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Enzymatic versus chemical deinking of non-impact ink printed paper

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Abstract

Enzymatic versus chemical deinking is examined for MOW and photocopy prints. Several enzymatic preparations and two fibre/ink particle separation methods are tested. Deinking was monitored by image analysis and standard pulp and paper characterisation procedures. The effectiveness of the fibre/ink particle separation method depends on the ink particle's size: for smaller particles a washing step is recommended whereas for larger particles, the use of flotation is necessary. The enzymatic treatment is a competitive alternative for MOW and photocopy paper deinking. However, the process requires the selection of an adequate enzymatic preparation for each paper grade.

Keywords: Paper pulps; Non-impact inks; Deinking; Enzymes; Image analysis

1. Introduction

The development of papermaking processes with low environmental impact finds in the use of enzymes a suitable option, especially when deinking is considered (Kim et al., 1991; Jeffries et al., 1994; Heise et al., 1995; Jobbins and Franks, 1997; Bajpai and Bajpai, 1998; Knudsen et al., 1998). In fact, traditional deinking involves the use of large quantities of chemical products (Shrinath et al., 1991), which makes the method expensive and highly environmentally damaging. On the contrary, the biological treatments can favour ink particle detachment from the fibres without discharge of pollutants. According to their specificity, the enzymes can either act directly on the fibres or on the ink film. When cellulases/hemicellulases are used (as in this work), the release of ink particles into suspension is generally attributed to the cellulose hydrolysis on the fibre/ink inter-bonding regions, which facilitates ink detachment (Kim et al., 1991). Additionally, these enzymes can remove small fibrils from the surface of the ink particles thus altering the relative hydrophobicity of the particles, which facilitates their separation in the flotation/washing step (Jeffries et al., 1994). Enzymatic technology has been described as especially advantageous to deink high quality wastepaper, namely mixed office waste (MOW), which reuse is usually limited by the high content of non-contact inks (toners). Toners are very difficult to remove by the application of current methodologies because they contain thermoplastic binders that polymerise and fuse onto

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the paper fibres during the high-temperature printing process; when these fibres are chemically treated, the toner particles usually remain as large, flat, rigid particles that separate very poorly from fibres during the fibre/ink separation stages (Quick and Hodgson, 1986; Shrinath et al., 1991).

In the present work, a comparison is made between the enzymatic and chemical deinking of samples obtained from the disintegration of different non-impact inks prints. The effect of each method on the contaminants removal (ink amount) and on the pulp and paper properties is examined.

2. Methods and materials

2.1. Enzymes

The endoglucanase, cellulase and xylanase activities presented in Table 1 were measured using the carboxymethylcellulose (CMCase), filter paper (FPase) and xylan oat spelt assays, as described in Wood and Bhat (1988) and Bailey et al. (1992). Released sugars were measured by the dinitrosalicylic acid method (DNS), using glucose as standard (Bernfeld, 1955).

2.2. Paper pulps

Three paper pulps were used: (i) MOW, a mixture of office wastepaper, was an industrial paper pulp supplied by the paper company Renova, S.A. (Torres Novas, Portugal); (ii) MIX, which consisted of a mixture of laser, inkjet and photocopy prints, was disintegrated in a laboratory pulper (Lam'Deinkit, Licar S.A.-Tolosa, Guipúzcoa) for 15 min at 4% consistency (in tap water), 25 °C and 1500 rpm, and then recovered by dewatering through a 200-mesh wire; (iii) PHOT, photocopy paper, was disintegrated in the same pulper for 20 min at 10% consistency, 58 °C and 750 rpm, and was recovered as described above.

2.3. Enzymatic deinking

Pulp (25 g on oven-dry basis) was suspended in distilled water and disintegrated for 10 min. Then, the enzyme was added to the mixer according to the values mentioned in Table 1. The enzymatic preparations were diluted (in 10% of the total reaction volume), in order to achieve a better dispersion. The reaction with the pulp occurred for 30 min at 11% consistency, pH 7.0 and 50 °C, with continuous slow mixing. The 30-min period was selected according to a previous work (Pala et al., 2001). The relatively high consistency of 11% was chosen because it prompts fibre/fibre attrition, favouring ink detachment; additionally, it would be advantageous for industrial usage. For the same reason the enzymatic assays were carried out at the natural pulp pH (~7.5). To inactivate the enzyme, the pulp suspension was boiled for 10 min. The

Table 1
Enzyme characterisation and concentrations used in the pulps treatment

Enzyme	Supplier	FPase		CMCase	Xylanase	
		FPU/ml[a]	FPU/g[b]	U/ml[a]	U/ml[a]	U/g[b]
Xylanase Cd.	UBC	0.04	0	0.02	1800	103
Viscozyme L	Novo Nordisk	16	1.3	9.1	710	57
Celluclast 1.5L	Novo Nordisk	57	0.5	26.0	680	5
Buzyme 2523	Buckman	3	0.1	5.3	33	1
Pentopan mono	Novozymes	55 (FPU/g)	0.5	n.d.	11 590 (U/g)	107
AXC	Biocon	206 (FPU/g)	0.5	n.d.	272 355 (U/g)	654
Novozym 342	Novozymes	20	0.5	n.d.	1598	40
T. viride CCMI 84	INETI	17 (FPU/g)	0.07	n.d.	315 (U/g)	1.3
A. terreus CCMI 498	INETI	3.4 (FPU/g)	0.03	n.d.	165 (U/g)	1.3
IOGEN celulase	IOGEN Corp.	87	0.5	380	1100	6
SAFISYM CP.	SAF–ISIS	48 (FPU/g)	0.5	707 (U/g)	814 (U/g)	9

n.d.: not determined.

[a] Enzymatic activity in the cocktails as provided by the suppliers; UBC: University of British Columbia, Canada; INETI: Instituto Nacional de Engenharia e Tecnologia Industrial, Lisboa, Portugal.

[b] Enzyme dosage used in the pulp treatments expressed per gram of oven-dry pulp.

cellulose degradation was quantified using the DNS method. The released ink was immediately separated from the fibres as described ahead to avoid redeposition. The fibres were afterwards recovered for testing.

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 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. The chemical products were added in the following dosages: 2% NaOH and 2% Na_2SiO_3 (w/w). The 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.

2.5. Fibre/ink particle separation step

A preliminary study on the effectiveness of the fibre/ink particle separation step was conducted after enzymatic (Celluclast 1.5L) and/or chemical (NaOH + Na_2SiO_3) treatment of two samples presenting ink particles of different size (MOW and MIX). Three procedures were assayed:

2.5.1. Washing

The pulps were washed with running tap water (≈30 l) through a 200-mesh wire and recovered for testing.

2.5.2. Flotation

The pulps were floated in a laboratory flotation unit developed and optimised at Minho University laboratories. The flotation device (Fig. 1) was based on an airlift reactor (Vicente and Teixeira, 1995), operated with 4.5 l of sludge (0.6% consistency) for 20 min at room temperature and 1.14 l air/min. At the beginning of the process a flotation aid (Rheocol OCP—Allied Colloids, 0.74% (w/w)) was added.

In a preliminary set of assays, this unit was compared with a commercial laboratory flotation unit (Lam'Deinkit, Licar S.A.-Tolosa, Guipúzcoa). It was observed that the airlift reactor removed ink more efficiently, and furthermore it allowed a more controlled and reproducible flotation, and a lower fibre loss.

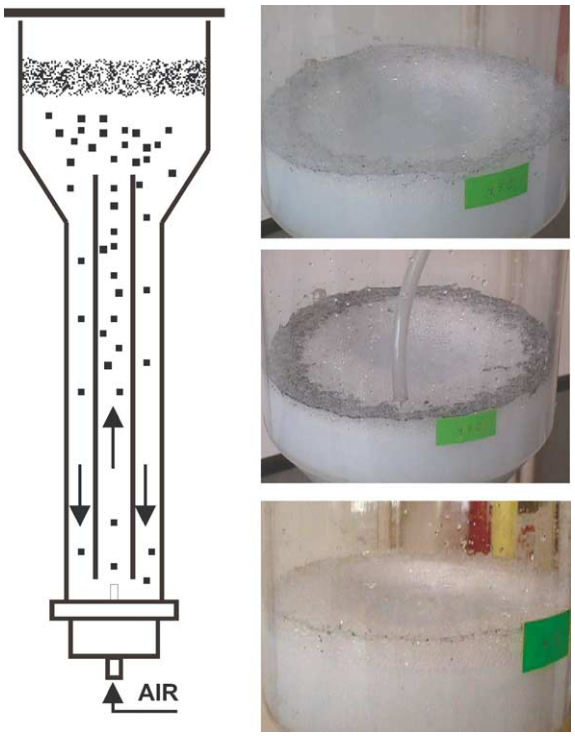

Fig. 1. Flotation device. The airlift operation is characterised by the liquid and solid phases' cyclic flow, which is established by the difference between the fluids densities in the down comer (descending tube) and in the riser (ascending tube). This variation rises from the injection of air through the reactor's bottom. At the top of the reactor there is a degasification zone, where the gas used in the impulsion is released and the formed foam and retained ink are collected by suction.

2.5.3. Flotation and washing

The pulps were subsequently floated and washed, following the experimental procedures described previously. The flotation aid was added to the pulps at the beginning of the flotation step.

2.6. Deinking evaluation

The physical and mechanical properties of 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, Silverspring). The same magnification and lightning were used throughout the work in order to obtain comparable results (Zeyer et al., 1995a,b). A 4× objective was chosen, as a reasonable compromise between image enlargement and analysed area. All handsheets were analysed in the same side (opposite to the wire 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/m^2 handsheet, 40 images were obtained and treated. The area analysed in each image of 438 528 pixel was of about 13 mm^2. The total area analysed in each handsheet was about 5.2 cm^2. 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

In the present work, the deinkability of different paper pulps is evaluated. The tested pulps are representative of different printing methods and probably of different ink formulations. These samples also diverge on the amount of dirt and ink particles size (Tables 2–3 and Fig. 2), therefore requiring the optimisation of the fibre/ink particle separation process (Section‘3.1) before accessing the effectiveness of the chemical and enzymatic deinking agents (Section 3.2). On Section 3.1, two pulps (MIX and MOW) were used to test the separation methods available. The deinking assays were then carried out with MOW and a

Table 2
Quantification of deinking efficiency after different fibre/ink separation routines (MOW and MIX)

Assay[a]	Mixed office wastepaper		Laser/inkjet/photocopy-printed wastepaper	
	Ink area (ppm)	Deinking efficiency (%)[c]	Ink area (ppm)	Deinking efficiency (%)
Enzymatic deinking				
Control (F)	7024			
Celsluclast 1.5L (F)	6544	**7**	n.t.	
Control (W)	4890			
Celluclast 1.5L (W)	3428	**30**	n.t.	
Non-treated pulp	**8507**[b]			
Chemical deinking				
Control (F + W)	3018		11 224	
Chemical (F + W)	2864	**5**	9718	**13**
Control (F)	6589		8908	
Chemical (F)	3728	**43**	8047	**10**
Control (W)	4280		11 752	
Chemical (W)	2815	**34**	11 793	**0**
Non-treated pulp	**7545**[b]		**16 941**	

n.t.: not tested.

[a] Fibre/ink separation routines: (F + W) Flotation + Washing; (F) Flotation; (W) Washing.

[b] In both samples 50% of the particles have a diameter below 34 μm.

[c] Deinking efficiency expressed as percentage of the respective control.

Table 3
Quantification of fibre degradation and deinking efficiency after enzymatic and chemical treatment (MOW and PHOT)

Assay	Mixed office wastepaper					Photocopied wastepaper				
	% Solubilisation	Ink area (ppm)	Deinking efficiency (%)[c]	Ink particles count	Ink particles median size (μm^2)	% Solubilisation	Ink area (ppm)	Deinking efficiency (%)[c]	Ink particles count	Ink particles median size (μm^2)
Enzymatic deinking										
Control ENZ		3109		850	822		7625		455	3141
Xylanase Cd.	3.1	2625	**16**	422	836	3.5	6381	**16**	352	2567
Viscozyme L	1.7	3174	**0**	872	895	n.t.	n.t.	n.t.	n.t.	n.t.
Celluclast 1.5L	1.1	2471	**21**	457	806	1.3	7953	**0**	437	2896
Buzyme 2523	1.0	2302	**26**	310	689	n.t.	n.t.	n.t.	n.t.	n.t.
Pentopan mono	2.5	2200	**29**	214	940	2.8	6696	**12**	328	3292
AXC	2.3	1789	**42**	164	896	2.6	5911	**22**	294	3045
Novozym 342	0.8	2313	**25**	369	1179	n.t.	n.t.	n.t.	n.t.	n.t.
T. viride CCMI 84[a]	1.1	2372	**24**	325	1037	n.t.	n.t.	n.t.	n.t.	n.t.
A. terreus CCMI 498[a]	0.8	2850	**8**	583	867	n.t.	n.t.	n.t.	n.t.	n.t.
IOGEN celulase	0.5	1910	**39**	290	1403	n.t.	n.t.	n.t.	n.t.	n.t.
SAFISYM CP.	1.3	2432	**22**	317	1597	n.t.	n.t.	n.t.	n.t.	n.t.
Chemical deinking										
Control CHEM		2839		745	1233		6337		381	2000
Chemical deinking	0	1968	**31**	262	1042	0	4006	**37**	208	1806
Non-treated pulp[b]		**5331**		**1351**	**746**		**14 976**		**861**	**2119**

n.t.: not tested.

[a] Marques et al. (2003).

[b] The same batch of non-treated pulp was used in both enzymatic and chemical assays.

[c] Deinking efficiency expressed as percentage of the respective control.

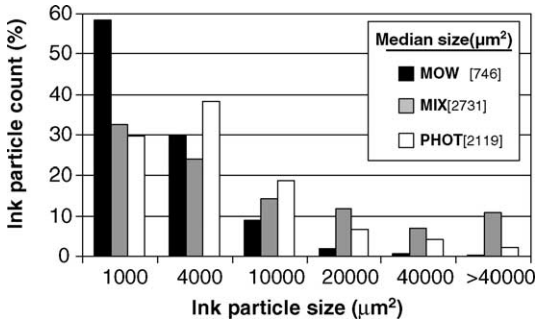

Fig. 2. Particle size distribution for the different non-treated pulp samples. The different MOW batches used in the present work (ink area: 8507, 7545 and 5331) have similar ink particle size distributions.

different pulp, PHOT (with ink particles size similar to MIX), since MIX was hardly deinked.

3.1. Fibre/ink particle separation step evaluation

Most pulps present a wide range of ink particles sizes thus requiring an adequate planning of the fibre/ink particle separation step in order to achieve effective deinking: the small particles determine the ISO brightness, whereas the large ones affect the general appearance of the paper sheets. Considering the MOW pulp, extensive washing was sufficient to effectively remove the dispersed ink. By contrast, the chemically treated MIX paper seems to require the use of flotation (Table 2). According to Harrison (1991), washing and flotation provide an optimal fibre/ink separation when the ink particles size is comprised between 1–10 and 10–150 μm, respectively. As a matter of fact, in MOW, 50% of the particles have a diameter below 34 μm (average diameter: 55 μm) whereas in MIX, 50% of the particles have a diameter below 59 μm (average diameter: 157 μm) (Fig. 2). Ink removal depends also on the nature of the deinking process. In office paper grades, where polymeric inks are predominant, the action of alkali in the pulping operation is expected to avoid the fragmentation of the ink films, allowing the particles to be released as large specks (Ow et al., 1995; Azevedo et al., 1999). On the other hand, the action of enzymes may be quite unpredictable in this regard (Kim et al., 1991; Jeffries et al., 1994; Zeyer et al., 1994; Ow et al., 1995; Jobbins and Franks, 1997; Treimanis et al., 1999). One must therefore be aware of the ink particles modification during the chemical/enzymatic treatment, in order to choose the best fibre/ink separation methodology. Indeed, the flotation efficiency strongly depends on the type of treatment: 7% of the ink is removed when the MOW pulp is enzymatically treated whereas 43% is removed when it is chemically treated. This difference may be due either to a reduction of the ink particles size in the enzymatically treated pulp, or to a modification of the ink/fibre surface properties due to enzyme adsorption.

In addition to ink removal, washing and flotation also modify the pulp and paper properties (Fig. 3), as they alter the amount of fines and mineral fillers in the pulps. When fillers are removed, the inter-fibre interactions increase and the paper strength is improved; on the contrary, when fines are removed, the paper sheets become more permeable and less dense, and the paper strength decreases. Due to their size (<2 μm), washing

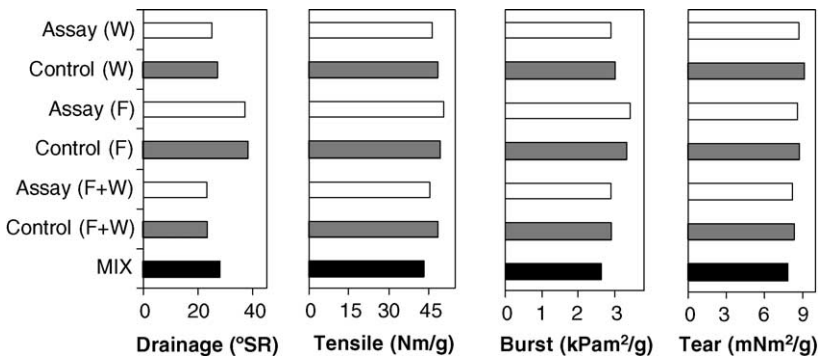

Fig. 3. Effect of the fibre/ink separation process on the pulp and paper strength properties (chemically treated MIX): (F + W) Flotation + Washing; (F) Flotation; (W) Washing. The other pulp samples (enzymatically/chemically treated MOW) present similar results.

is more efficient than flotation in the removal of both fines and fillers. However, retention/removal of these small materials also depends on their surface properties: if they are sufficiently hydrophobic they are removed in flotation (Drabek et al., 1998; Deng, 2000); if they are sufficiently hydrophilic they are removed in washing. The present study reveals that the MIX washed pulps have lower degree of drainability (°SR) than the floated ones. Although the strength properties are not significantly modified in the floated pulps, the tensile and burst indices tend to be higher, and the tear index to be lower (Fig. 3). In either case, a more effective removal of hydrophilic fines by washing is probably the reason for this effect.

Although a strength decrease is detected after the successive flotation and washing processes (relatively to the isolated flotation step, Fig. 3), the washing step is strongly recommended to assure the flotation aid total removal. The adsorption of surfactant onto the fibres surface alters the fibres surface properties, reducing the strength of the inter-fibre bounds and decreasing the paper strength. The strength loss was probably not detected after flotation assays since the loss of fines was low, favouring the amount of established inter-fibre bounds, which balanced the decrease in strength.

3.2. Chemical versus enzymatic deinking

According to the previous Section, the pulps used in this study were either washed (MOW) or floated and washed (PHOT). The first set of assays, with several enzymes, was performed with MOW. Afterwards, some of the more effective enzymes for MOW deinking were tested on PHOT samples (Fig. 4 and Table 3).

In a previous study, the action of cellulases was shown to be detrimental to the paper strength (Pala et al., 2001). Therefore, in order to preserve paper quality, the development of an enzymatic deinking process requires the control of both the enzymatic modification of the fibres and the ink removal. Among the tested enzymes, IOGEN celulase, *A. terreus* CCMI 498, *T. viride* CCMI 84 and Celluclast 1.5L provided the more interesting results. As Fig. 4 shows, the paper strength of the treated MOW was improved in all cases; when CCMI 498 was used, drainage was also improved (5% decrease in the °SR). Xylanase Cd., Viscozyme L, AXC and Novozyme 342 lead to a moderate strength decrease. Finally, Buzyme 2523, Pentopan mono and SAFISYM CP. are responsible for a significant strength decrease, while increasing drainage (10–14%).

It is difficult to establish a straightforward relationship between the enzymatic activity, the % solubilisation and the pulp and paper properties modification (Pala et al., 2001). Although Pentopan mono and AXC have predominantly xylanolytic activity (FPase:Xylanase activity ratio of 1:214 and 1:1308, respectively), which is not usually related to a significant strength reduction (Jackson et al., 1993; Stork et al., 1995; Pala et al., 2001), Fig. 4 points out that these preparations may, in fact, be detrimental to the paper fibres. Regarding the tested preparations, for the same total celulase activity (0.5 FPU/g o.d. pulp: Celluclast 1.5L, Novozyme 342, IOGEN celulase and SAFISYM CP.), the endoglucanolytic and xylanolytic activities vary widely (FPase:CMCase:Xylanase ratio, 1:0.5:10, 1:–:80, 1:4.4:12 and 1:14.6:18, respectively). Moreover, the interfacial properties modification caused by the enzymes adsorption on the fibre surface may be an additional contribution to the modification of the pulp and paper properties (Pala et al., 2001).

Enzyme preparations may include chemical products that interfere with the deinking process. The use of surfactants is an example of a deinking aid, which is also known to contribute to the enzymes performance and stability during the pulping stage (Kim et al., 1982; Park et al., 1992; Jeffries et al., 1995; Duff et al., 1995; Jobbins and Franks, 1997). In the present work, we speculate that this might be the case for Buzyme 2523, SAFISYM CP. and Novozyme 342 because the respective control assays (with denatured enzyme) did not present the same characteristics of those obtained either when no enzyme was added or when other denatured enzymatic preparations were used (e.g. Celluclast 1.5L, Viscozyme L, AXC) (data not shown).

As it was expected, the use of chemical products increased the strength indexes and decreased the drainage properties. NaOH favours swelling and consequently increases the fibres bonding potential by enhancing their flexibility, conformability and surface area; as the fibre/water interactions are modified (fibres become more hydrophilic), the fibres water uptake increases and drainage is hindered (Bhat et al., 1991; Marton et al., 1993). The results are comparable with the ones obtained with some of the tested

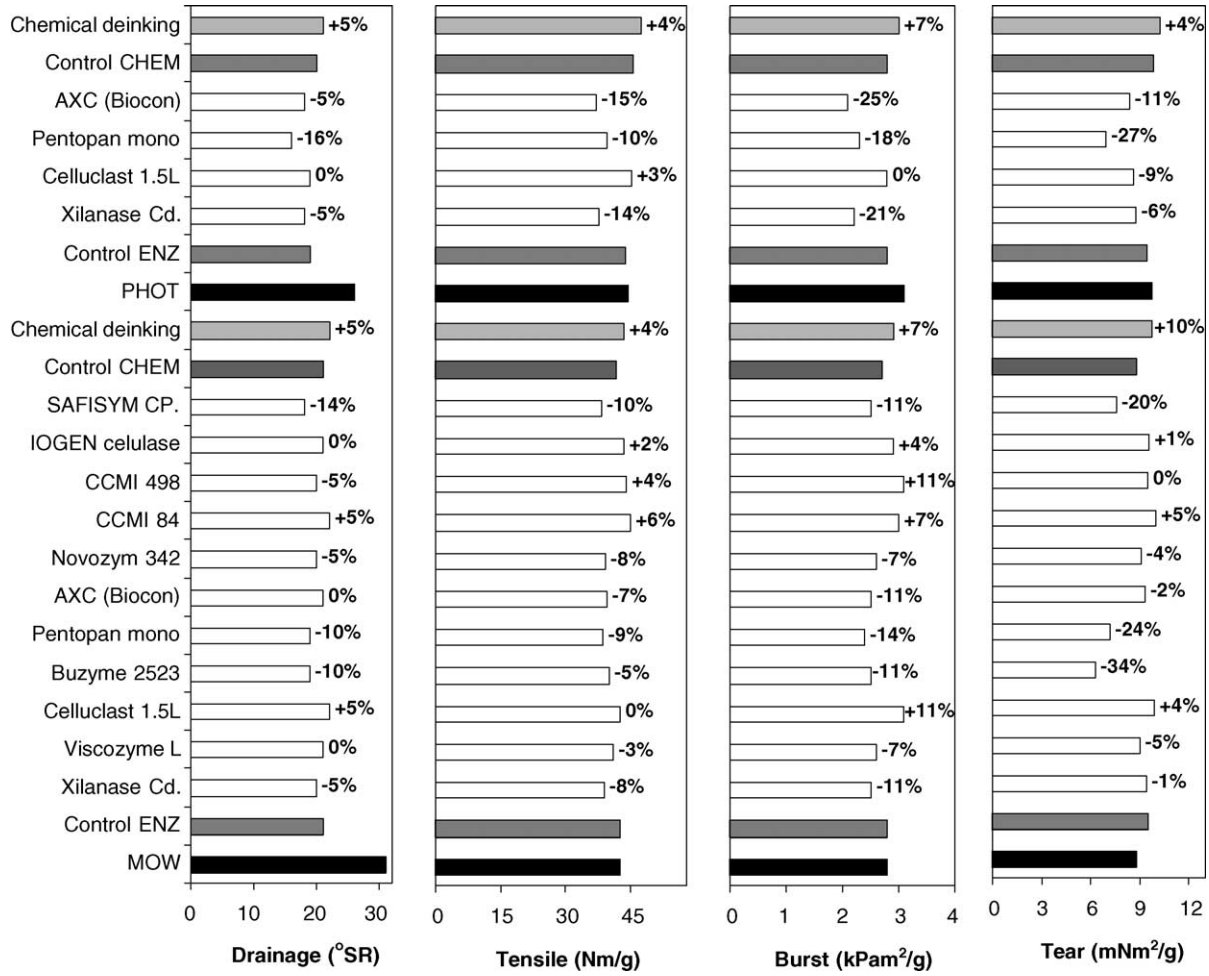

Fig. 4. Effect of the enzymatic and chemical treatments on the pulp and paper properties (MOW). Drainage, tensile, burst and tear variation in enzymatic/chemical assays is expressed as percentage of the respective control. "Control ENZ" values are the average of all enzymatic control assays performed with each pulp; considering the *Buzyme 2523*, *SAFISYM CP*. and *Novozyme 342* preparations, control assays were performed in the absence of denatured enzyme.

enzymes, namely, IOGEN celulase, *A. terreus* CCMI 498 and Celluclast 1.5L.

Considering the IA results, only Viscozyme L was rather ineffective as a deinking agent (Table 3). With respect to the other enzymes, which allow different deinking efficiencies, it was not possible to establish a key activity (or activities) for ink removal. In fact, although the cellulolytic and/or xylanolytic activities are frequently related to effective deinking trials, it is difficult to establish the relative contribution of each one to the deinking process (Kim et al., 1991; Prasad et al., 1992; Prasad, 1993; Jeffries et al., 1994). According to some works, the major contribution is given by the endoglucanases (Franks and Munk, 1995; Gübitz et al., 1998). In other cases, xylanases are considered to provide the main activity (Berlin et al., 1997). The wide range of results is probably due to the use of quite different paper samples (Rutledge-Cropsey et al., 1994; Zeyer et al., 1994; Jeffries et al., 1995).

The preparations Buzyme 2523, Novozyme 342, *T. viride* CCMI 84, IOGEN celulase and SAFISYM CP. affected the ink particle size distribution profile (Table 3). Buzyme 2523 favoured the ink film frag-

mentation or/and the larger ink particles removal, originating in an increase in the small particles amount; the other preparations (particularly, IOGEN celulase and SAFISYM CP.) contributed to the smaller particles removal. The ink particle size modification seems not to affect the pulp deinkability, namely during the fibre/ink separation step. This is a very interesting aspect since the enzymatic treatment is sometimes related to the ink films fragmentation (Kim et al., 1991; Ow et al., 1995; Treimanis et al., 1999), thus being necessary to control the enzymatic action in order to maintain the ink size in a range suitable to the separation process.

Regarding polymeric inks, it is generally assumed that the chemical treatment does not induce fragmentation (Ow et al., 1995; Azevedo et al., 1999; Wielen et al., 1999). In fact, alkali is responsible for fibre swelling, which favours ink detachment as large particles and avoids the toners partial removal; additionally, NaOH reduces the mechanical action on the fibres surface, thus decreasing the release of the fine particles. On the contrary, when non-polymeric inks are present, NaOH can act directly on the ink film, breaking its structure and dispersing the ink. Considering the MOW heterogeneity, it is possible that this mechanism is also occurring, although to a small extent, justifying the ink particle median size decrease after the chemical treatment. It must be underlined that chemically treating PHOT samples, which include photocopied prints exclusively, increases the ink particle median size (data not shown).

According to the results, the enzymatic process is as efficient as the chemical one to deink MOW. This is particularly evident with Celluclast 1.5L, *T. viride* CCMI 84 and IOGEN celulase, which favour both ink removal and strength increase.

The results obtained with PHOT are also shown in Fig. 4 and Table 3. Although the extent of strength modification depends on the tested sample, the effect of the enzymatic preparations on the fibres is generally the same: except for Celluclast, which did not affect paper strength, all the preparations are detrimental to strength while favouring drainage. A different fibre composition or the different fibre/ink separation methodology (as seen in Section 3.1) is probably responsible for the more significant strength loss in PHOT relative to MOW (Fig. 4).

The PHOT sample is more difficult to deink. As the polymeric inks are strongly adhered to the fibres they in are difficult to detach from the paper and to reduce in size to a range suitable to either flotation or washing separation; according to Rao and Stenius (1998), the inner layer of the dry toners is the more resistant to the removal and dispersion. Nevertheless, the chemical deinking used in this work proved to be effective (Table 3). Considering PHOT, enzymatic deinking is possible but less effective than the chemical one.

4. Conclusions

According to this study, the use of enzymes is a possible and competitive strategy to deink recycled pulps. However, a thorough enzyme selection and the optimisation of the process are needed in order to accomplish a good quality final product. In this work, no particular glycanolytic activity could be related to a better deinking effectiveness. Different pulps may react differently to similar deinking protocols, either enzymatic or chemical. The enzymatic process effectiveness depends more critically on the furnish characteristics than the chemical one. Considering the wide variability on the industrial wastepaper supplies, this is probably the most important disadvantage of this methodology. Concerning the MOW sample, some particularly effective enzymes were identified: *Celluclast 1.5L, T. viride CCMI 84* and *IOGEN celulase* contribute to both ink removal and paper strength increase. The maximum ink removal was obtained by treating MOW with the commercial preparation AXC (42%); unfortunately this enzymatic mixture decreases the paper strength. Regarding the PHOT paper, the more effective deinking was achieved when the chemical procedure was used (37% versus 12–22%); furthermore, although enzymes favour ink removal, their action significantly affects the paper strength properties.

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