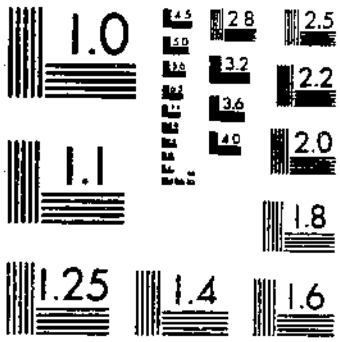
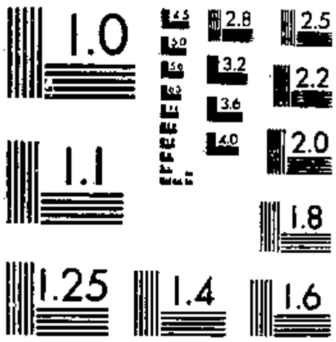
TB 1361 (1966) USDA TECHNICAL BULLETINS UPDATA
FIBER AND PAPERMAKING CHARACTERISTICS OF BAMBOO
HAUN, J R CLARK, T F WHITE, G A 1 OF 1

START



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

FIBER AND PAPERMAKING CHARACTERISTICS OF BAMBOO

Technical Bulletin No. 1361

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE

Acknowledgment

The fiber and chemical studies described in this bulletin were performed by the Herty Foundation, Savannah, Ga., through research contracts with the U.S. Department of Agriculture under the provisions of the Research and Marketing Act of 1946. This bulletin reports the final results of these studies.

Washington, D.C. Issued August 1966

Contents

FIBER AND PAPERMAKING CHARACTERISTICS OF BAMBOO

By J. R. HAUN, formerly *horticulturist, Crops Research Division;* T. F. CLARK, *chemical engineer, Northern Utilization and Development Division;* and GEORGE A. WHITE, *agronomist, Crops Research Division, Agricultural Research Service*

SUMMARY

Chipped bamboo culms of *Phyllostachys meyeri* and *P. bambusoides* compare favorably in density to hardwood and softwood logs not debarked. Stacked whole culms are more bulky than logs because of the airspace in bamboo culms.

As a rule, bamboo fibers are about the same length as those of hardwoods but are shorter than those of most coniferous woods. Length-to-width ratios are higher than those of wood fibers. The fibers of the tropical bamboo, *Bambusa vulgaris,* are longer than those of other bamboo species. It was the only bamboo studied whose fiber approximated the length of southern pine fiber.

High length-to-width ratios indicate that bamboo fibers are flexible and strong rather than stiff and brittle. Slender, pliable fibers are better for most paper because they give softness and smoothness rather than hardness and coarseness to the product. These characteristics indicate that bamboo may have a possible use in the manufacture of high-quality material for facial tissue and for book, bond, and stationery paper products. The various cooking procedures had no appreciable effect on bamboo average fiber length or fiber width.

Bamboo raw material and pulp were analyzed for ash, pentosan, and lignin content. A suitable method was developed for the determination of lignin because the methods used on wood were not entirely satisfactory for bamboo. The chemical composition of bamboo culms is not widely different from that of other material used in paper making. However, considerable chemical variation was evident among the species of bamboo. Pulping procedures affected the chemical composition of bamboo about the same way they affect other papermaking materials.

Of the several pulping methods used, the most promising were the kraft single-stage and the Raitt two-stage processes. For pulp of the same yield, the latter process gave better delignification, therefore better bleachability, with less removal of strength-giving pentosans than did the kraft process. The net consumption of chemicals was less in the

Raitt process than in the kraft process. For equivalent yield and brightness, the chlorine required to bleach pulp cooked by the Raitt process was less than that required to bleach pulp cooked by the kraft process. Bleachable bamboo pulp made by either method did not need refining before it was screened. Bamboo can be pulped readily with less power and chemicals than wood.

Considering the unbleached pulp yields, bleaching by use of standard procedures produced satisfactory brightness without undue loss of yield or strength. The bleaching of bamboo pulp consumes less chlorine as a rule than the bleaching of wood pulp.

Any of the bamboo species studied could be used for papermaking because there were only minor pulping differences among them. The choice of species to grow, therefore, depends largely on agronomic characteristics and availability of propagating material. Of the tropical bamboos, *Bambusa vulgaris* had somewhat superior papermaking characteristics.

Bamboo pulps are especially suited to papers that require softness and absorptivity. The qualities of bamboo pulp that favor its use for these types of papers are attributed in part to the slenderness and pliability of the fibers. Bamboo appears to be suitable for the following products:

a. Unbleached pulp for the manufacture of cable insulation and fruit wrapper; pattern, industrial saturating, and toweling papers; and very light dry-formed board.

b. Bleached pulp for the manufacture of absorbent molding, Bible, bread wrapper (waxed), and cigarette papers; cellulosic fiber media; sanitary papers requiring softness; and blends for high-quality writing and airmail stationery.

Other research on bamboo has shown the apparent suitability of *Phyllostachys bambusoides* for dissolving pulp (*8*)[1] and structural board (*6*). This species may also be suitable for making newsprint-type papers, but this possibility requires additional investigation (*7*).

INTRODUCTION

Bamboo has been grown in the United States on a limited basis for more than 50 years. It has been utilized mainly for ornamental purposes and to a limited extent for fishing poles. The Chinese have used it for centuries as a papermaking material, and in India it is one of the main raw materials used in the manufacture of paper.

Because of bamboo's potentiality as a new crop for the United States, fiber and chemical studies were carried out by the Herty Foundation to determine the suitability of domestic bamboo for paper pulp. The first study by the Herty Foundation was started in 1953 to determine the comparative fiber dimensions and pulping characteristics of 21 species of bamboo. The second study, started in 1954, was designed to obtain additional comprehensive data on the pulping, bleaching, and paper-

[1] Italic numbers in parentheses refer to Literature Cited, p. 16.

making characteristics of six species of bamboo selected from among those studied in 1953. The gross physical properties of bamboo were also studied. Preliminary reports on some phases of this work have been published (*12, 13, 14*).

BAMBOO SPECIES STUDIED

Since 1919 the U.S. Department of Agriculture has introduced and grown bamboo at its Plant Introduction Station, Savannah, Ga. This station has one of the most extensive collections of hardy bamboos in the world. Many species have been widely distributed by the station to various parts of the United States and are now available in the nursery trade.

The economically important species of bamboo include both the tropical (generally clump types) and the temperate (generlly running types) species. The U.S. Department of Agriculture's collection in Savannah consists mainly of temperate species. Material for the study of several tropical species was obtained from the Federal Experiment Station at Mayaguez, P. R., in order that the pulping characteristics of the tropical bamboos could be compared with those of the temperate bamboos. The tabulation that follows shows the species of bamboo studied by the Herty Foundation in 1953-54.

Temperate species from Savannah, Ga., and Plant Introduction No.:

Phyllostachys arcana McClure	77007
P. aurea A. & C. Riv.	75153
P. aureosulcata McClure	55713
P. bambusoides Sieb. & Zucc.[1]	40842
P. congesta Rendle	80149
P. dulcis McClure[1]	73452
P. flexuosa A. & C. Riv.	52686
P. meyeri McClure[1]	116768
P. nidularia Munro	63696
P. nigra 'Henon' (Lodd.) Munro[1]	24761
P. pubescens Mazel ex. H. de Leh.	80034
P. purpurata 'Solidstem' McClure	77006
P. purpurata 'Straightstem' McClure	77001
P. rubromarginata McClure	67398
P. viridis (Young) McClure[1]	77257
P. vivax McClure[1]	82047

Tropical species from Mayaguez, P.R., and Plant Introduction No.:

Bambusa longispiculata Gamble	178809
B. tulda Roxb.	21002
B. tuldoides Munro	80875
B. vulgaris Schrad.	
Guadua angustifolia Kunth	132895

[1] Studied by the Herty Foundation in 1954.

Gross Physical Characteristics

The diameter, volume, and density of samples of three bamboo species and for hardwoods and softwoods are shown in table 1. According to the table, *Phyllostachys meyeri* has smaller culms than *P. bambusoides*. However, the culms of any bamboo are variable, depending on the age of plant, and on soil, climate, and other factors. Consequently, culm sizes shown in table 1 are not necessarily representative for a particular species. The approximate maximum sizes of culms measured by McClure (*5*) for three species of bamboo also studied by the Herty Foundation in 1954 were—

	Culm height, feet	*Culm diameter, inches*
P. meyeri	33	$1\frac{7}{8}$
P. nigra 'Henon'	50	3
P. bambusoides	75	$5\frac{3}{4}$

TABLE 1.—*Volume and density of bamboo culms and of softwood and hardwood logs* [1]

Species	Units			Piled volume of a cord occupied by culms or logs	Oven-dry weight	
	Kind	Number per cord	Average diameter		Bulk density	Density of solid portion
			Inches	*Cubic feet*	*Pounds/cord*	*Pounds/cubic foot*
Phyllostachys meyeri	Culms	3,988	0.97	100	1,772	[2] 40.9
P. nigra 'Henon'	Culms	2,223	1.30	83	1,143	34.0
P. bambusoides	Culms	880	2.02	79	1,200	[2] 34.8
Softwood (pine)	Logs	45–100	7–10	[3] 83	[4] 1,575–2,576	19–31
Hardwood	Logs	45–100	7–10	[3] 83	[4] 1,745–3,405	21–41

[1] Data for bamboo culms obtained from Stevens (*13*) and for logs, from Forest Products Laboratory Technical Note No. 191 (*15*).

[2] Value determined by displacement using chipped culms.

[3] Based on an average volume of 65 percent wood and 35 percent bark and airspace in a freshly stacked pile. Solid volume content for a cord of bark-free logs is about 1.15 to 1.2 times that for logs with bark.

[4] Basis green volume.

Bamboo culms have been assumed to require considerably more space than pine logs on a weight basis and thus would be impractical to handle and store. Data in table 1 indicate that whole culms may be more bulky than pine logs, but that chipped culms compare more favorably on a density basis.

Determination of Fiber Dimensions

Preliminary experiments were performed to determine an appropriate method for macerating culms that would minimize damage to the fibers. These experiments are described in the appendix.

Maceration of Specimen

Maceration procedure consisted of cooking internodal strips of about 2 mm. by 2 mm. by 25 mm. for 20 minutes at 15 p.s.i. steam pressure with a 10-percent NaOH solution (i.e., 100 grams per liter); soaking 3 days in distilled water with three changes of water; and then dispersing for 45 seconds in an Osterizer.[2] Later the Osterizer was replaced by a Hamilton-Beach Blendor. A 15-second period with the blendor running at low speed was found best for dispersal.

[2] Trade names are used in this publication solely to provide specific information. Mention of a trade name does not constitute a guarantee or warranty and does not signify that the product is approved to the exclusion of other comparable products.

Nieschlag et al. (*9*) determined bamboo fiber dimensions by modifying the maceration techniques of Spearin and Isenberg (*11*) and of Jarman and Pickering (*4*). This modification involved boiling samples for 1 hour in 1-percent NaOH; draining, washing with hot 5-percent acetic acid, and then digesting the material in an acidic (acetic acid) solution of sodium chlorite until cellular bundles were fairly well separated. Maceration was usually completed in 6 to 8 hours.

Preparation of Slides

Ten-gram samples of the macerated raw material were dispersed in distilled water in a 500-ml. Erlenmeyer flask. By progressive decantation and dilution with distilled water, the fiber dispersions were reduced to a consistency that weighed about 0.1 gram per liter. The actual fiber concentration was varied somewhat according to average fiber length.

Four test tubes 6 inches long and 0.75 of an inch in diameter were filled with the fiber suspension, taking care to shake the Erlenmeyer flask vigorously before filling each test tube. Next, three drops of a 1-percent solution of Congo Red, or of Methylene Blue, were added to the contents in each of the test tubes and let stand 1 hour. Methylene Blue was best for use on bleached fibers.

After standing 1 hour, each tube was shaken well and a little of the fiber suspension removed with a 5 mm.-diameter pipette. A drop of fiber suspension was placed on one end of each of two slides. Eight slides were prepared from fiber suspensions in the four test tubes. Careful manipulation made it possible to deposit approximately 25 fibers on each slide. The slides were placed on a Temco hot plate adjusted to 50° C., and the water was evaporated slowly.

Measurement of Fiber

Slides with fiber suspensions were placed on the stage of an ACM Projektina that enlarged the image 10 times and projected it on a ground-glass screen. Fibers in the suspension were aligned parallel with the major axis of the slide by use of a microscope needle, taking care to straighten each fiber in order to facilitate measurement. The length of each fiber was then determined to the nearest 0.1 of a millimeter by use of the calibrated grid on the Projektina.

The slides were then transferred to the mechanical stage of a binocular microscope where fiber widths were measured by use of a 43-power objective lens, a 10-power ocular lens, and a micrometer scale. The resulting 430-power magnification made possible the measurement of fiber widths to the nearest 0.001 of a millimeter. A minimum of 200 measurements was made for each average dimension reported.

Evaluation of Fiber Measurements

Fiber measurements (for each average dimension reported) were evaluated by the following procedure:

1. The total range of fiber lengths was divided into intervals of 0.1 of a millimeter. The number of fibers in each length-interval was recorded, and the percentage of fibers *a* in the interval was calculated.
2. The mean length *b* of the fibers in each interval was calculated.

The mean fiber length $\bar{b}'$ of the entire lot was determined by multiplying the interval average lengths by the interval percentages, adding the interval products and dividing the sum by 100, as follows: Mean fiber length $b' = \frac{\Sigma\ (ab)}{100}$.

3. The mean fiber width c' was obtained by substituting the interval mean fiber width c in the preceding formula, thus: Mean fiber width $c' = \frac{\Sigma\ (ac)}{100}$.

4. The mean weighted fiber area was calculated from the sum of the products of the lengths × widths × percentages of frequency, as follows: Mean weighted fiber area $= \frac{\Sigma\ (abc)}{100}$.

5. Finally the frequency distribution of fibers by weight per length interval was calculated by dividing the interval fiber area (frequency a × length b × width c) by the mean weighted fiber area $\left(\frac{\Sigma\ (abc)}{100}\right)$. Thus, the frequency distribution by weight

$$= \frac{abc}{\Sigma\ (abc)} \times 100.$$

Fiber Dimension Data

In most cases, measurements of fiber length and fiber width were made on raw material obtained from several places on each culm. Fiber lengths and widths of the lower one-third (base) and the upper two-thirds of the culms were averaged (table 2). The length-to-width ratios are means of ratios of the upper and lower portions of culms and, therefore, differ slightly from ratios that would be obtained by using average length and width means shown in table 2. Analyses of variance were performed and Duncan's Multiple Range test applied to each set of data.

TABLE 2.—*Mean fiber dimensions of bamboo raw material*

Species	Mean fiber length [1]	Mean fiber width [1]	Length-to-width ratio [1]
	Mm.	*Mm.*	
Bambusa vulgaris	2.28 a	0.0096 bcde	240 a
Phyllostachys rubromarginata	1.77 b	.0093 cde	190 b
P. purpurata 'Straightstem'	1.72 bc	.0096 bcde	176 bcd
B. tuldoides	1.70 bc	.0097 bcde	176 bcd
P. viridis	1.69 bc	.0114 ab	146 cdef
P. meyeri	1.62 bc	.0092 cde	156 bcdef
P. aurea	1.61 bc	.0108 abcd	149 bcdef
Guadua angustifolia	1.60 bc	.0111 abc	148 cdef
B. tulda	1.56 bc	.0096 bcde	161 bcdef
P. flexuosa	1.54 bc	.0096 bcde	160 bcdef
P. arcana	1.52 bc	.0117 a	130 ef
B. longispiculata	1.48 bc	.0082 e	182 bc
P. nidularia	1.48 bc	.0090 de	166 bcde
P. purpurata 'Solidstem'	1.48 bc	.0091 de	162 bcdef
P. nigra 'Henon'	1.43 bc	.0089 de	145 cdef
P. vivax	1.38 bc	.0102 abcd	134 ef
P. bambusoides	1.37 bc	.0104 abcd	132 ef
P. pubescens	1.30 bc	.0093 cde	140 def
P. aureosulcata	1.26 bc	.0082 e	156 bcdef
P. dulcis	1.20 c	.0096 bcde	124 f

[1] For a given measurement, two means followed by the same letter or letters are not significantly different at the 5-percent level according to Duncan's Multiple Range test. The same degree of significance applies to ratios of length-to-width.

Chemical Properties of Bamboo

Bamboo for analysis was cut from whole culms by use of a power saw and identified as to position on the culm and number of nodes per section. Samples were then split lengthwise with an ax into pieces about ¾ of an inch wide and 6 inches long and then fiberized in the 015 Jackson & Church refiner mill.

The fiberized raw material was taken from the refiner mill and further reduced in size in an Abbe mill that had 1/16-inch perforations. It was then screened on a set of Syntron sieves to obtain material that passed through a 50-mesh sieve but was retained on a 100-mesh sieve.

Bamboo fiberized raw material was analyzed for ash, lignin, and pentosan by TAPPI[3] standard methods, as follows:

a. Ash content, by use of TAPPI method T 15 m-48.

b. Lignin content, by use of TAPPI method T 13 m-45. The time of digestion in 72-percent H_2SO_4 was extended to 20 hours.

c. Pentosan content, by use of TAPPI method T 18 m-20. Krober's table (*2*) was used for converting weights of furfural glucoside to pentosan.

The results of analyses of variance for duplicate determinations of ash, pentosan, and lignin in samples of bamboo raw material from the lower one-third of culms are given in table 3.

TABLE 3.—*Composition of bamboo raw material from lower one-third of culms*

Species	Ash[1]	Pentosan[1]	Lignin[1]
	Percent	*Percent*	*Percent*
Bambusa tulda	6.2 a	18.5 e	19.7 g
Phyllostachys bambusoides	2.1 b	22.3 a	32.2 b
P. vivax	1.8 bc	22.3 a	24.5 e
P. purpurata 'Solidstem'	1.8 bc	21.0 ab	26.9 d
P. aureosulcata	1.8 bc	20.6 bcd	21.2 fg
B. tuldoides	1.4 cd	19.4 de	19.6 g
P. flexuosa	1.4 cd	20.1 cd	24.4 e
P. meyeri	1.2 de	21.0 abc	23.0 ef
P. viridis	1.0 de	18.4 e	21.6 fg
P. rubromarginata	1.0 de	22.2 a	36.8 a
P. nigra 'Henon'	1.0 de	18.2 e	29.3 c
Pine chips	.8 e	14.4 f	27.0 d

[1] For a given measurement, two means followed by the same letter or letters are not significantly different at the 5-percent level according to Duncan's Multiple Range test.

In contrast to the procedure described in the foregoing paragraphs, a fairly simple and rapid method for the determination of lignin has been developed by the Agricultural Research Service's Northern Utilization Research and Development Division. This method, which is a modification of the procedure described by Aronovsky et al. (*1*), involves 2 hours digestion in 80-percent sulfuric acid at 5° C., dilution to 3 percent, and boiling for 1 hour. The residue is then recovered and weighed with correction for ash content determined by ignition of the dried residue.

[3] Technical Association of the Pulp and Paper Industry. Also the name of the official publication of this Association. All publications of the Technical Association of the Pulp and Paper Industry may be obtained from the offices at 360 Lexington Avenue, New York, N. Y. 10017.

PREPARATION AND EVALUATION OF BAMBOO PULP

Exploratory Techniques

Studies were conducted with small amounts of raw material to determine the chemical-to-bamboo ratio required to neutralize organic acids and solubilize the cementing substance (lignin) enough to separate fibers for the determination of pulp yields. For this purpose, small digesters having a capacity of 900 ml. were made from 8-inch lengths of 3-inch pipe closed at one end by a welded plate and at the other end by a threaded cap having a thermometer well. The digesters were heated in an oil bath over a gas flame.

Bamboo for these digesters was prepared by cutting culms into sections with a power saw and splitting the sections into splinters. Both nodal and internodal sections were included. Splinter dimensions ranged from 1 to 10 mm. tangential, 1 to 6 mm. radial, and 74 to 202 mm. longitudinal. Mean dimensions were 5 by 3 by 150 mm., respectively. Splinters from each culm section were distributed equally among digesters.

The exploratory pulping studies and their results are described in the appendix.

Raitt Two-Stage and Kraft Single-Stage Cooking Processes

Comparative cooking studies using the Raitt and kraft processes were conducted with constant chemical-to-bamboo ratios on larger samples of material from various species of bamboo than described under "Exploratory Techniques." In these studies, the material was cooked in a 5-gallon or larger digester, and the results allowed an adequate evaluation of the pulp.

Bamboo for these two processes was prepared from basal sections (lower one-third) of culms by chipping in a Carthage 4-knife chipper. This machine made good chips, but it also made a lot of splinters. Splinters were separated by hand and chopped into suitable size with a hatchet.

Treatments given the bamboo chips and splinters follow.

1. Raitt two-stage cooking (*10*): Using 20 grams per liter active alkali (calculated as NaOH) at a liquor volume of 8 to 1, bamboo was cooked for 1 hour at 100° to 110° C., followed by cooking 1 hour at 150° C. Then using the same liquor volume containing 50 grams per liter active alkali (calculated as NaOH), the material was cooked 2 hours at 130° to 140° C.

2. Kraft single-stage cooking: Using 15-percent active Na_2O (calculated on moisture-free bamboo) and an 8 to 1 liquor volume, bamboo was cooked 2 hours at 160° to 170° C.

Fiber dimensions of the pulp prepared by the kraft process were determined according to the techniques described in the section "Determination of Fiber Dimensions." Results of these determinations are shown in table 4.

Kraft-cooked pulps were prepared for chemical analysis by oven drying followed by pulverizing in an Abbe mill. The content of ash, lignin, and pentosans is shown in table 5. Methods used for the various constituent analyses were:

a. Ash content, TAPPI method T 211 m-44.

b. Lignin content, TAPPI method T 22 m-50. Digestion time was extended to 20 hours.

c. Pentosan content, TAPPI method T 19 m-20. Krober's table (*2*) was used for converting weights of furfural glucoside to pentosan.

TABLE 4.—*Fiber dimensions of bamboo pulp prepared from the basal sections of culms in 5-gallon digesters by the kraft process*

Species pulped	Fiber dimensions [1]		
	Length	Width	Length-to-width ratio
	Mm.	*Mm.*	
Bambusa vulgaris	2.09 a	0.0109 ab	192 ab
B. longispiculata	1.80 ab	.0088 de	204 a
B. tulda	1.78 bc	.0108 ab	160 defgh
Phyllostachys rubromarginata	1.66 bc	.0091 cde	182 bc
P. nigra 'Henon'	1.65 bc	.0090 cde	184 bc
B. tuldoides	1.64 bc	.0097 abcde	170 cdef
P. flexuosa	1.63 bc	.0094 bcde	174 bcd
Guadua angustifolia	1.62 bc	.0112 a	144 hi
P. purpurata 'Straightstem'	1.54 bcd	.0087 de	177 bcd
P. meyeri	1.50 bcd	.0098 abcde	153 efghi
P. viridis	1.48 bcd	.0104 abc	142 hi
P. aurea	1.44 cd	.0088 de	165 cdefg
P. nidularia	1.44 cd	.0085 e	169 cdef
P. congesta	1.43 cd	.0084 e	170 cdef
P. vivax	1.43 cd	.0101 abcd	140 i
P. aureosulcata	1.23 d	.0084 e	146 ghi

[1] For a given measurement, two means followed by the same letter or letters are not significantly different at the 5-percent level according to Duncan's Multiple Range test.

TABLE 5.—*Composition of bamboo pulp prepared from the basal sections of culms in 5-gallon digesters by the kraft process*

[Results are duplicate determinations]

Species pulped	Ash [1]	Pentosan [1]	Lignin [1]
	Percent	*Percent*	*Percent*
Bambusa vulgaris	2.36 a	20.1 b	7.6 d
Phyllostachys congesta	2.25 ab	26.6 a	9.7 c
P. aurea	1.85 ab	14.9 c	6.6 d
Pine chips	1.50 ab	9.0 d	21.3 a
P. viridis	1.25 ab	20.7 b	5.0 e
P. bambusoides	1.15 ab	20.5 b	17.3 b
P. vivax	0.90 b	19.8 b	18.0 b

[1] For a given measurement, two means followed by the same letter or letters are not significantly different at the 5-percent level according to Duncan's Multiple Range test.

Representative data for some properties of the pulps produced by the Raitt two-stage and the kraft single-stage processes are shown in table 6. TAPPI method T 200 m-45 was used to evaluate the strength and other physical characteristics of the bamboo pulps. Refining by beating was performed in a 1½-pound Valley beater, and pulp was sampled at intervals to determine freeness and sheet making. A Rice-Barton Dynapulper was used in lieu of the British disintegrator for clearing the pulps before sheet making. Based on a test from one cook, the dynapulper appeared to have no appreciable effect on the freeness of the stock. The beater bedplate clearance chamber did not have water inlets, but by exercising care, it was possible to keep the pockets free of accumulated fiber. Instead of the standard 5,500 grams on the bedplate lever arm, a total of 6,440 grams was used. Because the experimental results were subjected only to comparative interpretation, these departures were justified. Freeness was determined by use of TAPPI method T 227 m-50.

Handsheet forming was done by use of Noble and Wood equipment and procedure, except that sheets were dried on an electric hot plate instead of on a drum dryer. Six handsheets were made for each freeness determination. One of these sheets was preserved for reference; the other sheets were measured, tested, and the results averaged.

TABLE 6.—*Some physical properties of bamboo pulps prepared by Raitt two-stage and kraft single-stage processes and refined to 400 ml. Canadian Standard (C.S.) freeness*

Pulping method and species tested	Pulp yield	Beating time	Burst factor	Tear factor
	Percent	*Minutes*	*G./sq. cm./g./sq. m.*	*G./g./sq. m.*
Raitt two-stage:				
Bambusa longispiculata	41	62	22.0	132
B. tuldoides	45	53	22.6	103
B. vulgaris	41	45	30.2	154
Guadua angustifolia	44	60	18.6	135
Phyllostachys bambusoides	44	40	20.3	85.4
P. nigra 'Henon'	46	41	17.8	92.7
P. purpurata 'Solidstem'	44	48	31.1	151
Kraft single-stage:				
P. viridis	49	47	22.2	110
P. flexuosa	50	28	81.1	93.3
P. meyeri	55	27	22.5	81.6
P. nidularia	54	48	22.6	77.4
P. purpurata 'Straightstem'	53	43	41.5	108
P. rubromarginata	54	48	85.4	110
P. vivax	53	89	81.1	79.8
Pine chips	57	56	43.6	106

After conditioning (TAPPI method T 402 m–49), the sheets were trimmed 7 13/16 inches square so that the weight in grams divided by the thickness in mils (1 mil = 0.001 of an inch) gave the "apparent density", i.e., grams per cubic centimeter of sheet volume. Each sheet was weighed to the nearest 0.05 of a gram and calipered in four places to the nearest 0.0005 of an inch. From these data the weight per ream of 500 sheets (24″ by 36″) and the apparent density were calculated.

Bursting strength of handsheets was determined with two pops on the Mullen tester (Model C), one from each side of the sheet. The results were averaged and divided by the ream weight to obtain the burst factor.

Tearing strength of handsheets was determined with 6 pieces cut 2.5 inches square and torn according to TAPPI method T 414 m–49. The instrument reading was multiplied by 2.66 to obtain the grams of force that would be required to tear the 16 sheets stipulated in the method. This result was divided by the ream weight in pounds to give the tear factor.

Pilot Plant Processing

Bamboo chips were cooked in a 60-cubic-foot Blaw-Knox station-

TABLE 7.—*Conditions used for the pulping of bamboo in pilot-plant studies*

Type of cook and number; bamboo species pulped [1]	First-stage conditions				Second-stage conditions					Total alkalinity of both stages (active Na_2O on basis of moisture-free bamboo)	Pulp yield	Permanganate number	Chlorine bleach	Brightness Photovolts
	Active Na_2O		Time on temperature	Liquid-to-solids ratio	Active Na_2O		Time on temperature	Sulfidity of liquor	Liquid-to-solids ratio					
	Concentration	On basis of moisture-free bamboo			Concentration	On basis of moisture-free bamboo								
	G./l.	*Percent*	*Hours*		*G./l.*	*Percent*	*Hours*	*Percent*		*Percent*	*Percent*		*Percent*	*Percent*
R 1; *Phyllostachys viridis*	15.6	5.6	2.0	3.59	43.4	37.0	3.0	0	3.53	42.6	34	9	8.2	73
R 2; *P. bambusoides*	15.6	6.5	1.0	4.16	51.9	34.5	0.5	0	6.66	41.0	37	19	13.9	84
R 3; *P. bambusoides*	18.7	7.8	1.0	4.16	51.9	21.6	0.5	0	4.17	29.4	36	21	14.5	—
R 4; *P. bambusoides*	11.8	4.4	1.0	3.73	36.8	14.0	3.0	34	3.30	18.4	42	21	9.0	—
R 5; *P. bambusoides*	13.2	4.2	1.0	3.18	37.7	13.8	3.0	34	3.67	18.0	41	23	10.7	—
R 6; *P. bambusoides*	14.6	4.5	2.0	3.08	40.8	12.8	2.0	34	3.14	17.3	44	19	—	—
R 7; *P. bambusoides*	11.5	4.2	1.0	3.65	37.0	13.7	2.0	23	3.71	17.9	43	—	10.9	—
R 8; *P. vivax*	13.6	6.8	2.0	5.00	37.6	14.2	3.0	19	3.73	21.0	37	23	7.0	—
R 9; 70 percent *P. bambusoides* and 30 percent *P. nigra* 'Henon'.	13.6	4.0	2.0	2.94	33.8	14.8	2.0	11	4.38	18.8	46	18	9.9	75
R 10; 70 percent *P. bambusoides* and 30 percent *P. nigra*.	11.9	5.1	1.0	4.29	40.0	16.4	2.0	4	4.10	21.5	48	25	9.2	—
R 11; 70 percent *P. bambusoides* and 30 percent *P. meyeri*.	14.6	5.8	1.25	3.98	35.1	14.0	1.75	0	4.00	19.8	42	17	9.2	69
R 12; 70 percent *P. bambusoides* and 30 percent *P. meyeri*.	14.6	5.8	1.25	3.98	35.1	14.0	1.75	0	4.00	19.8	41	15	9.2	69
R 13; 67 percent *P. bambusoides* and 33 percent *P. vivax*.	12.4	5.9	1.0	4.76	32.2	15.3	2.0	0	4.75	21.2	46	—	11.1	—
R 14; 70 percent *P. bambusoides* and 30 percent *P. vivax*.	15.1	5.8	1.0	3.84	36.3	14.0	2.0	0	3.86	19.3	49	—	13.3	64
R 15; *P. bambusoides*	15.0	6.7	1.25	4.44	37.4	16.7	2.25	0	4.47	23.4	49	—	5.2	—
R 16; *P. bambusoides*	14.7	7.0	1.25	4.76	36.7	17.6	2.25	0	4.80	24.6	42	—	10.0	77
K 17; *P. bambusoides*	40.5	18.1	3.00	4.47	—	—	—	0	—	18.1	41	—	6.0	—
R 18; *P. bambusoides*	15.3	7.0	1.25	4.58	34.1	15.7	2.25	0	4.60	22.7	42	—	10.0	77
R 19; *P. bambusoides*	13.7	6.2	1.25	4.53	36.2	15.9	2.25	0	4.39	22.1	51	—	12.2	—
K 20; *P. bambusoides*	42.0	19.2	3.0	4.57	—	—	—	0	—	19.2	40	—	9.6	69
R 21; *P. bambusoides*	14.7	6.1	1.25	4.15	38.9	15.1	2.25	0	3.88	21.2	37	—	7.4	—
R 22; *P. bambusoides*	14.7	6.0	1.25	4.08	38.8	15.1	2.25	25	3.89	21.1	43	—	4.6	72
R 23; *P. bambusoides*	15.5	6.4	1.25	4.13	39.5	15.4	2.25	25	3.90	21.8	36	18	9.5	75
R 24; *P. bambusoides*	15.0	6.3	1.25	4.20	38.9	15.1	2.25	25	3.88	21.4	43	16	11.7	65
R 25; *P. bambusoides*	15.4	6.1	1.0	3.96	38.4	15.1	1.5	21	3.93	21.2	41	20	7.3	66
R 26; *P. bambusoides*	15.4	6.1	1.0	3.96	38.4	15.1	2.0	21	3.93	21.2	43	20	7.8	70
K 27; *P. bambusoides*	40.0	18.0	2.0	4.50	—	—	—	23	—	18.0	45	27	8.2	57
R 28; *P. bambusoides*	14.3	9.1	1.0	6.36	35.4	15.7	2.5	22	4.43	24.8	40	22	9.4	67
K 27; *P. bambusoides*	32.2	18.1	3.0	5.62	—	—	—	29	—	18.1	40	19	8.3	69
K 30; *P. dulcis*	32.8	18.1	2.5	5.52	—	—	—	30	—	18.1	43	15	77.1	66

[1] The types of cook R and K refer to the Raitt two-stage and the kraft single-stage treatments, respectively. Numerals that follow these letters are for experimental identification.

ary vertical digester to provide enough pulp for the subsequent production of paper on the pilot-plant fourdrinier. The pilot-plant digester was made of stainless steel and had a conventional design for either direct or indirect heating. Pulping liquor used in the cooking of bamboo was heated indirectly by means of a heat exchanger. Pulping liquor was withdrawn from the midsection of the digester, pumped through the heat exchanger, and reintroduced into the digester at the bottom near the blow valve and through an inside distributing pipe near the top.

Bamboo was prepared for the pilot-plant digester in the same manner as is described in the section "Raitt Two-Stage and Kraft Single-Stage Cooking Processes." The conditions under which pulps were prepared for making into paper are shown in table 7. These pilot-plant studies showed that bamboo pulps require less chemical and less power for refining than pulps made from southern pine and southern hardwood.

PAPERMAKING

The experimental bamboo pulps made in the pilot-plant digester were used singly or in combination with conventional pulps to prepare furnishes for a variety of paper and pulp products. Conventional pulps used in the furnishes were commercial southern pine bleached kraft, commercial hardwood bleached soda, an oak groundwood, a flax pulp, and a rag pulp. Additives, fillers, dyes, pigments, and sizing agents (starch, clay, and alum rosin) were also included in the furnishes according to the characteristics needed in the final product.

Bleaching

Bleaching was accomplished by use of a three-stage procedure that involved chlorination, caustic extraction, and hypochlorite oxidation. A 75-pound Niagara-type tile-lined Valley beater was used to prepare slush stock of 3-percent consistency from the pulps described in table 7. Chlorination was performed in a 150-pound Hooker rubber-lined chlorinator that had a diameter of 2 feet and a height of 14 feet and was equipped with a rubber-lined side tube 8 inches in diameter.

Circulation of pulp in the chlorinator and side tube was accomplished with a centrifugal pump having a 4-inch inlet (suction) and 3-inch vertical discharge. The pump was driven 1,750 r.p.m. by a direct-connected 10 hp. motor. The permanganate number (TAPPI method T 214 m-50) was used to calculate the amount of chlorine required.

Chlorine was injected from a cylinder mounted on a platform scale directly into the stream of slush pulp as it was pumped through the rubber-lined side tube. After 30 minutes, an NaOH solution was added at the top of the chlorinator to neutralize the acids that had formed and to adjust the pH to the range of 10 to 11. Circulation was continued another 5 minutes. The stock was then pumped out to a 300-pound hollander-type tile-lined Valley beater equipped with an octagonal drum washer.

Caustic extraction was accomplished by adding NaOH to the pulp in the beater and then heating the pulp with direct steam. The amount of NaOH added was equal to 5 percent of the weight of oven-dry pulp. After heating for 1 hour at 50° C., the pulp was washed.

In the final stage, a calcium hypochlorite (HTH) solution was added, and the pH of the stock adjusted to a range of 9 to 10 by adding NaOH. The stock was circulated in the beater with hypochlorite for 1 hour, after which the pulp was washed. If a handsheet of the pulp lacked the required brightness, at least one more hypochlorite stage was carried out. Pulp was stabilized by the use of sulfurous acid formed in situ by injecting SO_2 from a cylinder of the liquefied gas. The final bleached pulp was pumped from the beater to a stock chest, run over the fourdrinier, and taken off as roll pulp or "wet laps" after the second press.

Brightness of the pulp was determined by a Photovolt instrument, which measured the reflectance in comparison with a standard white. Data on bleaching are shown in table 7.

Refining

In preparing the stock for the paper machine runs, a 300-pound hollander-type tile-lined Valley beater was used to break up laps or other forms of pulp; to mix the ingredients or "furnish"; and to waterlog, or "hydrate", the fibers. Refining of pulp was accomplished with either a Valley pony jordan or a Hermann claflin.

The prepared stock was pumped into agitated stock chests, then through a Valley 6-plate diaphragm screen to remove shives and coarse dirt, and finally through a Bird Dirtec centrifugal cleaner to remove fine dirt before being pumped into the regulating feedbox of the paper machine.

Machine Operation

Sheet forming and drying were carried out by using a Pusey-Jones fourdrinier with 31-inch wire and 28-inch trim. This machine was complete with shake, three 6-inch flat boxes, a 12-inch-diameter brass couch roll, and a jacketed top roll; rubber bottom and granite top first press; rubber bottom and stonite top reversed second press; Mount Hope expander roll; nine 24-inch-diameter dryers; 7-roll calender; and a Pusey-Jones winder.

Physical Properties

Basis weight, caliper, burst factor, tear factor, breaking length, folding endurance (Massachusetts Institute of Technology), porosity, and smoothness of machine papers were determined in accordance with TAPPI Standard Methods. Composition of the various furnishes and properties of the products as shown in table 8.

TABLE 8.—*Composition and physical characteristics of papers made on pilot fourdrinier*

Type of paper made	Type of cook, number, and percentage of bamboo pulp; percentage of other pulp [1]	Additives					Basis weight
		Size	Alum	Clay	Starch	Dye	
		Pct.	*Pct.*	*Pct.*	*Pct.*		*G./sq. m.*
Bond	R 1, 83 percent; bleached kraft, 17 percent.[6]	2	3	12	—	Paper blue and 1 percent TiO_2.	81.4
Bond	R 2, 80 percent; bleached kraft, 20 percent.	1	2	10	5	Paper blue	78.9
Bond	R 3, 80 percent; bleached kraft, 20 percent.	1	2	10	4	Paper blue	85.1
Saturating	R 4, 90 percent; bleached kraft, 10 percent.	—	—	—	—	—	166.8
Tissue	R 5, 90 percent; bleached kraft, 10 percent.	—	—	—	—	—	37.3
Wet strenght	R 6, 100 percent	2-percent uformite and 3.5-percent alum; adjust pH to 4.0.					93.2
Book	R 7, 66 percent; soda, 34 percent.[7]	1.5	3.0	25.0	—	—	72.7
Magazine	R 8, 56 percent; bleached kraft, 12 percent and soda, 32 percent.	1.5	2.0	26.0	—	3 percent TiO_2 and Brilliant blue 2R.	86.7
Saturating	R 9 and R 10; no other pulp	—	—	—	—	—	92.6
Saturating	R 11 and R 12; no other pulp	—	—	—	—	—	214.8
Saturating	R 13 and R 14; no other pulp	—	—	—	—	—	155.2
Bond	R 16 and R 18; no other pulp	2	2	15	4	Paper blue	258.1
Book	R 15 and R 20, 50 percent; soda, 25 percent; and bleached kraft, 25 percent.	1.1	1.5	25.0	—	Paper blue	81.2
Book	R 16 and R 21; no other pulp	1.0	2.0	30.0	—	Paper blue	96.0
Bond	R 22, 50 percent; rag pulp, 50 percent.	2.0	2.0	15.0	4.0	—	66.2
Tissue	R 23, 100 percent	—	—	—	—	—	38.2
Food container board.	R 15, 100 percent	1.9	1.9	—	—	—	22.7
Bond	R 23 and R 24, 50 percent; flax pulp, 50 percent.	3	2	30	—	—	95.4
Bible	R 23 and R 24, 50 percent; flax pulp, 50 percent.	3	2	50	—	—	44.6
Corrugating medium.	K 27, 100 percent	2	1	—	—	—	12.4
Colored wrapper.	K 27, 69 percent and K 29, 31 percent.	2.5	3.1	—	—	Congo red	45.5
Magazine	K 30, 22 percent and R 26, 46 percent; oak groundwood, 16 percent and soda, 16 percent.	—	—	10	2	1 percent TiO_2	69.5
Stationery	R 25, 63 percent and R 28, 37 percent.	2	3	11	2	—	79.1

TABLE 8.—*Composition and physical characteristics of papers made on pilot fourdrinier*

Caliper	Burst factor [2]	Tear factor [3]		Breaking strength		Massachusetts Institute of Technology double fold		Porosity		Smoothness section 8 ply	Brightness Photovolts
		MD [4]	CD [4]	MD [4]	CD [4]	MD [4]	CD [4]	WS [5]	FS [5]		
Mils	*G./sq. cm./g./sq. m.*	*G./g./sq. m.*	*G./g./sq. m.*	*M.*	*M.*						*Pct.*
6.2	8.5	45.5	54.0	2,050	980	1	1	6.2	6.0	91.2	68
4.9	8.1	44.4	58.8	2,700	1,180	1	1	34.8	34.3	65.2	70
4.5	28.1	60.0	77.6	5,870	2,820	15	11	211.0	211.4	70.8	68
11.2	25.3	12.0	12.6	5,680	3,260	189	160	10.5	11.0	—	—
2.6	22.6	48.0	51.0	5,000	1,970	1	1	30.8	34.2	77.6	70
6.2	20.4	78.8	83.7	4,580	2,360	50	47	2.7	2.7	46.4	—
4.5	12.6	48.1	57.8	2,940	1,100	1	1	9.3	9.3	116.4	76
5.6	18.8	50.8	58.8	3,690	1,850	4	2	36.4	36.4	117.2	68
7.1	16.0	76.7	78.8	4,250	1,580	3	1	7.7	7.8	24.0	—
13.5	18.7	82.1	84.4	4,670	2,[illegible]50	35	11	11.2	11.2	37.6	—
9.8	21.3	79.2	83.7	5,280	2,750	13	9	1.6	21.6	26.8	—
4.9	11.2	24.8	27.9	1,700	720	1	5	154.9	155.0	104.8	74
4.4	19.9	72.6	72.6	3,690	1,720	5	3	24.5	27.7	168.4	70
4.0	19.0	47.9	47.9	4,510	2,150	10	8	410.7	410.8	286.8	—
3.6	27.6	10.4	11.3	6,340	2,620	69	58	80.3	80.2	86.4	—
2.0	16.6	41.0	42.0	3,840	1,920	1	1	92	92	184.4	—
14.8	18.0	86.2	92.4	4,570	2,780	66	49	11.5	11.5	54.0	—
4.9	16.2	67.0	75.5	4,610	1,960	7	5	156	155	104.8	74
2.8	11.0	47.1	47.1	3,440	1,050	1	1	68.0	68.1	143.2	—
11.3	17.0	62.6	66.6	4,440	2,410	10	8	3.3	3.2	47.2	Not bleached. Too red for reading.
8.1	15.6	77.1	81.6	4,700	1,620	1	1	2.9	2.9	74.0	
4.0	22.3	61.9	73.4	5,470	2,400	1	1	62.4	62.4	106.8	68
8.9	28.1	63.2	69.6	5,300	2,280	15	9	65.8	65.8	90.0	73

[1] Letters R and K refer to the Raitt two-stage and the kraft single-stage treatment, respectively. The first numeral following these letters can be used to identify the species of bamboo in the cook and the conditions under which the pulp was made by referring to table 7. Where the percentage of bamboo pulp is not shown, the final composition of the pulp did not differ significantly from that shown in table 7.

[2] Burst factor—unit of measure is grams per square centimeter per grams per square meter.

[3] Tear factor—unit of measure is grams per gram per square meter.

[4] MD means machine direction; CD, across machine direction.

[5] WS means wire side up; FS, felt side up.

[6] Bleached kraft means this type of pulp made from southern pine and commercially available.

[7] Soda means this type of bleached pulp made from hardwood and commercially available.

LITERATURE CITED

(1) ARONOVSKY, S. I., NELSON, G. H., and LATHROP, E. C.
1943. AGRICULTURAL RESIDUE PULPS—BLEACHING STUDIES ON STRAW PULPS. Paper Trade Jour. 117-(25): 38–48, illus.

(2) Association of Official Agricultural Chemists.
1950. OFFICIAL METHODS. Ed. 7, 833–835. Washington, D.C.

(3) Food and Agriculture Organization.
1953. RAW MATERIALS FOR MORE PAPER. Tech. Rpt. 6: 128. Rome, Italy.

(4) JARMAN, C. G., and PICKERING, G. B.
1954. AN IMPROVED METHOD FOR THE PREPARATION OF ULTIMATE FIBRE. Colon. Plant and Animal Prod. 4: 350–351. [Great Britain]

(5) MCCLURE, F. A.
1957. BAMBOO OF THE GENUS PHYLLOSTACHYS UNDER CULTIVATION IN THE UNITED STATES. U.S. Dept. Agr., Agr. Handb. 114, 69 pp., illus.

(6) NAFFZIGER, T. R., CLARK, T. F., and WOLFF, I. A.
1961. STRUCTURAL BOARD FROM DOMESTIC TIMBER BAMBOO—PHYLLOSTACHYS BAMBUSOIDES. TAPPI 44-(2): 108–112.

(7) ——— CLARK, T. F., and WOLFF, I. A.
1961. NEWSPRINT FROM DOMESTIC TIMBER BAMBOO—PHYLLOSTACHYS BAMBUSOIDES. TAPPI 44-(7): 472–475.

(8) ——— MATUSZEWSKI, R. S., CLARK, T. F., and WOLFF, I. A.
1960. DISSOLVING PULPS FROM DOMESTIC TIMBER BAMBOO—PHYLLOSTACHYS BAMBUSOIDES. TAPPI 43-(6): 591–596.

(9) NIESCHLAG, H. J., NELSON, G. H., WOLFF, I. A., and PERDUE, R. E.
1960. A SEARCH FOR NEW FIBER CROPS. TAPPI 43(3): 193–201, illus.

(10) RAITT, W.
1925. BAMBOO AND GRASSES FOR PAPER PULP. World's Paper Trade Rev. 84: 562–568, 618–620.

(11) SPEARIN, W. E., and ISENBERG, I. H.
1947. THE MACERATION OF WOODY TISSUE WITH ACETIC ACID AND SODIUM CHLORITE. Science 105: 214.

(12) SPROULL, R. C.
1955. PRELIMINARY INVESTIGATIONS ON ALKALINE PULPING OF BAMBOO. TAPPI 38(10): 593–596.

(13) STEVENS, R. H.
1958. BAMBOO: THE FACTS AND THE PROBLEM. Chemurg. Digest 17(1): 8–12.

(14) ———
1958. BAMBOO OR WOOD? Southern Pulp and Paper Mfr. 21(3): 93, 94, 130, illus.

(15) U.S. Department of Agriculture.
1953. DENSITY, FIBER LENGTH, AND YIELDS OF PULP FOR VARIOUS SPECIES OF WOOD. Forest Prod. Lab. Tech. Note 191. Madison, Wis. (Revised.)

APPENDIX

Preliminary Experiments for Macerating Culms

The following methods were tried for preparing fiber macerates from bamboo culms:

1. Culms were cut into pieces ⅛ by ⅛ by 1 inch and macerated mechanically in a 015 Jackson & Church refiner. This method caused excessive breakage of fibers.

2. Culm pieces of similar size were boiled at atmospheric pressure in a 10-percent NaOH solution (TAPPI method T 10 m-47).

This treatment, designed for pulp and paper manufacture, was too mild to macerate the culm material. It did not affect the outer layer of the pieces.

3. Strips of culms were cut 3 to 9 mm. tangentially, 1 to 6 mm. radially, and 135 to 165 mm. longitudinally (average dimensions were about 5 by 2.5 by 150 mm.). The strips were cooked under the following conditions in small digesters (3 inches in diameter by 8 inches in length) immersed in an oil bath:

a. In water at 150° to 165° C. for 3 hours. In this treatment, the strips were softened enough to pull apart with the fingers, but the resultant slivers were too raw for separation into individual fibers without damage to the fibers.

b. In a 0.78-percent Na_2CO_3 solution (approximately equivalent to 4.45-percent Na_20) at 150° to 165° C. for 2 hours. This treatment did not soften the strips. The carbonate may have suppressed hydrolysis of carbohydrates (hemicelluloses) that would normally have occurred by unbuffered organic acids present or formed in the woody material. Hydrolysis could have caused fiber embrittlement and some fiber breakage. This would alter dimensions of fiber fragments but not of complete fibers. Some swelling might occur under alkaline conditions.

c. In a 1.4-percent NaOH solution (approximately equivalent to 1.0-percent Na_2O) at 150° to 165° C. for 1.5 hours. This treatment softened the strips more than when they were boiled in water alone for 3 hours, yet not enough to permit separation of the fibers without damage to them.

d. In 2.0- and 2.5-percent NaOH solutions at 150° to 165° C. for 1.5 hours. Strips cooked in this manner were softened more than they were when cooked in the 1.4-percent solution but still were not soft enough for damage-free separation of fibers.

4. About 5 grams of matchstick-size pieces of culm were boiled for 20 minutes in water to expel air; immersed in a hypochlorite solution (Chlorox 1:1) for 2 hours; washed in distilled water; immersed in a 3-percent Na_2SO_3 solution at 70° C. for 15 minutes; washed in distilled water; immersed in Chlorox again for 2 hours; washed; immersed in a 3-percent Na_2SO_3 solution at 70° C. for 15 minutes; washed in distilled water; placed in a 500-ml. Erlenmeyer flask with 125 ml. of distilled water, shaken vigorously, decanted, and diluted until there were only about 25 fibers in one drop. This treatment produced bleached fibers that would not stain readily, but they were too fragile for reliable measurement.

5. About 5 grams of matchstick-size pieces of culm were boiled in water 30 minutes to expel air; boiled 30 minutes in a 10-percent NaOH solution; washed; placed in a 500-ml. Erlenmeyer flask with 125 ml. of distilled water, shaken vigorously, decanted, and diluted until there were only about 25 fibers in one drop. This method gave incomplete separation of the outer wall (0.5 mm. thick), although the inner wall was fairly well macerated. The method was repeated extending the period of boiling in water to 4 hours, but there was no improvement in results.

6. About 5 grams of matchstick-size pieces of culm were boiled in water 30 minutes to expel air;

heated to 70° C. in a 4-percent HNO_3 solution for 1 hour; and washed in a 1-percent NaOH solution. No maceration occurred.

7. Strips of culm 2 by 2 by 25 mm. (approximately) were immersed in a mixture consisting of equal volumes of glacial acetic acid and 10-percent Na_2O_2 (substituted for H_2O_2) for 48 hours at 60° C. (*3*). This treatment gave incomplete fiber separation.

8. About 1 gram of small strips of culm were soaked 3 days at room temperature in a 1:1 mixture of a 4-percent nitric acid plus 5-percent chromic acid; then heated to 60° C. for 3 hours. This treatment produced little change in the culm strips.

9. About 5 grams of internodal strips 2 by 2 by 25 mm. (approximately) were covered with a 10-percent NaOH solution in a Mason jar and heated at 15 p.s.i. in a pressure cooker for 18 minutes, then allowed to cool slowly for 30 minutes. The NaOH solution was poured off, the strips were washed, and then dispersed in a Waring Blendor for about 3 minutes. This method gave a fairly complete maceration of strips without excessive fiber breakage.

10. Nodal strips were subjected to the same treatment as the internodal strips described in the foregoing method, but the boiling at 15 p.s.i. was extended to 30 minutes. This was followed by 2 days of soaking in distilled water (three water changes), and finally by dispersing in an Osterizer for 30 seconds. The nodal splinters proved more resistant than the internodal ones.

11. Strips were cut from a single node, covered with 10-percent NaOH, heated at 15 p.s.i. for 30 minutes, soaked in distilled water 5 days with three changes of water, and then dispersed in the Osterizer for 30 seconds. This gave fairly good separation of the fibers. Variations of this method that were tried consisted of using pressures ranging from 5 to 15 p.s.i.; soaking for 3 to 4 days; dispersing in the Osterizer for up to 45 seconds.

Exploratory Pulping Studies

Cooking conditions and results of exploratory treatments were as follows:

1. Cooking in water only at temperatures of 160° to 170° C. for 1, 2, and 3 hours softened the bamboo slightly but did not pulp it. Yields (cooked bamboo) of the 2- and 3-hour cooks were 79 and 74 percent, respectively. The hydrolyzate was slightly acid.

2. Cooking with a 0.75-percent solution of Na_2CO_3 (equivalent to 2 percent of Na_2O on basis of moisture-free bamboo material) at a temperature of 150° to 165° C. for 1.5 hours did not soften the bamboo and resulted in a 98-percent yield of cooked bamboo.

3. Cooking with various concentrations of NaOH for 1.5 hours at temperatures of 150° to 160° C. failed to pulp the bamboo. Results are shown in table 9.

TABLE 9.—*Results of cooking bamboo at 150° to 160° C. in stated concentrations of NaOH*

Concentration of NaOH	Na_2O on basis of moisture-free bamboo	Yield of cooked bamboo	pH of hydrolyzate
	Percent	*Percent*	
1.36	3.6	92	5.6
1.90	5.3	90	6.6
2.40	6.6	90	7.8
2.50	6.8	85	9.0

4. Cooking in two stages.—The treatment was similar to that described by Raitt (*10*). First

stage: Bamboo was cooked at temperatures of 100° to 110° C. for 2.0 hours with 1.9-percent NaOH using the hydrolyzate from previous cooks fortified with additional NaOH until the final liquor contained 6.1 percent Na_2O (on the basis of moisture-free material). The final pH was 9.2. Second stage: Bamboo was cooked with kraft white liquor composed of 50 grams per liter of active alkali as Na_2O (equivalent to 18.7 percent Na_2O on moisture-free material) at temperatures of 145° to 150° C. for 1.5 hours. The final pH was 11.9. These procedures produced a pulp yield of 49 percent, and the bamboo was well pulped. This two-stage cook was applied to several species of bamboo with similar results in which yields ranged from 40 to 50 percent.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1966—219-231

END