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BLENDING IMPACT OF HARDWOOD PULPS WITH SOFTWOOD PULP ON TISSUE PAPER PROPERTIES

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ABSTRACT

The influence of proportions of bleached birch, eucalyptus, beech kraft pulps as well as the bleached aspen chemi-thermomechanical pulp (BCTMP) in the mixture with bleached pine kraft pulp on tissue paper properties was compared. Increase of bleached beech kraft pulp and aspen BCTMP proportion in a mixture with bleached pine kraft pulp leads to significant rise of porosity ε as well as bulk. The water absorption after immersion increased significantly with increase of aspen BCTMP content in the mixture while other hardwood pulps in the mixture had only moderate impact. Increasing of bleached beech and eucalyptus kraft pulps content in the mixture continually increased initial water absorption. As a result of blending of bleached birch kraft pulp with bleached pine kraft pulp, bulk softness improved and the tensile index increased slightly. The increased content of bleached birch and beech kraft pulp in the mixture increased the brightness while the addition of aspen BCTMP and bleached eucalyptus kraft pulp increased of coordinate b* value. Mixed pulps with properties suitable for different types of hygienic products were selected.

KEYWORDS: Hardwood kraft pulp, softwood kraft pulp, chemi-thermomechanical pulp, water absorption, tensile index, bulk softness, optical properties, tissue paper.

INTRODUCTION

The expenses of fibre typically accounts for more than 50% of the total cost of hygienic papers production, depending on their properties such as softness, bulk density, strength and absorption capacity. The highest quality tissue paper products are mainly made of pulp, usually a mixture of long-fibre pulp of softwood wood with short-fibre pulp of hardwood wood. Hygienic products made of 100% hardwood pulp can be very soft, but are less rigid than from softwood pulp. Their disadvantage is also the degradation of strength during embossing. Additives may be used to increase the strength, but they affect the cost and the resulting properties of tissue paper.

Tissue hygiene products are produced to meet the desired properties for a particular application within the market. Overall, absorbency, softness and strength are the most important characteristics used to assess the quality of pulp products. Wet strength and absorbency are considered to be the most important functional properties of kitchen towel products (de Assis et al. 2018). Other properties such as softness, brightness and appearance are commonly considered as secondary properties in this case. But as determined by Kim et al. (1994), there are customers who are sensitive to softness in case of kitchen towels and do not demand a perfect drying of the surface.

Bleached pulps are often added to bleached softwood pulps to improve printability of speciality papers. Because of the price difference between softwood and hardwood pulps, it makes sense to optimize the softwood pulp blending in paper without compromising the desired end product properties of the hygienic product and production efficiency. Together, pulp, producing technology and know-how provide quality to the final hygienic product. Kraft pulp of softwood varies in tensile strength and strength at beating is also different. Higher strength at a given degree of beating allows a reduction in its blending while maintaining the resulting strength. If a higher strength is obtained by using less energy for beating and less blending of the softwood pulp, it becomes an additional advantage which results in lower costs. If the fine content of the pulp is high, dewatering will be impaired and dust will be generated on the paper machine. For soft and bulky tissue papers, only beating of softwood pulp is recommended.

The use of bleached kraft hardwood pulp has long been increasing due to it special suitability for the production of hygienic paper, especially eucalyptus pulp, but also because of the price difference between bleached softwood and hardwood kraft pulp. Another advantage of bleached hardwood pulps is that they do not need to be milled. Higher proportion of hardwood pulp also improves formation, resulting in drying energy savings (Haynes 1990). The beating of hardwood and softwood pulps to obtain mixed pulp can be carried out separately or together. Hardwood pulps are more sensitive to beating process of higher intensity (Annergren and Hagen 2009) while softwood requires sufficient degree of force (Biermann 2018). Practice has shown that both a separate and mixed beating can be successfully used to produce a high quality end product. Generally, mixed refining is being performed on smaller machines, where the flow of individual components is small. Measured fibre strength properties and energy consumption indicate that some fibres are better to be beaten separately but some fibres favour mixed beating (Lumiainen 1996). For this reason, a combined system with separate beating for different pulps followed by mixed beating, offers a good alternative because of the benefits from both separate and mixed systems. Chauhan et al. (2011) studied beating behaviour of three hardwood pulps and one softwood pulp mixed in different proportion. The results showed that fibre length was not affected either beated together or separately in PFI mill and strength properties of mixed beated pulps were either slightly better or comparable to these of separately beated pulps.

Absorbency and softness are mostly influenced by porosity, creping and fibre composition. Papers with a low bulk density have high porosity leading to increased absorbency and softness. Other properties affecting water absorption and softness are type of wood, delignification processes, stiffness, bulk, additives, wet strength, basis weight, thickness, etc. For example, specialty types of mechanical pulp can produce highly porous tissue paper compared to chemical pulps. In addition to selecting the pulp type itself, the functional properties of tissue papers can be improved in several ways. Nanocellulose can also improve absorbency and strength. The refining of the fibrous raw material is a critical operation of the papermaking process and has significant effect on fibre properties. It often determines how well the technical requirements of the product are met. Subsequent processes, such as forming and drying, are influenced highly by the conditions used in refining. Applying of higher specific edge load for refining of bleached kraft birch and eucalypt pulp leads to better absorbency of tissue paper (Gigac and Fišerová 2008). Removal of xylan in the eucalyptus pulp slurry was found to increase bulk and absorbency and to decrease the tear and tensile strength (Gomes et al. 2011). The effect of xylan removal and sorption on fibre properties of pine pulp was also studied (Schonberg et al. 2001). The location and the charge of xylan have a considerable impact on the formation of interfibre bonds. Scott Bond-values correlated with the amount of surface xylan on fibre surfaces, whereas tensile strength was affected by the total amount of xylan and particularly by the total charge of the fibres.

In addition to the question of whether to beat the pulps separately or mixed, it is important to set the optimum blending of hardwood pulp to softwood. The effect of higher blending of eucalyptus pulp with pine pulp on tensile strength, hand-felt softness, bulk and water absorbency (capillary rise of water) using an on-site paper machine was studied by Chang et al. (2018). The results of their study showed that the increase of hardwood pulp content (75-85%) had no effect on water absorption or bulk, while the effect on tensile strength was modest and hand-felt softness only changed at the highest hardwood pulp content. However, Chang et al. (2018) only studied the effect of hardwood pulp addition within a small range of content (75-85%).

Mechanically treated pulps which have harder fibres provide greater paper bulk and thus higher water absorption capacity. On the other hand, high content of fines present in mechanical pulps increases the density of tissue paper and creates problems with dusting and linting (Axelsson 2001). Bleaching of mechanical pulps with peroxide can improve absorbency rate due to reduction of extractives content and provide higher brightness, lower fibre stiffness, better fibre bonding, lower dusting, better brightness stability (Johnson 1978).

Chemically treated fibres have elastic fibres, resulting in better binding and softness. In the chemi-thermomechanical pulp (CTMP) processing process, wood chips are impregnated with a weak sodium sulphite solution at alkaline pH prior to overpressure. The effect of this treatment is to make lignin softer and thus the fibre breakage during refining will be concentrated to the middle lamella rich in lignin. This leads to the formation of a higher amount of long fibres and a lower amount of fine particles and chips at a certain power in comparison to thermomechanical pulp (TMP). The high content of long fibres is important for all products requiring high density, so CTMP technology is especially suitable for such products. CTMP is one of the fastest growing products in the pulp and paper industry and has balanced properties of hardwood and softwood (Nanko et al. 2005). However, long fibres can cause problems with poor formation on the machine, which can result in poor surface properties, therefore shorter fibres are desirable. Short and stiff fibres can be obtained from hardwood CTMP such as birch pulp or by cutting long fibres in softwood CTMP with low consistency beating. CTMP provides better strength than TMP pulps due to higher binding strength; while at the same time it has better absorbency and absorption rate. The disadvantage of using CTMP is their low opacity. Therefore, such types of pulp are mainly used to produce paper with low added value and short durability, because they turn yellow in the light. This is due to the oxidation of phenolic groups of lignin to quinones under the light and air influence. However, bleached chemi-thermomechanical pulp (BCTMP) from weakly coloured wood species as aspen can be a good option. BCTMP is increasingly used in the manufacture of woodfree printing (Hu et al. 2009) and office papers and multi-layer folding cartons as well as tissue papers. The highest potential market for aspen BCTMP is in growing printing and writing paper grades (Cheyne 1990, Granndfeldt and Dahlin 2003). The content of aspen BCTMP typically used in specialty paper ranges from 15% to 30%, depending on the paper grade.

The objective of the work was to determine the effect of the addition of hardwood pulps to softwood pulp on properties of tissue paper in order to select the composition of mixed pulp with an optimal balance between water absorption, softness and tensile index.

MATERIAL AND METHODS

Bleached kraft pulps

Bleached pine kraft pulp made from young pine wood Södra Black (Pine), bleached beech kraft pulp from Bukocel (beech), bleached birch kraft pulps Södra Gold (birch), TCF bleached eucalyptus kraft pulp Pontevedra (eucalyptus) and bleached aspen chemi-thermomechanical pulp (Aspen BCTMP).

Methods

Pulp beating and preparation of handsheets

All types of pulp were separately beaten to 20°SR in a laboratory Jokro mill according to ISO 5264-3 (1979). Low drainage resistance was chosen for all tested pulps as pulp beating markedly reduces the water absorption, bulk softness and brightness (Fišerová et al. 2019). The hand sheets (60 $g{\cdot}m^{-2}$) were prepared in the sheet former Rapid Köthen according to the standard ISO 5269-2 (2004).

Preparing of mixed pulps

Bleached pine kraft pulp was mixed with 20, 40, 80 and 100% of bleached birch, eucalyptus and beech kraft pulps or aspen BCTMP.

Analysis

Porosity ε was calculated according to the equation given in literature (Daub et al. 1986).

The bulk was calculated from the apparent bulk density determined according to ISO 534:2011. W*ater absorption after immersion for time of 10 s* was determined according to the standard ISO 5637 (1989).

The tensile index was determined according to ISO 1924-2a.

The bulk softness was calculated from the bending stiffness determined at 15° and 10 mm distance between the clamp and the knife-edge according to the TAPPI T 556 pm-95 method.

The brightness was determined according to ISO 2470-1:2016 and coordinate b value according to ISO 5631-1:2015.*

Water penetration dynamics were measured by the ultrasound device PDA C.02 (Emtec, Radnor, PA, USA) with a frequency of 2 MHz. Water with a surface energy of 72 $mJ{\cdot}m^{-2}$ was used as the test liquid. Ultrasound signal intensity (USI) change was obtained at 43 ms - 60 s using the SC algorithm. The algorithms for calculating initial water absorption was designed from the USI drop in 200 ms and. A more detailed description of this method as well as an evaluation process of the initial water absorption has already been published (Stankovská et al. 2019).

RESULTS AND DISCUSSION

Handsheets properties of mixed pulps

The porosity and bulk of pulp handsheet significantly influences the water absorption after immersion and initial water absorption (Stankovská et al. 2019) as well as softness (Morais et al. 2019). The effect of hardwood pulp blending on porosity ε is shown in Fig. 1a. The porosity ε of birch pulps, having higher flexibility and thus fibre flattening, was lower than the porosity of other pulps and decreased slightly from 0.59 to 0.54 with increasing of birch pulp content in the mixture with pine pulp. As the eucalyptus pulp content in the mixed pulp increased, there was only a slight change in porosity ε. A more pronounced effect of hardwood pulp addition to pine pulp on porosity ε was shown at higher content (80 and 100%) of beech pulp and of aspen BCTMP. The bleached aspen kraft pulp had the highest porosity ε (0.66). Aspen BCTMP has more flexible fibres due to higher lignin content and lower porosity ε, resulting in a more rigid structure with low tendency to collapsiveness of fibres which leads to less binding and higher porosity. Bulk of handsheets (Fig. 1b) is an important property for tissue paper because the thickness and volume of the paper correlate well with the absorbency as well as bulk softness. Blending of hardwood pulps with pine pulp, with the exception of birch pulp led to bulk increasing. The bulk rose particularly rapidly with increased aspen BCTMP content by about 3-23% and of beech pulp by 5-15%.

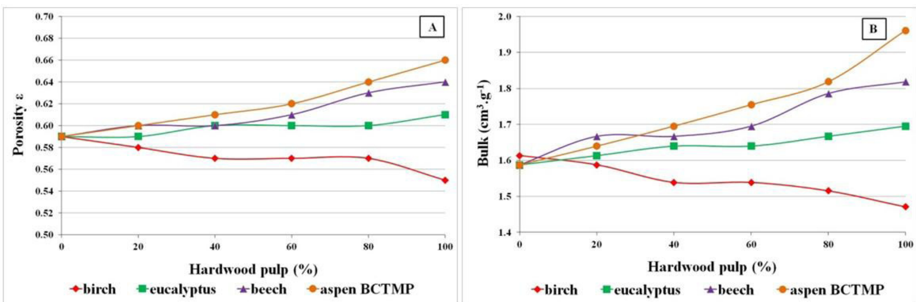

Fig. 1: Blending impact of bleached birch, eucalyptus, beech kraft pulp and bleached aspen BCTMP with bleached pine kraft pulp on porosity (a) and bulk (b).

The effect of the bleached birch, eucalyptus, beech kraft pulp or aspen BCTMP blending with bleached pine kraft pulp on water absorption after immersion (WA) is shown in Fig. 2a. Mixed pulp from aspen BCTMP had significantly higher water absorption after immersion (282-514%) than other mixed pulps (243-311%). The water absorption after immersion of aspen BCTMP was 1.8-1.9 times higher, which also corresponds to high bulk and porosity ε (Fig. 1a, b). The water absorption after immersion increased significantly (by 17-113%) with increasing of aspen BCTMP content in the mixed pulp. Increasing of the eucalyptus pulp content resulted in a 12-29% increase in water absorption after immersion; while for beech pulp, the impact of blending was less pronounced (7-12%). With higher beech pulp content (60-100%) in the mixed pulp, the water absorption after immersion remained unchanged.

Fig. 2b shows the effect of hardwood pulp addition to pine kraft pulp on initial water absorption. Increasing the hardwood pulp content in the mixed pulp resulted in the increase of initial water absorption by 1.6 to 3.2 times for beech pulp, by 1.4 to 2.4 times for aspen BCTMP, and 1.2 to 2.4 times for eucalyptus pulp.

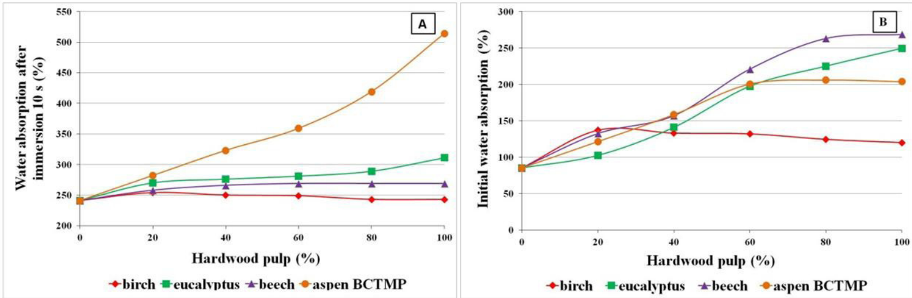

Fig. 2: Blending impact of bleached birch, eucalyptus, beech kraft pulp and bleached aspen BCTMP with bleached pine kraft pulp on water absorption after immersion (A) and initial water absorption (B).

Fig. 3a shows the effect of the hardwood pulp blending with the pine pulp on the tensile index. As a result of birch pulp blending, the tensile index increased slightly by 2-6%. With increase content of other type of hardwood pulps, the tensile index decreased. Tensile index of beech pulp blending dropped significantly already at its content of 20% (by 21%), and with a further content increase of 40-80%, the decrease was less pronounced (by 29-37%). On the contrary, the tensile index of aspen BCTMP decreased by 6% with its content of 20% in the mixture, while it declined more markedly at higher content (by 21-59%). The tensile index of the eucalyptus pulp blending declined evenly with content increasing by 4-17%. At 20% of content in the mixture, the tensile index of eucalyptus and aspen pulp was similar. The higher tensile index of birch pulp blending is due to the presence of longer fibres and a lower Runkel ratio. The effect of birch pulp blending with pine pulp has not been demonstrated significantly as both pulps have a similarly low Runkel ratio. Our results are different than those of published by Finn (Finn 1991), where the effect of birch pulp blending with pine pulp on tensile strength was also studied. However, in their work, °SR between pine pulp and birch pulp in the mixture differed.

The softness of the tissue paper can be measured directly as surface softness, e.g. by the tissue softness analyzer (TSA Emtec) or indirectly by the photoclinometric method with oblique surface illumination to determine the optical surface variability of tissue paper products (Gigac et al. 2019 a, b). The subjective pairwise method can also be used to determine the softness of hygiene products (Gigac et al. 2018). In our work, softness was determined as the bulk softness, calculated from the bending stiffness determined at 15° and 10 mm distance between the clamp and the knife-edge. The effect of hardwood blending on the bulk softness of the mixed pulps is shown in Fig. 3b. The addition of aspen BCTMP had no effect on bulk softness of mixed pulp. With content of 20% and 40% birch pulp in the mixture, the bulk softness increased slightly by 3%, and further addition had no effect. Increasing content (from 40%) of beech and eucalyptus pulp caused a significant decrease in bulk softness of mixed pulp; the curve of slope for both pulps was identical.

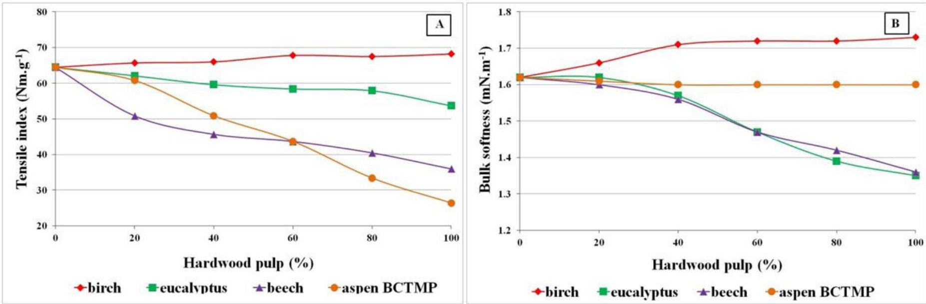

Fig. 3: Blending impact of bleached birch, eucalyptus, beech kraft pulp and bleached aspen BCTMP with bleached pine kraft pulp on tensile strength (a) and bulk softness (b).

Fig. 4a illustrates the effect of blending hardwood pulps with softwood pulp on the brightness. The brightness of bleached pine kraft pulp was 82.5% ISO. With birch and beech pulp addition, brightness increased by 0.1-1.5% ISO (birch) and by 0.1-0.7% (beech). Increased content of eucalyptus pulp resulted in a slight decrease in brightness by 0.4-1% ISO. In case of aspen BCTMP, a significant decrease in brightness by 3.8% ISO at content of 20% occurred, and further addition in the mixture led only to a minimal change. Fig. 4b shows the blending effect of hardwood pulps with pine pulp on the coordinate b* value, which indicates the yellowness. Bleached pine kraft pulp had the coordinate b* value of 6.02. Increasing the eucalyptus content lead to a slight increase in the coordinate b* value, while a significant increase in the coordinate b* occurred with increasing of aspen BCTMP content in the mixed pulp. Increasing of beech and birch pulp proportion in the mixture resulted in a decrease in the coordinate b* value, the shape of both curves was identical.

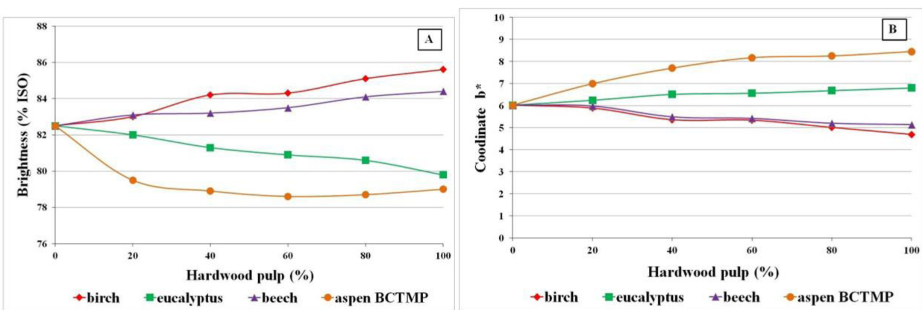

Fig. 4: Blending impact of bleached birch, eucalyptus, beech kraft pulp and bleached aspen BCTMP with bleached pine kraft pulp on brightness (a) and coordinate b (b).*

Selection of mixed pulp for tissue paper

Fig. 5 shows a relationship between tensile index and water absorption after immersion (A); and between tensile index and the initial water absorption (B) of mixed pulps. Bleached pine kraft pulp had the high tensile index (64.5 $\mu m \cdot g^{-1}$) but water absorption after immersion (241%) and the initial water absorption (85%) were low. The aim of blending of hardwood beech, eucalyptus or aspen BCTMP with pine pulp was to increase the tensile index and retain good water absorption.

The most suitable pulp appears to be eucalyptus pulp of 20-80% content in the mixture when higher water absorption after immersion of 270-289% and tensile index of 57.9-62.1 $Nm{\cdot}g^{-1}$ as well as brightness of 80.6-82% ISO were found (Fig. 4a). The initial water absorption at this eucalyptus pulp content in the mixture was high (198-225%; Fig. 5b). With increasing content of the aspen BCTMP, the water absorption after immersion markedly increased (323-514%), but the tensile index dropped significantly to 26.4-50.9 $Nm{\cdot}g^{-1}$ even with content of 40%. A content of 20% aspen BCTMP enabled higher water absorption after immersion (282%) as well as high tensile index of 60.8 $Nm{\cdot}g^{-1}$ and coordinate b* value (6.99, Fig. 4b), whereas brightness was lower (79.5% ISO, Fig. 4a). For tissue papers, however, the water absorption after immersion is more beneficial than the initial water absorption. The mixture with bleached birch kraft pulp had high tensile index (65.7-68.2 $Nm{\cdot}g^{-1}$), but low water absorption after immersion as well as the initial water absorption, which were not affected by increased its content (243-254% and 120-137%). The mixture of beech pulp with pine pulp had high initial water absorption (221-269%) at higher content of beech pulp, but very low tensile index (36-43.7 $Nm{\cdot}g^{-1}$). The water absorption after immersion of this mixture was lower than of the mixture of eucalyptus kraft pulp or aspen BCTMP with pine kraft pulp.

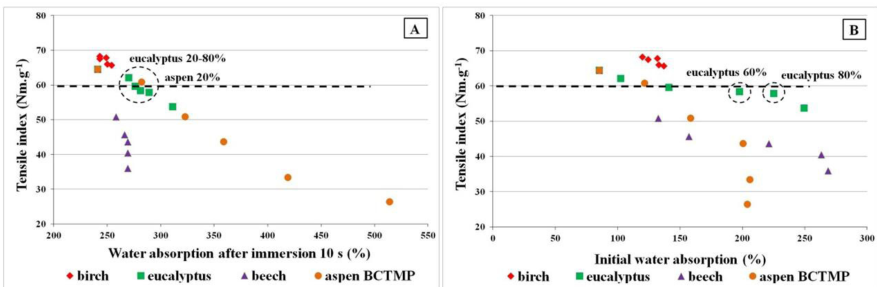

Fig. 5: Relationship between tensile index and water absorption after immersion (a); and between tensile index and initial water absorption (b) of the mixture of bleached birch, eucalyptus, beech kraft pulps and aspen BCTMP (20, 40, 60, 80 and 100%) with bleached pine kraft pulp.

In Fig. 6 is a relationship between bulk softness and water absorption after immersion (A); and between bulk softness and initial water absorption (B) of the mixed pulps. Bleached pine kraft pulp with high tensile index had higher bulk softness (1.62 $m{\cdot}N^{-1}$) but low water absorption after immersion as well as initial water absorption. Although birch pulp of 40-100% content in the mixture had higher bulk softness (1.69-1.73 mN^{-1}) and tensile index (59.7-68.2 $Nm{\cdot}g^{-1}$) and brightness (84.2-85.6% ISO, Fig. 4a), absorption properties were low (243-250% and 120-133%). The mixture of birch pulp with pine pulp is suitable for the production of tissue paper which requires high softness and dry strength, but the drawback is low water absorption. After addition of 20% beech pulp to pine pulp, higher bulk softness (1.60 mN^{-1}) with good water absorption after immersion (258%) was reached (Fig. 6a), but the tensile index was low (50.9 $Nm{\cdot}g^{-1}$, Fig. 5). The addition of aspen BCTMP to pine pulp resulted in a high bulk softness (1.60-1.65 mN^{-1}) and also water absorption after immersion (282-514%); and at the aspen BCTMP content of 20%, higher tensile index (60.8 $Nm{\cdot}g^{-1}$, Fig. 5) was also obtained.

Mixed pulp with a 20% of eucalyptus pulp had high tensile index of 62.1 $Nm{\cdot}g^{-1}$ as well as bulk softness of 1.63 mN^{-1} and brightness of 82% ISO (Fig. 4a), although water absorption after immersion was slightly lower (270%) compared to aspen BCTMP, but was still higher than other types of hardwood pulps in the mixture. Thus the mixture of low content of eucalyptus pulp can be more preferably used for toilet paper and facial papers production where softness is the most important property while absorbency is not being targeted as the most important. However, water absorption can be further increased by rising of eucalyptus pulp proportion to 60%, when the water absorption after immersion of 281% and tensile index of 58.4 $Nm \cdot g^{-1}$ were reached; the disadvantage was reduction of bulk softness (1.47 mN^{-1}). Thie higher eucalyptus content blending could be suitable for the manufacture of tissue papers, where not such a high softness is required as kitchen towels or napkins, or higher softness could be achieved after subsequent treatment of the paper e.g. by creping.

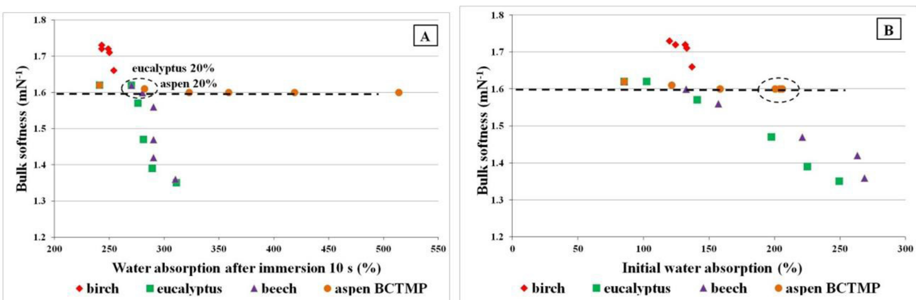

Fig. 6: Relationship between bulk softness and water absorption after immersion (a); and between bulk softness and initial water absorption (b) of the mixture of bleached birch, eucalyptus, beech kraft pulps and aspen BCTMP (20, 40, 60, 80 and 100%) with bleached pine kraft pulp.

CONCLUSIONS

The mixed pulp from bleached beech kraft pulp and bleached pine kraft pulp had good initial water absorption but low bulk softness, the problem also was a low tensile index, even at very low content of beech pulp in the mixture. The mixture of bleached birch kraft pulp with bleached pine kraft pulp had high tensile index as well as bulk softness, but a very poor absorbency, even at low content of birch pulp. The mixed pulp with 20% of aspen BCTMP has proven to be suitable for the production of tissue papers with high tensile index, bulk softness as well as high absorption capacity. This type of mixed pulp is optimal for the production of tissue products where high brightness is not required, but on the contrary, where higher yellowness is desired. Further increasing of aspen BCTMP content in the mixture with bleached pine kraft pulp has shown to be undesirable as it has an adverse effect on the tensile index. Bleached eucalyptus kraft pulp with a 20% addition to bleached pine kraft pulp has shown to be suitable for the production of tissue papers with higher bulk softness and tensile index and moderately high absorbency and high brightness. Higher content (40-60%) of bleached eucalyptus kraft pulp in the mixture increased the water absorption as well as tensile index but it reduced the bulk softness. The mixed pulp with a higher proportion of bleached eucalyptus kraft pulp can be used to produce kitchen towels that do not require such high softness; also after subsequent treatment e.g. creping can be used to produce other types of tissue paper.

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