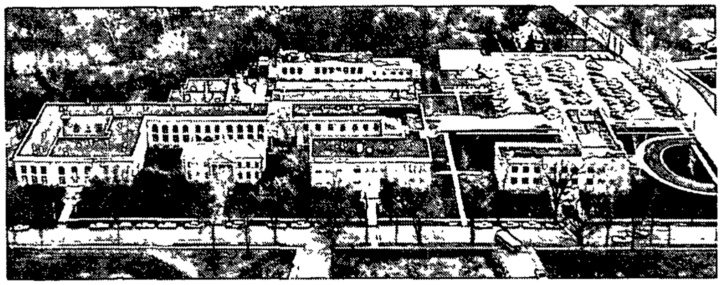

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ESTIMATION OF PULPING YIELD IN CONTINUOUS DIGESTERS FROM CARBOHYDRATE AND LIGNIN DETERMINATIONS

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Estimation of pulping yield in continuous digesters from carbohydrate and lignin determinations

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ABSTRACT

Indirect methods for the estimation of pulping yield, called the Cellulose Method and the Carbohydrate-Lignin Method, are described and evaluated. Both methods employ chemical analysis of the pulp and assume that the amount of cellulose in the pulp, expressed as a fraction of the wood, is essentially constant in a kraft cook. The Carbohydrate-Lignin Method provides more information about the pulping process and more accurate yield estimates than either the Cellulose Method or the widely used yield <u>vs</u>. kappa number plots.

kraft cook. In this procedure, pulp yield is computed from Eq. (1):

$$\text{Pulp yield} = (\text{Y cell})(\text{C+H+L+O})/\text{C} \tag{1}$$

where Y cell = amount or yield of cellulose, based on o.d. wood, and C, H, L, and O represent the weight fractions (based on o.d. pulp) of cellulose, hemicellulose, lignin, and other pulp components.

Prior to use of this method, Y cell for each wood species being pulped is determined from laboratory cooks in which wood and pulp are accurately weighed.

The yield estimation procedure shown in Eq. (1) may be employed in two ways, called the Cellulose and Carbohydrate-Lignin methods, depending upon the extent to which the pulp is analyzed. In the Cellulose Method, estimation of pulp yield involves only dividing Y cell by the cellulose fraction of the pulp (C+H+L+O = 1). This estimate includes all pulp components and gives an overall yield value.

It is often desirable to estimate the yield of the major individual components of a pulp, i.e., the carbohydrates and the lignin, and for this case Eq. (1) is rewritten to exclude the "other" components (extractives, inorganics, etc.):

$$\text{Pulp yield} = (\text{Y cell})(\text{C+H})/\text{C} + (\text{Y cell})(\text{L/C}) \tag{2}$$

The (Y cell)(C+H)/C portion of Eq. (2) represents the carbohydrate yield, while the (Y cell)(L/C) portion is indicative of lignin yield. Estimation of yield using Eq. (2) is, accordingly, termed the Carbohydrate-Lignin Method. Pulp yield given by Eq. (2) will be less than that given by Eq. (1) due to the exclusion of the "other" components normally present in minor quantities. However, as will be shown, Eq. (2) provides more precise yield estimates than Eq. (1).

Cellulose in pulp is estimated by insertion of individual carbohydrate data obtained by TAPPI Test Method T 249 pm-75 into Eq. (3).

$$\text{Cellulose in (softwood) pulp} = \text{Glucan} - \text{Mannan}/3 \qquad (3)$$

Lignin is determined directly [T 222 os-74 or by a modified procedure for small samples (3)] or estimated from kappa number (T 236 os-76).

Use of the constant yield of cellulose from wood as the basis of methods of yield estimation was originally proposed by Rydholm (4) and has been used extensively by Green (5). The objective of the current study is an evaluation of the methods based on that concept.

Determination of cellulose yield

Depending on wood species, the cellulose yield calculated on a dry wood basis remains constant at about 40% throughout sulfite pulping and may decrease to about 35% during kraft pulping (6). The cellulose loss in kraft pulping of softwoods occurs in the initial stage of the cook (7-8). From a series of laboratory cooks of slash pine, cellulose yield was found to remain essentially constant at 37.3% over a pulping yield range of 49.7 to 68.7% (7). A similar study on loblolly pine produced an average Y cell value of 36.0% (8). Thus, within the normal operating range of any given kraft mill, Y cell may be expected to be essentially constant for a given softwood species.

Because cellulose yield during the kraft pulping of hardwoods has been inadequately documented, it was studied in the current investigation. Data in

Table I show that cellulose yield remained essentially constant over a kappa number range from 70 to 16 for the one hardwood studied. Available cellulose yield values are summarized in Table II.

Table I and II here

Use of methods

Carbohydrate determinations were performed thirteen times on a loblolly pine kraft pulp. Estimated pulp yields were computed using the Cellulose Method and the Carbohydrate-Lignin Method; a Y cell value of 36.0 was used in the calculations. Data in Table III illustrate the precision of the estimates, which is better than that reported for carbohydrate determinations in T 249 or in earlier work in this laboratory (9). The improved precision results from use of carbohydrate data as a ratio in the yield estimations. This is best demonstrated by considering the computation of carbohydrate yield in Eq. (2): Because cellulose (glucan) is the predominant (and least precisely determined) carbohydrate in the pulp studied, an error in C will be matched by a similar error in C+H. Thus, errors in C will have little effect on the (C+H)/C ratio and on the estimated carbohydrate yield.

Table III here

Overall pulp yields estimated by the Cellulose Method have a higher variance than yields determined by the Carbohydrate-Lignin Method. Therefore, in situations where only lignin and carbohydrates are of interest, the lower variance offered by the Carbohydrate-Lignin Method makes its use preferable.

Application of cellulose and carbohydrate-lignin methods to commercial pulps

Pulp samples taken from a continuous digester pulping mixed softwoods during four days of a kraft mill's normal production and three days of a polysulfide kraft trial were submitted for analysis. Those samples analyzed were selected at random from hourly samples taken during the trials. Typical data and sample yield calculations are shown in Table IV. Estimated yields shown in Tables IV and V are based on carbohydrate and Klason lignin determinations performed in this laboratory. Y cell values were determined by the company submitting the samples. The mill's long-term inventory data indicate 47-48% yield from kraft pulping.

Table IV and V here

These results demonstrate the utility of these methods for estimating yield improvements resulting from process changes in a continuous digester. In addition, the Carbohydrate-Lignin Method can indicate why a change in yield occurred. Carbohydrate data revealed that the yield of the polysulfide pulp was enhanced by improved retention of mannan.

Yield estimates obtained by the Cellulose Method were not sufficiently precise to distinguish between the yields from the kraft and polysulfide processes. However, the Carbohydrate-Lignin Method showed a significant difference in carbohydrate yield.

Discussion

The Carbohydrate-Lignin Method is proposed as an alternative to the widely used yield vs. kappa plots. Both methods require laboratory pulping to generate either Y cell values or yield-kappa lines. Although the yield-kappa method demands that the laboratory- and mill-made pulps have an identical lignin-pulp composition relationship, the Carbohydrate-Lignin Method requires only that a constant amount of cellulose is unchanged during mill and laboratory pulping.

In the yield-kappa method the precision of the yield estimates is controlled by the precision of the measured kappa numbers. Coefficients of variation of kappa numbers, and thus of estimated yields, of the kraft and polysulfide pulps used in this investigation were 5.7 and 8.7%, respectively. These values may be compared with the coefficients of variation of estimated yields of the same two pulps of 2.1 and 2.4% by the Cellulose Method and 0.8 and 1.2% by the Carbohydrate-Lignin Method. Thus, because of its better precision, use of the Carbohydrate-Lignin Method is preferred to use of either the Cellulose Method or the yield-kappa method when yields of carbohydrates and lignin are of principal concern.

The yield-kappa method offers a time advantage in analysis of the pulp made in the mill, because only kappa numbers need to be determined. However, the more extensive analytical requirements of the Carbohydrate-Lignin Method should be minor compared with the total effort put into a pulp mill trial. Thus, use of the Carbohydrate-Lignin Method may be justified, because it provides more information about the pulping process and more accurate estimates of component yield.

The Carbohydrate-Lignin Method is a valuable technique for estimating pulping yield in a continuous digester.

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I. Cellulose content of pulp during kraft cooking of white oak[a]

Time at max. temp., hours	Total yield[b], %	Kappa[b] No.	Cellulose[b] in pulp, % of wood
0	57.6	69.5	36.2
0.25	53.6	48.4	36.9
0.50	52.0	41.1	35.8
1.0	49.5	19.5	34.6
1.5	50.4	19.1	35.6
1.8	49.9[c]	15.9[c]	36.6[c]

[a] 13.0% effective alkali, 25% sulfidity, 4:1 liquor-to-wood ratio, 170°C maximum temperature, time to maximum temperature approximately 105 minutes.
[b] Average of analyses of two pulps.
[c] Average of analyses of four pulps.

II. Yield of cellulose after pulping, as percentage of dry wood

Wood	Process	Cellulose Yield	Reference
Norway spruce	Sulfite	41	6
Birch	Sulfite	40	6
Scots pine	Kraft	35	6
Birch	Kraft	34	6
Slash pine	Kraft	37.3	7
Loblolly pine	Kraft	36.0	8
White oak	Kraft	36.0	This study
Mixed softwoods	Kraft	36.0	Unpublished[a]
Mixed softwoods	Polysulfide	36.5	Unpublished[a]

[a]See Table V.

III. Precision of estimated pulp yield

	Average	Standard deviation	Variance	Repeatability
Cellulose Method				
Pulp yield, %	48.2	0.55	0.302	1.52
Carbohydrate-Lignin Method				
Carbohydrate yield, %	45.6	0.22	0.048	0.61
Lignin yield, %[a]	2.1	0.024	0.0006	0.066
Pulp yield, %	47.7	0.24	0.058	0.66

[a]Lignin determined by six Klason lignin measurements.

IV. Typical data and sample calculation for mill trial kraft pulp[a]

Date and time	5/27,0500
Carbohydrates, % of o.d. pulp	
Araban	0.6
Xylan	6.6
Mannan	7.6
Galactan	1.0
Glucan	79.3
Total carbohydrates	95.1
Cellulose, from Eq. (3)[b,c]	76.8
Cellulose, % of total carbohydrates[d]	80.8
Klason lignin, % of o.d. pulp[c]	5.5

Pulp yield (Cellulose Method), % = 36.0/0.768 = 46.9 (1)

Pulp yield (Carbohydrate-Lignin Method), % = 36.0/0.808 + (36.0)(0.055)/0.768

= 47.2 (2)

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[a]Y cell = 36.0, from laboratory pulping studies.
[b]Used as decimal fraction in Eq. (1).
[c]Used as decimal fraction in computing lignin yield in Eq. (2).
[d]Used as decimal fraction in computing carbohydrate yield in Eq. (2).

V. Estimated improvement in yield of pulp from a continuous digester

Kraft[a]

	Carbohydrate-Lignin Method	Cellulose Method
Carbohydrate yield, %	44.7 ± 0.27[b]	--
Lignin yield, %	2.5 ± 0.10	--
Total pulp yield, %	47.2 ± 0.35	47.1 ± 0.93

Polysulfide kraft[c]

	Carbohydrate-Lignin Method	Cellulose Method
Carbohydrate yield, %	46.1 ± 0.41	--
Lignin yield, %	2.4 ± 0.15	--
Total pulp yield, %	48.5 ± 0.46	48.1 ± 0.90

[a] 7 samples, 4 days, Y cell = 36.0.
[b] 95% confidence limits.
[c] 9 samples, 3 days, Y cell = 36.5.