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Influence of fiber fractionation on kraft paper properties of European black pine and European aspen

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Abstract: In this study, the kraft pulps of European black pine (*Pinus nigra* Arn.) and European aspen (*Populus tremula* L.) were fractionated according to fiber length in a Bauer McNett classifier and effects of fiber fractionation on paper properties were investigated. Bauer McNett screens used for European black pine and European aspen were 16, 30, 50, and 100 mesh and 30, 50, 100, and 200 mesh, respectively. The handsheet surface of each fraction was observed by field emission scanning electron microscopy (FE-SEM). The results showed that handsheet properties were statistically significantly affected by fiber fractionation. The effect of fiber fractionation on tensile and burst indices of handsheets depended on the wood species. However, tear index, apparent density, and surface roughness of handsheets showed similar trends in the two species.

Key words: Bauer McNett, European aspen, European black pine, fiber fractionation, paper properties

1. Introduction

Fiber dimensions have a remarkable influence on the papermaking potential of pulp. The paper properties (strength, surface roughness, porosity, density, etc.) are significantly affected by fiber length, fiber width, cell wall thickness, fiber flexibility, and fiber collapsibility (Pulkkinen et al., 2006). Hardwood fibers have been generally used to achieve good surface properties, while softwood fibers are used for high strength. Therefore, fiber sources used in pulp mill have been appropriately selected according to the quality requirements of the final product.

Fiber fractionation means separation of mixed fibers into two or more parts based on properties such as length, flexibility, and coarseness (Gooding and Olson, 2001; Sood et al., 2005). In mill scale, pulp can be fractionated in hydrocyclones, or in pressure screens using slotted or holed screen plates/baskets (Asikainen et al., 2010). However, Bauer McNett or Clark fiber classifiers are used in the laboratory. The traditional approach in fiber preparation is to use the fibers collectively without fractionating them. Although this approach facilitates the process design, it ignores the opportunity to use the natural advantages of the individual fiber fractions (Gooding and Olson, 2001). On the other hand, fractionation of pulp furnish offers the potential to produce customer-valued products from fiber sources. Thus, papermakers can produce paper with optimum properties for specific applications by controlling process variables such as the refining conditions, use of additives, and dewatering conditions at the wet end (Sood et al., 2005; Azizi Mossello et al., 2010b).

Abubakr et al. (1995) in recycled fiber, Demuner (1999) in bleached eucalyptus kraft pulp, Reyier (2008) in Norway spruce (*Picea abies*), and Hafrén et al. (2014) in mixed softwood (lodgepole pine, Sitka spruce, Western balsam fir) studied the effects of fiber fractionation on paper properties. Huang et al. (2012) investigated the fiber morphology of each fraction after fiber fractionation of Jack pine (*Pinus banksiama*) thermomechanical pulp. However, there are no published data related to effects of fiber fractionation on paper properties of European black pine (*Pinus nigra* Arn.) and European aspen (*Populus tremula* L.). In this scope, the objective of this study was to determine the effects of fiber fractionation on handsheet properties of European black pine and European aspen.

2. Materials and methods

The wood samples of European black pine and European aspen were obtained from Bartın Province in Turkey. They were debarked and chipped into approximately 3.0–1.5–0.5 cm in size. Chips were air-dried and stored with less than 10% moisture content until used.

Table 1 shows the kraft pulping conditions of European black pine and European aspen. Kraft pulping was done in an electrically heated laboratory cylindrical type rotary

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digester of 15 L. Chips (750 g, oven-dried basis) for each cooking experiment were cooked in the digester. After cooking, pulps were washed with tap water to remove residual liquor. After washing, pulps were disintegrated, washed with tap water, and screened on a slot screen of 0.15 mm (TAPPI T 275).

The Bauer McNett classifier (model with 4 classifier chambers) was used for fiber fractionation of kraft pulps according to TAPPI T 233 cm-06. In fiber fractionation of European black pine pulp, R16 (1.190 mm, retained fibers of a 16-mesh screen), P16/R30 (0.595 mm, i.e. passed 16 mesh, retained 30 mesh), P30/R50 (0.297 mm), and P50/R100 (0.149 mm) classifier screens were used. In fiber fractionation of European aspen pulp, R30, P30/R50, P50/R100, and P100/R200 classifier screens were used. Fiber morphology of each fiber fraction was determined with a light microscope. Fiber dimensions of each fractions were measured (n: 100). The aspect ratio (fiber length/fiber width) and flexibility ratio [(lumen width/fiber width) × 100] were calculated using the measured fiber dimensions.

Handsheets of 75 g/m^2 from each fiber fraction, made with a Rapid-Kothen Sheet Former (ISO 5269-2), were conditioned (TAPPI T 402). Tensile index, tear index, burst index, and apparent density of the handsheets were measured according to the T494, T414, T403, and T220 TAPPI standards, respectively. Also, roughness of the handsheets was determined according to the ISO 8971-2 standard method.

The handsheets of each fiber fraction were coated with gold (80%) and palladium (20%) using a sputter coater (Quorum Q150 T) and were observed by field emission scanning electron microscopy (FE-SEM) (Tescan MAIA3 XMU) operating at 10 kV. The coating thickness was approximately 10 nm.

The data of handsheet properties for each fiber fraction were subjected to analysis of variance (ANOVA) and Duncan test at 0.05 probability level. Different lowercase letters used in figures denotes that the difference in the average values of properties among the compared groups was statistically significant.

3. Results and discussion

The results of Bauer McNett and fiber morphology for European black pine and European aspen are shown in Table 2. It can be seen that the fiber length and fiber width of both species decreased with increasing screen mesh.

Table 1. Kraft pulping conditions of European black pine and European aspen.

Conditions	European black pine	European aspen
Active alkali (%)	20	16
Sulfidity (%)	25	20
Temperature (°C)	170	
Time to max. temperature (min)	90	
Time at max. temperature (min)	60	
Total cooking time (min)	150	
Liquor/chip ratio	4/1	

Table 2. The results of fiber fractionation of European black pine and European aspen.

Wood species	Fiber fractions	Fiber ratio (%)	Fiber length (mm)	Fiber width (μm)	Double wall thickness (μm)	Lumen width (μm)	Aspect ratio	Flexibility ratio
European black pine	R16	65.8	3.32 ± 0.02	40.40 ± 0.1	21.20 ± 0.3	19.20 ± 0.2	79.70	47.52
	R30	17.2	2.75 ± 0.04	39.00 ± 0.1	18.25 ± 0.2	20.75 ± 0.3	72.56	53.21
	R50	7.6	2.13 ± 0.04	37.10 ± 0.5	20.35 ± 0.1	16.75 ± 0.1	62.26	44.15
	R100	3.9	1.33 ± 0.02	35.10 ± 0.2	19.25 ± 0.3	15.85 ± 0.2	38.46	44.16
	R200 + fines	5.5	-	-	-	-	-	-
European aspen	R30	38.1	1.27 ± 0.01	25.0 ± 0.1	11.35 ± 0.1	13.65 ± 0.2	50.40	54.60
	R50	30.6	1.09 ± 0.01	24.5 ± 0.1	11.50 ± 0.1	13.00 ± 0.1	45.31	53.06
	R100	25.9	0.89 ± 0.02	23.7 ± 0.1	11.80 ± 0.2	11.90 ± 0.1	38.40	50.21
	R200	2.1	0.60 ± 0.01	21.4 ± 0.1	12.20 ± 0.1	9.20 ± 0.2	32.24	42.99
	Fines	3.3	-	-	-	-	-	-

Also, increased screen mesh resulted in lower fiber aspect ratio. The weight percentage of long fiber fractions was 83% and 68.7% for European black pine and European aspen, respectively.

Fiber fraction had a statistically significantly effect on tensile index ($P < 0.05$). Also, effect of fiber fraction depended on the wood species (Figure 1). Tensile indexes of R16, R30, R50, and R100 fractions in European black pine kraft pulp were determined as 39.71 Nm/g, 45.30 Nm/g, 43.96 Nm/g, and 34.86 Nm/g, respectively ($P < 0.05$). These results can be explained by long and stiff fibers of lower screen numbered fractions, which have poor bonding characteristics (Huang et al., 2012). Tensile index depends on bonding ability of fibers (Rydholm, 1967; Levlin, 1999, Dutt et al., 2009; Jahan and Rawshan, 2009). Flexible fibers produce large contact areas for fiber-to-fiber bonding. In European aspen samples, tensile indexes of R30, R50, R100, and R200 fractions were found as 33.22 Nm/g, 38.47 Nm/g, 42.20 Nm/g, and 46.85 Nm/g, respectively. This result can be attributed to increasing vessel element numbers in high screen mesh fractions. Thin-walled vessel elements collapse during papermaking, and their wide surface increases the interfiber bonding. On the other hand, it can be ascribed to the high apparent density of handsheets of high screen mesh numbered fractions. Higher density indicates better interfiber bonding in the sheet. A positive correlation between screen mesh number and tensile index has also been reported in previous studies (Reyier, 2008; Hafrén et al., 2014).

The relationships between the fiber fraction and tear index of handsheets are presented in Figure 2. As can be seen in Figure 2, the tear index of handsheets

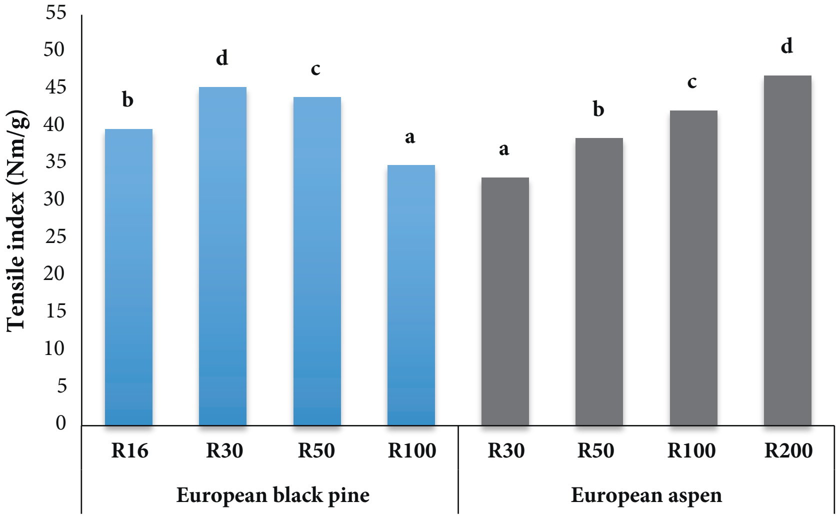

Figure 1. Effect of fiber fractionation on the tensile index of handsheets.

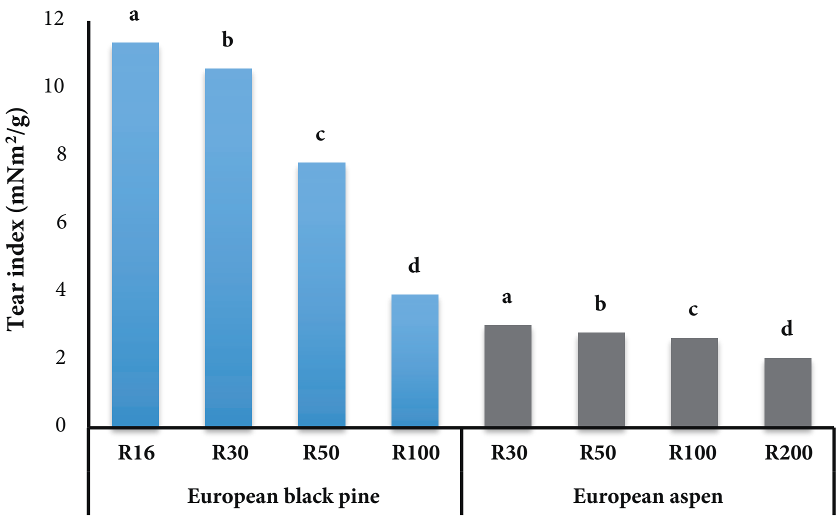

Figure 2. Effect of fiber fractionation on the tear index of handsheets.

of both species decreased significantly ($P < 0.05$) with increasing screen number. The highest tear index values were determined in the R16 fraction at 11.35 mNm^2/g for European black pine and in the R30 fraction at 3.03 mNm^2/g for European aspen. Increase in tear index with decreasing screen mesh numbers could be attributed to a positive correlation between fiber length and tear index (Casey, 1961; Horn, 1978; Seth and Page, 1988; Mohlin, 1989; Horn and Setterholm, 1990; Seth, 1990; Scott et al., 1995; Retulainen, 1996; Levlin, 1999; Shin and Stromberg, 2005, Azizi Mossello et al., 2010a), and also higher aspect ratio of longer fiber (Rydholm, 1965; Shakhes et al., 2011) (Table 2). In addition, the increase in fiber flexibility (a higher sheet density and better interfiber bonding) causes a higher tear index (Bronkhorst and Bennett, 2002). On the other hand, the decrease in tear index with increasing screen mesh numbers could be ascribed to increasing vessel elements numbers with decreasing screen mesh numbers. The vessel elements are generally short and thin-walled, with pitting and open ends (Li et al., 2012). The vessel element-rich fractions cause a decrease in the tear index compared to that of vessel element-poor fractions (http://www.eucalyptus.com.br/capitulos/ENG04_vessels.pdf). Abubakr et al. (1995) noted that tear index of long fiber fractions in recycled pulp fractionation was higher than that of short fiber fractions.

The relationships between the fiber fractions and burst index of handsheets are presented in Figure 3. Burst index of European black pine handsheets decreased with increasing screen mesh ($P < 0.05$), while burst index of European aspen handsheets increased with increasing screen mesh ($P < 0.05$). The lowest and highest burst index values of European black pine samples were determined in R100 and R30 fractions as 1.43 kPa m^2/g and 1.99 kPa m^2/g, respectively. This result can be explained by fiber flexibility differences between R100 and R30 fractions (Table 2). Also, it can be attributed to decreasing fiber length with increasing screen mesh (Table 2). The lowest and highest burst index values of European aspen samples were found in the R30 and R200 fractions at 1.12 kPa m^2/g and 1.90 kPa m^2/g, respectively. The high burst index with rich vessel element fractions can be ascribed to improved fiber bonding due to collapsed vessel elements during papermaking. In recycled pulp fractionation, higher burst index of long fiber fractions than short fiber fractions was reported by Abubakr et al. (1995).

As can be seen in Figure 4, apparent density of handsheets in both species was positively correlated with increasing screen mesh ($P < 0.05$) (Figure 4). These results can be explained by short and narrow fibers of higher screen numbered fractions, which give a compact structured paper due to more fibers per area. The lowest apparent density values were determined in the R16 fraction at 470 kg/m^3 for European black pine and in the R30 fraction at 580 kg/m^3 for the European aspen. A positive correlation between apparent density and mesh screen was also reported by Reyier (2008). It is known that the relationship between bulk and apparent density is negatively correlated. Demuner (1999) noted that the fine fractions produced sheets with lower bulk than the coarse fractions.

The results indicated that roughness of handsheets increased with increasing screen mesh ($P < 0.05$) (Figure 5). Roughnesses of R16, R30, R50, and R100 fractions in European black pine kraft pulp were determined as 1566 mL/min, 1228 mL/min, 1053 mL/min, and 826 mL/min, respectively. In European aspen samples, roughnesses of R30, R50, R100, and R200 fractions were found as 1275 mL/min, 891 mL/min, 654 mL/min, and 536 mL/min, respectively. These findings can be explained by shorter

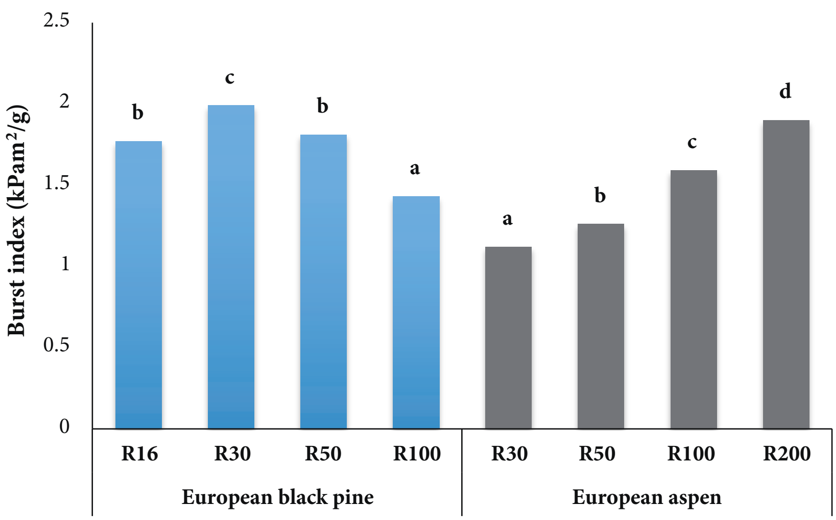

Figure 3. Effect of fiber fractionation on the burst index of handsheets.

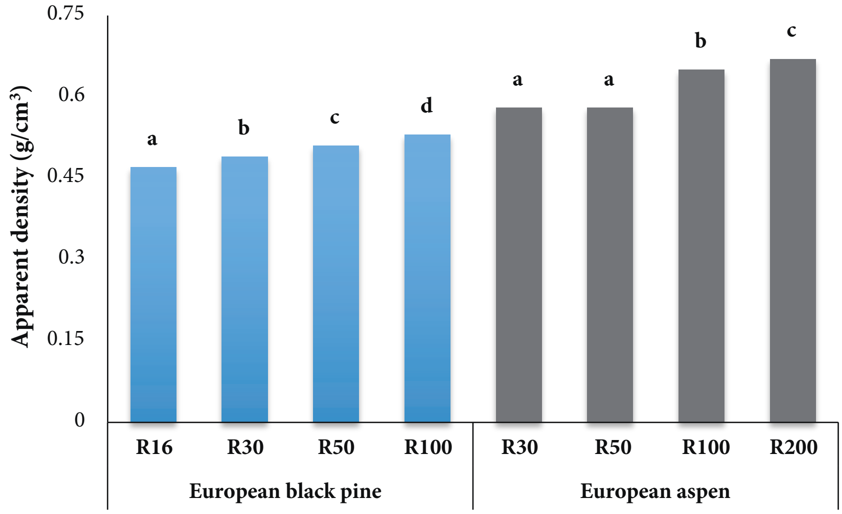

Figure 4. Effect of fiber fractionation on the apparent density of handsheets.

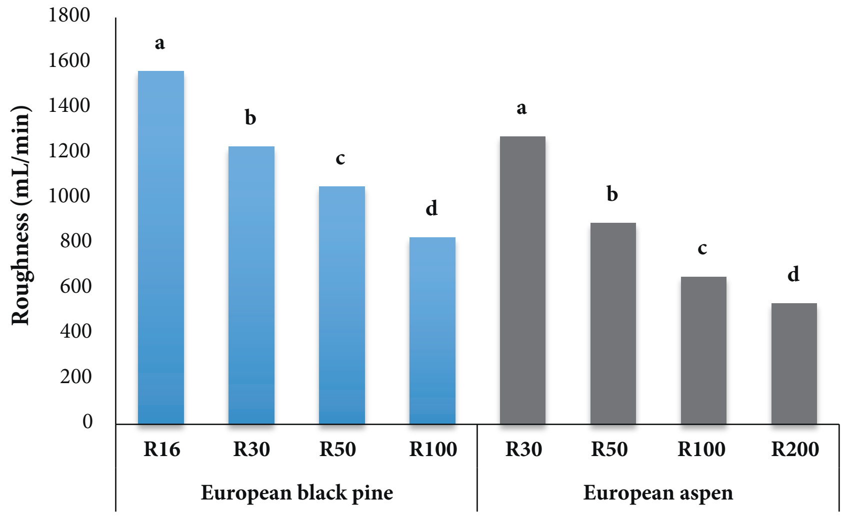

Figure 5. Effect of fiber fractionation on the roughness of handsheets.

and finer fibers of high screen mesh fractions (Table 2; Figures 6 and 7). This result can also be attributed to the action of vessel elements in fractions of European aspen samples that are rich in vessel elements (Malik et al., 2004). Demuner (1999) reported that the smoothness of fine fractions was higher than that of coarse fractions. FE-SEM handsheet micrographs of each fractionation of European black pine and European aspen are shown in Figures 6 and 7, respectively.

In conclusion, the results of this study have shown that the handsheet properties were statistically significantly affected by fiber fractionation. In European black pine samples, tensile index, tear index, burst index, and roughness of handsheets decreased with increasing screen mesh number. In European aspen samples, tear index and roughness of handsheets decreased with increasing screen mesh number, while tensile index and burst index increased. Apparent density of handsheets in both species was positively correlated with increasing screen mesh. Fiber fractionation may not be technically feasible for mill-scale paper production, but papermaking from unfractionated fibers ignores the opportunity to use the natural advantages of the individual fiber fractions. Also, selective refining of fractions results in paper quality improvements. More studies related to effects of fiber fractionation (especially the effect of vessel element-rich and element-poor fractions) on paper properties of other lignocellulosic materials have to be carried out.

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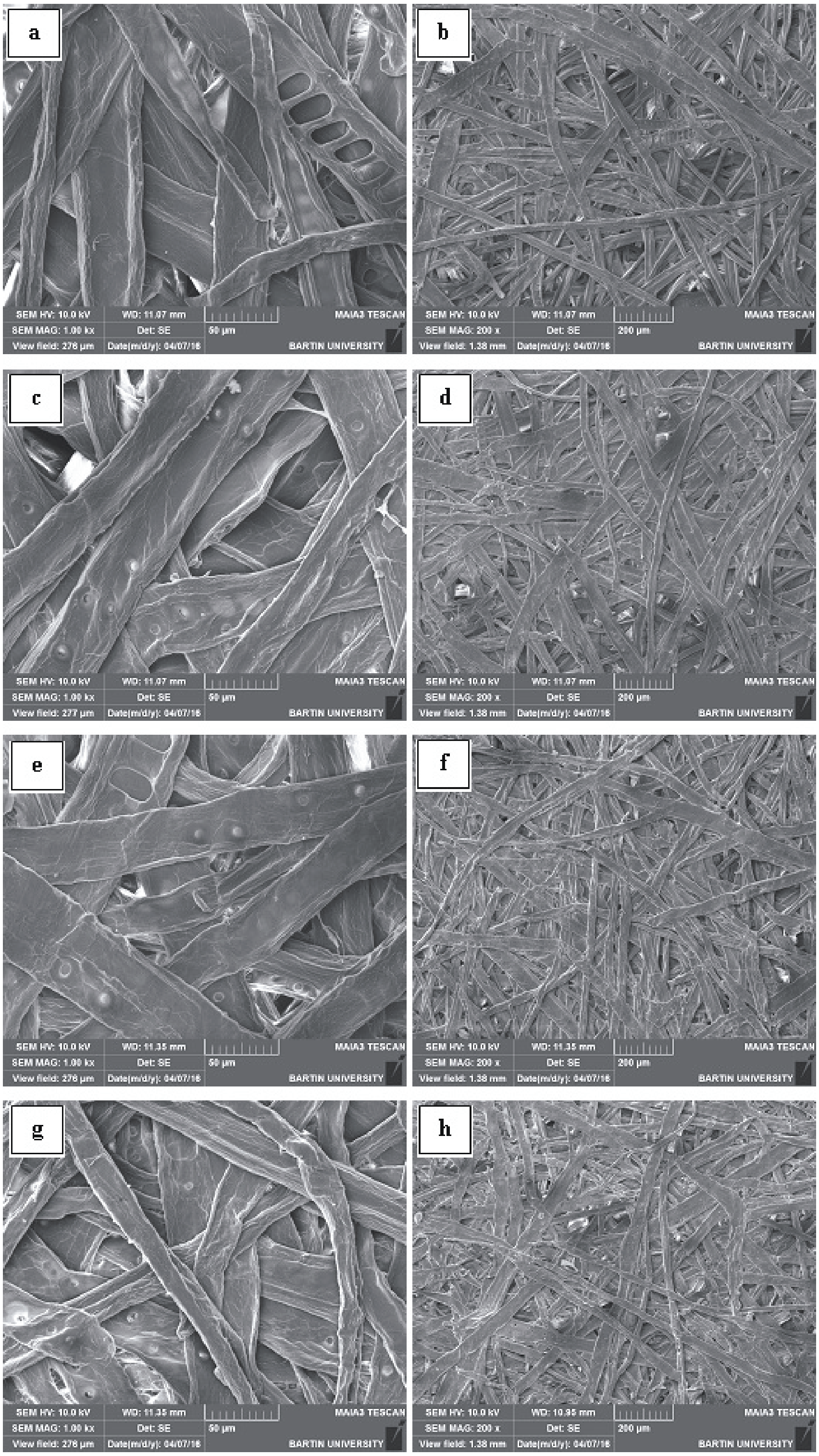

Figure 6. FE-SEM handsheet micrographs of each fractionation of European black pine kraft pulp: a, b) R15; c, d) R30; e, f) R50; g, h) R100.

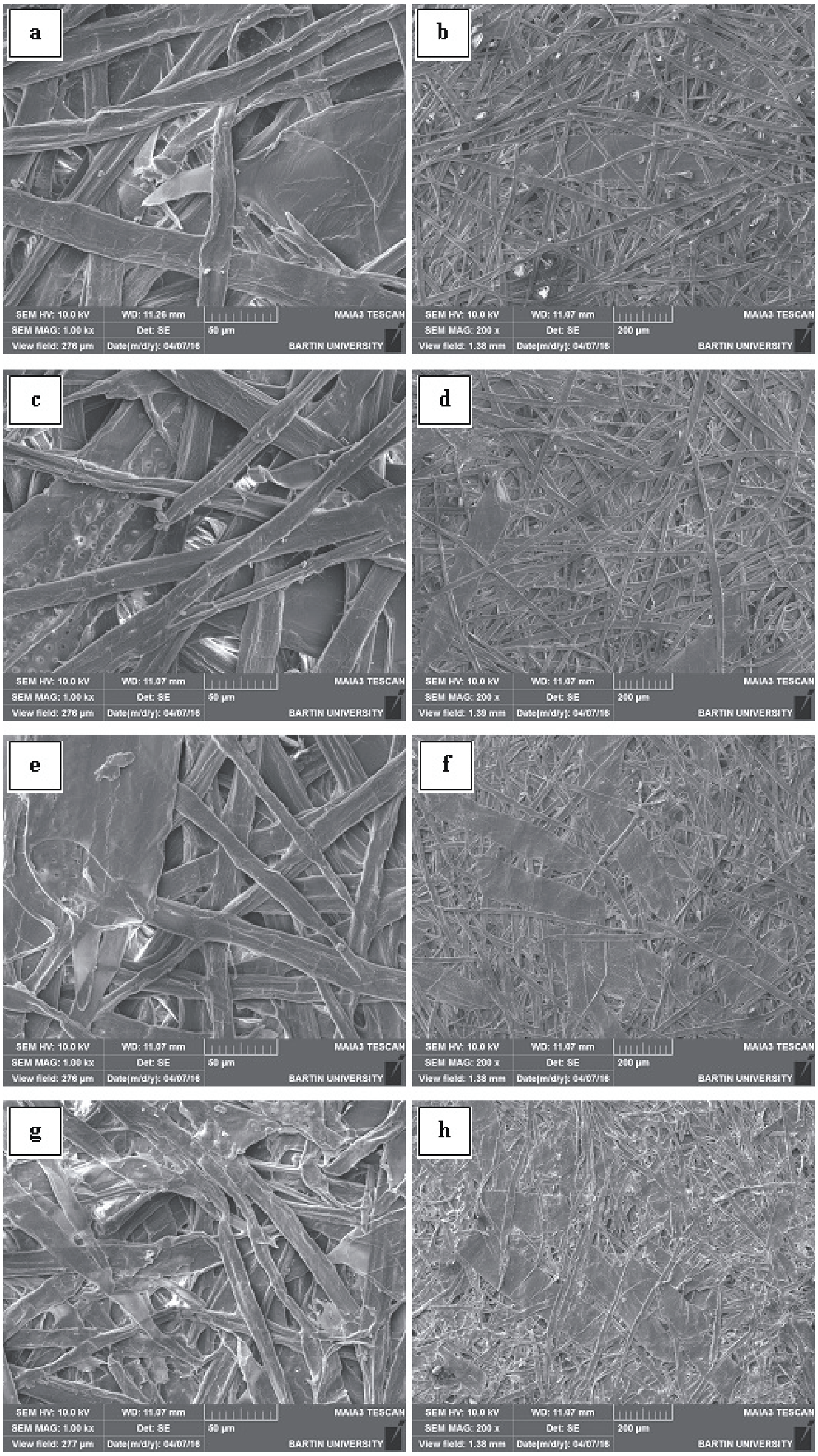

Figure 7. FE-SEM handsheet micrographs of each fractionation of European aspen kraft pulp: a, b) R30; c, d) R50; e, f) R100; g, h) R200.

References

Abubakr SM, Scott GM, Klungness JH (1995). Fiber fractionation as a method of improving handsheet properties after repeated recycling. TAPPI J 78: 123-126.

Asikainen S, Fuhrmann A, Robertsén L 2010. Birch pulp fractions for fine paper and board. Nord Pulp Pap Sci 25: 269-276.

Azizi Mossello A, Harun J, Resalati H, Ibrahim R, Shmas SRF, Tahir PM (2010a). New approach to use of kenaf for paper and paperboard production. Bioresources 5: 2112-2122.

Azizi Mossello A, Harun J, Tahir PM, Resalati H, Ibrahim H, Shamsi SRF, Mohmamed A (2010b). A review of literatures related of using kenaf for pulp production (beating, fractionation, and recycled fiber). Mod. Appl Sci 4: 21-29.

Bronkhorst CA, Bennett KA (2002). Deformation and failure behaviour of paper: tear strength. In: Mark RE, Habeger CC, Borch J, Lyne MD, editors, Handbook of Physical Testing of Paper, Vol. 1. 2nd ed. New York, NY, USA: Marcel Dekker Inc., pp. 388-395.

Casey JP (1961). Pulp and Paper Chemistry and Chemical Technology. Vol. 2, Papermaking. New York, NY, USA: Interscience Publishers Inc.

Demuner BJ (1999). Opportunities for market pulp differentiation via fractionation. In: 5th International Paper and Board Industry Conference – Scientific and Technical Advances in Refining, 29–30 April 1999, pp. 1-14.

Dutt D, Upadhyay JS, Singh B, Tyagi CH (2009). Studies on *Hibiscus cannabinus* and *Hibiscus sabdariffa* as an alternative pulp blend for softwood: an optimization of kraft delignification process. Ind Crop Prod 29:16-26.

Gooding RW, Olson JA (2001). Fractionation in a Bauer-McNett classifier. J Pulp Pap Sci 27: 423-428.

Hafrén J, Fernando D, Gorski D, Daniel G, Salomons FA (2014). Fiber- and fine fractions-derived effects on pulp quality as a result of mechanical pulp refining consistency. Wood Sci Technol 48: 737-753.

Horn RA (1978). Morphology of Pulp Fiber from Hardwoods and Influence on Paper Strength. Madison, WI, USA: USDA Forest Service Forest Products Laboratory.

Horn RA, Setterholm VC (1990). Fiber morphology and new crops. In: Janick J, Simon JE, editors. Advances in New Crops. Portland, OR, USA: Timber Press, pp. 270-275.

Huang F, Lanouette R, Law KN (2012). Morphological changes of jack pine latewood and earlywood fibers in thermomechanical pulping. Bioresources 7: 1697-1712.

Jahan MS, Rawshan S (2009). Reinforcing potential of jute pulp with *Trema orientalis* (Nalita) pulp. Bioresources 4: 921-931.

Levlin JE (1999). General physical properties of paper and board. In: Levlin JE, Söderhjelm L, editors. Pulp and Paper Testing, Papermaking Science and Technology, Book 17. Jyväskylä, Finland: Fapet Oy, pp. 137-162.

Li Z, Zhai H, Zhang Y, Yu L (2012). Cell morphology and chemical characteristics of corn stover fractions. Ind Crop Prod 37: 130-136.

Malik RS, Dutt D, Tyagi CH, Jindal AK, Lakharia LK (2004). Morphological, anatomical and chemical characteristics of *Leucaena leucocephala* and its impact on pulp and paper making properties. J Sci Ind Res India 63: 125-133.

Mohlin UB (1989). Fiber bonding ability – A key pulp quality parameter for mechanical pulps to be used in printing papers. In: International Mechanical Pulping Conference, Helsinki, Finland, pp. 49-57.

Pulkkinen A, Ala-Kaila K, Aittamaa J (2006). Characterization of wood fibers using fiber property distributions. Chem Eng Process 45: 546-554.

Retulainen E (1996). Fiber properties as control variables in papermaking. Part 1. Fibre properties of key importance in the network. Pap Puu 78: 187-194.

Reyier S (2008). Bonding ability distribution of fibers in mechanical pulp furnishes. Licentiate Thesis. Mid Sweden University, Sundsvall, Sweden.

Rydholm SA (1965). Pulping Process. New York, NY, USA: Interscience Publisher.

Scott WE, Abbott JC, Trosset S (1995). Properties of Paper: An Introduction. Atlanta, GA, USA: TAPPI Press.

Seth RS (1990). Fibre quality factors in papermaking - I. The importance of fibre length and strength. In: Proceedings of Material Research Society Symposium, San Francisco, CA, USA, pp. 125-141.

Seth RS, Page DH (1988). Fiber properties and tearing resistance. TAPPI J 71: 103-107.

Shakhes J, Marandi MAB, Zeinaly F, Saraian A, Saghafi T (2011). Tobacco residuals as promising lignocellulosic materials for pulp and paper industry. Bioresources 6: 4481-4493.

Shin NH, Stromberg B (2005). Impact of cooking conditions on physical strength of Eucalyptus pulp. In: Colóquio Internacional sobre Cellulose Kraft de Eucalipto, Concepción, Chile, 2005.Sood YV, Pande PC, Tyagi S, Payra I, Nisha AG, Kulkarni AG (2005). Quality improvement of paper from bamboo and hardwood furnish through fiber fractionation. J Sci Ind Res India 64: 299-305.