EFFECT OF XYLANASE TREATMENT ON DEWATERING PROPERTIES OF BIRCH KRAFT PULP

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In this study it was shown that the enzymatic removal of xylan from ECF-bleached birch kraft pulp enhances the water removal from the pulp, especially in the late stages of pulp drying. The effect of xylanase treatments on dewatering was clarified by using a moving belt former (MBF), a press simulator (MTS), and an IR-drying equipment, to simulate and to measure dewatering properties on wire, press and drying sections of a paper machine. The xylanase treatment slightly increased the pulp freeness indicating improved pulp drainage properties. At the moving belt former, however, no significant changes that would indicate enhanced dewatering in forming were observed. The xylanase treatments slightly enhanced the dewatering in wet pressing and furthermore, at the thermal drying the xylanase treatment had a positive effect on the dry solid content (DSC) development, and time to reach the 95% dry solids content was reduced by up to 15%. This was also confirmed by the decrease in the fiber saturation point (FSP) values and the amount of bulk water. Our results indicate that the xylanase treatment affected the water-binding xylan in the fiber cell wall, yielding enhanced dewatering properties, without deteriorating the pulp and paper properties.

Keywords: Enzyme treatment; Xylanase; Fiber modification; Biotechnology; Fiber and pulp properties; Dewatering; Sheet properties

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INTRODUCTION

Enzymes are biological catalysts with high selectivity, reaction speed, and efficiency. Commercially available enzymes for the modification of pulp fibers include cellulases, hemicellulases, and laccases. Generally, hemicellulases are hydrolytic enzymes active on the hemicellulose fraction of the lignocellulose. The endo-1,4-β-xylanases (EC 3.2.1.8) randomly cleave the backbone of the xylan, leading to the release of oligomeric xylan fractions (Dhiman et al. 2008). Currently there is a growing interest to use enzymes for the modification of fibers to save production costs, reduce energy consumption, and most importantly to improve or even change fiber properties. The most important enzyme applications in pulp and paper making are xylanase-aided bleaching, cellulase- and hemicellulose-enhanced refining and drainage, enzyme-aided deinking, and control of disturbing compounds such as stickies and pitch components (reviewed by Kenealy and Jeffries 2003). Moreover, it can be stated that xylanase-aided bleaching is one of the most studied and widely spread enzymatic applications in the pulp and paper industry today (Bajpai 2004). In addition to the pulp and paper industry, xylanase is applicable in the food, feed, and textile industries (Dhiman et al. 2008; Collins et al. 2005). The use of cellulases and hemicellulases to enhance refining (Noe et al. 1986; Comtat et al. 1985) and to improve drainage (Wong and Mansfield 1999; Baipai 1999; Buchert et al. 1998) in papermaking has been studied for many years. When cellulase mixtures have been applied to enhance the pulp drainage it has been observed that the effect is mainly caused by the endoglucanase fraction of the mixture (Oksanen et al. 2000). On the other hand, xylanase and mannanase treatments have shown only slight improvements of the Schopper-Riegler (SR)-value. Nevertheless, up to 40% improvements in drainage have been reported when treating secondary fibers with a cellulase/hemicellulase enzyme mixture (Bhardwaj et al. 1996). This is not surprising, as EG treatments of different pulps have been shown to improve drainage especially when applied to pulps with low initial freeness (Kamaya 1996). However, excessively long treatment times or too high cellulase dosage will lead to the opposite effect, with deteriorated pulp strength properties (Oksanen et al. 1997a; Pere et al. 1995).

Although the possibility to enzymatically enhance the pulp drainage is well known and has been applied also in mill scale, the enzyme effects on the fiber wall ultrastructure and the drainage properties through the whole paper machine process are still poorly understood. In addition, the majority of the previous studies on the effects of enzyme treatment on dewatering have been carried out on softwood pulp or recycled pulp, and thus the applicability of the enzymes on the virgin hardwood pulp needs clarification. Since about 25% to 30% (Dhiman et al. 2008) of hardwood pulp consists of water-absorbing hemicellulosic materials, the enzymatic removal of xylan is likely to have a positive effect on pulp dewatering properties. The xylan removal has been shown earlier for instance to improved resistance to pressing (Maloney et al. 1998b) and to higher tendency of fiber hornification (Oksanen et al. 1997b) and collapsibility (Moss et al. 2006) during drying.

Thus, the objective of this study was to evaluate the effect of enzymatic removal of xylan on the dewatering properties of hardwood kraft pulp and to clarify the mechanism of the enzymatic fiber modification and its effect on dewatering, fiber, and sheet properties. Based on our results xylanase is a promising tool for specific enhancement of drainage properties of hardwood kraft pulp.

EXPERIMENTAL

Enzyme Treatments of Pulp

Two batches of never-dried and dried (50%/50%) mill-refined ECF-bleached birch kraft pulps from a Finnish fine paper mill were treated with commercial xylanase (Ecopulp®TX 200A, AB Enzymes, Finland). The xylanase and endoglucanase activities of the enzyme product were analyzed by quantifying reducing sugars released from 1% birch xylan (Fluka 95588) or hydroxyethylcellulose (Fluka) substrates with 3,5-dinitrosalicylic acid (Sigma D-0550) (Bailey et al. 1992; Pere et al. 1995). The activity assays were carried out at 50°C in 0.1 M Tris-HCl buffer pH 7.5. Absorbance at 540 nm was read with spectrophotometer (Hitachi U-2000, Tokyo, Japan). Under the conditions used in the enzyme assays the enzyme product contained 90 000 nkat/ml endo-xylanase and 102 nkat/ml endo-glucanase activity. The enzyme was added to the pulp samples at a dosage level from 13 to 200 nkat xylanase/g pulp. The enzyme treatments were carried out at 50°C, pH 7.5, 4 to 5% pulp consistency and 30 minutes treatment time.

Carbohydrate Analysis

The carbohydrate content of pulp was determined with the total hydrolysis of carbohydrates by sulfuric acid, after which the monosaccharides obtained were reduced to the corresponding alditols by sodium borohydride and subsequently converted to their acetyl derivatives (Janson 1970; Sjöström et al. 1966). The carbohydrate separation was done with a gas chromatograph (Shimadzu 17-A, Japan) with a NB-1701 column (film thickness 0.25 µm, length 25 m, internal diameter 0.32 mm, Hnu Nordion, Finland) and FID-detector (Japan).

The carbohydrates released in the pulp filtrates by the xylanase treatment were analyzed after acid hydrolysis with 72% sulfuric acid and pH adjustment according to Hausalo (1995). The resulting monosaccharides were separated using an anion exchange column (Dionex CarboPac PA20, width 3 mm, length 150 mm) and quantified by pulsed amperometric detection (HPAEC-PAD) with a Dionex DX-500 (Oriola Espoo, Finland) liquid chromatograph.

Analysis of Water and its Fractions in the Fiber

To estimate the amount of water retained by the fiber, the FSP (fiber saturation point) of the pulps was determined. FSP measures the water within the cell wall of a saturated fiber and in this study solute exclusion technique with dextran as molecular probe was used (Stone and Scallen 1968). The centrifuged sample solution was measured with a polarimeter (Autopol IV, Rudolph Research, UK).

The heat-flux differential scanning calorimeter (Mettler 821e, Mettler-Toledo, Switzerland) was used for determining the amount of freezing and non-freezing bound water located in micropores of the fibers (Maloney et al. 1998a) but also to determine the pore size distribution (PSD). The amount of water in the macropores (bulk water) was calculated by subtracting the water in the micropores from the FSP value. In this work, micro size refers to pores between the fibrils in the cell wall with a fibril structure ranging from 10 to a few hundred nm, and the term macropore is used for slit-like natural aperture pits having a diameter of up to 4 µm. In all the above measurements, the amount of water is expressed as grams of water per grams of dry fiber.

Process Simulation and Dewatering Measurements

The devices used for simulating the papermaking process included a Moving Belt Former (MBF) for sheet forming, a press simulator (modified MTS 810) for wet pressing, and an infra red dryer (IR) for drying the sheets (Eom 2005). The main difference between MBF and use of a conventional sheet mould is the pulsating vacuum dewatering. As in the real papermaking processes, the pulsation changes the direction of the water flow in a fast rate, disrupting the formed web and thereby creating more realistic dewatering conditions than a standard sheet mould. In addition, pulp consistency in MBF´s headbox is in same range, from 0.2% to 0.1%, as in a headbox of the real paper machine. In MBF, the vacuum was set to 30 kPa, and sheet basis weight (dry) was 60 g/m^2. The development of solids content in wet pressing was measured with MTS where the samples were first pressed with 2 MPa and then with 6.4 MPa using 20 ms press pulses. In the drying simulator, the wet pressed samples were exposed to IR radiation (single-sided contact simulator with MX-50 Moisture Analyzer, A&D, UK) producing 185°C drying temperature in the drying chamber and resulting in the evaporation of the remaining water from the inside of the fibers.

Dewatering from the stock and web was evaluated by several methods. First, the filtration resistance (Canadian standard freeness, CSF) of the pulps was determined according to ISO 5267-2 standard. After the sheet forming in MBF, the dry solids content of the wet samples was measured to estimate differences in forming section dewatering. In the wet pressing, the dry solids content of the wet sheet was defined both after the 1st and the 2nd pressing. In IR-drying the samples were continuously weighted until 95% solids content was reached. The coefficients for the phase of constant drying rate were calculated from the mass-time curves by detecting the differences in the drying of the fibers. In addition to the direct measurements of the drying rate, the fiber-water measurements were used for estimating the drying properties of the fibers.

Analysis of Pulp and Paper Properties

The laboratory sheets were prepared according to EN ISO 5269-1 and tested according to ISO 534 (modified density), ISO 2470 (ISO-brightness), ISO 2471 (modified opacity), ISO 9416 (modified light scattering), EN ISO 1924-2 (tensile index), and ISO 15361 (zero span) standards. Pulp viscosity was defined according to the SCAN-CM 15:99 standard in a copperethylenediamine solution (Volusol product number 5761.500) with a capillary viscometer (viscosity tube Laborexin Oy, Finland).

RESULTS AND DISCUSSION

Hydrolysis of Birch Kraft Pulp with Xylanase

To estimate the effect of the enzyme treatment on pulp yield, the filtrates after the enzyme treated pulps were analyzed for dissolved sugars (Fig. 1). The pulp filtrates from xylanase treatments mainly contained sugars originating from xylan, indicating that the used commercial product was applicable for the selective xylan hydrolysis. The result was also supported by the xylanase assay carried out for the enzyme product. The pulp yield reduction caused by the enzyme treatments was relatively low, up to 0.58% of pulp dry weight, which corresponds to 2.6% of the pulp xylan with the highest xylanase dosage (200 nkat/g).

Effect of Enzymatic Treatment on Pulp and Fiber Properties

Based on PSD measurements the main share of the pores present in the pulp were larger than 10 nm in size (Fig. 2). It has been estimated that the diameter of a xylanase belonging to the glycoside hydrolase family GH 11 is in the range 3 to 5 nm (Suurnäkki et al. 1996) , indicating that the xylanase enzyme could easily penetrate inside the cell wall and therefore alter the dewatering properties of the cell wall. . In addition, it has also been shown earlier that endoglucanase can efficiently hydrolyze pulp carbohydrates and lower the viscosity more than the xylanases (Dickson and Wong 1998; Kibblewhite and Clark 1996). This is not surprising, as the pulp viscosity is highly dependent on the degree of polymerization (DP) of the pulp cellulose.

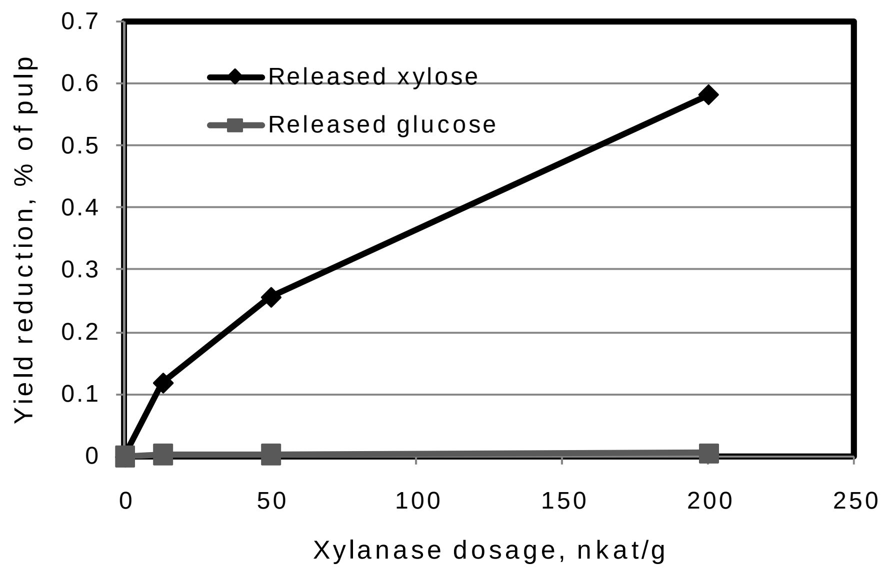

Fig. 1. Pulp yield reduction caused by the xylanase (Ecopulp TX 200A) treatments of mill refined birch kraft pulp. The yield reduction was quantified by the analysis of released sugars from the enzyme pulp filtrate after acid hydrolysis and the obtained carbohydrates where then subtracted from the corresponding reference sample. The mannose, arabinose and galactose content of the pulp filtrates were below the detection limit.

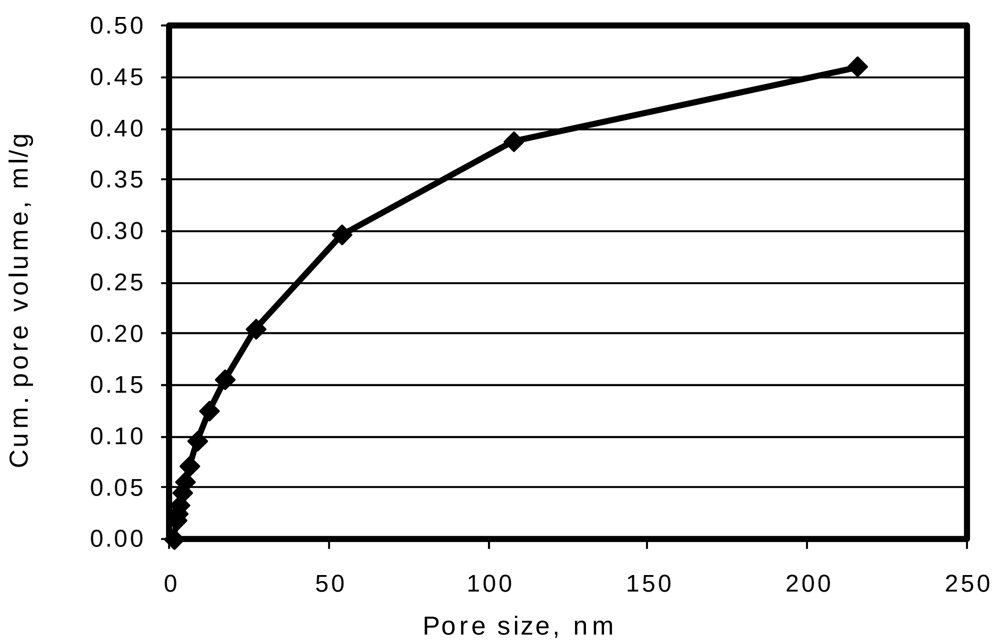

Fig. 2. The pore size distribution of the mill refined birch kraft pulp was determined with a heat-flux differential scanning calorimeter using an isothermal step method

As presented in Fig. 3, the fiber saturation point (FSP) values decreased slightly for the xylanase-treated pulp. Although the difference is within the measurement error, the trend is slightly downwards. The difference between the reference and the highest xylanase dosage was 0.08 g/g, representing a relative difference of approximately 6%. The decrease in FSP suggests a reduction of the xylan content. Lesser swelling due to the enzymatic removal of pulp xylan has been reported by Oksanen et al. (1997b) and Moss et al. (2006). Kibblewhite and co-workers have also shown slight decreases in FSP-values when bleached pine slabwood were treated with xylanase and different cellulases (Kibblewhite and Clark 1996).

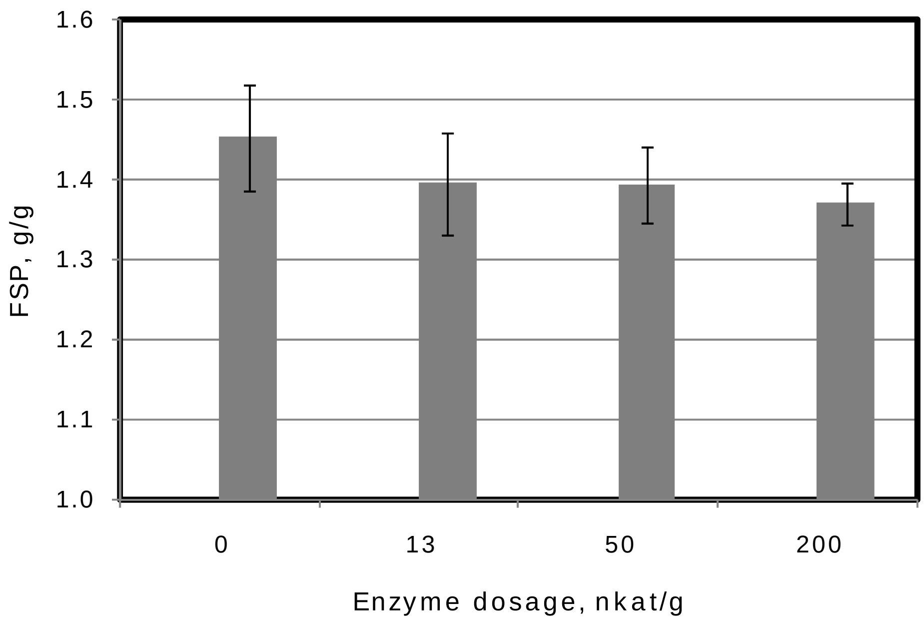

Fig. 3. Fiber water content measured with FSP for xylanase (Ecopulp TX 200A) treated mill refined birch kraft pulp. FSP was measured by solute exclusion technique with dextran as a molecular probe. The enzyme dosages were 0, 13, 50 and 200 nkat/g. 95% confidence intervals of 6 parallel samples are also shown in the figure.

In Fig. 4 it can be seen that the freeness value slightly increased from 470 ml to 500 ml after the xylanase treatment. Decreased filtration resistance reflects changes in the specific surface area that is strongly influenced by the fines content and external fibrils on fibers, and it is probable that the measured increase in freeness results from the enzyme action on these pulp components. In fact, it has been shown earlier that xylanase acts on pulp xylan, especially on the fiber surface, i.e. on the outer fiber surface and on the surfaces of the accessible fiber pores (Kantelinen et al. 1993). The carbohydrate composition of the used birch pulp was 77% glucose, 22% xylose and 1% mannose. Thus, it seems likely that by removing the water absorbing xylan by enzymatic treatment it can have a positive effect on the drainage properties. Previous studies have also shown slight improvements of drainage properties analyzed by freeness measurement after xylanase treatment of hardwood pulps (Noe et al. 1986).

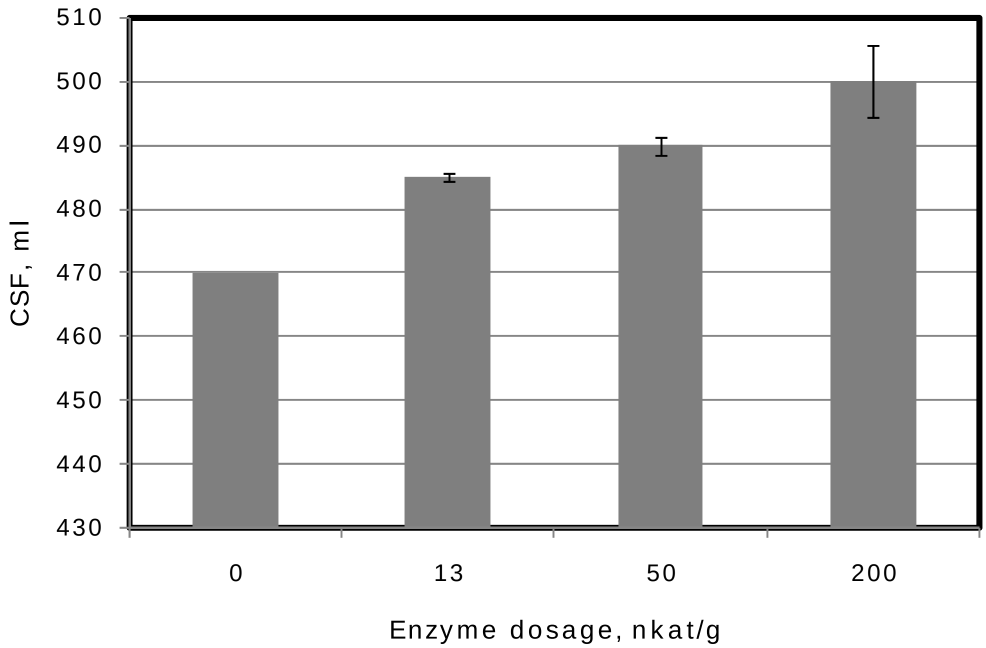

Fig. 4. Freeness (Canadian standard freeness, CSF) for xylanase (Ecopulp TX 200A) treated mill refined birch kraft pulp. The enzyme dosages were 0, 13, 50 and 200 nkat/g. Standard deviations of 2 parallel samples are shown in the figure.

Water components within the fibers of xylanase treated and reference pulps are presented in Fig. 5. The amount of water in the micropores (total bound water, TBW) of xylanase treated pulps was 0.7 g/g, and it was at the same level as the reference. The division of total bound water into freezing and non-freezing water showed approximately equal amounts of both components in all test dosage levels, indicating that the enzyme did not alter the structure of the micropores. The only change was in the amount of bulk water: the lower xylanase dosage resulted in a decrease of 0.05 g/g and the higher dosage cut off a further 0.04 g/g. However, changes of approximately this magnitude were measured in the FSP values, and since the FSP is used in the calculation of bulk water, the results indicate that pore structure of the fiber changed only at the macro scale, not in the micro scale. In past work, similar trends in macropore water amounts have been reported when pulp xylan content was reduced with acid hydrolysis (Maloney et al. 1998b).

Teleman and co-workers (2001) have shown that only one third of birch pulp xylan is accessible to xylanase action and that this xylan fraction is situated on the surfaces of the pulp microfibrils. On the other hand, Suurnäkki and co-workers (1996) have shown that the xylanase action is distributed almost uniformly between the surface and the inner cell walls of both pine and birch fibers. In addition, it has been shown that the total pore volume of fibers is decreased after the removal of xylan and glucomannan from bleached kraft pulp by enzymatic treatment (Oksanen et al. 1997b). Therefore, it can be suggested that xylanase is active mainly on the pulp surface and on the surface of the macropores but not within the micropores, resulting in an increase in freeness and a decrease in pulp FSP and the amount of bulk water.

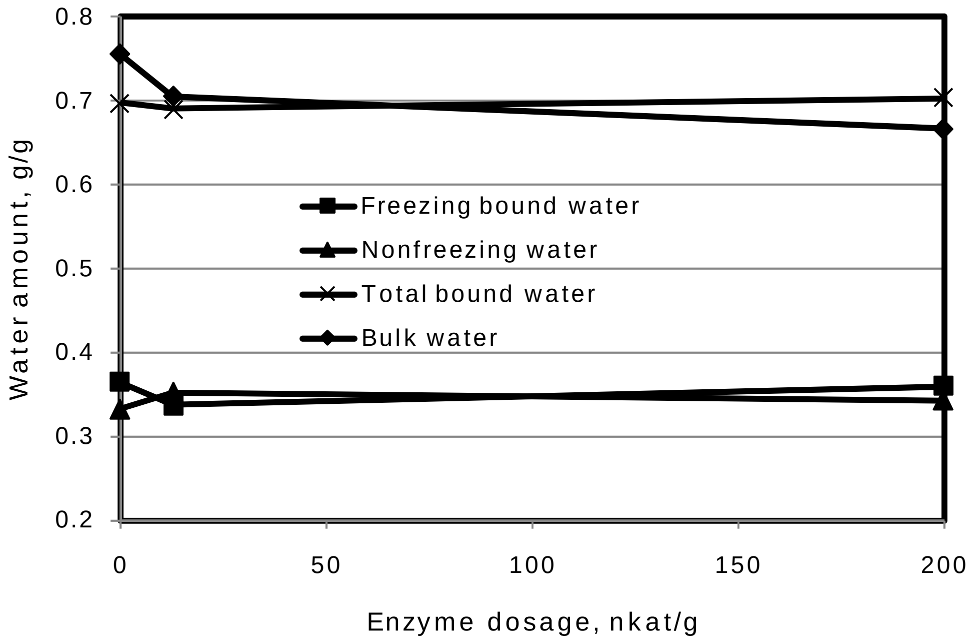

Fig. 5. Water fractions for xylanase (Ecopulp TX 200A) treated mill refined birch kraft pulps. A heat-flux differential scanning calorimeter was used to determine the freezing and non-freezing bound water. The total bound water corresponds to the amount of water in the micropores and the bulk water to the amount of water in the macropores (FSP values-micropore water). The enzyme dosages were 0, 13, 50 and 200 nkat/g.

Effect of Enzymatic Treatment on Dewatering Properties

The effect of enzyme treatment on paper machine dewatering was clarified by simulating the forming, press section and drying with MBF, MTS, and IR-drying equipment, respectively. The development of the web solids content in sheet forming and in the two wet pressing nips is presented in Fig. 6. After the sheet forming and the first press nip, the solids content was 16% and 28%, respectively, and no significant differences were observed between the xylanase treated pulp and the reference pulp. In the 2nd pressing the enzyme treated pulps seemed to have a different response compared to the reference: xylanase pulps produced approximately 3%-units higher solids content than the reference.

As presented in the previous chapter, the enzyme treatment increased slightly the freeness value of the pulps (Fig. 4) and consequently the expectation was that dewatering in the forming and press section would improve as well. However, apart from the 2nd pressing of xylanase treated pulp, no improvement was observed. Past studies have shown that particularly endoglucanase increases freeness and can in that way improve machine runnability (Wong and Mansfield 1999). Also, earlier studies with an enzyme mixture of cellulase and xylanase have shown that drainage time of softwood pulp can be decreased (Hernadi 2002). It has been suggested that as the enzymes are mainly active on the pulp surfaces, their action can remove fibrils from the fiber surface and thereby improve pulp drainage. The explanation for unchanged dewatering in the forming and first press nip could be the differences in the dewatering conditions in freeness measurement and MBF; in the first the flow through the web is clearly slower than in the latter (dewatering takes typically 5 to 20 seconds in freeness whereas MBF it takes 2 to 4 seconds) and as fast flow compresses the network producing web of higher density, the filtration resistance becomes higher. Previous work has shown enhanced collapsibility/flexibility of xylanase-treated softwood fibers (Mansfield et al. 2000), which could, in turn, contribute to higher density of wet webs. Thereby, it can be speculated that the effect of reduced specific surface area seen in the freeness measurement is offset by the higher web density, lower porosity, and reduced permeability of the wet web in the MBF forming and first pressing.

The improvement of solids content in the 2nd pressing with the xylanase treatment could be related to easier dewatering of the cell wall under compression (Fig. 6). There is a common observation that in compression of porous material the largest pores collapse first, followed by sequentially smaller pores (Paulapuro 2001), and at the ingoing solids content of approximately 30%, the water is squeezed out from cell wall macropores as well as from the inter fiber space. It seems that the xylanase has acted on the outer layers of the cell wall and macropores, reducing the rigidity of cell wall, thereby making the fiber more responsive to compression and possibly also leading to irreversible pore closures, i.e. wet hornification (Maloney et al. 1997) and reduced rewetting of the cell wall. Maloney and co-workers (1998b) suggested that xylan in the cell wall resists compression and when it is even partially removed by acid hydrolysis, the response of the pulp to pressing can be improved. In addition to changed cell wall strength, xylanase has acted on the fiber - as measured by FSP and water amount in micropores - so that the amount of water in macropores has decreased to some extent and this possibly explains part of the increase in solids content.

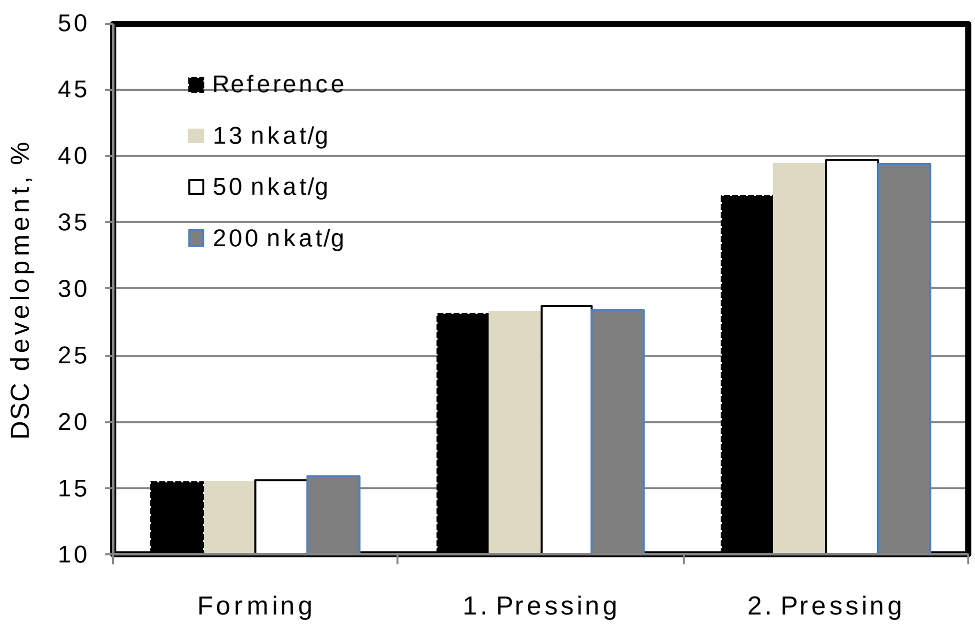

Fig. 6. Dry solids content (DSC) of xylanase (Ecopulp TX 200A) treated mill refined birch kraft pulps after MBF forming and 1st and 2nd MTS wet pressing. The enzyme dosages were 0, 13, 50 and 200 nkat/g.

The drying section dewatering, simulated with IR-drying, improved when the pulp was treated with xylanase (Fig. 7). Time to reach 95% solids content was 72 seconds for the reference, whereas the enzyme-treated pulps reached the same dryness in 62 to 64 seconds, representing a difference of 13% to 15%. Also the coefficients of linear fits to curves in the constant evaporation rate period (16 s to 29 s) were 15% to 21% higher with the xylanase pulps compared to the reference. It should be noted that, to begin with, there is a 2.4% solids content difference in favor of the treated pulps and this could have some effect on the dynamics of drying, but it is unlikely that the evaporation rate at the constant period would change much if the solids content difference would be compensated. Instead, it is possible that the changes the enzyme has induced in the fiber surface and cell wall pore structure contribute to easier water removal from the macro-pores.

In addition, further investigations on how especially the drying section dewatering is affected when different paper making chemicals, such as fixatives and PCC, are added to the pulp furnish verified the results (Lähdeniemi 2009). In addition, the results are also supported by the laboratory studies carried out by Bajpai and co-workers (2006), who have shown that a mixture of cellulases and hemicellulases can result in steam consumption savings in the paper machine dryer. Indeed, the higher solids content after press section results in reduced steam consumption and drying energy in the dryer section or, in case of dryer restricted process, increased paper machine speed.

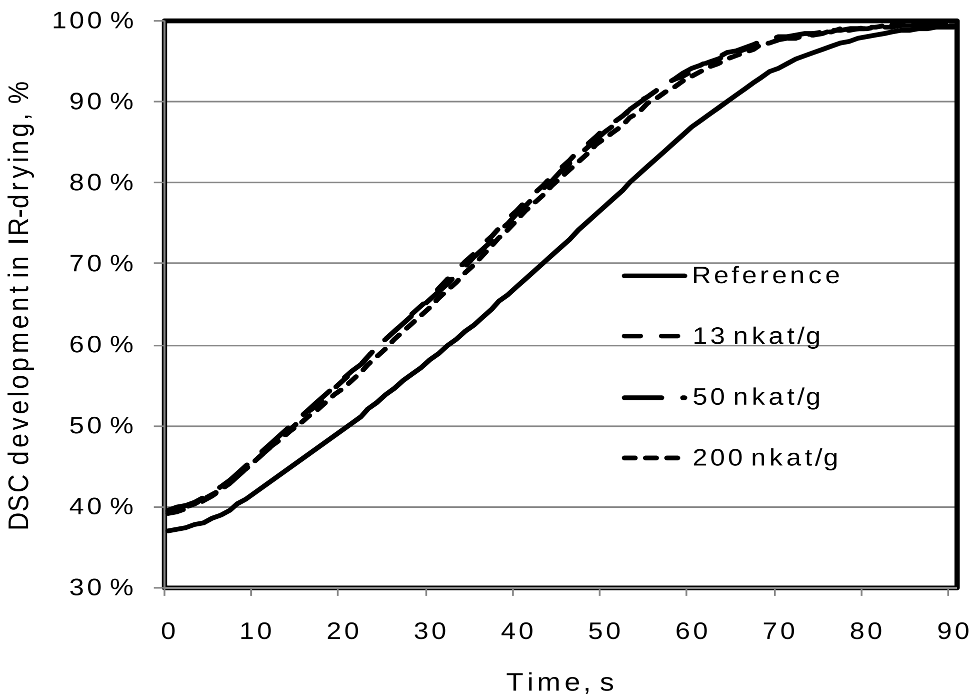

Fig. 7. Development of dry solids content of xylanase (Ecopulp TX 200A) treated mill refined birch kraft pulps in IR-drying. The enzyme dosages were 0, 13, 50 and 200 nkat/g.

Effect of Enzymatic Treatment on Paper Properties

The sheet properties of the enzyme-treated pulps are presented in Table 1. It can be seen that the tensile indices at a given density generally increased slightly for xylanase-treated pulps compared to the reference. In other words, the overall sheet strength of the enzyme treated pulps was positively affected by the enzyme treatments. On the other hand, past work have shown a slight decrease in tensile index values when refined softwood pulp had been treated with CBH and xylanase (Oksanen et al. 1997a), whereas the tensile index values significantly decreased for EG-treated pulp (Pere et al. 1995). Moreover, it has been shown that irregular zones in the fiber wall are preferentially attacked by cellulases (Ander et al. 2008) and which in turn significantly can affect the paper strength (Gurnagul et al. 1992).

The zero-span test is often used as a measurement to estimate the single fiber strength and can be measured for both wet and dry samples. The zero-span strength for xylanase treated samples was not compromised and even somewhat higher values were obtained in some dosage points (Table 1). In past work, wet zero span breaking length has been reported to significantly decrease for xylanase treated birch pulp (Noe et al. 1986), but this might have been caused by the cellulase impurities in the enzyme sample. According to Pere and co-workers (1995), wet and dry zero-span values decreased for EG-treated softwood pulp, whereas wet zero-span stayed at approximately similar or at slightly decreased level for CBH and xylanase treated pulp (Dickson and Wong 1998).

The brightness values increased after xylanase treatment (Table 1). The results can be explained by the removal of chromophoric xylan (hexenuronic acid) from the surface of the fibers and fines (Kenealy and Jeffries 2003, Bajpai 2004). Previous investigations have shown that xylanase used in pulp bleaching hydrolyzes xylan deposited on the fiber surface and in that way enhances the effect of the bleaching chemicals (Kenealy and Jeffries 2003). The pulp used in this study is already bleached kraft pulp and thus the increased brightness is probably obtained only by the xylan removal.

Table 1. Sheet Properties of Xylanase (Ecopulp TX 200A) Treated Mill Refined Birch Kraft Pulps. The enzyme dosages were 0, 13, 50 and 200 nkat/g

Enzyme and dosage (nkat/g)	Density (kg/m^3)	ISO-Brightness (%)	Tensile index (Nm/g)	Zero span tensile index WET (Nm/g)	Zero span tensile index DRY (Nm/g)
Reference	720	90.7	59.9	125	152
Xylanase, 13	718	91.3	61.6	122	155
Xylanase, 50	718	91.7	61.2	129	158
Xylanase, 200	722	92.1	61.2	128	154

Based on these results, it can be concluded that the effects of the xylanase treatment on the handsheet properties were only minor, the main difference being the increased brightness of the pulp. Although earlier studies have shown beneficial changes in pulp dewatering properties by the endoglucanase treatment, concomitant deterioration of fiber strength properties have often been observed. The low effect on the paper properties can be considered as a benefit of the xylanase treatment compared to endoglucanase treatment.

CONCLUSIONS

1. The main benefit of the xylanase treatment of bleached hardwood kraft pulp was the improved dewatering properties, especially in the second wet pressing and in thermal drying simulated with IR-drying. The time to reach the 95% dry solids content was reduced by up to 15% by the xylanase treatment, which can lead to reduced drying energy consumption in the dryer section of the paper machine or alternatively increased paper machine speed. The shorter drying time and higher evaporation rate in the xylanase treated pulps reveals that the enzyme influences the fiber cell wall properties in a manner that potentially makes the water flow from inside the fiber easier.
2. The simulation of the paper making process showed that although the freeness of the enzyme treated pulps increased, the dewatering in forming section or in the first press nip was not improved. This is possibly due to higher flexibility of the enzyme treated fibers, producing higher wet web density, lower porosity and permeability, and consequently higher filtration resistance at flow rates comparable to the paper machine.
3. The mechanism of xylanase´s action on the bleached hardwood kraft pulp was further clarified. The xylanase treatment decreased the FSP values but not the amount of water in the micropores (expressed as TBW), suggesting that the enzyme had an effect on the macropore structure of the fibers, consequently resulting in reduced amount of water carried within the cell wall.
4. The effect of the xylanase treatment on the paper strength properties was only minor and neither the pulp yield nor the fiber strength was compromised. The pulp brightness was improved, which could be beneficial, permitting reduced use of bleaching chemicals or optical brightening agents. Therefore, it can be concluded that with the xylanase treatment improvements in the pulp dewatering properties were obtained without significant unwanted side-effects.

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