Effect of Alkali Pectinase Pretreatment on Bagasse Soda-Anthraquinone Pulp

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Pectinase pretreatment prior to bagasse soda-anthraquinone (AQ) pulping was conducted, and the effects of pectinase pretreatment on the pulp strength properties, energy consumption, and pulpability were evaluated in this study. Considering the pulp properties, the optimal conditions for the pectinase pretreatment were a pectinase dosage of 60 U/g (with respect to oven-dry bagasse) and 60-min treatment time. Compared with the control pulps obtained under the same treatment conditions with enzyme pretreatment (just without enzyme addition), the pretreated pulps attained a reduction in kappa number of 17.8% and an increase in total pulp yield of 15.8%. Moreover, higher breaking length, burst factor, and tear factor after soda-AQ pulping were found in the pectinase-pretreated samples, which suggests some improvements in pulp strength properties. With pectinase treatment, a 1% reduction in alkali charge and 20% decrease in pulping time were observed in subsequent pulping stages without affecting the pulp properties. Pectinase treatment prior to pulping seems to be a promising, economically feasible, and eco-friendly concept.

Keywords: Bagasse; Pectinase pretreatment; Soda-AQ pulp; Properties; Pulpability; Energy consumption

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INTRODUCTION

Bagasse is a residue by-product from the production of cane sugar. For each ton of cane sugar crushed after juice has been extracted, approximately 300 kg of bagasse is retrieved (Khristova *et al.* 2006). Therefore, a number of pulp and paper mills are using bagasse for paper production. However, a major problem restricting the increased use of bagasse as a raw material in the papermaking industry is the absence of an economically feasible and adequate treatment technique for good pulping efficiency and obtaining paper with satisfactory properties.

An effective method to solve this problem is to develop new technology that potentially improves pulping efficiency during the papermaking process. Many investigations of bagasse pulping have been reported worldwide (Khristova *et al.* 2006; Huang *et al.* 2008), including biopulping (Martin-Sampedro *et al.* 2011). Biopulping is the biological pretreatment of the lignocellulosic substrate to modify sample composition such as lignin content, with the aim of facilitating fiber separation or lignin removal in a subsequent mechanical or chemical pulping process. The concept of biopulping is based on the use of lignin-degrading fungi (*e.g.*, white rot fungi) or fungal enzymes to treat wood chips prior to conventional pulping (Mendonca *et al.* 2008; Singh and Singh 2014). The main disadvantages of fungal pretreatment are slow fungal growth (approximately 2 to 4 weeks), maintenance of aseptic and optimal treatment conditions, and yield loss caused by fungal degradation of polysaccharides along with the degradation of lignin. Therefore, the direct application of enzymes on the lignocellulosic substrate has been explored. Enzymatic pretreatments can reduce energy consumption (Ramos *et al.* 2004; Maijala *et al.* 2008), enhance conventional mechanical and chemical pulping (Zhao *et al.* 2002), and increase the rate of delignification (Kaur *et al.* 2010).

The enzymes used in biopulping include cellulases, hemicellulases, ligninolytic enzymes such as lignin peroxidases and manganese peroxidases, and pectinases. Among these enzymes, pectinase is potentially useful in biopulping because of its selective removal of pectin. Pectin has a high molecular weight and is hydrophobic, negatively charged, and acidic. Complex polysaccharides are present in the primary cell wall and comprise, along with lignin, the major components of the middle lamellae, which usually has negative effects on biopulping, whether chemical or physical (Jayani *et al.* 2005; Pedrolli *et al.* 2009). The location and structure of pectin has been assumed to hinder the accessibility of some chemical or enzymes to lignin, although their amount in most raw material used in the paper industry is fairly low. High-pectin containing biomass sources include sugar beet pulp (Spagnuolo *et al.* 1997) and citrus processing waste (Widmer *et al.* 2010). Bagasse contains approximately 1% galacturonic acid (on DM basis). Enzymatic pectin removal in the traditional retting (softening) process results in disassembly of fiber bundles in fibrous crops and improves further fiber processing. Pectinases are known to hydrolyze pectin, and its degradation can facilitate the removal of waxes, which could lead to a considerable reduction in the rate of chemicals consumption and effluent discharge. This pretreatment with pectinase would not affect the cellulose backbone and thus would avoid fiber damage, unlike the drastic chemistry conditions conventionally used. Klug-Santner *et al.* (2006) reported that a purified endo-pectate lyase from *Bacillus pumilus* BK2 could remove up to 80% of the pectin of cotton, and it did not show any side activities on other celluloses and hemicelluloses. Additionally, by incorporating pectinase in alkaline peroxide bleached or alkaline-treated pulp, harmful pectins or galacturonic acid in the aqueous phase of the pulp are depolymerized and consequently rendered harmless to the papermaking process by lowering the cationic demand of the pulp and the filtrates from peroxide bleaching (Ricard and Reid 2004). There are numerous studies regarding the use of pectinase for biobleaching, but not for biopulping, particularly for non-woody materials (*e.g.*, bagasse).

The goals of this work were to investigate the potential of pectinase pretreatment for enhancing conventional soda-AQ pulping of bagasse and to evaluate the effects of pectinase pretreatment prior to chemical pulping on soda-AQ pulping. Pulp properties and handsheet properties were investigated to interpret the differences in pulping results from the pectinase-pretreated bagasse and the control.

EXPERIMENTAL

Materials

Bagasse samples were supplied by a sugar refinery (Guangxi province, China). The enzymes used in this work was pectinase (Sukehan, China) and contained 3000 U/mL of pectinase, as well as small amounts of ligninase, xylanase, and mannase.

Enzymatic Pretreatment

Bagasse was pretreated prior to pulping with the crude pectinase. Bagasse samples were treated with pectinase in transparent plastic bags, after which the bags were immersed in a water bath with a constant temperature of 55 °C. The ratio of liquor to bagasse (oven-dry weight) was 7:1 (L/Kg). The initial pH value (pH 9) was adjusted with an acetate buffer (200 mM). Enzyme dosages ranged from 30 to 90 U/g of the oven-dried bagasse. Similarly, to achieve the best enzymatic efficiency, treatment time from 20 to 100 min was optimized. The optimal conditions for enzymatic treatment were obtained by treating the bagasse with pectinase under various reaction conditions. The control tests were conducted under the same treatment conditions with enzyme pretreatment (just without enzyme addition).

Production of Pulps

Bagasse samples treated enzymatically and controls were subjected to soda-AQ pulping in an oil bath rotating digester. Cooking conditions were as follows: variable alkali dosage (13% to 16%), 0.05% anthraquinone, 5:1 (L/Kg) ratio of liquor to bagasse, maximum temperature 158 °C, heating time 100 min, and variable holding time (at maximum temperature) from 20 to 100 min. Bagasse samples were pulped with alkali dosages ranging from 13% to 16% to evaluate the reduction in requirement of pulping chemicals. Similarly, bagasse samples were treated with different holding times at maximum temperature to assess the reduction in pulping time. After cooking, the residual alkali in the black liquor was determined, and the Kappa number of the pulp samples was determined according to TAPPI T236 om-99 (2004). Pulp yield was measured by drying 20 to 25 g of the wet pulp and determining the mass after evaporation. Total drying pulp mass was calculated and pulp yield was expressed as % of initial raw material. Values were given as average of three independent determinations for each sample.

Preparation and Testing of Handsheets

Handsheets were formed from soda-AQ pulp according to TAPPI T205 sp-02 (2002). The brightness, breaking length, burst factor, tear factor, and tightness of the handsheets were determined according to TAPPI T217 wd-77 (2004), TAPPI T494 om-01 (2001), TAPPI T403 om-10 (2010), TAPPI T414 om-04 (2004), and ISO 438 (1980), respectively.

RESULTS AND DISCUSSION

Optimization of Enzymatic Treatment Process

The optimal temperature and pH for the enzymatic process were 55 °C and 9.0, respectively, according to the pectinase activity provided by the enzyme manufacturer. The effects of pectinase dosage and pretreatment time on soda-AQ pulping are shown in Tables 1 and 2.

Table 1 shows that pectinase pretreatment had obvious effects on pulp yield, Kappa number, and residual alkali. The Kappa number decreased with increasing pectinase dosage. Also, the Kappa number decreased by 21.76% and 17.82%, respectively, compared with the control, with pectinase dosages of 90 and 60 U/g. The main reason for the Kappa number reduction is that pectinase can act on pectin substances, including structural polysaccharides in the middle lamella and primary cell wall of bagasse samples (Kashyap *et al.* 2001). The pretreatment increased the porosity of bagasse, which facilitated the diffusion and impregnation of chemicals into the bagasse and the extraction of degraded lignin during subsequent chemical cooking.

Table 1. Effects of Pectinase Dosage on Bagasse Soda-AQ Pulping

Pectinase dosage (U/g)	Pulp yield (%)	Kappa number	Residual alkali (g/L)	Pulp brightness (%ISO)	Breaking length (km)	Burst factor (kPa.m^2/g)	Tear factor (mN.m^2/g)	Tightness (g/cm^3)
Control	49.46 ±0.01	19.58 ±0.07	3.78 ±0.02	35.00 ±0.05	1.87 ±0.05	3.22 ±0.03	6.25 ±0.06	0.44 ±0.08
30	54.33 ±0.04	16.68 ±0.02	3.31 ±0.06	35.43 ±0.04	1.94 ±0.02	3.32 ±0.02	6.55 ±0.07	0.45 ±0.07
45	55.90 ±0.06	16.21 ±0.04	4.45 ±0.01	35.81 ±0.06	2.08 ±0.03	3.58 ±0.01	6.69 ±0.05	0.45 ±0.08
60	57.27 ±0.11	16.09 ±0.01	4.85 ±0.07	35.91 ±0.07	2.19 ±0.04	4.00 ±0.04	6.90 ±0.06	0.45 ±0.09
75	56.42 ±0.01	15.69 ±0.06	4.93 ±0.06	35.91 ±0.03	2.12 ±0.01	3.75 ±0.05	6.49 ±0.08	0.45 ±0.05
90	56.01 ±0.02	15.32 ±0.03	5.19 ±0.07	35.91 ±0.08	1.99 ±0.03	3.45 ±0.07	6.32 ±0.07	0.45 ±0.07

Enzymatic treatment time was 60 min. Cooking conditions were as follows: alkali dosage of 13% and holding time of 100 min at maximum temperature.

The content of residual alkali in the black liquor increased with increasing pectinase dosage, illustrating that pectinase pretreatment could effectively reduce the consumption of active alkali during the process of soda-AQ pulping. The pulp yield decreased with enzyme dosage of 75 and 90 U/g and the highest yield of pulp was gained with pectinase dosage of 60 U/g. This was mainly due to pretreatment with a high dosage enzyme because it increased the accessibility of bagasse and the extraction of some components, thus lowering the yield. However, pulp brightness was not remarkably affected by pectinase pretreatment. The results given in Table 1 also show the physical properties of the handsheets. Slightly higher physical properties after soda-AQ pulping, including breaking length, burst factor, and tear factor were found in the pectinase-pretreated samples, and the best physical strength was gained when the pectinase dosage was 60 U/g. These results may be due to an increase in average fiber length and variations in the level of bonding after pectinase pretreatment (Bajpai. 1999). However, a slight decrease of physical properties with pectinase pretreatment at high dosage was observed, which may be due to high dosage enzyme leading to some destruction of fiber properties. The tightness values were similar to those of the control. Therefore, pretreatment with pectinase dosage of 60 U/g was determined to be the best for improving the soda-AQ pulping.

Table 2. Effects of Treatment Time on Bagasse Soda-AQ Pulping

Treatment time (min)	Pulp yield (%)	Kappa number	Residual alkali (g/L)	Pulp brightness (%ISO)	Breaking length (km)	Burst factor (kPa.m^2/g)	Tear factor (mN.m^2/g)	Tightness (g/cm^3)
Control	49.46 ±0.05	19.58 ±0.05	3.78 ±0.04	35.02 ±0.03	1.88 ±0.05	3.25 ±0.06	6.20 ±0.04	0.44 ±0.05
20	55.07 ±0.07	17.02 ±0.04	3.50 ±0.03	35.55 ±0.06	1.97 ±0.04	3.37 ±0.02	6.50 ±0.03	0.44 ±0.04
40	56.37 ±0.09	16.71 ±0.07	4.70 ±0.05	35.72 ±0.05	2.12 ±0.05	3.87 ±0.04	6.72 ±0.02	0.45 ±0.05
60	57.27 ±0.07	16.09 ±0.05	4.85 ±0.06	35.91 ±0.05	2.19 ±0.03	4.00 ±0.03	6.90 ±0.01	0.45 ±0.06
80	57.04 ±0.09	15.66 ±0.04	5.07 ±0.02	35.91 ±0.03	2.12 ±0.04	3.86 ±0.03	6.48 ±0.05	0.45 ±0.06
100	56.83 ±0.09	15.16 ±0.02	5.16 ±0.04	35.91 ±0.01	2.00 ±0.03	3.75 ±0.02	6.44 ±0.04	0.45 ±0.05

The dosage of pectinase was 60 U/g. Cooking conditions were as follows: alkali dosage of 13% and holding time of 100 min at maximum temperature.

Compared with the control pulps, pectinase pretreatment resulted in lower Kappa number and higher residual alkali, with the extension of treatment time (shown in Table 2). Pulp yield was improved with treatment time from 20 to 60 min, and after that, it was slightly decreased. With treatment times of 60 and 100 min, the Kappa number decreased by 17.8% and 22.57%, respectively, with respect to that of the control. Similarly, the content of the residual alkali increased from 3.78 g/L for the control to 5.16 g/L for the treatment time of 100 min. The highest yield of pulp was obtained at 60 min. However, the pulp brightness did not noticeably increase with the extension of treatment time. When the treatment time was 60 min, the best physical strength, including breaking length, burst factor, and tear factor, were achieved after pectinase treatment. However, the increase in treatment time did not improve the tightness of the handsheets. Therefore, the optimal efficiency of pectinase pretreatment prior to soda-AQ pulping was achieved at the treatment time of 60 min. Although the enzyme was more functional at values greater than 60 min, exhibited by a 22.57% decrease in Kappa number and a 36.51% increase in residual alkali at 100 min, the extension of treatment time did not clearly improve the brightness, pulp yield, or the physical properties of the handsheets. These results are similar to the findings of Garmaroody and Pulkkinen (Pulkkinen *et al.* 2006; Garmaroody *et al.* 2011). In consequence, the optimal time for pectinase pretreatment was determined to be 60 min. The optimal conditions for pectinase pretreatment of bagasse prior to soda-AQ pulping were thus as follows: 55 °C, pH 9.0, 60 min, and pectinase dosage of 60 U/g.

Effects of Pectinase Pretreatment on Alkali Dosage during Soda-AQ Pulping

Tables 1 and 2 show that the content of residual alkali increased after pectinase pretreatment. Alkali dosage is an important index to assess pulping costs. Therefore, it is necessary to study the effects of pectinase pretreatment on the alkali dosage during soda-AQ pulping process. The bagasse was pretreated with pectinase under the aforementioned optimal conditions. Afterwards, both the pectinase-pretreated bagasse and the control were cooked at the following conditions: holding time 100 min and variable alkali dosages (13% to 16%). The influence of alkali dosage on pulp yield, Kappa number, and residual alkali are shown in Fig. 1.

With increasing alkali dosage, the pulp yield and Kappa number decreased, but the content of residual alkali increased during the soda-AQ process. Also, compared with the control pulp, higher yield and lower Kappa number were gained after pectinase pretreatment when the alkali dosage was identical. The results mean that the same amount of delignification could be achieved with less alkali. For example, to achieve a Kappa number of approximately 11.89, the alkali dosage requirement was 15% for the pectinase-pretreated bagasse, but it was 16% for the control. Under these conditions, the pulp yield and residual alkali were 53.31% and 6.5%, respectively, for the pretreated bagasse and 50.71% and 7.9%, respectively, for the control. These results suggest that pectinase pretreatment prior to cooking could result in a 1% reduction in alkali dosage during subsequent pulping stages. The main reason for the alkali dosage reduction was that pectinase pretreatment degraded the pectins present in the bagasse and facilitated the accessibility of alkali to the lignin layers in pulps. Similarly, Sharma and Satyanarayana (2006) observed that pectinase pretreatment prior to ramie fiber pulping reduced the alkali dosage and the associated alkalinization of water bodies. Consequently, water pollution decreased.

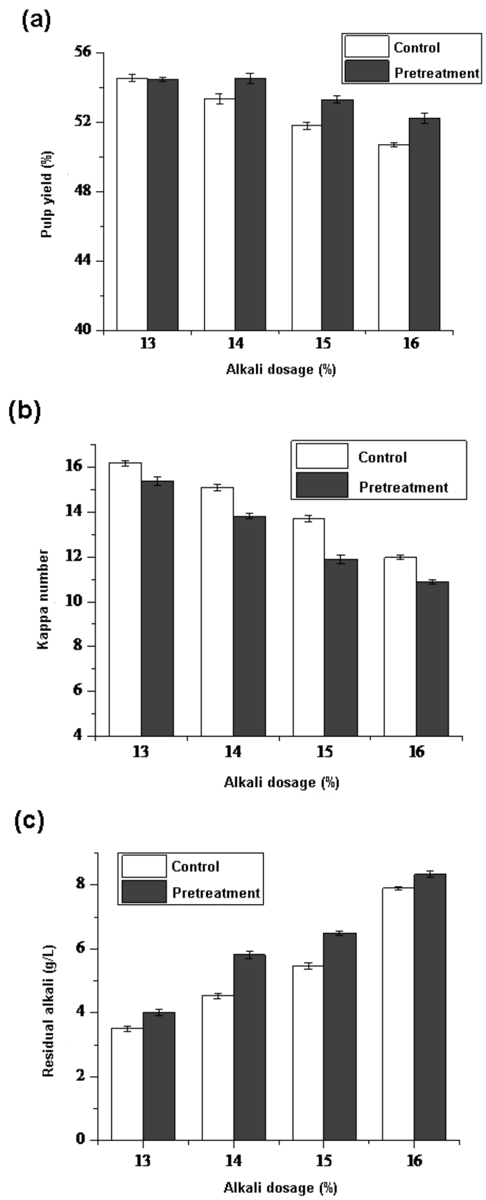

Fig. 1. Effects of pectinase pretreatment and alkali dosage on (a) pulp yield, (b) kappa number, and (c) residual alkali, during soda-AQ pulping

Effects of Pectinase Pretreatment on Holding Time during Soda-AQ Pulping

During the soda-AQ pulping process, pulp yield is the main index for pulp and paper mills. Increasing the holding time would reduce the yield, but its decrease is also one of the most important methods for preventing energy consumption and assessing pulping costs. It is therefore essential to study the effects of pectinase pretreatment on holding time during soda-AQ pulping.

The bagasse was pretreated with pectinase under the aforementioned optimal conditions. Then, both the pectinase-pretreated bagasse and the control were cooked at the following conditions: 16% alkali dosage and variable holding time (from 20 to 100 min). The influence of holding time on the pulp yield, Kappa number, and residual alkali are shown in Fig. 2.

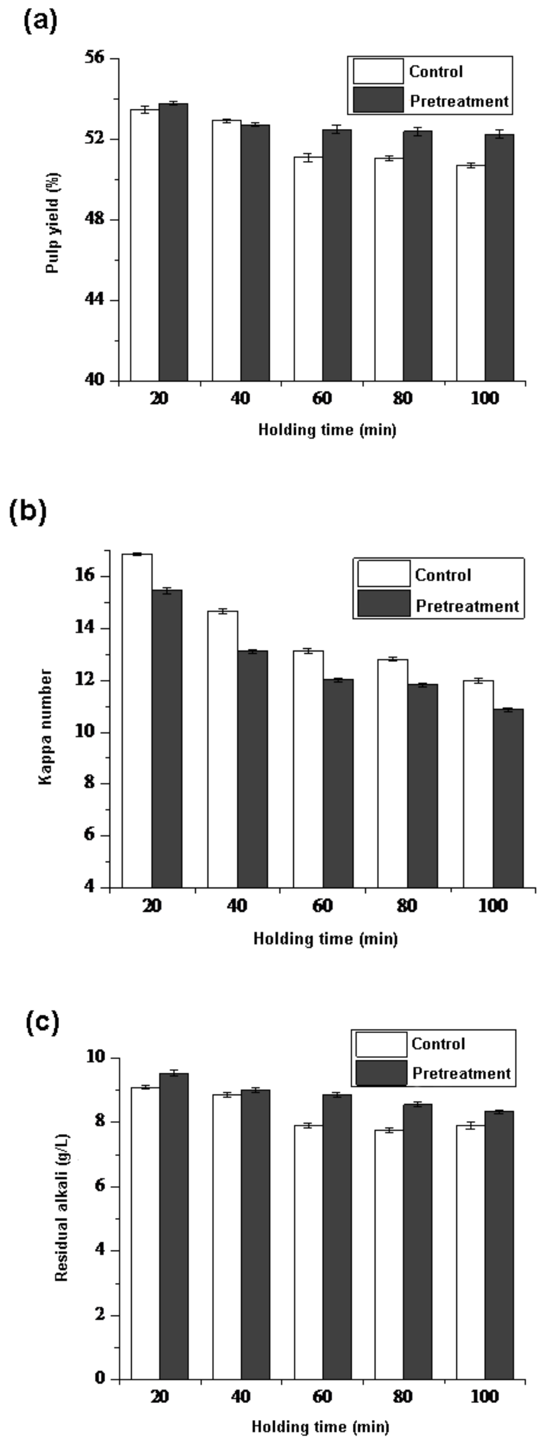

Fig. 2. Effects of pectinase pretreatment and holding time on (a) pulp yield, (b) kappa number, and (c) residual alkali, during soda-AQ pulping

With increasing holding time, the Kappa number noticeably decreased, while the pulp yield and residual alkali were only slightly reduced. Compared with the control, lower Kappa number at the same holding time could be achieved by pectinase pretreatment. Moreover, a short holding time was required to obtain an identical amount of delignification at a slightly higher yield of pulp. After pectinase pretreatment, the pulping time could be shortened to 20 min, at which soda-AQ pulp with lower Kappa number and higher yield could be obtained. This may occur because pectinase pretreatment promoted the penetration of reagents into the bagasse, facilitating the soda-AQ pulping process. This result is in concordance with that reported by Martin-Sampedro *et al.* (2011). After pectinase pretreatment, the optimal cooking conditions were as follows: 1% smaller alkali dosage and 20 min less holding time, compared with the control.

Effects of Pectinase Pretreatment on Soda-AQ Pulp Properties

Results indicated that pectinase treatment could reduce the needed alkali charge by 1% and pulping time by 20% with similar pulp yield, Kappa number, and residual alkali to the controls. In this part of the study, the aim was to investigate the effects of pectinase pretreatment on soda-AQ pulp properties in the case of reducing alkali charge and pulping time. Moderate pulping conditions were selected to cook the pretreated and control samples. To be specific, the bagasse was pretreated with pectinase under the aforementioned optimal conditions. The cooking conditions of pectinase pretreated samples were as follows: alkali dosage of 13% and holding time of 60 min. The cooking conditions of the control samples were as follows: alkali dosage of 14% and holding time of 80 min. The brightness and physical strength properties of the handsheets are shown in Table 3.

Table 3. Brightness and Physical Strength Properties of Handsheets

	Brightness (%)	Breaking length (km)	Burst factor (kPa.m^2/g)	Tear factor (mN.m^2.g^{-1})
Control	30.66 ±0.04	1.82 ±0.05	3.37 ±0.02	8.17 ±0.11
Pretreatment	29.71 ±0.05	2.08 ±0.07	3.72 ±0.09	8.14 ±0.09

Compared with the control, there was a gain of 14.3% in breaking length and 10.4% in tear factor. However, the brightness and burst factor were similar to those of the control. These results indicate that pectinase pretreatment prior to soda-AQ pulping consumed fewer chemical reagents and obtained higher pulp productivity without affecting the pulp properties. Consequently, pectinase pretreatment may be a promising method for improving delignification, decreasing energy consumption, and saving chemicals. These results are consistent with the finding of Jacobs-Young *et al.* (1998), who reported that through enzyme pretreatment, the diffusion of sodium hydroxide in pulp increased, both in the tangential direction and the longitudinal direction.

CONCLUSIONS

1. The optimal conditions for pectinase pretreatment were a pectinase dosage of 60 U/g and 60 min treatment time, considering good pulpability. Pectinase pretreatment prior to soda-AQ pulping resulted in a 17.8% reduction in Kappa number and 15.8% increase in total pulp yield. Moreover, there were obvious improvements in pulp physical properties such as breaking length, burst factor, and tear factor in the pectinase-pretreated samples.

2. Pectinase-treated bagasse, when subjected to the chemical pulping sequence, resulted in a 1% reduction in alkali dosage and a 20% decrease in pulping time, with equivalent pulp properties to the control pulp. Less chemical consumption and pulping time with pectinase pretreatment would ultimately lead to a reduction of the environmental impact of papermaking processes. Thus, pectinase pretreatment can be considered an environmentally friendly technology for the pulp and paper industry.

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