Fiber Modification With Enzymes for Improving Refining and Drainage

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ABSTRACT

A number of Cellulase based enzymes have proved quite successful and viable in improving the refiining and drainage characteristics of various pulps. A number of mills in India and abroad are using these enzymes for Fiber modiciation purpose. The dosage required varies depending upon the fiber furnish and mill conditions. Generally a dosage of around 50-100 gms is sufficient. These enzymes have been tested both on the lab scale as well as on commercial scale in mills. Every mill has to determine the viability of using these enzymes as its effect varies with the mill conditions and the fiber furnish. This paper deals with the case studies and general information regarding the various enzymes being used for this purpose.

Introduction

Wood fibers are composed mainly of cellulose and hemicellulose microfibrils encrusted in lignin-carbohydrate matrices. They are multi-layered structures that can have internal delamination and external fibrillation after chemical and/or mechanical processing. Wood pulp can be treated with enzymes. This biochemical treatment reduces the amount of mechanical treatment needed to reach the desired fiber properties. Less mechanical action and less energy are required. Since refining requires significant energy input as well as capital investment for equipment, helping the refining process could provide numerous benefits. In the last few years, interest in the use of enzymes as a way of modifying fibre properties to improve the beatability/refinability and drainage of pulps has increased (Thomas and Murdoch, 2006; Bharadwaj et al., 1996; 1997; Bajpai et al 2005; 2006; Jones, 2007; Mora et al., 1986; Noe et al., 1986). The use of commercially produced enzymes in paper making is relatively new. Typical enzymes include amylases, proteases, lipases, xylanases and cellulases. Produced in nature by fungi, bacteria and protozoans, cellulases break down the cellulose walls of plant fibre. There are several kinds of cellulases which differ structurally and mechanistically. These enzymes can be classified into two broad groups according to the specific function they perform. Endo-cellulases break internal bonds to disrupt the crystalline structure of cellulose to expose individual polysaccharide chains. Exo-cellulases on the other hand cleave two to four units from the ends of the cellulose chains resulting in much smaller tetra- or disaccharide molecules. In paper making, the enzymes used are principally of the endo-cellulase type. When used to treat paper making pulps, fibre modification enzymes deliver a number of beneficial effects on the manufacturing process and paper properties. The main process related impacts are seen in reduction in refining energy, substitution of expensive pulps by more cost effective ones, increase in dewatering, lowering of drying energy, and reduction in starch use. In some cases increases in machine speeds and therefore productivity have been realised. Effects on paper quality include increase in tensile strength, higher bulk, porosity and tissue softness (Thomas and Murdoch, 2006; Hoekstra and Yoder, 2006; Bajpai et al., 2006). Successful applications result in delivering substantial return on investment (ROI) for the paper makers. There are a number of running applications using these fibre modification enzyme products in the paper industry.

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Experimental

Study was conducted with ECF bleached tropical hardwood Kraft pulp, long fibre fraction (LF) of bamboo Kraft pulp, and a mixture of 40% NDLKC & 60% LF bamboo pulp - normally used for producing ESKP (extensible sack Kraft paper). Three commercial enzymes were studied. Commercial Enzyme 1 and 2 contained both cellulase and xylanase activities and Commercial Enzyme 3 contained only cellulase activity. The pulps were treated with different enzymes at varying temperature, time and pH at pulp consistency of 4%. The pH of the pulp was adjusted with dilute H_2SO_4 or NaOH solution before addition of the enzyme. The reference pulps were incubated at the same conditions as the enzyme treated pulps prior to beating. Beating of the pulps was done in a PFI mill.

Plant-scale trials with commercial enzymes were conducted in different paper mills producing packaging, writing, printing, speciality and coated papers.

Moisture content of the pulp was determined as per Tappi Test Method T 210 cm-03. Laboratory beating of pulp (PFI mill) was done as per Tappi Test Method T 248 sp-00. Freeness of pulp (CSF) was determined as per Tappi test methods T 227 om-99. The drainability tests were conducted using the Schopper-Reigler Slowness tester modified by sealing the bottom orifice so that the total volume of water drained could be collected. The time for collecting 800 ml of water was noted (Litchfield, 1994). Hand sheets of the pulp were made according to Tappi Test Method T 205 sp-02. Physical strength properties were determined as per Tappi test methods T 220 sp-01.

Results and discussion

Laboratory Study

Tropical mixed hardwood pulp is very difficult to beat. Its initial °SR is 14.5 and to reach a °SR of 26 and 30, it requires about 3400 and 4250 revolutions in a PFI mill. Pretreatment of pulp with Commercial Enzyme 1 at a dose level of 0.01%; temperature, 50°C; pH 7.0; pulp consistency, 3%, reduced the energy requirement by ~18% (Table 1). Enzyme treated pulps when refined in a PFI mill, required 2800 and 3500 revolutions to reach a °SR of 26 and 30 respectively whereas control pulp required 3400 and 4250 revolutions to reach similar °SR. Increase of enzyme dose from 0.01% to 0.02% and extending the treatment time from 1.0 to 2.0 hours did not result in more reduction in refining energy. No adverse impact of enzyme treatment on physical strength properties of pulp was noted.

2. Plant-scale study

Trial 1

Plant-scale trials were conducted with Biorefine-L(+) in a mill producing mainly packaging grade paper during the manufacture of normal ESKP (60% unbleached bamboo long fraction Kraft pulp and 40% NDLKC) and high strength ESKP (100% long fraction bamboo pulp). The results are presented in Table 2. In case of high strength ESKP, there was a reduction in refining energy of 25 kWh/TP due to reduction in DDR (stock & machine) load (Table 2). There was also reduction in steam consumption of ~ 0.6 ton/ ton paper. The strength properties were not affected by enzyme treatment; in fact mill was able to produce high strength paper having low Gurley porosity without sacrificing other strength properties (Table 3). In case of normal ESKP, stock DDR was bypassed. Saving in power due to reduction in DDR load was 54 kWh/TP (Table 4). Saving in steam consumption was observed to be ~ 0.25 ton/ton paper. The strength properties were comparable (Table 5).

Trial 2

Another plant-scale trial with Fibercare-R & Biorefine-L was

Table 1: PFI refining of Commercial Enzyme 1 treated and control (no enzyme treatment) bleached mixed tropical hardwood Kraft pulp

Enzyme dose: 0.01%				
No. of PFI revolutions	°SR of control pulp	°SR of enzyme treated pulps		
		Cy 5%, Temp. 50°C, pH 7.0		
		1.0 h	1.5 h	2.0 h
0	14.5	15.0	15.5	15.5
2800		26.0	26.0	26.0
3400	26.0			
3500		30.0	30.0	30.0
4250	30.0			
6500	39.0			

Table 2: Effect of enzyme treatment on power consumption during manufacturing of ESKP high strength - *Process-scale trial results*

Particulars	Stock DDR kWh/Ton	Machine DDR kWh/Ton	Steam Ton/Ton paper
Control (no enzyme)	80.12	50.79	3.18
Trial (with enzyme)	62.34	43.57	2.55
Savings	17.79	7.40	0.63

Net savings in refining power: 25.19 kWh/ Ton

Conditions; Temperature, 40-45°C; pH, 6.8-7.5; Enzyme dose, 145 ml/TP; Dosing point, pit pulper

Table 3: Average physical strength properties of control and enzyme treated ESKP high strength - *Process-scale trial results*

Particulars		ESKP (HS) 90 GSM		ESKP (HS) 100 GSM	
		Control	Enzyme Trial	Control	Enzyme Trial
Total production (ton)		880	240	590	86
GSM (g/m^2)		91.8	91.3	101.7	102.0
Breaking length (m)	MD CD	4979 4190	5240 4597	5116 4158	5163 4495
Stretch (%)	MD CD	8.6 7.0	8.7 6.7	8.5 6.6	8.7 6.4
TEA (J/m^2)	MD CD	241 189	246 192	269 197	264 201
Tear factor	MD CD	103 121	100 116	109 129	108 123
Burst factor		42.0	42.6	41.7	41.3
Porosity (s/100 ml)	TS WS	10 11	8 9	11 12	8 9
Cobb (g/m^2)	TS WS	27 28	28 29	28 29	28 29

Table 4: Effect of enzyme treatment on power consumption during manufacturing of ESKP Normal - *Process-scale trial results*

Particulars	Stock DDR kWh/Ton	Machine DDR kWh/ Ton	Steam Ton/Ton paper
Control (no enzyme)	71.67	35.42	3.15
Trial (with enzyme)	0.00 (Bypassed)	52.79	2.90
Savings	71.67	17.38	0.25

Net savings in refining power: 54.29 kWh/ Ton

Conditions; Temperature, 40-55°C; pH, 6.8-8.0; Enzyme dose 110 ml/TP; Dosing point, pit pulper and Tridyne pulper

Table 5: Average physical strength properties of control and enzyme treated ESKP Normal - *Process-scale trial results*

Particulars		ESKP (N) 80 GSM	
		Control	Enzyme Trial (without stock DDR)
Total production (ton)		2560	130
GSM (g/m^2)		80.7	81.6
Breaking length (m)	MD	4657	4455
	CD	3577	3629
Stretch (%)	MD	8.40	8.47
	CD	6.30	6.04
TEA (J/m^2)	MD	189	192
	CD	129	129
Tear factor	MD	87	94
	CD	102	97
Burst factor		36.5	36.3
Porosity (s/100 ml)	TS	11	12
	WS	12	13
Cobb (g/m^2)	TS	28	27
	WS	29	28

conducted in white grades in a paper mill during the manufacture of base paper for coating (118, 122, 135, 155, 162 and 235 gsm). The furnish contained softwood and hardwood pulps in the ratio of 1:7.5. The enzyme dose was 100 g/T of pulp in both the streets. The reduction in refining energy was 70 kWh/TP in case of softwood pulp and 30 kWh/TP in case of hardwood pulp. There was a reduction in steam consumption on paper machine by approx. 0.5 T/ ton of paper (Table 6). By using this enzyme, the mill was able to eliminate the bottleneck of refining in softwood-street. The strength properties of the pulps were not affected by enzyme treatment.

Trial 3

Another plant-scale trial was conducted with Biorefine-L (+) in paper mill producing writing and printing paper. The trial was conducted on high gsm base papers (super coated art board 122 gsm and art paper 102 gsm). Positive advantages of this enzyme in several aspects during the trial were observed. Increase in dry line at wire, increase in couch vacuum and increase in ^{0}SR after stock refiners led to bypass one TDR (triple disc refiner) of 180 kW (Table 7). The strength and other properties were within the specified limits and comparable to those without trial run.

Two-stage enzyme treatment (Laboratory study)

A study was conducted in which Fibercare-D was added both to the unrefined and refined pulps (prerefining and post refining application). The results are presented in Table 8. It was found that pre-refining application, resulted in improved refining efficiency and strength improvement and post refining treatment resulted in increased fiber freeness and also better strength properties. The refining energy reduced by 16% and drainage improved by 20% when the enzyme was added to the unrefined and refined pulps at a dose level of 75 g/T and 75g/T respectively. The strength properties also improved with the exception of tear strength. It may be noted from Table 8 that the strength properties in two-stage treatment (with the exception of tear strength) were better in comparison to the single stage treatment. Another experiment was conducted in which unrefined and refined pulps were treated with Commercial Enzyme 3 at a dose level of 50 g/T and 50 g/T respectively. In this case, refining energy reduced by 12%, drainage improved by 14.5% and the strength properties were better in comparison to the single stage treatment.

The papermaker can take advantage of this in several ways, including the following: Lower refining energy to meet strength specifications, improved strength properties at equal refining energy, increase machine speed to produce more tons, decrease headbox or cylinder vat consistency for improved formation, increase refining energy for improved strength or lower basis weight. The two methods for adding enzyme can be combined for strength and drainage benefits. Keeping in mind that the enzyme is a catalyst, its function should continue from a pre-refining application into a

Table 6:Effect of enzyme treatment on power and steam consumption during coating base manufacture -- *Process-scale trial results*

Particulars	Power consumption kWh/T pulp		Steam* T/T paper
	Softwood	Hardwood	
Control	200	150	2.57
Trial	130	120	2.07
Savings	70	30	0.50

Conditions; Temperature, 40-45^{0}C; pH, 6.8-7.0; Enzyme dose 100 g/TP (in both the streets)

Table 7: Effect of enzyme treatment on power consumption during manufacturing of high gsm base papers (super coated art board 122 gsm and art paper 102 gsm) - *Process-scale trial results*

Condition	Normal (control)	Trial
Before refining	16 18	16 18
After refining (1 Conical, 1 TDR & 1 DDR)	23 25	25 28
After refining (1 Conical & 1 DDR)	---	23 25

Conditions; Temperature, 40-45^{0}C; pH, 6.8-7.0; RT, 1.5 h; Stock consistency, 4%; Enzyme dose, 200 g/TP (dilution 50:50); Dosing point, mixing chest post-refining effect. In other words, the enzyme should weaken the fiber walls prior to refining, then continue to work on the fibers, improving drainage after refining.

By two-stage enzyme treatment, the new fiber surfaces created by refining can be treated with a fresh dose. This appears to be most effective in providing strength and drainage benefits.

Mill # 1 :-

In one mill manufacturing sack kraft by using extensible sack kraft paper, there was a reduction in refining energy of 25 kWh/TP and about 20% saving in steam consumption per ton of paper. These observations were made by using a number of commercial enzymes manufactured by different suppliers. Mill was able to bypass one DDR when furnish was changed to 60% unbleached bamboo Kraft pulp (long fraction) and 40% NDLKC for producing normal ESKP. In this case, a reduction in energy requirement by about 54 kWh/TP and 8% saving in steam consumption per ton of paper was observed. Mill was able to produce high strength paper having low Gurley porosity without sacrificing other strength properties.

Mill # 2:-

Another plant-scale trial with same enzyme conducted in white grades in a mill producing mainly coated paper showed reduction in refining energy by about 70 kWh/TP for softwood pulp and 30 kWh/TP for hardwood pulp. Also, a reduction in steam consumption on paper machine by approx. 0.5 T/ ton of paper was observed. By using this enzyme, the mill was able to eliminate the bottleneck of refining in softwood-street. The strength properties of the pulps were not affected.

Mill # 3 :-

In one of the mills producing heavy gsm base papers, trial conducted with Commercial Enzyme 2 led to bypass one TDR (triple disc refiner) of 180 kW power rating. The strength and other properties were within the specified limits and comparable to those without trial run. Addition of Commercial Enzyme 3 to the unrefined and refined stock (pre-refining and post-refining treatments) at dose level of 75 g/T and 75 g/T respectively showed 17% reduction in refining energy, 20.0% improvement in drainage and improvement in strength properties (at 500 ml CSF). Reduction in refining energy was 12% and improvement in drainage was 14.5% when enzyme was added to the unrefined and refined stock at dose level of 50g /T and 50g /T respectively. The strength properties were better in this case also. Two-stage enzyme treatment appears effective in providing energy savings, drainage and strength benefits.

Conclusion

These studies indicate that enzymes based upon cellulase, modified cellulase can be used successfully for Fiber Modification i.e. for reducing the refining energy and other characteristics. The commercial viability has been also proved in a number of mills. Each mill should conduct trials, lab as well as plant scale to select the suitable enzyme for their furnish and mill conditions.

Table 8 : Treatment of unrefined and refined pulp with Commercial Enzyme 3 (two-stage enzyme treatment)

Particular	Control	50 g/T+50 g/T	75 g/T+75 g/T
Enzyme treatment before refining			
Enzyme dose (g/T)	0	50	75
PFI revolutions (Nos.)	2700	2700	2700
CSF (ml)	500	485	478
Energy saving (%)		12	16
Drainage Time (Sec.)	40.3	37.5	37.0
Improvement in drainage (%)		6.9	8.2
Bulk (cc/g)	1.30	1.30	1.30
Tensile index (Nm/g)	57.5	61.4 (+6.8)	62.9 (+9.4)
Burst index (kN/g)	3.81	4.30 (+12.9)	4.48 (+17.6)
Tear index (mN m2/g)	7.78	7.80	7.75
Porosity (sec/100 ml)	11.3	13.1 (+15.9)	15.2 (+34.5)
Double fold (no.)	78	82 (+5.1)	88 (+12.8)
Smoothness (ml/min)	145	140 (-3.4)	140 (-3.4)
Enzyme treatment after refining			
Enzyme dose (g/T)	0	50	75
CSF (ml)	498	499	500
Drainage Time (Sec.)	40.6	34.7	32.4
Improvement in drainage (%)		14.5	20.2
Bulk (cc/g)	1.31	1.30	1.30
Tensile index (Nm/g)	57.5	63.4 (+10.3)	63.1 (+9.7)
Burst index (kN/g)	3.81	4.6 (+20.7)	4.7 (+23.4)
Tear index (mN m2/g)	7.78	7.75	7.50
Porosity (sec/100 ml)	11.3	14.6 (29.2)	15.8 (39.8)
Double fold (no.)	78	88 (12.8)	75 (-3.8)
Smoothness (ml/min)	145	136 (-6.2)	130 (-10.3)

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