Effect of cooking temperature on kraft pulping of hardwood

AI VAN TRAN

ABSTRACT: This study investigates the effect of decreasing cooking temperature from 170°C to 165°C, 160°C, and 155°C on the kraft pulping of hardwood and the characteristics of the residual lignin in unbleached pulp. In order to maintain the same output, the active alkali charge was increased while the kappa number and the cooking time were held constant at 21±1 hours and 1 hour, respectively. Results on the cooking of rejects gave the estimation of total pulp yield as the sum of accepts and 65% of rejects. Thus, cooking at 165°C produced a pulp with the highest total yield, the lowest tear index, and the highest tensile index among the cooking temperatures studied. As the cooking temperature decreased, both the degree of oxygen delignification and the total kappa factor (total active chlorine charge ÷ kappa number) of an elemental chlorine free (ECF) bleaching sequence decreased. That, in turn, correlated with the ratios of optical densities of the 1330 cm^{-1} to 1270 cm^{-1} bands in the infrared spectra of residual lignins. The content of total phenolic hydroxyl groups in residual lignins, which decreased with decreasing cooking temperature, also correlated well with the bleachability, as measured by the total kappa factor, and functional groups such as copper number and carboxyl group of the bleached pulp.

Application: This study shows how changes in pulp cooking temperature affect pulp yield, pulp quality, and residual lignins. It may help some mills to modify their hardwood continuous digester operations for specific results.

In recent years there have been many attempts to correlate cooking parameters, such as temperature, component, and charge of white liquor and residual alkali in black liquor, with the structure of residual lignin or the bleachability of the resulting pulp in order to find ways to lower the cost of expensive chemicals used in elemental chlorine free (ECF) or totally chlorine free (TCF) bleaching processes [*1-6*]. One study found that, at the same kappa number, the bleachability and the yield of maple and birch were improved when a cook of low effective alkali (EA) and long cooking time was changed to one with high EA and short cooking time [*1*]. Another study obtained similar results for *Eucalyptus grandis* using the same approach [*2*]. However, the bleachability of *E. globulus* pulp deteriorated as the kappa number was decreased by lengthening the cooking time at a given active alkali (AA) charge [*3*]. Manipulation of cooking by increasing EA, thereby shortening the cooking time, would increase the output of the digester [*1, 2*]. On the other hand, prolonging cooking time would reduce the digester production [*3*]. It is worth noting that the cooking temperature in these studies was held constant.

Our objective was to examine the effect of a decrease in cooking temperature on the kraft pulping and the structural change of the residual lignin of hardwood. This study used a constant cooking time in order to maintain the same production. To compensate for the lowering of the cooking temperature, the active alkali (AA) charge was increased so that the same kappa number could be maintained. Other studies have indicated an increase in pulp yield, which was the sum of rejects and screened yield, in the cooking using a higher EA or AA and a shorter cooking time [*1, 2*]. Although this definition of pulp yield is widely used [*7, 8*], it does not take into account the difference in the kappa number of rejects and screened pulp. Even in a TAPPI symposium on the improvement of pulp yield, many papers used the same concept of pulp yield [*9 a-e*]. However, in a market pulp mill or an integrated mill with continuous digesters where the hanging basket method to determine pulp yield is impractical, the pulp yield is usually estimated using the ratio of total amount of screened pulp produced to the amount of wood chip consumed in a month. No knots or rejects are included in the calculation of pulp yield because they are returned to the digester or discharged to the hog fuel boiler. Therefore, the other purpose of this work was to study the pulping of the knots in order to define pulp yield clearly.

EXPERIMENTAL

Laboratory cooking and oxygen delignification

Wood chips were received from the mill and screened; chips between 5 mm and 29 mm were used for cooking. The screened wood chips were stored at 5°C, then cooked in 500 g o.d. batches at a 6:1 liquid-to-wood ratio in a 4.5 l rotary autoclave. The time to temperature was 50 min, with a time at maximum temperature of 60 min. The white liquor—also received from the mill—was stored in a refrigerator for no more than a week. The AA and sulfidity of the white liquor were 108 g/l (as Na_2O) and 30%, respectively. The cooking was ended by cooling the autoclave under a stream of water. The resulting pulp was screened on a 6-cut screen, dewatered and stored in a cold room. The cooking experiments of wood chips were repeated in quadruplicate.

The mill also provided knots from its hardwood kraft fiber line. The well-

Cook sample	AA (%)	Kappa number	Accepts (%)	Rejects (%)	Total yield (%)	Initial AA (g/l)	Residual AA (g/l)	AA cons. (%)
R1	14.8	12.6	64.7	0.2	64.8	24.72	4.50	81.8
R2	12.5	14.1	66.1	0.2	66.3	20.84	3.49	83.3
R3	9.4	14.7	66.7	0.7	67.2	15.63	2.02	87.1
R4	6.3	17.6	68.8	1.0	69.5	10.42	0.81	92.3
R5	4.3	21.5	66.5	5.4	70.0	7.17	0.08	98.9
R6	2.6	27.2	52.3	22.6	67.0	4.37	0.00	100.0

Note : AA cons. = AA consumed

I. Pulping results of the knots from hardwood fiberline.

drained knots did not need further washing. They also were stored in a refrigerator. The cooking conditions of the knots were similar to those of the wood chips except that the temperature was fixed at 170°C. The pulp from the knots was processed in the same way as that of the wood chips. The knots cooking experiments were conducted in duplicate.

Oxygen delignification (OD) was carried out using the same autoclave. OD conditions were 100°C, 42 min retention time, 10% pulp consistency, 3% oxygen, and 3.15% sodium hydroxide. The study carried out OD experiments in duplicate. Details of the OD are described elsewhere [*10*].

Isolation of residual dioxane lignin in unbleached pulp

The procedure for isolating and purifying the residual dioxane lignin in unbleached pulp has already been reported [*11*].

Spectral analysis

The FT-IR spectra of the isolated dioxane lignins were recorded with a Jeol JIR-AQS 20M series FT-IR spectrophotometer.

Bleaching

Bleaching was done using water baths, polyethylene bags and the $D_{100}ED_1D_2$ sequence. Bleaching conditions are described later. Final brightness was 85%-86% ISO.

Physical properties of bleached pulps

The bleached pulps were beaten in a PFI mill according to the method of Japanese Industrial Standards (JIS) P8221-2 and pulp strengths were determined as described in the methods of JIS P8113 (tensile index) and P8116 (tear index). Details of these methods were given previously [*11*].

Analytical methods

The following TAPPI standard methods were used :T 226-cm-85 (kappa number), T 254-om-85 (pulp viscosity), T 237 om-93 (carboxyl content),T 430 om-94 (copper number),T 203 cm-93 (?-cellulose),T 223 cm-84 (pentosan), T 625 cm-85 (organic matter in black liquor) and T 650 om-89 (total solids in black liquor). Phenolic hydroxyl groups of the isolated dioxane lignins were determined by the Δε method [12]. ISO brightness was measured with a Technibrite Micro TB-1C. Total organic carbon (TOC) in black liquor was determined using a Shimadzu Total Organic Carbon Analyzer TOC-500.

RESULTS AND DISCUSSION

Cooking of knots and the determination of total pulp yield

To attain the target kappa number of 21±1, the mill knots required a surprisingly low AA charge of 4.3% (**Table I**).The accepts in the range of kappa number of 12 to 22 varied from 65% to 69% and except for the cook with kappa number 21.5 (cook R5) the rejects of the other cooks were below 1%. In practice, the knots were returned to the digester and cooked again with the incoming wood chips with a AA charge of around 15% (**Table II**).Thus the accepts and rejects of the knots were approximately 65% and 0.2%, respectively. It is reasonable then to estimate the total pulp yield as the sum of the accepts and 65% of the rejects. This definition is apparently different from the one presently used widely in the literature.

Compared to the initial knots with a kappa number of 77.4, the rejects of cook R5 had a higher kappa number, 83.3. This indicates that the lignin of the knots was condensed during the repulping. It is therefore advantageous to have a low rejects content in any given cook.

Effect of cooking temperature on pulp yield from wood chips

As the cooking temperature was lowered from 170°C to 165°C, 160°C and 155°C, the AA charge was increased from 14.9% to 17.2%, 21.1% and 27.3%, respectively, in order to maintain a kappa number of 21±1.

The total pulp yield was highest at 165°C (Table II). This was unexpected because the residual alkali was lowest at 170°C. It was already shown that a cook with a low residual alkali would give a high pulp yield [*2*].

The increase in the AA charge led to a decrease in the rejects in spite of a decrease in cooking temperature which, in turn, resulted in a lower H factor. However, a decrease in the cooking temperature did not affect the accepts as it was almost constant in the cooking temperature range of 155°C to 165°C. On the other hand, the cook at 170°C gave a lower accepts and a higher rejects than did the other cooks. Apparently, the concentration of the white liquor affected its penetration into the wood chips. Thus, a high cooking temperature, and therefore a low AA, negatively affect the accepts.

Analytical results of the unbleached pulps showed that although the holocellulose content of the pulps above was approximately equal, the contents of α-cellulose increased and pentosan decreased at the cooking temperatures of 160°C and 155°C (Table II). This indicates the lower pulp yields of the cooks at 160°C and 155°C and the higher content of C6-carbohydrates of the cook at 165°C. In order to corroborate these analytical results, the black liquor was analyzed (**Table III**). Due to the increase of the AA charge, the pH, total solids and inorganic contents increased and the organic contents, in turn, decreased with decreasing cooking temperature. This demonstrates that the composition of the black liquor was greatly affected by the dosage of cooking liquor and thus not related to the pulp yield. In contrast, the TOC content of the black liquor was quite indicative of the pulp yield. A plot of the TOC content and the total pulp yield gave a relationship with a correlation coefficient of 99.86%.

[$y = -0.0667*x^2 + 6.5631*x - 157.33$ where y :TOC(%) and x : total pulp yield (%)].

Since the TOC content of the black liquor from the cook at 165°C was lowest, its total pulp yield was expectedly highest among the pulps studied.

Cooking temp. (°C)	AA (%)	Kappa number	Accepts (%)	Rejects (%)	Total yield (%)	H factor	Residual AA (g/l)	AA cons. (%)	Holocellulose (%)	α-cellulose (%)	Pentosan (%)
170	14.9	21.0	43.8	10.4	50.6	1021	0.8	96.9	96.7	84.8	10.4
165	17.2	21.1	47.8	5.0	51.0	665	1.5	94.8	97.0	84.5	10.5
160	21.1	21.6	48.0	3.8	50.5	441	3.4	90.4	96.9	86.5	9.3
155	27.3	22.0	47.7	2.7	49.5	277	7.2	84.3	96.1	88.4	7.4

Notes : 1) AA cons. = AA consumed
2) Holocellulose, a-cellulose, pentosan were based on o.d. unbleached pulp

II. Analytical results of various pulps cooked at different temperatures.

Cooking temp. (°C)	pH	TS (%)	Inorganic contents (%)	Organic contents (%)	TOC (%)
170	12.4	10.5	6.0	4.5	4.01
165	13.2	11.6	7.0	4.6	3.92
160	13.5	13.0	9.1	3.9	4.02
155	13.7	14.8	11.8	3.0	4.13

III. Analytical results of black liquors from various cooks at different temperatures.

Cooking temp. (°C)	Inlet kappa number	Outlet kappa number	OD degree (%)
170	21.0	11.2	46.8
165	21.1	11.8	44.1
160	21.6	12.2	43.5
155	22.0	12.9	41.5

IV. Oxygen delignification (OD) of various pulps cooked at different temperatures.

Oxygen delignification (OD) and bleaching of pulps from different cooking temperatures

Under identical OD conditions, the OD degree decreased with decreasing cooking temperatures (**Table IV**). Similarly, the degree of delignification across the $D_{100}ED_1D_2$ sequence decreased with the lowering of cooking temperature. This is due to the increase of kappa number of the bleached pulp. Consequently, in order to attain the same final brightness of 85%-86% ISO, the total kappa factor (TKF = total active chlorine charge ÷ kappa number) decreased as the cooking temperature was lowered from 170°C to 155°C (**Table V** and **Fig. 1**). Note that the kappa factor of the D_{100} stage remained constant at 0.22.

These results can be understood in the context that both oxygen and chlorine dioxide react with the phenolic hydroxyl group and generate carboxyl groups and some depolymerization [*13*]. Thus, the phenolic hydroxyl group would be expectedly scarcer as the pulp undergoes successive OD and chlorine dioxide bleaching stages. As will be demonstrated below, the phenolic hydroxyl group in the residual lignin decreased with decreasing cooking temperature. Consequently, the OD degree decreased and less chlorine dioxide was consumed, thus lower TKF resulted, with the decrease of cooking temperature. Furthermore, because the residual lignins of the pulps cooked at low temperatures contained less phenolic hydroxyl groups, less chlorine dioxide was consumed and thus more lignin remained in the pulp resulting in a lower delignification degree across the bleaching process.

The lowering of cooking temperature resulted in a high residual alkali which, in turn, was the consequence of the high AA charge. However, the superior bleachability, as measured by the TKF, of the pulps produced at low cooking temperatures and therefore high residual alkalis could not be explained on the basis of the carboxyl content as suggested by other research [*2*] because these pulps contained lower carboxyl contents. Neither could the resulting copper numbers account for the inferior bleachability of the pulps cooked at high temperatures and thus with low residual alkalis. The copper number was intended as an indication of reducing end (aldehyde and carbonyl) groups in the bleached pulp.

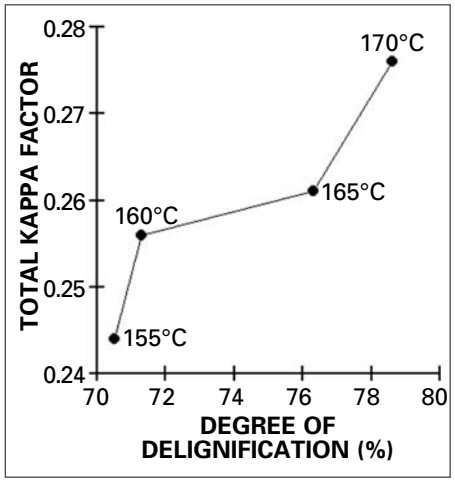
Physical properties of bleached pulps

At a given tensile strength the apparent density of the pulp cooked at 155°C was highest, that of 165°C lowest, and those of 170°C and 160°C in between (**Fig. 2**). A similar trend, but with minor differences, was observed for the tear index of which the pulp cooked at 170°C was highest, followed by the pulps cooked at 160°C and 155°C, and that cooked at 165°C lowest (**Fig. 3**). The apparent

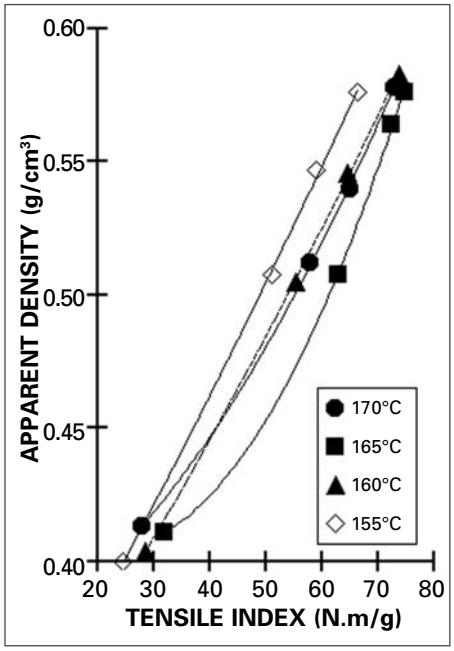
Cooking temp. (°C)	ClO_2 (D100) (%)	NaOH (E) (%)	ClO_2 (D1) (%)	ClO_2 (D2) (%)	TKF	Brightness (ISO %)	Final kappa number	Delignification degree (%)	Carboxyl (meq/100g)	Copper no. (g CuO/100g)	Viscosity (mPa.s)
170	0.937	1.53	0.090	0.15	0.276	85.3	2.4	78.6	11.56	0.1793	26.7
165	0.987	1.61	0.065	0.12	0.261	86.2	2.8	76.3	10.43	0.1246	23.3
160	1.021	1.63	0.065	0.10	0.256	85.5	3.5	71.3	9.94	0.0875	24.9
155	1.079	1.71	0.050	0.07	0.244	85.7	3.8	70.5	9.76	0.0845	26.2

1) Bleaching conditions : D_{100} stage: temperature, 58°C; time, 25 min.; pulp consistency, 4%. E stage: temperature, 70°C; time, 66 min.; pulp consistency, 14%. D_1 stage: temperature, 75°C; time, 117 min.; pulp consistency, 14%. D_2 stage: temperature, 75°C; time, 117 min.; pulp consistency, 14%.
2) TKF : total kappa factor = total active chlorine charge ÷ kappa number

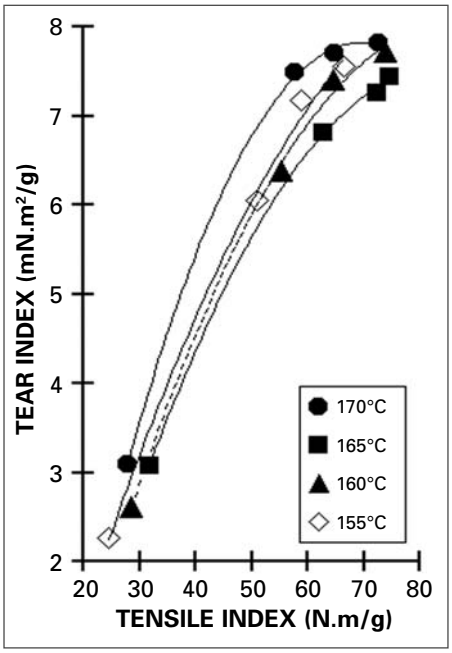
V. Bleaching results of various pulps cooked at different temperatures.



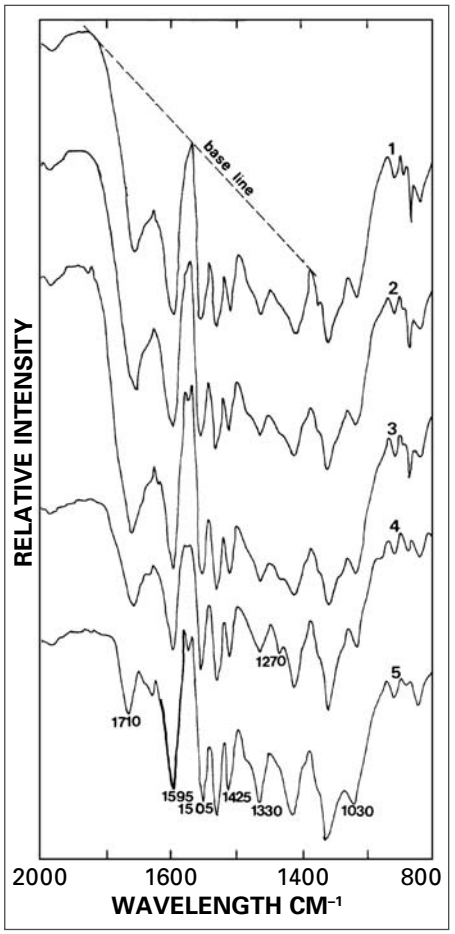
1. Correlation between degree of delignification and total kappa factor in the $D_{100}ED_1D_2$ bleaching.



2. Apparent density as a function of tensile index for different pulps cooked at various temperatures.



3. Correlation between tear index and tensile index for different pulps cooked at various temperatures.



4. FTIR spectra of residual lignins from different cooking temperatures. 1:170°C; 2:165°C; 3:160°C; 4:155°C; 5:Eucalyptus globulus.

Cooking temp. (°C)	Structure I (%)	Structure II (%)	Structure III (%)	Structure IV (%)	Total PhOH (%)
170	0.233	0.026	0.044	0.001	0.304
165	0.221	0.026	0.041	0.001	0.289
160	0.203	0.025	0.040	0.001	0.269
155	0.203	0.025	0.037	0.001	0.266

VI. Phenolic hydroxyl groups in residual dioxane lignins of various pulps cooked at different temperatures.

density results indicate that the pulp cooked at 165°C contained a lower number of fibers per given volume as compared to the other pulps. Furthermore, its tensile strength at a given tear index was also higher, suggesting that its interfiber bonding strength was highest among the pulps studied. However, because its tear index at a given tensile index was lowest it is conceivable that its fiber strength was low thus corresponding to its lower viscosity (Table V).

According to Gurnagul et al. [*14*], fiber strength is directly proportional to α-cellulose content for fibers of low fibril angle and pulped by processes that do not degrade cellulose. Furthermore, the loss of fiber strength at high α-cellulose contents is due to the degradation of cellulose, which in turn is a result of the localized (heterogeneous) degradation rather than the randomly homogeneous degradation. Earlier research has shown that during kraft cooking the paracrystalline cellulose regions are transformed into a fibril with alternating ordered and amorphous regions [*15*]. Research also has shown that amorphous regions are able to absorb energy when the fiber is under mechanical stress and thereby contribute to the greater strength of kraft pulp as compared to sulfite pulp, which contains fewer amorphous regions [*16*]. As shown in Table II, the α-cellulose content decreased with decreasing cooking temperature and simultaneously with increasing AA charge. Thus the lower fiber strength of the pulp cooked at 165°C is probably due to its lower number of amorphous regions formed at this combination of cooking temperature (165°C) and AA charge (17.2%).

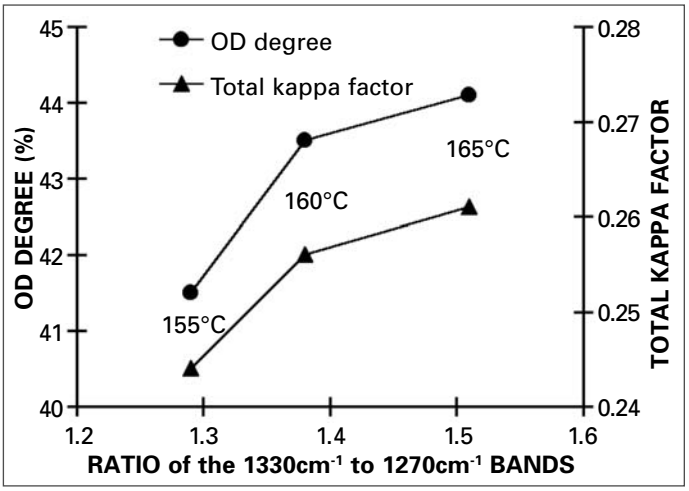
Sjoholm *et al.* suggested that carboxyl groups may increase the fiber strength by increasing hydrogen bonding within the fiber [*17*]. Because the carboxyl groups decreased with decreasing cooking temperature and increasing AA charge (Table V) and since the tear index of the pulp cooked at 165°C was lowest, it is apparent that carboxyl groups did not influence pulp strength in this case.

FT-IR spectral properties of residual dioxane lignins

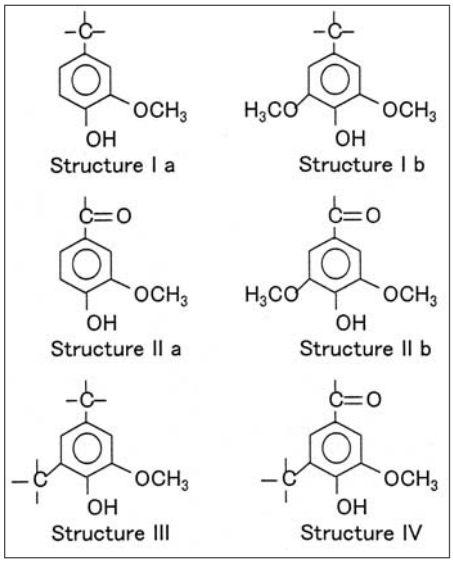
The FT-IR spectra of the residual dioxane lignins in different unbleached pulps before oxygen delignification are similar to that of the Chilean *E. globulus* wood (**Fig. 4**). The major absorption bands in these dioxane lignin preparations are the 1710 cm^{-1} (carbonyl groups), 1595 cm^{-1}, 1505 cm^{-1}, and 1425 cm^{-1} (aromatic skeletal vibrations), 1460 cm^{-1} (asymmetric C-H deformation), 1330 cm^{-1} (syringyl ring breathing with CO stretching), 1125 cm^{-1} (aromatic C-H deformation, syringyl-type), and 1030 cm^{-1} (aromatic C-H deformation, guaiacyl-type). The assignment of these bands is based on the literature [*18*]. There is no absorption band at 1230 cm^{-1} (syringyl ring breathing with CO stretching), which may have been displaced to the 1222-1224 cm^{-1} region. The reason is probably due to the dioxane - HCl hydrolysis method used in the isolation of residual lignins because the IR spectrum of the Chilean *E. globulus* wood contained a band at 1224 cm^{-1}. Generally, the 1230 cm^{-1} band appears in all IR spectra of mill wood lignins isolated from whole wood [*18*].

The band at 1270 cm^{-1} (guaiacyl ring breathing with CO stretching) did not exist in the IR spectra of the residual lignin of the pulp cooked at 170°C. However, this band became more pronounced as the cooking temperature decreased further to 165°C, 160°C, and 155°C. The result shows that the guaiacyl group was susceptible to degradation at cooking temperatures higher than 165°C.

The ratio of the optical densities of the 1330 cm^{-1} to 1270 cm^{-1} bands is known to correlate very well with the molecular ratio of syringaldehyde (S) to vanillin (V) yielded in the alkaline nitrobenzene oxidation of wood meals and/or lignin preparations [*19, 20*]. Since the 1270 cm^{-1} band was absent in the IR spectra of the residual lignin of the pulp cooked at 170°C, the ratios of the optical densities of the 1330 cm^{-1} to 1270 cm^{-1} bands in the pulps cooked at 165°C, 160°C, and 155°C were computed. Note that the optical densities of the bands at 1330 cm^{-1} and 1270 cm^{-1} in each spectrum were calculated in relation to that of the 1505 cm^{-1} band, which was assigned a value of 100. A common base line drawn in the region of 1100 cm^{-1} to 1800 cm^{-1} on the charts of these spectra was used for this purpose (Fig. 4). The way of drawing the base line and the method of calculation of the optical densities were adopted from the literature [*19*].



5. Correlations between OD degree, total kappa factor and ratio of the 1330 cm^{-1} to 1270 cm^{-1} bands.



6. The structures of phenolic hydroxyl groups which were determined in this study.

The optical density of the 1270 cm^{-1} band in the pulps cooked at 165°C, 160°C, and 155°C increased from 38.5% to 42%. However, the optical density of the 1330 cm^{-1} band decreased from 58.1% and 58% to 55% as the cooking temperature dropped from 165°C to 160°C and 155°C, respectively. Therefore, the ratios of the 1330 cm^{-1} to 1270 cm^{-1} bands decreased with decreasing cooking temperature from 165°C to 155°C or otherwise with increasing AA charges. The results suggest that the syringyl group was susceptible to degradation at high AA charges.

For the cooking temperatures from 155°C to 165°C, the OD degree increased with increasing ratios of the 1330 cm^{-1} to 1270 cm^{-1} bands (**Fig. 5**). As already shown, the guaiacyl group was poor and the syringyl group was rich at 165°C. Conversely, the content of the guaiacyl group was high and that of the syringyl group low at 155°C. The results suggest that OD may, in part, be aided by the syringyl group but not by the guaiacyl group. Furthermore, the total kappa factor also increased with increasing ratios of the 1330 cm^{-1} to 1270 cm^{-1} bands, thus suggesting that chlorine dioxide, similar to oxygen, may react favorably with the syringyl group rather than with the guaiacyl group. A plot of the degree of delignification across the $D_{100}ED_1D_2$ sequence and the ratios of the 1330 cm^{-1} to 1270 cm^{-1} bands gave a relationship with a correlation coefficient (R^2) of 1.00 for the temperature range of 155°C to 165°C.

$(y = 134.42*x^2 - 350.02*x + 298.33,$
where y: degree of delignification across the $D_{100}ED_1D_2$ sequence and
x: the ratios of the 1330 cm^{-1} to 1270 cm^{-1} bands).

The relationship indicates that the degree

of delignification increased along with the increasing ratios. The conclusion is that the abundance of the guaicyl group or a depletion of the syringyl group would hinder delignification in bleaching, similar to OD.

Phenolic hydroxyl groups of residual dioxane lignins

The phenolic hydroxyl (PhOH) groups are used extensively to characterize residual lignins. In this work, the PhOH contents of structures I, II, III, and IV (**Fig.6**) in residual dioxane lignin preparations were obtained using the UV method [*12*]. As discussed previously [*11*], the PhOH content studied contained PhOH groups from both guaiacyl and syringyl units although the UV method has mainly been used for the guaiacyl group. As shown in **Table VI**, the sum of PhOH contents of structures I and III makes up more than 90% of total PhOH, thus showing that PhOH groups in residual lignins are almost exclusively of non-conjugated structures. On the other hand, the values of structure IV were negligible, indicating that the conjugated C_5-linked structure is almost non-existent in the residual lignin of hardwood kraft pulp. The contents of PhOH I, III and total PhOH in the residual lignins decreased gradually with decreasing cooking temperature from 170°C to 155°C. The results suggest that lignin was extensively degraded, therefore more fragmented, and as a consequence more new free hydroxyl groups were formed at high temperature (170°C) than at low cooking temperature (155°C). Because oxygen reacts mainly with phenolic hydroxyl groups, it is understandable that the degree of OD decreased along with decreasing PhOH contents, and therefore with decreasing cooking temperature (compare Tables IV and VI). The content of PhOH II was fairly constant for all lignins studied. This suggests that the cooking temperature and AA charge did not affect the conjugated structure in hardwood residual lignin. Although residual lignins after OD were not isolated and characterized in terms of PhOH, plotting the total kappa factor, delignification degree in bleaching, carboxyl group, and copper number against the total PhOH content (Table VI) gave relationships with correlation coefficients (R^2) from 0.89 to 0.99. The results suggest that OD did not alter residual lignin to a great extent as expected and that the PhOH in residual lignin influenced the bleachability and functional groups of the bleached pulps.

CONCLUSIONS

1. The cooking of rejects led to the establishment of total pulp yield of hardwood kraft pulp as the sum of accepts and 65% of rejects.
2. In this context, the pulp cooked at 165°C had the highest total yield among the cooking temperatures studied, i.e. 170°C, 165°C, 160°C, and 155°C. This pulp also had the highest apparent density and the highest tensile index, but the lowest tear index. All the pulps were prepared under constant conditions of kappa number of 21±1 and cooking time of 1 hour in order to maintain the same output. Thus, the active alkali charge was increased to compensate for the decrease of the cooking temperature.
3. As the cooking temperature decreased, the oxygen delignification degree, total kappa factor, delignification degree across the bleaching process, the carboxyl group and copper number (i.e. aldehyde and carbonyl groups) in bleached pulps decreased. These characteristics also correlated well with the ratios of optical densities of the 1330 cm^{-1} to 1270 cm^{-1} bands in the infrared spectra of the residual lignins. An examination of the 1270 cm^{-1} and 1330 cm^{-1} bands suggests that the guaiacyl group was prone to degradation by the cooking temperature and the syringyl group by the active alkali charge. The results on phenolic hydroxyl groups also suggest that the residual lignin consisted mainly of non-conjugated structures which were lowered with decreasing cooking temperature.
4. It seems that a high cooking temperature (i.e. 170°C) would degrade residual lignin in a way that more free phenolic hydroxyl groups were created. In contrast, a low cooking temperature (i.e. 155°C), in spite of its higher active alkali charge, would preserve the residual lignin structure to some extent because of its lower free phenolic hydroxyl groups and the increase in the guaiacyl group. This helps to explain the high oxygen delignification degree and the low bleachability (i.e. high total kappa factor) of the pulp cooked at 170°C. The opposite is true for the pulp cooked at 155°C. **TJ**

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INSIGHTS FROM THE AUTHOR

With the objective of cutting cost, I have tried to optimize the hardwood continuous digester (CD) in my mill. In an approach different from the mill operation, I wondered if there is a cooking temperature at which the pulp yield would be highest and how this optimum cooking temperature would affect the oxygen delignification (OD) and bleaching processes.

My previous researches (references 10 and 11) are not directly related to the present paper, although the aim of those works were also to cut operational costs. There is not enough information in any textbook to answer the needs of a kraft pulp mill of today, particularly on lowering operational costs. Although the needs of a particular mill may differ from those of another mill, I still believe that my present paper may provide some answers to the questions of whether there is an optimum cooking temperature for a particular CD, how to calculate the pulp yield in a mill, how to set the limit of rejects in a hardwood kraft pulp mill, etc.

Like any other R&D person, I would like to use the most sophisticated analytical tools in my research. In this case, I would have liked to use a 13C-NMR to analyze the isolated residual lignins. Because my company could not afford to satisfy that desire, I settled on using FT-IR to find out the effect of cooking temperature on the syringyl and guaiacyl moieties in the isolated residual lignins.

I think that any CD using a particular mixture of hardwoods does have an optimum cooking temperature to produce the highest pulp yield although the tearing strength, as a result, would be sacrificed to some extent. Moreover, the pulp yield can be calculated as the sum of accepts and 65% of rejects, and the rejects content is best set below 1%.

Based on the findings in this study, the logical next step is to optimize our softwood CD.

—Ai Van Tran

Tran is principal research scientist, Technical Department, Daio Paper Corporation. 5-1 Kamiya-cho, Iyomishima, Ehime, Japan 799-0492; email avtran@daio-paper.co.jp