Enhancement of Wood Pulps by Cellulase Treatment

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ABSTRACT

Earlier reports of the use of cellulases on pulp fibers have provided mixed results. A hitherto unreported cellulase source for the pulp and paper industry, *Chrysosporium lucknowense*, is now a commercial reality. This cellulase has now been evaluated in a variety of pulp and paper applications. The results of mill scale trials where the *Chrysosporium* cellulase has been applied to a variety of raw materials in mill settings will be shared as part of this presentation.

INTRODUCTION

In the nearly 50 years since the pioneering studies describing the interaction of cellulases and cellulose fibers by Reese and Mandels , there have been some limited successes in the application of cellulases to cellulose fibers.

The more successful use of commercial cellulases has been in the textiles area (1) where cellulases have been adopted as a part of the garment wet processing industry to provide special effects in the finished garments like the stone washing of blue jeans. This application has been able to take advantage of the very aggressive nature of the cellulases produced by *Trichoderma* sp. fungal systems.

Despite the potential promise of the application of cellulases to pulp and paper, there has been limited use of these materials to enhance manufacturing issues in this industry. An earlier paper (2) describes freeness/drainage improvements using the commercial cellulases available in the late 1980’s. A more recent report (3) describes work at laboratory and pilot plant scale of pulp treatment using a *Trichoderma* sp. preparation. These authors observed pulp fiber shortening; they also report lower refining energy requirements to achieve given drainage targets. Other published uses of cellulases in pulp and paper have included deinking (4,5) and pulp fiber modification to achieve production of a softer tissue(6,7).

The recent availability of a commercial cellulase preparation produced by *Chrysosporium lucknowense* (8) has expanded the library of cellulase systems available for application in the pulp and paper industry. The intention of this presentation is to describe several examples of its application to systems where a pre-treatment of fibers provides a down-stream advantage in reduced refining energy and/or reduced steam requirements in drying of the treated pulp. These advantages are obtained with no change of physical properties of the cellulase-treated pulps.

EXPERIMENTAL

The cellulase preparation used in the series of mill trials outlined here was the commercially available FiberZyme LBR. This is a formulation which contains the Chrysosporium cellulase; in the discussion that follows it will be noted as CellA. It was added in all cases to the pulps via pulper addition. The operating parameters used in these trials are provided in Tables I and II. The pulper operating conditions and the types of pulps used dictated the optimum cellulase dosing, and these levels are also shown in Tables I and II.

The test data provided here were supplied by the respective mills, and were not necessarily performed under TAPPI Standard Test Conditions.

RESULTS AND DISCUSSION

Mill 1—The product manufactured during these trials was extensible sack kraft papers. As outlined in Table I, the mill employs unbleached bamboo kraft and OCC to make this grade. Extensible kraft is not a widely-used or manufactured paper grade, and the end-use properties that contribute to good performance in this grade center heavily on tensile energy absorption (TEA) and porosity of the final product. The porosity is important in the filling of the finished sacks by materials like cement and flour, where the ability of air to move through the sack wall is important for optimum bag filling.

To achieve the necessary TEA and porosity, standard manufacturing practice (9) involves a high-consistency refining stage to induce an amount of curl into the fiber prior to the paper machine. During normal operation of this particular mill, the bamboo kraft pulp and OCC are treated in separate pulping lines prior to being combined prior to a double roll press . The high-consistency pulp was fed from the press to the high-consistency refiner; after dilution, this pulp was normally further refined in a low-consistency pump-through refiner to achieve the desired drainage for the paper machine.

Table I. Selected Operating Conditions for Mill 1 CellA Evaluation Trials

Paper Grade	Extensible Sack Kraft
Pulp 1 (% of Total)	High Yield Bamboo Kraft (60)
Pulp 2 (% of Total)	OCC (40)
ml Cellulase/ton, Pulp 1 (Res. Time, min.)	120 (60)
ml. Cellulase/ton, Pulp 2 (Res. Time, min)	160 (90)
REFINING OF MERGED PULPS	
Refiner 1 (KWHr/T)	High Consist. (136)
Refiner 2 (KWHr/T)	Double disk, pump through (0)
PAPER MACHINE/FURTHER TREATMENT	
Paper Machine Type (mpm)	Fourdrinier (470)
Paper Post-treatment	Clupak unit between drying stages

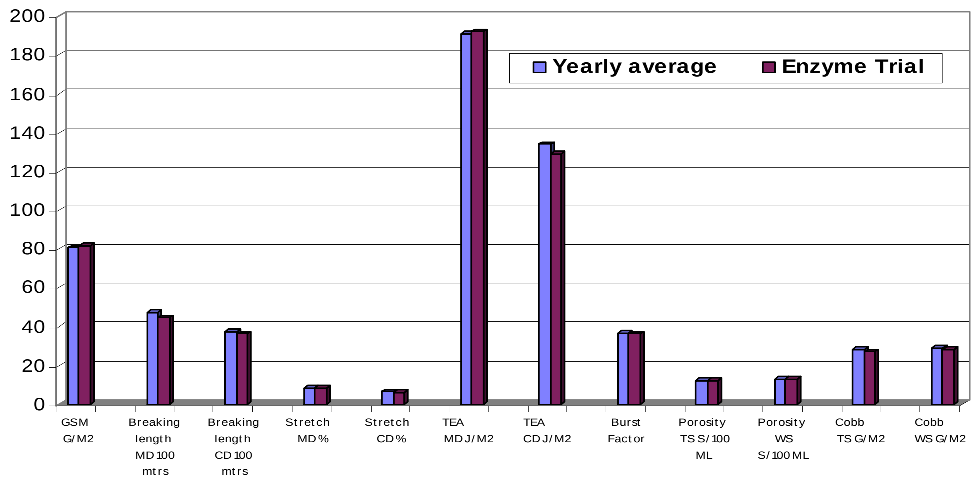
The use of the CellA cellulase treatment allowed the mill to by-pass the low-consistency, pump-through refiner while marginally increase the refining energy applied during the high-consistency stage (128 vs. 136 KWHr/T). This low-consistency refiner would normally apply 65 KWHr/T under normal operation. There was a slight increase in refining energy applied to the final stock just before the paper machine (45.5 KWHr/T vs. 40 KWHr/T. The total refining energy requirements across all three refiners were calculated to have been reduced by approximately 50 KWHr/T.

One additional feature of the extensible sack manufacturing process involves some method to achieve some kind of relaxation of the finished sheet. In another manufacturing example, air-borne drying has been used to achive this relaxation. In this particular case, the relaxation is achieved mechanically between and initial and the final drying stages.

The operating conditions during the period of CellA use were changed minimally, in that no changes of pH and pulper temperatures were necessary to achieve the desired effects. It was found that the two pulp furnishes did respond differently to the CellA cellulase in that the never-dried fiber required less cellulase to achieve the desired final results than did the already dry OCC waste stream.

Figure 1 provides comparative paper properties from this trial compared with the mill's yearly average of the same physical properties. As indicated earlier, the TEA and porosity values are of prime importance in this particular grade. Both of these properties compare favorably with the yearly average results.

FIGURE 1.
Property Profiles of Extensible Sack Kraft Produced With and Without CellA Cellulase



During the trial, it was realized that the cellulose conditioned the pulp to increase the efficiency of the refining stages. With some further optimization it was possible to achieve sufficient fiber treatment in the high consistency refiner, allowing the diluted pulp after high consistency refining. In addition to an energy saving component (50KWhr/Ton), this approach should allow some product improvement through greater retention of fiber curl imposed during high consistency refining.

MILL 2—The second example discussed here is the application of the CellA cellulase to a line manufacturing a heavy-weight, wood-free coating rawstock. The major details relating to that period during enzyme addition are provided in Table II, and represent those conditions after equilibrium was achieved.

The raw materials used by the mill are dry-lap pulps, namely a softwood bleached kraft from the Northwestern U.S. while the majority of the pulp used was a bleached hardwood pulp originating from Southeastern Asia. The enzyme preparation was added at the batch pulpers, where the operating pH was less than 7, and temperatures were 40 ºC. The pulp was then pumped to storage chests; the total storage time was 4 – 5 hours prior to pumping the stock to the refiners.

The treated softwood pulp was refined using Conflo refiners in series prior to placing the treated, refined pulp in the mixing chest. Prior to enzyme, the softwood refining step was the rate limiting process for this line. After enzyme addition, it was found that the softwood refining energy requirement dropped from 205 KWhr/T to a final refining energy requirement of 130 KWhr/T. This improvement in refining energy requirements allowed improved pulp throughput and removal of the softwood refining limitations.

Table II. Selected Operating Conditions for Mill 2 CellA Evaluation Trials

Paper Grade	Heavy-wt., woodfree, coating rawstock
PULP(S)	
Pulp 1 (% of Total)	SE Asia Bl. HW Kraft (80)
Pulp 2 (% of Total)	NW U.S. SW bleached kraft (20)
CellA CELLULASE ADD. RATES	
ml Cellulase/ton, Pulp 1 (Res. Time, min.)	120 (4-5 hr)
ml. Cellulase/ton, Pulp 2 (Res. Time, min)	100 (4 - 5 hr)
PULP REFINING	
Refining, Pulp Line 1 (KWHr/T)	2 Conflos in series (120)
Refining, Pulp Line 2 (KWHr/T)	2 Conflos in series (130)
PAPER MACHINE/FURTHER TREATMENT	
Paper Machine Type (mpm)	Fourdrinier with top-former (950)
Paper Post-treatment	Coated 2-side

The treated hardwood pulp was refined in parallel lines of Conflo refiners in series, similar to the softwood line layout. Again, a decreased refining energy requirement was observed for the treated hardwood pulp. In this case, the refining energy requirements went from 150 KWhr/T to 115 KWhr/Ton.

Table III. Coating Rawstock Physical Properties From Mill 2 CellA Addition Trial.

PROPERTY	UNITS	CellA TRIAL	PRE-TRIAL
Basis Wt.	gsm	154	154
Thickness	micron	194	198
Density	g/cc	0.794	0.781
Breaking Length, MD	Km	5.18	5.31
Breaking Length, CD	Km	2.71	2.86
Stretch, M	%	1.84	1.63
Stretch, CD	%	4.2	4.4
Burst Factor		22.62	20.9
Tear Factor		73.99	67.9
Double Fold, MD	No.	44	63
Double Fold, CD	No.	22	30
Ash Content	%	13.21	13.78
Bending Stiffness, MD	mN	829	956
Bending Stiffness, CD	mN	421	488

An additional potential energy saving was identified through the use of less steam to produce the final rawstock sheet. This savings was estimated to be 200 to 400 kg of steam/ton of finished product. The reason for this, we believe, is a higher solids sheet obtained through better drainage and pressing in the wet end when using the treated pulp.

A comparison of the physical properties of rawstock from this trial and mill data from a month earlier period are shown in Table III. The tear and tensile properties of the paper produced during the CellA trial fall within the range of those values in the several months leading up to this trial. That cannot be said for both the Double Fold and Bending Stiffness values in that both of them are significantly different from the pre-trial values. Without further experiments to define the role of cellulase treatment on the separate pulps used in this work, an explanation should be withheld. It has been demonstrated earlier that cellulase treatment of certain pulps can provide a tissue having an improved softness perception (6,7). Bending stiffness can be related to this effect, and the change in this value here may simply be another confirmation of that role of cellulases in pulp treatment.

LABORATORY TREATMENT AND REFINING STUDIES –Several laboratory experiments were performed using market bleached kraft pulps, both hardwood and softwood, wherein the pulps were subjected to CellA cellulase treatment. A portion of the treated pulp was subjected to a refining action via a PFI mill. Photomicrographs were made of the fibers treated under the various conditions, and the photomicrographs are included here as Figures 2 a – d (Softwood) and Figures 3 a – c (Hardwood). The titles under the photomicrographs define the treatment(s) that that fiber had received.

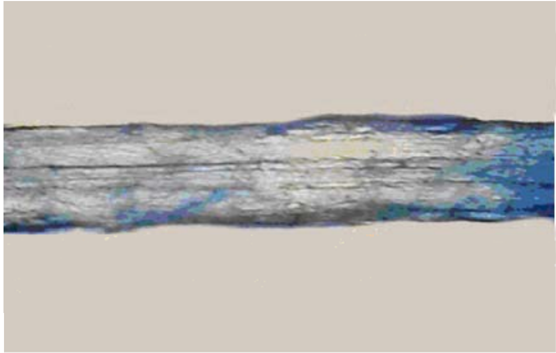


Fig. 2a. Softwood Control
With no enzyme or PFI Treat

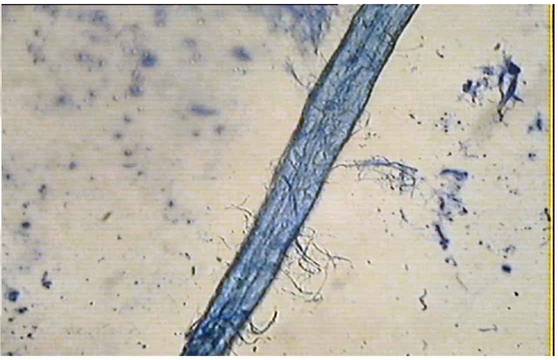


Fig. 2b. Softwood Control With PFI Treatment.

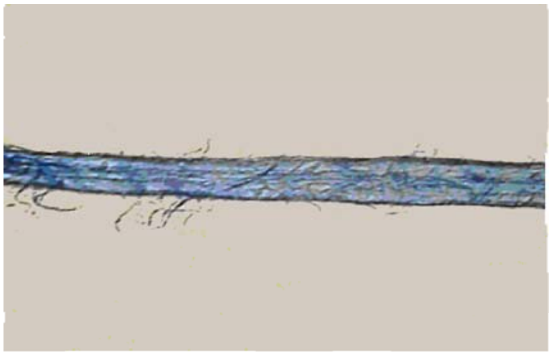


Fig. 2c. Softwood Fiber + CellA Cellulase
With no PFI Treatment.

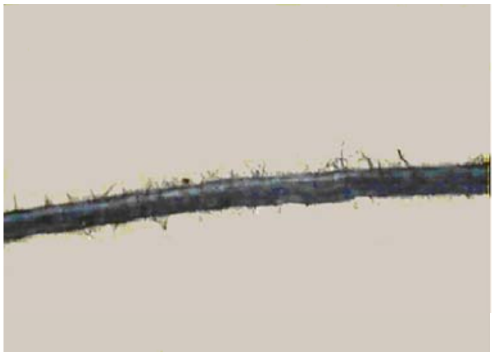


Fig. 2d. Softwood + CellA Cellulase and
PFI Treatment

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Not unexpectedly, the control softwood shows no indication of fibrillation, but the control fiber with PFI treatment shows some moderate amount of fibrillation, and the fibrils produced appear to be rather long. Without some internal scale, it's difficult to tell, but the fibrils produced with the CellA cellulase treatment alone are also rather on the longer side (Fig. 2c.). It's instructive to see that the cellulase can achieve some fibrillation when used as a fiber treatment. When cellulase treatment is combined with a comparable amount of PFI action to that in Fig. 2b., the population of fibrils along the fiber is much greater. It's also interesting to note that the fiber surface here appears to be much different than comparable fiber photomicrographs of cellulase fibers taken after treatment with the more aggressive cellulases that have been the norm.

The eucalyptus pulp fibers in the next series of fibers are lacking the Control + PFI treatment. It's instructive to note that use of the cellulase without mechanical action does not appear to generate much fibrillation in the treated fiber. Only when combined with the PFI refining action does there appear to be a significant fibril density along the fiber.

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Fig 3a. Eucalyptus Control:
No Enzyme or PFI Refining.

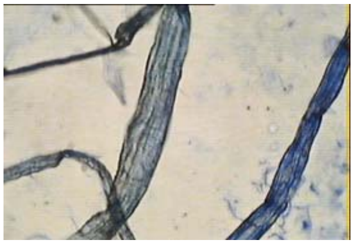

Fig. 3b. Eucalyptus + CellA Treat.
No PFI Refining.

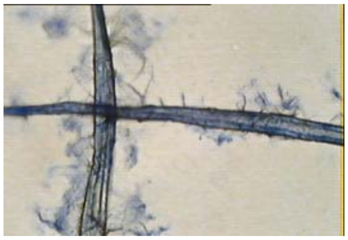

Fig. 3c. Eucalyptus + CellA Treat.
And PFI Refining.

It is not our intention here to attempt to describe the mechanism involved in the change of the fiber wall to allow fibrillation to occur with the combined action of cellulases and mechanical treatment of wood pulps. We consider the use of cellulases in this fashion as a means of preconditioning the cell wall which leads to the improved fibrillation and, as described above, leads to a lower mechanical energy requirement.

SUMMARY

In the paper entitled, "Cellulases: Agents for Fiber Modification or Bioconversion? The effect of substrate accessibility on cellulose enzymatic hydrolyzability," Esteghlalian and co-workers (10) discuss the role of various types of cellulases best suited to do each of the jobs required. They argue that multicomponent cellulases are best suited for cellulose hydrolysis of lignocellulose materials while monocomponent cellulases are better suited for fiber modification. This appears to be the case for the *Trichoderma* sp. cellulases, and Federal funding has been directed through NREL in such an effort to achieve a more efficient lignocellulosic biomass conversion system.

This does not necessarily appear to be the case with the CellA cellulase system, and the results shown above would demonstrate that use of the CellA cellulase with a proper mechanical post-treatment can produce a paper-making fiber that possesses improved fibrillation without deleteriously altering the drainage of the treated fiber. Appropriate adjustments of enzyme dosage and refiner loading must be made to accommodate the fibrous raw material(s) used in each instance.

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