

Enhanced removal of toners from office waste papers by microbial cellulases

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SUMMARY

Office waste papers (100% toner printed) were treated with a commercial cellulase preparation in a pilot scale (2300 kg per run). Waste paper was fiberized for 5 min. at 16% consistency prior to enzyme addition, and enzyme treatment was continued for 30 min. at 50°C pH 8.5 or 7.9. Enzyme loading rates were 0.4 L/1000 kg. Surfactant (0.125%) was present during fiberization and enzyme treatment. Residual ink counts in the enzyme-treated test sheets were 26 ppm; heat-killed controls were 258 ppm. Freeness and brightness also increased. Strength properties and fiber length were essentially unchanged

INTRODUCTION

Office waste paper is one of the fastest growing segments of the recycled fiber industry. However, the toners used in xerographic and laser printers present a special challenge. They consist of thermoplastic polymers of styrene and butadiene, acrylic or polyester along with carbon black or other pigments (1). They are fused to the surface of the paper where they intermingle with the fibers.

Toner particles are rigid, insoluble and difficult to disperse and detach from fibers. As a consequence, papers made from recycled office waste having high toner content contain conspicuous specs. Recycled office waste with more than 15% toner content commands a lower price, and is recycled into less valuable paper materials.

Cellulase treatment of recycled fibers has been shown to enhance drainage (2). We therefore reasoned that cellulases might also facilitate deinking processes because they involve many washing and separation steps. We focused on the removal of toners from office waste papers because they present the biggest problem in recycling and the bleached chemical fibers in such papers have the greatest potential for higher value uses.

The first reported use of cellulases for deinking was with newsprint in 1991 (3, 4). The researchers employed fiberization at 4% consistency at a pH of 4.7. Prasad et al. (5) carried out a similar enzyme treatment on newsprint at 3% consistency, pH 5.5 and observed a marked increase in brightness. More recently, Woodward et al. (6) demonstrated a similar effect using cellulases with newsprint in a recycling system. The use of enzymes for deinking has recently been reviewed (7). The biggest problem with this technique is that results differ among experimental trials. This appears to be attributable to the large number of variables affecting enzyme performance. Some of these include toner quantity and type, the type and amount of sizings, and the presence of other contaminants.

Our initial studies used acid-sized papers composed principally of bleached chemical fibers. We found that a number of commercially-available cellulases alone would facilitate toner removal better than conventional chemical deinking processes used either with or without enzymes (8, 9). Subsequent studies showed that with alkaline-sized papers, it was necessary to employ enzymes active in the neutral to alkaline region along with surfactants to counter the effects of the sizings. Mechanical action also plays a major role in toner removal (10).

The objective of our current studies is to evaluate and overcome the barriers to commercial scale up. We have found that in continuous processing of 2300 kg batches of 100% toner-printed office waste paper, cellulases greatly reduce the residual particle count while increasing brightness and freeness.

MATERIALS AND METHODS

Paper furnish. In preliminary bench-scale trials, paper recovered from our facility was used. It consisted of a single stock of alkaline-sized office bond containing 30% recycled fibers printed with various toners from both xerographic and laser printers. It was 75 g/m² weight and contained approximately 12% ash (8, 9). In a separate study of the effects of sizings, three commercial brands of xerographic papers were used. Each had either rosin/alum, alkenyl succinic anhydride (ASA) or alkyl ketene dimer (AKD) as internal sizing (10). For pilot plant trials, mixed office waste with all three sizings were used but the exact composition of the paper is unknown.

Stock preparation. For initial bench-scale trials, the paper furnish was hammer milled to pass through a 20 mm screen. For pilot scale trials, five 454 kg bales of hand-sorted office waste paper (100% toner) were selected for each of the three runs. Bales were broken and mixed in a high consistency pulper. Sufficient water was added to each batch of paper to attain a consistency of 12% in the case of bench scale trials and 16% in the case of pilot plant studies. Sulfuric acid was used to adjust pH prior to the fiberization stage in some instances. Surfactant was added at a final rate of 0.1% (DI 600) in bench scale trials and at a rate of 0.125% (BRD 2340) for pilot plant studies. All additions were based on the dry weight of fiber.

Enzyme treatment. For bench scale trials, a 5 L capacity Hobart mixer equipped with a water jacket was used to fiberize the pulp. For pilot scale trials, a one ton scale Voith high consistency pulper was employed. In bench-scale studies, fiberization was carried out for 15 min. at 50°C prior to enzyme addition. Enzyme treatment was carried out for 20 min with mixing at 11% consistency. For pilot scale studies, fiberization was carried out for 5 minutes at 50°C 16% consistency. Enzyme was then added and enzyme pulping was carried out at 14% consistency for an additional 30 min. Following enzyme pulping diluted fiber stock (3% consistency) was held in a dump chest at 45°C for 2 to 3 h prior to flotation.

Enzyme deinking efficacy was determined by treating a single batch of pulp with various amounts of enzyme for 20 min. at 50°C. All experimental trials were compared to controls to which heat-killed enzyme was added.

Enzymes. All enzymes were provided by commercial enzyme suppliers. They were used without modification, fractionation, or combination, but each stock was diluted in water prior to pulp application. The amount of diluted enzyme solution added to fiberized pulp was never less than 10% of the fiberized pulp volume. This practice was to assure that good contact with the all fiber occurred upon addition. Novozyme 342™, Denimax L™, Celluclast 1.5 L™, and Pulpzyme HB™ were provided by Novo Industries. Liftase™ Exp A40, Liftase Exp 80, and Liftase Exp X125 were experimental preparations provided by Genencor. (Use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service).

Novozyme 342 and Denimax L are obtained from *Humicola insolens*. All other enzymes used in this study are derived from *Trichoderma reesei*. All enzyme preparations contained a mixture of cellulases, and xylanases, and the ratios of carboxymethyl cellulase to filter paper activity varied widely. The Liftase series of preparations were fractions of *T. reesei* enzyme containing different amounts of cellulase and xylanase. Pulpzyme HB was a xylanase that did not contain appreciable cellulase activity.

Flotation and screening. For bench-scale studies, flotation was carried out in an 8-L laboratory flotation cell. Each pulped sample was diluted to 1% consistency and floated for 3 min. For pilot plant studies, a Voith continuous flotation unit was employed.

Hand sheet preparation and testing. Hand sheets were prepared according to TAPPI Test Method 205. Particle counts were performed on a Hewlett Packard Scan Jet IIc and analyzed with software from Optomax, Burlington, MA. Five hand sheets from each experiment were tested on both sides. Canadian Standard Freeness was measured by TAPPI T 277.

RESULTS AND DISCUSSION

Enzyme dosing rate. The enzymes were most effective when added at low rates. With some preparations, deinking efficiency actually decreased at the highest dosing rates. Heat killed control runs consistently showed much lower rate of toner removal than active enzyme trials. The adverse effect of higher enzyme dosing is not completely understood, but could be due to increased fibrillation.

Efficiency of enzymatic deinking did not follow a consistent pattern with respect to enzymatic activities as measured against carboxymethyl cellulose or filter paper. Deinking efficiency was not a function of xylanase activity. The most effective enzyme preparation tested (Novozyme 342) consists of a complex of seven different endoglucanases and cellobiohydrolases (11)

Freeness increased with enzyme dose, but was more pronounced when enzyme treatment was carried out at 11% than at 14% consistency. The combination of enzyme treatment and surface abrasion at high consistency could decrease freeness and result in poorer toner particle separation.

Effect of sizings Of the three sizings tested, paper sized with ASA was the easiest to deink and paper sized with rosin/alum was the most difficult to deink. Deinking efficiency was affected by the water resistance of the sheet prior to repulping. Paper with high water resistance deinked poorly.

Effect of surfactant. Surfactant had a strong effect on the enzymatic deinking efficiency. Control pulps deinked with heat inactivated enzyme showed 120 ppm of residual toner. Pulps treated with enzyme alone had about 44 ppm, and pulps treated with enzyme and surfactant had only about 8 ppm.

Effect of pulping consistency. The deinking effect increased with consistency such that pulps treated with enzyme at 12% consistency showed about the same amount of toner removal as pulps treated at 17% consistency without enzyme addition. The effects of enzyme and mechanical action, however were complementary. Pulping with enzymes at the lower consistency reduced residual toner particles by about 33% while pulping with enzymes at the higher consistency reduced residual toner particles by more than 50%.

Pilot plant studies. Enzyme treatment was most effective when the pulp pH was reduced to less than 8.0 by acid addition. At the 0.04 to 5.0 mm particle size range, the TAPPI dirt count decreased from 258 ppm in the control sample to 26 ppm in the pH-adjusted enzyme trial. Decreases in other particle size ranges were similar (Table 1). The BOD of process water decreased with enzyme treatment and both brightness and CSF increased. Toner removal was most conspicuous immediately following the flotation stage. CSF and brightness increased with enzyme treatment; fiber length and strength properties were essentially unchanged (Table 2).

CONCLUSIONS

These studies have shown that cellulase treatment in the presence of surfactant and mechanical agitation can increase the efficiency of enzymatic deinking. This effect is probably due to increased flotation efficiency resulting from greater detachment of toner particles from fiber surfaces, but it may also result from increased washing efficiency as a result of improved drainage properties.

Table 1. Residual ink in various particle sizes following deinking.

Tappi dirt count	Control	Enzyme run 1 ^a	Enzyme run 2 ^b
0.04-5.0 mm	258	173	26
0.02-5.0 mm	417	239	47
Less than 0.02	167	99	24

^a No pH adjustment (pH =8.4) ^b pH adjusted to 7.9

Table 2. Fiber properties following deinking.

Property	Control	Enzyme run 1 ^a	Enzyme run 2 ^b
CSF (ml)	510	570	565
Kajaani (mm)	1.88	2.01	1.87
Tensile index (kN·m/g)	0.0410	0.0431	0.0412
Burst index (kPa·m ² /g)	2.2	2.42	2.34
Tear index (mN·M ² /g)	4.28	4.39	4.25
Brightness gain (pts)	8	9	10

^a No pH adjustment (pH =8.4) ^b pH adjusted to 7.9

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