SODA PULP COOKED FROM RAPESEED STRAW

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The paper deals with batch soda cooking of pulp from rapeseed straw. Preliminary runs were focused on determining the effect of active alkali charge and liquor-to-straw ratio upon the delignification degree of pulp. Then, further investigation was carried out under the established optimum cooking parameters, viz. active alkali charge of 19%, liquor-to-straw ratio of 5:1 and anthraquinone charge of 0.1%, to determine the effect of the delignification degree, which is directly proportional to the H-factor, upon the total yield, kappa number and amount of rejects in the H-factor interval from 800 to 2,800 h. For soda-AQ cooks of straw, stalks and silique valves, the total pulp yield, kappa number and amount of rejects decreased with an increasing H-factor. The highest total yield and degree of delignification were found for soda-AQ pulp cooked from stalks only. On the contrary, the silique valves gave the lowest total yield. The degree of polymerisation of the pulp cooked from straw, stalks and silique valves increased with an increasing H-factor, the greatest values being measured for the pulp from stalks. The colour properties of the pulps from straw and stalks, including brightness, which ranged between 30 and 34, were found not to differ significantly between the pulps. However, the tensile strength of the handsheets made from once dried and repulped pulp was found to be markedly lower in comparison with that of never dried pulp.

Keywords: rapeseed straw, soda-anthraquinone pulping, degree of polymerisation, colour properties, tensile strength

INTRODUCTION

Nowadays, the largest amount of pulp and paper is produced from wood. However, increasing concerns about future fibre supplies and potential increases in wood costs have strengthened the interest in alternative sources. Moreover, in many countries, wood is not available in sufficient quantities to meet the rising demand for pulp and paper. In China and India, over 70% of the raw material used by the pulp and paper industry comes from non-woody plants.[1] Agricultural residues (bagasse, straw), wastes from other industries, and cultivated annual plants are the most important non-woody raw materials for the pulp industry.[2] However, only a few annual plants, such as reed, bamboo and some of the grasses, are harvested specially for pulp and paper production.[3] As pulps from plant stalks, with the exception of bamboos, are generally short fibered,[3] they are not suitable to produce papers with substantial strength. Of course, short fibre pulps can be readily used for the production of common, writing and printing papers, as well as for specialty papers, such as bible, filter, cigarette, currency, insulating and condenser papers, where the strength is not an important factor.[4] Also, the high hemicelluloses content makes stalk fibres ideally suited for the production of corrugating medium.[3]

Rapeseed (*Brassica napus* L. convar. *napus*), ranking among short fibered annual plants, is a dominant agricultural crop in many countries over the world. Hence, rapeseed straw, as an agricultural residue, can be used as a renewable source of cellulosic fibres. To assess its papermaking potential, a systematic investigation of fibre characteristics,[5] pulping processes and physical properties of chemical pulps has been performed continuously during the last decade.[6] Rapeseed straw is easily pulped using the soda process both without and with anthraquinone (AQ) as a catalyst of delignification in cooking liquor.[7–10] Neutral sulphite semi-chemical[11–13] and chemi-mechanical[14,15] processes offer further possibilities for industrial processing of rapeseed straw, yielding from 3 to 10 t/ha, depending mainly upon climate conditions.

The objective of our work was to determine the optimum cooking parameters, namely active alkali charge and liquor-to-straw ratio, and then, to investigate the influence of the degree of delignification of soda-AQ pulp cooked under the optimum conditions from rapeseed straw and its

main components, stalks and silique valves, upon the total yield and amount of rejects. The optical and strength properties of handsheets prepared from the soda-AQ pulps obtained, with an average degree of polymerisation, were measured as well.

EXPERIMENTAL

Rapeseed straw (*Brassica napus* L. convar. *napus*, in our case winter line genotype Labrador), collected from a field in Polabian lowlands near the city of Pardubice (Czech Republic), was used for the pulping process. Raw materials consisted mainly of stalks, but approximately one third of the total amount represented valves of siliques. After removing natural dirt, the rapeseed straw was manually cut to 1 to 2 cm pieces, which were used for laboratory soda pulping. The chemical composition of both basic components of rapeseed straw, stalks and silique valves, was reported in our previous paper.[10]

Batch 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. On the basis of pulping experiments performed earlier,[8,10] the temperature regime was established, *i.e.*, at first heating from room temperature to 105 °C for 45 min, then dwelling at 105 °C for 30 min, followed by heating to 160 °C for 30 min, and finally dwelling at the cooking temperature. The batch cooks were ended as soon as the H-factor reached a value corresponding to the desired degree of delignification. As in our preceding paper,[10] the H-factor in hours was calculated from the following equation

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

where τ is cooking time (in min) and k_r is the relative rate constant defined[16] as:

$$k_r = \exp\left(45.8 - 17610/T\right) \qquad (2)$$

where T is the temperature of cooking, in K.

The first set of experiments was focused on investigating the effect of active alkali (AA) charge and liquor-to-straw ratio upon the degree of delignification, and included soda cooks of stalks without anthraquinone addition ended at an H-factor equal to 1,660 h, and of rapeseed straw with anthraquinone addition ended at an H-factor of 820 h. The second set of experiments comprised soda-AQ cooks of rapeseed straw, stalks and silique valves. These cooks for various raw materials were ended at six levels of delignification, indicated by the H-factor value within the limits of 800 to 2,800 h. For soda-AQ cooks, the charge of anthraquinone was always 0.1%, based on o.d. raw material.

After the cooking process, the cooked pulp was refined, thoroughly washed with tap water and screened to remove rejects using a 10 mesh sieve. After drying at 105 °C, the total yield, kappa number and degree of polymerisation of the soda-AQ pulps cooked from straw, stalks and silique valves were determined. The kappa number was determined according to ISO 302. The average degree of polymerisation was determined by a viscosity test using a FeTNa solution (iron (III) sodium tartrate complex) as a solvent for the soda-AQ pulps, according to ISO 5351/2-1981. The average degree of polymerisation, *DP*, was evaluated by the following relationship:

$$DP = K_m^{-1} \frac{\tau - \tau_0}{\rho\tau_0\left[1 + k\left(\dfrac{\tau - \tau_0}{\tau_0}\right)\right]} \qquad (3)$$

where τ is the efflux time of solution (s), τ_0 is the efflux time of solvent (s), ρ is pulp concentration (g/L), k, and K_m are empirical constants equal to 0.3, and 8.14×10^{-4} L/g, respectively.[17]

The remaining pulps cooked from rapeseed straw and stalks only, in the second set of experiments, were repulped using a Lorentzen&Wettre pulp disintegrator for 10 min at 1% consistency and 300 rpm. These pulps were cooked to an H-factor ranging from 800 to 2,800 h, and were used to make sheet samples on a handsheet forming machine, which were then tested for their optical and strength properties. It is worth mentioning that the beating degree of the repulped pulps was 15 °SR, *i.e.*, by 2 °SR greater in comparison with that for the pulp refined after cooking.

The colour properties of all prepared handsheets were objectively evaluated using a Lorentzen & Wettre Elrepho SE 071/070R spectrophotometer. For each soda-AQ pulp cooked to a different degree of delignification, the brightness and colour coordinates were determined at least 40 times. Colour measurements were made on 10 locations for each sample, and the arithmetic mean of these measurements was calculated for each level of delignification. For describing the colour properties of the handsheets made from unbleached soda-AQ pulp, the colour space CIE $L^*a^*b^*$, the most widespread method of evaluation of colour or colour changes, was applied.[18] In this colour system, L^* indicates the lightness or darkness of the colour in relation to the scale extending from white ($L^* = 100$) to black ($L^* = 0$), and a^* and b^* are the chromaticity coordinates.[19] These coordinates indicate colour directions, *i.e.*, $+a^*$ and $-a^*$ represent the red and green directions, respectively, and $+b^*$ and $-b^*$ are the yellow and blue directions, respectively. The chroma, C, calculated according to the following relationship:

$$C = (a^{*2} + b^{*2})^{1/2} \qquad (4)$$

represents the saturation of colour. The colour hue can be expressed as a hue angle, h, (in degrees) defined as:

$$h = \mathrm{arctg}\,(b^*/a^*) \qquad (5)$$

Thus, the hue angle starting at $+a^*$ axis is equal to 0°, 90°, 180° and 270° for red, yellow, green and blue colour, respectively.[20]

The tensile strength of the handsheets prepared from once dried unbeaten unbleached pulps was measured on a TIRAtest 26005 device. The tensile properties, such as tensile index, breaking length and relative elongation, were measured on strips, with a length of 150 mm and width of 15 mm, cut from handsheets of basis weight ranging from 68 to 84 g/m^2. Before measuring strength, the handsheets were air-conditioned in a conditioning room under a constant temperature of 23±1 °C and relative humidity of 50±2%. All the strength measurements were performed in at least 20 replicates per each tested sample. Under the same conditions, the zero-span breaking length was measured as well.

RESULTS AND DISCUSSION

Cooking parameters

In the first set of the preliminary soda pulping runs, the influence of the active alkali (AA) charge and liquor-to-straw ratio upon the degree of delignification and amount of rejects was investigated. The batch soda cooks of stalks only, without AQ addition, and the soda-AQ cooks of straw formed from a blend of stalks and silique valves were stopped at an H-factor of 1,660 h and 820 h, respectively.

The influence of the AA charge ranging within the limits of 0.17 to 0.21 g of Na_2O per g of oven-dry straw on the kappa number and amount of rejects expressed as a mass fraction in cooked pulp is illustrated in Fig. 1. The kappa number and amount of rejects show similar trends for stalks and rapeseed straw. With increasing AA charge, both the kappa number and the amount of rejects decrease. As expected, the presence of AQ in the cooking liquor brought a higher rate of delignification. Although, at the cooking temperature, the duration for cooking stalks was twice longer than that for straw, *i.e.*, 130 min and 65 min, respectively, the reduction in the kappa number of the soda-AQ pulp from straw, in comparison with that of the soda pulp from stalks only, was achieved between 10 and 19, depending on the AA charge (cf. Fig. 1). The addition of AQ had a positive effect on the amount of rejects in pulp, which decreased with increasing AA charge for soda and soda-AQ processes. It must be noted that, for a more synoptical comparison of the dependencies shown in Fig. 1 (as well as further in Figs. 2-7), thin lines were drawn between experimentally measured points. These lines do not express the course of the given variables between defined values for individual soda and soda-AQ cooks.

The effect of the liquor-to-straw ratio ranging from 5:1 to 9:1 upon the kappa number and amount of rejects was investigated at an AA charge of 0.19 g of Na_2O per g of oven-dry straw. Fig. 2 shows how the kappa number increased with increasing the liquor-to-straw ratio.

Similarly, the amount of rejects increased with increasing the liquor-to-straw ratio, nevertheless, in the case of soda-AQ pulp, the mass fraction of rejects was less than 1%. With respect to the decreasing driving force, which decreases as the cooking liquor is more dilute and the concentration of active alkali drops, the degree of delignification expressed by the kappa number decreased with increasing the liquor-to-straw ratio. It is worth mentioning that, in comparison with wood chips, the liquor-to-raw material ratio is usually greater in the case of light bulky materials, such as straw. For example, liquor-to-straw ratios of 8 and 10 were reported for canola straw soda pulping,[7,9] and organosolvent pulping of amaranth, lavatera, sverbiga and schavnat,[21] respectively.

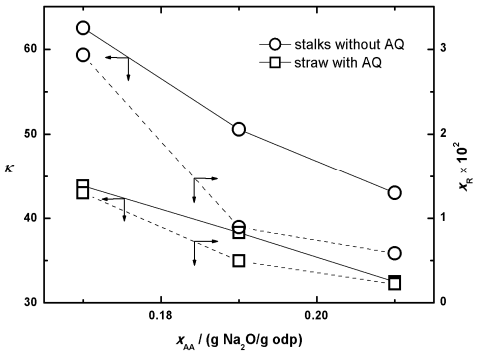

Figure 1: Kappa number, κ, and amount of rejects, x_R, as a function of AA charge, x_{AA}, at L/S = 7 for pulp cooked from rapeseed straw and stalks (solid line: κ vs. x_{AA}, dashed line: x_R vs. x_{AA})

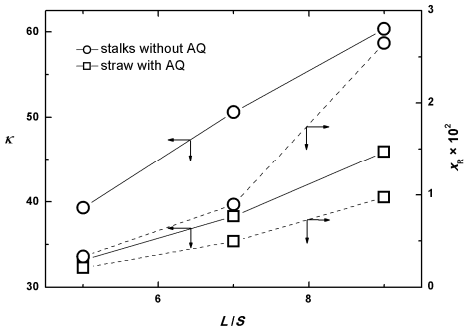

Figure 2: Kappa number, κ, and amount of rejects, x_R, as a function of liquor-to-straw ratio, *L*/*S*, at AA charge of 0.19 g Na_2O/g odp for pulp cooked from rapeseed straw and stalks (solid line: κ *vs*. *L*/*S*, dashed line: x_R *vs*. *L*/*S*)

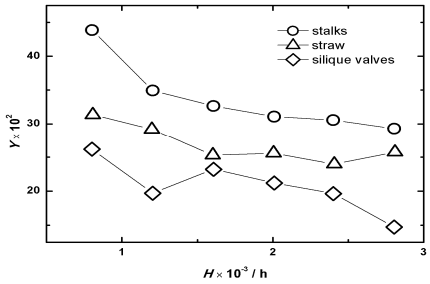

Figure 3: Dependence of total yield, *Y*, on H-factor, *H*, for pulp cooked from rapeseed straw, stalks and silique valves

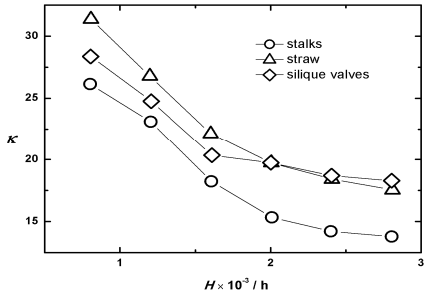

Figure 4: Dependence of kappa number, κ, on H-factor, *H*, for pulp cooked from rapeseed straw, stalks, and silique valves

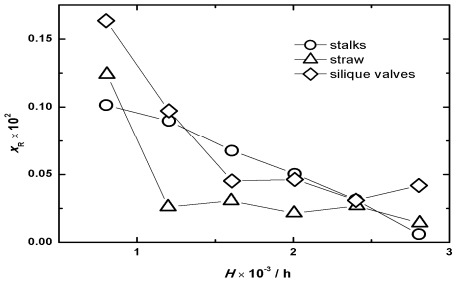

Figure 5: Dependence of rejects amount, x_R, on H-factor, *H*, for pulp cooked from rapeseed straw, stalks, and silique valves

The changes in AA charge and liquor-to-straw ratio had an impact on the total yield of pulp cooked by both processes. With increasing AA charge, the total yield dropped from 40.9% to 26.4%, and from 34.9% to 30.0%, for soda pulp from stalks only and soda-AQ pulp from straw, respectively. When increasing the liquor-to-straw ratio, the total yield increased from 36.0% to 37.7%, and from 28.6% to 34.6% for soda pulp from stalks and soda-AQ pulp from straw, respectively. On the basis of the preliminary results, further pulping runs were carried out at an AA charge of 0.19 g of Na_2O per g of oven-dry straw and a liquor-to-straw ratio of 5:1. Under these cooking conditions, the total yield, kappa number and amount of rejects were of 36.0% and 28.6%, 39.3 and 33.2, 0.33% and 0.21% for soda pulp from stalks only and soda-AQ pulp from straw, respectively.

Soda-AQ pulping of rapeseed straw components

The rapeseed straw used for soda-AQ pulping was a blend of two basic components, stalks and silique valves, included in the mass ratio of 2:1. Hence, the soda-AQ pulping of rapeseed straw and its components was performed at various degrees of delignification directly proportional to the H-factor ranging from 800 h to 2,800 h. The dependencies of the total yield, kappa number and amount of rejects determined for rapeseed straw and its components, stalks, and silique valves, are illustrated in Figs. 3, 4 and 5, respectively. As expected, all dependencies decrease more or less with an increasing H-factor. The highest total yield was achieved for stalks (cf. Fig. 3). This fact can be ascribed to the different cellulose content in the stalks and silique valves. In our previous paper,[10] cellulose contents of 33.90 wt% and 28.35 wt% were determined by a method according to Seifert[22] for stalks and silique valves, respectively. Surprisingly, although silique valves comprise less lignin (14.14 wt%)[10] in comparison with stalks (21.35 wt%),[10]the kappa number of the pulp obtained from stalks was lower than that of the pulp from silique valves at all H-factor levels (cf. Fig. 4). It seems that the delignification of silique valves is not as deep as in the case of

stalks. As follows from Fig. 5, the amount of rejects in the pulp cooked from silique valves is comparable to that found in the pulp from stalks, in the H-factor range from 1,200 h to 2,400 h. Moreover, for stalks, the amount of rejects decreases almost linearly with an increasing H-factor, however, in case of silique valves and straw the amount of rejects decreases strongly with increasing H-factor up to 1,600 h, and then the influence of the degree of delignification upon the amount of rejects is negligible.

Degree of polymerisation

The number of repeating units in a polymeric chain is termed as the degree of polymerisation and has an impact upon some properties of pulp fibres, such as mechanical characteristics. Generally, the degree of polymerisation of cellulose depends on the type of wood species and the pulping conditions. For all raw materials – rapeseed straw, stalks and silique valves – the average degree of polymerisation had an increasing trend with increasing the degree of delignification (Fig. 6). This fact can be attributed to the dissolution of hemicelluloses during the cooking process, which contributes to the relatively higher content of cellulose in the pulps delignified to a higher degree, given by the higher value of the H-factor. Comparing straw, stalks and silique valves, the highest degree of polymerisation was attained for the pulp from stalks, which contains a greater amount of cellulose than the silique valves, according to our results reported earlier.[10] Using FeTNa as solvent, Kačík *et al.*[17] measured average degrees of polymerisation of 1,097, 1,496 and 1,597 for unbleached pulps cooked from hardwoods, Turkey oak and white oak, respectively. For a pulp cooked from cannola stalks and delignified to kappa number ranging from 24.2 to 70.7, Enayati *et al.*[9] determined a degree of polymerisation within the limits of 1,408 to 1,579 and found that a higher alkali charge, as well as longer cooking time, resulted in an increase in pulp viscosity, which is in agreement with our results.

Colour properties

As mentioned in Experimental, the colour properties of the handsheets made from unbleached soda-AQ pulps from rapeseed straw and stalks only were evaluated by means of parameters L^*, a^*, b^* and ISO brightness, and are summarised in Table 1. It must be noted that, with respect to the low pulp yield attained for silique valves (cf. Fig. 3), the mass of pulp was not sufficient for making handsheets. Hence, the colour and tensile properties were determined for the pulps made from rapeseed straw and from stalks only.

The brightness, as well as lightness, L^*, had the lowest value for the lowest delignification degree at the H-factor of 800 h, while, for a higher delignification degree at the H-factor within the limits of 1,200 to 2,800 h, both parameters were slightly higher (Table 1). For the pulps from straw and stalks only, the values of chromaticity coordinates a^* and b^*, similarly to those for brightness and lightness, vary in a narrow interval. In spite of this, it is obvious that coordinate a^* increased with an increasing coordinate b^* for the pulps from stalks, while, for the pulp from straw, the dependence between the colour coordinates is not evident, except for their decrease with an increasing H-factor from 800 to 1,200 h (Table 1). For comparison with the brightness values ranging from 30.4 to 34.6% ISO in our work, Mousavi *et al.*[9] achieved a brightness of 17.2 and 18.2% ISO for unbleached soda-AQ pulp from rapeseed straw cooked at kappa number of 42.8 and 24.3, respectively. Fišerová *et al.*[23] reported a brightness of 27.7% ISO to 24.5% ISO, depending on the beating degree, for soda-AQ pulp cooked from hemp stalks. Mohta *et al.*[24] measured a brightness of 37.2 for unbleached soda-AQ bagasse pulp.

As follows from Fig. 7, the brown colour of the pulps prepared at the lowest degree of delignification (H-factor = 800 h) has the highest saturation given by the highest chroma value. For the pulp from stalks only, the chroma decreases with an increasing degree of delignification, but, for the pulps from straw, the chroma also decreases up to the H-factor of 2,000 h and then an increase of chroma is obvious for H-factor values of 2,400 and 2,800 h. The shift of brown colour described by the hue angle, h, is obvious for the pulps cooked at H-factor values of 800 and 1,200 h (cf. Fig. 7). For a higher delignification degree in the interval of the H-factor of 1,200 to 2,800 h, the differences in the hue angle seem to be insignificant. In general, the overall colour change, ΔE^*, defined as $(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$ is an important indicator that assesses the colour change based on changes in all parameters, L^*, a^*, b^*.

In the case of unbleached soda-AQ pulps from rapeseed straw and stalks only, the overall colour

changes were smaller than 2.5 and could be classified as "small difference, visible with high-quality filter".[18] Considering the colour properties, mainly brightness, the soda-AQ process seems to be suitable for producing bleachable grade pulp from rapeseed straw.

Table 1
Effect of delignification degree on colour properties of soda-AQ pulp from rapeseed straw and stalks only

H-factor, h	Brightness, % ISO	*L**	*a**	*b**
Stalks				
802	31.21	71.74	4.12	16.52
1 205	34.12	73.64	3.70	15.71
1 607	34.29	74.02	3.71	15.69
2 010	34.59	73.67	3.58	15.43
2 401	34.60	73.84	3.53	15.37
2 804	33.81	73.13	3.51	15.14
Straw				
807	30.36	70.89	4.04	16.27
1 199	32.96	72.78	3.80	15.82
1 602	33.18	72.95	3.76	15.77
2 004	33.60	73.24	3.68	15.72
2 407	33.04	72.90	3.80	15.89
2 809	33.26	72.68	3.79	16.08

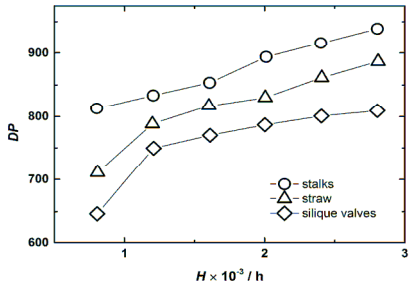

Figure 6: Dependence of degree of polymerisation, *DP*, on H-factor, *H*, for pulp cooked from rapeseed straw, stalks and silique valves

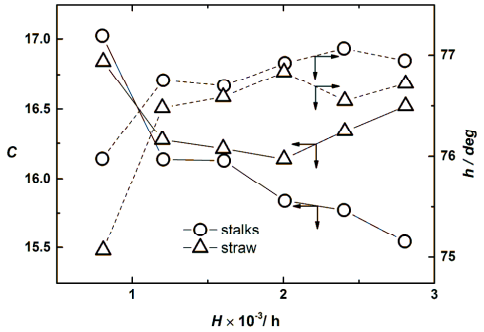

Figure 7: Dependence of chroma, *C*, and hue angle, *h*, on H-factor, *H*, for pulp cooked from rapeseed straw and stalks (solid line: *C* vs. *H*, dashed line: *h* vs. *H*)

Tensile properties

As mentioned above, the tensile properties were measured for soda-AQ pulps cooked from rapeseed straw and stalks only. The handsheets used for tensile measurements were prepared by repulping dried unbleached pulp. Since the overall strength of a paper sheet depends on both strength of fibre network and strength of individual fibres, the tensile index and zero-span tensile index were evaluated. The dependencies of the tensile index and zero-span tensile index on the degree of delignification, which is directly proportional to the H-factor, are shown in Figs. 8 and 9, respectively, where average values, within 95% confidence intervals, are illustrated.

The tensile strength results showed that the influence of the delignification degree on the tensile index is not unambiguous. The highest values of tensile index and zero-span tensile index were measured for the soda-AQ pulps cooked at an H-factor of 1,600 h. On the contrary, the pulp cooked from rapeseed straw at an H-factor of 2,800 h gave the lowest values of tensile index (Figs. 8 and 9). Comparing the tensile index and zero-span tensile index for both pulps, it is evident that, for the pulp from rapeseed straw, the zero-span tensile index was higher than the tensile index, except for the H-factor equal to 1,600 h. However, for the pulp cooked from stalks only, the zero-span tensile index was higher than the

tensile index only for the low kappa number pulp (H-factor of 2,000 to 2,800 h), while the high kappa number pulp (H-factor of 800 to 1,600 h) showed lower values of the zero-span tensile index in comparison with the tensile index.

However, both the tensile index and zero-span tensile index were too low in comparison with the results obtained in our previous paper,[10] where, for never dried unbeaten soda-AQ pulp cooked from rapeseed straw and stalks only, zero-span tensile index and tensile index of 37 N m/g and 41 N m/g, respectively, were achieved. The reason for this may be a phenomenon known as hornification, which refers to the stiffening of the polymer structure that takes place in lignocellulosic materials upon drying or water removal. When pulp fibres are dried, the internal fibre volume shrinks, because of structural changes in pulp fibres. The loss in swelling ability of once dried fibres is thought to depend on an increase in interfibrillar bonding through the cross-linking between cellulose fibrils when the fibre wall collapses during drying. If fibres are resuspended in water, the original water-swollen state is not regained.[25,26] A similar decrease in the tensile index from 46 N m/g to 20 N m/g for never dried and dried hardwood bleached kraft pulp was reported by Somwang *et al*.[27] On the basis of confocal laser-scanning microscope observations, the authors[27] ascribe the decrease in the strength of interfibre bondings to larger interfibre unbonded areas in the handsheet made of dried pulp.

Besides a decrease of the tensile index, hornification had a negative impact on the relative elongation of the handsheets. While the relative elongation had a value of around 1.7% for never dried unbeaten soda and soda-AQ pulps in our previous paper,[10] this handsheet parameter varied between 0.8 and 0.9% for all soda-AQ pulps tested in the present paper.

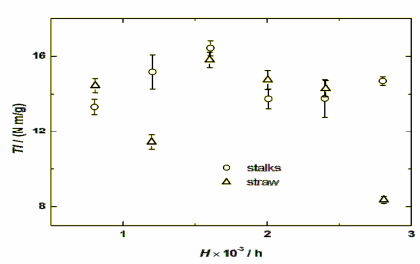

Figure 8: Dependence of tensile index, *TI*, on H-factor, *H*, for pulp cooked from rapeseed straw and stalks

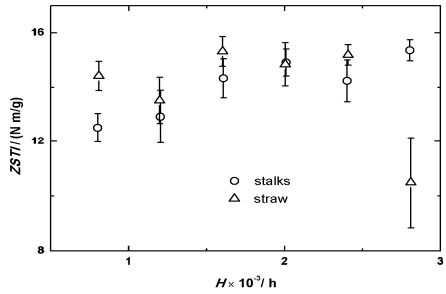

Figure 9: Dependence of zero-span tensile index, *ZPTI*, on H-factor, *H*, for pulp cooked from rapeseed straw and stalks

CONCLUSION

The preliminary runs, focused on the investigation of suitable soda cooking parameters, with and without anthraquinone addition, showed that the active alkali charge of 19%, based on o.d. straw, and the liquor-to-straw ratio of 5:1 are sufficient to prepare soda and soda-AQ pulp with a low amount of rejects. Therefore, in the second set of batch soda cooks, with 0.1% anthraquinone addition, aimed at preparing bleachable pulp with a kappa number below 20, the influence of the H-factor, which is directly proportional to the delignification degree, upon the total yield, kappa number and amount of rejects was investigated. Comparing two basic components of rapeseed straw, namely stalks and silique valves, the greater total yield along with deeper delignification degree were achieved for the soda-AQ pulp cooked form stalks only. The differences in the amount of rejects, mainly at higher H-factor, were not significant.

The unbleached soda-AQ pulp was characterised by its degree of polymerisation, colour properties and tensile strength. The average degree of polymerisation increased with increasing the H-factor for both components, probably due to increased hemicellulose removal, and achieved greater values for the pulp made from stalks, comprising a greater amount of cellulose. Overall colour changes of the unbleached pulps within the measured interval of the H-factor were not noticeable. However, the brightness of about 34% ISO, measured for the soda-AQ pulp from stalks, at an H-factor greater than 1,200 h, indicates that the stalks seem to be a suitable raw material for bleachable grade pulp production. The tensile strength characteristics measured showed that drying unbleached soda-

AQ pulp brought a significant decrease in the zero-span tensile index, as well as in the tensile index, which were determined to have decreased to approximately half of the values for never dried pulp.

In conclusion, rapeseed straw is an agricultural residue that has a high potential to be used as a non-wood raw material for pulp and paper production, mainly in the countries suffering from a lack of wood. Hence, this work contributes to spreading the knowledge on pulps prepared by the soda-AQ process. Our next work will be devoted to the bleaching process of soda-AQ pulp prepared from rapeseed straw.

ACKNOWLEDGEMENTS: This work was supported by the Internal Grant Agency of the University of Pardubice under the research project SGSFChT_2015003.

SYMBOLS

a^*	chromaticity coordinate
b^*	chromaticity coordinate
C	chroma defined by eq. (4)
DP	degree of polymerisation
h	hue angle defined by eq. (5), deg
H	H-factor defined by eq. (1), h
k	empirical constant in eq. (3)
k_r	relative rate constant defined by eq. (2)
K_m	empirical constant in eq. (3), L/g
L^*	lightness
L/S	liquor-to-straw ratio
T	temperature, K
TI	tensile index, N m/g
x_{AA}	mass fraction, g Na_2O/g odp
x_R	mass fraction of rejects
Y	total yield
$ZSTI$	zero-span tensile index, N m/g

Greek letters

κ	kappa number
ρ	concentration, g/L
τ	time, min, s

Abbreviations

AA	active alkali
AQ	anthraquinone
odp	oven-dry pulp

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