EFFECTS OF SURFACTANT APPLICATION ON *ACACIA* HYBRID KRAFT PULP PROPERTIES

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Received January 16, 2022

Acacia hybrid kraft pulping, with the addition of different non-ionic commercial surfactants, as well as its subsequent elemental chlorine free (ECF) bleaching, was studied. The characteristics of bleachable pulps made by conventional kraft and by kraft-surfactant pulping methods were investigated. The results revealed that the type and dosage of the surfactants during the production of *Acacia* hybrid kraft pulp had no significant influence on the kappa number, screen yield, and reject. On the other hand, the extractive content and brightness of *Acacia* hybrid bleached kraft pulp were considerably affected by the types and dosages of surfactants used. The addition of 0.1% LAE (linear alcohol ethoxylate) on oven-dried chips lowered the extractive content by 58.20%, whereas 0.125% PEG (polyethylene glycol esters of fatty acids mixed with block copolymer of ethylene oxide with propylene oxide) on oven-dried chips reduced the brightness by 2.78%. Furthermore, the addition of surfactants had no discernible effect on the specks of dirt.

Keywords: *Acacia* hybrid, non-ionic surfactant, kraft pulp, extractive content

INTRODUCTION

Acacia hybrid is the progeny of natural and artificial crossings between *Acacia mangium* and *Acacia auriculiformis.*[1] Compared to the parent species, this hybrid grows quicker, is less sensitive to disease, and is more tolerant to marginal soil types.[2] According to Kha,[3] the stem volume of *Acacia* hybrid was 2-3 times that of *A. mangium* and 3-4 times that of *A. auriculiformis* at the same age in Vietnam. Furthermore, as this hybrid has better fiber properties, chemical composition, and density than its parent, it is expected to produce a higher pulp yield and give improved paper strength.[4] Kardiansyah *et al*.[5] used superior clones of *Acacia* hybrid from Wonogiri, Central Java, Indonesia, namely Clone 44, Clone 16 and Clone 25, aged 6 years, as raw material for dissolving pulp. Their research revealed that the *Acacia* hybrid Clone 44 could produce dissolving pulp that met the specifications for rayon pulp (Indonesian National Standard/SNI 0938:2010), with the exception of the dichloromethane extractive content parameter, which was 2.23%, when the SNI for rayon pulp specified a maximum of 0.20%.

Since the extractive content in wood can trigger the formation and deposition of pitches on pulp and equipment,[6–8] it can influence the efficiency of wood processing for pulp and papermaking. As a result, the need for chemicals during the pulping and bleaching operations will increase, involving higher process and production costs. In addition, the pulp and paper produced will be of poor quality, and the appearance of dirt particles on paper may potentially result in the factory's shutdown.[4,9–11]

Using additives in the form of surfactants during pulping is one way to control and eliminate the pitch problem produced by extractives.[6,12] Surfactants are used as cooking additives to reduce the surface tension between the liquor and the chips, resulting in chip wetting.[13–15] This aids in the dispersal of extractable material from capillaries and vessels. The liquor is able to penetrate deeper and more quickly into the chips when extractives are eliminated.[16] Pulping is more uniform when the liquor can penetrate deeper into the chips, resulting in reduced kappa number, lower screen rejects, lower resin content, and enhanced black liquor residual active alkali.[13–15]

Surfactants have been proven to have an impact on pulping results in recent investigations. When producing wheat straw soda pulp, Mollabashi *et al*.[17] applied non-ionic surfactants. The results revealed that using either of the investigated surfactants enhanced pulp yield, while maintaining the same kappa number, reduced screen rejects, decreased the burst and tensile index, but raised the tear index. The use of both surfactants also improved the brightness of both unbleached and bleached pulp samples.

Non-ionic surfactants were utilized on bamboo and mixed hardwoods by Mishra *et al*.[18] Dichloromethane extractives, kappa number and rejects were reduced, whereas unbleached pulp brightness, unbleached and bleached pulp yield, and physical strength properties improved. Furthermore, when some of the non-ionic surfactant treated unbleached pulps were bleached using the C-Ep-H-D bleaching sequence (C: chlorination stage, Ep: alkali extraction reinforced with hydrogen peroxide, H: sodium hypochlorite stage, D: chlorine dioxide stage), a significant reduction in chemical oxygen demand (COD), total suspended solids, total dissolved solids, and chloride was seen when compared to the blank trial.

Parthasarathy *et al*.[19] found that a surfactant-based digester additive reduced the active alkali charge in mixed hardwood soda–anthraquinone (AQ) pulping. Cooking time and temperature were reduced considerably, which enhanced bleached pulp yields and brightness.

The effects of numerous non-ionic commercial surfactants and their doses on soda pulping and elemental chlorine free (ECF) bleaching of soda and soda-surfactant pulps of bagasse were studied by Hamzeh *et al*.[20] The use of surfactants during bagasse soda pulping reduced kappa number, reduced alkali consumption during pulping, and increased the yield and brightness of the resulting pulp, according to the findings. The strength properties of bleached pulps made using surfactants were superior to those of pulp made with traditional soda pulping.

Duggirala[21] investigated how the addition of a non-ionic surfactant affected the cooking rate of southern US pine chips on kraft pulping in the lab. The H factor was reduced, the screen yield was raised, and the number of rejects was decreased.

On southern US mixed pines[14] and mixed hardwoods,[13] the effect of several anionic and non-ionic deresinator surfactants for kraft pulping was also noted. Except for residual alkali active, the results showed that alkylated diphenyloxide disulfonate (anionic surfactant) and alcohol ethoxylate (non-ionic surfactant) produced the best results in extractive levels reduction, kappa number, and rejects. Moreover, Duggirala[15] investigated the effect of a non-ionic surfactant on kraft-AQ pulping with a US southern pine mix and discovered that the H-factor and incremental total yield were reduced.

Manji[22] published the results of a short-term mill trial of AQ-surfactant pulping of coastal softwoods from British Columbia using a kraft continuous digester. The addition of an anionic surfactant to kraft-AQ pulping reduced residual effective alkali and bleached dirt count and increased brownstock production, according to the findings. Laurito[16] applied a blend of anionic and non-ionic surfactants that were designed specifically to help with the introduction of liquor during the *Eucalyptus* kraft cooking process. When compared to conventional cooking outcomes, the results showed that alkali consumption was lower for all kappa levels and boosted total yield and screen yield. Additionally, the use of additive cooking reduces the number of rejects at all levels of kappa studied.

Baptista *et al*.[23] investigated four different types of surfactants in the pulping and bleaching of *Pinus pinaster* and found that non-ionic surfactants provided the best results. They discovered that, while brightness increased, kappa number, chemical consumption, and screen rejects decreased. Ghaffarzadeh[24] investigated how different surfactants affected soda pulping of wheat straw and poplar. Surfactants improved pulp yield and reduced screen reject, according to the findings.

Although surfactants have been found to improve the pulping characteristics of softwoods and hardwoods, there is very little information on their usage as pulping additives in the kraft pulping of *Acacia* hybrid, which produces high extractive levels of bleached kraft pulp. Therefore, the objective of this study is to investigate the impact of different non-ionic surfactants and their dosage on *Acacia* hybrid kraft pulping and ECF bleaching.

EXPERIMENTAL

Wood samples of *Acacia* hybrids used in this study were obtained from a plantation in Alas Kethu, Wonogiri, Central Java, Indonesia, established and managed by the Center for Forest Biotechnology and Tree Improvement (CFBTI). Sampled trees were 5 years old. The top and bottom branches of these trees were discarded, while the rest was chipped to 3 × 3 × 0.3 cm size. The moisture content was measured after the chips had been thoroughly air-dried.

Kraft pulping of *Acacia* hybrids was done – for the reference cook – at 165 °C for 150 minutes with 25% active alkali (as Na_2O) and 18% sulphidity based on the dry weight of chips. Modified cooks were performed, under the same pulping conditions, with a variety of commercial non-ionic surfactants, namely, polyethylene glycol esters of fatty acids mixed with block copolymer of ethylene oxide with propylene oxide (PEG), polyethoxylene ether phosphate (PEP), and linear alcohol ethoxylate (LAE). Based on oven-dry chips, surfactants were dosaged at 0.075, 0.1 and 0.125%. Pulping trials were carried out with 200 g of o.d. chips in a 3 L autoclave on a rotating digester, with a liquor to wood ratio of 4:1. The pulps were properly washed with water on a flat screen after cooking and collected on a 200 mesh screen. Gravimetrically, the screened pulp yield and screened rejections were calculated as a percentage of oven-dry chips. The acceptable kappa numbers for the pulps were determined using SNI ISO 302:2014.

A five-stage $D_{HT}E_PD_1D_2$ sequence was used in the bleaching trials. At 90 °C for 60 minutes, the D_{HT} stage (a ClO_2 delignification stage at a high temperature) was conducted. In the D_{HT} stage, the ClO_2 charge was 0.22×KN/2.63. For the peroxide reinforced extraction E_p step, the alkaline extraction stage was performed at 70 °C for 60 minutes with a charge of 1% NaOH and 1% H_2O_2. The temperature was set at 75 °C for 180 minutes in the D_1 and D_2 stages (the ClO_2 bleaching stage). In the D_1 and D_2 stages, the ClO_2 charges were 1% and 0.5%, respectively.

According to SNI ISO 3688:2014, standard handsheets (200 g/m^2) were made from bleached pulp without refining. The pulp sheets were conditioned for 24 hours at room temperature. The brightness of the bleached pulp was then measured using an Elrepho Spectrophotometer in compliance with SNI ISO 2470-1:2016. TAPPI T 213 om-15 and SNI 8401:2017 were used to assess dirt specks and extractive content of pulp sheets, respectively. The effects of surfactants on pulp qualities were investigated using two-way ANOVA, and the means were compared using Tukey's HSD (honestly significant difference) multiple comparison test at 95% and 99% confidence levels.

RESULTS AND DISCUSSION

Pulping results

No surfactant was used in the reference cooks (control). A comparison of the effects of the surfactants used and their dosages on *Acacia* hybrid pulp characteristics is presented in Table 1. The use of surfactants had no significant effect on screen yield, rejects, or kappa number, according to ANOVA, despite the fact that screen yield, reject (except for PEP with 0.075% dosage), and kappa number all decreased (Table 1). The pulping yield and delignification rate both reduced in most cases as the dosage of surfactants was raised.[20]

Table 1
Effects of surfactants and their dosages on *Acacia* hybrid unbleached kraft pulp properties

Surfactant		Yield (%)		Kappa No.	Extractive content (%)
Type	Dosage (%)	Screen	Rejects		
Control	0	51.71	0.34	17.65	0.34
PEG	0.075	51.41	0.09	17.38	0.23
	0.1	50.67	0.25	16.66	0.25
	0.125	45.58	0.09	16.69	0.13
PEP	0.075	51.40	0.40	17.55	0.25
	0.1	50.71	0.10	16.83	0.19
	0.125	51.14	0.15	17.03	0.22
LAE	0.075	50.84	0.25	17.63	0.39
	0.1	51.54	0.17	17.52	0.21
	0.125	50.67	0.10	17.34	0.16

The screen yield tended to be lower with an increasing PEG surfactant dosage. This is in contrast to the results reported by Mollabashi *et al.*,[17] Partharasathy *et al.*[19] and Hamzeh *et al.*,[20] who established that adding surfactants enhanced the screen yield of bagasse, wheat straw, and mixed hardwood soda pulps, respectively. Adding surfactants to the soda pulp cooking liquor may have a synergistic effect on carbohydrate protection and lignin condensation reaction decrease.[20] The use of surfactants can improve delignification selectivity (reduced carbohydrate solubility at a specific level of lignin dissolution), which is impacted by surfactants that can act as co-solvents, resulting in good pulp quality, higher yield, and higher kappa number.[20,25]

The PEG applied in this study is made up of ethylene oxide and propylene oxide block copolymers (EO/PO block copolymer). Duggirala[13] found that the addition of EO/PO block copolymer additives to mixed hardwood kraft pulp at a dosage of 0.1% (on o.d. chips) reduced rejects by 6.67%. Surfactants as pulping additives lower the surface tension between the cooking liquor and the lignocellulosic material, resulting in faster solution penetration and more uniform cooking, lower kappa number, and rejects.[15,18,23]

When compared to the reference pulp (control), the addition of non-ionic surfactants was able to lower kappa numbers in this investigation. This is in agreement with the findings of the study reported by Duggirala,[13] Mollabashi *et al.*,[17] Partharasathy *et al.*,[19] and Hamzeh *et al*.[20] The addition of 0.100% PEG reduced the kappa number from 17.65 to 16.66, a reduction of 5.61%. With the addition of LAE, the decrease in kappa number becomes more pronounced as the dosage is increased. In this case, using higher dosages of LAE promotes phase separation in the bi-phase system, which increases lignin dissolution in the polymer phase and decreases lignin condensation, resulting in lower kappa numbers.[26]

Bleaching results

The extractive content (dichloromethane) and brightness of *Acacia* hybrid bleached kraft pulp were significantly affected by the application of different types and dosages of surfactants during kraft pulping, as shown in Figures 1 and 2.

Figure 1 shows that using LAE (linear alcohol ethoxylate) at a dosage of 0.100% reduces the extractive content by 58.20%, when compared to the control (without surfactant additions). The involvement of surfactants (as pulp additives) in decreasing the surface tension between cooking liquor and wood chips, so that the surface of wood chips is not damaged, can induce a decrease in extractive levels.[14,15] When surfactants wet the hydrophobic surface of extracted materials, they help disperse extracts from wood chips, allowing the cooking liquor to penetrate deeper and faster.[16]

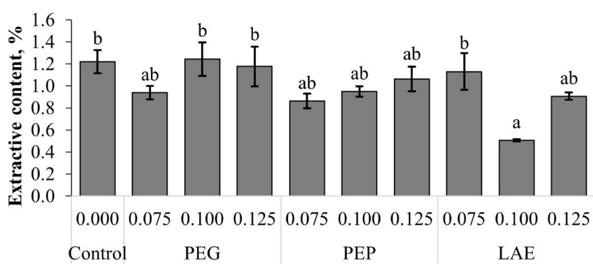

Figure 1: Effect of surfactants on extractive content (dichloromethane) from *Acacia* hybrid bleached kraft pulp (the difference between letters in the figure is significant at 99% confidence level)

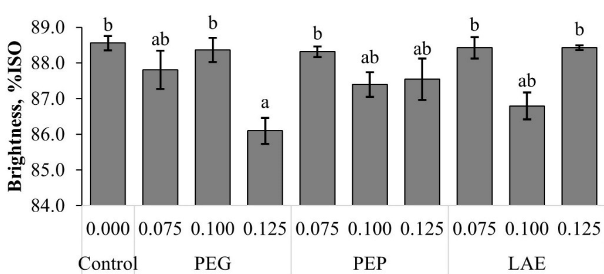

Figure 2: Effect of surfactants on brightness of *Acacia* hybrid bleached kraft pulp (the difference between letters in the figure is significant at 99% confidence level)

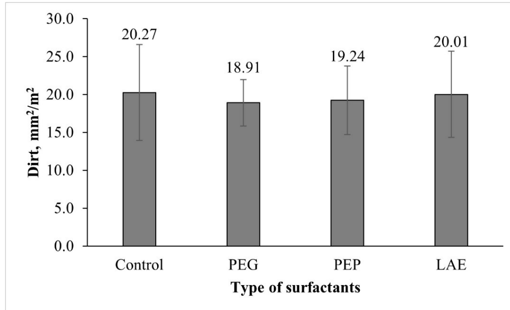

Figure 3: Effect of surfactants on specks of dirt from *Acacia* hybrid bleached kraft pulp sheet

Figure 2 shows that using 0.125% PEG reduced the brightness by 2.78%, compared to the control. This is in contrast to the results of Mollabashi *et al*.[17] and Hamzeh *et al*.,[20] who found that surfactants increased pulp brightness when compared to the control pulp. According to Dai,[27] lipophilic extractive compounds that are inert to bleaching chemicals will accumulate on the surface of the fiber, preventing bleaching chemicals from penetrating the fiber wall or lignin fragments from diffusing out of the fiber wall. The inhibiting mechanism may have an impact on bleaching.

In the pulp and paper making process, wood fiber material with high extractive chemicals is undesirable because it might generate "pitch" (a dark stain on the pulp/paper sheet surface).[28,29] Dirt is a form of particle adhering to bleached pulp that can come from both water processes and raw materials, such as bark.[30] Equipment operations, such as centrifugal cleaning, as well as low and high density, can eliminate dirt specks during the pulping process. Furthermore, chemicals such as surfactants or dispersants can be used to decrease dirt particles.[31] As shown in Figure 3, ANOVA results reveal that the surfactant type and dosage have no significant effect on the dirt specks of the *Acacia* hybrid bleached kraft pulp.

The findings of this study are in agreement with those of Manji,[22] who applied anthraquinone (AQ) as an additive in the production of softwood kraft pulp at a dosage of 0.05% (on o.d. chips). The specks dirt, before and after AQ was added, which was 1–5 per square feet and 1–4 per square feet, respectively, revealed no significant difference. The results demonstrate that when AQ is combined with anionic surfactants, at a dosage of 0.05% (on o.d. pulp), the specks of dirt are reduced to 1–2 per square feet.

CONCLUSION

The type and dosage of the surfactants used in *Acacia* hybrid kraft pulping had no effect on the screen yield, rejects, kappa number, and specks of dirt. However, surfactant types and dosages have a significant impact on the extractive content and brightness of *Acacia* hybrid kraft pulp. The extractive content reduced by 58.20%, when LAE was added at 0.1% on oven dried chips, whereas brightness reduced by 2.78%, with the addition of 0.125% PEG on oven dried chips.

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