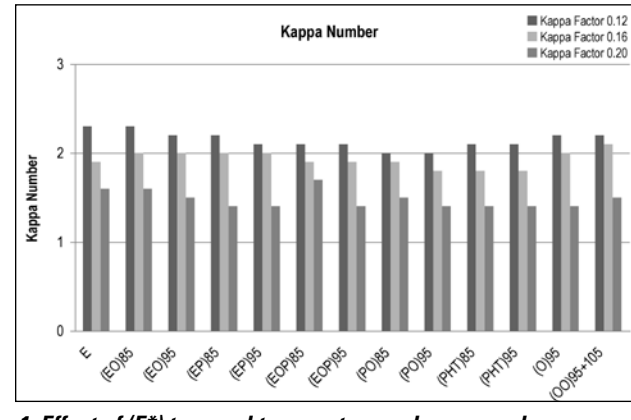
I. Characterization of the original pulp sample.

Hot chlorine dioxide (D_{HT}) stages, final chlorine dioxide stages (D), extraction stages (E), and extraction stages with peroxide (EP) were performed using polyethylene bags. Single (O) and double (O/O) oxygen delignification, oxidative extraction with oxygen (EO), oxidative extraction with oxygen and peroxide (EOP), oxidative extraction with peroxide pressurized with oxygen (PO), and high-temperature peroxide extraction stages (P_{HT}) were performed in a Quantum mixer/reactor, model Mark V. A detailed description of bleaching methods, conditions, and analytical procedures is given in Appendices A, B, and C.

RESULTS AND DISCUSSION

Effect of kappa factor and type of extraction on results measured after extraction

Figure 1 shows the kappa number values after $D_{HT}(E^*)$ stages for kappa factors 0.12, 0.16, and 0.20. Minor and statistically insignificant (5% probability, Tukey test) differences in kappa number were observed among the various types of extraction for a given kappa factor, regardless of (E*) temperature. Significant kappa-number differences were observed at the various kappa factors, regardless of extraction type and tempera-



1. Effect of (E*) type and temperature on kappa number measured after extraction for kappa factors of 0.12, 0.16, and 0.20.

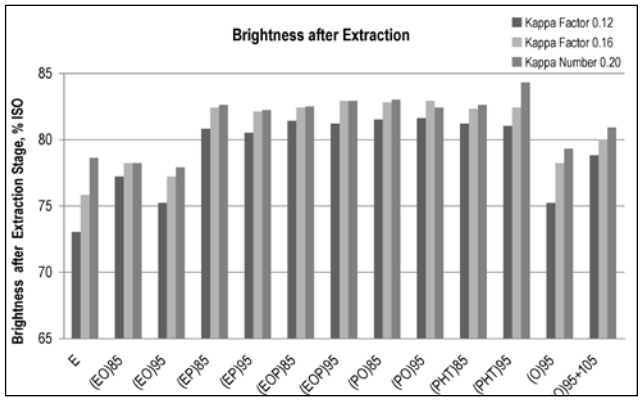
ture. For example, the average (E*)-stage kappa-number values at kappa factors 0.12 and 0.20 were 2.1 and 1.5, respectively.

As should have been expected, brightness measured after extraction was significantly affected by the type of extraction (**Fig. 2**). Simple extraction (E) produced a brightness that was significantly (5% probability, Tukey test) lower than all the others for kappa factors 0.12 and 0.16. For kappa factor 0.20, simple extraction (E) produced a brightness similar to those achieved with extractions containing oxygen (EO, O, O/O). Extractions containing peroxide (EP, EOP, PO, and P_{HT}) produced similar brightness values, regardless of temperature and kappa factor, but much higher than those not using peroxide. It is worth noting that the impact of peroxide use on brightness is much more significant for the lower-kappa-factor treatments.

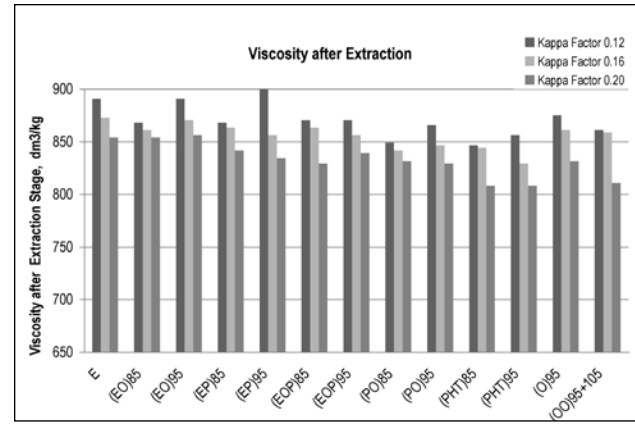
Kappa number and brightness values measured after extraction indicate that the use of peroxide in the extraction is critical when dealing with eucalyptus pulp. This derives from the fact that the kappa number after extraction for these pulps is due largely to the presence of HexA. For example, the average kappa number after extraction at kappa factor 0.12 was 2.1 (Fig. 1), with 1.5 units due to HexA and only 0.6 units due to lignin itself. Therefore, the use of a delignifying agent such as oxygen in the extraction stage brings about very little brightness gain because there is little lignin there to remove, whereas the use of brightening agents such as peroxide has a very strong effect. The peroxide works mostly by brightening the traces of lignin (0.6 kappa units) existing in the pulp at this point.

The effects on brightness of hydrogen peroxide addition to extraction stages were similar under atmospheric and pressurized conditions for all kappa factors and temperatures, except for a P_{HT} stage at kappa factor 0.20, where higher temperature enabled the highest brightness to be achieved after the extraction stage.

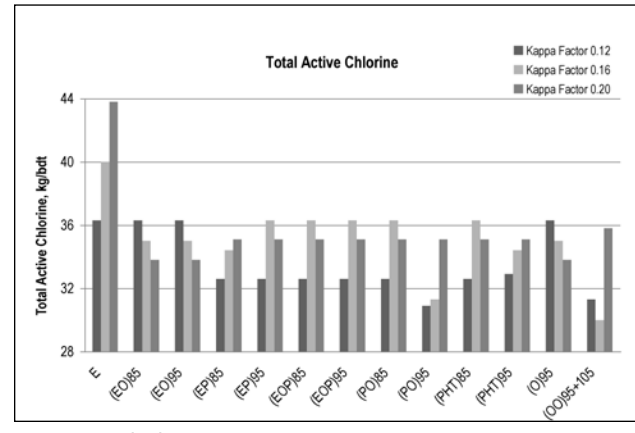
Figure 3 shows the impact of extraction type and temperature on pulp viscosity measured after extraction. Differences in viscosity among the various treatments were statistically insignificant (5% probability, Tukey test), but there was a slight trend toward lower viscosity values for pulps treated with peroxide in the extraction stage. Moreover, there was a clear trend toward lower viscosities with pulps treated at higher kappa factors. This had been anticipated because at higher kappa factors, more oxidant was applied, and more cellulose degradation was expected.



2. Effect of (E) type and temperature on brightness measured after extraction for kappa factors of 0.12, 0.16, and 0.20.*



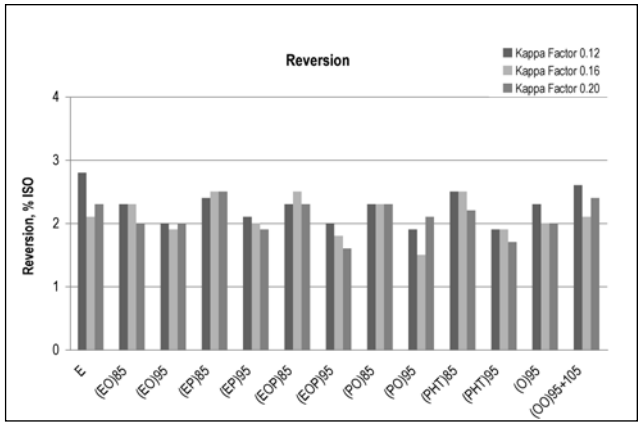
3. Effect of (E) type and temperature on pulp viscosity measured after extraction for kappa factors of 0.12, 0.16, and 0.20.*



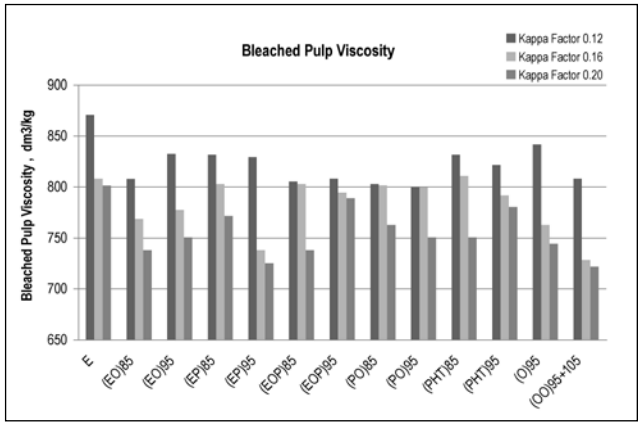
4. Effect of (E) type and temperature on total active chlorine (TAC) demand for kappa factors of 0.12, 0.16, and 0.20. TAC = (ClO_2*2.63 + H_2O_2*2.09), expressed in kg/ADT of pulp.*

Effect of kappa factor and type of extraction on final bleaching results

The total active chlorine consumption (TAC) was calculated according to the following formula: TAC = (ClO_2*2.63 + H_2O_2*2.09), expressed in kg/ADT of pulp. At a kappa factor of 0.12, the addition of oxygen in the oxidative extraction stage improved the final brightness for similar TAC consumption (**Fig. 4**). As expected, when peroxide was added to the oxidative extraction stage, the target brightness of 91% ISO was achieved with a significantly lower TAC demand compared with E and (EO) type extractions. The use of peroxide in the extraction incorporates the benefits of both oxygen and peroxide at the same time. This is explained by the slight peroxide decomposition that always occurs in peroxide bleaching stages, which gives rise to the minimum amount of oxygen required for lignin attack. Therefore, it can be stated that



5. Effect of (E) type and temperature on pulp brightness reversion for kappa factors of 0.12, 0.16, and 0.20.*



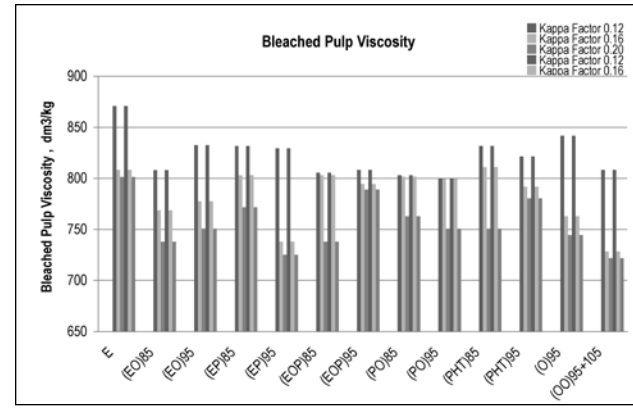
6. Effect of (E) type and temperature on final pulp viscosity for kappa factors of 0.12, 0.16, and 0.20.*

an (EP) extraction has a similar function to an (EOP) extraction when dealing with eucalyptus pulp. For the 0.12 kappa factor, the lowest TAC at 91% ISO brightness was attained with a (PO) stage run at 95°C. It is worth noting, however, that the O/O stage run at 95°C /105°C resulted in the second-lowest TAC requirement without using hydrogen peroxide.

Increasing the kappa factor from 0.12 to 0.16 or 0.20 in the first hot chlorine dioxide stage (D_{HT}) did not improve brightness or TAC regardless of (E*) stage type or temperature. The only exception to this rule was the O/O-stage extraction, for which kappa factor 0.16 resulted in the lowest TAC demand. Therefore, it can be generally stated that 0.12 is likely the optimum kappa factor for bleaching eucalyptus pulp to 91% ISO brightness, if only the bleaching chemical requirement is considered.

Pulp quality

The effect of extraction-stage type and temperature on brightness reversion for kappa factors 0.12, 0.16, and 0.20 is shown in **Fig. 5**. It can be observed that brightness reversion was not significantly affected by the type and temperature of the extraction stage. However, there is a statistically insignificant (5% probability, Tukey test) trend toward lower brightness



7. Effect of (E) type and temperature on bleaching chemical costs for kappa factors of 0.12, 0.16, and 0.20.*

reversion at higher kappa factors. This can be explained by the fact that pulps bleached at higher kappa factors use more chlorine dioxide to achieve the target brightness. It is well known that sequences using more chlorine dioxide result in pulps of lower brightness reversion because of more complete elimination of HexA.

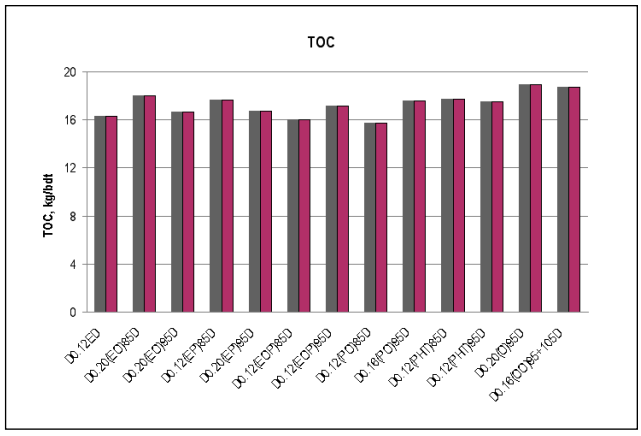
Figure 6 shows the impact of extraction type and temperature on final pulp viscosity. Again, there were no statistically significant (5% probability, Tukey test) differences in viscosity among the various treatments, but there was a slight trend toward lower viscosity for higher kappa factors in the D_{HT} stage.

Bleaching chemical costs

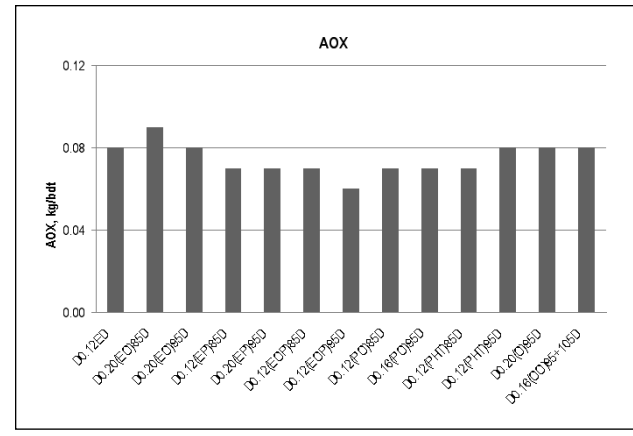
We calculated chemical costs based on the doses of the various reagents applied in each bleaching stage, assuming the following reagent prices (US$/kg): O_2 = 0.10; H_2O_2 = 0.85; ClO_2 = 1.00; NaOH = 0.50; H_2SO_4 = 0.08. Possible differences in utility costs (temperature differences) and wood costs (yield loss differences) were not considered in the cost calculations. Bleach chemical costs were generally lower when extraction was reinforced with peroxide and when lower kappa factors were used in the D_{HT} stage (**Fig. 7**). Although the lowest chemical costs were achieved with the (PO) stage run at 95°C at kappa factors 0.12 and 0.16, these values were a little lower than those for (EP), (EOP), and P_{HT} treatments. If one included the cost of steam to raise the temperature from 85°C to 95°C, this cost differential would probably disappear. In addition, the capital cost for a full-blown pressurized (PO) stage would shift the economics unfavorably in the case of a bleach plant retrofit as opposed to a regular (EOP) stage. Similar observations were made by Ragnar [14] and Süss et al. [15].

EFFLUENT LOAD

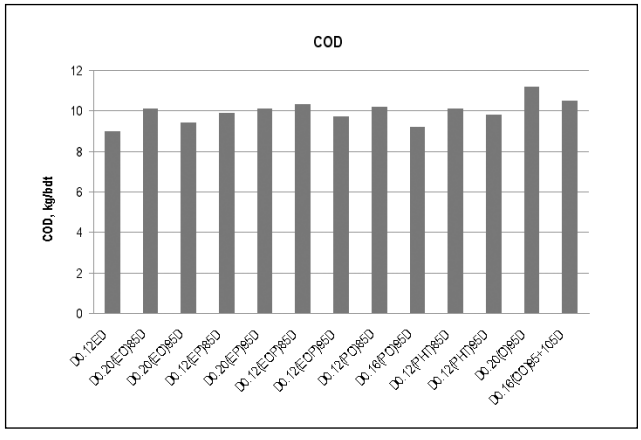
The combined effluent loads from the D_{HT}(E*)D sequence for selected (E*) types and kappa factors are shown in **Figs. 8–11**. The combined effluent TOC values were generally similar for extractions with oxygen and peroxide (Fig. 8), with a trend toward higher values when pressurized peroxide (PO),



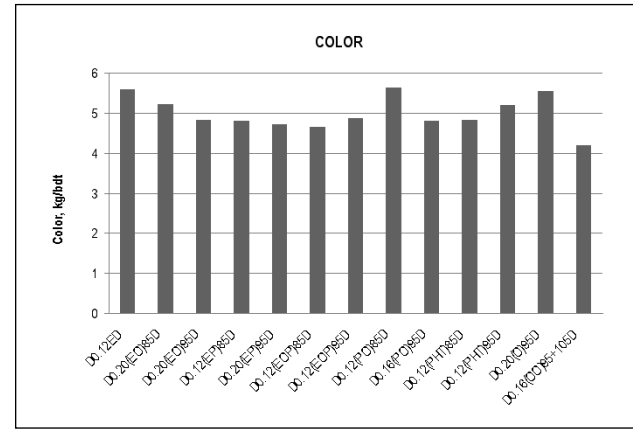
8. TOC loads of $D_{HT}(E^*)D$ bleaching filtrates for selected bleaching alternatives.



10. AOX loads of $D_{HT}(E^*)D$ bleaching filtrates for selected bleaching alternatives.



9. COD loads of $D_{HT}(E^*)D$ bleaching filtrates for selected bleaching alternatives.



11. Color loads of $D_{HT}(E^*)D$ bleaching filtrates for selected bleaching alternatives.

hot peroxide (P_{HT}), or oxygen delignification (O, O/O) was used. The lowest TOC values were obtained with conventional (E) and oxygen-reinforced (EO) extractions. This result suggests that modern concepts of extraction for eucalyptus pulps, based on the use of peroxide at high temperatures, cause small penalties in bleaching yield. However, such penalties are likely more than compensated for by the significant chemical cost savings. The trends observed for COD loads (Fig. 9) were similar to those discussed above for TOC. As expected, the extractions containing peroxide resulted in the lowest AOX values, reflecting the lowest demand of total active chlorine (Fig. 10). The highest AOX values were observed for simple (E) and oxygen-reinforced extractions (EO). The same trend was observed also for effluent color (Fig. 11), except that higher color values were also obtained for $(PO)_{85}$, O, and P_{HT} extractions.

CONCLUSIONS

It can be concluded that the optimum kappa factor for bleaching eucalyptus pulp with the $D_{HT}(E^*)D$ sequence is approximately 0.12, regardless of the type and temperature of the subsequent (E*) stage. The (E*) stage must contain peroxide to guarantee cost-effective bleaching, but the use of oxygen is optional. Increasing (E*) temperature from 85°C to 95°C has insignificant benefits for reagent bleaching costs except for the (PO)-stage case. Although the (PO) stage run at 85°C–95°C proved to be the best approach for the second stage of the $D_{HT}(E^*)D$ sequence considering cost effectiveness, pulp quality, and effluent load, if the steam cost were taken into consideration, this cost differential would probably disappear. **TJ**

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APPENDIX A

Detailed laboratory testing procedures

Following testing for each bleaching stage under the conditions described in Appendix C, liquor samples were squeezed out of the pulp to be analyzed for pH, TOC, active chlorine residual, and peroxide residual. Then the pulp was washed with the equivalent of 9 m^3 of distilled warm water per ton of pulp. The experiments were run in duplicate, except when indicated.

• High-Temperature Chlorine Dioxide Delignification (D_{HT})

This bleaching stage was carried out with a 300-g oven-dry pulp sample in polyethylene bags. The pulp sample was mixed with 100°C heated water, and the desired amount of chlorine dioxide and sulfuric acid were added and thoroughly mixed. Following this, the initial pH was measured, and the bag was sealed airtight and placed in a heating bath at the

INSIGHTS FROM THE AUTHORS

One of the available options for improving pulp bleaching efficiency cost-effectiveness and pulp quality and minimizing effluent load is to optimize alkaline extractions. To improve bleaching processes, the authors have performed several studies on eucalyptus kraft pulp, addressing issues such as methods for hexenuronic acid removal, retrofit of a conventional bleaching sequence to ECF pressurized hydrogen peroxide, and low-environmental-impact sequences for attaining high brightness levels. The present work focuses on alkaline extraction of eucalyptus kraft pulp.

Identifying the best extraction approach considering only cost-effectiveness, pulp quality, and effluent load proved to be a challenge. Parameters studied included kappa number, viscosity, effluent load, and others, but excluding steam cost. It was found that a low kappa factor of 0.12 and a simple (PO) stage can provide a pulp which offers good quality, an acceptable effluent load, and cost-effective manufacture.

The many mills worldwide that use eucalyptus pulp stand to benefit from the results of this research. The authors intend to conduct ongoing studies on improvements to eucalyptus pulp bleaching.

Lewis Shackford works with GL&V USA Inc. in Nashua, N.H. and Carlos Santos with GL&V Brasil Ltda. in Campinas SP, Brazil. Jorge Colodette is a full professor in the Forest Engineering Department of the Federal University of Viçosa, Viçosa MG Brazil (UFV). Ericka Alves is a Ph.D. student in the Department of Paper and Bioprocess Engineering, State University of New York (SUNY), Environmental Science and Forestry (ESF), Syracuse, N.Y. USA; she can be contacted at efalves@syr.edu.

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desired temperature.

• Alkaline Extraction (E) or Oxidative Extraction with Hydrogen Peroxide (EP)
Alkaline extractions were carried out in polyethylene bags with a 280-g oven-dry pulp sample. The pulp samples were thoroughly mixed with water and sodium hydroxide for (E) stages, with hydrogen peroxide also added for (EP) stages, made into thin pads, sealed airtight, and preheated to the desired temperature in a microwave oven.

• Oxidative Extraction with Oxygen (EO) or Oxidative Extraction with Oxygen and Peroxide (EOP)
These bleaching stages were carried out with a 280-g oven-dry pulp sample. The experiments were carried out in a Quantum mixer/reactor, model Mark V. For (EO) stages, the desired charges of sodium hydroxide and oxygen were added to the reactor after the desired temperature was reached; for (EOP) stages, hydrogen peroxide was also added. After the pressurized time had elapsed (15 min), the reactor pressure was released and the reaction maintained for the remaining time (75 min) at the desired temperature (85°C or 95°C).

• Oxidative Extraction with Pressurized Peroxide (PO) or High-Temperature Peroxide Extraction (P_{HT})
These bleaching stages were carried out with a 280-g oven-dry pulp sample under the conditions described in Appendix C. The experiments were carried out in a Quantum mixer/reactor, model Mark V. The desired charges of sodium hydroxide, hydrogen peroxide, and oxygen were added to the reactor after the desired temperature was reached, and the initial pH was measured. For the (PO) stage, the reactor was maintained pressurized for the entire experiment (90 min) at the desired temperature (85°C or 95°C). For the P_{HT} stage, after the pressurized time had elapsed (15 min), the reactor pressure was released and the reaction maintained for the remaining time (75 min) at the desired temperature (95°C). For both cases, the total elapsed time was 90 minutes.

• Single-Stage Oxygen Delignification (O) or Double-Stage Oxygen Delignification (O/O)
These stages were carried out with a 280-g oven-dry pulp sample under the conditions described in Appendix C. The experiments were carried out in a Quantum mixer/reactor, model Mark V.

- For the single (O) stage, the desired charges of sodium hydroxide and oxygen were added to the reactor after the desired temperature was reached. The initial pH of the mixture was then measured. The reactor was maintained pressurized for the entire experiment (90 min) at the desired temperature (95°C).
- For the double (O/O) stage, the desired charges of sodium hydroxide and oxygen for the first stage were added to the reactor after the desired temperature was reached. The initial pH of the mixture was then measured. At the end of the desired time for the first stage, the reactor pressure was released. The oxygen and alkali doses for the second stage were then added. The pressure was adjust-

APPENDIX B: TEST METHODS

Parameter	Procedure
Pulp kappa number	TAPPI T236 cm-85
Pulp viscosity	TAPPI T230 om-94
Pulp hexenuronic acid content	Vuorinen, T., Teleman, A., Fagerstrom, P., Buchert, J., and Tenkanen, M., *Proc. 1996 Intl. Pulp Bleaching Conf.*, TAPPI Press, 1:43(1996). [16]
Handsheet formation for reflectance tests	TAPPI T218 sp-97
Pulp brightness	TAPPI T525 om-92
Pulp brightness reversion	TAPPI UM 200: 4 hours at 105±3°C and 0%RH, after acclimation of handsheets for 12 hours in a temperature- and humidity-controlled room (50±2%RH at 23±1°C).
Pulp metals	All metals were analyzed by atomic absorption with a CG 7000 spectrophotometer using hollow cathode bulbs after wet ashing of the pulp samples according to CPPA G.30P standard.
Analysis of ClO_2 and H_2O_2 in solutions and residuals	Kraft, P., In: McDonald, R.G. (ed.), *Pulp & Paper Manufacture*, 2nd ed., Vol. 1. McGraw-Hill, New York, 1967: 628 [17]
Effluent COD	CPPA H.3
Effluent color	CPPA H.5
Effluent AOX	SCAN P 69:94
Effluent total organic carbon (TOC)	Direct reading using TOC equipment (infrared detection) – *TAPPI Standard Methods for the Examination of Water and Wastewater*, 1995 [18]

APPENDIX C: BLEACHING CONDITIONS

Variable	O	O/O	D_{HT}	E	(EO)	(EP)	(EOP)	(PO)	P_{HT}	D
Consistency, %	12	12	12	12	12	12	12	12	12	12
Temperature, °C	95	95/105	90	85	85–95	85–95	85–95	85–95	85–95	75
Time, min	90	30/60	120	90	15+75	90	15+75	90	15+75	180
Pressure, kPa	400	500/300	-	-	200+0	-	200+0	500	500+0	-
O_2, kg/ADT	15	10/5	-	-	4	-	4	4	-	-
Kappa factor	-	-	0.12; 0.16; 0.20	-	-	-	-	-	-	-
ClO_2 as act Cl_2, kg/ODT	-	-	11.3;15.0;18.8	-	-	-	-	-	-	Var.
H2O2, kg/ODT	-	-	-	-	-	3.0	3.0	3.0	3.0	-
NaOH, kg/ODT	15.0	15.0	-	5.7	5.7	10.0	10.0	10.0	10.0	Var.
H_2SO_4, kg/ODT	-	-	Var.	-	-	-	-	-	-	-
Final pH, average	10.5	10.5	2.7	10.5	10.5	10.5	10.5	10.5	10.5	4.5

ed back to the desired value for the second stage, and the temperature was increased to the predetermined value for the second stage. The slurry was maintained in the reactor for the additional reaction time necessary to complete the second stage.

• Bleaching with Chlorine Dioxide (D)

These bleaching stages were carried out in polyethylene bags with a 230-g oven-dry pulp sample under the conditions described in Appendix C. The pulp sample was thoroughly mixed with water, chlorine dioxide, and sodium hydroxide for pH control, made into a thin pad, sealed airtight, preheated to the desired temperature in a microwave oven, and placed into a heating bath kept at constant temperature.

CORRECTION

The following paper has been corrected and re-posted to the TAPPI website:

Examining interrelationships between caliper, bending, and tensile stiffness of paper in testing validation

BY CANTWELL G. CARSON AND ROMAN E. POPIL

As originally printed in the December, 2008 issue of TAPPI JOURNAL, certain figures in this paper were incorrect due to errors inadvertently introduced during the layout process. To access the corrected version, click on the title above.

We apologize to the authors and to readers for any inconvenience these errors may have caused.