

Factors influencing MOW deinking: Laboratory scale studies

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Abstract

The deinking of MOW is examined at laboratorial scale. The effect of deinking aids, pre-washing and mixing are studied. The operating conditions during pulp treatment affect the pulp and paper properties, interfering with the mechanism of ink removal and modifying the ink particle characteristics. Pre-washing the pulp facilitates the deinking process. Cellulolytic enzymes and deinking chemicals are comparable in terms of ink removal ability.

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1. Introduction

The use of recycled fibres for paper manufacture is highly desirable. However, the production of a good quality paper requires an adequate modification of the secondary fibre properties and the removal of a large amount of contaminants, namely stickies, sizing and coating agents, mineral fillers and inks. The selection of equipments and recycling techniques is a difficult task that greatly depends on the type of furnish available for production, thus leading to new research in the recycling field. One of the factors that should be considered is the ink formulation [1], which renders the deinking process particularly difficult, due to the constant modification of its chemical composition.

Generally, the industrial process for removing wastepaper contaminants involves re-pulping, screening, cleaning, washing and flotation [2,3]. Attempting to reflect the industrial process, the laboratory deinking trials frequently include four sequential stages, namely sample preparation, pre-washing, pulp treatment and fibre/ink particles separation. Each stage contributes to the overall effectiveness of deinking. Two goals are envisaged: (i) the detachment of the ink particles from the fibre surface; (ii) the removal or separation of the ink particles.

In order to favour deinking, chemical products have been used for a long time [1]. More recently, enzymes appeared as an alternative deinking aid [4]. Enzymatic deinking is advantageous for industrial usage because it is efficient, quick and has a low environmental impact [2–7]. However, due to the high heterogeneity of the paper provisions, the behaviour of a particular paper sample during recycling remains to large extent unpredictable. More data are required, to help understanding the action mechanism and the development of an economic and effective process.

In the present work, mixed office wastepaper (MOW) deinking is studied at laboratory scale; the effect of pH, deinking aids, pre-washing and mixing on the deinking process is examined. The office grades are generally more difficult to deink because, during printing, the thermoplastic synthetic polymers present in the laser and photocopy toners fuse at high temperature and adhere strongly to the fibres surface [8–10]. The high-quality fibres content in this paper, however, justifies its re-utilisation.

2. Methods and materials

The office wastepaper samples were treated according to the general protocol presented in Fig. 1. The experimental plan was organized in order to analyse: (i) the effect of the deinking aids (chemical products and/or enzymes) on pulp

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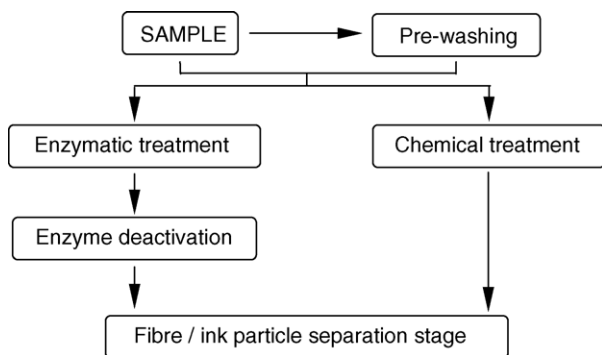


Fig. 1. General deinking sequence.

Table 1
Enzyme characterisation and dosages applied to the pulps

Enzyme	FPase		CMCase	Xylanase
	FPU (ml) ^a	FPU (g) ^b	U (ml) ^a	U (ml) ^a
Celluclast 1.5L	57	0.5	26.0	680
Buzyme 2523	3	0.1	5.3	33

^a Enzymatic activity in the cocktails as provided by the suppliers.

^b Enzyme dosage used in the pulp treatments expressed per gram of oven-dry (o.d.) pulp.

deinkability; (ii) the contribution of a pre-washing stage; (iii) the effect of attrition, caused by mixing the pulp, on the fragmentation and detachment of the printed ink films.

2.1. Enzymes

Two commercial enzymatic preparations were selected to perform this study: Celluclast 1.5L and Buzyme 2523. The first has been referred as an effective deinking aid [6,7,11]; the second was found to be efficient, in a preliminary set of assays [12], on the deinking of several paper pulps, namely a chemical pulp (MOW, 84% of ink removed), a mechanical pulp (51%) and a photocopy printed pulp (92%). The relevant hydrolytic activities of these preparations are presented in Table 1. The endoglucanase, cellulase and xylanase activities were measured using the carboxymethylcellulase (CMCase), filter paper (FPase) and xylan oat spelt assays, respectively, as described in Wood and Bhat [13] and Bailey et al. [14].

Reducing sugars were measured by the dinitrosalicylic acid method (DNS), using glucose as standard [15].

2.2. Paper pulp

The pulp used in this work was kindly supplied by the paper company *Renova*, S.A. (Torres Novas, Portugal). It was obtained by disintegrating mixed office wastepaper (MOW) on the Renova mill, and provided as high consistency pulp slurry. In order to evaluate the pre-washing stage contribution to deinking, a preliminary washing step (as described in Section 2.5) was conducted immediately after the sample preparation: a “washed” mixed office wastepaper was obtained (WMOW).

2.3. Enzymatic deinking

The pulp (25 g on oven-dry basis) was suspended in distilled water and disintegrated for 10 min in a 250 ml plastic container using a *Heidolph* overhead stirrer (model RZR-1) and a propeller especially designed for this work (Fig. 2). Then, the enzyme was added to the mixer according to the values shown in Table 1. The enzymatic preparations were previously diluted (in 10% of the total reaction volume), in order to achieve a better dispersion. According to the conditions defined in a previous work, the deinking reaction was allowed for 30 min at 11% consistency, pH 7.0 and 50 °C, with continuous slow mixing [16,17]. To inactivate the enzyme, the pulp suspension was boiled for 10 min. The cellulose degradation was quantified using the DNS method. To avoid redeposition, the released ink was immediately separated from the fibres, as described ahead. The fibres were finally recovered for testing.

In order to test the effect of the mechanical action on enzymatic deinking some treatments occurred in the absence of mixing, after disintegrating the pulp for 1 min; to evaluate the benefit of using surfactants during enzymatic deinking, Celluclast 1.5L was supplemented with a commercial surfactant (Rhecol OCP—Allied Colloids) in other assays.

Control assays with denatured enzyme were made in parallel. Each experimental condition (enzymatic assay or control) was assayed twice and a good reproducibility was found. The

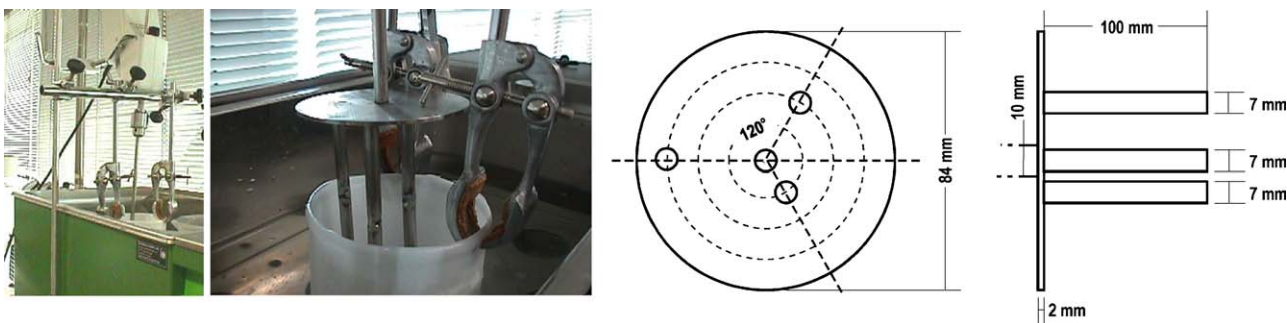


Fig. 2. Enzymatic/chemical treatment of pulp slurries at UM laboratory facilities (from the left to the right) pulp treatment device, propeller detail, propeller design.

coefficients of variation of the determined physical properties and ink amount did never exceed 2% and 5%, respectively.

2.4. Chemical deinking

Except for the final boiling, the chemical deinking assays were carried out as described above (Section 2.3); the effect of the mechanical action was also tested in this case. The concentration of chemical products was 2% NaOH and 2% Na₂SiO₃ (w/w); the final pH in the pulp suspension was 11.4.

Control assays were made with distilled water in the absence of chemicals. As for the enzymatic assays, each experimental condition was assayed twice with good reproducibility. The experimental conditions used were selected in a preliminary set of assays with different amounts of NaOH, corresponding to pH values of 9.9, 10.4 and 11.0.

2.5. Fibre/ink particle separation step

According to results shown elsewhere, small ink particles present in MOW are best removed by washing [17]. MOW fibres were preferably washed with running tap water (≈ 30 l) through a 200-mesh wire and then recovered for testing. In other assays, the pulps were floated in a laboratory flotation unit as described in Pala et al. [17].

2.6. Deinking evaluation

The physical and mechanical properties of the pulp and paper, and the amount of ink present in paper sheets, before and after the deinking treatment, were characterised as follows.

2.6.1. Pulp and paper testing

Handsheet preparation and determination of the pulp and paper properties followed the usual standard procedures: drainage rate (ISO 5267/1), handsheet preparation (ISO 5269/1), burst (ISO 2758), tensile (ISO 1924/2) and tear strength (ISO 1974).

2.6.2. Image analysis

The image analysis (IA) system is composed of a magnification lens (Olympus, model SZ-ST), illumination device (Olympus, model TL2), monochromatic CCD-camera (Sony, model AVC-DSCE), a CMA-D5CE adapter (Sony, Tokyo) and an image analysis interface DT-3152 (Marlboro, MA). The images were randomly acquired using the commercial software Image Pro Plus 3.0 (Media Cybermetrics, Silver-spring). The same magnification and lightning were used throughout the work in order to obtain comparable results [18,19]. A 4 \times objective was chosen, as a reasonable compromise between image enlargement and analysed area. All handsheets were analysed from the same side (opposite to the mesh side). Particle counts, shapes and sizes were examined using commercially available software (Globalab Image 3.2, Data Translation, Marlboro). To ensure the reproducibility

of the image analysis, a suitable threshold value was selected to identify the contaminants and that value was conserved throughout the work. For each 60 g/m² handsheet, 40 images were obtained and treated. The area analysed in each image of 438528 pixel was of about 13 mm². The total area analysed in each handsheet was about 5.2 cm². The dimension of the smallest detectable particle was 297 μm^2 (10 pixel), equivalent to a diameter of 19 μm , assuming a spherical geometry.

3. Results and discussion

3.1. Chemical treatment

As shown in Table 2, the chemical treatment increases the burst and tensile indexes, decreasing the tear index and the drainage rate. The extent of these modifications depends on the pH, being lower for the higher pH values [20]. Sodium hydroxide affects the fibre swelling and conformability [21–23] and also the fibre/fibre attrition during the mechanical mixing of the pulps [24]. Swelling, which is at large extent responsible for the pulp and paper properties modification, depends on electrokinetic and osmotic effects [25–29]. For high NaOH concentrations, the ionic strength in the pulp suspension increases, reducing both the electrokinetic and osmotic effects, and in consequence, also the tensile and burst strengths; tear is not affected because it is not directly related to the number of interfibre bonds (determined by swelling). While acting on paper fibres (making them swell), NaOH contributes to ink removal as it favours the detachment and fragmentation of the adhered ink (based on Wielen et al. [10]). Additionally, it may also act directly on the printed ink film and weaken its structure, leading to fragmentation [1]. In samples as complex as MOW it is possible that the two mechanisms occur at the same time; however, the action of the chemical products is limited to the non-polymeric printed inks. According to the IA results, an effective ink removal is achieved by chemically treating the MOW pulps, especially when high dosages are used (Table 2). Moreover, the ink particle size distribution profiles indicate that the ink films are dislodged from the fibre surface as large particles, which are efficiently removed from the suspension during the flotation step (Fig. 3). In fact, the small particles amount is similar in all samples (treated and non-treated), while fewer large particles are present in the treated samples; this modification explains the median size decrease after the chemical treatment.

3.2. Enzymatic deinking

Table 2 also shows the results of MOW's enzymatic deinking with Celluclast. As discussed in a previous work [16], low enzyme dosages are recommended in order to preserve paper strength. The hydrolytic activity used (0.5 FPU/g o.d., which corresponds to 1–1.2% of fibres solubilisation) allowed the strength indexes maintenance and the drainage improvement.

Table 2
Effect of the chemical/enzymatic deinking on the pulp and paper properties and ink particles characteristics (MOW)

Assay ^b	Pulp and paper properties ^a				Image analysis results			
	D	Ts	B	Te	Ink area (ppm)	Efficiency ^c (%)	Particle count	Median size (μm)
Enzymatic deinking								
Non-treated	30	28.6	1.9	7.7	8507		1774	1254
Control (F)	42	36.2	2.5	8.1	7024		1579	1194
Celluclast (F)	-7	+1	+4	+1	6544	7	1670	1283
Control (W)	20	26.4	1.8	8.3	4890		640	1344
Celluclast (W)	+5	+8	+15	+4	3428	30	571	1426
Control (W + S)	20	27.5	1.8	8.2	4718		672	1393
Celluclast (W + S)	0	0	+6	0	4288	9	603	1314
Chemical deinking								
Non-treated	34	37.7	2.5	9.2	10484		1253	1283
Chemical (pH 9.9)	47	44.2	2.9	8.4	4879	n.d.	1008	896
Chemical (pH 10.4)	45	42.2	2.8	8.9	4545	n.d.	902	776
Chemical (pH 11.0)	43	41.6	2.7	9.3	3621	n.d.	869	716

^a Physical properties in the enzymatic assays are expressed as % relatively to the respective control: (D, °SR) drainage; (Ts, Nm/g) tensile index; (B, (kPam²/g) burst index; (Te, (mNm²/g) Tear index.

^b Fibre/ink particle separation step: (F) flotation; (W) washing; (+S): with surfactant; in the chemical treatment, the fibres were separated from the ink particles by flotation; different “non-treated samples” correspond to different supplies of MOW.

^c Deinking efficiency, expressed as % of ink area reduction relatively to the control; (n.d.) not determined.

An ink removal of 7% (for floated pulps) and 30% (for washed pulps) was obtained. According to the IA results, Celluclast does not alter the ink particles distribution profile in MOW (not shown); washing is more effective than flotation in separating the ink particles from the enzymatically treated fibres, presumably because of the ink particles' median size in the samples [17]. Intensive enzymatic degradation leads to excessive fibrillation and ink fragmentation, which is undesirable [5,6,11,30]. Indeed, assays with higher enzymatic loads yield paper with poor properties without improving ink removal (data not shown). In another assay, this enzymatic preparation was complemented with a commercial surfactant (as in Jobbins and Franks [7] or Jeffries et al. [11]). The presence of surfactant does not favour deinking (only 9% – compared to 30% – without the surfactant, of the ink was removed when it was used); it is possible that either the type and/or the surfactant dosage were inadequately selected. In fact, the best enzyme/surfactant combination is difficult to estab-

lish because it greatly depends on the deinking conditions (pH, mixing, temperature, consistency, period of operation) [7,11,31,32].

Different supplies of MOW were used in the chemical and enzymatic assays (Table 2). However, the comparison of the final ink content (ink area) for the more efficient conditions used in this work (Celluclast/W versus Chemical/pH 11.0) shows that the deinking effect is comparable. Regarding the physical properties of the paper supplies (non-treated samples), the quality of the one used in the chemical assays is superior. The improvement in paper strength appears to be more significant after the chemical treatment, an effect that is counterbalanced by the one in the drainage rate, which the enzymes quite improve (Celluclast/W and Chemical/pH 11.0 versus the respective non-treated samples).

In contrast with Celluclast, Buzyme diminishes all the strength indexes, a limitation in the use of this enzyme (Table 3). Moreover, the effectiveness of Buzyme to deink MOW is apparently lower than Celluclast's (19% maximum efficiency versus 30%, for non pre-washed pulps). The two enzymatic preparations present a different FPase:CMCase:Xylanase ratio (1:0.5:12 in Celluclast and 1:1.8:11 in Buzyme, Table 1), which may explain these results. Considering that Buzyme was applied to the fibres at a lower dosage (0.1 versus 0.5 FPU/g o.d. pulp), the endoglucanolytic activity seems to be quite critical to the manipulation of this pulp. However, no direct relationship should be established between the enzymes activity and the deinking efficiency. Other effects must be considered, namely the properties of the enzymes (processivity, adsorption, etc.), the presence of non-identified (synergistic) secondary activities [16] and the presence of chemical products in the commercial enzymatic preparations that interfere with the deinking process [17].

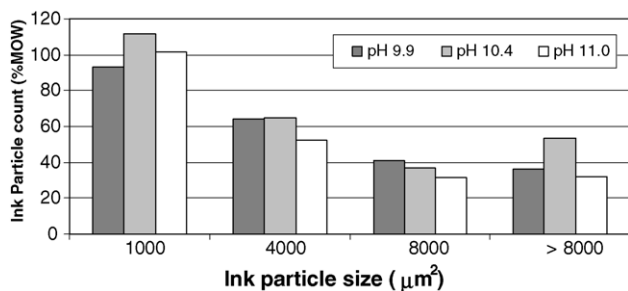


Fig. 3. Ink particle size distribution profiles after MOW chemical treatment. Particle count in the chemically treated samples expressed as % relatively to the number of particles in the non-treated MOW. Considering an increasing size range, the ink particle count in MOW is 521, 522, 147 and 63, respectively.

Table 3
Effect of the pre-washing stage and mixing on the pulp and paper properties and ink particles characteristics (MOW)

Assay ^b	"Washed" mixed office wastepaper															
	Mixed office wastepaper					Image analysis results										
	Pulp and paper properties ^a					Image analysis results										
	D	Ts	B	Te	Ink area (ppm)	Eff. ^c (%)	Particle count	Median size (µm)	D	Ts	B	Te	Ink area (ppm)	Eff. ^c (%)	Particle count	Median size (µm)
Enzymatic deinking ^d																
Control (P/m)	23	37.3	2.4	9.1	5681	19	577	1164	20	37.2	2.4	10.1	3676	7	432	1152
Buzyme 2523 (P/m)	-9	-10	-13	-33	4599	19	498	1134	-5	-7	-8	-38	3402	7	316	1283
Control (A/m)	22	37.9	2.4	8.9	6351	12	928	1000	19	35.6	2.3	9.4	4436	14	689	1224
Buzyme 2523 (A/m)	-5	-4	+4	-15	5569	12	928	1074	+5	+1	+4	-14	3805	14	610	1164
Chemical deinking																
Control (P/m)	23	40.1	2.6	9.9	4280	34	653	1522	20	37.5	2.6	10.2	3306	11	482	1418
Chemical (P/m)	+13	+6	+15	-2	2815	34	555	1283	-5	-1	0	+2	2956	11	457	1194
Control (A/m)	21	38.2	2.4	9.8	7137	26	958	1134	18	34.6	2.4	10.1	3575	-	578	1104
Chemical (A/m)	-5	-4	+4	-1	5298	26	958	1045	+6	+10	+8	-3	3909	-	628	1045
Non-treated	33	35.7	2.4	8.6	7545	26	1628	925	21	37.7	2.5	9.9	4674	-	997	985

^a Physical properties in enzymatic and chemical assays expressed as % relatively to the respective control: (D, %SR) drainage; (Ts, Nm/g) tensile index; (B, kPam²/g) burst index; (Te, mNm²/g) tear index.

^b (P/m) presence of mixing; (A/m) absence of mixing; after treatment, ink was removed by washing in all assays.

^c Deinking efficiency.

^d % Solubilisation after treatment with Buzyme 2523: 0.7% (A/m) and 0.9% (P/m); Controls (A/m and P/m) (were made in the absence of denatured enzyme as explained elsewhere [17]).

3.3. Contribution of a pre-washing step and mixing

Pre-washing the pulps before chemically or enzymatically treating the fibres, and mixing during treatment, also influences deinking (Table 3). When MOW is washed immediately after paper disintegration, about 38% of the initial ink is removed (non-treated sample: washed versus non-washed MOW), without changing the ink particle profiles of the two samples (data not shown). In addition to ink removal, a significant improvement of the pulp and paper physical properties is detected, which is probably due to the removal of fillers and fines [17]. These modifications may render the fibres less difficult to deink, because the dislodged ink particles redeposition on the fibres surface and its penetration in the porous structure of the fibres is avoided [5,6,33], and also because, in the absence of additives, the fibres become more accessible/susceptible to the deinking aids action. In fact, when pulps are pre-cleaned, lower residual ink values are obtained after treatment (Table 3). Moreover, exception made for the Chemical P/m assays, the fibres generally tend to develop better strength properties during the enzymatic/chemical treatments (controls versus assays, in MOW and WMOW).

Mixing favours mass transfer and promotes fibre erosion. Therefore, the lower strength loss (Buzyme, MOW and WMOW) and the lower strength restore (chemical products, MOW) in the A/m paper-sheets (control versus assays, Table 3) may be explained by a deficient dispersion of the deinking aids on the pulp suspension, which limits the hydrolytic activity (0.7% solubilisation versus 0.9%) and the chemical products effect on the fibres. In the case of the enzymatic treatments, the fibres surface may also suffer excessive erosion by the combined hydrolytic and mechanical actions; the severe fibrillation mechanism turns the fibre structure more vulnerable and affects the bonding potential and collapsibility of the fibres. In fact, when mixing was used during the enzymatic treatment more permeable sheets were obtained: MOW (2242 ml/min versus 1863 ml/min); WMOW (2384 ml/min versus 2092 ml/min).

Excessive fibre erosion may also be related to the combined action of mixing and chemical treatment; that may explain the lower strength gain in the mixed-WMOW (as compared with the one in the mixed-MOW). It is clearly shown that mixing is favourable to the ink removal, especially when a large amount of contaminants is present in the pulps. Indeed, lower residual ink area values and ink particle counts are detected in the mixed MOW and WMOW samples. The simultaneous mixing/deinking aids action favours the removal of the strongly adhered polymeric inks present in office-wastepaper. In fact, the lower ink particles median size in the A/m chemically treated samples (relatively to the P/m's) indicates that in the absence of mixing the smaller particles stay adhered to the fibres and are not removed. Considering this synergistic effect, some authors suggest the use of deinking aids immediately at the beginning of the paper recycling cycle [5–7,31,33–37]. However, it is important to remark that the effectiveness of mixing on the ink particle

removal depends on the mixing conditions [38,39] and different conditions (e.g. period and intensity of mixing) may lead to different results.

4. Conclusions

Enzymes can be deinking aids as effective as chemicals, although the results depend on the type of enzymatic preparation used. The hydrolytic activity is frequently associated to a reduction on the paper mechanical properties. However, in the current case, an improvement in tensile, burst and tear indexes was found. Comparing with the chemically treated pulps, these strength indexes are lower but, on the other hand, the enzymatically treated pulp drainability is better. Balancing these effects, enzymatic deinking is an alternative to the intensive use of chemical products in the conventional process, especially if the lower environmental impact of enzymatic deinking is taken into account.

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References

- [1] Shrinath A, Szewczak JT, Bowen JJ. A review of ink-removal techniques in current deinking technology. *Tappi J* 1991;74(7):85–93.
- [2] Heise OU, Unwin JP, Klungness JH, Fineran Jr WG, Sykes M, Abubakr S. Industrial scaleup of enzyme-enhanced deinking of non-impact printed toners. *Tappi J* 1996;79(3):207–12.
- [3] Knudsen O, Young JD, Yang JL. Long-term use of enzymatic deinking at Stora Dalum plant. In: Seventh International Conference Biotech. Pulp Paper Industry. 1998. p. A17–20.
- [4] Bajpai P, Bajpai PK. Deinking with enzymes: a review. *Tappi J* 1998;81(12):111–7.
- [5] Kim T-J, Ow SS-K, Eom T-J. Enzymatic deinking method of wastepaper. In: TAPPI Pulping Conference Proceedings. 1991. p. 1023–31.
- [6] Jeffries TW, Klungness JH, Sykes MS, Rutledge-Cropsey K. Comparison of enzyme-enhanced with conventional deinking of xerographic and laser-printed paper. *Tappi J* 1994;77(4):173–9.
- [7] Jobbins JM, Franks NE. Enzymatic deinking of mixed office waste: process condition optimization. *Tappi J* 1997;80(9):73–8.
- [8] Johnson DA, Thompson EV. Fiber and toner detachment during repulping of mixed office waste containing photocopied and laser-printed paper. *Tappi J* 1995;78(2):41–6.
- [9] Kakogiannos A, Johnson DA, Thompson EV. Laboratory high-consistency dispersion studies of laser-printed office copy paper, Part II. *Tappi J* 1998;81(4):159–65.
- [10] Wielen LCV, Panek JC, Pfromm PH. Fracture of toner due to paper swelling. *Tappi J* 1999;82(5):115–21.
- [11] Jeffries TW, Sykes MS, Rutledge-Cropsey K, Klungness JH, Abubakr S. Enhanced removal of toners from office waste papers by microbial cellulases. In: Sixth International Conference Biotech. Pulp Paper Industry. 1995. p. 141–4.
- [12] Pala H, Gama FM, Mota M. Preliminary studies on enzymatic deinking. In: Seventh International Conference Biotech. Pulp Paper Industry. 1998. p. C189–92.
- [13] Wood TM, Bhat KM. Methods for measuring cellulase activities. *Methods Enzymol* 1988;160(9):87–112.
- [14] Bailey MJ, Biely P, Poutanen K. Interlaboratory testing of methods for assay of xylanase activity. *J Biotechnol* 1992;23:257–70.
- [15] Bernfeld P. Amylases, α and β . *Methods Enzymol* 1955;1(17):149–52.
- [16] Pala H, Lemos MA, Mota M, Gama FM. Enzymatic upgrade of old paperboard containers. *Enzyme Microb Technol* 2001;29:274–9.
- [17] Pala H, Mota M, Gama FM. Enzymatic versus chemical deinking of non-impact ink printed paper. *J Biotechnol* 2004;108(1):79–89.
- [18] Zeyer C, Venditti RA, Puangchinda KW, Heitmann JA. The distribution of impurities in pulp and paper: the effects of the random distribution of impurities on image analysis. *Tappi J* 1995;78(2):168–75.
- [19] Zeyer C, Venditti RA, Heitmann JA. The effect of sample size on the confidence interval for image analysis of impurities in pulp and paper. *Tappi J* 1995;78(2):176–9.
- [20] Pala, H. Utilização de Xilanases e de Celulases na Reciclagem de Fibras de Papel. PhD Thesis. Escola de Engenharia da Universidade do Minho 2002.
- [21] Bhat GR, Heitmann JA, Joyce TW. Novel techniques for enhancing the strength of secondary fibre. *Tappi J* 1991;74(9):151–7.
- [22] Marton R, Brown A, Granzow S, Koepf R, Tomlinson S. Recycling and fibre structure. *Prog Paper Recycl* 1993;3(2):58–70.
- [23] Chen Z-X, Heitmann JA, Chang H-M. Secondary fibre quality enhancement—alkaline and oxygen treatment. *Paper Technol* 1998;40(9):45–9.
- [24] Azevedo MAD, Drelich J, Miller JD. The effect of pH on pulping and flotation of mixed office wastepaper. *J Pulp Paper Sci* 1999;25(9):317–20.
- [25] Scallan AM, Grignon J. The effect of cations on pulp and paper properties. *Svensk Papperstidning* 1979;82(2):40–7.
- [26] Grignon J, Scallan AM. The effect of pH and neutral salts upon the swelling of cellulose gels. *J App Polym Sci* 1980;25:2829–43.
- [27] Katz S, Liebergott N, Scallan AM. A mechanism for the alkali strengthening of mechanical pulps. *Tappi* 1981;64(7):97–100.
- [28] Lindstrom T, Carlsson G. The effect of chemical environmental on fiber swelling. *Svensk Papperstidning* 1982;85(3):R14–20.
- [29] Scallan AM. The effect of acidic groups on the swelling of pulps: a review. *Tappi J* 1983;66(11):73–5.
- [30] Treimanis A, Leite M, Eisimonte M, Viesturs U. Enzymatic deinking of laser-printed white office wastepaper. *Chem Biochem Eng* 1999;13(2):53–7.
- [31] Sykes M. Enzymatic deinking of sorted mixed office waste: recommendations for scale-up. In: Sixth International Conference Biotech. Pulp Paper Industry. 1995.
- [32] Kaya F, Heitmann Jr JA, Joyce TW. Influence of surfactants on the enzymatic hydrolysis of xylan and cellulose. *Tappi J* 1995;78(10):150–7.
- [33] Zeyer C, Joyce TW, Heitmann JA, Rucker JW. Performance study of enzymatic deinking using cellulase/hemicellulase blends. In: Sixth International Conference Biotech. Pulp Paper Industry. 1995. p. 169–72.
- [34] Prasad DY. Enzymatic deinking of laser and xerographic office wastes. *Appita* 1993;46(4):289–92.
- [35] Jeffries TW, Klungness JH, Sykes MS, Rutledge-Cropsey K. Preliminary results of enzyme-enhanced versus conventional deinking of xerographic printed paper. In: TAPPI Rec. Symposium Notes. 1993. p. 183–8.
- [36] Zeyer C, Joyce TW, Heitmann JA, Rucker JW. Factors influencing enzyme deinking of recycled fiber. *Tappi J* 1994;77(10):169–77.

- [37] Bennington CPI, Sui OS, Smith JD. The effect of mechanical action on waste paper defibering and ink removal in repulping operations. *J Pulp Paper Sci* 1998;24(11):341–8.
- [38] Putz H-J, Götsching L, Renner K, Jokinen O. Enzymatic deinking in comparison with conventional deinking of offset news. In: *TAPPI Pulping Conference Proceedings*. 1994. p. 877–84.
- [39] Ackermann C, Putz H-J, Götsching L. Effect of pulping conditions on deinking of wood-containing recovered paper grades. *Pulp Paper Can* 1999;100(4):37–41.