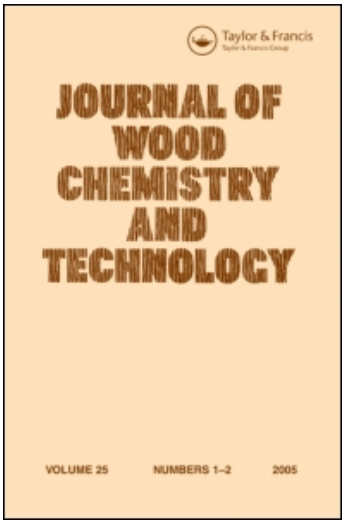

Journal of Wood Chemistry and Technology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597282

Charge-Transfer Complexes in Kraft Lignin Part 1: Occurrence

G. S. Furman[ab]; W. F. W. Lonsky[ac]
[a] The Institute of Paper Chemistry, Appleton, Wisconsin [b] Kimberly-Clark Corporation, Neenah, WI [c] Kimberly-Clark Corporation, Roswell, GA

To cite this Article Furman, G. S. and Lonsky, W. F. W.(1988) 'Charge-Transfer Complexes in Kraft Lignin Part 1: Occurrence', Journal of Wood Chemistry and Technology, 8: 2, 165 — 189
To link to this Article: DOI: 10.1080/02773818808070678
URL: http://dx.doi.org/10.1080/02773818808070678

JOURNAL OF WOOD CHEMISTRY AND TECHNOLOGY, 8(2), 165-189 (1988)

CHARGE-TRANSFER COMPLEXES IN KRAFT LIGNIN
PART 1: OCCURRENCE

G. S. Furman* and W. F. W. Lonsky*
The Institute of Paper Chemistry
Appleton, Wisconsin 54912

Dedicated to Prof. Dr. Karl Kratzl

ABSTRACT

Charge-transfer complexes were found to occur between kraft lignin and an added model quinone, 3,5-di-tert-butyl-1,2-benzoquinone. The occurrence of charge-transfer interactions was also apparent in an oxidized kraft lignin with an increased quinone content. In these systems, free phenolic groups within the lignin were considered the donor species and ortho-quinones the complementary acceptor moieties. Carbon-14 labeling revealed that the quinone content of the investigated kraft lignin averaged 3%. These quinones were determined to have a molar absorptivity of 528 L/mol-cm. Upon sodium borohydride reduction of this lignin, only one-third of the absorbance decrease could be accounted for by this number of quinones. The remaining two-thirds of the decrease in absorbance was assigned to the disruption of charge-transfer complexes. The quinones, therefore, played a dual role as a chromophore by participating as acceptor species in these complexes.

* Present addresses: G. S. Furman, Kimberly-Clark Corporation, Neenah, WI 54956; W. F. W. Lonsky, Kimberly-Clark Corporation, Roswell, GA 30076.

INTRODUCTION

A major drawback to the kraft pulping process is the dark-colored pulps which are obtained. This dark color requires the pulps to be extensively bleached for many end uses. As is well known, the dark color of kraft pulps originates with residual lignin not removed during the pulping process. In the area of lignin utilization the dark color of kraft lignin has also posed problems, hindering the use of kraft lignin as a feedstock for the production of more valuable products.

With the major advantages to be gained from the prevention of this color, investigation into its cause has been a continuing area of interest in the field of lignin chemistry. Chromophores including transition metal complexes,[1,2] quinonemethides,[3] quinones,[4,5] free radicals,[6,7] and combinations of these, joined to form extended chromophore systems,[8] have been proposed and investigated. However, the chromophores which have been identified are not present in sufficient quantities to account for the total color which is observed.[1,9] Consequently, the origin of color in kraft lignin remains poorly understood.

Charge-transfer complexes (CTC's) are defined as weak associations between electron donating and accepting moieties. Characteristic of CTC's is the appearance of at least one additional electronic absorption band, separate from the absorption bands of the individual donor and acceptor species.[10] With the appropriate combination of donor and acceptor, the CT absorption band occurs in the visible region of the electromagnetic spectrum. In this event, the complexes are colored.

Based on evidence available in the literature pertaining to distinct molecules, kraft lignin contains appropriate functional groups within its polymeric matrix for CT interactions to occur. Most likely among these functional groups are free phenolic structures playing the roles of donors, and quinonoid structures

playing the complementary roles of acceptors. Numerous examples exist in the literature of phenol-quinone CT interactions, both of an intermolecular[11,12] and an intramolecular[13,14] nature. Similar quinhydrone structures were previously proposed by Steelink[6] in 1963 based on data obtained from electron paramagnetic resonance spectra of kraft lignin derivatives.

The results which follow will indeed demonstrate the existence of phenol-quinone charge-transfer complexes in several kraft lignin systems. Part 2 of this paper will examine the significant contribution these complexes make to the color of kraft lignin.

RESULTS AND DISCUSSION

If CTC's in kraft lignin are actually composed of a phenol-quinone interaction, the quinone concentration will be a limiting factor. The loblolly pine kraft lignin employed in this study contained a relative abundance of free phenolic groups, 58 per 100 C_9 units (Mansson reported 63 per 100 C_9 units for an industrial pine kraft lignin[15]). In comparison, kraft lignin contains a relative scarcity of quinone groups; Iiyama and Nakano estimated approximately 4 quinone groups per 100 C_9 units.[5] In order to increase the likelihood of CT interactions and, consequently, make them less difficult to observe, emphasis was placed on increasing the ortho-quinone content of the lignin. Ortho-quinones were chosen based on their predominance in kraft lignin as a result of the pulping process.

CTC's in Model Systems

Addition of a model quinone, 3,5-di-tert-butyl-1,2-benzoquinone, to a solution of kraft lignin produced an extra absorbance in the spectrum of the two components not present in spectra of the individual components (see Fig. 1). This additional absorbance, shown

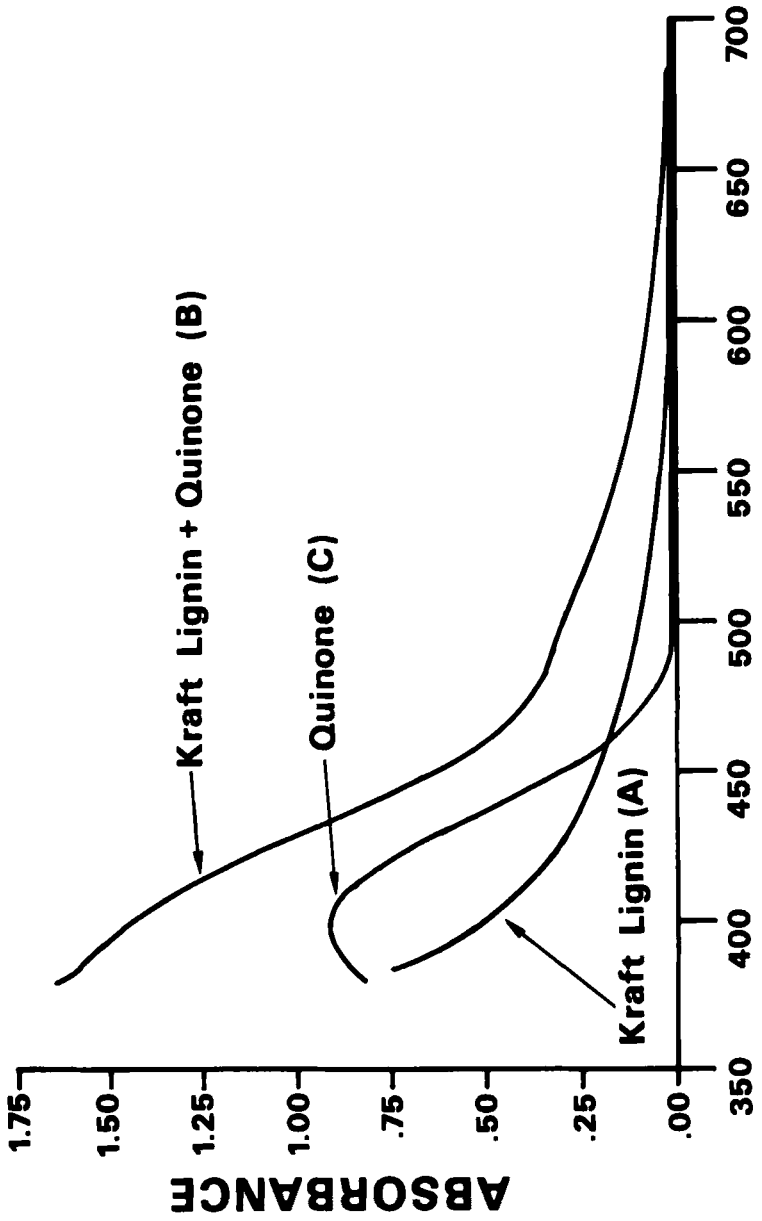

Figure 1. Visible spectra of (A) kraft lignin [1.63 x 10^{-3}M], (C) 3,5-di-tert-butyl-1,2-benzoquinone [5.00 x 10^{-4}M], and (B) kraft lignin plus quinone [same concentrations]; 2-methoxyethanol as solvent.

clearly by the difference spectrum in Fig. 2, was due to a CT interaction between the kraft lignin and the added quinone. The CT absorption band had a maximum of 494 nm and a molar absorptivity of approximately 360 L/mol-cm, based on the assumption that every quinone participated in a complex.

Several factors affected the CT absorption. Significantly, acetylation of the lignin eliminated the occurrence of this absorption. Also, a relationship was observed between the absorbance at the CT maximum and the concentration of the quinone which was added to the lignin. As is shown by Fig. 3, the absorbance linearly increased at low quinone concentrations before leveling off at higher concentrations. In Fig. 3, the quinone concentration is plotted as a molar ratio according to the phenolic content of the lignin. Both this relationship and the effect of acetylation pointed to the fact that free phenolic groups in the kraft lignin were acting as donating moieties in this CTC.

Substitution of a model phenol in place of the kraft lignin in the above system supported the results that were found. Again, a CT absorption was observed, this time between 2-methoxy-4-methylphenol and 3,5-di-tert-butyl-1,2-benzoquinone. This complex had a maximum absorption at 428 nm in n-hexane, with a molar absorptivity of 131 L/mol-cm (again assuming complete complexation of the quinone). The CT absorption band between the model phenol and quinone was substantially reduced in intensity (79 L/mol-cm) and slightly shifted to shorter wavelengths (424 nm) when the phenol was acetylated. Although acetylation did not completely remove the model phenol CT band as in the case for kraft lignin, identical results were not expected considering the large differences between the two systems. The steric hindrance imposed by the derivatization apparently had a much greater effect in the lignin system, where the constraints imposed by the remainder of the lignin molecule also appear to be an important factor.

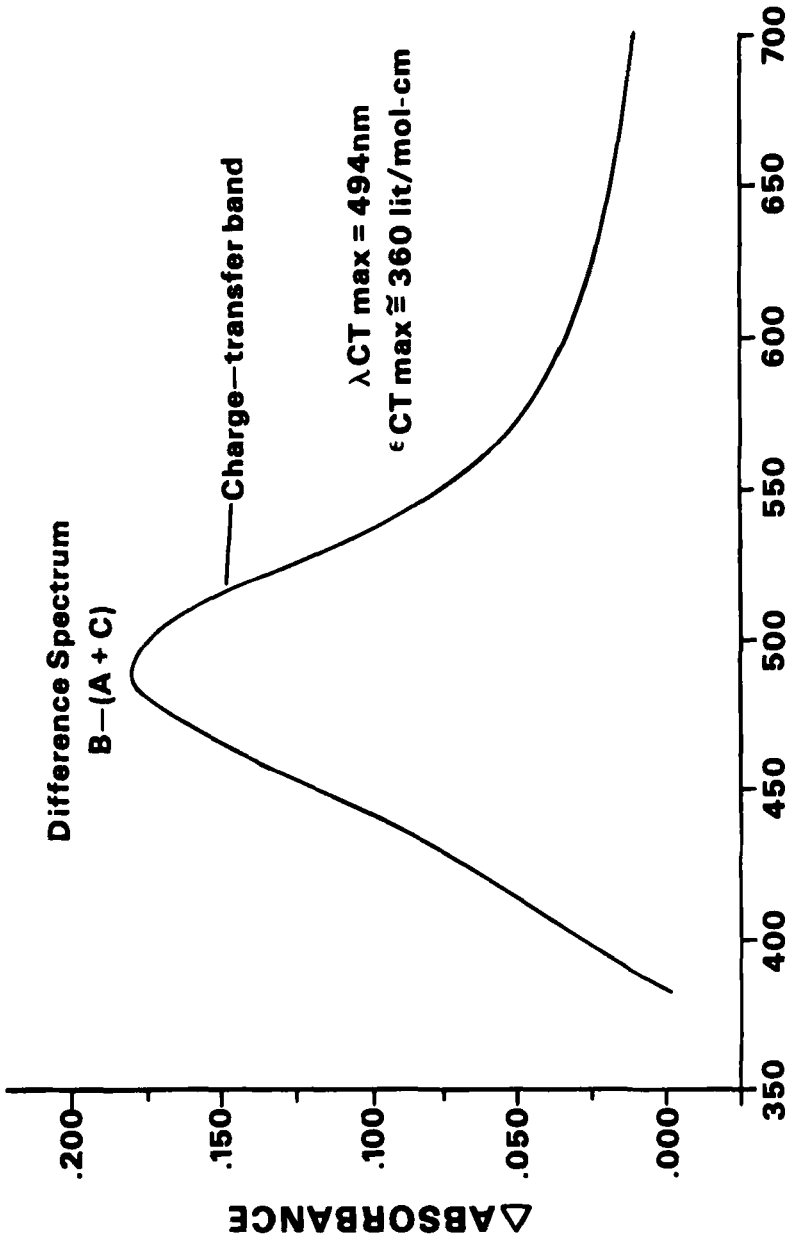

Figure 2. Difference spectrum from Fig. 1.

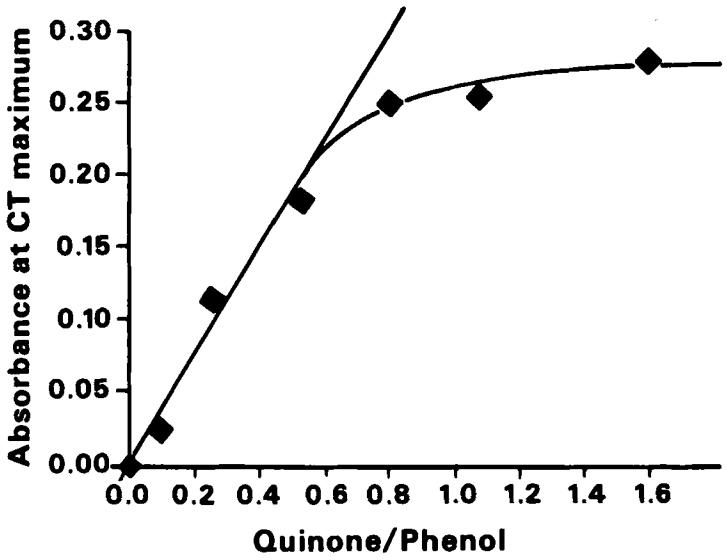

Figure 3. Effect of quinone/phenol ratio on absorbance of CTC between kraft lignin and 3,5-di-tert-butyl-1,2-benzoquinone.

CTC's in Oxidized Kraft Lignin

In another line of investigation, ortho-quinone structures were incorporated into kraft lignin by a periodate oxidation method. These structures were retained in the kraft lignin when the periodate oxidation was quenched by the addition of ethylene glycol:

$$\text{Kraft Lignin} \xrightarrow[H^+,\ 0°C]{NaIO_4} \xrightarrow{HOCH_2CH_2OH} \text{"Quinone Lignin"}$$

The presence of ortho-quinones in the lignin was verified by visible, FTIR, and ^{13}C NMR spectroscopy. The oxidized lignins

were much darker in appearance than the original lignins. Visible spectra revealed the increase in absorbance was centered near 430 nm. The π-π^* absorption band of ortho-quinones occurs in this region of the spectrum.[16]

FTIR spectra of the oxidized lignins (see Fig. 4) showed a strong new absorption band at 1663 cm^{-1}. The position of this carbonyl absorption was in good agreement with the results of Otting and Staiger,[17] who found the carbonyl stretching band of ten ortho-benzoquinones occurred in the range from 1667 to 1656 cm^{-1}. St. Berger and Rieker[18] report two carbonyl absorptions for ortho-benzoquinones, with the more intense band appearing at approximately 1668 cm^{-1} and a much weaker band at ~ 1690 cm^{-1}. In Figure 4, the smaller carbonyl absorption at 1690 cm^{-1} is not evident and is likely obscured by the 1717 cm^{-1} absorption. Difference spectra between the original and oxidized lignins, however, did give evidence of the appearance of a shoulder on the 1663 cm^{-1} absorption band, occurring around 1690 cm^{-1}. In addition a significant decrease in the aromatic skeletal vibration at 1512 cm^{-1} clearly indicated the oxidation of ring structures to ortho-quinones.

^{13}C NMR spectra of reductively acetylated, periodate oxidized lignins revealed an upfield shift in the phenolic acetate carbonyl peak (Fig. 5), resulting from steric crowding in the newly formed ortho-diacetate structures. The steric crowding effect was confirmed in model compounds.

The dark color of the periodate oxidized kraft lignin is evidenced by the difference spectrum between the oxidized and original lignins, given in Fig. 6. The rationale behind the incorporation of quinones within kraft lignin was to enhance the likelihood of CT interactions. The skewed shape of the difference band in Fig. 6 led to speculation that this band was composed of two separate components, the quinone band and a CT band.

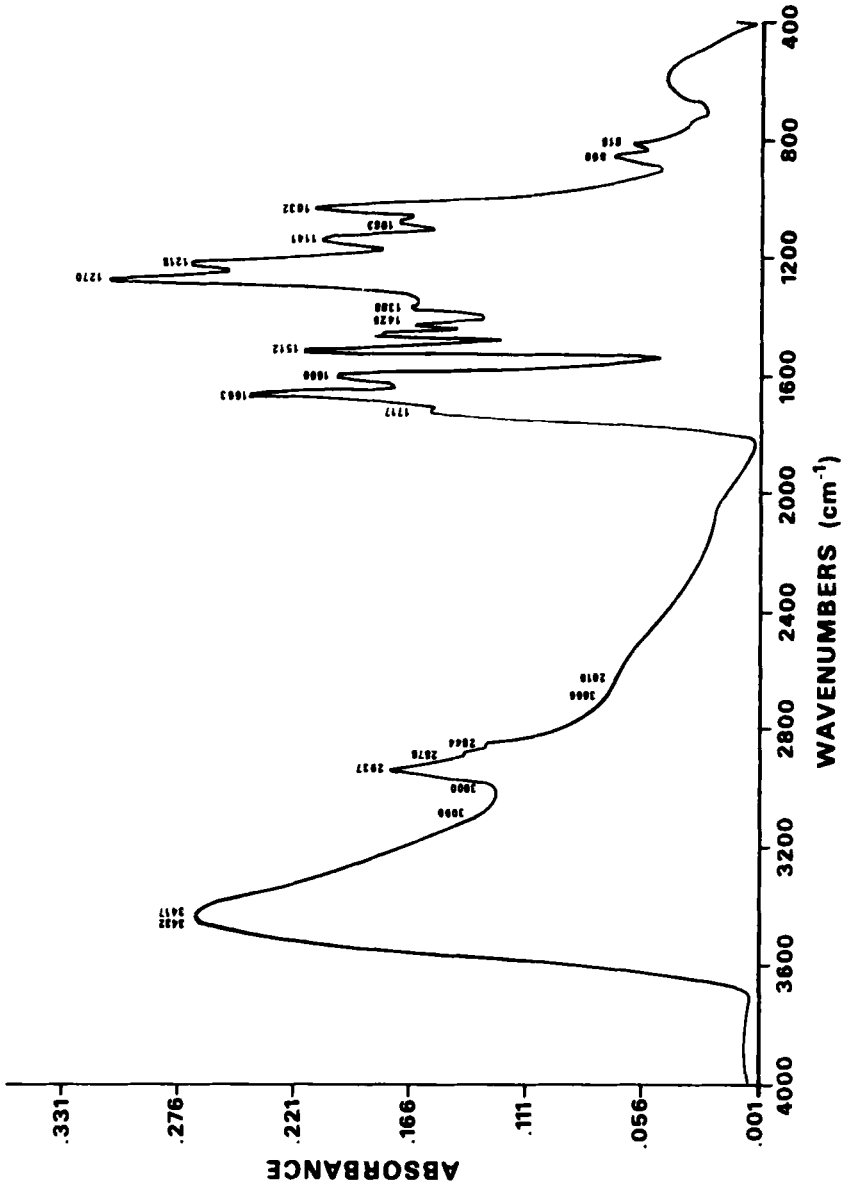

Figure 4. FTIR spectrum of periodate oxidized (two minutes) kraft lignin; ethylene glycol added to halt oxidation.

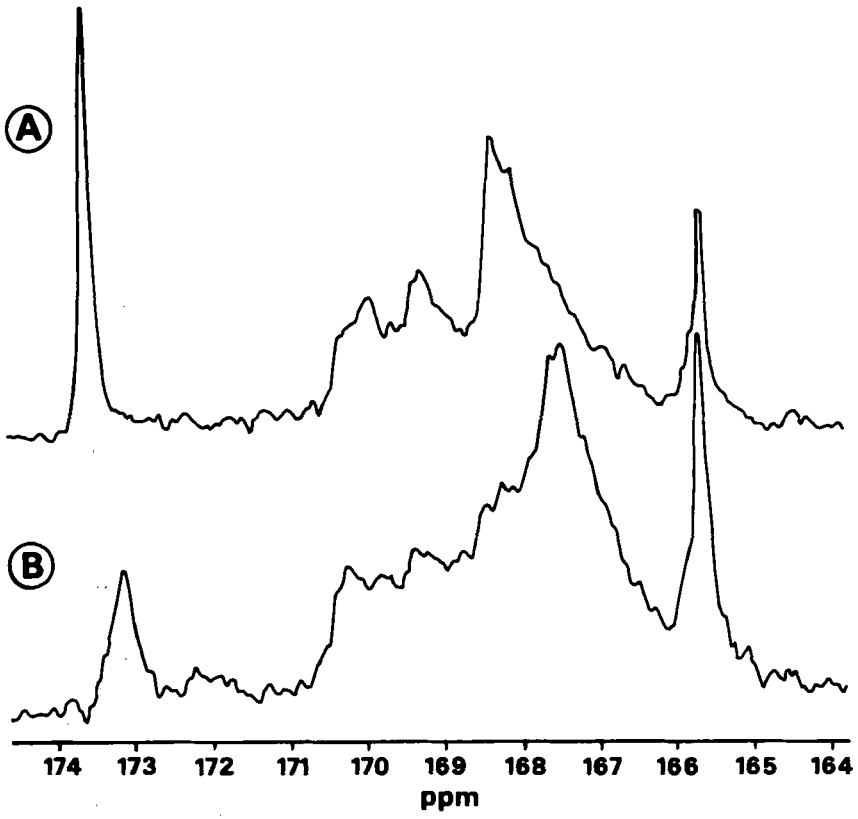

Figure 5. ^{13}C NMR spectra of: (A) the acetylated kraft lignin and of (B) the reductively acetylated periodate oxidized kraft lignin. Absorptions at 169.9, 169.2, and 168.3 ppm correspond to the 1°, 2°, and aromatic acetates, respectively. Peaks at 173.6 and 165.9 ppm are HOAc and Ac_2O impurities from the acetylation procedure.

That there was indeed a CT component present in this lignin was demonstrated by the effects of solvent, pressure, and derivatization on spectra of the oxidized lignin. Charge-transfer complexes in solution are influenced by the polarity of the solvent surrounding them. For the weak π-π CT interactions considered here, increases in solvent polarity result in slight red

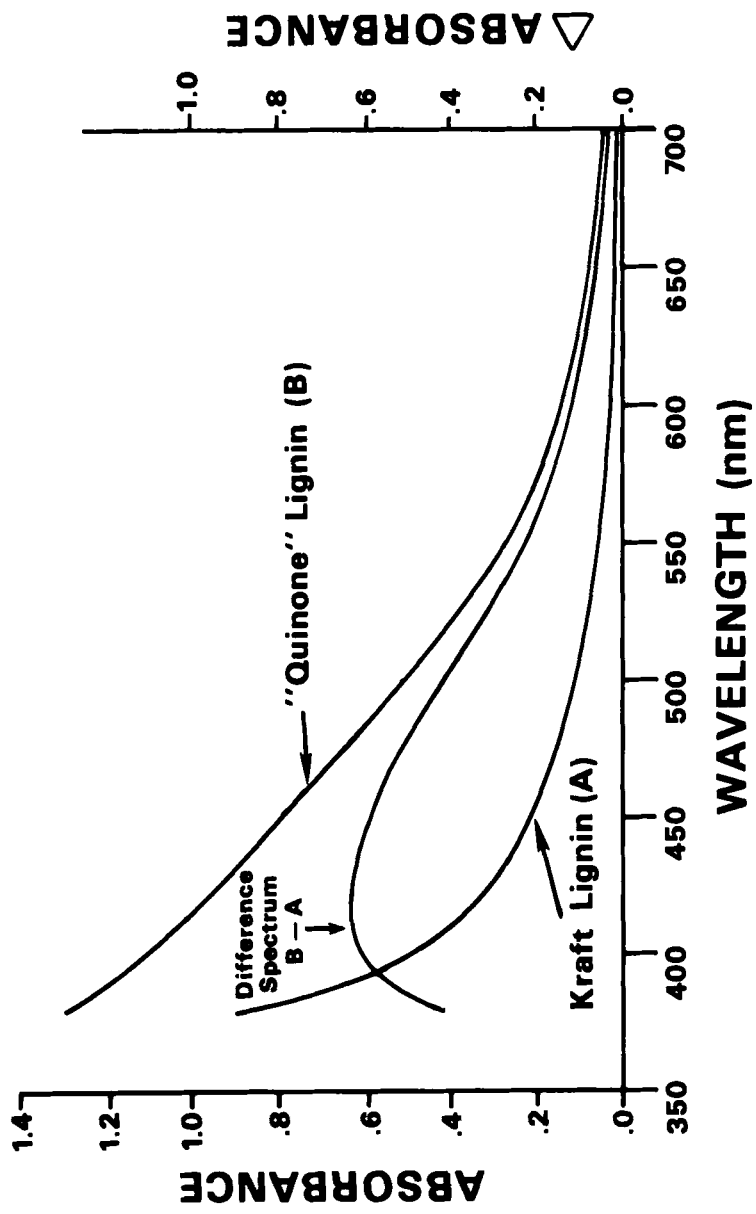

Figure 6. Visible spectra of "quinone lignin" and original kraft lignin; difference spectrum also shown (refer to right hand scale).

shifts and decreases in intensity of the CT absorbance band.[19] Difference spectra between the periodate oxidized, or "quinone lignin," and the original kraft lignin in the solvents 2-methoxyethanol and DMF are shown in Fig. 7. In terms of physical constants DMF is the more polar solvent, having both a dielectric constant and a dipole moment which are approximately twice as large as those for 2-methoxyethanol.[20] As shown in Fig. 7, the absorption maximum was slightly red-shifted in DMF, occurring at 434 nm, compared to 430 nm in 2-methoxyethanol. At the maximum, the absorbance was 25% more intense in 2-methoxyethanol than in DMF. The solvent behavior of the difference band, therefore, indicated the presence of a CTC in the quinone lignin.

Changes in ambient pressures also have relatively strong influences on weak CTC's. Offen[21] has summarized these effects. In short, CT absorption maxima shift red and increase in intensity with increasing external pressures. In this study, solutions of the quinone and original kraft lignins were subjected to pressures up to 360 MPa. Their resultant spectra were then examined for indications of CT behavior. The difference band between the quinone lignins and original lignins in 2-methoxyethanol, see Fig. 8, increased in intensity and showed a general red shift at high pressures. Since difference spectra are compared in Fig. 8, increases in the lignin's absorbances due to the increased concentrations of the lignin solutions at these high pressures canceled out. The pressure behavior of the quinone lignin in 2-methoxyethanol again indicated the presence of CTC's.

Finally, derivatization of the quinone lignin provided qualitative evidence of the presence of CTC's in this lignin. The derivatizations included acetylation and reductive acetylation of the quinone lignin. The results of these acetylations are shown by the visible spectra given in Fig. 9. Both derivatizations significantly reduced the visible absorbance of the quinone lignin.

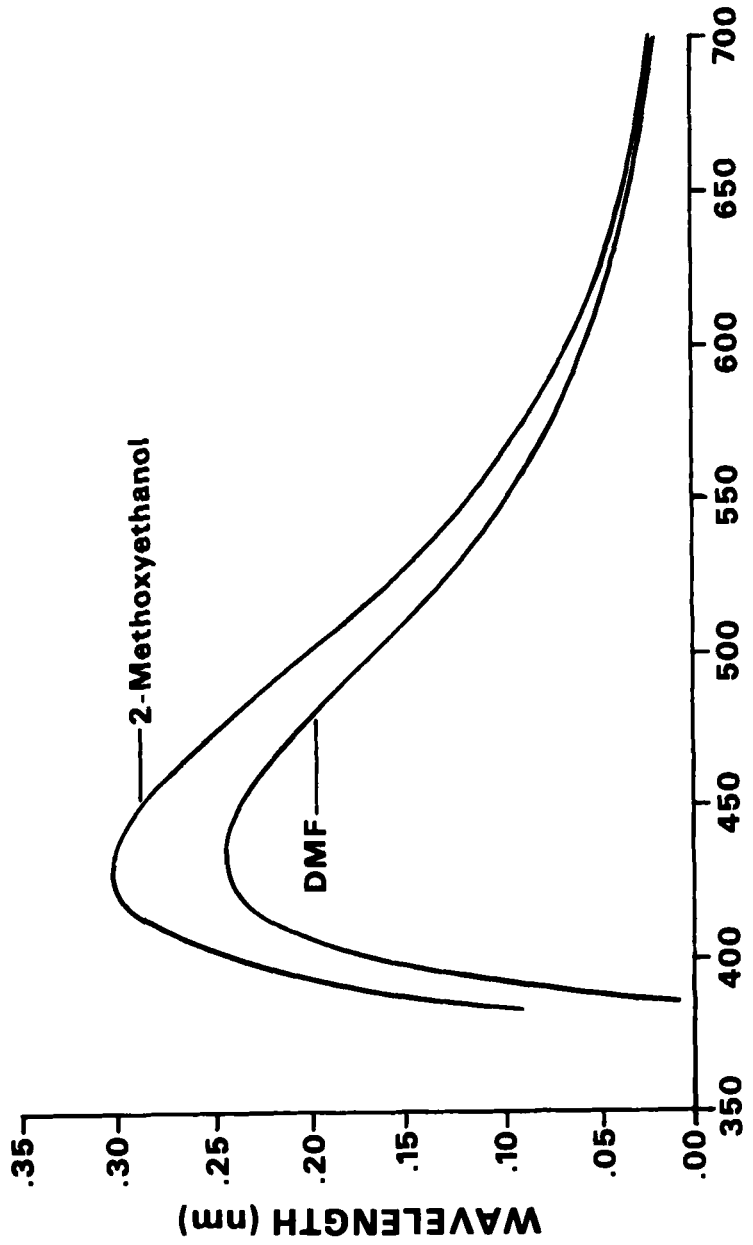

Figure 7. Difference spectra between "quinone lignin" and original kraft lignin; concentrations of subtracted lignins were 7.5 mg/25 mL of solvent.

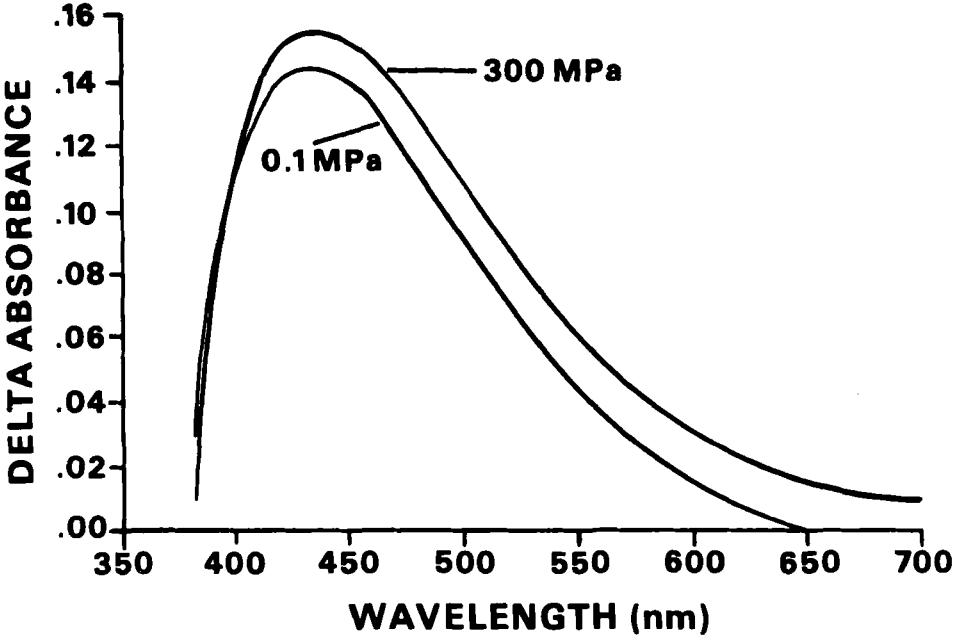

Figure 8. Quinone lignin minus original lignin in 2-methoxyethanol.

In the case of acetylation, free phenolic groups in the lignin were derivatized to the corresponding acetates. Since free phenolic groups are involved as donating moieties in the proposed CTC, this would necessarily disrupt these complexes. When model acceptors were added to acetylated kraft lignin, the observed CTC's were completely eliminated. The effect of acetylation was similar for the quinone lignin; the decrease in absorbance was caused by the disruption of CTC's. In the case of reductive acetylation, besides the removal of CTC's due to the acetylation of phenolics, quinones were reduced to catechols and then also acetylated. Consequently, two chromophore types were removed from the lignin, and, as shown in Fig. 9, reductive acetylation had the greater effect in reducing the lignin's absorbance.

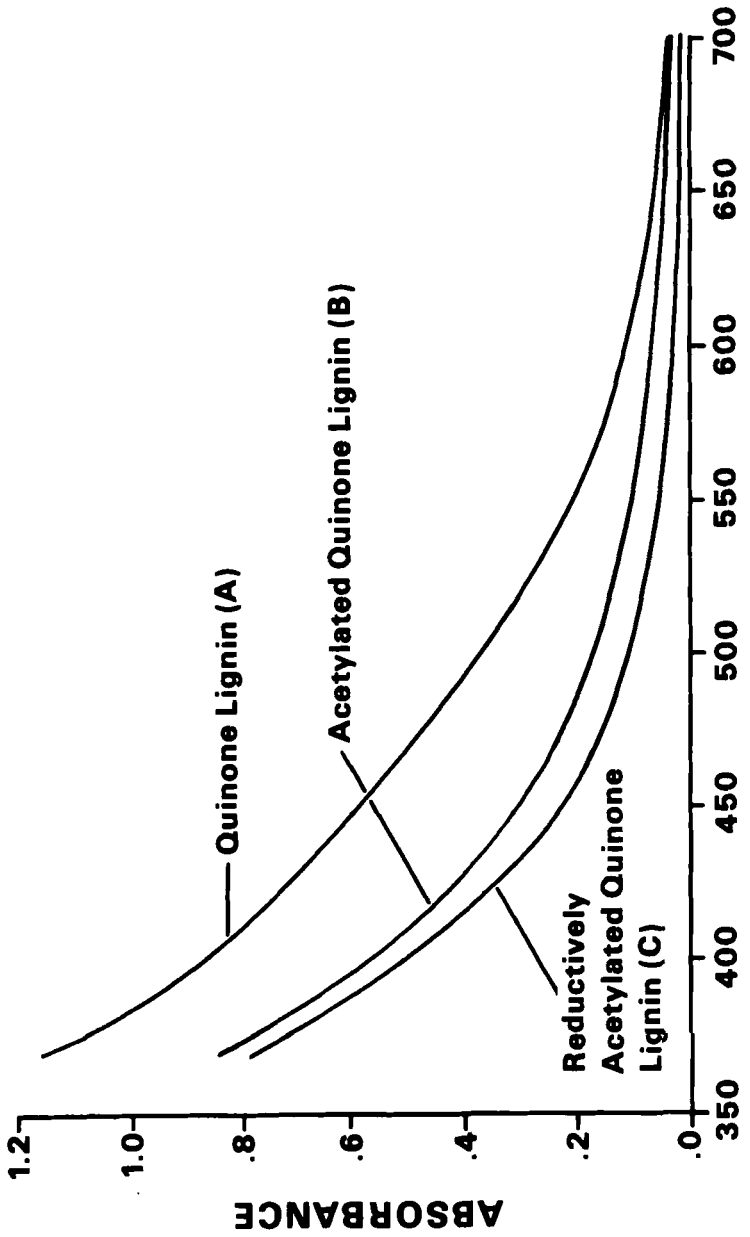

Figure 9. Visible absorption spectra of quinone lignin, acetylated quinone lignin, and reductively acetylated quinone lignin; concentration, 7.6 mg/25 mL DMF.

According to the above analysis, proper subtraction of the lignin spectra in Fig. 9 will yield the individual absorption bands of the quinone and CTC chromophores. These difference spectra are presented in Fig. 10. The spectrum (A-C) is a measure of both the quinone and CTC chromophores, the spectrum (A-B) is a measure for the CTC's in the quinone lignin, and the spectrum (B-C) a measure for the quinones in this lignin. The derivatizations, therefore, were successful in separating the difference band into its two component absorptions.

CTC's in Kraft Lignin

The observance of CTC's when quinonoid model compounds were added to kraft lignin and within oxidized kraft lignin pointed out the CT capabilities of kraft lignin. The occurrence of CTC's in unaltered kraft lignin should also be expected. However, since the quinone content in the original kraft lignin was much smaller than in the oxidized lignin, evidence for the occurrence of CTC's was more difficult to obtain. In order to ascertain if CTC's were present in the original lignin, the following approach was taken. First, the actual number of quinones present in this lignin was determined. Next, an absorbance was assigned to this number of quinones, based on their calculated molar absorptivity. Finally, the additional absorbance present in the quinone region of the spectrum, that could not be directly assigned to the quinones, was assigned to charge-transfer interactions.

The concentration of quinones in the original kraft lignin was determined by a carbon-14 labeling technique. In this technique, outlined below, quinones were labeled as radioactive acetates. The activity of the lignin was, therefore, directly related to the concentration of the quinones present in it.

$$\text{Kraft Lignin} \xrightarrow[C_5H_5N]{(CH_3CO)_2O} \text{Acetylated Kraft Lignin} \xrightarrow[C_5H_5N,\ Zn]{(CH_3{}^{*}CO)_2O} \text{Reductively Acetylated *Kraft Lignin}$$

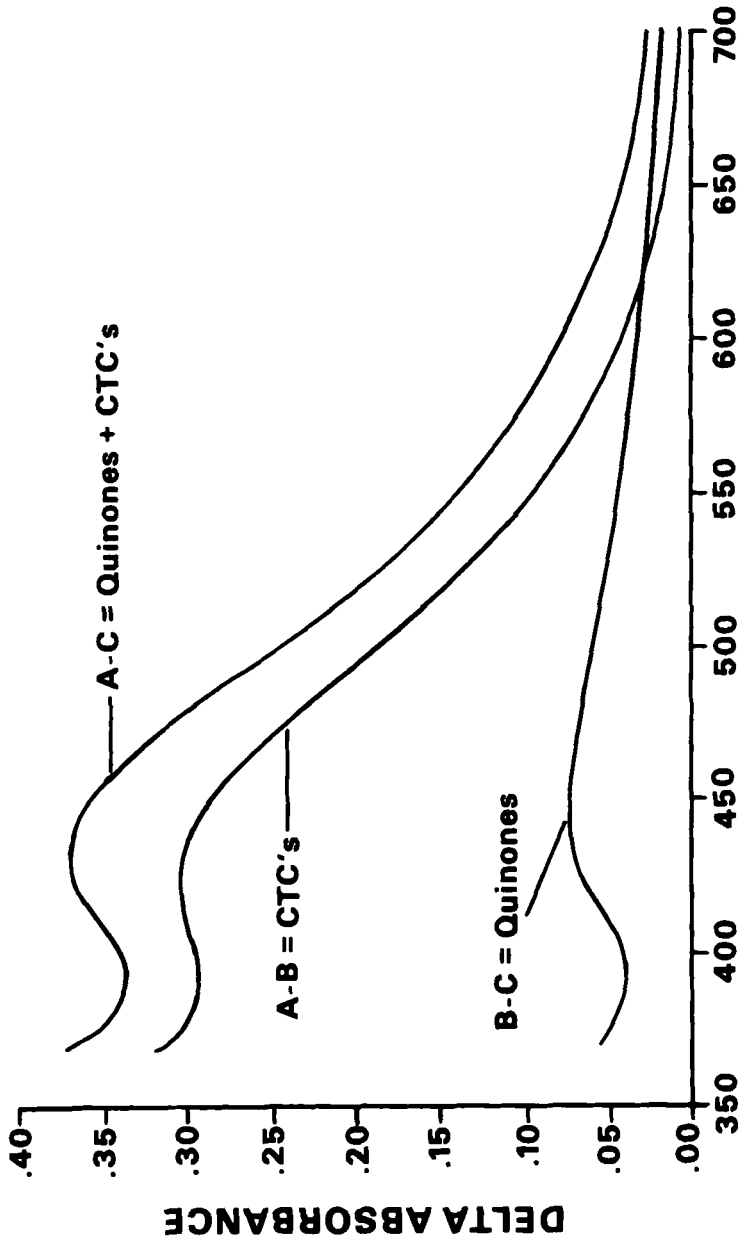

Figure 10. Difference spectra from Fig. 9.

The activities from several sets of lignins are given in Table 1. The control lignins were exposed to the radioactive acetic anhydride but not under reducing conditions. They served to establish the background radiation introduced to the lignins from acetate exchange and impurities. The raw data, in counts per minute (cpm), were converted to disintegrations per minute (dpm) from the determined efficiencies of the samples. The "Net DPM" values were obtained by subtracting the control dpm values from the corresponding sample dpm values after normalizing the samples to an activity per mg basis. The "Actual DPM" values are dpm values for the samples on a total weight basis. From these values and the specific activity of the radioactive acetic anhydride (1.62×10^4 Bq/mmol), the number of millimoles of labeled acetic anhydride incorporated within the lignin samples was calculated. This value was equal to the millimolar quantity of quinones in the sample, since each acetic anhydride molecule contained two radioactive carbons, and since there were two sites for acetylation in each quinone. Finally, the quinone concentration for each sample was calculated by dividing the molar quantity of quinones by the molar quantity of acetylated lignin in that sample. For the original kraft lignin, the quinone concentration averaged 3.05%. Other quinone concentrations in Table 1 follow the expected trends.

A molar absorptivity was calculated for the quinones in the original kraft lignin from their concentration and a corresponding absorbance. The absorbance was obtained from the difference spectrum between the acetylated and reductively acetylated original kraft lignins. This spectrum revealed the quinone maximum occurred at 431 nm, with an intensity of 0.026 AU (2-methoxyethanol as solvent.) Substituting the values of concentration and absorbance into Beer's Law, a molar absorptivity of 528 L/mol-cm for the quinones in the original kraft lignin was calculated. This value was similar to the molar absorptivities found by

Table 1. Activities and quinone concentrations of kraft lignins.

Lignin Type	Sample No.	CPM[a]	% Efficiency	DPM	DPM/ mg	Net DPM/ mg[b]	Actual DPM	mmol of *Ac_2O[c]	Quinone Conc., %
Control	1	882	5.91	14,924	350.3	--	--	--	--
	2	942	5.90	15,966	366.2	--	--	--	--
Original kraft lignin	3	3466	16.28	21,290	481.7	123.45	5,456	5.61	3.13
	4	3937	18.20	21,632	475.4	117.15	5,330	5.48	2.97
$NaBH_4$ reduced	5	6147	37.85	16,240	384.8	26.55	1,120	1.15	0.67
	6	6113	35.12	17,406	381.7	23.45	1,069	1.10	0.60
Quinone lignin[d]	7	1212	3.53	34,334	725.9	367.65	17,390	17.9	10.61
	8	1807	13.76	13,132	795.9	437.65	7,221	7.42	12.61
	9	2307	6.70	34,433	812.1	453.85	19,243	19.8	13.09

[a]At least three separate determinations each; at 95% confidence level, values within 1% of the mean.

[b]Net DPM = (sample DPM) - (average control DPM).

[c]Values multiplied by 1000.

[d]Lignin was previously treated with sodium borohydride, diimide, and EDTA, then periodate oxidized 40 seconds.

Imsgard and coworkers[2] for the ortho-quinones of acetoguaiacone and isoeugenol (600 and 741 L/mol-cm, respectively).

Knowing the molar absorptivity and the concentration of the quinones in the original kraft lignin, the absorbance at the quinone maximum actually due to quinones, and that due to their participation in CTC's, was calculated. Spectra resulting from the sodium borohydride reduction of the lignin (this treatment removed quinones and consequently CTC's) were used to calculate the total absorbance due to these two chromophores. Difference spectra between the original and sodium borohydride reduced kraft lignins revealed a drop in absorbance averaging 0.091 AU (at 431 nm). Of this total drop in absorbance, only 0.0284 AU or 31.2% was calculated to be from the quinone absorbance.

The remainder of the decrease in absorbance was assigned to CTC's. This meant the major portion (68.8%) of the absorbance decrease at 431 nm was due to the removal of CTC's. If every quinone is assumed to be participating in CT complexation, a molar absorptivity for the complex of 1163 L/mol-cm may be calculated. This assumption is reasonable, considering the high phenol to quinone ratio in the original kraft lignin. This molar absorptivity is typical of the values found for other phenol-quinone CTC's.[13,14]

Nature of CTC's in Kraft Lignin

From the observations made on CT interactions in systems involving kraft lignin, charge-transfer complexes in kraft lignin may be generally described as follows. Interactions are predominantly between free phenolic and ortho-quinone structures in lignin, acting as the donating and accepting halves of the complex, respectively. CT interactions are expected to be primarily intramolecular due to the steric constraints present between large lignin molecules. In addition, hydrogen bonding may

play an important role in attracting the two halves of the complex into close proximity, thereby allowing CT interactions to occur.

EXPERIMENTAL

Lignin Isolation and Analysis

Loblolly pine chips were cooked to a kappa number of 39 employing the following conditions: effective alkali, 16%; sulfidity, 27.5%; final temperature, 173°C; cooking time, 3 h (90 min to final temp.). The kraft lignin was isolated by acid precipitation (pH 2-3 with H_2SO_4) of the resultant black liquor. H_2S was removed from the acidified black liquor using a rotary evaporator, and the precipitated lignin was then collected by centrifugation. The lignin was washed to a neutral pH with distilled water, dried thoroughly, and ground to a uniform powder.

Excess carbohydrate material was removed from the lignin based on the carbohydrates insolubility in 2-methoxyethanol. In this procedure, the lignin was dissolved in an excess of 2-methoxyethanol (Mallinckrodt AR), and the insoluble carbohydrate material filtered off. The lignin in solution was recollected by removal of the 2-methoxyethanol on a rotary evaporator. The oily residue was dried over P_2O_5 in a vacuum desiccator, treated with distilled water, and collected by filtration. It was redried and ground to a uniform powder.

Ash contents, elemental compositions, and methoxyl contents were determined at the Microanalytical Laboratory of the University of Vienna, Waehringestrasse 38, A-1090 Vienna, Austria. These contents were as follows: 63.46% C, 5.87% H, 26.49% O, 3.53% S, 14.74% OMe, and 0.66% ash. Carbohyrate analyses were determined by the alditol acetate method.[22] The lignin contained 1.3% carbohydrates after the 2-methoxyethanol treatment, predominantly of the xylose variety. The phenolic hydroxyl content of

the kraft lignin (58 per 100 C_9 units) was determined according to the aminolysis method given by Månsson.[15]

Instrumental Methods

Electronic absorption spectra were recorded on a Perkin-Elmer 320 Spectrophotometer. High pressure electronic spectra were obtained on a modified Cary Model 14 spectrophotometer at the University of California at Santa Barbara. The high pressure optical cell, window assembly, and sample capsule have been described by Dawson and Offen.[23] Data storage and manipulation were accomplished with Apple III computers interfaced to the spectrophotometers. Solution spectra of lignin samples were obtained in either spectroscopic grade DMF (Baker), or 2-methoxyethanol (Burdick and Jackson).

Infrared spectra of lignin samples were recorded as KBr pellets on a Nicolet 7199C Fourier Transform Infrared Spectrometer.

Carbon-13 NMR spectra were recorded on a Joel FX100 Fourier Transform NMR Spectrometer using TMS as a reference. Spectra of the reductively acetylated lignins, shown in Fig. 5, were obtained in $CDCL_3$ solution (200-300 mg/0.5-0.6 mL) using a 5 mm tube. For these samples, 60,000 to 65,000 transients were accumulated using 70° pulses, one second apart. The spectra were recorded at a temperature of 52°C.

Lignin Preparations

Lignin samples were acetylated in pyridine/acetic anhydride (2:1 by volume). After standing overnight at room temperature, the reaction mixtures were hydrolyzed over crushed ice. The acetylated lignin precipitate was collected by suction filtration. The lignin was then washed with cold distilled H_2O followed by cold 0.01N HCl and cold distilled H_2O again. It was then dried over P_2O_5 and KOH.

Reductive acetylation of lignin samples was also carried out in pyridine/acetic anhydride (2:1). Zinc dust (20-30% by weight of lignin) was used as the reducing agent. The reaction flask, equipped with a $CaCl_2$ tube, was placed in a 100°C glycerol bath for one hour. The mixture was continuously stirred during this time. After cooling to room temperature, any excess Zn dust was removed by filtration and washed with several mL of a 1:1 mixture of acetic acid and pyridine. The combined filtrates were hydrolyzed over crushed ice and the reductively acetylated lignin collected as above.

Periodate oxidation of kraft lignin was conducted in a manner similar to that given by Marton and Adler.[24] However, the oxidation was halted by the addition of a large excess of ethylene glycol instead of SO_2. Following addition of the ethylene glycol, the reaction solution was stirred for a few minutes and then poured into a large volume of cold distilled water. The precipitated, oxidized lignin was concentrated by centrifugation and collected by filtration. It was washed with cold distilled water and dried over P_2O_5 and KOH in a vacuum desiccator.

Sodium borohydride reduction of kraft lignin was conducted similarly to the procedure given by Marton.[25]

Labeling Techniques

Quinone groups in kraft lignin were tagged as carbon-13 or carbon-14 acetates using the reductive acetylation procedure outlined above. The reductive acetylations were performed on kraft lignin which had been acetylated twice previously, and by using the appropriately labeled acetic anhydride. Carbon-13 enriched $(CH_3{}^*CO)_2O$ (90%) was obtained from Stohler Isotope Chemicals, Waltham, MA. Carbon-14 labeled $(CH_3{}^*CO)_2O$ (liquid under vacuum; specific activity 20 mCi/mmol) was purchased from Amersham Corp., Arlington Heights, IL.

Activities of radioactive lignin samples were determined on a Beckman LS 380 Liquid Scintillation System. The samples (40-50 mg) were dissolved in 10 mL of dioxane cocktail [naphthalene (100 g) and 2,5-diphenyloxazole (5 g) in 1 liter of dioxane] and placed in glass vials for counting. The efficiencies of these samples were determined by the internal standard method.[26]

Compounds

The compounds 2-methoxy-4-methylphenol and 3,5-di-tert-butyl-1,2-benzoquinone were purchased from Eastman Kodak Company and Aldrich Chemical Company, respectively. 1-Acetoxy-2-methoxy-4-methylbenzene was synthesized from the corresponding phenol using a method similar to that given by Ludwig and coworkers.[27]

ACKNOWLEDGMENTS

The authors would like to acknowledge the use of equipment and assistance of H. W. Offen and M. Fetterolf of the University of California at Santa Barbara. Portions of this work were used by G. Furman as partial fulfillment of the requirements for the Ph.D. degree at The Institute of Paper Chemistry. Discussions with D. R. Dimmel and R. H. Atalla throughout the course of this work are gratefully acknowledged.

REFERENCES

1. S. I. Falkehag, J. Marton, and E. Adler, Adv. in Chem. Ser., 59, 75(1966).
2. F. Imsgard, S. I. Falkehag, and K. P. Kringstad, Tappi, 54, 1680(1971).
3. J. M. Harkin, Adv. in Chem. Ser., 59, 65(1966).
4. J. Gierer, Sven. Papperstid., 73, 571(1970).
5. K. Iiyama and J. Nakano, Japan Tappi, 27, 530(1973).

6. C. Steelink, T. Reid, and G. Tollin, J. Amer. Chem. Soc., 85, 4048(1963).

7. C. Steelink, Adv. in Chem. Ser., 59, 51(1966).

8. J. Marton, In: "Lignins Occurrence, Formation, Structure, and Reactions," p. 679, K. V. Sarkanen and C. H. Ludwig (eds.), Wiley-Interscience, New York, 1971.

9. L. Lonsky, W. Lonsky, K. Kratzl, and I. Falkehag, Monats. Chem., 107, 685(1976).

10. R. Foster, "Organic Charge-Transfer Complexes," p. 33-93, Academic Press, New York, 1969.

11. H. Tsubomura, Bull. Chem. Soc. Jap., 26, 304(1953).

12. K. Kalninsh, J. Chem. Soc., Faraday Trans. 2,80, 1529(1984).

13. H. A. Staab and W. Rebafka, Chem. Ber., 110, 3333(1977).

14. Y. Miyahara, T. Inazu, and T. Yoshina, Tetra. Lett., 23, 2189(1982).

15. P. Månsson, Holzforschung, 37, 143(1983).

16. M. B. Rubin, Fortschr. Chem. Forsch., 13, 251(1969).

17. W. Otting and G. Staiger, Chem. Ber., 88, 828(1955).

18. St. Berger and A. Rieker, In: "The Chemistry of Quinonoid Compounds," Part 1, p. 163-229, S. Patai (ed.), J. Wiley, New York, 1974.

19. K. M. C. Davis, In: "Molecular Association," Vol. 1, p. 151-213, R. Foster (ed.), Academic Press, New York, 1975.

20. C. Reichardt, "Solvent Effects in Organic Chemistry," Verlag Chemie, New York, 1978.

21. H. W. Offen, In: "Molecular Complexes," Vol. 1, p. 117-49, R. Foster (ed.), Elek Science, London, 1973.

22. L. G. Borchardt and C. V. Piper, Tappi, 53, 257(1970).

23. D. R. Dawson and H. W. Offen, Rev. Sci. Instrum., 51, 1349(1980).

24. J. Marton and E. Adler, U.S. pat. 3,071,570(Jan. 1, 1963).

25. J. Marton, Tappi, 47, 713(1964).

26. C. T. Peng, "Sample Preparation in Liquid Scintillation Counting," p. 32, Amersham Corp., Arlington Heights, IL.

27. C. H. Ludwig, B. J. Nist, and J. L. McCarthy, J. Amer. Chem. Soc., 86, 1186(1964).