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Bleached Kraft Pulps From Blends of Wood and Hemp. Part II – Structural, Optical and Strength Properties of Pulps

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Abstract
The beatability, strength, structural and optical properties of bleached kraft pulps from blends of birch or pine with hemp stalks in a proportion of 80/20 weight % were studied. It was found that these pulps generally have comparable properties to those of bleached pulps from birch and pine. The properties of bleached pulps produced from 80/20 weight % blends of pine or birch with hemp woody-core such as the breaking length, burst, and light scattering proved to be comparable or better than those of bleached pulps from wood. However, the replacement of a part of birch or pine with hemp-woody core negatively affected their bulk, air-resistance, and tearing resistance. Taking into consideration the results presented in Part I and Part II of the study, it can concluded that hemp stalks are better fibrous raw material for the manufacturing of papermaking intermediates partially free of wood fibres than hemp woody-core.

Key words: *bleached birch/hemp kraft pulp, bleached pine/hemp kraft pulps, bleached birch and pine kraft pulps, structural, optical properties, strength properties.*

Abbreviations

HFRMs – hemp fibrous raw materials
PFRMs – plant fibrous raw materials
Hs – hemp stalks
Hwc – hemp woody-core
B – birch
P – pine
TEA – tensile energy absorption

Introduction

In the first part of the paper, a comparison of the yield of bleached kraft pulps obtained from the common processing of pine or birch with hemp stalks or hemp woody-core with a share of hemp fibrous raw materials (HFRM) in a blend of 20 wt. % with the yield of bleached kraft pulps from birch or pine was presented. The intrinsic viscosity of bleached pulps from wood/HFRM blends was also determined, as well as the effect of the production of bleached pulps from these raw material blends on their fractional composition and basic fibre properties [1].

These studies demonstrated that from the point of view of yield, fractional composition, and fibre length of bleached pulps, the preparation of pulps from wood/hemp stalk blends is more preferable than from a wood/hemp woody-core blend.

This paper presents the results of a comparison of the beatability and properties of handsheets of bleached pulps made from blends of wood and HFRMs with the properties of handsheets prepared from 100% bleached birch or pine pulps.

Experimental

Pulps used in the study

In this study the properties of bleached pulps from the following blends of plant fibrous raw materials (PFRMs) were used: birch/hemp stalks (denoted as B/Hs), birch/hemp woody-core (B/Hwc), pine/hemp stalks (P/Hs), and pine/hemp woody-core (P/Hwc). These pulps were obtained in the same way as described in Part I of the work, i.e. by the blending of wood chips with appropriately prepared HFRMs in a proportion of 80 and 20 weight % (on an oven-dried basis), the pulping of prepared samples of PFRMs using the kraft pulping method, the screening of unbleached pulps in a screen sorter, the blending of refined rejects with screened pulps, the delignifying of pulps obtained with oxygen, and finally bleaching them in a D_0ED_1 sequence. The detailed conditions of pulping, oxygen delignification and bleaching processes, i.e. the number of chemicals used in these processes, methods of calculating of number of these chemicals, the number of liquid and pulp consistencies, as well as process temperatures and their duration were the same as given in Part I of work [1].

Beating of pulps, handsheet making and determination of their properties

Pulps were beaten in a Jokro beater according to the PN-EN 25264-3 standard [2]. After beating, Schopper-Riegler freeness was determined according with PN-EN ISO 5267-1 [3]. Pulp handsheets of 75 ± 3 g/m^2 basis weight were prepared according to the PN-EN ISO 5269-1 standard [4], while determination of the properties of these handsheet pulps involved the methods presented in ***Table 1***.

Table 1. *Methods and equipment used in research.*

Type of analysis	Analytical method	Device
Basis weight	PN-EN ISO 536:2012 [5]	Quadrant weight (Lorentzen-Wettre, Sweden)
Thickness/bulk	PN-EN ISO 534 [6]	Thickness meter 1011 (PTA, Germany)
Air resistance	ISO 5636-5:2003 [7]	Densometer 4101 (Troy, USA)
Tensile strength	PN-EN ISO 1924-2 [8]	Tensile strength tester BZ2.5/TN1S (Zwick/Roell, Germany)
Burst strength	ISO 2758:2008 [9]	Mullen burst tester, (Lorentzen-Wettre, Sweden)
Tear strength	PN-EN ISO 1974 [10]	Tear tester ProTear (Thwing-Albert, USA)
Folding endurance (tensile force 0.5 kg)	TAPPI T 423 om-89 [11]	Schopper tester (WPM, Germany)

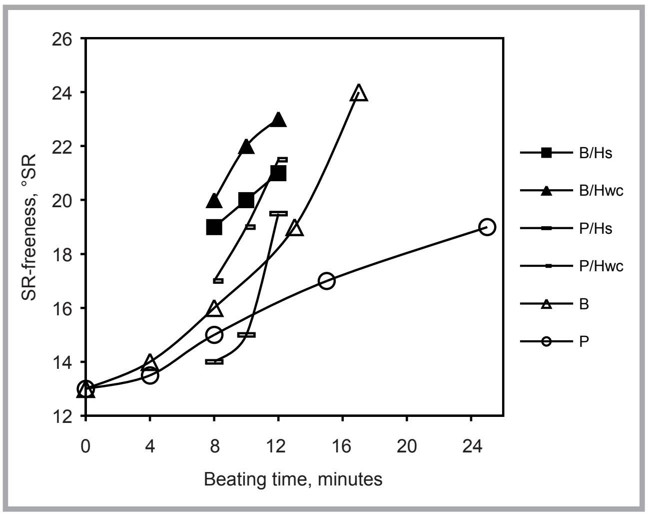

Figure 1. *Schopper-Riegler freeness vs beating time for B/Hs, B/Hwc, P/Hs, P/Hwc, B and P pulps.*

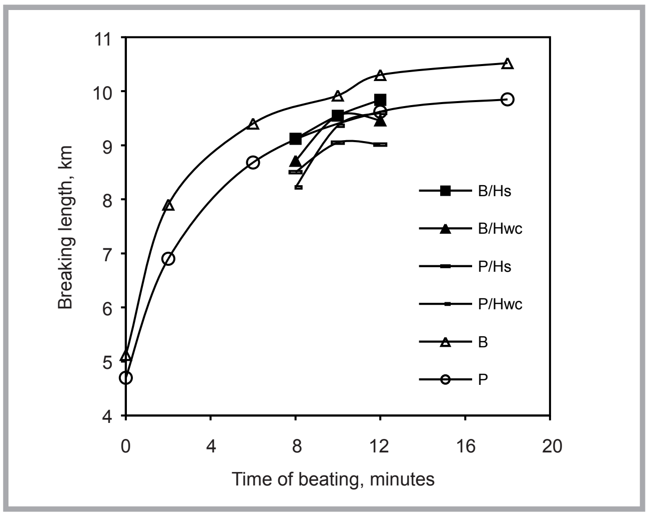

Figure 2. *Breaking length development of bleached pulps from wood/HFRM blends and birch or pine vs the beating time in a Jokro mill.*

Elaboration of results

From each pulp of a certain degree of beating, two sets, each of ten handsheets, were prepared. The uniformity of the formation of each handsheet was then visually examined against a light source to choose two sets each of the six best formatted handsheets. These two sets of handsheets were then used for determination of the pulps' properties. Thus the results of the determination of the pulps' SR-freeness, breaking length, burst force, tear index, fold endurance, bulk, Gurley air-resistance and light scattering coefficient are the arithmetic average of the determination of these properties of these two sets of handsheets. Deviations from the arithmetic mean of the determinations of these properties on average amounted to 1-2°SR, 05-0.9 km, 20-35 kPa, 0.84-1.2 mN · m^2/g, 150-300 folds, 0.035-0.054 cm^3/g, 4-15 seconds, and 20-34 cm^2/g, respectively.

Results and discussion

An important feature of pulps for making paper and cardboard is their susceptibility to beating. The main objective of this treatment is to reduce the stiffness of the fibres and to fibrillate them externally; but with a side effect – the generation of fines. The main indicator of the degree of beating of pulps employed in laboratory and industrial practice is still their freeness. Pulps are subjected to beating to a certain degree of freeness. The higher the freeness to which pulps must be beaten, the greater the consumption of energy [12].

Figure 1 shows the evolution of the Schopper-Riegler freeness of bleached pulps from birch- or pine/HFRM blends and only birch or pine after their beating in a laboratory Jokro mill. The beating times were relatively short due to the very quick reduction in fibre stiffness in the beating of pulps in the Jokro mill.

Figure 1 shows that the freeness of birch and pine pulps after 12 minutes of beating in a Jokro mill was 18 and 16°SR, whereas this index for B/Hs, P/Hs, B/Hwc, and P/Hwc pulps was 21.0, 19.5, 23.0, and 21.5°SR, respectively. The SR-freeness of bleached pulps from the common processing of wood and HFRMs was therefore higher by 3-5.5°SR than in the case of birch or pine pulps. This results from the higher freeness of pulps from HFRMs, reported by other authors [13-16]. However, the difference in SR-freeness between pulps is relatively low, and there is a small risk of slowing down the papermaking process on a paper machine when using pulps from wood/HFRM blends as a fibrous intermediate. On the other hand, assuming freeness as the degree of pulp beating, it can be stated that by replacing 20% of the wood with HFRMs, the amount of energy needed for the beating of pulps from such blends of PFRMs would probably be a little bit lower.

Figure 2 shows a comparison of the breaking length of bleached pulps made of wood/HFRMs blends with that of birch or pine pulp.

Data in this ***Figure 2*** show that replacing 20% of the wood with HFRMs allows to obtain handsheets with a high breaking length. As can be seen, this property of pulps from B/HFRM or P/HFRM blends is comparable or slightly lower than that of pine pulp. This can result from the good bonding ability of hemp woody-core fibres due to their low coarseness and cell wall thickness [13].

Bleached pulps are used for the manufacturing of paper bags, the top layers of sacks, solid cardboards, and corrugated board liners. Although in the case of the three latter paper products bleached pulps are used only for their top layers, they can also have a certain effect on the properties of the entire products [17]. One of the important properties of paper bags, sacks, solid cardboards, and corrugated boards is their resistance to forces perpendicular to their surface exerted on the walls of the paper package by the contents [18, 19]. This property characterises the burst force or burst strength index. Results of the determination of the burst force of handsheets of similar basis weight made from bleached pulps from a wood/hemp blend against the background of the burst force for pure birch and pine bleached pulps are presented in ***Figure 3***.

Burst strength generally depends on the same factors as tensile strength. In many cases changes in burst caused by beating are analogues, as in the case of the latter property [20-25]. Possible discrepancies in the course of the change in the tensile and burst strengths of two pulps may result from differences in the stretch at break between these pulps [26]. The dependence of these characteristics of papers on the degree of bonding of fibres confirm the results of the burst force

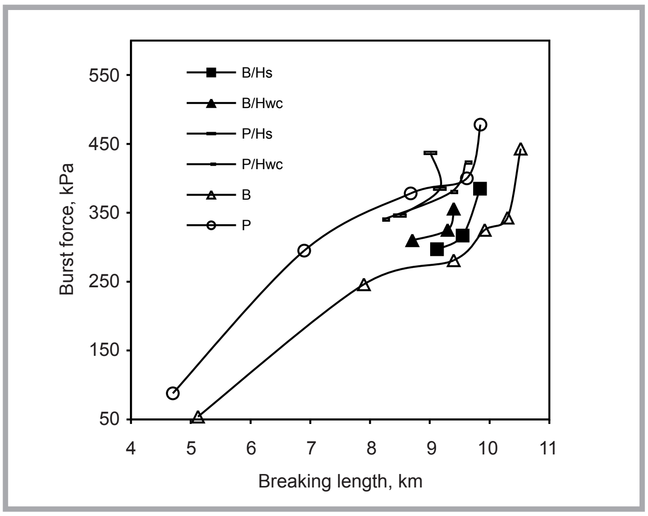

__Figure 3.__ Burst force of bleached pulps from wood/hemp blends and birch or pine pulp vs their breaking length.

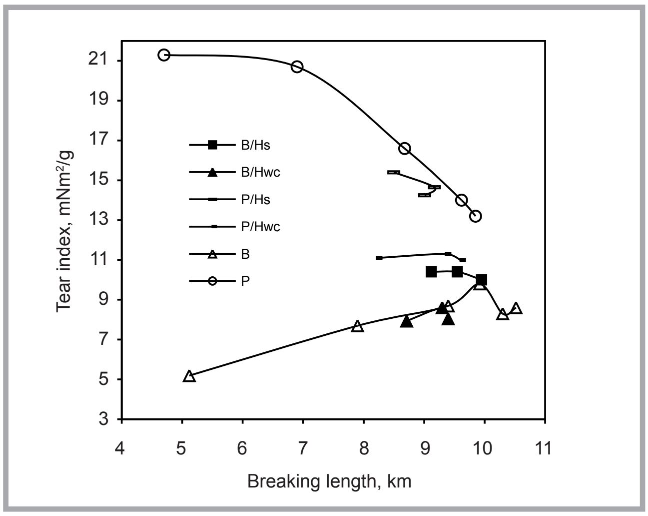

__Figure 4.__ Tear index of bleached pulps from wood/HFRM blends and bleached birch or pine pulp vs their breaking length.

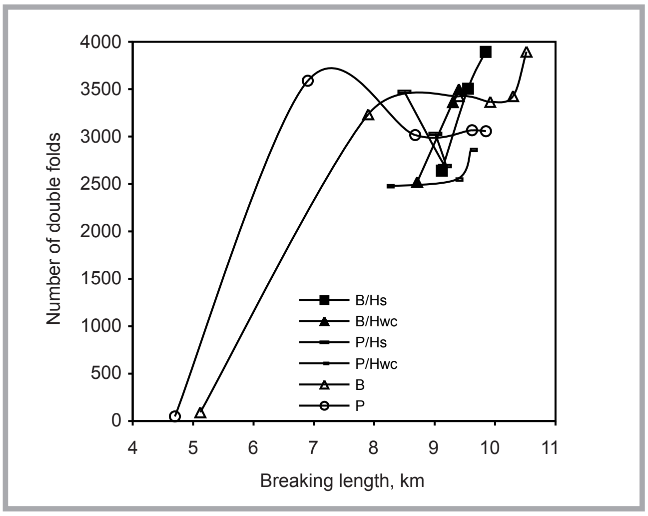

__Figure 5.__ Number of double folds of bleached pulps from wood/HFRM blends and bleached birch or pine pulp vs their breaking length.

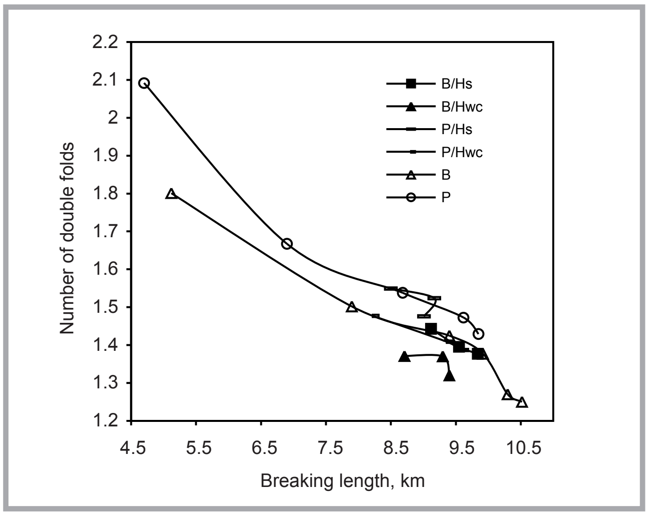

__Figure 6.__ Bulk of pulps from wood/HFRM blends vs their breaking length.

determined for bleached birch or pine pulps. As shown in ***Figure 3***, handsheets of bleached pine pulp have higher levels of this property than thoses of birch pulp, which probably results from a higher average length of pine fibres and a higher stretch at break of handsheets of the former pulp than for the latter. Results of the determination of the burst force of pulps from wood/HFRM blends indicate that the replacement of 20% of pine wood with these HFRMs should not have a significant negative impact on the burst strength.

Tear resistance is an important property of white papers intended for roll printing, during which paper is subjected to stress concentrated at its edges. This characteristic is also important for sack papers, where the low tear resistance allows further, uncontrolled tearing of paper in the case of small interruption in the continuity of the sack. Carlson [27] showed that the tear resistance of sack papers may be important for the resistance of sacks filled with cement for the results of the flat drop test, because this ratio of sacks made of paper with higher tearing resistance and lower values of TEA was comparable with that of sacks having higher TEA and lower tear resistance.

Figure 4 shows the tearing resistance of handsheets made of pulps obtained as a result of the common processing of wood and HFRMs. This feature of pulps depends strongly on the length of the fibres [12, 20, 25, 28-30], their degree of bonding [12], and their fibre strength [31].

The data in ***Figure 4*** indicate that the replacement of 20 wt. % of birch with hemp stalks slightly improves the tear index of the bleached fibrous intermediate obtained from such a blend and slightly lowers this feature of the fibrous intermediate obtained from a P/Hs blend. Our findings indicate that replacement 20% of birch or pine with the same amount of Hwc has an adverse effect on the tear resistance of pulps, which is particularly evident in the case of bleached kraft pulp from the P/Hwc blend (***Figure 4***). The lower values of tear resistance of the P/Hwc pulp than for the pine pulp can be explained by the reduction in the average length of fibres of the former pulp in comparison with latter by 16-31%, as resulted from Part I of this work [1], which is a consequence of the low length of fibres of hemp woody-core, reported by a few authors [13, 32].

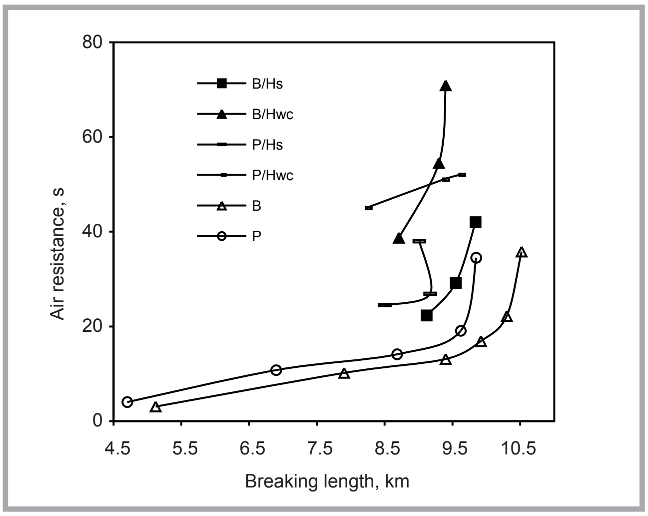

Figure 7. Air-resistance of pulps from wood/HFRM blend and birch or pine vs their breaking length.

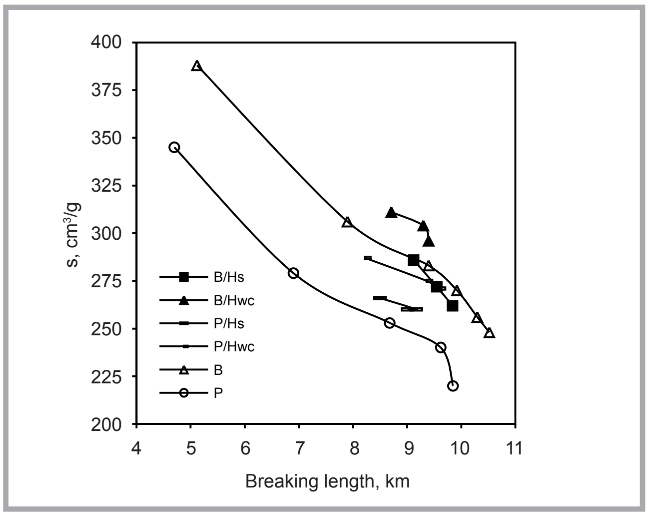

Figure 8. Light scattering ability of pulps from wood/HFRM blends and birch or pine vs their breaking length.

In its daily use, some papers may be exposed to repeated folding and wrinkling, and their ability to resist such stresses is one of their most important quality criteria. This feature of papers is characterised by results of the double fold test. This test has been used in many studies related to paper properties. It was, among others, established that the number of double folds of papers depends strongly on the basis weight of handsheets [33], the initial load of paper [34], the beating time and tensile strength of pulps [34, 35, 23], as well as the fibre length and coarseness [22]. But there are few data in literature on the effect of the presence of fibres other than woody ones in papers on the results of this test. Taking this into consideration, we determined the number of double folds using the handsheets prepared from wood/HFRMs pulps and compared it with the results of determination of the number of double folds of handsheets prepared from birch or pine. These results are presented in ***Figure 5***.

Figure 5 shows that the maximum number of double folds of paper strips made from wood/HFRM blends is high and comparable to that of paper strips made of birch or pine pulp. Data in ***Figure 5*** also indicate that when the basis weight of paper handsheets is comparable, the fibres of pulps are not shortened and the cellulose in them is not degraded, this property of handsheets depends primarily on the degree of fibres bonding in a sheet, which is evidenced by the comparative maximal values of the number of double folds of pine and birch pulps, as well as those from wood/HFRM blends. Apart from that, one can also state that long bast fibres of a different structure than that of wood fibres do not increase the number of double folds of handsheets of paper.

Results of determining the bulk of pulps obtained from blends of wood and HFRMs are shown in ***Figure 6***, against the background of this property of bleached pulps from pine or birch. Bulk is the property important for printing and writing paper [36], copy papers [37], solid cardboard liners [19, 38, 39], hygiene papers [40, 41], as well as sack papers [27, 42] and filter papers [43]. The high bulk of bleached pulps gives the possibility of the stronger calendering of printing and writing papers made using these pulps to obtain the desired stiffness of papers (e.g. copy paper), as well as solid cardboards, although the stiffness of the latter products is mainly obtainable by using mechanical or chemimechanical pulps [19, 39]. The bulk of pulps also influences the water absorption of paper products [40], as well as the softness of tissue paper [39, 44].

Figure 6 shows that the bulk of handsheets of bleached kraft B/Hs and P/Hs pulps is comparable to that of handsheets made from bleached birch or pine kraft pulp. Maintenance of the bulk of handsheets from wood/H pulp at the level of that of pulps from wood can be attributed to the presence of stiff primary and secondary hemp bast fibres in hemp stalks. The high stiffness of these fibres results from their thick walls, narrow lumen, the high degree of crystallinity of the cellulose of which they are composed [13, 45, 46], and the high content of cellulose [13, 47]. The presence of the latter fibres in hemp bast showed in the results of length distribution determination of pulp from hemp bast fibres, in which the fraction of fibres with lengths of 1-3 mm was clearly visible [45]. On the other hand, a clearly negative effect on the bulk was disclosed with the replacement of both species of wood with hemp woody-core (Hwc). In this case, the bulk of handsheets was lower than for those of birch and pine pulps by 5 and 10%, respectively. The reason for this is certainly the low coarseness of hemp woody-core fibres [13, 45] and their high collapsibility.

Figure 7 shows a comparison of the air-resistance of handsheets made from bleached pulps from wood/HFRM blends in comparison with those of birch or pine pulps.

High air permeability (low air-resistance) is desirable in the case of blotting paper, sack paper [27, 42, 48, 49], as well as for filter papers [43, 49, 50]. On the other hand, lower values of air-permeability are required for papers which have to protect various goods against the access of air, such as parchment and impregnated papers [49], as well as for printing grades of paper e.g. those printed with the rotogravure printing technique, in which higher sheet porosity leads to a higher level of ink absorption and, thus, a less desirable printed look [51]. In regard to sack paper, source literature indicates that standard kraft sack paper should have an air-resistance of no more than 20 s/100 ml [48]. ***Figure 7*** shows that sheets prepared from bleached kraft pulps from birch or pine fulfil this condition, with air-resistance being low even at a breaking length of 9 km. For pulps from wood/HFRM blends, the condition of the air-resistance of handsheets being less than 20 s/100 ml is more realistic for pulps from wood/hemp stalk blends. However, the pulp of such blends would require a shorter beating time. The increased air resistance of pulps from wood/HFRM blends observed can be explained by the presence of thin walled hemp woody-core fibres, as well as by the higher number of fines in these pulps [13, 45]. A strong negative impact of the cell wall thickness and fines on the air-resistance was highlighted in references [52] and [53], respectively.

An important feature of the fibrous intermediates used in the production of graphic papers is the ability to scatter light. It determines the opacity of papers [54, 55], and thus their basis weight and the amount of filler which must be used to achieve a given level of the former property of papers. Results of the determination of light scattering ability are shown in ***Figure 8***.

As can be seen in ***Figure 8,*** the light scattering ability of the pulp obtained from processing birch or pine with hemp stalks is similar or higher in comparison with that from birch or pine pulp, respectively. The replacement of a portion of birch and pine wood with hemp woody-core clearly and positively influences the light scattering ability of the pulps. This probably results from the significant increase in the number of fibres in pulps from wood/hemp woody-core blends, as we showed in the first part of the work concerning the common processing of wood and hemp fibrous raw materials into bleached kraft pulps [1].

Conclusions

1. Replacement of 1/5 of wood with hemp stalks and hemp woody-core changes the SR-freeness of bleached kraft pulps from these blends by 3-5.5°SR after their moderate beating in a Jokro mill.
2. Bleached kraft pulps from wood/HFRM blends are characterised by good strength as well as structural and optical properties, which are generally comparable with those of bleached pulps from birch and pine.
3. The good tensile strength and burst of such pulps are due to the presence of woody-core fibres, while the good bulk and tear are the effect of the presence of long, primary and secondary bast fibres, which are slightly susceptible to flattening.
4. The breaking length, burst strength, and optical properties of bleached kraft pulps from wood/hemp woody-core blends are comparable with or better than those of bleached birch and pine kraft pulps. However, the replacement of a part of birch and pine with hemp-woody core negatively affects the bulk, and air and tear resistance of the bleached kraft pulps produced.
5. Taking into consideration the results presented in Part I and Part II of the study, one can conclude that hemp stalks are better fibrous raw material for the production of papermaking intermediates partially free of wood fibres than hemp woody-core.

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