Response of xylanase-treated kraft pulp to Escher-Wyss and PFI refining

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EXECUTIVE SUMMARY

To enhance the processing of kraft pulp, alternative means are being sought to reduce energy consumption during refining and/or improve the resultant fibre properties. In the present study the effects of treating an unbleached kraft pulp derived from *Pinus radiata* with a commercial xylanase enzyme were investigated using Escher-Wyss and PFI refining. The Escher-Wyss mill, a laboratory scale conical refiner, is considered to give a closer representation of mill scale refining than the PFI mill. This is largely because Escher-Wyss refining is performed at lower stock consistency with greater control over total energy application. The results of our investigation supported previous observations indicating that there is a greater development of handsheet properties after PFI than Escher-Wyss refining. Escher-Wyss refining, however, revealed greater modification of fibre characteristics by xylanase treatment, when compared to the control, than was observed after PFI refining.

For Escher-Wyss refining xylanase treatment of the commercial, never-dried pulp resulted in an approximately 50% saving of the energy required to achieve a given apparent density. Handsheet properties indicated that the primary effect of the enzymatic treatment was an increase in apparent density. Further analyses of xylanase-treated fibres showed that they were more flexible, making them more conformable in the wet state to permit better consolidation of the fibre web. The mechanism altering fibre flexibility remains to be elucidated. The fibre properties and pulp refinability achieved with xylanase treatments could lead to the development of new processes for pulp and paper manufacture.

ABSTRACT

The effects of a xylanase enzyme on the properties of an unbleached softwood kraft pulp were investigated after Escher-Wyss and PFI refining. Escher-Wyss refining revealed greater modification of fibre characteristics after enzymatic treatment, with the energy required to achieve a given apparent density reduced by approximately 50%. There was little change in intrinsic fibre strength and the tensile strength-apparent density relationship. The enhanced consolidation of the fibre web was apparently the result of higher fibre flexibility.

Application:

Treatment with xylanase enzyme improves the refinability of unbleached softwood kraft pulp, particularly for low consistency refining.

Keywords:

kraft pulp, refining, xylanase, enzyme, physical properties, fibre flexibility, consolidation

INTRODUCTION

The continued profitability of manufacturing pulp and paper products requires constant effort to enhance processing efficiencies and product quality. Alternative means to achieve these goals include the use of enzymes to selectively modify and improve pulp fibre properties. For kraft pulp, crude cellulases, monocomponent cellulases, mannanases, xylanases and the laccase-mediator system have all been evaluated *(1–8)*. Although pulp treatment with cellulases has led to improvements in tensile strength in certain cases, reaction conditions must be carefully controlled because these enzymes tend to weaken intrinsic fibre strength. The earliest work on xylanase treatment *(1)* suggested that this enzyme could improve pulp refinability. However, the results were not completely conclusive because the loss of intrinsic fibre strength indicated the presence of cellulases in the treatment. More recent work showed that xylanase can modify fibre properties without the loss in fibre strength *(4, 5)*. In contrast, limited effects were observed after pulp treatment with mannanase *(6)* or the laccase-mediator system *(8)*.

Our initial screening of different enzymes on laboratory *(4)* and commercial *(9)* kraft pulps derived from *Pinus radiata* confirmed that xylanase is a class of enzyme that is able to favourably modify pulp properties with limited deleterious effect on intrinsic fibre strength. With one exception *(4)*, treatment with xylanase consistently produced sheets of higher apparent density at a given level of PFI refining, while demonstrating increased tear index and slightly decreased tensile index at a given apparent density *(9, 10)*. A selective increase in the tear index at a given tensile index was also observed in certain cases, and the observed decrease in tensile strength at a given apparent density was eliminated by decreasing enzyme loading.

The aforementioned investigations employed the PFI mill, in which refining is typically performed at high consistency (10%) with numerous fibre-to-fibre contacts *(11)*. In contrast, the Escher-Wyss mill is a laboratory-scale conical refiner that is recognised for providing a closer representation of mill scale refining *(12)*. Besides permitting the control of specific edge load and total energy application, Escher-Wyss refining is also performed at lower stock consistencies (typically 2 to 5%) with less fibre-to-fibre contacts and more fibre cutting (especially at high specific edge loads).

Since pulps refined with the PFI and Escher-Wyss mills are known to show different trends in the development of physical properties *(13)*, it is important to compare PFI refining of xylanase-treated pulp with Escher-Wyss refining. In the present study this comparison was made using a commercial xylanase (Pulpzyme HC) on an unbleached kraft pulp.

EXPERIMENTAL

Xylanase Treatment

A kraft pulp derived from *Pinus radiata* (never-dried, unbleached, medium coarseness) was obtained from Tasman Pulp and Paper (Kawerau, New Zealand) *(9)*. This unbleached pulp was treated with Pulpzyme HC, a commercial xylanase preparation obtained from Novo Nordisk (Denmark), at a loading of 2 µkat/g. The activity of the xylanase was determined on birchwood xylan (Sigma, USA) according to the DNS-based method of Bailey *et al. (14)*.

The pulp slurry was initially stabilised at pH 7 and the enzyme was added with the dilution water needed to bring the preheated pulp to a consistency of 5%. The pulp was then mixed thoroughly using a hand-held mixer and incubated at 50°C for 2 hours. After the enzymatic treatment an aliquot of the filtrate was collected for carbohydrate analysis. The pulp was adjusted to pH 12 with sodium hydroxide and held at room temperature for 15 minutes, then well washed to neutral pH. The control pulp was treated in the same manner except that no enzyme was added. Due to the large amounts of pulp required (1.2 kg for each treatment), treatment was carried out in 6 separate plastic bags with pulp samples being pooled later.

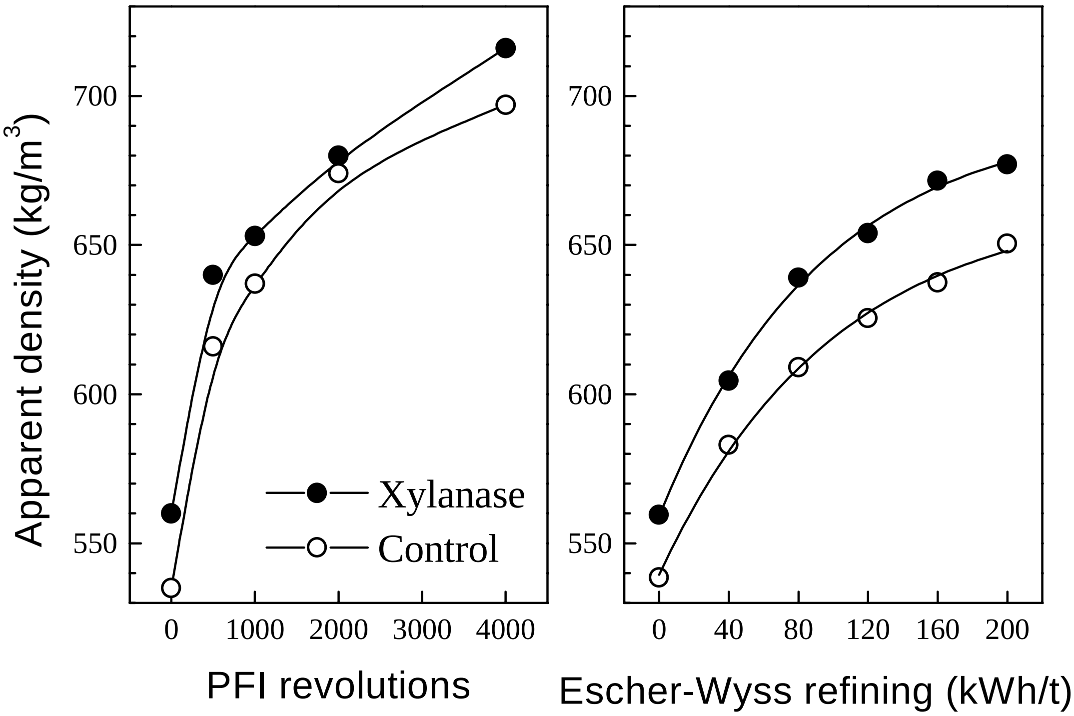
Pulp Refining and Testing

PFI refining was performed once with an applied load of 3.4 N/mm, at 10% pulp consistency. Escher-Wyss refining was performed twice using the Escher-Wyss conical refiner with a specific edge load of 0.5 Ws/m, refiner speed set at 1500 rpm, and pulp consistency at 3.5%. Handsheets were prepared and evaluated in accordance with APPITA standard procedures. All data from physical testing are reported on o.d. bases. Fibre curl measurements were made on the never-dried fibres from Escher-Wyss refined pulps (0, 40 and 160 kWh/odt), using the technique of Miller *(15)*. Fibre flexibility was evaluated on never-dried fibres from Escher-Wyss refined pulp (40 kWh/t), using the method of Steadman and Luner *(16)*, while microcompressions were determined by polarised illumination *(17)*.

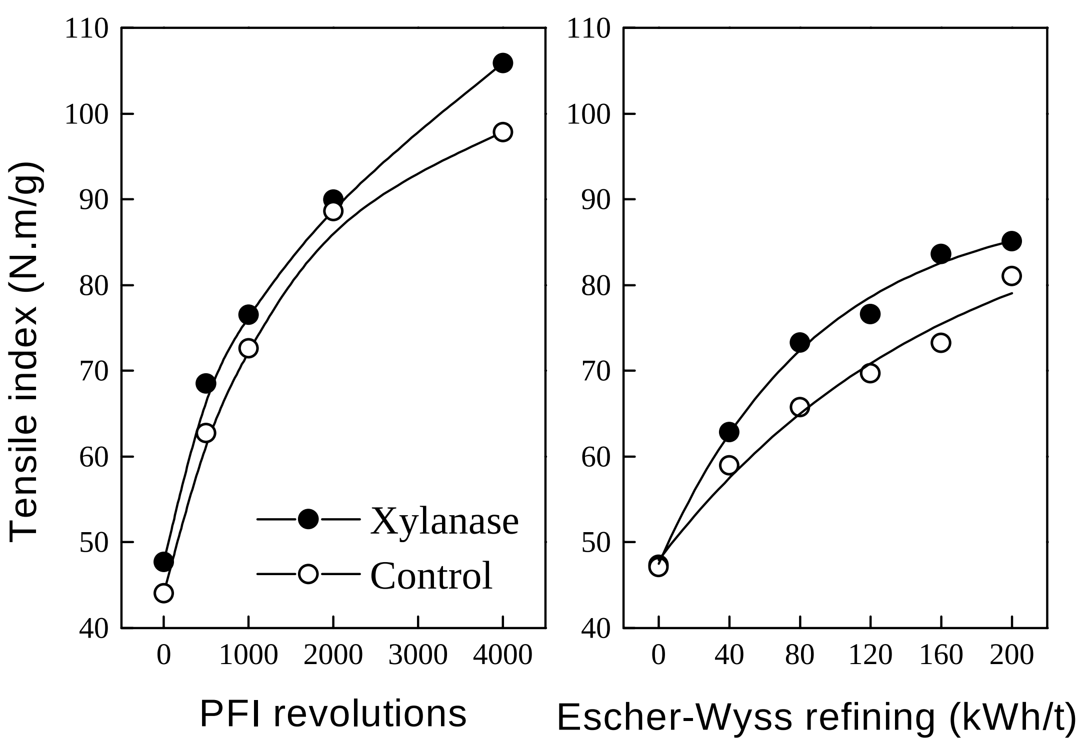
RESULTS AND DISCUSSION

Pulp and Handsheet Properties with Refining

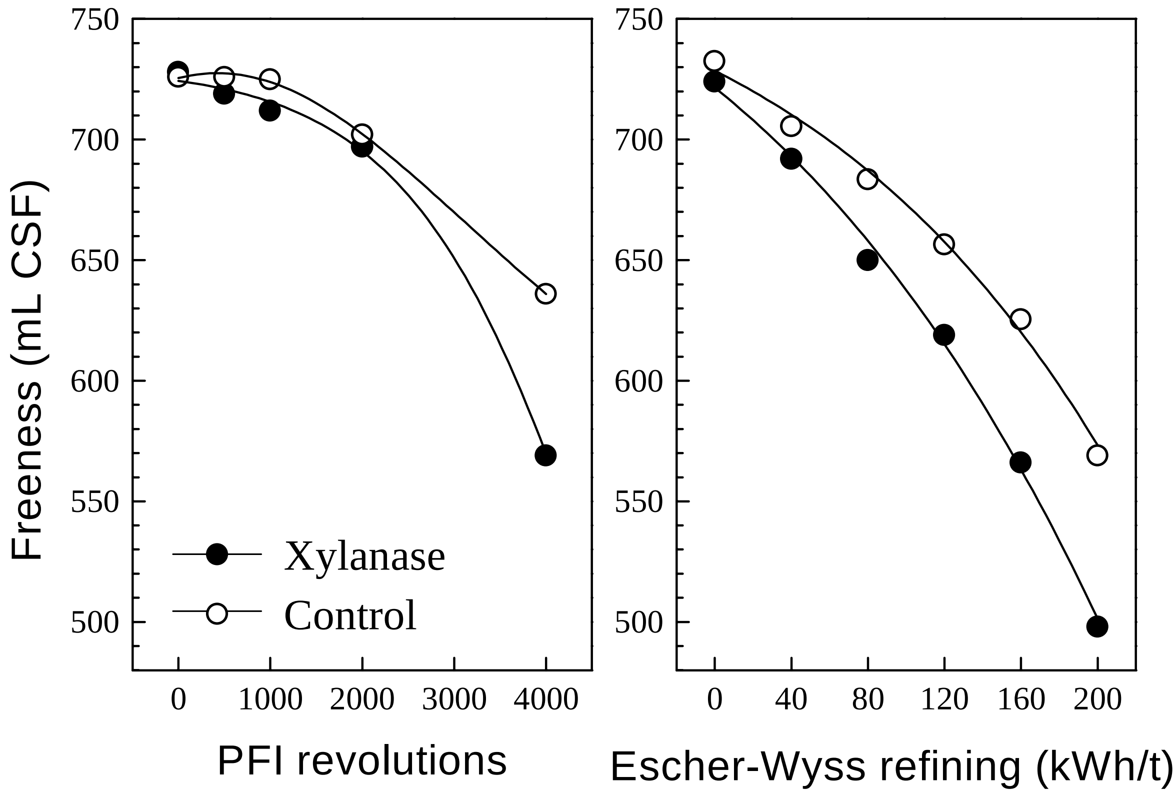
The development of apparent density with refining appeared to be greater for the PFI refined pulps, extending up to 700 kg/m^3 for the control fibres after 4000 revolutions of refining (**Figure 1**). With Escher-Wyss refining, sheet density for the control fibres seemed to plateau at 630 to 650 kg/m^3 after 160 to 200 kWh/t of refining. This general trend also applied for properties such as tensile (**Figure 2**) and tear indices. In contrast, pulp freeness showed greater development after Escher-Wyss than PFI refining (**Figure 3**).



1. Sheet density versus refining level for PFI and Escher-Wyss refined pulps.

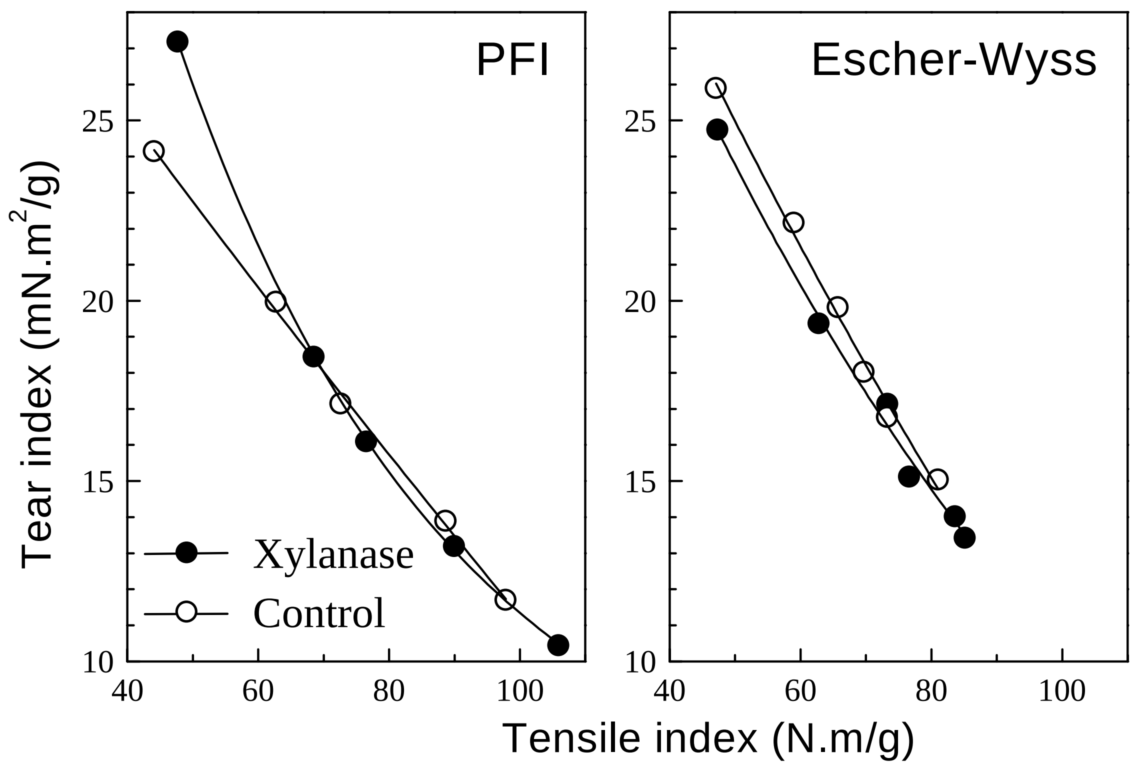


2. Tensile index versus refining level for PFI and Escher-Wyss refined pulps.



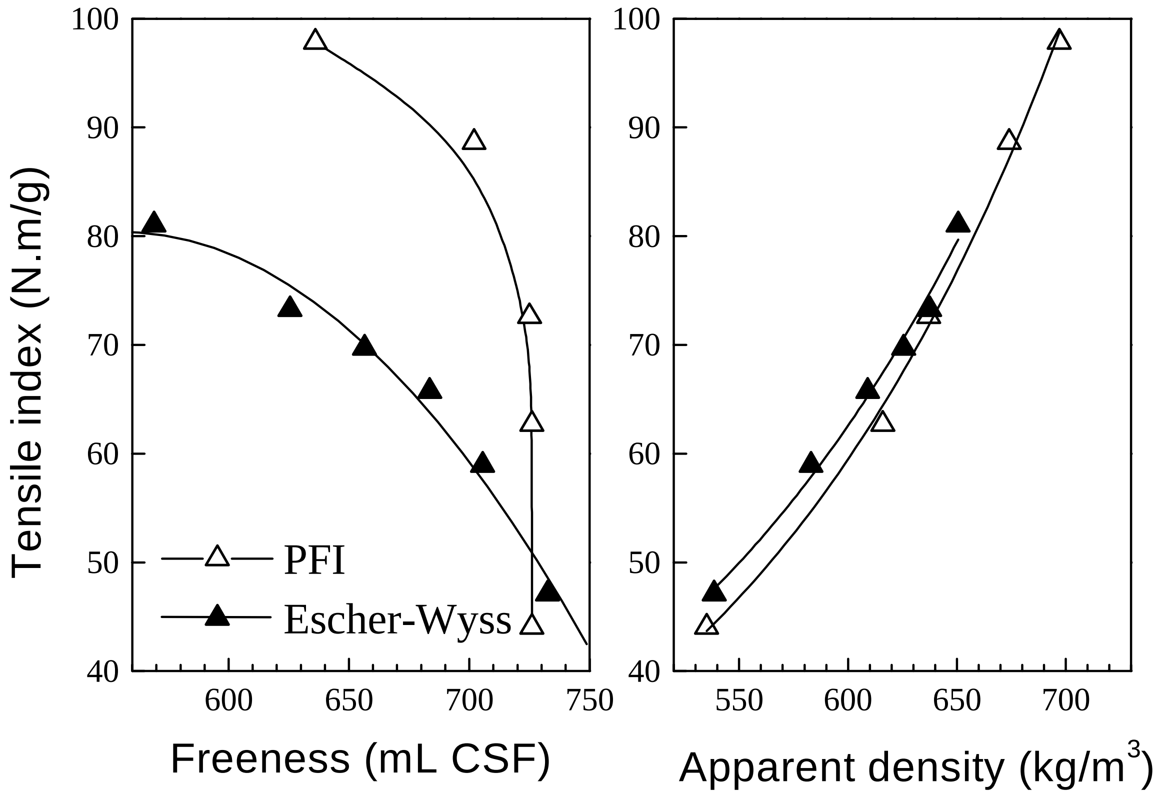
3. Freeness versus refining level for PFI and Escher-Wyss refined pulps.

Xylanase treatment yielded an initial increase in apparent density, even before refining (Figure 1). With PFI refining this initial increase in apparent density was maintained at approximately 20 kg/m^3. In contrast, there were additional increases in apparent density with increasing Escher-Wyss refining. Compared to the control fibres refined with the Escher-Wyss mill, the xylanase-treated fibres required almost 50% less energy to achieve a given apparent density. Other pulp and handsheet properties such as freeness (Figure 3), tensile index (Figure 2), and tear index showed similar trends with xylanase treatment and refining in the two refiners. However, the overall tear-tensile relationship was not greatly affected by the enzymatic treatment or by refiner type (**Figure 4**).



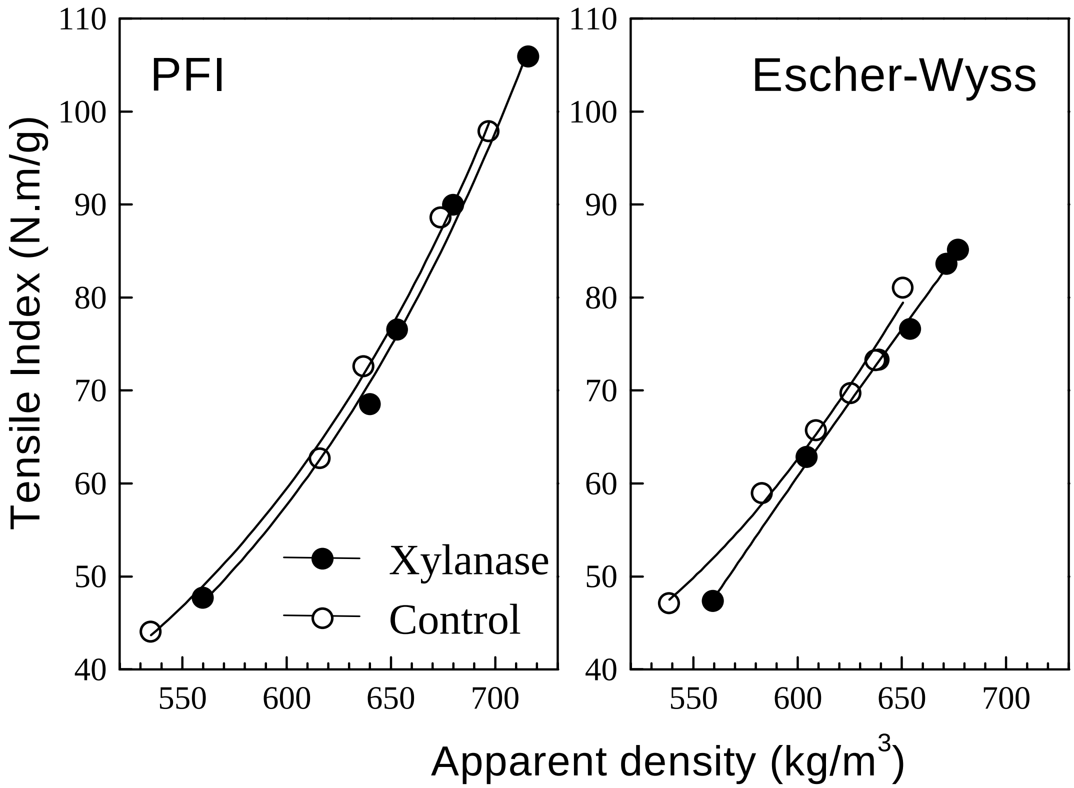
4. Tear index versus tensile index for PFI and Escher-Wyss refined pulps.

There was considerable difference between refiners in the development of tensile index at a given freeness, but very little in the development of tensile index at a given apparent density (**Figure 5**). As freeness can vary greatly between refiner types as well as for different pulps, it is not suitable for the comparative evaluation of pulps *(18)*. Further comparisons in the present study were therefore generally based on sheet density.



5. Tensile index versus freeness and sheet density for PFI and Escher-Wyss refined pulps after control treatment.

When tensile (**Figure 6**) and tear indices were plotted against apparent density, no discernible difference could be found between the control and the xylanase-treated fibres. There was also no evidence of substantial changes in the wet zero span tensile index, T.E.A. index tensile stiffness index, scattering coefficient, air resistance and Sheffield roughness at a given sheet density (data not shown). A consistent effect of xylanase treatment after refining in either mill was a small increase in brightness at a given sheet density. As most differences in physical properties, between the xylanase-treated and the control pulps, tended to become insignificant when plotted as a function of apparent density, it is likely that the increase in apparent density before and during refining is the primary effect of the xylanase treatment.



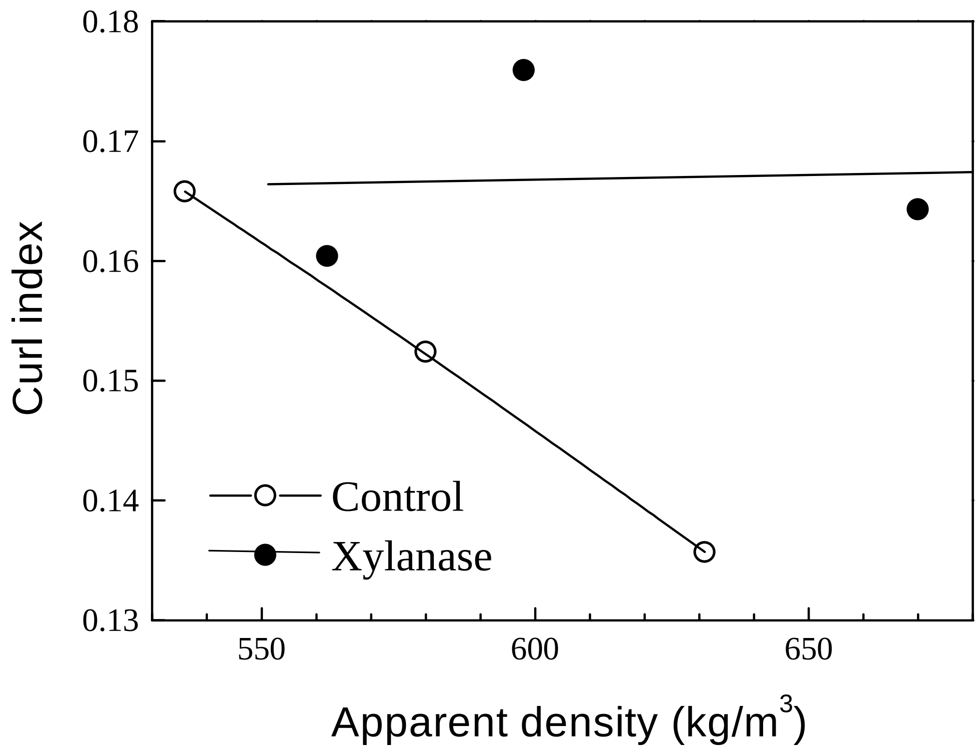
6. Tensile index versus sheet density for PFI and Escher-Wyss refined pulps.

PFI refining is regarded as not being very energy efficient, as it imparts many impacts between fibres but at a low intensity *(19)*. Escher-Wyss refining results in greater fibre cutting than PFI refining, an effect that can be minimised by reducing the specific edge load. The lowering of specific edge load also increases the tensile index at a given tear index as a result of increased development of the fibre surface with minimal wall disruption *(20)*. Even at the low specific edge load used in the present study (0.5 Ws/m), Escher-Wyss refining resulted in more fibre cutting than PFI refining (data not shown) and correspondingly lower pulp freeness. These phenomena indicate that the effects that varying edge loads have on xylanase-treated fibres, and how they relate to a commercial scale operation, warrant investigation.

Mechanisms of Handsheet Densification for Escher-Wyss refined pulps

The analysis of treatment filtrates showed that xylanase action was highly selective for the removal of xylan, with 7.0 mg of xylan solubilised per gram of pulp. Since the xylan content of the pulp was 6.8% *(9)*, approximately 10% of total xylan was solubilised during the enzymatic treatment. These results are comparable to previous values obtained with similar and higher enzyme loadings *(9, 10)*. The enzyme charge of 2 μkat/g was very high and probably not commercially viable, however, it was chosen for the present study to ensure maximum effect. In future studies enzyme charge could be optimised in terms of cost of application versus energy savings achieved. Treatment with xylanase resulted in a slight decrease (approximately 1%) in fibre length compared to the control. This will account for some of the increase in apparent density seen with xylanase treatment. However, the decrease in fibre length only occurred after refining and cannot account for the initial increase in apparent density before refining.

The presence of fibre curl is known to raise the bulk of a sheet *(21)*. Therefore, it was possible that the increase in apparent density after xylanase treatment was facilitated by the removal of fibre curl. An analysis of curl after Escher-Wyss refining showed that for the control pulps, there was a direct relationship between a decrease in curl of the fibres in the pulp and an increase in apparent density of handsheets. In contrast, for the xylanase-treated pulps, apparent density appeared to be independent of fibre curl. Furthermore, the observed curl index at a given sheet density was generally greater than that of the corresponding control pulp (**Figure 7**). Therefore, the increase in apparent density resulting from xylanase treatment could not be attributed to the removal of fibre curl.



7. Curl index versus sheet density for Escher-Wyss refined pulps. The two samples with the least apparent densities were unrefined.

An analysis of fibre flexibility demonstrated that the xylanase-treated fibres were significantly more flexible than the control fibres (**Table I**). The more conformable nature of the xylanase-treated fibres in the wet state would be expected to produce denser handsheets, irrespective of fibre curl. During stock preparation higher fibre flexibility may be responsible for the maintenance of fibre curl in the Escher-Wyss refiner (Figure 7). Effective fibre flexibility is also known to increase with refining *(22, 23)* and this has been explained by an increase of microcompressions and dislocations in the fibre wall with refining *(11, 17)*. Although a direct correlation between fibre flexibility and microcompressions has been shown by Hartler and Nyrén *(24)*, the present investigation did not reveal a significant increase in the frequency of microcompressions or nodes in association with the increase in flexibility for the xylanase-treated fibres (**Table I**). The reasons for this are unclear, but the results suggest that some other mechanism is involved in altering the flexibility of the xylanase-treated fibres.

Sample	Fibre flexibility, $\log(N^{-1}\ m^{-2})$	Micro-compressions, number/mm	Nodes, number/mm
Control	11.61	52.3	2.2
Xylanase	11.81	53.5	2.0
LSD*	0.09	3.8	0.4

*Least Significant Difference between samples at 95% confidence level.

I. Fibre flexibility of unbleached, never-dried fibres and frequency of fibre wall dislocations for Escher-Wyss refined pulps (40 kWh/odt)

CONCLUSIONS

Treatment of an unbleached softwood kraft pulp with Pulpzyme HC xylanase resulted in approximately 50% saving in the energy consumption required to achieve a given apparent density using the Escher-Wyss refiner. The energy saving was less prominent in the PFI mill. After Escher-Wyss refining, pulps treated with Pulpzyme HC had a decreased freeness with minimal changes in tear and tensile index at a given apparent density; the tear/tensile relationship remaining essentially unchanged.

The primary effect of xylanase treatment was an increase in apparent density brought about by enhanced fibre flexibility. The higher fibre flexibility facilitated greater conformability in the formation of a more closely packed, denser sheet. However, the altered flexibility was not associated with an increased frequency of cell wall dislocations, so that the mechanism is yet to be determined.

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