SOLVING THE PROBLEMS OF RECYCLED FIBER PROCESSING WITH ENZYMES

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The pulp and paper industry has started applying new, ecologically sound technology (biotechnology) in its manufacturing processes. Many interesting enzymatic applications have been proposed. Implemented technologies tend to change the existing industrial process as little as possible. Enzymes have great potentials in solving many problems associated with the use of recycled fiber, especially related to deinking, drainability, hornification, refining, and stickies. Based on the promising results of mill-scale trials, several mills in the world have started using enzymes for deinking. The potentials of cellulase enzymes have also been demonstrated for reducing the energy requirement in pulp refining, improving the machine runnability and stickies control when using recycled fiber. They have the important benefits in that they can be considered a "green" product. They are natural occurring compounds with little adverse impact on the environment. This paper deals with the importance of recycling of paper, problems associated with the recycling, and potentials of enzymes in solving these problems. A few case studies have also been included.

Keywords: Paper recycling; Enzymes; Deinking; Refining; Drainability; Stickies; Hornification

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INTRODUCTION

The recovery and reuse of paper has been practiced as long as papermaking itself. However, it really became established as an industry only during the second half of the last century. Between the 1950's and the mid 1980's, principally straightforward supply and demand issues drove the economics of the recovered paper industry. From the mid 1980's, the demand for the use of post consumer paper products in the production of new paper products has risen dramatically. Some of this demand has been driven by politics and some by consumer demand and environmental factors.

Recovery and use of secondary fiber for paper production is increasing all over the world. Japan's recovery rate reached 71.1% in 2005, and the use of recycled fiber in paper and board production reached 60.3% (higher than the target of 60% set by Japan Paper Association). Boise, Idaho has introduced 50% recycled fiber in copy paper called 'Boise ASPEN 50'. In India, about 38% of total paper production is based on secondary fiber, which is increasing with time. About 40% of the total paper production in the world was based on the secondary fiber in 2006 (Sixta 2006). Paper recycling offers several advantages (Bajpai 2006). Substitution of virgin pulp with recycled fibers saves on wood for making pulp, which reduces the exploitation of old forests, important for their biodiversity. Every ton of recycled fiber saves an average of 17 trees plus related pulping energy. By using wastepaper to produce new paper, disposal problems are reduced. For every ton of paper used for recycling, the savings are at least 30,000 liters of water, 3000 to 4,000 kWh of electricity and 95% of air pollution. It also saves around 2.3 m^3 of landfill volume. Recovering paper for recycling often saves communities money they would have had to spend on disposal. Producing recycled paper involves 28 to 70% less energy consumption than virgin paper and uses less water. This is because most of the energy used in papermaking is the pulping needed to turn wood into paper. Recycled paper produces fewer polluting emissions to air and water. Recycled paper is not usually rebleached and when it is, oxygen is normally used instead of chlorine. This reduces the amount of dioxins released into the environment as by-products of the bleaching process. High-grade papers can be recycled several times, providing environmental savings every time. Wastepaper pulp requires less refining than virgin pulp and may also be co-refined with hardwood pulp or combined hardwood/softwood pulps without significant damage. The kinds of deinked pulp suitable for use in printing papers usually impart special properties to the finished papers compared with papers made from wood pulp, such as increased opacity, less curling tendency, less fuzziness, and better formation.

Greater utilization of recycled fiber is expected in the future. However, several problems are associated with the recycling of fiber. The main problem areas are in deinking of different types of post consumer paper, drainability of recycled fiber, hornification (inability to regain the original water–swollen state due to stiffening of the polymer structure of pulp during drying), and stickies control. Enzymes can be used to overcome these problems to a great extent in addition to assist in refining the fibers recovered from old kraft paper and paperboard products such as old corrugated cartons (OCC), which require very high energy.

ENZYMATIC DEINKING

The primary objectives in recycling paper are to remove ink and other contaminants while retaining optical and strength properties of the fibers. In the last fifteen years or so, enzyme assisted deinking has been shown to represent a potential environmentally friendly alternative to conventional alkaline deinking processes (Bajpai and Bajpai 1998; Bajpai *et al.* 1999, 2004). In most cases cellulases represent the best choice; however, other enzymes such as hemicellulases, amylases, and lipases can help in order to optimize the process depending on the type of paper and ink.

Enzymatic approaches of deinking involve attacking either the ink or the fiber surfaces. Lipases and esterases can degrade vegetable oil based inks. Pectinases, hemicellulases, cellulases, and ligninolytic enzymes alter the fiber surface or bonds in the vicinity of the ink particles, thereby freeing ink for removal by washing or floatation (Bajpai and Bajpai 1998).

The exposure of recovered newsprint to high temperature in closed containers accelerates the oxidation and polymerization of ink particles, called the summer effect (Haynes 2000). The 'summer effect' refers to a period during the summer months when mills experience a loss in pulp brightness. Oxidized and polymerized ink particles are prone to fragmentation during alkaline deinking and are difficult to remove by the subsequent floatation process. This results in significant reduction of brightness and cleanliness of the final pulp. Neither conventional nor sulfite deinking are effective in dealing with the summer effect. Though sulfite deinking has been shown to give relatively better deinking performance as compared to alkaline deinking (Chezic *et al*. 2004) no improvement in the brightness has been achieved. However, combining enzymes with sulfite chemistry significantly enhances sulfite deinking to achieve deinking of aged newsprint at neutral pH. The potential of combining cellulase enzymes with sulfite deinking to achieve a superior natural deinking strategy for deinking of old news print (ONP)/old magazine paper (OMG) was also examined by Zhang et al. (2008). They reported substantial improvement in the deinking performance of ONP/OMG in 70:30 ratio as compared to either cellulase enzyme or sulfite deinking.

Deinking with enzymes under acidic to neutral conditions should reduce the overall chemical requirements and minimize yellowing of reclaimed papers that is normally observed by conventional alkaline deinking. The use of enzymes could lead to a reduction of the pulping time, thus saving energy and potentially increasing production. Besides the greater decrease in the ink area, the mild alkaline conditions used with enzymes have a positive impact on stickies problems at the mill scale. An additional positive effect can also be expected as a consequence of being able to reduce the addition of non-ionic surfactants, due to their slow biodegradation in the water treatment plant.

Case Studies

The deinked pulp obtained after deinking of sorted office waste with hydrolytic enzymes showed higher brightness (1.0-1.5 points) and whiteness (2.7-3.0 points) and lower residual ink as compared to chemically deinked pulp (Bajpai *et al*. 2004) as shown in Table 1. It was possible to obtain pulp of <10 ppm dirt count with combination of cellulase and alpha-amylase enzymes resulting in reduced chemical consumption (Table 2). COD and color loads were lower in case of effluents generated during enzymatic deinking (Table 3).

Table 1. Deinking of Sorted Office Waste with Different Hydrolytic Enzymes Alone and in Combination (based on Bajpai *et al*. 2004)

Deinking with	*Brightness, %ISO*	*CIE Whiteness*	*Dirt count, ppm*	*Yield, %*	*Ash, %*
Hemicellulase	81.5	71.4	15	70.6	6.0
Alpha-amylase	80.2	69.1	19	70.8	6.1
Cellulase	81.6	71.5	12	71.0	6.1
Cellulase + alpha-amylase	81.7	71.5	8	70.9	6.2
Cellulase + hemicellulase	81.3	71.7	13	71.2	6.2
Cellulase + hemicellulase + alpha-amylase	81.5	71.5	7	70.8	6.2
Chemicals (control)	80.1	69.2	16	71.1	6.3

Initial brightness 61.1 %ISO; Initial whiteness 53.6;
Initial ash content 14.20%; Dirt count in sorted office waste 2997 ppm

Table 2. Generation of Pollutants in Different Stages of Deinking of Sorted Office Waste (based on Bajpai *et al*. 2004)

Parameter	*Enzymatic deinking with same chemicals**	*Enzymatic deinking with less chemicals***	*Chemical deinking (Control)*
COD, kg/TP	39.8	36.8	40.7
TSS, kg/TP	20.1	20.2	19.9
Color, kg/TP	7.71	8.57	10.50

**NaOH 1%; sodium silicate 1%; H_2O_2 0.5%; surfactant 0.2%; soap 0.001%*

***Surfactant 0.2%; soap 0.001%*

Table 3. Chemical Consumption in Deinking Process *(based on Bajpai et al. 2004)*

Chemicals, kg/T sorted office waste	*Chemical deinking*	*Enzymatic deinking*
Enzyme	---	0.4
Sodium hydroxide	26.0	16.0 (–10)
Sodium silicate	10.0	Nil (–10)
Hydrogen peroxide	25.0	20.0 (–5)
DTPA	2.0	2.0
Surfactant	2.0	2.0
Coagulating/ flocculating agent	3.0	3.0

Treatment of 100% multiprints furnishes with cellulase and amylase enzymes at pH 7 to 7.5 improved the pulp brightness by 2 ISO points in the laboratory investigation as a part of the EUREKA Enzyrecypaper Project (Gill *et al*. 2007). The ink particles released on treating with amylase enzymes appeared to be more hydrophobic than ink particles released on treating with cellulase. During the mill trial using highly specific amylases, the brightness was significantly improved up to 8 points. The ash content also was reduced to a great extent after flotation and washing, resulting in a change of the final pulp characteristics.

Mixed office waste often contains a large variety of dyed papers. The color must be removed to make the pulp suitable for reuse. For this reason, it is frequently an underutilized source of waste papers. Usually, several chemical bleaching agents such as ozone, oxygen, hydrogen peroxide, or sodium hydrosulfite have been used to bleach secondary fibers. Now, there is an alternative color stripping process for secondary fibers – the laccase-mediator system. In a study by Arjona *et al*. (2007), a bleaching sequence included an enzyme stage called laccase-mediator system stage (L), a hydrogen peroxide stage (P), and a sodium hydrosulfite stage (Y) on a mixture of different colored writing and printing papers (green, yellow, red and blue). After the application of an L-P-Y bleaching sequence, a pulp with optical properties near to eucalyptus fully bleached pulp was obtained. The application of L-P sequence resulted in the pulp optical properties near to the final pulp from K-P-Y sequence where K is a stage applied in the same conditions of L stage but without enzyme. The L-P-Y sequence reaches a color removal of 90% and saves chemicals in the final stages.

IMPROVING THE DRAINABILITY OF SECONDARY FIBER

Recycled fibers have lower strength and higher drainage resistance than virgin fibers. These differences limit the paper quality and the speed at which paper machines can operate. The mechanical properties of fibers, as well as their ability to swell, are diminished after they are exposed to pulping and drying conditions imposed during the paper making cycle. Freeness reduction during beating is much faster for secondary fibers. For equivalent beating times, a sheet containing recycled fibers is less dense and usually more absorptive than virgin fiber stock. The fines that are created when secondary fibers are beaten consist largely of microfribils that were strongly coupled to each other when they were originally dried on the paper machine. When liberated during refining, they increase the specific surface area of suspension more than the swelling potential. They start to behave as fillers, with a small effect on strength but a large effect on the drainage properties. In general, the greater the degree of refining of the virgin fibers, the lower is the recovery potential of sheet properties that are a direct function of fiber bonding such as burst strength and tensile strength. Folding endurance of recycled paper is also considerably lower than for sheets made from virgin stock. Sheet density decreases each time the fibers are recycled. The strength losses may be the result of loss in binding potential, either in the strength of the inter-fiber bonding or in their number.

The potential of improving the drainage rates of recycled fibers by cellulase mixtures was discovered in the late eighties (Fuentes and Robert 1986). Researchers from La Cellulose du Pin were the first to show that a mixture of cellulase and hemicellulase enzymes increases the freeness of pulp. Improved drainage and faster machine speeds, resulting from increased freeness, yields significant savings in energy and thus in overall cost. The endoglucanase activity is a prerequisite for drainage improvement of recycled pulps.

Several commercial enzymes are available which improve the drainage of secondary fibers. A commercial cellulase enzyme preparation (Pergalase A-40) based on *Trichoderma* has been used in several mills to improve drainage (Pommier *et al.* 1990). These types of enzymes are applied after refining/ beating of the pulp, mainly to improve the dewatering. Recently, a cellulase enzyme with endoglucanase activity (FiberCare® D) developed by Novozymes has been reported to substantially increase the runnability of recycled furnishes and reduces the steam consumption in drying of paper on treating the pulp with enzyme after refining (Shaikh and Luo 2009).

Case Studies

The effectiveness of several commercial carbohydrate-modifying enzymes was examined for improving the drainage of secondary fibers (Bhardwaj *et al.* 1995). Drainage improvement over the control was substantial with Pergalase A-40 (a mixture of cellulase and hemicellulase) when the old corrugated carton (OCC) pulp was treated after refining (Table 4). The drainage improvement was 11.7% (with 0.1% enzyme) and 21.3% (with 0.2% enzyme) at a reaction time of 30 min for low freeness pulp. An increase of the reaction time to 180 min improved the drainage by 25.4% (with 0.1% enzyme) and 31.7% (with 0.2% enzyme). The pulp retained most of the required strength properties when treated with Pergalase either at 0.1% enzyme addition and a reaction time of 45 min or at 0.2% enzyme addition and a reaction time of 30 min. Increase of reaction time beyond 30 min with 0.2% enzyme resulted in deterioration of strength properties. Pergalase treatment on pulps of different initial freeness showed that the lower the initial freeness, the higher the gain.

Table 4. Effect of Enzyme Treatment on the Drainability of OCC Pulp (based on Bhardwaj *et al.* 1995)

Enzyme dose, % o.d. pulp	*Reaction time, min*	*Drainage time for 800 ml, sec*	*Improvement in drainage, %*
0	--	31.5	--
0.1	30	27.8	11.7
0.1	45	26.5	15.9
0.1	60	26.1	17.1
0.1	120	25.1	20.3
0.1	180	23.5	25.4
0.2	30	24.8	21.3
0.2	60	22.8	27.6
0.2	180	21.5	31.7

Conditions: pH 5.0; temperature, 50 ^{o}C; pulp consistency 5%; initial CSF of pulp 490 ml

When the pulp was treated with enzyme, the freeness increased without any loss of the mechanical properties in the paper, and when mechanical refining preceded the enzymatic treatment, better physical properties were obtained at freeness similar to the control one. In other words, better physical properties can be obtained at an identical drainability. The increase in freeness can enhance the capacity of a secondary fiber preparation plant, increase machine speed or pulp dilution in the head box, and ultimately produce paper of better quality. Conditions must be modified to each particular situation to maximize the freeness increase. In addition to an increase in freeness, regular use of enzymes under optimum conditions may produce beneficial secondary effects such as greater reliability of the paper machine.

The effectiveness of a cellulase enzyme having predominantly endoglucanase (EG) activity was evaluated in the laboratory and paper mills for improving the freeness and drainability of different types of recycled pulps (Shaikh and Luo 2009). On treating the refined pulps with enzyme, the improvement in Canadian standard freeness (CSF) was observed by 13.1% in ONP, 19.3% in old corrugated container (OCC) and 40.5% in mixed waste (MW), as shown in Table 5.

Table 5. Impact of Enzyme Treatment on CSF Value of Different Grades of Pulp (based on Shaikh and Luo 2009)

Pulp grade	*CSF, ml*	
	Control (before enzyme treatment)	*After enzyme treatment**
OCC	419	500 (19.3%)
MW	304	427 (40.5%)
ONP	168	190 (13.1%)

** Values in parenthesis show percent improvement*

Using OCC and addition of enzyme at different levels, the CSF value increased with the increase in enzyme dose. However, there was no appreciable change in the tensile and compression strengths of the handsheets prepared from the enzyme-treated pulps (Table 6). In fact, the EG activity of cellulase partially hydrolyzes the amorphous and low molecular components of cellulose present in the form of fine fribils and colloids. This helps in dewatering of the pulp, as these components constitute very small fraction of the pulp but have very high specific surface area and hold maximum water (Bajpai *et al*. 2006).

Table 6. Effect of Enzyme Dose on CSF and Strength Properties of Pulp (OCC) (based on Shaikh and Luo 2009)

Enzyme dose, g/TP	*CSF, ml*	*Compression strength, Nm/g*	*Tensile strength, Nm/g*
Nil	300	22.0	45.0
50	353	22.5	45.5
100	368	23.0	45.5
200	388	21.5	43.0
500	422	22.0	43.0

Functional additives are generally introduced to improve retention and drainage on the paper machine and quality of the final product. The high specific surface area of the colloidal fraction of the furnish readily adsorbs a great amount of the additives without a perceptible benefit. The unproductive consumption of additives often necessitates compensation with higher additive dosing levels. Preferential EG enzyme activity upon the colloidal fraction is expected to modify the overall response of the furnish to functional additives. The impact of enzymatic treatment on the drainage of OCC pulp, conditioned with various levels of cationic polyacrylamide (CPA) was evaluated (Shaikh and Luo 2009). It is shown in Table 7 that the requirement of CPA decreased to a great extent for the same drainage rate when pulp was treated with enzyme.

Table 7. Impact of Enzyme Treatment on the Need for Cationic Polyacrylamide (CPA) for Drainage Control of OCC Pulp (based on Shaikh and Luo 2009)

10 sec filtrate weight, g	*CPA requirement, kg/TP*	
	Control (no enzyme treatment)	*After enzyme treatment*
470	0.0	--
540	0.13	0.0
600	0.60	0.35
650	0.84	0.58
700	1.10	0.80

The improvement in drainage of the pulp by enzyme treatment was demonstrated in the mill trials to observe the change in machine runnability (Shaikh and Luo 2009). Figure 1 shows the increase in machine speed for the production of 200 g/m^2 liner on enzyme dosing at a North American mill. Due to enhanced dewaterability, a 6-7% reduction in steam consumption within in the dryer section was also observed. It was also possible to increase the ring crush by two points. A similar trial with enzyme treatment (100 g/TP) before refining in an European mill, producing towel and tissue, showed an increase in machine speed from 1650 m/min to 1750 m/min for tissue and from 1600 m/min to 1750 m/min for towel productions. The specific refining energy also was reduced by 12.5%, probably due to the presence of some celobiohydrolase (CBH) activity in the enzyme product, which helps in pulp refining (Bajpai *et al*. 2006). Shaikh and Luo (2009) have also reported steam savings on enzyme treatment in the mill trials at Asian mills producing various basis weight papers from OCC pulp.

For improving the drainability (freeness) of secondary fiber, treatment with cellulase alone generally leads to loss in pulp brightness. Furthermore, when used in combination with a drainage aid polymer, the loss in brightness is even more pronounced. A method using a mixture of cellulase and pectinase enzymes has been described to accomplish the goal of simultaneously increasing freeness (drainage) without loss of brightness and physical properties (Olsen *et al.* 2000). As seen in Table 8, treatment with cellulase alone gave very high improvement in CSF value (190 ml) but not the brightness, and treatment with pectinase alone though resulted in greater enhancement of brightness (1.6 points) but very little improvement in CSF value (only 70 ml). However, treatment with the combination of both the enzymes resulted in appreciable improvement in CSF (130 ml) while 1.6 points enhancement in brightness (same as that with pectinase alone).

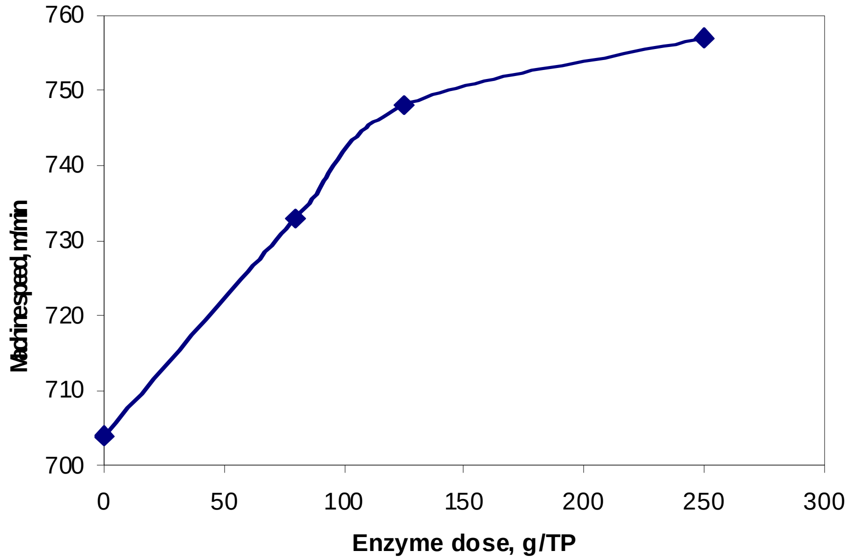

Fig. 1. Effect of enzyme dose on machine speed using OCC and MW pulps to produce 200 g/m^2 liner at a North American mill (based on Shaikh and Luo 2009)

Table 8. Improving the Drainability of Deinked Secondary Fiber Pulp by Treating with Cellulase and Pectinase Enzymes at pH 5.5 (based on Olsen *et al*. 2000)

S. No.	*Treatment*	*CSF*, ml*	*Brightness, %GE*
1	Control	330	80.7
2	Cellulase (1 l/TP)	520 (190)	81.6
3	Pectinase (1 l/TP)	400 (70)	82.3
4	Cellulase (1 l/TP) + Pectinase (1 l/TP)	460 (130)	82.3

** Values in parenthesis indicate increase in freeness (CSF value) over control.*

REDUCING REFINING ENERGY

The pretreatment of pulps with cellulase enzymes having cellobiohydrolase (CBH) as major activity has been found to result in decreased energy requirements for refining without any appreciable impact on pulp strength (Bhardwaj *et al.* 1996; Wolfaardt 2002; Bajpai *et al.* 2006; Zhang *et al.* 2008). This application of enzymes in papermaking is picking up. Hornification of the recycled pulp is also reversed to some extent by the use of cellulase and hemicellulase enzymes (Wolfaardt 2002; Zhang *et al.* 2008). In fact, the hornification occurs because of increase in the degree of cross-linking in the fiber microstructure due to interfibril hydrogen bonding and formation of esters, especially lactone (lactone is present in hornified pulps but not in never dried pulps). Gentle refining is necessary in case of hornified recycled fiber, or the fiber will be damaged. However, more refining is required to improve the re-swelling of the fiber for developing the required strength properties of paper by increasing interfiber bonding. By conventional refining of recovered fiber, breakage of the fiber into fines is more pronounced than the fibrillation. In contrast, by enzyme treatment the fiber swelling increases and the fiber becomes more flexible, resulting in improved fibrillation and less breakage into fines.

Case Studies

The effectiveness of commercial enzymes has been examined for energy savings in refining of different pulps (Bhardwaj *et al*. 1996). Unbleached mixed pulp (60% waste corrugated kraft cuttings and 40% unbleached softwood pulp) was treated with enzyme. The beating time was reduced by 15% with two different enzyme samples (Table 9). In another case, a double-sorted old corrugated cartons (OCC) pulp sample was treated with Fibrezyme LBR before refining (Bajpai *et al*. 2006). The ^{o}SR of enzyme treated pulps were higher at the same PFI revolutions. The enzyme treated pulps required about 30% less energy to reach a ^{o}SR of 30 (Table 10).

Table 9. Effect of Enzyme Treatment on Beatability and Strength Properties of Mixed Pulp (60% waste corrugated kraft cuttings and 40% softwood) (based on Bhardwaj *et al*. 1996)

Enzyme	*Reduction in beating time, %*	*^{o}SR*	*Tensile index, Nm/g*	*Breaking length, m*	*Tensile energy absorption, J/m*	*Burst index, kN/g*
Control		28	34.05	3473	32.25	2.26
Enzyme 2	15.0	28	34.88	3558	28.90	2.23
Enzyme 3	15.0	28	34.79	3549	27.50	2.21

Conditions: temperature, 50 ^{0}C; pulp consistency, 4%; reaction time, 3 h; enzyme dose, 0.05% on o.d. pulp; pH, 5.0 with enzyme 2 and 7.0 with enzyme 3

Table 10. PFI Refining of Enzyme Treated and Control (no enzyme treatment) OCC Pulps (based on Bajpai *et al*. 2006)

No. of revolutions	*^{O}SR*					
	Control	*Cy 5%, 50^{O}C, 1 h*		*Cy 5%, 50^{O}C, 2 h*		
		Enzyme (0.02%)	*Enzyme (0.03%)*	*Enzyme (0.02%)*	*Enzyme (0.03%)*	*Enzyme (0.04%)*
2000	26.0	32.0	32.0	34.0	33.0	34.5
2900	31.0	37.5	38.0	38.0	38.5	39.0
3400	36.0	40.5	40.5	41.5	42.0	43.0
3750	40.0	45.5	46.0	46.0	46.5	47.5

STICKIES CONTROL

One of the major consequences of fiber recycling is dealing with stickies that are comprised of various components of the recycled paper types used by the mills. Stickies can cause runnability and quality problems in case of recycled fiber, and their variable nature and composition make them difficult to control. A new approach to stickies control has been developed that uses esterase type enzymes to break down the stickies in to smaller and less tacky particles (Fitzhenry *et al*. 2000; Jones 2003; Van Haute 2003; Zimmermann 2004; Jones 2005).

Stickies are tacky, hydrophobic, pliable organic material found in recycled paper systems. They exhibit a broad range of melting points and different degrees of tackiness, depending on their composition. Stickies are composed of a variety of materials including adhesives, styrene-butadiene latex, rubber, vinyl acetate, and hot melts, etc.

Enzymes are highly specific in nature; they exhibit a very specific action when applied. A specific enzyme will catalyze a specific type of chemical reaction, meaning that enzymes can be used to target specific areas. This also means that the enzyme used to control stickies will not necessarily affect the fiber or other papermaking additives. The trick is to find the enzyme that will break down stickies.

A study of the chemical composition of stickies reveals that most contain a number of ester-type chemical bonds that link the basic building blocks of the stickies together. A number of esterase-type enzyme mixtures have been studied to find the one that had the ability to break down the stickies. Breaking the ester bonds reduces the size of the sticky by breaking it in to smaller components. A key advantage of this approach is that once broken down, the chance of the particles re-agglomerating further along the process is greatly reduced. Another important effect on the stickies is the enzymatic modification of the surface of the stickies. This change results in less tacky stickies (Jones 2005). These enzymes have been proven to reduce downtime, decrease cleaning chemical costs and increase machine-clothing life better than historical stickies control technologies (Eng and Covarrubias 2005; Covarrubias and Eng 2006; Kimura 2006; Sokol and Huszar 2005).

More mills now have single-stream recycling, which means that old newspapers (ONP) probably include old magazines (OMG), and old corrugated containers (OCC). The increased use of single-stream recycling processes has resulted in more stickies. Buckman Laboratories, Canada, manufactures Optimyze, which contains an esterase, which breaks up the ester bonds in PVA stickies. This is particularly effective in pH range 6.5-10 and temperature range of 25-60 ^{o}C (Covarrubias and Jones 2005). Buckman's Optimyze Plus range also includes an enzyme, which acts on wood pitch. Buckman is developing an enzyme product combined with a dispersant that would disperse and stabilize the stickies. The enzyme is then more likely to penetrate the stickies rather than just acting on the surface (Jones 2008).

In all the early work, esterase was added to the stock, but Jones (2005) has shown that applying the enzyme directly onto paper machine clothing also reduces stickies deposition. Positive results were obtained by applying enzyme to forming fabric and press felts. The enzyme is applied through a shower bar and full coverage is important. The enzyme detackifies the stickies, so the cleaning showers can remove them more effectively. In 2004, the US-EPA gave Optimyze a Presidential Green Chemistry Challenge Award. Optimyze is now used in many mills around the world.

Case Studies

On treatment of old newsprints and old magazines (ONP/OMG) with esterase type enzyme in a mill trial, a dramatic reduction in the size of the sticky particles is observed (Jones 2003) as shown in Fig. 2. The stickies content of all the sizes and the total stickies were much less on enzyme treatment as compared to those without enzyme (pre-trial results). The bigger size stickies are totally absent in the recycled fiber treated with enzyme.

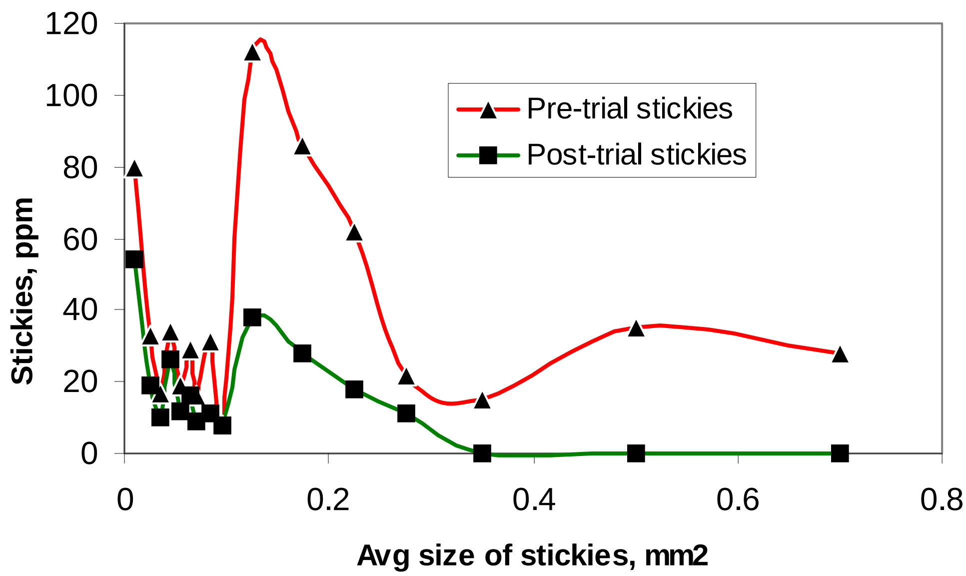

Fig. 2. Size distribution of stickies in finished stock – plant trial with Optimyze™ of Buckman on ONP/OMG *(based on Jones 2003)*

When the recycled fiber from mixed office waste (MOW) was treated with esterase enzyme in a mill trial, the total stickies content was reduced appreciably (Jones 2003). Without enzyme treatment of MOW, it was not possible to increase the recycled fiber content in the final furnish beyond 50%. Even then, the total stickies were more than 250 ppm (Table 11). However, on treating the recycled fiber from MOW with enzyme, total stickies content could be reduced to around 100 ppm, and that was with a higher content (60%) of recycled fiber.

In another MOW mill, the recovered fiber was treated with enzyme to reduce the percentage of high brightness virgin pulp in the final furnish without compromising on brightness of the finished stock. With addition of 35% high-bright pulp, the normal brightness gain from coarse screen to finish stock was only 12 to 14 points when no enzyme treatment was given to the recovered fiber (Jones 2003). However, after esterase enzyme (Optimyze of Buckman) treatment of MOW recovered fiber, it became possible to get a brightness gain of more than 15 points, even when the high bright pulp content was only 15-20%.

Table 11. Results of Esterase Enzyme (Optimyze) Evaluation in a Mill Using MOW Furnish – Stickies Content vs. Recycled Fibre Content in Furnish (based on Jones 2003)

Day & time	*Recycled fibre content, %*	*Total stickies, ppm*
Day 1		
9 AM (Pre-trial: no enzyme)	50	250
11 AM	60	420
2:30 PM (enzyme addition)	60	1200
4:30 PM	60	906
5:45 PM	60	390
Day 2		
2 PM	60	110
3:30 PM	60	30
5:30 PM	60	110

Several mill-scale studies related to the production of tissues, newsprint, writing, and packaging papers from recovered or recycled paper have been reported (Sokol and Huszar 2005). The use of enzyme has been found to enhance the screening efficiency, reducing the amount of rejects. It resulted in the reduction of stickies by 70-90%, generated clean cellulose fiber and big contaminant particles that were easily removable from the system. In other mill studies with enzymes produced results such as 90% reduction in stickies and increased brightness across the deinking facility, production performance improvements, reduction in the use of cleaning solvents, and a 95% reduction in down time caused by stickies (Covarrubias and Eng 2006).

CONCLUSIONS

Enzymes have great potential in solving many problems associated with the use of recycled fiber if the appropriate enzyme cocktail is applied under optimum conditions. They have the important benefit in that they can be considered a "green" product. They are natural occurring compounds with little adverse impact on the environment. Several mill trials for deinking, drainability improvement, refining of OCC, and stickies control have proved the effectiveness of enzyme treatment in secondary fiber processing. Enzymatic deinking improves the quality and yield of deinked pulp, enzyme treatment before refining reduces the specific energy requirements and generation of fines, and treatment after refining improves the drainability of recycled pulp, resulting in improved runnability of the paper machine and decreased steam consumption in the dryer section of the machine. Stickies problems associated with the recycled fiber can also be controlled to a great extent with the help of enzymes. However, certain application conditions need to be met when using any enzyme to ensure their most effective use. Enzymes have specific pH and temperature ranges in which they are effective. Specific enzyme formulation will vary widely based on furnish (fiber, ink composition, printing process, etc.), deinking process, equipment configuration, and the desired specifications of the deinked pulp.

New tools for fiber modification are being developed using genetic engineering, which will enable the development of new enzymes for their applications in pulp and paper industry. Then, present limitations and problems with the enzymes are expected to be overcome to a great extent.

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