

Effect of eucalyptus bark contamination during pulping of mixed southern hardwoods

RICARDO B. SANTOS AND PETER W. HART

ABSTRACT: The use of eucalyptus as a partial replacement for mixed southern hardwoods can result in significant amounts of eucalyptus bark being incorporated into the chips going to the digester. When eucalyptus is first harvested, the bark peels off in large sheets, which will pass through chippers designed for southern hardwood. After being cut for more than about 4–6 weeks, the bark tightens onto the bole of the tree and again passes through chippers not designed for eucalyptus. As a result, significant quantities of eucalyptus bark could go to the digester. This study describes the effect of pulping eucalyptus bark in the laboratory. A series of control studies were performed on eucalyptus and mixed southern hardwood bark. The results show that incorporating bark into the cook results in increased kappa number, decreased pulp yield, and increased alkali consumption. If the percentage of applied active alkali is increased to counteract the increased alkali consumption, increased hexenuronic acid is generated

Application: These data could be used to help justify in-woods debarking of eucalyptus to avoid contamination issues or to predict potential operational problems associated with partial substitution.

Several efforts are underway to increase the sustainability and supply of short fiber within the southern United States by establishing cold-tolerant eucalyptus plantations [1,2]. Through the establishment of eucalyptus plantations, a ready supply of short-fiber wood could be made available to a kraft mill during periods of inclement weather when harvesting of native trees is difficult or impossible. Also, as is being currently realized in Brazil and other countries with large eucalyptus plantations, the establishment of short-rotation eucalyptus stands, with an estimated time to harvest of 7–12 years, could be used as a conservation effort for native-growth southern hardwoods [3,4].

Plantation efforts are being aggressively pursued along the Gulf Coast of the United States for partial substitution of mixed southern hardwoods [2]. Recent studies have suggested that as much as 30% to 50% of the wood supply could be substituted with cold-tolerant *Eucalyptus benthamii* grown within the United States, without negatively affecting the physical properties of the resulting kraft pulp products [1].

One potential practical problem with the incorporation of cold-tolerant eucalyptus into the existing pulp supply is the handling of eucalyptus bark. When eucalyptus is first harvested, the bark typically falls off in large sheets [5,6]. Hickory bark seasonally exhibits similar characteristics [7–9]. After being harvested for 5–6 weeks, the bark tightens to the bole of the tree and is extremely difficult to remove. After about 6 months of storage, the bark again starts to fall off the logs in long strings and sheets. When eucalyptus is blended into the mixed southern hardwood supply, the bark is not successfully removed during the debarking process; it passes into the

chipper along with the stem of the tree. When the trees have been freshly harvested, the sheets of bark do not break down; they do not fall through the rollers and slots within the bark-ing drum and log conveyors. When the eucalyptus trees have been allowed to age slightly (only 4–6 weeks after harvest), the bark is tightened onto the boles of the tree and not successfully removed by the debarking drum. Either way, excessive amounts of eucalyptus bark are passed from the debarking process into the chipper and along to the digester [5].

When pure eucalyptus species are harvested in Central America, South America, and other countries with extensive eucalypt plantations, the bark is frequently removed at the time of harvest. In some instances, the bark is left in the field. In others, the bark is collected and transported separately to the mill site as a boiler fuel to supply energy and steam for mill operations. Sometimes the trees are harvested, transported, and immediately processed through traditional rotary debarking drums with larger slots and roller conveyors with larger spacing than is typically used for mixed southern hardwoods. These larger slots and spacing would allow an excessive amount of white wood loss if they were used in a typical mixed southern hardwood processing facility. Also, tree harvesters and portable, in-woods chain flail debarkers used in the southern United States are not routinely equipped to remove and collect bark during harvesting. Therefore, when eucalyptus is used as a partial replacement for mixed southern hardwoods, a substantial amount of eucalyptus bark will be incorporated into the chips going to the digester.

The effect of small levels of mixed southern hardwood bark contamination of chips going to the digester has been

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well documented. Bark has been shown to consume an excessive amount of the active processing chemical (alkali) during the cooking process [10]. The bark reduces pulp yield. It also negatively affects the cleanliness of the resulting pulp [11].

Because eucalyptus bark behaves differently in the field and during the debarking and chipping processes, our study has attempted to determine the effect of eucalyptus bark on the pulping process and resulting pulp. If the results from this study suggest that the incorporation of substantial amounts of eucalyptus bark negatively affects the pulping process, they could potentially be used as a justification for establishing in-field debarking practices for eucalyptus plantations grown within the United States. Conversely, if the results suggest that eucalyptus bark content has only a minimal effect on the pulping process and resulting pulp properties, there would be no justification for substantial alterations to the existing process when eucalyptus is blended into the existing short-fiber supply.

EXPERIMENTAL

Raw material

E. benthamii and U.S. eastern hardwood bark and chips were collected in areas around the southern United States. Eucalyptus samples (logs and bark) were gathered from 5-year-old plantations in Beaumont, TX, USA. These logs were immediately hand debarked. A 50-gallon trash bag was filled with bark strips ranging from $\frac{3}{4}$ in. to about 1 in. in width. The strips were sent to Richmond, VA, USA, where they were manually cut with scissors into strips about 1 to 1 $\frac{1}{2}$ in. in length. The debarked trees were sent to North Carolina State University (Raleigh, NC, USA) and chipped in a laboratory chipper. The chips were screened in a vibratory laboratory screen. Accepts of 4–8 mm in thickness were used in the laboratory cooks. Mixed hardwood chips and hardwood bark samples were gathered from a mill in east Texas. The hardwood and the eucalyptus chip and bark strip samples were air dried before pulping. To perform wood chemistry analysis, a small amount of chips was ground and sieved (after knots and bark were removed). The wood meals (40–60 mesh) were then Soxhlet-extracted for 24 h with benzene-ethanol 2:1 (v/v) (TAPPI Standard Test Method T 264 om-88 “Preparation of wood for chemical analysis”), and samples were characterized. Pure bark samples were also ground and analyzed.

Kraft cooking

Cooking experiments were performed using two different conditions (all in duplicate). First, cooks were performed with a target H-factor of 750 and active alkali (AA) of 18%. Then, to further understand bark behavior, cooks were performed with 750 H-factor at different AA ratios. Cooks were performed with pure wood (eucalyptus and mixed hardwoods), pure eucalyptus bark, and pure mixed hardwood bark, as well as with mixed hardwood chips artificially spiked with varying amounts of the eucalyptus bark strips.

The system used to reproduce batch digester technology

was an MK 1/K409 digester (M/K Systems; Peabody, MA, USA) with 7 L capacity, electrically heated through electronic controls containing peripheral equipment such as a pressure gauge, heat exchanger, and circulation pump. All of the cooks were performed at a 4:1 length-to-width ratio. The sulfidity of the cooking liquor was 34% on an AA basis for all cooks. The cooks were heated to a maximum cooking temperature of 168°C over about 45–50 min. Depending on the goal of each cook, the time at temperature was varied to obtain the desired H-factor of 750. The kappa number of the resulting pulp was measured following TAPPI Standard Test Method T 236 om-13 “Kappa number of pulp.” Because the purpose of the current work was to determine the effects of bark intrusion under mill conditions, the residual effective alkali (rEA) was allowed to vary because the effect on rEA was one of the response variables. All cooks were performed in at least duplicate, with the average kappa number, average percent rejects, and average yields being reported here. Selected cooks were performed several more times over a period of 3 months to ensure the findings were reproducible.

All pulps after cooking were collected in muslin bags and washed and pressed repeatedly until clean. After they were washed, the pulps were screened on a pilot-scale vibratory flat screen with 0.008 in. slots. Accepts were collected in a muslin bag and all rejects were collected in a tared aluminum pan and dried in an oven at 105°C overnight for reject determination.

Wet chemistry analysis

Carbohydrate analysis was performed by North Carolina State University according to their standard laboratory testing methods. Tests were performed in duplicate. Average results are presented here. Carbohydrates were determined from acid hydrolysis followed by high-performance anion-exchange chromatography analysis. Each of the tested samples' carbohydrate composition was determined by acid hydrolysis. We hydrolyzed 0.1 g of sample with 1.5 mL of 72% sulfuric acid at room temperature with occasional stirring for 2 h. The mixture was then diluted to 3% sulfuric acid using deionized water, transferred to a vial, sealed, and heated to 120°C for 1.5 h. The resulting suspension was filtered, and the filtrate was analyzed for monomeric sugar. Fructose was added as internal standard.

The monomeric sugar content was determined by injecting 2.5 mL samples into a high-performance anion-exchange chromatography with pulsed amperometric detection (HPAE-PAD) on a Dionex IC-3000 chromatography system (Dionex; Sunnyvale, CA, USA). Sugars were separated using a Dionex Carbo-Pac PA1 guard and analytical columns connected in series. Water was used as an eluent at a flow rate of 1.0 mL/min. The column temperature was 18°C. A post-column base 40 mM sodium hydroxide was added to improve detection by pulsed amperometry. The post-column flow rate was 1.0 mL/min.

Lignin was analyzed to determine its amount in the raw materials and in the resulting pulps. Lignin analysis was per-

formed using TAPPI Standard Test Method T 222 om-98 "Acid-insoluble lignin in wood and pulp" and TAPPI Useful Method UM 250 "Acid-soluble lignin in wood and pulp."

Additionally, lignin was also extracted and subjected to nitrobenzene oxidation to determine the syringyl/vanillin (S/V) ratio of the lignin in the resulting materials. Nitrobenzene oxidation for S/V ratio determination was performed according to the method of Chen [12], which is described as follows. We ground 20 o.d. grams of wood or pulp to make 200 mg of wood meal in the 40–60 mesh size range. The sized meal was reacted with 7 mL of 2 N aqueous sodium hydroxide and 0.4 mL of nitrobenzene in a stainless steel bomb at 170°C for 2.5 h. After 2.5 h, the hot stainless steel bomb was cooled immediately by immersion in ice water, and 1 mL of 5-iodovanillin (80 mg in 5 mL *p*-dioxane) was added as an internal standard.

The reaction mixture was extracted with dichloromethane (CH_2Cl_2) four times and the organic phase (CH_2Cl_2 phase) was discarded. The remaining water phase (alkali solution) was then acidified with 2 N hydrochloric acid to pH 2–3. The acidified solution was further extracted again with CH_2Cl_2 three times, and this organic phase (CH_2Cl_2 phase) was collected for analysis. The CH_2Cl_2 phase was dried over sodium sulfate, $\text{Na}_2\text{SO}_4(\text{s})$, and the volume was adjusted to 100 mL. One milliliter of this solution was dried by rotatory evaporation at 30°C. The dried product was dissolved in 50 μL of pyridine, and 50 μL of *N*-methyl-*N*-(trimethylsilyl) trifluoroacetamide (MSTFA) was added. The solution was shaken for 15 min at 50°C.

The derivatized mixture was then directly injected (2 μL) onto the gas chromatograph. Quantitative gas chromatograph analysis was carried out on an Agilent/HP 6890 gas chromatograph (Santa Clara, CA, USA) equipped with a flame ionization detector and HP-1 column (30 m $\times$ 0.32 mm inside diameter, 0.25 μm). The injection temperature was 200°C, the detector temperature was 270°C, and the column flow rate was 2 mL of helium/min. The column was held for 3 min at 120°C and raised at 5°C/min to 200°C, followed by 10°C/min to 260°C, and was kept isothermal at 260°C for 5 min. S/V was determined by the molar ratio of the amount of syringaldehyde divided by the sum of vanillin and vanillic acid. Syringic acid was not included because the amount was negligible in all cases.

Hexenuronic acid content of the pulps was determined by following the procedure described by Vuorinem et al. [13].

Bark extractives pH was measured using a non-standard mill developed test using boiling water. The test was performed by boiling 5 o.d. grams of bark in 100°C water for 1 h then allowing the sample to cool to room temperature. The pH was then measured. Boiling the sample alters some of the chemical composition of the bark. The main goal of this test is to predict the effect of differing barks on a kraft cook performed well above the boiling temperature of 100°C, and these chemical changes would occur during the pulping process anyway. Therefore, the small changes resulting from 100°C boiling for 1 h (1 H-factor) should be of minimal importance for comparison of different levels of bark effects. The

acid groups released during the boiling process directly react with the applied alkali well before any of the major delignification type pulping reactions occur.

Residual black liquor analysis was performed following a standard ABC titration method. Black liquor solids were determined gravimetrically. The organic-to-inorganic ratio was determined according to the method outlined by Andrews et al. [14].

Fiber quality analysis

We used a fiber quality analyzer to determine the fiber characteristics of the different samples (length, width, fiber distribution, etc.). Samples were obtained by suspending 20 mg, o.d. weight of wet fiber, in 20 mL of deionized water and disintegrated in a British standard disintegrator for 8 min. The liberated fibers were placed into 300 mL of deionized water, stirred, and placed in the fiber quality analyzer. The beaker was rinsed with water three times to guarantee that all fibers were counted. Each reported value is the average of two tests.

Handsheet physical properties

Board grade 120 g/m² handsheets were made following TAPPI Standard Test Method T-205 "Forming handsheets for physical tests of pulp," with the following exceptions. The amount of pulp, 36 g, was disintegrated with 25000 revolutions in a British disintegrator instead of the prescribed 24 g. The resulting 10 handsheets were pressed at 50 psi between blotters and steel plates per the standard. The pressed handsheets were placed in rings on steel plates and air dried. The dried sheets were conditioned according to TAPPI Standard Test Method T 402 "Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products." After conditioning for at least 24 h, the sheets were tested for basis weight, caliper, tensile strength, and tear resistance following TAPPI T 220 "Physical testing of pulp handsheets." Internal bond strength was measured following TAPPI Standard Test Method T 541 "Internal bond strength of paperboard (z-direction tensile)." Testing of the formed handsheets was conducted according to various TAPPI Standard Test Methods:

- T 410 "Grammage of paper and paperboard (weight per unit area)"
- T 411 "Thickness (caliper) of paper, paperboard, and combined board"
- T 414 "Internal tearing resistance of paper (Elmendorf-type method)"
- T 541 "Internal bond strength of paperboard (z-direction tensile)"
- T 494 "Tensile properties of paper and paperboard (using constant rate of elongation apparatus)"
- T 489 "Stiffness of paper and paperboard (Taber-type stiffness tester)"

Caliper tests with TAPPI Standard Test Method T 411 were performed with hard platen. Tear resistance tests with TAPPI Standard Test Method T 414 were conducted using a single ply sheet and three test measurements per sheet sample. Tensile

	Ash	Water Extraction	Benzene/Ethanol Extraction	Klason Lignin	ASL*	Total Lignin	S/V	Gluc	Xyl	Gal	Ara	Total Sugars
U.S. hardwood bark	4.6	16.9	7.5	27.1	0.8	27.8	1.12	33.7	12.6	2.7	4.7	53.7
Eucalyptus bark	6.8	21.8	7.0	32.3	0.8	33.0	1.66	28.4	8.9	3.4	4.2	44.9
U.S. hardwood chips	0.6	6.3	4.4	24.9	0.9	25.8	2.10	40.1	15.1	2.8	1.8	59.9
Eucalyptus wood chips	0.5	5.0	3.1	27.5	0.9**	28.4	2.63	38.7	14.5	4.3	4.6	62.1

* ASL = acid soluble lignin; S/V = syringyl/vanillin; Gluc = glucose; Xyl = xylose; Gal = galactose; Ara = arabinose.

** The ASL reported for eucalyptus wood chips is rather low. Typical values for this wood species have been reported in the 3%-4% range [15,16].

I. Composition analysis of barks and chips.

tests with TAPPI Standard Test Method T 494 were carried out with samples cut to 15 mm width strips and the clamps set at 4 in. separation.

RESULTS

Raw material characterization

Table I shows the chemical characterization of the wood samples used in this study. These tests were performed by North Carolina State University according to their standard methods. Samples were characterized for ash content, extractives in water and benzene-ethanol, lignin content (Klason lignin and acid soluble lignin), S/V, and sugars. Southern U.S. hardwood bark and chips samples (hardwood bark and chips) were significantly different than eucalyptus bark and chip samples (eucalyptus bark and chips). Eucalyptus bark had higher ash, water extractives, S/V, and lignin amounts, whereas hardwood bark showed higher amounts of carbohydrates. Both sets of wood chips were similar in ash, water extractives, acetone extractives, and carbohydrates content. Major differences were found in the amount of lignin and the S/V ratio of that lignin, with eucalyptus chips showing higher values than the hardwood chips. The eucalyptus bark had a water soluble pH of 4.5; the mixed hardwood bark water soluble pH was 5.1. The lower pH value for eucalyptus suggests a greater potential for pitch and extractives deposition.

The fact that both bark samples have significantly higher amounts of extractives than either set of wood chips suggests that incorporating bark into a cook could potentially lead to pitch and deposition problems and an increase in white liquor consumption. Commercial operations are not able to completely remove bark from the chips entering the digester. As a result, several of these problems are experienced to varying degrees in operating pulp mills. Saponification of the extractives to their sodium salts will consume caustic and reduce the amount of residual in the spent cooking liquor. Because eucalyptus bark has about 4 percentage points higher extractives content than hardwood bark, incorporation of eucalyptus bark should increase the alkali consumption and pitch deposition problems to a greater extent than would hardwood bark.

Pulping of pure bark and chips

Cooking of 100% bark and 100% chip samples was performed using the same cooking conditions to establish the end points for the blended samples being cooked later. **Table II** shows the pulp yield, kappa number, and rEA of the spent cooking liquor for 100% bark and 100% chips for both eucalyptus and mixed southern hardwoods. As expected, hardwood bark pulping showed lower yield with a higher kappa number than hardwood chips. Most of the 18% AA applied as cooking liquor was consumed, with about four times lower rEA left in the bark spent liquor as compared with the chips' liquor samples.

The eucalyptus bark sample ended up with an even higher kappa number and absolutely no rEA left in the cooking liquor. Effectively, the pulping process stopped somewhere in the middle of the cook because of the lack of liquor available to continue the pulping reactions. We believe the final kappa number would have been lower if the cook had not run out of alkali. This theoretical cook with remaining alkali was not experimentally obtained in the current work.

The very high consumption of alkali during cooking suggests that if a substantial amount of bark (especially eucalyptus bark) was processed in conjunction with standard wood chips, the bark would consume an inordinate amount of cooking chemicals and potentially leave low levels of cooking alkali for the chips. By substantially reducing the amount of alkali available for cooking, lower pulp yield and quality could be a result.

In addition to the chemical properties of the resulting pulps, the length-weighted fiber length and width were determined for each of the resulting pulps (brownstock pulps were used). We used a fiber quality analyzer to measure the fiber length and width. **Table III** shows the fiber characteristics for each of the bark pulps and pure chip pulps used in the current study. The eucalyptus bark had a fiber length twice that of the eucalyptus chips and 40% longer than the fiber length of the mixed hardwood chips or bark. The eucalyptus chip fiber was 30% shorter than the mixed hardwood fiber. The eucalyptus pulps also had thinner fibers than the corresponding southern hardwood fibers.

Sample	Total Yield, %	Kappa No.	rEA, g/L
Eucalyptus bark	46.1 ± 0.5	64.6 ± 0.76	0.0 ± 0.00
Hardwood bark	40.4 ± 0.0	28.3 ± 0.28	0.95 ± 0.04
Eucalyptus chips	46.7 ± 0.2	15.5 ± 0.21	3.3 ± 0.07
Hardwood chips	47.2 ± 0.19	16.9 ± 0.49	4.2 ± 0.07

*Note: As these comparisons are performed under non-ideal and not constant kappa and rEA conditions, the yield results represent as obtained values, not just carbohydrate values. These results were used to compare constant cooking conditions, not constant pulp conditions.

II. Total yield, kappa number, and spent cooking liquor residual effective alkali (rEA) for pure bark and chip samples cooked with 18% applied EA and a 750 H-factor* (± values are standard deviations).

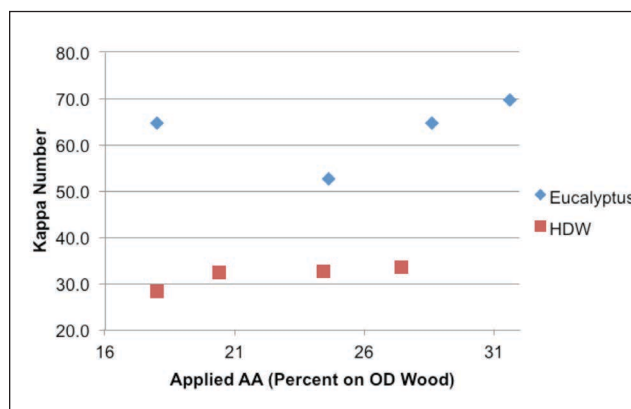
Sample	Length Weighted Fiber Length, mm	Length Weighted Fiber Width, μm
Eucalyptus bark	1.4 ± 0.031	20.4 ± 0.141
Hardwood bark	1.0 ± 0.028	21.0 ± 0.070
Eucalyptus chips	0.7 ± 0.014	16.8 ± 0.071
Hardwood chips	1.0 ± 0.018	19.3 ± 0.000

III. Length weighted fiber length and width for eucalyptus and mixed southern hardwood bark and chip pulps (± values are standard deviations).

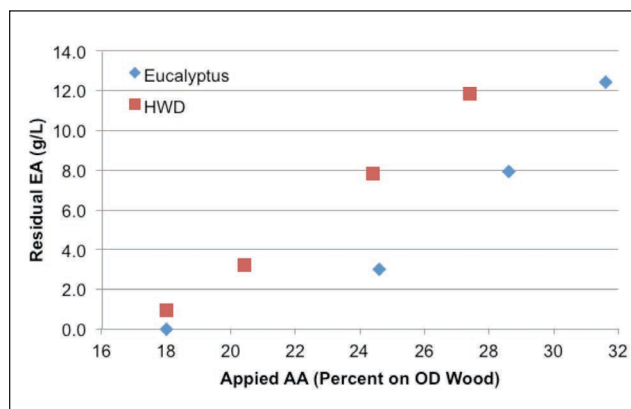
Pulping of bark at different black liquor rEA levels

The eucalyptus bark showed reduced cooking performance even though it had a high lignin S/V ratio as compared to U.S. eucalyptus hardwood bark (Table I). In general, higher S/V ratios tend to delignify easier than wood with lower S/V ratios [17,18]. This fact, in conjunction with the extremely low rEA from the eucalyptus and the mixed southern hardwood bark cooks, resulted in the decision to perform several bark cooks with a 750 H-factor and increasing amounts of applied AA. Kappa number, yield, and rEA were determined for each of these cooks. **Figure 1** shows the effect of increased applied alkali charges on the kappa number of the resulting bark pulp cooks to a 750 H-factor. When only 18% AA was applied, the eucalyptus bark cook ran out of cooking liquor (**Fig. 2** shows details), thus stopping the pulping reactions before the completion of the cook. As a result, a relatively high pulp yield (**Fig. 3**) was obtained at a high kappa number. When the AA applied was increased to about 25% on o.d. material, the kappa number dropped substantially (Fig. 1) as did the pulping yield (Fig. 3). The rEA increased from 0 to about 3 gal/L (Fig. 2).

Starting from the highest applied AA and working backwards, it is noted that both the eucalyptus bark cooks and the mixed southern hardwood bark cooks tend to exhibit a near-



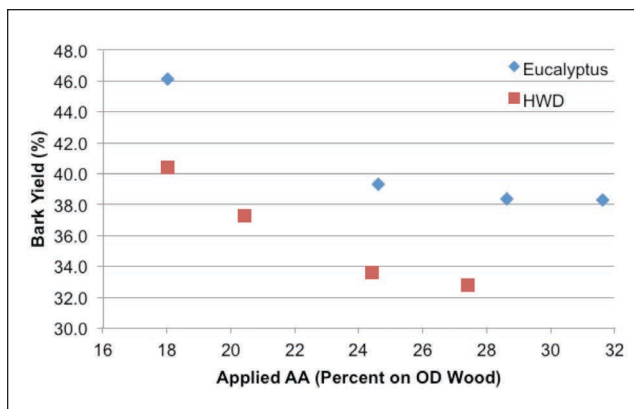
1. Kappa number of bark cooks performed with increasing amounts of applied active alkali (AA). All cooks pulped to 750 H-factor.



2. Residual effective alkali (rEA) of bark cooks performed with increasing amounts of applied AA. All cooks pulped to 750 H-factor.

linear decrease in rEA as the applied AA is decreased. Extrapolating both lines back to zero residual suggests that the eucalyptus bark will require an AA charge of about 22% applied AA, whereas the mixed southern hardwood bark only needs about 17% applied AA to start generating rEA in the cook. As the eucalyptus bark has a higher kappa number and

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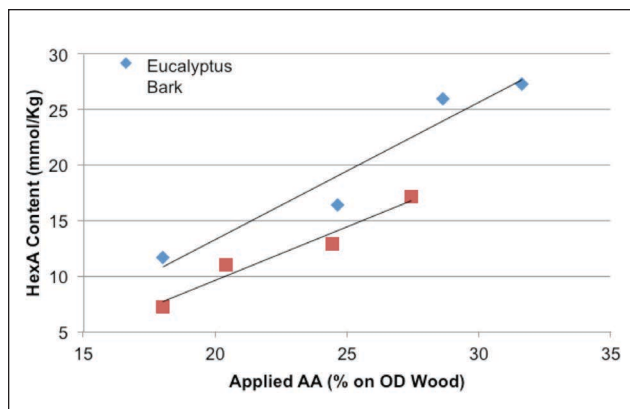
3. Yield of bark cooks performed with increasing amounts of applied AA. All cooks pulped to 750 H-factor.

higher extractives content, it is not unreasonable to expect the eucalyptus bark to consume a greater amount of alkali as compared to the mixed southern hardwood bark.

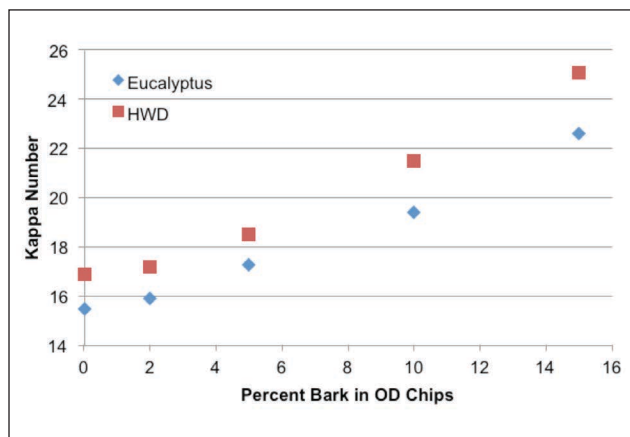
A close examination of Fig. 1 shows that the eucalyptus kappa number first drops when the amount of alkali is increased enough to generate a residual in the spent cooking liquor. After the alkali charge is further increased, the yield shown in Fig. 3 starts to stabilize into a very slow drop and the kappa number actually increases toward an asymptotic value. Considering that the kappa number is a measure of the weight percent lignin left in the pulp, the resulting increase in kappa suggests the yield should increase as well because there is simply more lignin in the pulp. However, the results show a decrease in yield. As the lignin content increased and the yield decreased, other constituents in the bark had to decrease substantially. Therefore, these constituents other than lignin had to react faster than the lignin, resulting in lost overall yield and increased lignin content that appears to be somewhat resistant toward alkaline pulping chemicals.

A similar trend, although far less pronounced, was seen with the mixed southern hardwood bark. The first datum point (cooked with 18% AA) already had a reasonable amount of residual. We did not see a drop in kappa as we did with the eucalyptus bark, but we did see a slight increase in kappa number and decrease in yield.

The kappa number of the pulp continued to increase as the AA and resulting rEA in the spent cooking liquor continued to increase. We therefore decided to check the resulting pulp for compounds that could potentially consume oxidants, resulting in an erroneously high kappa number being reported. The most probable compound to check for would be hexenuronic acid (HexA). HexA has been well documented to consume potassium permanganate and be reported as increased kappa number. For each 11.9 mmol HexA found in 1 kg o.d. pulp, the kappa number of the pulp will exhibit a value 1 kappa unit higher than that predicted from the pulp's lignin content alone [19,20]. **Figure 4** shows the HexA content of each of the bark cooks performed at increasing applied AA levels. Both the southern hardwood and the euca-



4. Hexenuronic acid content of bark pulps cooked with increasing amounts of applied AA. All cooks pulped to 750 H-factor.



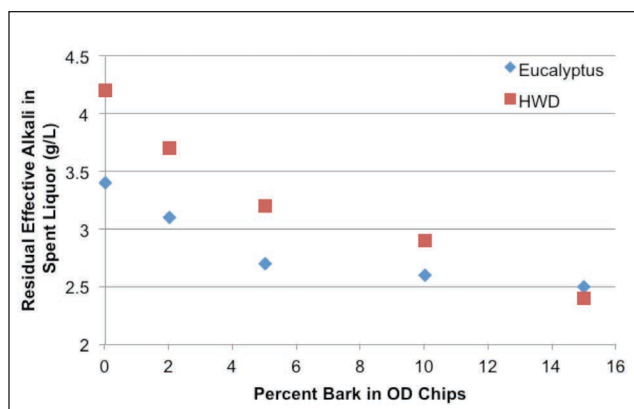
5. Kappa number as a function of bark content. Pulps were cooked to 750 H-factor with 18% applied AA.

lyptus bark cooks show a nearly linear increase in HexA content with increasing AA addition and resulting increased rEA in the spent liquor. As expected, the eucalyptus bark cooks exhibit a higher HexA content at any given applied alkali charge as compared to the mixed southern hardwoods. At the higher applied AA levels, the HexA content alone accounts for more than 2 kappa units in the resulting pulp.

Co-cooking bark and chips at constant H-factor and applied AA

When cold-tolerant eucalyptus is used as a partial replacement for southern hardwoods, they are typically harvested and blended into the existing wood stream. Ideally, to ensure good blending, the eucalyptus chips would be kept separate after debarking and chipping and blended from the separate storage piles. In practice, this would not be the case because the additional storage space and reclaim equipment would be cost-prohibitive. Therefore, the eucalyptus logs and chips will be randomly distributed as they are delivered to the mill and processed with other southern hardwood species.

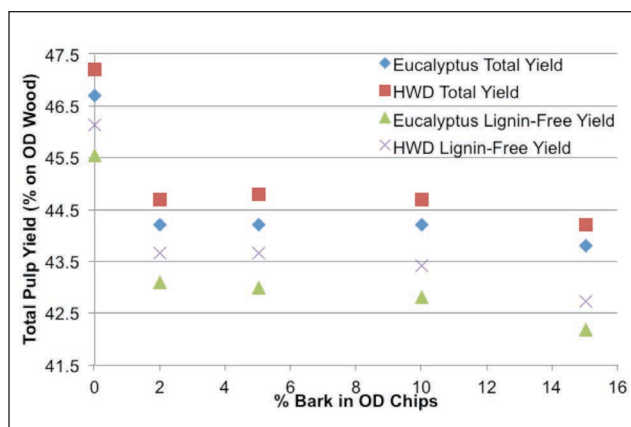
As mentioned previously, when processed through conventional debarking systems optimized for southern mixed



6. The rEA in spent cooking liquor as a function of bark content. Pulps were cooked to 750 H-factor with 18% applied AA.

hardwoods or southern pine, some amount of eucalyptus bark ends up in the accepted chips going to the digester. Several sets of cooks were performed with varying percentages of eucalyptus and mixed southern hardwood bark to determine the effect of bark intrusion into the wood stream. Chips and bark samples were manually blended before cooking to ensure accurate amounts on an o.d. basis. The samples were cooked at a 750 H-factor with 18% applied AA. Each sample was cooked in triplicate and averages were calculated.

Figure 5 shows the kappa response to the presence of bark in the chips. As the amount of bark in the cook increased, the kappa number also increased. This is to be expected because the bark preferentially consumes the alkali in the cook, resulting in an effectively lower amount of alkali being available to react with the chips. **Figure 6** shows the rEA in the cooking liquor. Figure 6 clearly shows that the presence of bark in the cook results in a significant increase in liquor consumption. When 2% of bark is present, only small increases in the kappa number of about 2% result. At 5% bark, the increase in kappa number is about 10%. At



7. Total pulp yield as a function of bark content. Pulps were cooked to 750 H-factor with 18% applied AA.

10% and 15% bark levels, the increase in kappa number is 26% and 47%, respectively.

Figure 7 shows the effect of bark on the total pulp yield. Even a small amount of bark (as little as 2% on o.d. wood) negatively affects the yield. A small amount of bark has a significant effect on the total pulp yield. To better examine the effect of bark on carbohydrate yield, the lignin portion of the fiber was calculated using the approximate relationship of $\text{kappa} \times 0.147 = \text{wt\% lignin}$ and subtracted from the total pulp yield. When examined on a lignin-free basis to correct for the increasing kappa number, it appears that increasing the amount of bark in the chips has a significant negative effect on the total pulp yield.

Effect of bark content on pulp physical properties

The pulps obtained in duplicate cooks were blended and made into board-grade handsheets for physical property testing. **Table IV** shows the test results. For mixed hardwoods and eucalyptus, the pulps obtained from pure bark samples exhibited a lower tensile strength, elastic modulus, and Taber

	Tensile (index at break), lbf/in.	Elastic Modulus, psi	Taber Stiffness, mN-m	Z-direction Tensile, psi	Tear Resistance, g-force
Eucalyptus bark	33.1	324000	9.5	80.8	106.7
Eucalyptus chips	44.8	768000	11.3	57.2	80.3
Eucalyptus 5% bark	56.9	819000	14.6	47.7	95.4
Eucalyptus 10% bark	57.9	788000	14.0	51.2	97.6
Hardwood bark	20.0	278000	12.5	30.8	61.7
Hardwood chips	25.1	439000	13.3	31.7	63.4
Hardwood 5% bark	27.1	473000	16.1	26.6	65.1
Hardwood 10% bark	28.4	479000	16.5	25.4	65.6

IV. Physical properties of unbeaten pulp handsheets made from pulps cooked with varying amounts of bark in the chips.

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stiffness than did the pure chip samples. For mixed hardwoods, the internal bond, as measured by z-direction tensile (ZDT), and tear resistance were lower as well. The eucalyptus bark pulps actually showed improvement in the ZDT and significant improvement in tear resistance. The increased tearing resistance is not a particular surprise because the eucalyptus bark fiber length is actually twice that of the eucalyptus chip fiber length. What is surprising is that including 5% or 10% bark in the cooks resulted in increased tensile, modulus, and stiffness. Including bark in the cooks resulted in a decrease in the ZDT for eucalyptus and mixed hardwoods. It is possible that the increased kappa numbers of these pulps are responsible for the changes in physical property results seen in these tests. Previous work would tend to support this hypothesis [21,22].

CONCLUSIONS

Incorporating mixed hardwood and eucalyptus bark into the chips going to the digester results in decreased pulp yield and increased kappa number for any given set of cooking conditions. The presence of bark results in a significant and rapid consumption of the applied cooking liquor, with a preference for the bark to consume the alkali. The resulting spent cooking liquor has a lower than normal rEA. Increasing the amount of alkali in the cook to bring the rEA back to typical levels results in a significant increase in the amount of HexA generated in the pulping process. Eucalyptus bark tends to consume more AA and have a higher HexA content than do comparable amounts of mixed southern hardwood bark.

The presence of bark in the chips decreases the pulp yield and increases the kappa number when cooked under similar conditions as bark free chips. The presence of bark in the chips tends to enhance the tensile strength, modulus, and

Taber stiffness of the resulting fiber. The presence of eucalyptus bark substantially improves the tearing resistance of the pulp. **TJ**

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ABOUT THE AUTHORS

We began this study as part of the partial substitution of cold tolerant eucalyptus project because there was a need to understand the effect of eucalyptus bark on pulping. Because of the debarking behavior of eucalyptus bark, an increase in bark contamination is expected if this project moves forward.

Previous work with bark has shown similar results, except that the eucalyptus bark seems to have even greater negative effects on alkali consumption, pulp contamination, and lost yield than traditional mixed southern hardwood bark.

The constituent analysis of the bark was the most difficult aspect of this work. North Carolina State University was engaged to assist in this effort.

The fibrous content of the eucalyptus bark significantly enhanced the tear resistance properties of the resulting pulp. The eucalyptus bark consumed a substantially higher amount of alkali than mixed southern hardwood bark. Both findings were somewhat

surprising.

These data could be used to help justify in-woods debarking of eucalyptus to avoid contamination issues.

Alternately, this work could be used to predict potential operational problems associated with partial substitution.



Santos



Hart

Santos is senior power house engineer, Westrock, Covington, VA, USA. Hart is director, Fiber Tech and Innovation, WestRock, Atlanta, GA, USA. Email Hart at peter.hart@westrock.com.

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