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BLEACHED KRAFT PULP FROM PRE-EXTRACTED BEECH WOOD

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ABSTRACT

Beech chips were pre-extracted with hot water and green liquor prior to kraft pulping. The total pulp yield of green liquor pre-extracted chips equivalent to 10 % wood weight was approximately the same as that from the original chips, while the pulp yield from hot water pre-extracted chips was lower by 4.2 %. Effective alkali charge was reduced by about 3 % in kraft pulping of green liquor pre-extracted chips, and by about 1 % in kraft pulping of hot water pre-extracted chips when compared with original chips. The pulps from pre-extracted chips demonstrated higher oxygen delignification efficiency and bleachability in the sequence $D_0(EO)D_1D_2$ as in case of reference pulp from original chips. Consumption of chlorine dioxide in bleaching of pulps from hot water pre-extracted chips was lower by about 17 % at 5 % wood weight loss and 20.5 % at 10 % wood weight loss, while in case of pulp from green liquor pre-extracted chips it was lower only by about 5 % at the same weight loss compared with the reference pulp. The overall yield of bleached pulps from hot water pre-extracted chips was lower by 1.2 and 3.1 %, respectively (at 5 and 10 % wood weight loss), of the pulp from green liquor pre-extracted chips by 0.2 % in comparison with the reference pulp. Brightness reversion and beatability of bleached pulps from pre-extracted chips was lower as compared with the reference pulp, mainly in case of pulps from hot water pre-extracted chips. Tensile index of bleached pulps prepared from pre-extracted chips was lower, however tear index was higher in comparison with the bleached reference kraft pulp.

KEYWORDS: Beech wood, pre-extraction, hot water, green liquor, kraft pulping, bleaching, strength properties.

INTRODUCTION

Pulp and paper mills represent a major platform to be used more effectively as an abundant, renewable bioresource – wood. Kraft pulp mills are the primary candidates to be trasformed into biorefineries, as they have the infrastructure to process biomass feedstock. One biorefinery concept involves pre-extraction of hemicelluloses, which are normally combusted in the chemical recovery boiler of a pulp mill. The extract of hemicelluloses oligomers or polymers may be used as feedstock for transportation fluids, polyester polymers and chemicals.

Extraction of a part of hemicelluloses from wood chips prior to the pulping process and conversion to marketable high added value products exceeding the fuel value of hemicelluloses more than 20 times may considerably improve financial situation of a pulp mill (van Heiningen 2006). The extracted hemicelluloses can be used directly in polymeric form for novel industrial applications (Ebringerová et al. 1994, Gabrielii et al. 2000, Jain et al. 2000), either they can serve as a monosaccharides source for the bioethanol (Niu et al. 2003) or the value added chemicals production (Carvalheiro et al. 2008). Therefore, interest to extract hemicelluloses from wood before pulping and to utilize extracted hemicelluloses has greatly increased in recent years.

Extraction of hemicelluloses before pulping can be carried out by alkaline or acidic treatment by steam processing, or with hot water (autohydrolysis), which leads mainly to generation of soluble oligomers or low-molecular weight polymers. The amount of hemicelluloses extracted depends on severity of the pre-treatment conditions. Selection of the hemicelluloses extraction process is critical and depends on its efficiency, selectivity, and compatibility with existing pulping technology. However, since the cost of kraft pulp is still the most significant factor, it is essential that the pulp yield and strength properties are maintained after the pre-extraction. Hemicelluloses pre-extraction from hardwood chips with various alkaline solutions prior to kraft pulping has been investigated (Helmerius et al. 2010, Sixta and Schild 2009, Jin et al. 2010). Alkaline solutions are directly accessible in kraft mills, for all that are very attractive to the industry. Therefore, much attention has been given to green liquor and white liquor. Green liquor (sodium carbonate and sodium sulphide), white liquor (sodium hydroxide and sodium sulphide) and caustic can be used to extract hemicelluloses from wood chips without severely affecting the pulp yield and quality (Yoon et al. 2011, Walton et al. 2010, Fišerová et al. 2013a).

A process of hot water pre-extraction of hardwood before pulping to extract hemicelluloses is an environmentally friendly technology, which takes advantage of the readily available hemicelluloses component of hardwood species. Hot water extracts containing mainly xylose and other xylan-originated degradation products such as xylans of lower degree of polymerization, xylose oligomers, acetic acid, and furfural. Kraft pulping and bleaching of hot water pre-extracted wood has several advantages and disadvantages with respect to conventional pulping and bleaching of the original wood. The advantage of extracted hardwood chips compared to those non-extracted for kraft pulping is the reduced chemical charge and/or cooking time required to obtain bulkier pulp of similar kappa number, however with a drawback of lower strength properties (Fišerová et al. 2013b). Alternatively, the major drawbacks of performing an autohydrolysis stage prior pulping are the decreased pulp yield and limited strength of pulps, derived from cellulose depolymerisation and decreased residual xylan content. Van Heiningen and co-workers (Yoon at et al. 2008, Yoon and van Heiningen 2008, Tunc and van Heiningen 2008a, b, 2009) suggest an approach of water prehydrolysis into alkaline pulping concepts to realize a biorefinery.

Therefore, the pre-extraction should solubilise a part of hemicelluloses under optimal conditions. The pre-extracted chips enriched mainly in cellulose and lignin which will be processed in kraft pulping. Integration of a hemicelluloses pre-extraction process into a pulp mill causes minimal changes in the final properties of the pulp, which is the main product, and minimal disruption to the normal operation (Yoon et al. 2008, Mendes et al. 2009, Helmerius et al. 2010).

The objective of this study was to find out the influence of hot water and green liquor pre-extraction of beech wood chips on kraft pulp yield, bleachability, beatability and strength properties of bleached pulps in comparison with the reference pulp from original chips.

MATERIAL AND METHODS

Material

Beech wood (*Fagus sylvatica* L.) mill chips were used in this study. Natural dirt was removed (Tappi test method T 265 cm-09) and the chips of 20x20x3 mm dimensions were used for laboratory pre-extraction and kraft pulping experiments.

Methods

Hemicelluloses pre-extraction

Wood chips were extracted with hot water (WE) and kraft green liquor solution corresponding to 3 % Na_2O charge (GLE) on oven dry wood weight (ODW). Green liquor of total titratable alkali 121.7 g Na_2O/L (156 g Na_2CO_3/L, 35 g Na2S/L and 3.5 g NaOH/L) was received from a kraft pulp mill. The extraction experiments were performed in a series of six laboratory autoclaves, each of 0.75 L volume. The autoclaves were filled with 100 g ODW screened beech wood chips. The liquor-to-wood ratio was 4:1. The time to maximum extracting temperature 160°C was constantly 60 min and the dwell time at this temperature to remove with hot water 5 % wood weight was 14 min and 10 % wood weight was 30 min, with green liquor to remove 10 % wood weight was 48 min.

Kraft pulping

Pre-extracted beech wood chips were pulped after draining the extraction liquor without chips washing. The volume of residual extraction liquor in chips was about 1/3 of the total liquor. The kraft pulping experiments were performed similarly to the pre-extraction. White liquor of 25 % sulphidity plus fresh water was added to obtain a liquor-to-wood ratio 4:1 at the required effective alkali (EA) charge. Effective alkali charge was 12 % in kraft pulping of green liquor pre-extracted chips, 14.5 % and 14 % of hot water pre-extracted chips, while 15 % (all as Na_2O) in reference kraft pulping. The reference kraft pulping experiments of original beech wood chips were carried out at 170°C. The heating time to this temperature from 100°C was constantly 90 min and the dwell time ranged from 30 to 60 min. The corresponding H-factors changed from 432 to 1122 hrs. The kraft pulping experiments of pre-extracted wood chips were performed at constant temperature of 170°C. The dwell time at this temperature ranged from 15 to 60 min, and the corresponding H-factors ranged from 230 to 918 hrs. Pulps were disintegrated in a laboratory pulper and thoroughly washed. The wet pulps were placed in a refrigerator for measurement of total pulp yield. Reject content, kappa number and strength properties of pulps were determined after screening on a laboratory screen with 0.25 mm slots.

Oxygen delignification

The reference kraft pulp (Reference KP) prepared from original beech wood chips (kappa number 16.8), the pulp from green liquor pre-extracted chips at 10 % wood weight loss (10 % GLE) of kappa number 17, the pulp from hot water pre-extracted chips at 5 % wood weight loss (5 % WE) of kappa number 16.8 and 17.1 at 10 % wood weight loss (10 % WE), were delignified by oxygen in two stages (OO). In the first stage of oxygen delignification, NaOH and $MgSO_4$ charges on oven-dry pulp were of 1-2.5 and 0.15 %, respectively. The experimental conditions of two-stage oxygen delignification were as follows:

Stage	1	2
Reaction time (min)	30	60
Temperature (°C)	90	100
Consistency (%)	10	10
Pressure (MPa)	0.6	0.3

Bleaching

The same bleaching conditions were applied for oxygen delignified kraft pulps of kappa number of about 8, prepared from the original and pre-extracted beech chips. The bleaching sequence was $D_0(EO)D_1D_2$. The bleaching in individual stages was performed at 10 % pulp consistency. The ClO_2 charge in D0 stage was 0.7 % ClO_2 (0.23 kappa factor), temperature 60°C, reaction time 60 min and initial pH 2.5. The NaOH charge in EO stage was 1 %, temperature 75°C, pressure 0.3 MPa and reaction time 60 min. After the EO stage, each pulp was divided into four equal portions, which were then bleached in the D_1 stage with 0.4, 0.8, 1.2, and 1.6 % ClO_2 charge. Each of the four resulting D_1 pulps was bleached in the D_2 stage with 0.3 % ClO_2 charge. The D_1 and D_2 stages were conducted for 180 min at 80°C and initial pH 4 and 4.5, respectively.

Analyses

White liquor was prepared and analysed according to TAPPI test method T 624 cm-85. Kappa number of pulp was determined according to ISO 302: 2004. Brightness of pulp was determined according to ISO 2470-1: 2009 and brightness reversion according to TAPPI Useful Methods UM 200. The kraft pulps were beaten in a laboratory Jokro mill to 20, 30, 40 and 50°SR. Drainage resistance of pulps was determined according to ISO 5267-1 2001 standard. Hand sheets (80 $g.m^{-2}$) were prepared on a Rapid Köthen sheet former according to ISO 5269-2 2004 and were tested for tensile index (ISO 1924-2 2008) and tear index (ISO 1974).

RESULTS AND DISCUSSION

Kraft pulping

The goal of pre-extraction is to obtain a relatively high yield of hemicelluloses in extract, but at the same time to minimize degradation of polysaccharides in pre-extracted wood. Yield of kraft pulps prepared from beech chips pre-extracted with hot water at 5 % and 10 % of wood weight loss and with 3 % Na_2O green liquor charge at 10 % wood weight loss were compared to the kraft reference pulps from original beech chips. The relationship between total pulp yield and kappa number of kraft pulps prepared from original, hot water and green liquor pre-extracted beech chips is shown in Fig. 1. The total pulp yields of pre-extracted chips were lower in comparison with the kraft reference pulp at the same kappa number. At kappa number 20, the yield of pulp from chips pre-extracted with hot water at 5 % wood weight loss [5 % WE-KP (14.5 % EA)] was 46.7 % and at 10 % wood weight loss [10 % WE-KP (14 % EA)] 44.2 %. The yield of pulp from chips pre-extracted with green liquor at 10% wood weight loss [10 % GLE-KP (12 % EA)] was 48.2 % and the pulp yield from original chips [Reference KP (15 % EA)] was 48.4 % at the same kappa number. Yields of pulps prepared from chips pre-extracted with hot water were significantly lower (by 1.7 and 4.2 %, respectively) than the yield of reference kraft pulp. Yield of pulp from chips pre-extracted with green liquor was about 0.2 % lower than the yield of reference kraft pulp.

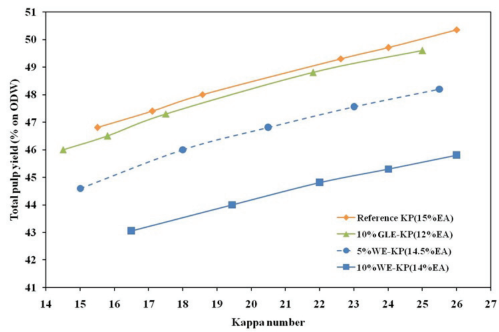

Fig. 1: Total pulp yield versus kappa number of pulps prepared from original, hot water and green liquor pre-extracted beech chips at 5 % and 10 % wood weight loss.

Total yield of pulp prepared from hot water pre-extracted chips was significantly lower. Similar results were achieved in our previous experiments (Fišerová et al. 1989). Hot water extract pH and pulp yields were lower than from green liquor pre-extracted chips. Polysaccharides, particularly cellulose undergo degradation in alkaline conditions due to peeling reactions, by which reducing end-groups of the cellulose chains are cleaved off, due to random alkaline hydrolysis. In acidic conditions of pre-extraction, hydrolysis causes formation of the new reducing end-groups, which results in severe yield loss in subsequent alkaline pulping.

The results showed that the extraction agent and wood weight loss had influence on the kraft pulp yield prepared from pre-extracted chips. The lower yield of kraft pulps prepared from hot water pre-extracted chips is attributed both to the removal of hemicelluloses during the pre-extraction and to the increased sensitivity of polysaccharides towards alkaline degradation as a result of acidic conditions in pre-extraction.

Effective alkali charge was reduced in kraft pulping of pre-extracted chips, but more in pulping green liquor pre-extracted chips. Hot water pre-extracted chips at 10 % wood weight loss were delignified with 14 % EA charge, whereas chips pre-extracted with green liquor were delignified with 12 % EA charge only. In reference kraft pulping of original beech chips EA charge was 15 %. Lower EA charge in kraft pulping was applied for reason of wood weight loss in pre-extraction. Additional reasons for lower EA charge in pulping is higher pH of green liquor extract (approximately 1/3 extract volume enters into pulping) and lower lignin content in pre-extracted chips. At the same kappa number pulp yields were higher which resulted in lower alkali consumption in dissolution of hemicelluloses.

A higher content of total monosaccharides at equal wood weight loss was reached in hydrolysed hot water extract. At 10 % wood weight loss in hydrolysed hot water extract the total monosaccharides content was 6.5 % on ODW and in hydrolysed green liquor extract 2.8 % on ODW (Fišerová and Opálená 2012). The same content of monosaccharides was in hydrolysed hot water extract at 5 % wood weight loss. At the same wood weight loss, the total monosaccharides content in hydrolysed green liquor extract was approximately twice lower than in hydrolysed hot water extract. This correlates with higher pH of green liquor solution. At these conditions, the lignin solubility is higher and degradation reactions of polysaccharides are more intensive in generation of saccharinic acids and other products (Tunc and van Heiningen 2011).

Pulp bleaching

The kraft pulps from the original and pre-extracted beech chips were bleached with (OO)D_0(EO)D_1D_2 sequence. In oxygen delignification experiments kraft pulp from original beech chips [Reference KP (15 % EA)], pulps from pre-extracted chips with green liquor at 10 % wood weight loss [10 % GLE-KP (12 % EA)], with hot water at 5 % [5 % WE-KP (14.5 % EA)] and at 10 % wood weight loss [10 % WE-KP (14 % EA)] were treated. The kappa number of unbleached pulps entering OO stage was approximately 17. The delignification degree (in %) defined as the kappa number drop during oxygen delignification divided by initial kappa number prior to oxygen delignification increased with NaOH charge (Fig. 2). The delignification degree increased more in case of pulps from hot water pre-extracted chips. The same effectiveness of oxygen delignification of these pulps was achieved at lower NaOH charge in comparison to the reference pulp, in that case delignification degree was higher at the same NaOH charge. Delignification degree of 50 % was reached in case of pulp prepared from hot water pre-extracted chips with 1 % NaOH charge and pulp from green liquor pre-extracted chips with 1.7 % NaOH charge at 10 % wood weight loss whereas in case of reference kraft pulp with 2 % NaOH charge. The results confirmed that the kraft pulps from pre-extracted chips responded better to oxygen delignification, first of all the pulps from hot water pre-extracted chips. The effectiveness of oxygen delignification of the pulp from hot water pre-extracted increased moderate with increasing the wood weight loss.

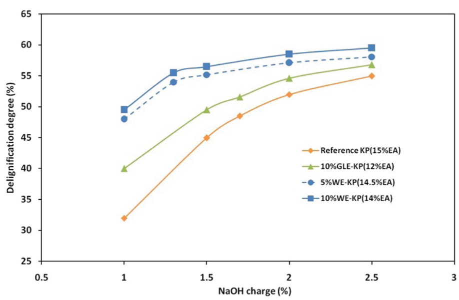

Fig. 2: Delignification degree versus NaOH charge in OO stage of the reference kraft pulp and of pulps prepared from beech chips pre-extracted with hot water and green liquor at 5 % and 10 % wood weight loss.

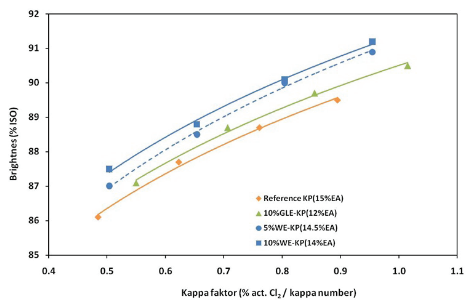

Fig. 3: Brightness versus kappa factor in D_0(EO)D_1D_2 sequence of the reference kraft pulp and of pulps prepared from beech chips pre-extracted with hot water and green liquor at 5 % and 10 % wood weight loss.

Higher oxygen delignification effectiveness of the beech wood kraft pulps from hot water pre-extracted chips may be connected with better accessibility to oxygen due to lower hemicelluloses and xylan content, respectively, in comparison with the reference kraft pulp. This can be contributed to opening of the fibre super molecular structure through hemicelluloses removal, allowing lignin to react more easily. These results corresponds with the finding of others researchers (Zou et al. 2002, Sixta 2006).

The oxygen delignified kraft pulps from the original and pre-extracted beech wood chips having a kappa number of about 8.5 were bleached by the sequence D_0(EO)D_1D_2, at the same conditions in individual stages. The consumption of ClO_2 in D_0, D_1 and D_2 stages was expressed as kappa factor defined as a consumption of active chlorine on kappa number unit of oxygen delignified pulp entering to the bleaching. Brightness of kraft pulps from original and pre-extracted chips after $D_0(EO)D_1D_2$ bleaching sequence at a different kappa factor is shown in Fig. 3. Brightness 89 % ISO of pulps from hot water pre-extracted chips was achieved at kappa factor 0.69 and 0.66, respectively, of pulp from green liquor pre-extracted chips at 0.79 and of the reference kraft pulp at kappa factor 0.83. Consumption of ClO_2 in the bleaching of pulps from hot water pre-extracted chips was lower by 16.9 and 20.5 %, respectively, and of pulp from green liquor pre-extracted chips was lower only by 4.8 % than of ClO_2 consumption in bleaching of the reference kraft pulp.

The improved bleaching efficiency of the pulps from hot water pre-extracted chips may be attributed to lower content of hemicelluloses thereby of hexenuronic acids, weaker lignin carbohydrate complex, an increase in the content of free phenolic hydroxyl groups of lignin, and lower ash content (Amidon et al. 2011). Hexenuronic acids readily consume electrophilic reagents such as chlorine dioxide. The results of our bleaching experiments also confirmed that bleached pulps from pre-extracted chips contain less hexenuronic acids at the same brightness level than the reference pulp.

High brightness and good brightness stability are the desired properties of bleached kraft pulps. Brightness reversion or yellowing of a pulp represents a loss of brightness occurring after bleaching, either during drying or upon storage of the pulp. The relationship between brightness reversion and brightness of the pulps bleached by the sequence $(OO)D_0(EO)D_1D_2$ is shown in Fig. 4.

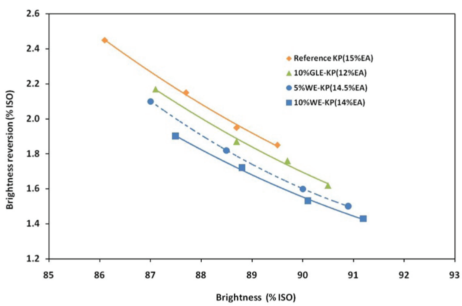

Fig. 4: Brightness reversion versus brightness of the reference kraft pulp and of pulps prepared from beech chips pre-extracted with hot water and green liquor at 5 % and 10 % wood weight loss bleached by the (OO) $D_0(EO)D_1D_2$ sequence.

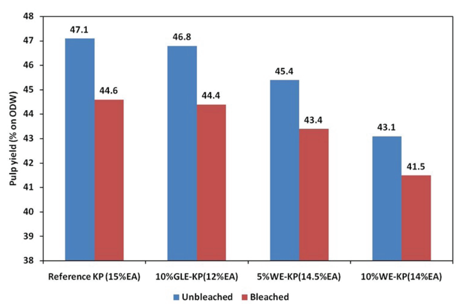

Fig. 5: Yields of the unbleached and bleached reference kraft pulp and pulps prepared from beech chips pre-extracted with hot water and green liquor at 5 % and 10 % wood weight loss.

Brightness reversion decreased in the following order: reference pulp > pulp from green liquor pre-extracted chips at 10 % wood weight loss > pulp from hot water pre-extracted chips at 5% wood weight loss > pulp from hot water pre-extracted chips at 10 % wood weight loss. Lower brightness reversion of bleached pulps prepared from pre-extracted chips when compared with the reference kraft pulp at the same brightness level correlate with lower content of hexenuronic acids. The presence of hexenuronic acids in pulps is known to be one contributing factor to brightness reversion (Ek et al. 1995).

Figure 5 compares yields of unbleached and bleached reference kraft pulp and pulps from green liquor and hot water pre-extracted beech wood chips. The pulping yields of unbleached pulps were determined from the kraft pulping delignification curve at kappa number level entering into oxygen delignification stage (Fig. 1). The yield of unbleached pulp from hot water pre-extracted chips was lower by 1.7 and 4.0 %, respectively (at 5 and 10 % wood weight loss), of the pulp from green liquor pre-extracted chips by 0.2 % in comparison with the yield of unbleached reference kraft pulp. The overall yields of the bleached kraft pulps were calculated taking into account the pulp yield loss in bleaching. The overall yield of bleached pulp from hot water pre-extracted chips at 5 % wood weight loss was lower by 1.2 % and at 10 % wood weight loss by 3.1 %, of the pulp from green liquor pre-extracted chips at 10 % wood weight loss by 0.2 % in comparison with the yield of bleached reference kraft pulp. The loss of pulp yield during oxygen delignification and bleaching with the $D_0(EO)D_1D_2$ sequence of the pulp from hot pre-extracted chips was 2.0 and 1.6 %, respectively (at 5 and 10 % wood weight loss), of the pulp from green liquor pre-extracted chips 2.4 %, while of the reference pulp 2.5 %. The loss of pulp yield in bleaching was lower in case of unbleached pulp from pre-extracted chips with lower pulping yield.

The results showed that the lower is the yield in kraft pulping the lower is the yield loss in the bleaching process. This is connected with lower content of hemicelluloses in pulps from pre-extracted chips. In the bleaching process the negative impact of hot water pre-extraction on the overall yield of bleached pulps was reduced with increased of wood weight loss in comparison with the bleached reference pulp.

Fig. 6 shows the evolution of drainage resistance (in °SR) with the beating time of bleached kraft pulps from the original and pre-extracted beech wood chips. Beatability of bleached pulps from pre-extracted chips was lower than of the reference kraft pulp. At 30°SR, the beating time of the bleached pulps increased in the following order: Reference pulp (23 min) < pulp from green liquor pre-extracted chips at 10 % wood weight loss (24 min) < pulp from hot water pre-extracted chips at 5 % wood weight loss (27 min) < pulp from hot water pre-extracted chips at 10 % wood weight loss (37 min). The bleached pulps from hot water pre-extracted chips seemed to require more beating energy by about 17 and 60 %, respectively, to attain the same drainage resistance than the bleached reference kraft pulp. This was caused most likely by the lower content of hemicelluloses.

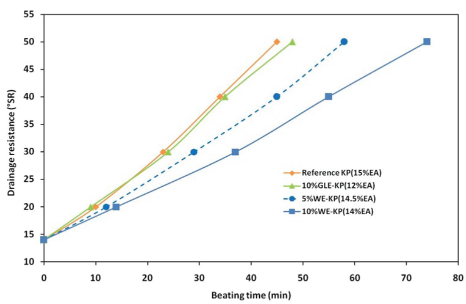

Fig. 6: Drainage resistance versus beating time of the bleached reference kraft pulp and pulps prepared from beech chips pre-extracted with hot water and green liquor at 5 % and 10 % wood weight loss.

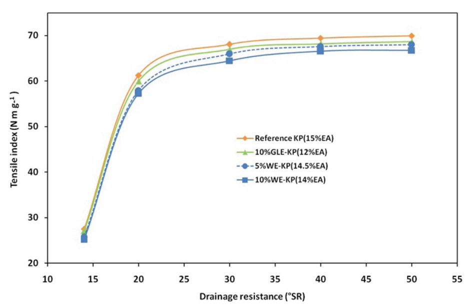

Fig. 7: Tensile index versus drainage resistance of the bleached reference kraft pulp and pulps prepared from beech chips pre-extracted with hot water and green liquor at 5 % and 10 % wood weight loss.

Tensile strength of each pulp type increases by beating (Fig. 7). There are indications that fibre/fibre joint strength also increases with beating due to changes in the physical structure of the fibre surface that makes new surfaces available of molecular bonding. Tensile strength of bleached pulps from pre-extracted chips was lower in comparison to the reference kraft pulp at a same drainage resistance. At 30°SR, tensile index of bleached pulps from original and pre-extracted chips were in the range 64-68 $N.m.g^{-1}$. The tensile index of the bleached pulps from hot water pre-extracted chips was lower by about 2.5 and 6 %, respectively (at 5 and 10 % wood weight loss), in comparison to the reference pulp, whereas the tensile index of the pulp from green liquor pre-extracted chips was only by about 1 % lower.

The results confirmed that the tensile index of bleached pulps increased with beating degree in the whole region of the drainage resistance measured in this work, even if, for the drainage resistance greater than 30°SR, an increase of tensile index is negligible, while the tear index increased substantially up to drainage resistance of 30°SR, and then decreased (Fig. 8). At 30°SR, tear indexes of bleached pulps were in the range 9.5-10.3 $mN.m^2.g^{-1}$. The tear index of bleached pulps from pre-extracted chips was higher in comparison to the reference kraft pulp at the same drainage resistance. The tear index of bleached pulps from hot water pre-extracted chips at 5 % wood weight loss was higher than the reference kraft pulp by about 4 % and at 10 % wood weight loss by about 8 %, whereas the tear index of the pulp from green liquor was only by about 2.5 % higher.

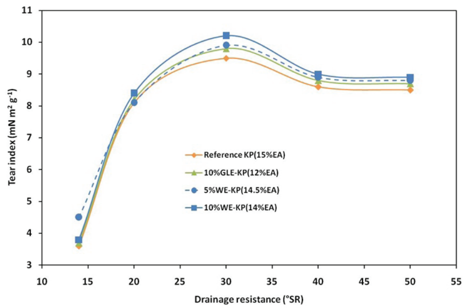

Fig. 8: Tear index versus drainage resistance of the bleached reference kraft pulp and pulps prepared from beech chips pre-extracted with hot water and green liquor at 5 % and 10 % wood weight loss.

CONCLUSIONS

Pre-extraction of hemicelluloses from beech wood can be used prior to kraft pulping in order to use hemicelluloses for biofuels or chemicals production. The total monosaccharides content in hydrolysed green liquor extracts was markedly lower as in hydrolysed hot water extracts at the same wood weight loss. Approximately, the same total monosaccharides content was in hydrolysed hot water extract at 5 % wood weight loss as in hydrolysed green liquor extract at 10 % wood weight loss.

A major advantage of the green liquor pre-extraction of beech wood is that the yield of kraft pulp remain essentially the same as that of reference kraft pulp from original chips. The unbleached pulp yield from hot water pre-extracted chips was lower in comparison with the reference kraft pulp at the same kappa number. The pulp yield decreased with increase of extracted wood amount, at 5 % wood weight loss about 1.7 % and at 10 % wood weight loss about 4.2 %. Potential benefit of hemicelluloses pre-extraction with green liquor is reduction of alkali charge in the pulping process from 15 to 12 % EA.

Kraft pulps prepared from pre-extracted chips with hot water and green liquor were more effectively delignified with oxygen than the reference pulps from original chips, particularly the pulps from hot water pre-extracted chips. The bleachability of pulps from hot water pre-extracted chips, by the $D_0(EO)D_1D_2$ bleaching sequence, was significantly better than that of the reference pulp, resulting in a decrease of chlorine dioxide consumption required for the same brightness level. Bleachability of the pulp from green liquor pre-extracted chips was only moderately better than that of the reference pulp. The loss of pulp yield in oxygen delignification and bleaching using the $D_0(EO)D_1D_2$ sequence was much lower for the pulps from hot water pre-extracted chips than for the reference pulp. Negative impact of hot water pre-extraction in the bleaching process on the overall yield of bleached pulps decreased in comparison with the bleached reference pulp.

Bleached pulps from pre-extracted chips had a lower brightness reversion in comparison with the reference pulp at the same brightness level, particularly the pulps from hot water pre-extracted chips.

Beatability of bleached pulps from hot water pre-extracted chips was much lower than of the bleached reference pulp, but in case of pulp from chips pre-extracted with green liquor was only slightly lower.

Tensile index of bleached pulps from pre-extracted chips was lower than that of the bleached reference pulp. On the other hand, tear index of bleached pulps from pre-extracted chips was higher than that of the bleached reference pulp, first of all of bleached pulps from hot water pre-extracted chips.

Pre-extraction of beech wood hemicelluloses with hot water before pulping improved the efficiency of pulping and bleaching to a high brightness, but the overall pulp yield was lower in comparison with the pulp from green liquor pre-extracted chips and the reference pulp.

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