SODA PULPING OF RAPESEED STRAW

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The aim of this work was to conduct batch soda pulping of rapeseed straw (species *Brassica napus* L. convar. *napus*) without and with addition of anthraquinone as a catalyst in the cooking liquor. To characterize the chemical composition of rapeseed straw, cellulose, holocellulose, lignin, ash, and extractives were determined. The effect of anthraquinone addition upon the degree of delignification, total yield, and amounts of rejects was investigated. For selected samples of pulp, the fibre length, degree of polymerization, as well as strength properties of soda and soda-AQ pulps were measured as well. The results obtained showed that the content of lignin in rapeseed straw is lower than that in softwoods. The presence of anthraquinone in cooking liquor accelerates delignification, however, for a given H-factor, lower kappa number and total yield were achieved, compared with cooking without anthraquinone. Also, anthraquinone in cooking liquor had a positive effect upon the decrease of rejects, mainly at a lower H-factor. The unbleached soda pulp comprising short fibres, below 1 mm, presented greater tensile strength in comparison with waste paper.

Keywords: rapeseed straw, delignification, soda pulp, yield, anthraquinone

INTRODUCTION

Wood has been the dominant fibre source in the pulp and paper industry in the world so far, although non-wood fibre material has been increasingly developing in recent years. In many countries where wood is not available in sufficient quantities, an alternative to replace short wood fibres for printing papers is to use non-wood fibres from annual plants or agricultural residues. Thus, the efforts of searching for new pulp sources may be conditioned by the shortage of short-fibre material, on the one hand, and, parallel overproduction of some agricultural crops, on the other hand.

The most commonly used commercial method in pulping of non-woody species is still soda process, using sodium hydroxide as a cooking chemical. The addition of anthraquinone (AQ) to the cooking liquor can not only affect pulp yield, but also increase the rate of delignification, leading to lower lignin levels for equivalent cooking conditions.

In the past decade, the soda-AQ process has been utilized to produce pulps from kenaf bark,[1] okra stalks,[2] weed (*Ipomea carnea*), hemp,[3] amaranth, orache, Jerusalem artichoke,[4] industrial grass,[5] bamboo,[6] dhaincha (*Sesbania aculeata*),[3,7] and rice straw.[8] Using the conventional soda process without anthraquinone addition, pulps have been produced from canola stalks,[9] and rapeseed straw[10] as well. The alkali charge expressed as NaOH changed from 14% (ref.[1]) to 23% (ref.[4]), maximum cooking temperature varied in the range of 160 °C (ref.[1,2,7]) to 180 °C (ref.[7,8]), and liquor-to-raw material ratio within the limits of 4:1 (ref.[3,6]) to 8:1 (ref.[9]). The anthraquinone charge on o.d. material basis ranged from 0.1% (ref.[1,3,4,6,7]) to 1% (ref.[8]).

Rapeseed is the third most important oilseed crop after soybean and palm. As a result of high demand for vegetable oils and biodiesel, the world wide planted area for rapeseed increases continuously. At present, the planted area in the Czech Republic achieved nearly 400 thousand hectares. After harvesting, the amount of rapeseed straw remaining in the fields is of 2.8 to 4.5 t/ha.[11] With respect to this, it can be estimated that at least 1 million tons of rapeseed straw are annually produced in the Czech Republic. Owing to the extreme coarseness of the rapeseed straw, it cannot be used as cattle feed, however, it could be used in various products, including pulp and paper production.

The objective of this paper was to conduct batch soda pulping of rapeseed straw and to

investigate the effect of anthraquinone addition on the degree of delignification. For rapeseed straw formed from stalks and valves of siliques and for stalks used only as pulping material, the dependencies of the total yield and kappa number upon H-factor were evaluated. Thus, this study continues the investigation of chemical pulping of rapeseed straw and extends the results of soda pulping reported in the previous work[10] over the area of soda pulping with athraquinone as a catalyst of delignification.

EXPERIMENTAL

Rapeseed straw (*Brassica napus* L. convar. *napus*, in our case line genotype Labrador) collected from the field in Polabian lowlands near the city of Pardubice was used for the pulping process. Raw materials consisted mainly of stalks, but approximately one third of the total amount were valves of siliques.

At first, the chemical analysis of rapeseed straw was performed according to Tappi Test Methods.[12] Ash (TAPPI T 211 om-02) and silica (TAPPI T 245 cm-98) contents, as well as extractives contents by Soxhlet extraction with acetone, ethanol, and with 7:3 mixture of ethanol to toluene by volume (TAPPI T 280 pm-99), as well as Klason lignin (TAPPI T 222 cm-02) using 72% sulphuric acid, in the stalks and in silique valves, were determined after milling to powder randomly taken samples in a laboratory vibratory mill. The holocellulose content was determined using the method of Wise *et al.*[13,14] The cellulose content was determined by the Seifert method described in ref.[15] and alpha-cellulose content according to Tappi T 203 cm-99. The water solubility of the raw material was determined in accordance with TAPPI Test method T 207 om-93 and the 1% sodium hydroxide solubility – according to TAPPI T 212 om-88.

Prior to cooking experiments, the rapeseed straw was cut into 2-3 cm length chips. The moisture content of the straw was within 6 and 10%, depending on the relative humidity of the air. Soda and soda-AQ pulping of rapeseed straw was carried out in a laboratory rotary digester, comprising six autoclaves of 750 cm^3 capacity, immersed in an oil bath. The mass of o.d. raw material in each reactor was approximately 48 g of stalks and 39 g of straw. On the basis of trial pulping experiments carried out for the liquor-to-raw material ratio in the range of 5:1 to 9:1 and alkali charge ranging from 17% to 21%, the cooking conditions were selected when the amount of rejects was acceptable. Hence, the next batch cooks giving pulps to produce handsheets were performed at the liquor-to-raw material ratio of 5:1, alkali charge of 19% expressed as Na_2O per o.d. raw material, and cooking temperature of 160 ºC. When anthraquinone was added to the cooking liquor, its charge was 0.1% per o.d. raw material. The temperature regime was as follows: 45 min heating to 105 ^oC, 30 min dwelling at 105 ^oC, 30 min heating to 160 ^oC, and then dwelling at cooking temperature. The batch cooks were ended as soon as the H-factor reached a value from 500 to 2,600 h. The corresponding pulping time at the cooking temperature was varied from 40 to 220 min.

After the cooking process, the cooked pulp was refined, thoroughly washed with tap water, and screened using a 10 mesh sieve. The pulp, from which handsheets were made on a handsheet forming machine, was beaten in a laboratory ring beater to the beating degree of 48-64 SR, determined by the Schopper-Riegler method, according to ISO 5267-1 standard. The handsheets made of unbeaten and beaten pulp were tested for the strength properties using a TIRA test 26005 device. For every handsheet having a grammage of 80-85 g m^{-2}, the tensile strength was determined at least 20 times.

Using the Kajaani instrument, the average length of the fibres was measured as well. The average degree of polymerization of rapeseed straw fibres was determined from the limiting viscosity number, using a capillary viscometer. Viscosimetric measurements were performed in accordance with T230 om-89 TAPPI Test Method, however, pulp fibres were dissolved in cadoxen, a solution of cadmium oxide in aqueous ethylene diamine.

RESULTS AND DISCUSSION

Chemical composition

The chemical composition of a plant gives an idea of how feasible the plant is as a raw material for paper making. Cellulose is the principal component in fibres. The non-cellulose components of the cell walls include hemicellulose, pectins, lignin and proteins, and also certain minerals.

The chemical characteristics of stalks and silique valves are summarised in Table 1. The ash content of stalks is lower than that of silique valves, which is in agreement with previously reported results,[10] but much greater than in hardwood (0.55% in oak, 0.64% in beech) or in softwood (0.41% in spruce, 0.25% in pine).[16] The ash content in stalks is lower than that reported by Enayaty *et al.*[9] for canola stalks (8.2%). With regard to spent liquor recovery, a positive finding is that the silica content is much lower, approximately only 0.145% for stalks and 0.081% for silique valves from the ash, in comparison with previous results,[10] where silica content was determined as about 3%. Generally, it is known that the chemical composition of plants depends on the plant genotype, the plant part from which the sample is derived, and on the climate. It may be a reason why some values of the chemical composition determined in this study differ from

those reported in the preceding paper,[10] where rapeseed straw, genotype Ontario, was collected from the field in Bohemia-Moravian Highlands. Housseinpour *et al.*[17] reported a silica content of 0.32% in rapeseed stalks ash.

Table 1
Chemical composition (in mass %) of rapeseed straw

Sample	Ash	Silica	Holocellulose	Cellulose	α-cellulose	Lignin
Stalks	4.449	0.0064	76.15	33.90	28.83	21.35
Valves of siliques	7.832	0.0063	71.59	28.35	25.73	14.14

Table 2
Extractives (in mass %)

Sample	Acetone	Ethanol toluene	Ethanol	Cold water	Hot water	1% NaOH
Stalks	2.556	5.305	3.644	7.141	5.061	30.81
Valves of siliques	5.121	17.41	4.192	15.53	1.032	43.85

The holocellulose content of stalks is greater than that of silique valves, which is in reasonable agreement with previously reported data[10] and, for stalks, it is similar to that of 74.5% reported by Enayati *et al*.[9] for canola stalks. The content of hemicelluloses, pectins, and proteins can be estimated as a difference between holocellulose and cellulose determined by the Seifert method. Then, the content of these components is 42.2% in stalks and 43.2% in silique valves, even if a small amount of hemicelluloses, namely pentosans in the case of annual plants, can slightly increase the cellulose content, determined according to the Seifert method.[15]

As expected, the alpha-cellulose content of the silique valves is lower than that of stalks, which is much lower than that of 42% determined for canola stalks.[9] The alpha-cellulose content is similar to that of 28.5% for Jerusalem artichoke.[4] Similarly, the lignin content in the silique valves was found to be substantially lower than that of stalks, in good agreement with the previous paper,[10] and also lower than that of 17.3% for canola stalks.[9] The lignin content in stalks was comparable with that of oak (21.37%), but lower than that of beech (24.47%), spruce (30.44%) and pine (29.53%).[16]

It should be noted that a comparison of the chemical composition of rapeseed straw with those of wheat straw, hemp, rice straw, kenaf, industrial grass, flax, bamboo, amaranth, orache, artichoke can be found in the previous paper.[10]

Besides the chemical analysis of the stalks and silique valves, the extractives in organic solvent, namely acetone, ethanol, and ethanol-toluene mixture, were determined (Table 2). For rapeseed stalks, the solubility in acetone, into which the lipophilic substances such as fat acids and resins leach,[14] is in close agreement with that of 2.50 mass % reported by Enayati *et al*.[9] for canola stalks. For all organic solvents tested, the solubility of stalks is lower than that of the silique valves. Nevertheless, the values determined in this paper are much lower than those reported in our previous work,[10] when a mixture of benzene-toluene was used. The extractives determined in ethanol-toluene mixture could not be compared with the results of other investigators, since no data for annual plants were found in the cited literature. Of course, the solubility in the ethanol-toluene mixture for stalks and silique valves is much greater than those of 2.64% and 2.70% for beech and spruce, respectively, and comparable with those of 10.54% and 10.37% for oak and pine, respectively.[16]

Water can extract inorganic compounds, monosaccharides, oligosaccharides, alcohols, colouring matters, tannin agents and some low molecular mass phenols.[4] For two main components of rapeseed straw, the cold water solubility was found to be greater than the hot water solubility, which is in agreement with Housseinpour *et al*.,[17] who found a cold water solubility of 13.8% and hot water solubility of 5% for stalks of rapeseed straw (hybrid genotype

hyola 401). However, Enayati *et al.*[9] reported a hot water solubility of 18.0% for canola stalks. The greater amount of extractives in cold water can be attributed to pectins, which may present better solubility in cold water in comparison with hot water. In the previous work,[10] the cold water solubility and hot water solubility were found to be of 12.53% and 13.35%, respectively, for a random sample of rapeseed straw containing stalks and silique valvesin the mass ratio of 2:1.

The solubility of the stalks and silique valves in 1% NaOH given in Table 2 is in good agreement with that of 34.9% determined in the previous work[10] for a random rapeseed straw sample. Enayati *et al.*[9] and Housseinpour *et al.*[17] reported 1% NaOH solubility of 46.1% and 50.3%, respectively. Besides substances soluble in water, resin acids, polyphenols, tannins, and fragments of hemicelluloses and lignin can leach into alkaline solutions.[14] The high content of extractives in alkaline solutions can be considered a drawback to the use of rapeseed straw for chemical pulping, thereby a lower pulp yield can be expected.

Soda-AQ pulping

H-factor selected for describing a batch cooking process is a cooking variable that combines cooking temperature and time into a single variable that indicates the extent of the delignification reaction. This variable is often used for comparison of cooks, varying reaction time and temperature. In contrast to the previous work,[10] where the H-factor was calculated from Vroom's equation derived for kraft pulping, in this work, the relationships valid for soda pulping were applied.[18] Thus, the H-factor was calculated, in hours, from the following equation:

$$H = \frac{1}{60}\int_{\tau=0}^{\tau=\tau} k_r d\tau \quad (1)$$

where τ is cooking time (in min) and k_r is a relative rate constant defined as:

$$k_r = \exp(45.8 - 17610/T) \quad (2)$$

where T is temperature of cook in °C.

At first, the effect of alkali charge and liquor-to-straw ratio on the degree of delignification and amount of rejects was investigated. At H-factor equal to 1,660 h, when only stalks were cooked without AQ presence in the cooking liquor, the results of the trial runs revealed that with increasing alkali charge ranging from 17% to 21% on o.d. stalks, the kappa number and amount of rejects dropped from 62 to 41 points and from 1.1 to 0.2%, respectively. The influence of liquor-to-straw ratio was tested within the limits of 5:1 to 9:1. With increasing liquor-to-straw ratio, the kappa number and amount of rejects increased in the limits of 39 to 60 and 0.2% to 1.0%, respectively. Since the alkali charge was maintained at 19%, the alkali concentration of the cooking liquor, as well as the driving force dropped with increasing liquor-to-straw ratio, which had a negative impact on the degree of delignification. Therefore, on the basis of preliminary runs, the alkali charge of 19% and liquor-to-straw ratio of 5:1 were chosen as suitable for the tested rapeseed straw and kept constant for further cooks. From an industrial perspective, the low liquor-to-straw ratio is convenient owing to the large amount of spent liquor incoming to recovery.

In Figure 1, the results obtained for rapeseed straw and stalks only are compared. As would be expected, the total yield, as well as the kappa number, decreased with increasing H-factor within the limits of 860 h to 2,580 h. Nevertheless, H-factor influenced the total yield for stalks much more markedly than for rapeseed straw. It has to be reminded that random samples of straw containing different amounts of stalks having various diameters were inserted into the digester vessels. This fact could influence the dependencies of the total yield determined experimentally. The lower total yield obtained for straw in comparison with stalks can be ascribed to the presence of silique valves having lower content of cellulose. The valves of siliques formed approximately one third of the straw mass.

It must be stressed that, for a more synoptical comparison of dependencies shown in Figure 1 (also in Figures 2-5), thin lines were inserted between points. In any case, these lines do not express courses of given variables between discrete values obtained experimentally.

The effect of the presence of anthraquinone in the cooking liquor upon soda cooks for stalks is demonstrated in Figure 2. The addition of AQ in the amount of 0.1% on o.d. raw material led to considerable changes in the total yield and kappa number. It confirmed that anthraquinone in the cooking liquor accelerates the delignification reaction. While with increasing H-factor the kappa number dropped from 66 to 38 for the cooking liquor without anthraquinone, the anthraquinone addition led to a substantial decrease in kappa number ranging within the

limits of 22.7 to 16. At the same time, the difference in kappa number decreased with an increasing H-factor. While for an H-factor of 860 h the kappa number decreased by 43 points, the decrease in kappa number by 22 points was attained for an H-factor of 2,590 h. The presence of anthraquinone influenced the total yield as well. For soda cook without anthraquinone, the total yield dropped in the range of 41% to 34% with increasing cooking time. However, in the case of anthraquinone presence in the cooking liquor, the total yield decreased from 36% to 32.5%. Thus, with increasing H-factor, the difference in the total yield decreased from 5% at an H-factor of 860 h to 1.5% at an H-factor of 2,590 h.

The influence of the presence of silique valves in the raw material used for soda-AQ cooking is shown in Figure 3. The stalks without valves of siliques gave greater total yield in comparison with a blend of stalks and silique valves. The increase in the total yield in the region of H-factor above 1,400 h for stalks can be probably attributed to random sampling. Kappa number decreased with increasing H-factor for both raw materials tested. Nevertheless, it was observed that the drop in kappa number is less steep with increasing cooking time. In contract to cooking without anthraquinone, the kappa number for the pulp from rapeseed straw is greater in comparison with that of the pulp produced from stalks.

Figure 4 is a plot of mass fraction of rejects versus H-factor, showing the influence of anthraquinone addition, when rapeseed stalks were used as raw material. It is clear that for the two lowest levels of H-factor, namely 840 h and 1,190 h, the presence of anthraquinone in the cooking liquor led to a significant decrease in the amount of rejects.

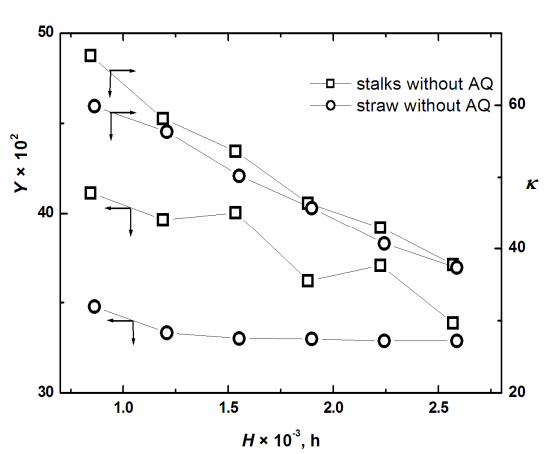

Figure 1: Total pulp yield, *Y*, and kappa number, *κ*, as a function of H-factor for soda pulps from stalks and rapeseed straw

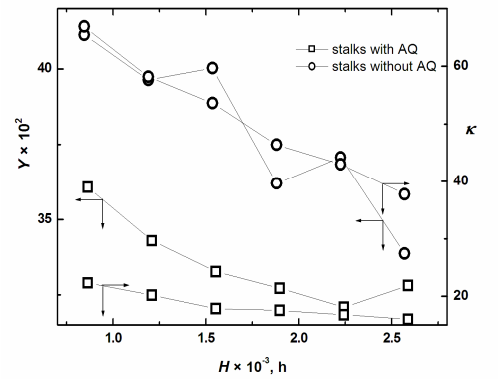

Figure 2: Total pulp yield, *Y*, and kappa number, *κ*, as a function of H-factor for pulp cooked from stalks without and with anthraquinone

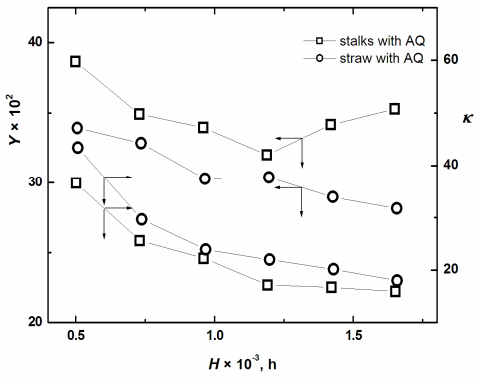

Figure 3: Total pulp yield, *Y*, and kappa number, *κ*, as a function of H-factor for soda-AQ pulps from stalks and rapeseed straw

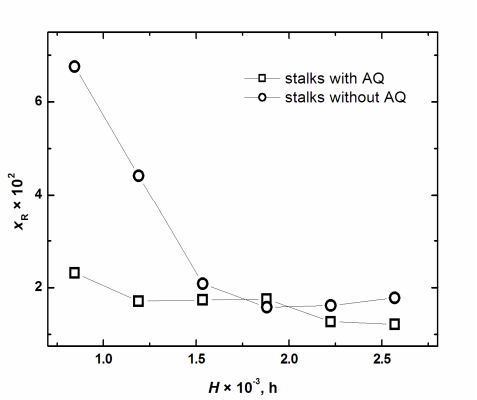

Figure 4: Effect of H-factor upon mass fraction of rejects, x_R, for pulp from stalks cooked with and without anthraquinone

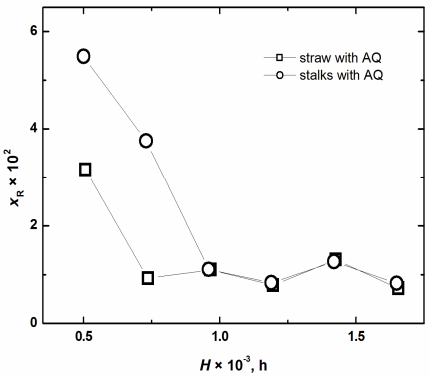

Figure 5: Effect of H-factor upon mass fraction of rejects, x_R, for soda-AQ pulp cooked from stalks and rapeseed straw

However, for H-factor within the limits of 1,530 h to 2,570 h, the influence of anthraquinone upon the amount of rejects is not remarkable. It is worth mentioning that the temperature profile of the cooks included dwelling at 105 °C for 30 min, while in the previous work[10] the dwelling period at 70 °C lasted only 20 min. Thus, a higher temperature of the dwelling period along with a longer time interval brought a lower amount of rejects in comparison with that obtained in a previous study.[10] Furthermore, Figure 5 demonstrates the influence of the composition of raw material upon mass fraction of rejects when anthraquinone was added into the cooking liquor. At two lowest levels of H-factor 500 h and 730 h, the pulp cooked from stalks comprised a markedly greater amount of rejects. However, for an H-factor ranging from 960 h to 1,560 h, the differences in the mass fraction of rejects were negligible.

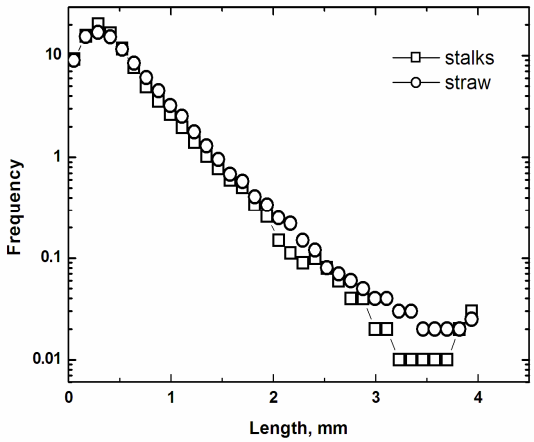

Figure 6: Distribution of fibre length for soda pulp cooked from stalks and rapeseed straw

Pulp characteristics

To characterize soda and soda-AQ pulps cooked from rapeseed straw, the fibre length, degree of polymerization, as well as tensile strength were measured.

Fibre length measurements revealed that the pulp comprised short fibres. The distribution of fibre length for soda pulp cooked from stalks and rapeseed straw is shown in Figure 6. The arithmetic average length and weighted average length were found as 0.41 mm and 0.77 mm, respectively, for unbeaten pulp produced from stalks, and 0.45 mm and 0.84 mm, respectively, for pulp cooked from straw. Thus, the degree of polydispersity is less than 2 for both pulps. For comparison, Enayati *et al.*[9] and Housseinpour *et al.*[17] reported a mean length of fibres of 1.17 mm for canola stalks, and 1.32 mm for rapeseed

stalks, respectively. The average length of fibres from rapeseed straw is similar to that measured for beech pulp when the arithmetic average and weighted average were of 0.51 mm, and 0.73 mm, respectively, while, for softwood pulp from a blend of pine and spruce, were measured as 1.46 mm and 3.35 mm, respectively.[19]

The degree of polymerization is directly proportional to the chain length of cellulose and has an impact upon some properties of pulp fibres, such as mechanical characteristics. The degree of polymerization was determined viscosimetrically for unbeaten pulp cooked with AQ from stalks and from straw containing valves of siliques delignified to kappa number values of 22.5 and 24.8, respectively. The average degree of polymerization, when Cadoxen was used as a solvent of cellulose, was found to be 917, and 943 for stalks and straw with silique valves, respectively. For comparison, degrees of polymerization of 396, 599, and 371 were also determined for beech unbleached kraft pulp, unbleached kraft pulp from softwood, and bleached kraft pulp from softwood, respectively. The low value of the degree of polymerization in the case of beech pulp corresponds with the short fibre length and can also be ascribed to the presence of hemicelluloses in the pulp. The low value measured for the bleached kraft pulp from softwood (blend of spruce and pine) can be attributed to the degradation of cellulose molecules during the bleaching process. Martínez *et al*.[20] measured a degree of polymerization of 700 for a blend of spruce and pine in the mass ratio of 1:1, while Yamashiki *et al*.[21] reported a value of 1,060 for white spruce. For a pulp cooked from canola stalks and delignified to a kappa number ranging from 24.2 to 70.7, Enayati *et al*.[9] measured the degree of polymerization within the limits of 1,408 to 1,579 and found that higher alkali charge, as well as longer cooking time, resulted in an increase in pulp viscosity. This fact is attributed to the hemicellulose dissolving during high-intensity cooking, which led to a higher degree of polymerization measured by the authors.[9]

The pulp tensile strength is influenced primarily by inter-fibre bonding and fibre strength. The former being dependent on fibre flexibility and external fibrillation, while the latter upon the degree of polymerization of cellulose and small-scale deformation, such as dislocations, slip-planes, buckling, cracklings, wrinkles, and folds. The tensile strength expressed as the breaking length for the pulp cooked from rapeseed straw without anthraquinone addition is summarized in Table 3. Comparing unbeaten and beaten pulp, it is evident that the breaking length is greater for the beaten pulp cooked from both stalks and straw comprising valves of siliques. The presence of silique valves in rapeseed straw results in lower breaking strength. The breaking length of rapeseed straw measured in this paper is much greater than that of 2.5 km found by Enayati *et al*.[9] for soda pulp cooked from canola stalks. In the previous paper,[10]the breaking length of the soda pulp from rapeseed straw having a beating degree of 66 SR achieved 6.92 km, while for unbeaten pulp only 3.17 km was measured. It must be noted that a different genotype of rapeseed (Ontario) was tested previously[10] and the charge of alkali that affected cellulose degradation was only 17%. In spite of these facts, it should be supposed that the breaking length of rapeseed pulp does not attain the values measured for unbleached softwood kraft pulp when, e.g., for virgin kraft pulp beaten at 19 SR the breaking length of 7.99 km was measured previously.[22]

Nevertheless, the zero-span breaking length characterizing the tensile strength of individual fibres randomly oriented in a sheet was found to be slightly greater for unbeaten pulp. It is worth mentioning that the zero-span breaking length of soda pulp is comparable with that of 3.915 km determined for softwood kraft unbleached pulp.[23] The relative elongation, slightly greater for beaten soda pulp, was much lower in comparison with that of 3.2% for virgin kraft pulp beaten to 19 SR.[22] The larger bonding area between fibres due to beating had a positive impact on the tensile energy absorption index, which is unambiguously greater for beaten pulp. The energy absorption index is an important variable of wrapping papers, namely sack papers. Generally, the tensile energy absorption index of sack papers produced industrially from unbleached softwood kraft pulp reaches about 1.5 J g^{-1} in the paper machine direction and 2.6 J g^{-1} in cross direction.[22] Similarly as for soda pulp, the tensile strength of soda-AQ pulp after beating was greater in comparison with unbeaten pulp for both stalks and straw including valves of siliques. Nevertheless, the presence of silique valves in the raw material led to a decrease in breaking length, as indicated in Table 4. The tensile energy absorption index was found to be greater for beaten pulp and for stalks in comparison with unbeaten pulp and rapeseed straw, respectively.

The zero-span breaking length of soda-AQ pulp from stalks is comparable with those of soda pulp, but, for soda-AQ pulp cooked from straw, the zero-span breaking length was found to be lower in comparison with soda pulp.

Table 3
Strength characteristics of soda pulp from rapeseed straw (*BL* breaking length, *ε* relative elongation, *TEAI* tensile absorption index, *ZPBL* zero-span breaking length)

Raw material	Kappa number	Beating degree, SR	*BL*, km	*ε*, %	*TEAI*, J g^{-1}	*ZPBL*, km
Stalks	31	13	4.06	1.7	0.47	4.41
		48	4.98	1.9	0.68	4.29
Straw	36	13	3.51	1.7	0.42	4.43
		51	4.96	1.8	0.63	4.08

Table 4
Strength characteristics of soda-AQ pulp from rapeseed straw (*BL* breaking length, *ε* relative elongation, *TEAI* tensile absorption index, *ZPBL* zero-span breaking length)

Raw material	Kappa number	Beating degree, SR	*BL*, km	*ε*, %	*TEAI*, J g^{-1}	*ZPBL*, km
Stalks	38	13	4.02	1.9	0.54	4.21
		59	5.14	1.8	0.67	4.09
	23	13	4.10	1.4	0.41	4.13
		59	6.45	2.3	1.05	4.51
Straw	41	13	2.77	1.5	0.28	3.90
		56	4.46	1.6	0.46	3.32
	25	13	4.08	1.5	0.47	4.54
		64	5.48	1.9	0.74	3.99

Furthermore, it should be mentioned that the pulp prepared from rapeseed straw presented good beatability. For a short beating time (approx. 30 s), the beating degree of about 60 SR was achieved.

CONCLUSION

Rapeseed straw can be considered as one of the possible sources of short fibre pulp, mainly in the regions lacking in hardwoods. Pulp fibres manufactured from rapeseed straw are short, with an average length less than 1 mm. The lignin content of rapeseed straw is comparable with that of hardwoods. Owing to the relatively great solubility of rapeseed straw in alkaline solutions, lower yields after soda pulping can be achieved.

Adding anthraquinone to the cooking liquor brings a greater rate of delignification. At a given H-factor, soda-AQ pulping provides pulp cooked to a lower kappa number, containing a lower amount of rejects, but also a decrease in the total yield must be taken into account.

The presence of silique valves in straw leads to a lower pulp yield and has also a negative impact on the strength characteristics of the pulp. The breaking length of beaten rapeseed straw pulp seems to be greater than that of waste paper, but lower in comparison with unbleached softwood kraft pulp.

Besides chemical pulping of rapeseed straw, chemi-mechanical and enzymatic-mechanical pulping processes offer other possibilities of rapeseed straw treatment. Hence, further study should be aimed at these processes.

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