Effect of Cellulase on Mixed Hardwood Pulp for Refining Energy

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Abstract

Biotechnology has emerged as a powerful tool for providing benefits to paper mills in various sections like pulping, bleaching, refining or beating and deinking. We have performed a laboratory scale study on mixed hardwood pulp for evaluating the effect of commercial cellulase enzyme by applying treatment taking different doses, reaction times and conditions that were compatible with an industrial application before the refining step. In pulp and paper industry, refining or beating is important in terms of better fibre- fibre bonding through fibrillation to achieve desired paper properties.

After the enzymatic treatment with cellulase on mixed hardwood pulp, it was refined in PFI mill in our laboratory. This treatment improved pulp quality by development of fibrillation and also affected physical strength properties of paper. There was a significant decrease in energy requirement, to achieve same level of Canadian Standard Freeness (CSF) of pulp. The fiber morphology difference before and after treatment was revealed by the microscopic observations performed by Scanning Electron Microscope (SEM). The SEM analysis showed the surface of cellulase treated fibre had some swelling and fibrillar phenomenon that lead to strong paper properties like tensile index.

Keywords - Cellulase, Pulp Refining, Fibre Morphology, Paper Strength, Energy Reduction.

Introduction

Enzymes are biocatalysts which are protein in nature. They enhance the rate of reaction by lowering down the activation energy for a chemical reaction. In paper industry, paper is manufactured by a mixture of fibre known as stock or furnish. The native shape of fibre has smooth appearance due to covering of lamina and is not acceptable for making a good quality paper. Therefore it is required to beat fibre so that lamina is removed and inner layer microfibrils get exposed. This phenomenon is known as fibrillation and is important in terms of inter- fibre bonding which is responsible to develop better strength properties. In paper mills this is achieved by the process of refining or beating, this step is very important as it consumes upto 30% of total electrical energy (Lecourt *et al*., 2010). Enzymes are necessary in order to develop better fibrillation or net formation which leads to better quality of paper and saving of electrical energy. Biotechnology has emerged as a powerful tool for saving energy demands in beating and drying operations and thereby beneficial to paper mills (Bhardwaj *et al*., 1996; Singh & Bhardwaj, 2010) in addition to biopulping and biobleaching (Choudhury *et al*., 2006).

A laboratory scale study was performed on mixed hardwood pulp for evaluating energy savings due to enzyme treatment in the papermaking refining process. The commercial enzyme used in study was a cellulase preparation. The different enzyme dosage and reaction times were used in the study. This treatment resulted in energy reduction with better pulp and paper quality than untreated pulp.

Materials and Methods

Pulp

Bleached mixed hardwood pulp provided by a leading mill in India.

Enzyme

A commercial cellulase preparation enzyme 'A' was supplied by Novozymes, Bangalore, India.

Pulp enzymatic treatments

The different dose of cellulase solution was added in the pulp suspension before refining, at a pulp consistency of 5%. In order to match with industrial conditions, temperature was fixed at 45 °C and pH was adjusted to 7 using a diluted H2SO4 solution. The pulp was treated with 0.2, 0.4, 0.6, 0.8 and 1.0 IU of cellulase / g o.d. (oven-dry) pulp for different reaction times 1hr, 2 hr, and 3 hr. This treatment was carried out in plastic bags kept in a water bath. After the enzymatic treatment for a particular enzymatic dose and reaction time, the pulp was filtered with a Buchner funnel using a laboratory vacuum pump. The filtrate was recirculated to avoid loss of fines. Then the pulp was washed with water to remove the enzyme and prepared to perform refining studies. Control pulps were treated in a similar mode except for the addition of the enzyme.

Refining, sheet forming and testing methods

All the pulp samples were beaten at a consistency of 10% to achieve a freeness level of 300±10. Laboratory beating of pulp by PFI mill was done as per Tappi Test Method T 248 sp-00 and Freeness studies were performed as per Tappi test methods T 227 om-04. The laboratory handsheets were prepared following the Tappi Test Method T 205 sp-02 and tested for physical properties as per Tappi test methods T 220 sp-01. Tensile index, tear index, burst index and double fold were determined by Tappi test methods T- 404 cm- 92, T- 414 om- 98, T- 403 om- 97 and T- 511 om- 96 respectively. Handsheets from unrefined pulp, control pulp and enzymatically treated pulps were compared for different strength properties. All the experiments were carried out in triplicate and experimental results were represented as the mean ± standard deviation at a confidence interval of 95%. Fibre surface analysis for handsheet was carried out using Scanning electron microscopy (SEM, Leo 435 VP, England) at desired magnifications.

Results and Discussion

Effect of cellulase on refining energy

The extent of refining for pulp samples at different PFI revolutions was monitored for a same level of Canadian standard freeness 300±10. The requirement of PFI revolutions decreased with respect to time of incubation as well as enzymatic dose (Fig. 1). In this study it was found that in case of untreated fibre the refining energy requirement was higher than in comparison to cellulase treated fibre (2hrs, 0.8IU/g) which showed a decrease of 22% PFI revolutions.

This may be due to the hydrolytic action of cellulase components like cellobiohydrolases or endoglucanases on the cellulosic fiber chain (Pere *et al.*, 1998; Suchy *et al.*, 2009). The main effect of cellulase action is fibrillation by acting on outer surface of fibre resulting in delaminated structure and also on cellulosic chain.

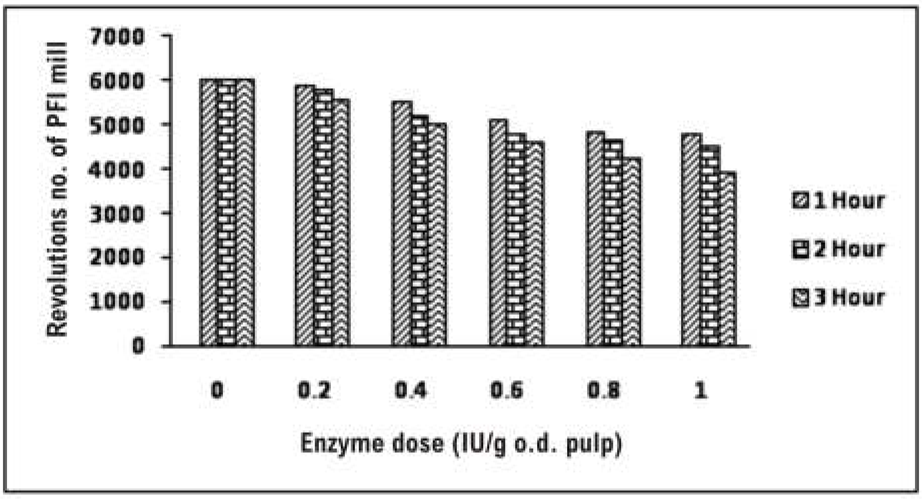

Figure 1: Effect of different doses of cellulase (IU/g o.d.) with respect to different incubation time (hrs) on the PFI revolution to achieve the freeness of 300.

Effect on Paper Properties

A paper property depends on factors associated with fibre like fibre length, coarseness, width, thickness or cutting. Unrefined fibre were found to be smooth (Fig. 3a) because of lamina covering with less or no fibrillation and thus possess poor strength properties, whereas properties were increased in case of enzymatically treated fibre than in comparison to control (untreated and refined) because of a higher degree of fibrillation (Table 1).

Table 1: Effects of cellulase treatment on properties of bleached mixed hardwood pulp.

Pulp properties	Untreated and unrefined pulp	Untreated and refined pulp	Cellulase treated and refined pulp
Revolutions requirement	0	6000	4650
Tensile index (Nm.g)	19.99±2.20	43.19±3.09	54.13±1.91
Tear index ($mN.m^2/g$)	2.59±0.26	5.01±0.72	4.64±0.27
Burst index ($kPa.m^2/g$)	0.25±0.32	4.11±0.28	4.20±0.30
Folding endurance*	0.45±0.17	0.92±0.21	0.924±0.23
Freeness, 300±mL; Cellulase dosage, 0.8 IU/g o.d. pulp, *denotes folding endurance = Log_{10} (no. of double folds).			

Tensile index represents overall sheet strength encompassing contributions from individual fibre strength and inter-fibre bonding (Page, 1969). Tensile strength was found to be maximum for an enzyme incubation of 2 hours time period which is showing 25% increment in comparison to control at dose of 0.8 IU/g (Fig. 2a). This enhancement can be attributed to a better fibrillation, flexibility, collapsibility of fibres and an increased surface area.

For a given tensile index the value of tear index provides an idea about paper web strength. In this study a decreased pattern was observed for higher incubation time while for other trials no major change was observed (Fig. 2b). A similar trend was also noticed by Lecourta *et al.* (2010). This property can be explained on an account of knowledge about fibre strength (Page & Macleod, 1992). There was a smaller increment in burst index which depends on fibre bonding enhanced by enzyme action as a result of fibrillation and inter- fibre bonding (Fig. 2c), and no major change was found in case of double fold property (Fig. 2d).

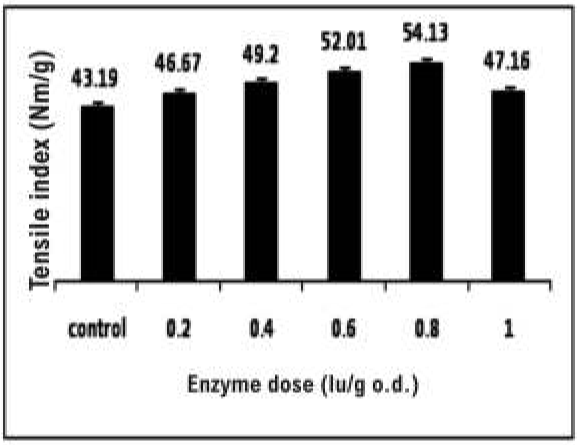

Figure 2a: Effect of various enzymatic doses (IU/g) on tensile index of bleached mixed hardwood pulp at 2 hrs. duration.

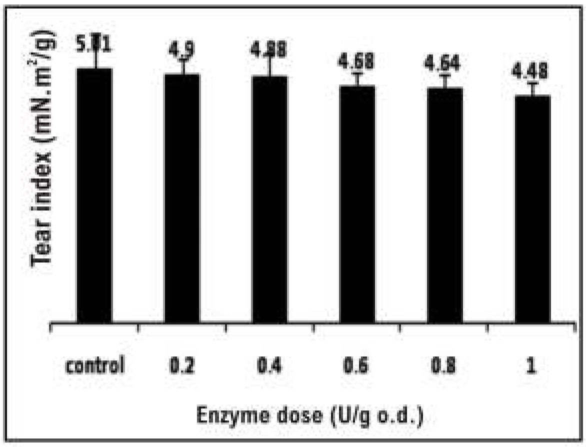

Figure 2b: Effect of various enzymatic doses (IU/g) on tear index of bleached mixed hardwood pulp at 2 hrs. duration.

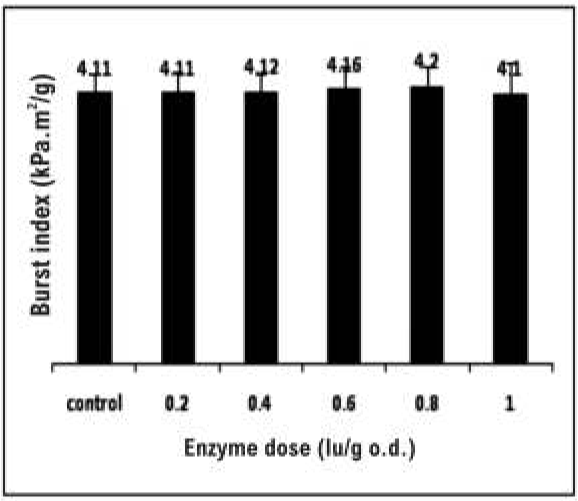

Figure 2c: Effect of various enzymatic doses (IU/g) on burst index of bleached mixed hardwood pulp at 2 hrs. duration.

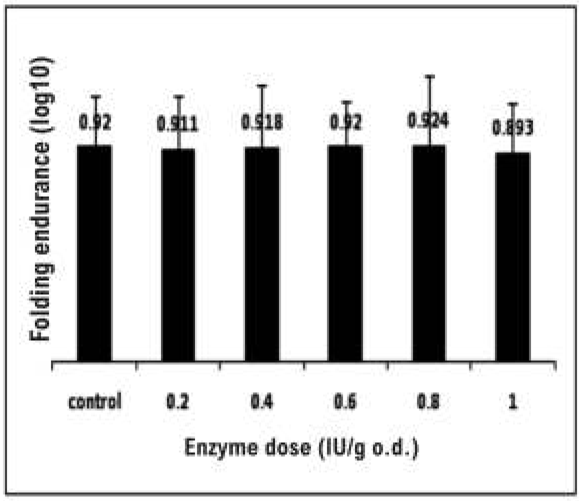

Figure 2d: Effect of various enzymatic doses (IU/g) on folding endurance of bleached mixed hardwood pulp at 2 hrs. duration.

Effect on fibre morphology

Cellulase dose and fibre morphology behavior was studied through images obtained by SEM. The fibres of unrefined pulp were smooth walled and without any fibrillation, also tubular in shape and in laminated form which accounts for a poor strength properties i. e. lower tensile index. There was development of fibrillation and roughness with mechanical action (Fig. 3b) and this phenomenon goes on increasing with curl and twist in treated pulp on addition of enzymatic dose as seen in photograph (Fig. 3c). It may be seen here that cellulose fibres are getting exposed, peeling mechanism occurred by removal of lamina. These modifications are in agreement with morphological studies performed by Fardim & Duran (2003).

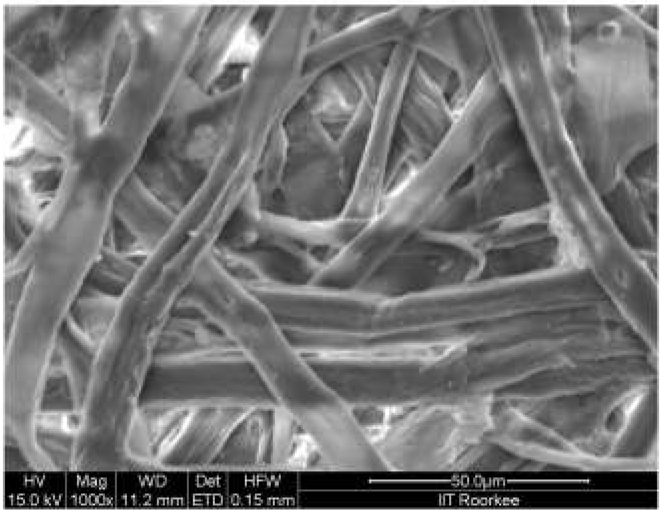

Figure 3a: Scanning Electron Microscope image of unrefined and untreated pulp.

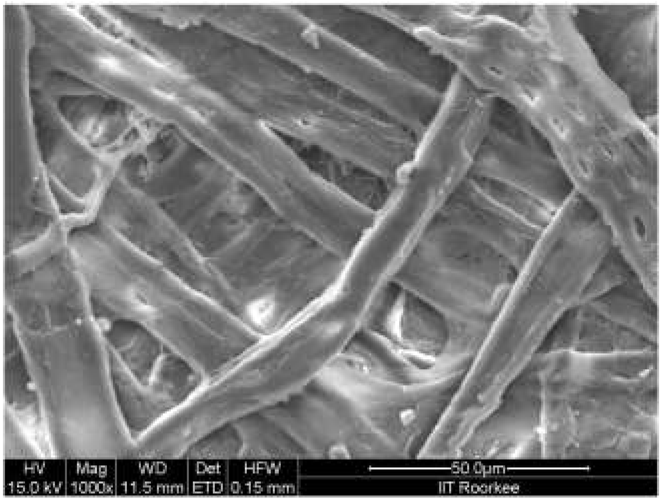

Figure 3b: Scanning Electron Microscope image of refined and untreated pulp (control).

Figure 3c: Scanning Electron Microscope image of cellulase treatment with 0.8 IU/g o.d and refined pulp.

Discussion

This study suggests that enzymes are useful in saving energy demands; there is a need to optimize enzymatic dose and reaction times for better results. The SEM analysis revealed more visible fibre wall dislocations and disruptions, cracks, fractures and higher level of internal fibrillation. In this study the optimal dose was 0.8 IU/g o.d. pulp and time duration 2 hours. This treatment allowed an increment in hydration factor of fibre, improved tensile and burst indices.

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