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STUDY OF THE EFFECT OF FIBER COMPONENTS ON THE STABILITY OF BOOK PAPERS

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ABSTRACT

Supplementing previously reported studies relating to the permanence of writing papers used for records, an investigation of the relation of papermaking materials and processes to the stability and other properties of book papers is in progress. This article reports the results of tests of a number of pulps commonly used in fine printing papers as regards the stability of experimental unsized papers made from them. The effect of filling and sizing materials, respectively, will be reported in subsequent papers.

The papermaking fibers used were representative commercial materials and consisted of four kinds of purified wood pulp, soda pulp and sulphite pulp (mixed in beater furnish), new rags (no. 1 white shirt cuttings), and old rags (no. 1 old whites and twos and blues, blended in the beater.) The pulps and half-stuffs ranged in quality from 78 to 93 percent of alpha-cellulose and from 3.8 to 0.4 in copper number. The composition of the beater furnishes was 85 percent of fiber and 15 percent of clay, which is a proportion commonly used for book papers.

The experimental papers made from the rags had the characteristics of good book papers and showed no appreciable change in the accelerated aging (heat) test, which indicates a very high degree of permanence. One of the purified wood pulps produced a relatively stable sheet of satisfactory book-paper quality. The papers made from two of the wood pulps were somewhat less stable in the accelerated aging test, but that made from the remaining purified wood pulp was strong and relatively stable. The paper produced from the mixture of sulphite pulp and soda pulp was considerably less stable than the papers made from the purer fibers. A close relation was shown between the cellulosic purity of the fibers and the stability of the unsized papers made from them, but only a small amount of alum and no rosin size were used in the manufacturing process. The effect of these variables on the stability of the papers will be studied in the second part of the investigation.

CONTENTS

I. INTRODUCTION

As a part of its program of research relating to the stability of papers used for records, the National Bureau of Standards is making a study of the relation of papermaking materials and processes to the strength, stability, and other properties of book papers. This study is the fourth

in a series planned to include all the important types of fibrous raw materials commonly used in the manufacture of record papers. The three preceding studies related to writing papers [1, 2, 3].[1]

A suggested classification and specification of book papers for record purposes published by the Bureau [4] comprise four classes, ranging from papers for permanent records to those suitable for temporary use only. The classification and specification were based on tests of commercial papers. The results of the tests showed that the stability of book papers, as was found also for writing papers, is not always commensurate with the quality of the fibers used in their manufacture. It is believed that papermaking studies made under the carefully controlled conditions possible with the semicommercial equipment of the Bureau should indicate the best practice for obtaining the optimum results with each kind of fiber and other raw materials. The commercial application of such knowledge should ultimately lead to improved quality of papers with respect to their endurance.

The study of book papers will necessarily be much more extensive than that of the writing papers [1, 2, 3] because of the greater variety of materials used in book papers. This is true not only with respect to the fiber components but also to the use of filling and coating materials. Because of the considerable time required to complete the program as a whole, it has been divided into three subprojects. The first is a study of the fibers commonly used. The other two will deal with the effect of filling and sizing materials and the effect of mineral coating materials, respectively, on the stability and strength of book papers. The present article is a report of the relation of chemical characteristics of fibers of different degrees of purity to the stability of papers made from them. The alpha-cellulose content and the copper number have been found to be closely related to the stability of paper—high alpha-cellulose content and low copper number being characteristics of stable paper. In this work consideration has been given also to beta- and gamma-celluloses and to pentosans.

II. FIBERS USED

It should be kept in mind that this is not a general study of the manufacture of book papers, but is a study made primarily to obtain information to assist in the specification of book papers for printed records. Since the papers to be made will therefore be limited to a sufficient number for this purpose only, the selection of fibrous materials to be employed in the investigation covered the range of those commonly used in the fine printing papers.

The fibers were obtained from commercial manufacturers. They consisted of four wood pulps produced with special pulping and bleaching treatments to obtain high purity and strength; soda pulp and sulphite pulp of the ordinary book-paper grade; new rags, the grade known commercially as no. 1 white shirt cuttings; and two grades of old rags, no. 1 old whites and "twos and blues."

III. PAPERMAKING EQUIPMENT

The Bureau paper mill contains equipment for the experimental manufacture of practically all types of paper under conditions which in general simulate those of industrial mills. Figures 1 and 2 show

[1] Numbers in brackets refer to the list of references at the end of this paper.

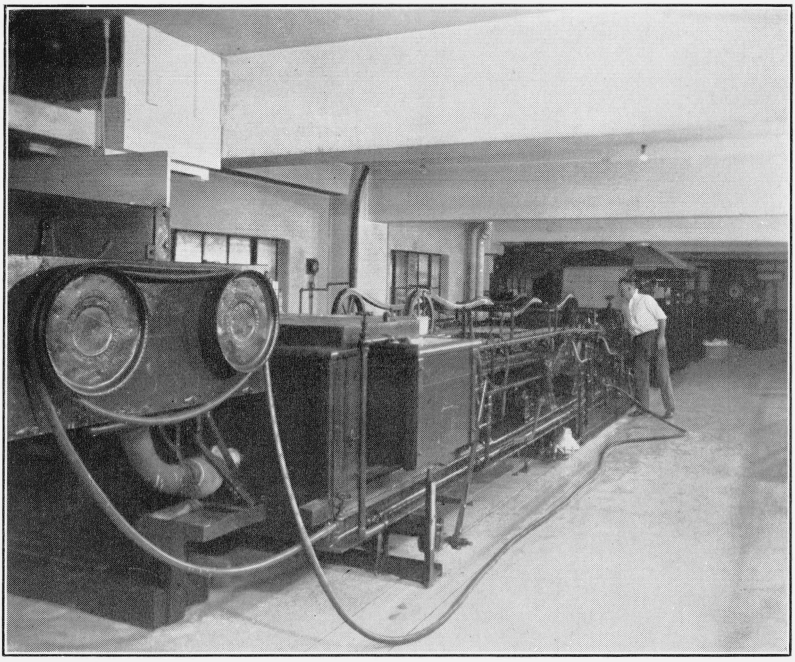

FIGURE 1.—*Fourdrinier machine viewed from wet end.*

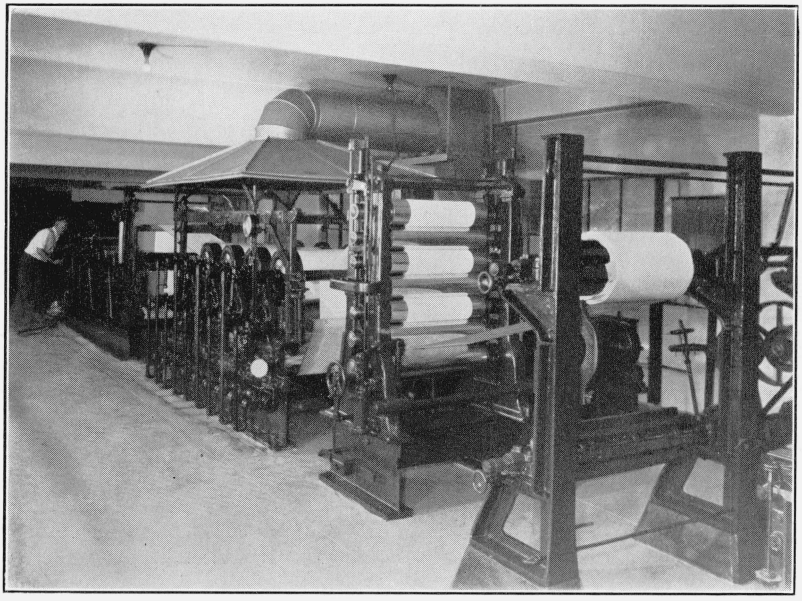

FIGURE 2.—*Fourdrinier machine viewed from dry end.*

the experimental paper machine. A complete description and other photographs of the equipment may be found in previous publications [5].

IV. PAPERMAKING PROCESSES

The methods of beating and paper-machine operation followed very closely those described in the other publications of this investigation [1, 2, 3]. The reader is referred to them for details.

V. TEST METHODS

The physical and most of the chemical tests of the fibrous materials and of the papers were made in accordance with the official methods [2] of the Technical Association of the Pulp and Paper Industry. An improved volumetric method developed at the Bureau by H. F. Launer was used to determine the alpha-, beta-, and gamma-celluloses. In this method the fibers are treated with an approximately $2M$ solution of sodium hydroxide. The entire alpha-cellulose residue, as well as portions of the filtrate, is quantitatively oxidized by dichromate, and the proportions of the constituents in the sample are calculated on the basis of the dichromate data alone.[3] The method used for determining the pentosans (complex carbohydrates widely distributed in plants which yield pentoses on hydrolysis) was essentially the same as the method that has previously been regularly used. The pH was determined electrometrically, using a quinhydrone and also a glass electrode.

The relative stability of papers cannot be determined by analysis of the original papers alone. Therefore, the pertinent physical and chemical tests were applied not only to the original papers but to samples that had been submitted to an accelerated aging test as well. This test is made at the Bureau by heating specimens of the paper for 72 hours at 100° C and then determining to what extent the paper has been altered in folding endurance, tearing strength, alpha-cellulose content, and copper number. For details of this test the reader is referred to previous discussions of the method [6].

VI. ANALYSES OF PAPERMAKING MATERIALS USED

1. FIBERS

Analyses showing the degree of cellulosic purity of the wood pulps and the various grades of rag half-stuffs (partially pulped rags that have been boiled, washed, and drawn out of weave) used in the manufacture of the papers are given in table 1. The pulps and half-stuffs ranged in quality from 78 to 93 percent of alpha-cellulose and from 3.8 to 0.4 in copper number. The method employed in preparing the rag half-stuffs was the same as that described in detail in an earlier publication [3].

[2] Copies of the methods can be obtained from the Technical Association of the Pulp and Paper Industry, 122 East 42d Street, New York, N. Y.

[3] The method will be described in detail later in a Bureau publication on the subject.

TABLE 1.—*Chemical test data on fibrous materials used*

Fibrous material	Alpha-cellulose	Beta-cellulose	Gamma cellulose	Pentosans	Copper number	Ash	Resin
	% [2]	% [2]	% [2]	%		%	%
Purified wood pulp *A* [1]	90.6	4.8	4.6	3.8	0.72	0.11	0.24
Purified wood pulp *B* [1]	87.8	6.7	5.5	6.0	.86	.19	.26
Purified wood pulp *C* [1]	88.0	6.2	5.8	5.6	.69	.10	.13
Purified wood pulp *D* [1]	84.1	4.7	11.2	10.3	.72	.16	.13
Sulphite pulp	82.0	5.4	12.6	6.2	3.34	.26	.70
Soda pulp	78.2	18.6	3.2	21.3	3.83	.42	.20
No. 1 new white rags, bleached half-stuff	93.0	6.4	.6	.8	.38	.12	----
No. 1 old white rags, bleached half-stuff	90.3	8.9	.8	.5	.41	.16	----
Twos and blues, bleached half-stuff	90.5	8.4	1.1	.5	.49	.22	----

[1] These pulps were produced by special cooking and bleaching treatments to obtain improved quality.
[2] Based on total cellulose.

2. CLAY

The clay used was a domestic commercial filler clay. The following analysis [4] shows its composition.

Loss at 105° C	0.3%.
Further loss on ignition	13.7%.
Silica (SiO_2)	45.3%.
Iron oxide (Fe_2O_3)	0.2%.
Alumina (Al_2O_3)	38.8%.
Titanium oxide (TiO_2)	1.8%.
Calcium oxide (CaO)	Not detected.
Magnesium oxide (MgO)	Not detected.

VII. DATA ON PAPERS MADE

The composition of the beater furnishes (materials blended in the beater), regardless of the kind of fibrous material, was 85 percent of fiber and 15 percent of clay, a proportion common for book papers. No rosin was added. Just enough alum (aluminum sulphate) was used to clear the water in the beater in the first few runs. After the amount required had been established the quantity was kept practically constant for the remaining runs irrespective of the appearance of the water.

Data relative to the beater furnish and the beating time for each paper-machine run and various measurements on the papers made are given in tables 2, 3, and 4.

[4] Made by Chemistry Division, National Bureau of Standards.

TABLE 2.—*Papermaking details and some physical properties of the book papers*

Paper machine run number	Beater furnish				Tests of papers [4]								
	Fiber [1]	Alum (based on dry furnish)	Beating interval	Acidity of stock at head box (quinhydrone method)	Weight: 25 by 40 inches, 500 sheets	Bursting strength	Tensile properties				Thickness	Opacity
							Breaking load [3]		Elongation at rupture			
							Machine direction	Cross direction	Machine direction	Cross direction		
		%	hr	pH	lb	*Points*[2]	kg	kg	%	%	in.	%
1102	Purified wood pulp *A*	0.4	5	6.7±	56.3	21	3.8	2.5	1.2	4.4	0.0036	90
1103	do	.4	5	6.7±	56.0	22	4.4	2.9	2.0	5.9	.0035	90
1104	Purified wood pulp *B*	.4	5	6.7±	54.2	33	6.8	4.0	2.7	6.3	.0034	88
1106	do	.5	6	6.8±	56.3	40	8.8	4.5	2.6	7.9	.0033	89
1105	75% of pulp *A*, 25% of pulp *B*	.4	5½	6.6±	56.5	24	5.3	3.1	2.1	5.9	.0037	89
1110	Purified wood pulp *C*	.5	5½	6.5±	57.5	33	7.1	4.4	2.5	8.0	.0036	87
1107	Purified wood pulp *D*	.5	5½	6.9±	53.9	34	8.4	5.7	2.3	7.6	.0033	82
1108	do	.5	6	6.2±	55.4	37	8.0	5.9	2.5	8.2	.0034	82
1111	50% of sulphite, 50% of soda pulp.	.5	5	6.7±	56.1	22	5.9	3.8	1.9	5.5	.0040	87
1112	do	.5	4	6.7±	54.9	22	5.5	3.4	1.5	3.5	.0039	87
1113	No. 1 new white rags (half-stuff).	.5	5	6.8±	56.0	17	4.6	3.1	2.5	5.0	.0036	90
1114	do	.5	5	6.9±	54.1	18	4.8	3.0	2.0	4.5	.0035	90
1115	Old rags [5] (half-stuff)	.5	5½	6.7±	55.8	15	3.7	2.4	2.0	4.0	.0040	92
1116	do	.5	4	6.5±	55.9	13	3.1	2.2	2.0	3.0	.0040	93

[1] Beater furnish for each run was 85 percent of fiber and 15 percent of clay.
[2] Bursting pressure, in pounds per square inch, through a circular orifice 1.2 inches in diameter.
[3] For test specimen 15 mm wide and 100 mm between jaws.
[4] All physical tests made at 65 percent relative humidity and 70° F.
[5] 50% of no. 1 old whites, 50% of twos and blues.

TABLE 3.—*Folding endurance and tearing strength data on the book papers*

Paper machine run number	Fiber composition	Tests of unheated papers [2]						Tests of heat-treated papers [3]		
		Folding endurance [1]				Tearing strength				
		Schopper		MIT						
		Machine direction	Cross direction	Machine direction	Cross direction	Machine direction	Cross direction	Folding endurance in percentage of initial strength, Schopper	Folding endurance in percentage of initial strength, MIT	Tearing strength in percentage of initial strength
		Double folds	*Double folds*	*Double folds*	*Double folds*	g	g			
1102	Purified wood pulp *A*	78	34	[4] 1,675	[4] 485	70	72	95	89	100
1103	do	74	32	[4] 1,715	[4] 400	66	70	100	85	103
1104	Purified wood pulp *B*	2,200	730	[5] 1,230	[5] 190	128	136	69	78	86
1106	do	3,300	2,000	[5] 1,750	[5] 660	104	128	80	79	95
1105	75% of pulp *A*, 25% of pulp *B*.	180	70	[4] 3,000	[4] 1,540	84	92	101	111	95
1110	Purified wood pulp *C*	1,760	1,140	[5] 890	[5] 260	109	96	83	78	95
1107	Purified wood pulp *D*	2,400	2,190	[5] 1,510	[5] 830	95	110	87	98	104
1108	do	1,830	3,820	[5] 1,520	[5] 2,020	93	102	83	80	102
1111	50% of sulphite, 50% of soda pulp.	85	44	[4] 1,120	[4] 395	54	60	57	68	95
1112	do	66	34	[4] 1,120	[4] 285	53	59	55	53	94
1113	No. 1 new white rags (half-stuff).	63	51	[4] 1,250	[4] 765	98	88	130	103	97
1114	do	143	65	[4] 2,866	[4] 1,078	95	91	105	90	104
1115	Old rags (half-stuff)	21	10	[4] 120	[4] 70	63	71	95	123	95
1116	do	11	8	[4] 80	[4] 50	66	66	109	98	98

[1] Test specimen 15 mm wide.
[2] All physical tests made at 65-percent relative humidity and 70° F.
[3] Samples heated at 100° C for 72 hours.
[4] Tests made at 0.5-kg tension.
[5] Tests made at 1-kg tension.

TABLE 4.—*Chemical data on the book papers*

Paper machine run number	Fiber composition	Original papers									Heat-treated papers [2]				
				Acidity							Change in content				
		Ash	Resin	Extract, Kohler-Hall method	pH of extract (glass-electrode method)	Alpha-cellulose, based on total cellulose	Beta-cellulose, based on total cellulose	Gamma-cellulose, based on total cellulose	Pentosans	Copper number	Alpha-cellulose	Beta-cellulose	Gamma-cellulose	Pentosans	Copper number
		%	%	% [1]		%	%	%	%		%	%	%	%	
1102	Purified wood pulp *A*	10.8	0.22	0.006	6.5±	90.2	3.2	6.6	3.9	0.70	−0.2	+0.2	0.0	0.0	+0.15
1103	do	11.5	.22	.006	6.5±	90.9	2.7	6.4	4.2	.71	−.7	+2.4	−1.7	−.2	.13
1104	Purified wood pulp *B*	10.7	.24	.011	6.4±	85.7	6.7	7.6	6.3	.88	−.2	+.2	.0	−.1	.29
1106	do	11.4	.26	.010	6.8±	85.2	6.2	8.6	5.6	.90	−1.0	+2.0	−1.0	.0	.17
1105	75% of pulp A, 25% of pulp *B*	11.0	.20	.001	7.3±	89.6	4.6	5.8	3.7	.77	−.4	+.4	.0	+.1	.17
1110	Purified wood pulp *C*	11.9	.13	.010	6.6±	85.1	8.7	6.2	5.6	.81	.0	+.3	−.3	−.1	.15
1107	Purified wood pulp *D*	12.2	.13	.010	6.7±	82.6	2.4	15.0	10.6	.85	−.4	+.2	+.2	+.1	.10
1108	do	12.4	.13	.008	6.7±	82.4	3.0	14.6	10.7	.87	−1.0	+.5	+.5	+.1	.10
1111	50% of sulphite, 50% of soda pulp	5.3	.40	.017	6.2±	77.8	14.5	7.7	13.9	2.75	−.4	−1.0	+1.4	+.1	.31
1112	do	5.7	.50	.021	6.1±	77.7	15.1	7.2	14.2	3.02	−1.0	+1.2	+.2	−.7	.27
1113	No. 1 new white rags (half-stuff)	11.6	.24	.004	7.0±	95.2	4.2	.6	.6	.33	+.2	−.6	+.4	.0	.03
1114	do	11.6	.22	.010	6.8±	95.0	4.2	.8	.8	.35	−.2	+.2	.0	−.1	.04
1115	Old rags (half-stuff)	12.7	.29	.001	7.3±	92.6	6.7	.7	.7	.43	−.6	+.3	+.3	.0	.05
1116	do	12.5	.36	.002	7.3±	92.8	6.5	.7	.8	.39	−1.0	+.9	+.1	−.1	.10

[1] Acidity expressed as percent of SO_3.
[2] Samples heated at 100° C for 72 hours.

Purified wood pulp A.—The procedure followed in the beating treatment of purified wood pulp *A*, runs nos. 1102 and 1103, was that considered suitable for producing a good book paper. The beaten fibers were long but remained separate and did not ball or clot during the beating, and screened, through 0.014-inch slots, exceptionally well for such long fibers. The beating time was 5 hours.

Because of difficulties in adjusting the paper machine and the weight of the paper during run no. 1102, the run was repeated (no. 1103). The finished papers of the two runs were considered very satisfactory. The data given in tables 3 and 4 indicate that they were also relatively stable, being little changed in alpha-cellulose content, copper number, folding endurance, and tearing strength after oven aging.

Purified wood pulp B.—The beating treatment given the pulp for run no. 1104 was similar to that given purified wood pulp *A*, runs nos. 1102 and 1103, but the beaten fibers seemed "brash" (were not soft and pliable) and the formation of the sheet was not good.

For machine run no. 1106 the beater was furnished lighter, that is, with lower stock consistency, to promote faster circulation of the stock, and the beater roll was lowered more rapidly to the plate to cut up the fibers more quickly. The pulp was beaten hard for 6 hours, yet the fibers remained long. The stock caused no trouble on the paper machine, and handled much better than that for run no. 1104. The results were better with the thinner consistency, but the paper seemed too hard and was not so well closed a sheet as is desirable for book paper.

It is apparent that the beater roll of the Bureau's 50-pound beater is not heavy enough, nor the beating tackle (bars of beater roll and bed plate) thin and sharp enough, to cut strong long-fibered pulp as quickly as is required to produce soft, bulky printing paper. The longer beating time required with the relatively light roll equipped with comparatively blunt tackle results in a sheet that is less opaque and harder than is suitable for book papers, but it would be satisfactory for writing papers.

The color of purified wood pulp *B* was not so good as that of pulp *A*. The test data on the cellulosic purity of the papers and their stability toward the heat test show the life expectancy of that made from pulp *B* to be less also.

After run no. 1104 was made it was learned that pulp *B* is not intended to be used as an entire fiber furnish for book paper, but is recommended as a part-furnish to increase the strength of the weaker pulp. The following run was made from such a mixed furnish.

Purified wood pulps A and B (mixed furnish).—The fibrous material of the beater furnish for run no. 1105 was 75 percent of purified wood pulp *A* and 25 percent of purified wood pulp *B*. The run was made to determine whether the addition of pulp *B* would strengthen the sheet without impairing its stability. The test data indicate that the addition of the small amount of the relatively strong pulp to the weaker pulp of greater stability gave a stronger sheet than the weaker pulp alone, without appreciably lessening the stability of the paper.

Purified wood pulp C.—Pulp *C* is recommended by the manufacturer for use if paper of fair strength for book purposes is wanted. Pulp *C*, run no. 1110, was more susceptible to hydration than pulp *A*, and the finished paper was harder than that made from pulp *A* (runs nos. 1102 and 1103), but softer than that made from pulp *B* (runs nos. 1104 and 1106). The color was better than that of pulp *B*. The test data show the paper to be strong and fairly stable.

Purified wood pulp D.—The beating treatment given the pulp for run no. 1107 was the same as that given the mixture of purified wood pulps *A* and *B*, run no. 1105. The fibers were long and clotted together even after the completion of the beating and were difficult to separate in the subsequent operations. For machine run no. 1108 the beater was furnished lighter to facilitate faster circulation and the beater roll was lowered rapidly to the plate to cut the fibers and produce free-beaten stock. The pulp was beaten for 6 hours, but the fibers still remained long. The finished papers of both runs were hard.

Again it is apparent that the beater roll and beating tackle are not suited to the requirements of hard long-fibered pulp to get the character of sheet for book papers. Different types of paper require different treatment in the beater. The making of book papers, in common with other papers requiring bulk and absorptive qualities, depends chiefly on quick beating with sharp tackle, the beater being furnished light and the beating being effected quickly enough to prevent excessive hydration yet producing the desired fraying and fibrillation of the individual fibers.

The test data show that pulp *D* and the papers made from it were strong and relatively stable. If the beating of the pulp could be carried out quickly to preclude excessive hydrating, or gelatinizing, effect on the fibers, a soft bulky sheet suitable for book paper would doubtless be produced and would have the necessary strength for severe service.

Sulphite and soda pulp mixture.—The pulp for the beater furnishes for runs nos. 1111 and 1112 was sulphite and soda, mixed in equal quantities. The beating treatment for run no. 1111 was merely a light brushing of the pulp. The water in the beater did not clear when the alum was added, and the machine water at the head box was not clear, but since the present subproject is limited to the pulps, no more alum was added. The stock was very free (drained quickly) on the paper-machine wire.

For machine run no. 1112 the percentages of pulps and clay were the same as for run no. 1111, but the beating was more drastic and of shorter duration. The behavior of the clay in the beater water and the machine water was the same as that reported for run no. 1111.

As indicated by the percentage of ash, table 4, the retention of clay in the papers was comparatively low. With regard to retention of filler, Steele [7] states that "Pigments can be retained in paper by any of three mechanisms, namely, filtration, coflocculation, and mechanical attachment." The appearance of the beater and machine waters of runs nos. 1111 and 1112 indicates that the flocculation was very low. Since the beater water for the other pulps was relatively clear, and since the same amount of alum was added and the same clay was used for all the runs, the retention of clay in the other papers must have been due mainly to mechanical attachment. The effect of larger amounts of alum, and of the use of rosin size, on the retention of clay in the sulphite-soda pulp mixture will be studied in the second part of the investigation of book papers.

The test data show that the papers were not of very high stability as regards retention of folding endurance, although the changes in alpha-cellulose content and in copper number were not large.

New rags.—The rag fiber of the beater furnish for runs nos. 1113 and 1114 was half-stuff made from no. 1 white shirt cuttings. As the severity of beating required for the new rags for book papers had not been determined, the furnish for run no. 1113 was given a fairly hard beating treatment. For run no. 1114 the beating interval was the same as for run no. 1113, but the operation was less drastic, leaving the fibers longer.

The papers made from the new white rags were very satisfactory as to character of sheet and judging from the test data were of a high degree of stability.

Old rags.—The beater furnish for run no. 1115 consisted of equal parts of half-stuffs made from no. 1 old whites and from twos and blues. The stock was prepared by a very mild beating action. Run no. 1116 was similar to run no. 1115 except that the beating treatment was of shorter duration and was more severe. The papers made were soft and of good formation. They were excellent book papers in appearance, and the test data indicate that they were also of good stability.

VIII. SUMMARY AND DISCUSSION

The data show that a number of the pulps commonly used in the manufacture of book papers are suitable for papers that must meet specifications requiring a high degree of permanence.

The experimental papers made from the rags (no. 1 white shirt cuttings or the mixture of no. 1 old whites and twos and blues) were excellent in appearance and possessed the softness, bulk, and opacity which are requisite characteristics of book papers. The fact that the folding endurance suffered no appreciable loss in the heat treatment indicates that very stable paper can be made from this type of fiber.

Purified wood pulp *A* produced a relatively stable sheet of satisfactory book-paper quality, although weaker than that made from purified wood pulps *B* or *C*. The folding endurance and tearing strength of book papers, however, are not such important factors as in the case of writing papers, which are subjected to greater stresses, but they are significant in interpreting the results of the aging treatment.

The paper made from purified wood pulp *B* or *C* used as an entire fiber furnish was stronger but harder and less stable to the heat test than that made from pulp *A*. The paper produced from purified wood pulp *D* also was hard but it was strong and of relatively stable quality. It is believed that the hardness of the papers made from these pulps was due to the beater not being suited to the requirements of strong long-fibered pulp to produce soft, opaque printing paper. Papers requiring bulk and absorptive qualities depend chiefly on quick beating with sharp tackle to prevent excessive hydration yet produce the desired fraying and fibrillation of the individual fibers. The longer beating time required with the relatively light roll and blunt tackle of the beater used at the Bureau resulted in a harder and less opaque sheet. If the beating were carried out quickly enough to preclude excessive hydration of the fibers a soft, bulky sheet of sufficient strength for severe service would doubtless be produced.

The paper produced from the mixture of sulphite pulp and soda pulp was considerably less stable than that made from the purer fibers. During the manufacturing process the water was not clear in

the beater nor at the head box, and the retention of clay in the paper was comparatively low, but since the next phase of the study of book papers includes detailed investigation of the effects of larger amounts of alum and the use of rosin size, no further consideration was given at this time to the behavior of the clay as regards retention.

Since clay is chemically inert, and not enough alum was used to adversely affect the papers, any deterioration occurring under the heat test must be ascribed to the cellulosic components. Resin is present only in such small amounts that it can be disregarded.

The changes in the beta- and the gamma-cellulose contents of the heat-treated papers were not significant enough to warrant the use of these values as criteria of the stability of the papers. The present belief that alpha-cellulose content and copper number are closely related to stability of paper, and that high alpha-cellulose content and low copper number, with very little change in these attributes when the papers are heated, are characteristics of stable paper, is supported by the data.

The pentosan content of the different papers was not appreciably changed by the heat treatment, and accordingly will receive little further consideration in this study.

Although the cellulosic purity of the pulps and the probable stability of the papers made from them were found to be related, it should be kept in mind that only a small amount of alum and no rosin size were used in the manufacture of the papers. Papers made from the same pulps may have different stabilities when quantities of these materials are added. The effect of these variables will be studied in the second part of this investigation.

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