SODA PULP COOKED FROM RAPESEED STRAW

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The paper deals with batch soda cooking of pulp from rapeseed straw. The preliminary runs were focused on determination of active alkali charge and liquor-to-straw ratio upon the delignification degree of pulp. For suitable cooking parameters, viz. active alkali charge of 19 %, liquor-to-straw ratio of 5:1, and anthraquinone charge of 0.1 %, the effect of the delignification degree directly proportional to the H-factor upon the total yield, kappa number, and amount of rejects was investigated 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, as well as amount of rejects decreased with increasing H-factor. The greatest 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 pulp cooked from straw, stalks, and silique valves increased with increasing H-factor, the greatest values were measured for pulp from stalks. The colour properties of pulp from straw and stalks including brightness found in the interval of 30 to 34 did not differ significantly each other. However, the tensile strength of handsheets made of pulp once dried and repulped was found to be markedly lower in comparison with 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. Increasing concerns for future fibre supplies and potential increases in wood costs have strengthened the pulp and paper industry´s 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 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 pulp industry.[2] However, only a few of annual plants, such as reeds, bamboos, some of the grasses, are harvested specially for pulp and paper production.[3] As pulps from plant stalks, with 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 like bible, filter, cigarette, currency, insulating, and condenser paper, where the strength is not important factor.[4] Also, the high hemicellulose content makes stalks fibres ideally suited for the production of corrugating medium.[3]

The rapeseed (*Brassica napus* L. convar. *napus*) ranking among short fibered annual plants is a dominant agricultural crop in many countries the world over. Hence, the rapeseed straw can be further renewable source of cellulosic fibres. To assess its papermaking potential, a systematic investigation of fibre characteristics,[5] as well as pulping and physical properties of chemical pulp was performed continuously during the last decade.[6] The rapeseed straw is easily pulped using soda process without and with anthraquinone (AQ, in short) 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 of the industrial processing of rapeseed straw produced as an agricultural residue whose yields from 3 to 10 t/ha depends mainly upon climate conditions.

The objective of our work was to determine suitable cooking parameters, mainly active alkali charge and liquor-to-straw ratio, and, for chosen cooking conditions, to investigate the influence of degree of delignification of soda-AQ pulp cooked 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 soda-AQ pulps characterised by their 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 the 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 total amount were 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. 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 the same, *i. e*., at first heating from a room temperature to 105 ^{o}C for 45 min, then dwelling at 105 ^{o}C for 30 min, followed by heating to 160 ^{o}C for 30 min, and finally dwelling at cooking temperature. The batch cooks were ended as soon as the H-factor reached a value corresponding to the desired degree of delignification. Similarly 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 a relative rate constant defined (ref.[16]) as

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

where T is temperature of cook in K.

The first set of experiments focused on the investigation of the effect of active alkali (AA, in short) charge and liquor-to-straw ratio upon the degree of delignification included soda cooks of stalks without anthraquinone addition ended at H-factor equal to 1,660 h and of rapeseed straw with anthraquinone addition ended at H-factor of 820 h, while 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 indicating by the H-factor value within the limits of 800 to 2,800 h. For soda-AQ cooks, the charge of anthraquinone always was 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 10 mesh sieve. After drying at 105 °C, the total yield, kappa number, and degree of polymerisation of 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 FeTNa solution (iron (III) sodium tartrate complex) as a solvent for soda-AQ pulps according to ISO 5351/2-1981. The average degree of polymerisation, *DP*, was evaluated from the following relationship

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

where τ is the efflux time of solution (s), τ_0 is the efflux time of solvent (s), ρ is the pulp concentration (g/L), k, and K_m are the 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 scope of the second set of experiments, were repulped using a Lorentzen & Wettre pulp disintegrator for 10 min at 1% consistency and 300 rpm. These pulps cooked at H-factor ranging from 800 to 2,800 h, from which sheet samples were made on a handsheet forming machine, were tested for physical properties, namely optical and strength ones. It is worth mentioning that the beating degree of repulped pulps was 15 °SR, *i. e.*, by 2 °SR greater in comparison with pulp refined after cooking.

Colour properties of all prepared handsheets were objectively evaluated using the spectrophotometer Lorentzen & Wettre Elrepho SE 071/070R. For each soda-AQ pulp cooked at different degree of delignification, the brightness and colour coordinates were determined at least 40 times. Colour measurements were taken on the 10 locations on each sample, and the arithmetic mean of these measurements was calculated for each level of delignification. For the description of colour properties of the handsheets made from unbleached soda-AQ pulp, the colour space CIE $L^*a^*b^*$, the most widespread method of evaluation 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

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

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

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

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 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 with strips, having a length of 150 mm and width of 15 mm, cut from handsheets of basis weight ranging of 68 to 84 g/m^2. Before strength measuring, the handsheets were air-conditioned in the conditioning room under a constant temperature of (23±1) °C and relative humidity of (50±2) %. All the strength measurements were performed at least on 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 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 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 Figure 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 amount of rejects decrease. As expected, the presence of AQ in cooking liquor brought the higher rate of delignification. Although, at cooking temperature, the time interval for stalks was two times longer than that for straw, *i. e.*, 130 min and 65 min, respectively, the reduction in the kappa number of soda-AQ pulp from straw in comparison with soda pulp from stalks only was achieved between 10 and 19, depending on AA charge (cf. Figure 1). The addition of AQ had a positive effect on an amount of rejects in pulp that decrease with increasing AA charge for soda and soda-AQ processes. It must be stressed that, for a more synoptical comparison of dependencies showed in Figure 1 (also in Figures 2–7), thin lines were inserted between points measured experimentally. In any case, these lines do not express courses of given variables between discrete 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. Figure 2 shows how the kappa number increased with increasing the liquor-to-straw ratio. Similarly, the amount of rejects increases with increasing the liquor-to-straw ratio, nevertheless, in case of soda-AQ pulp, the mass fraction of rejects was less than 1%. With respect to decreasing driving force, which decreases how 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 case of light bulky materials like straw. For example, the liquor-to-straw ratio of 8 and 10 was reported for canola straw soda pulping[7, 9], and organosolvent pulping of amaranth, lavatera, sverbiga, and schavnat[21], respectively.

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. With respect to the increasing 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 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

Rapeseed straw used to 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 in the limits 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 Figures 3, 4, and 5, respectively. As expected, all dependencies more or less decrease with 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 stalks and silique valves. In our previous paper[10], the cellulose content of 33.90 mass % and 28.35 mass % was determined by the method according to Seifert[22] for stalks, and silique valves, respectively. Surprisingly, although silique valves comprise less lignin (14.14 mass %)[10] in comparison with stalks (21.35 mass %)[10], the kappa number of pulp from stalks was lower than that from silique valves at all the levels of H-factor (cf. Fig. 4). It seems that delignification of silique valves is not so deep as in case of stalks. As follows from Figure 5, the amount of rejects in pulp cooked from silique valves is comparable to that found in pulp from stalks, mainly in the interval of H-factor ranging of 1,200 h to 2,400 h. Moreover, for stalks, the amount of rejects decreases almost linearly with 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 degree of delignification upon 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 (cf. Figure 6). This fact can be attributed to the hemicellulose dissolving during cooking process that contributes to the relatively higher content of cellulose in pulps delignified at higher level, given by the higher value of the H-factor. Comparing straw, stalks, and silique valves, the highest degree of polymerisation was attained for pulp from stalks which contain greater amount of cellulose than silique valves according our results reported earlier.[10] Using FeTNa solvent, Kačík et al.[17] measured the averages degree of polymerisation of 1,097, 1,496, and 1,597 for unbleached pulps cooked from hardwoods, Turkey oak, and white oak, respectively. For pulp cooked from cannola stalks and delignified to kappa number ranging from 24.2 to 70.7, Enayati et al.[9] determined the degree of polymerisation 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, in agreement with our results.

Colour properties

As mentioned in Experimental, the colour properties of handsheets made of unbleached soda-AQ pulps from rapeseed straw and stalks only were evaluated by means of parameters *L**, *a**, *b**, including ISO brightness and are summarised in Table 1. It must be noted that, with respect to low pulp yield attained for silique valves (cf. Figure 3), the mass of pulp was not sufficient for handsheet making. Hence, the colour and tensile properties were determined for pulps made of rapeseed straw and of 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 higher delignification degree at the H-factor within the limits of 1,200 to 2,800 h, both parameters were slightly higher (cf. Table 1). For pulps from straw and stalks only, the change in values of chromaticity coordinates *a**, and *b**, similarly as the brightness and lightness, is located in a narrow interval. In spite of this fact, it is obvious that the coordinate *a** increased with increasing coordinate *b** for pulps from stalks, while, for pulp from straw, the dependence between colour coordinates is not evident, except for their decrease with increasing H-factor from 800 to 1,200 h (cf. Table 1). For comparison with the brightness 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 beating degree for soda-AQ pulp cooked form hemp stalks. Mohta et al.[24] measured a brightness of 37.2 for unbleached soda-AQ bagasse pulp.

As follows from Figure 7, the brown colour of pulps prepared at the lowest degree of delignification (H-factor = 800 h) has the highest saturation given by the highest chroma value. For pulp from stalks only, the chroma decreases with increasing degree of delignification, but, for pulps from straw, the chroma also decreases up to the H-factor of 2,000 h and then an increase of chroma was obvious for the H-factor of 2,400 and 2,800 h. The shift of brown colour described by the hue angle, *h*, is obvious for pulps cooked at the H-factor of 800 and 1,200 h (cf. Figure 7). For higher delignification degree in the interval of the H-factor of 1,200 to 2,800 h, the differences in hue angle seems 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 case of unbleached soda-AQ pulps from rapeseed straw and stalks only, the overall colour changes were smaller than 2.5 and can 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.

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 of dried unbleached pulp. Since the overall strength of paper sheet depends on both strength of fibre network and strength of individual fibres, the tensile index, as well as zero-span tensile index were evaluated. The dependencies of the tensile index and zero-span tensile index on the degree of delignification directly proportional to the H-factor are shown in Figures 8, and 9, respectively, where average values along with 95% confidence intervals are illustrated.

The tensile strength results showed that the influence of delignification degree on the tensile index is not unambiguous. The highest values of tensile index and zero-span tensile index were measured for soda-AQ pulps cooked at H-factor of 1,600 h. On the contrary, the pulp cooked from rapeseed straw at H-factor of 2,800 h gave the lowest values of tensile index (cf. Figures 8, and 9). Comparing the tensile index and zero-span tensile index for both pulps, it is evident that, for pulp from rapeseed straw, the zero-span tensile index was higher than tensile index, except for the H-factor equal to 1,600 h. However, for 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 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, the zero-span tensile index and tensile index were achieved 37 N m/g, and 41 N m/g, respectively. 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] 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 strength of interfibre bondings due to larger interfibre unbonded areas in the handsheet made of dried pulp.

Besides a decrease of tensile index, hornification had a negative impact on a relative elongation of 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.

CONCLUSIONS

The preliminary runs focused on investigation of suitable soda cooking parameters with and without anthraquinone addition showed that at 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 low amount of rejects. Therefore, in the second set of batch soda cooks with 0.1% anthraquinone addition aimed at the preparation of bleachable pulp with the 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 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 increasing hemicellulose removal, and achieved greater values for stalks comprising greater amount of cellulose. The overall colour changes of unbleached pulps at the measured interval of H-factor were not noticeable. However, the brightness of about 34 % ISO measured for soda-AQ pulp from stalks at the H-factor greater than 1,200 h indicates that the stalks seem to be suitable raw material for bleachable grade pulp production. The tensile strength characteristics measured showed that drying of unbleached soda-AQ pulp brought a significant decrease in the zero-span tensile index, as well as tensile index which were determined approximately less than half of those for never dried pulp.

In conclusion, rapeseed straw as one of agricultural residues has a potential to be one of non-wood raw materials for pulp and paper production, mainly in the countries suffering from a lack of wood. Hence, this work contributes to spread knowledge of pulp prepared by soda-AQ process. Our next work will be devoted to bleaching process of soda-AQ pulp prepared from rapeseed straw.

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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Table headings

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

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 captions

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

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*)

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

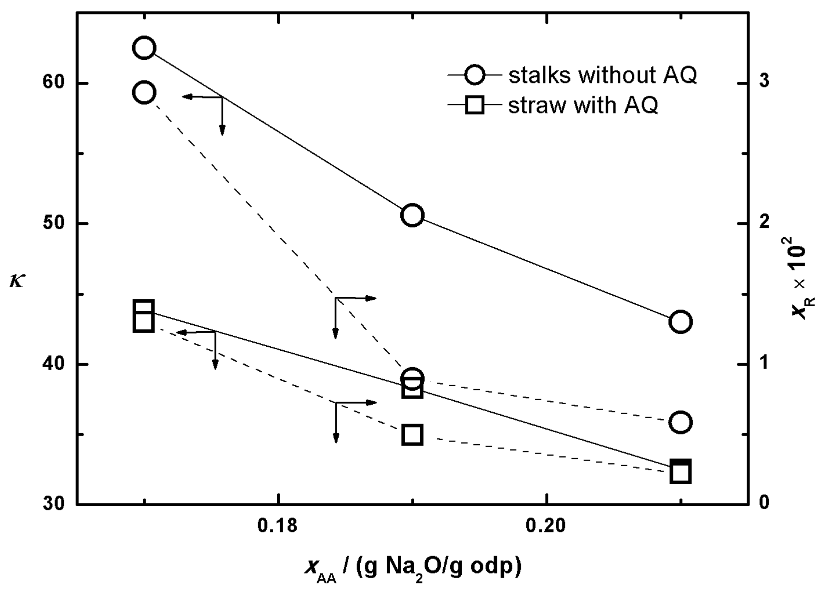

Figure 1: Kappa number, κ, and amount of rejects, x_R, as a function of AA charge, x_{AA}, at L/S = 7 for pulp cooked from rapeseed straw and stalks (solid line: κ *vs*. x_{AA}, dashed line: x_R *vs*. x_{AA})

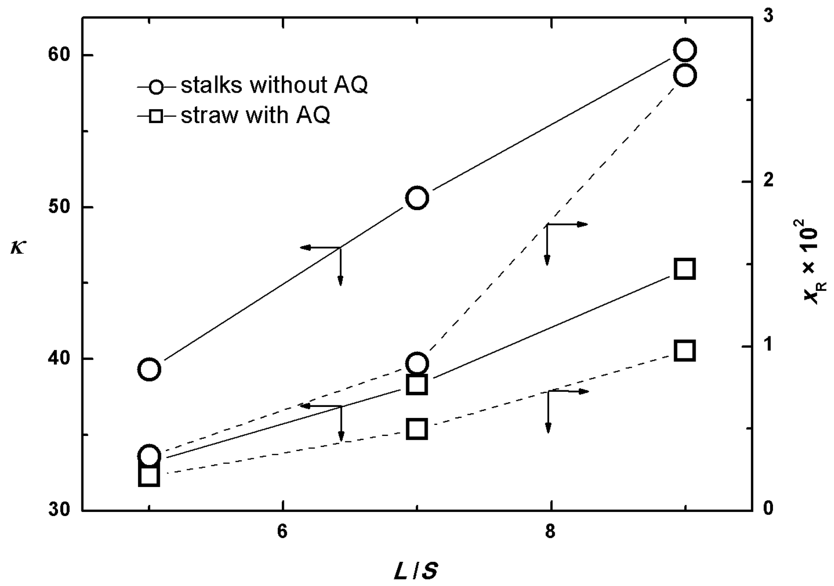

Figure 2: Kappa number, κ, and amount of rejects, x_R, as a function of liquor-to-straw ratio, L/S, at AA charge of 0.19 g Na_2O / g odp for pulp cooked from rapeseed straw and stalks (solid line: κ *vs*. L/S, dashed line: x_R *vs*. L/S)

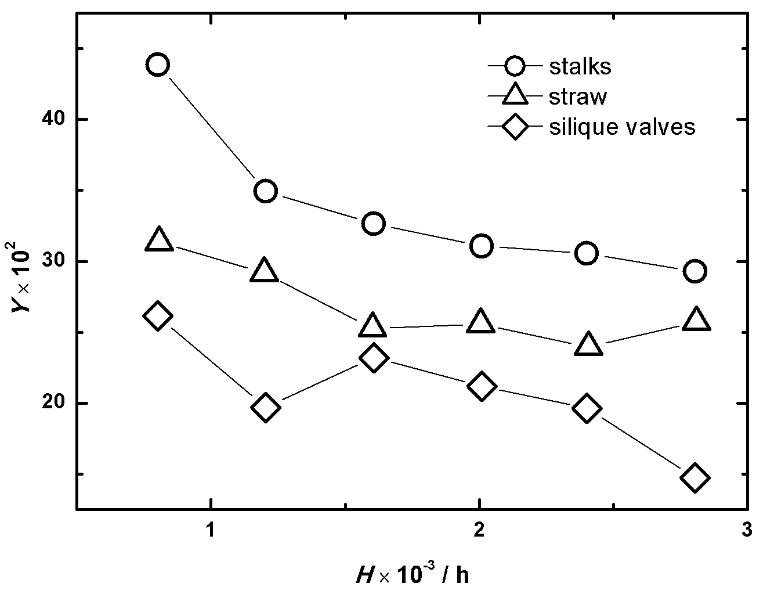

Figure 3: Dependence of total yield, *Y*, on H-factor, *H*, for pulp cooked from rapeseed straw, stalks, and silique valves

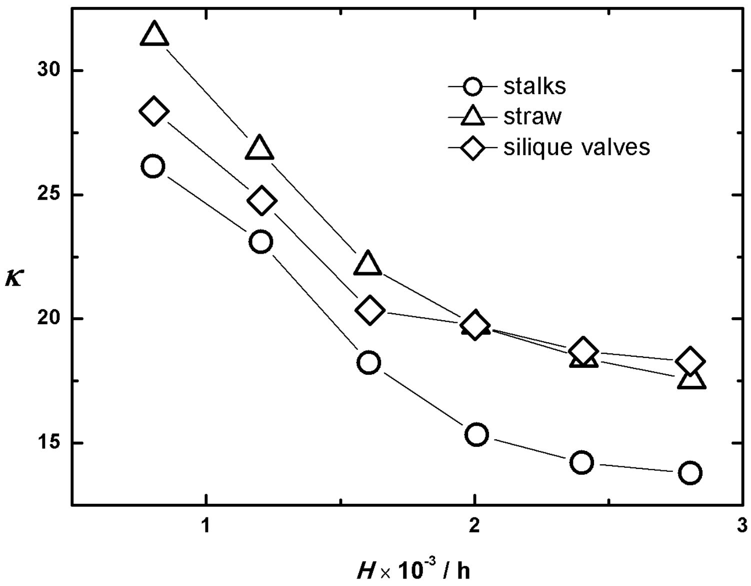

Figure 4: Dependence of kappa number, κ, on H-factor, H, for pulp cooked from rapeseed straw, stalks, and silique valves

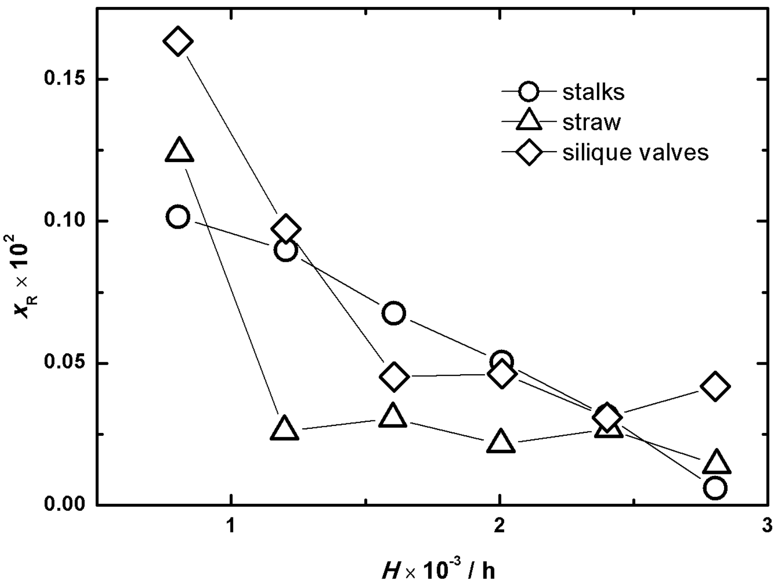

Figure 5: Dependence of rejects amount, x_R, on H-factor, H, for pulp cooked from rapeseed straw, stalks, and silique valves

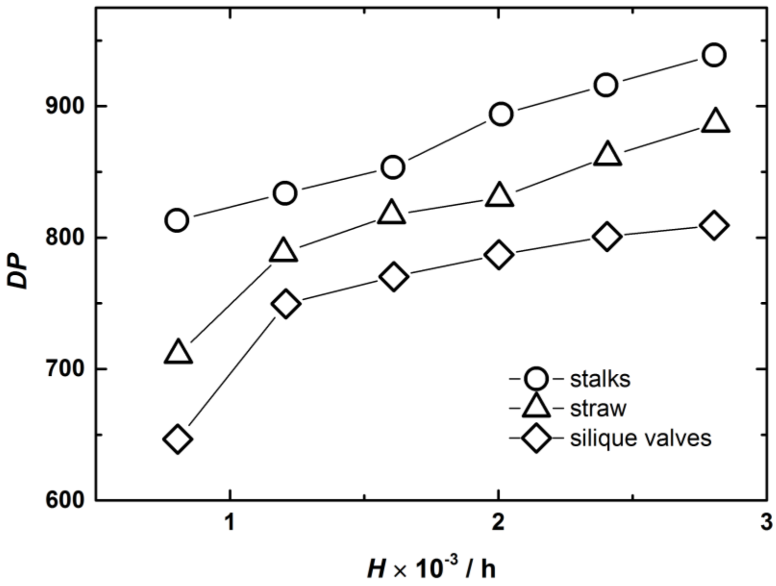

Figure 6: Dependence of degree of polymerisation, *DP*, on H-factor, *H*, for pulp cooked from rapeseed straw, stalks, and silique valves

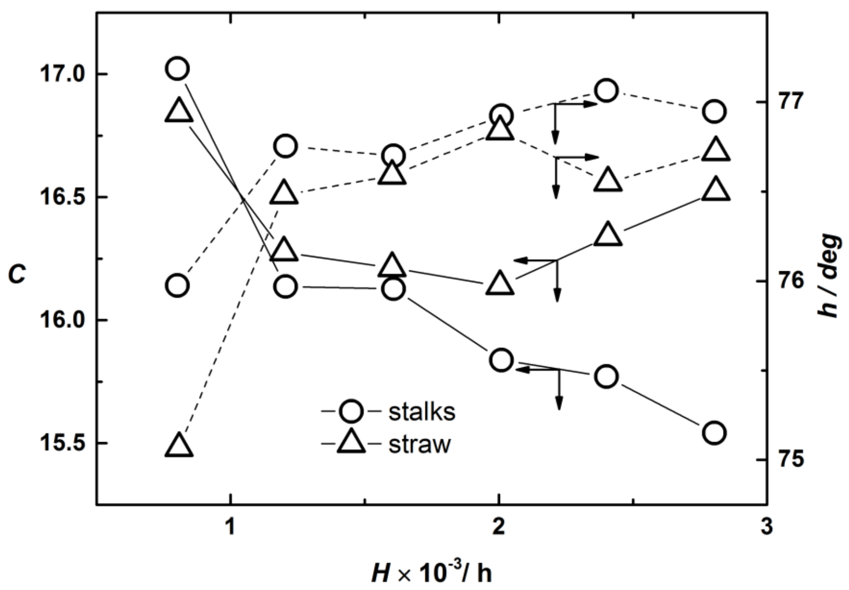

Figure 7: Dependence of chroma, *C*, and hue angle, *h*, on H-factor, *H*, for pulp cooked from rapeseed straw and stalks (solid line: *C vs*. *H*, dashed line: *h vs*. *H*)

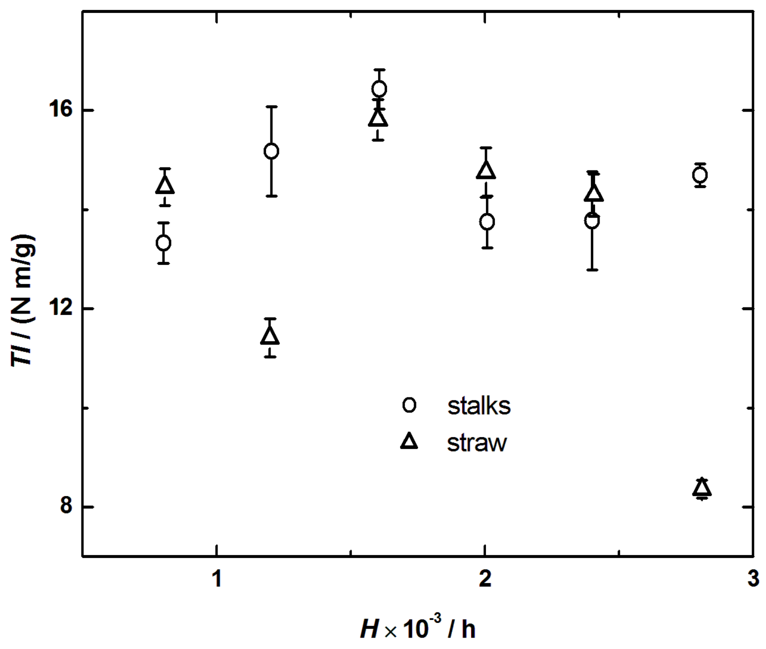

Figure 8: Dependence of tensile index, *TI*, on H-factor, *H*, for pulp cooked from rapeseed straw and stalks

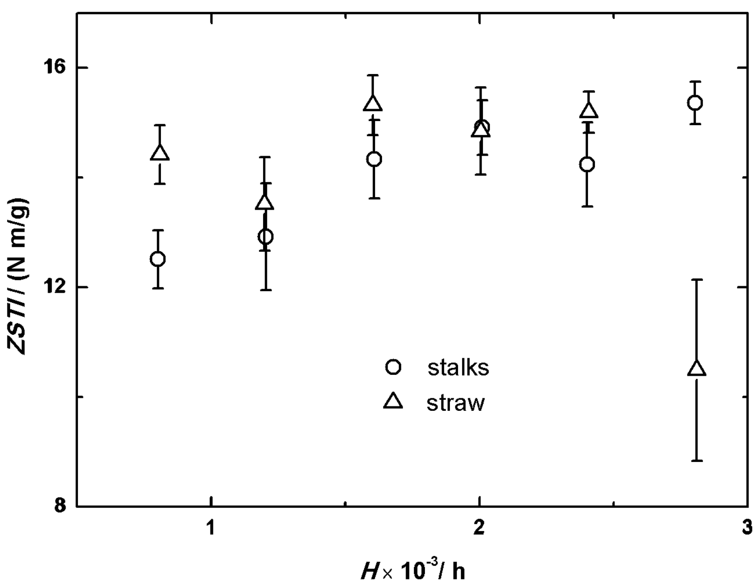

Figure 9: Dependence of zero-span tensile index, *ZPTI*, on H-factor, *H*, for pulp cooked from rapeseed straw and stalks