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ABSTRACT

A modified sulfate process is outlined for the conversion of oat, rye, and wheat straws to pulps which would be suitable for the production of typewriter, book, and other grades of paper. The variables in digesting, beating, screening, and bleaching were investigated separately for the optimum conditions. Pulps of the above grades were produced in large laboratory equipment. Test sheets from these pulps showed a yield of 38 to 43 percent of dry weight of raw material for wheat straw; 42 to 46 percent for rye straw; and 40 to 45 percent for oat straw.

CONTENTS

I. INTRODUCTION

The total production of wheat, oat, and rye straw in the United States during 1931, assuming a low yield value of three-quarters of a ton per acre and using the figures for acreage in production given in the 1932 Yearbook of Agriculture, was 84,621,000 tons, of which 60,039,000 tons was produced in the North Central area and Oklahoma and Texas. The distribution of tonnage in the latter figure was 48.5 percent of wheat, 46.6 percent of oat, and 4.9 percent of rye. Approximately 25,000,000 tons of paper could be produced from the straws grown in this central area of the United States. This is more than twice the quantity of paper now consumed annually in this country.

Straw is composed of cellulose, lignin, pentosans, and small amounts of other materials. The presence of a large amount of cellulose fibers in straws first suggested their use as a raw material for the manufacture of paper pulp. They have been employed from time to time in this country for the production of paper, but recent economic causes have limited such use. Approximately 600,000 tons is used annually for [1] [1] the making of strawboard and egg-case paper. In other countries such as Argentina and Chile, the Pomilio [2] process is being successfully used for converting straw into high-quality papers. In certain European countries other processes have been adopted to some extent. Chlorination processes, such as Pomilio's [3], Traquair's [4] (Mead Co.) and others, are patented. These all require chlorine and caustic, which are not available at sufficiently low prices in the Straw Belt of the United States at present; consequently, these processes were eliminated as possibilities in this study. Of the other methods in general use in the paper industry—the soda, sulfate, and sulfite—the sulfate process was chosen because a good yield of strong pulp can be obtained by its use. The initial experimental work made it apparent that in most respects commercial pulping conditions for wood are too drastic for straw. The factors in each process step were therefore investigated systematically. The plan was to develop on a large laboratory scale a process specifically suited to the production of a high yield of strong pulp from straw, and to define this process within fairly narrow limits.

II. EQUIPMENT USED

Digester A, figure 1, was a 15-gallon insulated steel shell, arranged for indirect heating by means of a steam jacket surrounding the sides and bottom, with a thermo-siphon, B, connecting at the top and bottom of the shell. It was fitted with a charging hole at the top and a sieved discharge at the bottom. Expansion chamber C, figure 1, fitted with a combination bleeder and blow-off line, was connected with the cover of the charging hole.

Beating engine A, shown in figure 2, was a 12-lb hollander type. The tub and roll were iron and the adjustable roll turned above a fixed V-bar bedplate. Both roll and bedplate were wood filled.

Screening apparatus B, in figure 2, was of the hinged, jig type, built around a typical 1- by 4-ft commercial bronze screen plate, machined with 0.004 in. slots. The stock compartment extended 18 in. above the plate and the enclosed space was fitted with gear-driven, bent brass stirring rods.

Purifier C, figure 2, was a rotating basket with solid walls, open at the top and fitted with several concentric retaining baffles on its inside periphery. It was 8 in. in diameter and 6 in. deep and was mounted in a steel shell. The basket revolved at 350 rpm and had a capacity of 2 to 3 gallons of liquid per minute.

Pulp concentrator D, in figure 2, was similar to a trommel type of screen. It consisted of a double-wire cylinder, no. 80 screen inside, reinforced with no. 30 screen on the outside, 4 ft long, and 11 in. in

[1] Figures in brackets throughout this paper refer to the numbered references on page 12.

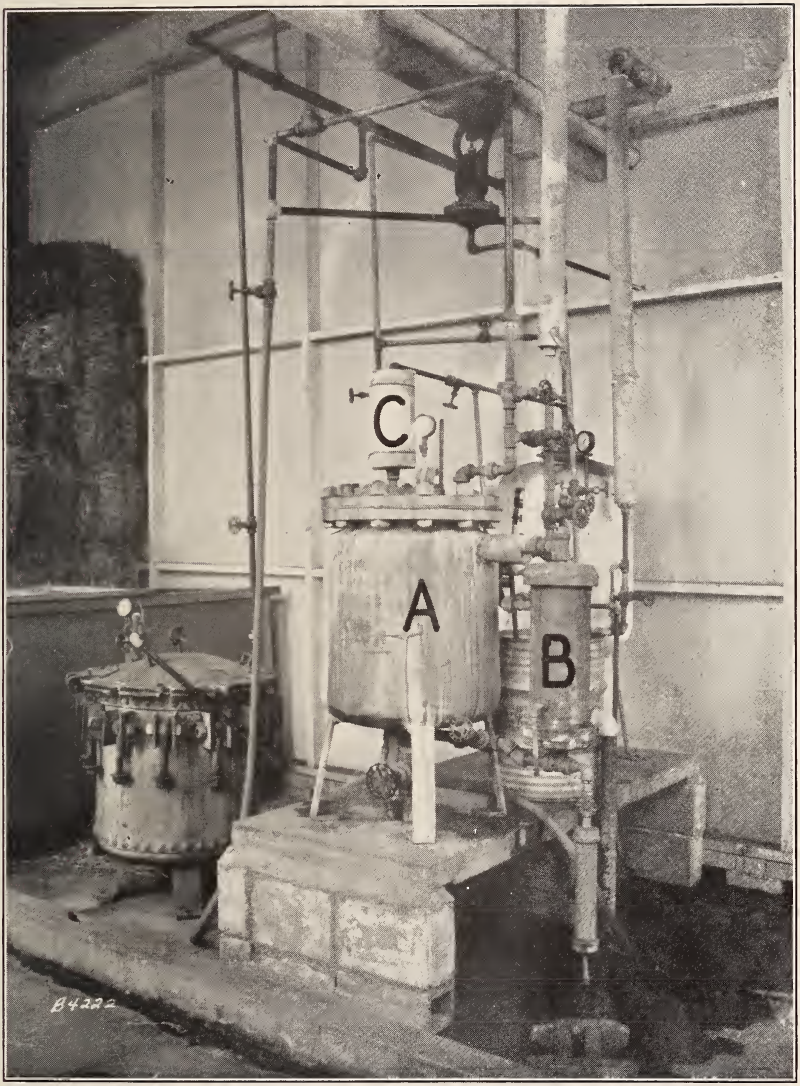

Figure 1.—*Digester equipment.*

A, Digester; B, thermo-siphon; C, expansion chamber.

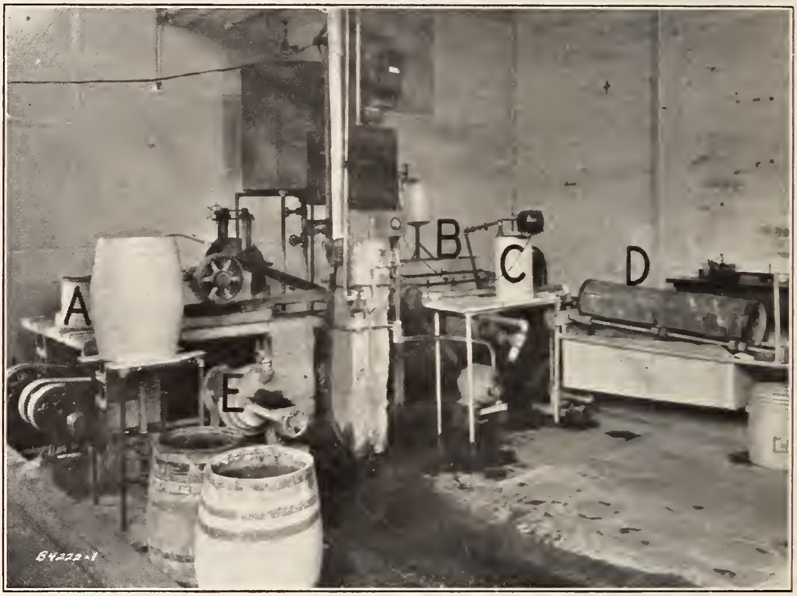

FIGURE 2.—*Pulping and screening equipment.*

A, Beater; B, screen; C, purifier; D, concentrator; E, jordan.

diameter. Two baffles were mounted on the inside surface in the form of screws. The cylinder was pitched 0.5 in./ft downward toward the discharge end and rotated at 15 rpm.

The jordan E, in figure 2, was of the standard type, 18 in. long, 8 in. in diameter at the inlet, and 11 in. in diameter at the discharge end. It operated at 400 rpm.

The sheet forming apparatus consisted of four parts; the mold, the sheet frame, the grid, and the suction box. The mold and the suction box were each 9 by 12 by 4¾ in. cypress boxes. The grid forming the top surface of the suction box was a perforated brass plate faced with no. 30 bronze screen. The sheet frame consisted of two hollow frames with 9 by 12 in. openings between which were clamped a no. 80 screen and a no. 30 reinforcing screen.

The hydraulic press was a diaphragm type with 9 by 12 in. bronze-faced platens. The press was equipped with a hand-operated hydraulic pump capable of producing a pressure of 200 $lb/in.^2$ on the plates.

The drying roll was a hand-operated, steam-heated dryer with a surface of polished, nickel-plated steel, which was 12.5 in. in diameter and 16 in. in length. The drier felt was heavy canvas wrapping around three-quarters of the roll.

The testing equipment consisted of a standard MIT folding tester, the usual tensile machine, and a Mullen burst tester. All physical testing was done at Iowa State College in a room maintained at 70° F and 70-percent relative humidity.

III. EXPERIMENTAL PROCEDURE

Many factors influence the preparation of paper pulp from any raw material. In this study, the effects of varying each factor discussed below were determined with the other conditions constant. These results made it possible to establish a fairly specific range of conditions for the process.

1. MECHANICAL PRETREATMENT

In the manufacture of paper from straw abroad it is common practice to shred the straw before chemical treatment to facilitate the loading and blowing of the digesters and, in general, the handling of the material. However, since the design of the digester used in this work was such that the cooked pulp was more easily washed in the digester, and more easily removed if whole straw was used, the stalks were used directly from air dry bales.

2. PRESTEEP

It was found that a preliminary treatment of the raw straw with hot water greatly improved the color of the cooked straw and decreased the amount of chemical needed in digesting and bleaching. Steeping at atmospheric pressure was found to be practically as effective as pressure steeping in its results, though it removed slightly less material than could be dissolved at higher pressures. This pretreatment lowered the amount of chlorine necessary for bleaching by 2 percent.

3. CHEMICAL COOKS

The cooking of cellulosic materials for the preparation of paper pulp is one of the most important phases of the process. In this step, varying any of a number of factors will affect the product. These factors are: pressure and temperature, the duration of cooking, the ratio of material to water, the total amount and concentration of chemicals, and, in the sulfate cook, the proportion of sodium sulfide to sodium hydroxide. The best conditions for these factors are given in the following sections, with the exception of the straw-to-water ratio, which is the maximum for the digester used—1 part of straw to 9 parts of water, by weight. Twelve pounds of air-dried straw was about the maximum amount which could be conveniently charged into the digester, and this weight was used throughout the work. 108 lb of water was required to cover the material and prevent undercooking at the surface.

(a) PRESSURE AND TIME STUDIES

Experiments were conducted with wheat straw at gage pressures of 35, 50, 65, and 85 lb/in.[2] with variations in cooking period of 1, 2, 3, 5, and 7 hours, using 10 percent of total chemical based on the air-dried straw, in the ratio of 3 parts of sodium sulfide to 7 parts of caustic soda, by weight, in each case. Each run was followed by 90 min. of beating, circulated screening, and two-stage bleaching. The results are given in table 1.

TABLE 1.—*Effect of pressure and duration of cooking on the yield, strength, and bleaching quality of pulp made from wheat straw digested with 3 percent of sodium sulfide and 7 percent of caustic soda*

Run	Digestion		Properties of hand sheets				Yield; weight of paper ×100÷ weight of straw	Bleaching quality
	Gage pressure	Time	Weight [1]	Bursting [2] strength	Folding [3] endurance	Tensile [4] breaking load		
	lb	hr	lb	*Points*	*Double folds*	kg	%	
120	35	3	48.1	43	1,200	6.7	45.2	Fair.
121	35	5	44.5	42	1,200	6.6	45.3	Good.
122	35	7	47.0	33	1,000	6.9	44.0	Do.
20	50	1	47.3	39	360	6.3	31.0	Fair.
123	50	3	44.1	42	930	6.3	41.7	Good.
92	50	5	49.6	40	780	6.4	44.4	Do.
107	65	1	47.6	41	790	6.0	41.8	Good.
106	65	2	50.6	47	990	6.5	42.1	Do.
101	65	3	52.5	46	1,300	6.6	44.4	Fair.
110	85	1	51.1	47	1,300	6.7	44.6	Fair.
104	85	2	44.0	40	920	6.4	44.2	Very poor.
102	85	3	53.6	50	1,600	6.6	36.8	Do.

[1] The figures given are typical and represent the weight of 500 sheets, 25- by 40-in.
[2] Bursting pressure, in pounds per square inch, through a circular orifice of 1.2 in. diameter.
[3] For test specimens 19 mm wide and 90 mm between jaws.
[4] For test specimens 15 mm wide and 90 mm between jaws.

It may be seen that all the high-pressure cooks yielded pulps with poor bleaching quality, and that excessive cooking time was required for good bleaching quality in low-pressure cooking. From a consideration of the strength and bleaching quality of the pulps, and the time and steam requirements for different cooks, it appeared that 50-lb pressure for 3 hr was optimum.

(b) CHEMICAL CONCENTRATION AND INTERCHEMICAL RATIO

The three straws—wheat, oat, and rye—were studied throughout a range of chemical concentrations and interchemical ratios, cooking 3 hours under 50 lb pressure and using uniform practice in steeping, beating, screening, and bleaching. The results are tabulated in tables 2, 3, and 4.

Bearing in mind the fact that pulps cooked with 3 percent of sodium sulfide had poor bleaching quality, unless at least 11 percent of caustic was also used, the tables indicate that the best results were obtained by the use of 2 percent of sulfide with 9 to 10 percent of caustic on oat straw; 1 to 2 percent of sulfide with 9 to 10 percent of caustic on raw straw; and 1 to 2 percent of sulfide with 8 to 10 percent of caustic on wheat straw.

Of the pulps from the three straws, that from oat straw was the strongest, but most difficult to bleach; that from rye straw was easiest to bleach, but brittle; while wheat straw was about intermediate between these two with respect to bleaching and strength.

TABLE 2.—*Physical properties and yields of pulp from oat straw cooked with different percentages of chemicals*

Run	Properties of hand sheets				Yield: weight of paper ×100÷ weight of straw	Chemical sodium sulfide	Chemical sodium hydroxide
	Weight [1]	Bursting strength [2]	Folding endurance [3]	Tensile breaking load [4]			
	lb	*Points*	*Double folds*	kg	%	%	%
34	57.1	71	970	8.9	41.0	1	8
25	58.8	70	1,200	8.9	42.2	1	9
35	54.6	62	1,000	8.7	40.1	1	10
36	54.8	69	1,300	8.4	45.1	1	11
21 to 23	56.2	78	1,400	9.6	46.3	2	8
22	57.0	70	1,700	8.5	45.4	2	9
24	59.6	80	1,100	11.2	41.4	2	10
26	57.7	78	1,600	9.5	43.7	2	11
9	57.1	78	2,100	8.8	50.2	3	6
10	59.2	88	2,000	10.2	47.1	3	7
11	55.9	67	1,500	9.1	44.5	3	8
12	58.0	77	1,800	10.2	47.1	3	9
13	54.3	64	980	7.6	42.6	3	10
14	56.4	65	870	8.0	44.2	3	11

[1] The figures given are typical and represent the weight of 500 sheets 25- by 40-inch.
[2] Bursting pressure, in pounds per square inch, through a circular orifice of 1.2 in. diameter.
[3] For test specimens 19 mm wide and 90 mm between jaws.
[4] For test specimens 15 mm wide and 90 mm between jaws.

TABLE 3.—*Physical properties and yields of pulp from rye straw cooked with different percentages of chemicals*

Run	Properties of hand sheets				Yield; weight of paper ×100÷ weight of straw	Chemical	
	Weight [1]	Bursting strength [2]	Folding endurance [3]	Tensile breaking load [4]		Sodium sulfide	Sodium hydroxide
	lb	*Points*	*Double folds*	kg	%	%	%
39	57.9	66	340	9.8	44.0	1	9
40	54.4	62	360	8.4	41.8	1	10
41	53.5	59	440	8.0	35.4	1	11
28	56.6	66	1,000	8.6	44.1	2	8
30	59.7	61	260	9.8	46.1	2	9
37	54.0	60	290	8.1	42.3	2	10
38	55.5	58	250	9.3	42.3	2	11
15	57.8	56	1,100	8.7	47.2	3	6
16	58.3	56	780	7.6	48.0	3	7
17	62.4	69	850	9.9	48.9	3	8
18	56.3	45	230	7.8	43.4	3	9
19	59.7	53	840	8.1	45.8	3	10
20	58.0	55	550	8.9	44.7	3	11

[1] The figures given are typical and represent the weight of 500 sheets 25- by 40-in.
[2] Bursting pressure, in pounds per square inch, through a circular orifice of 1.2 in. diameter.
[3] For test specimens 19 mm wide and 90 mm between jaws.
[4] For test specimens 15 mm wide and 90 mm between jaws.

TABLE 4.—*Physical properties and yields of pulp from wheat straw cooked with different percentages of chemicals*

Run	Properties of hand sheets				Yield; weight of paper ×100÷ weight of straw	Chemical	
	Weight [1]	Bursting strength [2]	Folding endurance [3]	Tensile breaking load [4]		Sodium sulfide	Sodium hydroxide
	lb	*Points*	*Double folds*	kg	%	%	%
f	59.6	58	1,200	6.9	41	1	8
i	50.8	46	910	6.7	37	1	9
b	57.9	51	780	6.8	38	1	10
a	61.8	59	410	6.4	35	1	11
h	51.6	47	670	6.7	40	2	8
e	58.8	56	790	7.4	40	2	9
d	65.0	62	740	8.6	39	2	10
c	59.1	64	660	7.1	41	2	11
j	47.4	42	640	6.4	42	3	7
k	45.4	40	580	6.2	41	3	8
l	49.7	41	610	6.8	39	3	9
m	47.3	37	510	6.5	38	3	10

[1] The figures given are typical and represent the weight of 500 sheets 25- by 40-in.
[2] Bursting pressure, in pounds per square inch, through a circular orifice of 1.2 in. diameter.
[3] For test specimens 19 mm wide and 90 mm between jaws.
[4] For test specimens 15 mm wide and 90 mm between jaws.

4. WASHING

It was found that poor yields were obtained when the pulp was washed in the beater through the medium of a rotary washer covered with a no. 80 screen. Recovery of fiber from the wash water by filtering indicated that the poor yields were caused by loss of fines through the washer wire. A method of washing the pulp in the cooker was adopted. This was accomplished by using four to five batches of hot water to take advantage of the leaching action, or a continuous washing with hot water for 10 to 15 min. When this was combined with three-stage bleaching and circulated screening, the yields were increased to over 40 percent.

5. BEATING

(a) MECHANICAL FIBER TREATMENT

A series of beating trials was made of pulps cooked at 50- or 65-lb pressure with 3 percent of sodium sulfide and 7 percent of caustic soda. The method was to feed the pulp into the beater with the roll raised to a 0.07-in. clearance until circulation was established at the desired consistency. The roll was then lowered to 0.0285-in. clearance. At definite intervals this clearance was reduced in steps to a minimum of 0.00285 in. The results indicated that after 90 min the strength remained practically constant and that further beating was unnecessary.

(b) MECHANICAL FIBER TREATMENT COMBINED WITH PARTIAL BLEACHING

To investigate multistage bleaching and recovery of fines, a series of experiments was made in which the cooked and washed pulps were beaten and partially bleached simultaneously. Two-fifths of the total bleach required was added at the start of the 90-min. beating period. The pulp was then allowed to stand for 2½ to 3 hr, before screening, to utilize the chlorine completely. The high dilution necessary for screening, together with the subsequent concentration for further bleaching, were attained by washing and draining between the bleaching stages. Further advantages of this method were a reduction in the amount of tailings and a consequent increase in the rate of screening, increased recovery of fines owing to their precipitation from a suspended state by the action of the bleach, and a resultant shortening of the processing time.

6. SCREENING AND SCREEN OPERATION

The usual commercial papermaking screens for the removal of undisintegrated fiber bundles and other objectionable material have slots that vary from 0.008 to 0.015 in., according to the grade of pulp desired, and have a production rate of from 21 to 30 pounds of bone dry pulp per hour per plate [5]. Straw pulp requires small slots to remove the objectionable material. Screens having 0.004-in. slots were investigated and found to be satisfactory. The use of these narrow screen slots required modifications in the usual methods of screening to obtain satisfactory production. Neil [6] investigated the modified method and determined the following optimum conditions for factors which affect the rate of screening: (1) Rate of agitation above the plate, 325 rpm; (2) amplitude, 1 to 1.5 in., and rate of vibration of the jig, 800 vpm; (3) consistency of the stock, 0.3 to 0.5 percent; (4) difference in head on the screen, 28 to 30 in.; and (5) the concentration of tailings in the stock above the plate, 0.3 to 0.5 lb of tailings allowed to accumulate and 15 min taken for cleaning. Observing these conditions, screening rates of 26 to 33 lb hr can be attained, which is comparable to wood-pulp screening and shows the advantage of improved screen control.

The dilute pulp suspension from the screen was passed through a centrifugal separator, described previously. This operation aided greatly in removing the denser impurities from the pulp. The separator removed material which amounted to 1.0 to 2.0 percent of the bone-dry straw and contained 30 to 60 percent of ash.

7. CONCENTRATING

The dilute pulp suspension from the screen and separator had to be concentrated in order to bleach the pulp efficiently. The continuous concentrator described previously proved to be very satisfactory for this purpose. The machine, with moderately free pulp, will concentrate from 0.5 percent consistency to 5 to 7 percent consistency at the rate of 5 to 6 pounds of bone-dry material per hour. It has the advantage of rapid and efficient concentration of pulp with low initial cost and low power consumption.

8. BLEACHING

Recent trends in pulp bleaching have been toward multistage or countercurrent methods, for the reason that the action of concentrated chlorine solutions has a decided weakening effect on the fibers, and also because the use of successive stages of bleaching reduces the time of treatment and the amount of chlorine necessary to produce a white fiber.

The effect of single-stage and multistage bleaching was determined [7] for wheat-straw pulp made by a 3-hr, 50-lb pressure cook, with 7 percent of caustic soda and 3 percent of sodium sulfide. The bleaching was accomplished in quart jars, using 20- to 25-gram samples at approximately 3-percent consistency. The samples were mixed with chlorine as sodium hypochlorite and allowed to stand for varying lengths of time, after which the liquor was drained off. The active chlorine content of the liquor was determined by titrating an aliquot portion with sodium thiosulfate in the presence of potassium iodide and acetic acid. The treated pulps were then washed clean with cold water, and made into sheets of approximately 42 lb per ream.

White pulp could be obtained in single-stage bleaching only when the bleaching agent was present in decided excess: 17 to 23 percent active chlorine based on the weight of the pulp. Poor yields were obtained by this method and the paper had poor strength, particularly folding endurance.

Two-stage bleaching decreased the amount of bleach necessary to produce a white pulp without the large losses in yield and in strength. Table 5 shows results typical of those obtained in this study.

While applying two-stage bleaching to larger scale experiments, it was observed that a loss of fine material could be minimized by addition of the bleach solution before washing or screening the beaten pulp. To take advantage of this, a three-stage bleaching process was evolved. Four percent of chlorine, based on the weight of the crude pulp (which was taken as one-half of the original raw material), was used for the first bleaching stage and was added during the beating process. This low percentage was used in order to reduce further the deleterious effect of the strong chlorine and not to waste the bleach on the coarse material which would later be screened out as tailings. After screening, centrifugal cleaning and concentrating, the pulp, diluted to 2- to 3-percent consistency, was again returned to the beater, where an additional 4 percent of chlorine was added and thoroughly mixed into the pulp. Sixteen hours was allowed for the action of this second stage of bleaching. Two percent of chlorine was then added and mixed with the pulp and allowed to act for 24 hr. The bleached pulp was washed on flat, no. 80 screens until the wash water was clean and gave no color with phenolphthalein.

TABLE 5.—*Properties of wheat-straw pulp bleached in two stages*

Ratio of Cl added in 1st to that added in the 2d stage	Time of treatment, in stages		Total Cl added ×100÷ bone-dry pulp	Cl remaining ×100÷ bone-dry pulp	Yield of bleached pulp	Properties of hand sheets				Color
	1st	2d				Weight [1]	Bursting strength [2]	Tensile breaking load [3]	Folding endurance [4]	
	hr	hr	%	%	%	lb	*Points*	kg	*Double folds*	
1:1	8	32	11.36	0.44	90.5	41.7	32	6.4	720	Good.
7:5	8	32	11.36	.46	92.7	41.9	32	6.3	470	Do.
8:5	8	32	11.36	.65	89.7	41.8	31	6.0	420	Do.
9:5	8	32	11.36	.67	88.7	37.3	26	5.5	430	Do.
2:1	8	32	7.71	.04	96.7	40.6	28	6.2	560	Poor
2:1	8	32	8.52	.12	86.3	38.3	29	5.7	800	Fair.
2:1	8	32	9.96	.39		38.8	29	5.9	600	Good.
2:1	8	32	11.37	.43	84.3	38.2	26	4.2	320	Do.
2:1	8	32	12.81	.60	86.3	38.3	25	5.6	530	Do.

[1] The figures given are typical and represent the weight of 500 sheets, 25- by 40-in.
[2] Bursting pressure in pounds per square inch through a circular orifice of 1.2 in. diameter.
[3] For test specimens 19 mm wide and 90 mm between jaws.
[4] For test specimens 15 mm wide and 90 mm between jaws.

9. FORMATION

The bleached and washed pulp was passed through the jordan at approximately 0.7-percent consistency, with the jordan plug set to give a light brushing action. This treatment was sufficient to float the fibers and insure good felting properties.

The jordaned pulp was diluted with water to a consistency of 0.6 percent. The suction box and mold were filled with water. Two-pound samples of the diluted pulp were poured into the mold and evenly distributed by hand. The water was removed by suction and the fibers allowed to mat on the 80 screen of the sheet frame. Suction was maintained for about 1 min after the visible water was removed. The sheet frame containing the felted fibers was removed and a piece of 12-oz canvas was stretched over the screen-covered grid. The sheet frame was then inverted over the grid, suction applied, and the wet sheet transferred to the canvas. The canvas backings and sheets were placed in a hydraulic press between felts and pressed for about 3 min at 200 lb/in^2. The pressed wet sheets were then removed from the press, stripped from the canvas, and dried on the roll drier at slightly over 100° C.

10. TESTING

The physical tests were made on samples from hand sheets. At least 10 samples, which had been conditioned for a minimum of 2 hr at 70° F and a relative humidity of 70 percent, were used for each test. Samples for test were taken from several hand sheets as follows: Mullen, 10 to 12 squares, 10 by 10 cm; tensile, 10 to 12 strips, 19 by 175 mm; folding, 10 to 12 strips, 15 by 135 mm. The weight per ream was determined from the weight of the conditioned Mullen test samples.

IV. DISCUSSION AND COMPARISON OF THE PROCESS WITH WOOD PROCESSES

Any attempt to give practical cost data on small-scale work would be, at best, only a rough approximation. The process in general, as outlined in this paper, made use of no new types of equipment, and the treatment was in accordance with established practice. Hence, amounts, yields, and time comparisons are of more significance than cost approximations derived from small-scale work. Such comparisons are given in table 6.

TABLE 6.—*Comparison of the sulfate process for straw pulp with standard wood processes*

Treatment	Sulfate process on straws	Sulfate process on wood	Soda process on wood	Sulfite process on wood
Amount (in tons) of bone-dry cellulosic material required per ton of pulp.	2.2 to 2.6	2.1 to 2.5[a]; 2.8 to 3.4[b]	2.5 to 2.6[a]; 2.3 to 3.6[b]	2.0 to 2.7[b].
Total chemical (%) for cooking based on the bone-dry raw material.	11.8 to 12.9	30 to 33[a c]; 16 to 17[b].	21 to 25[a c]	9.4 to 15[a] (as SO_2).
Time (hours) of cooking	4	4 to 5[a c]; 1.5 to 6[b].	4 to 5[a]; 4 to 6[b]	8 or less[a]; 20 to 30[a c]; 10.5 to 14.5[b].
Maximum temperature (°C) of cook.	147	170 to 181[b]	121[a]	125 to 160[a]; 120[b].
Yield (%) of the unbleached pulp	45 to 50		38 to 40[a]; 28 to 44[b].	37 to 50[b].
Bleach (%), as bleaching powder, required.	27		8 to 30+[a]; 8 to 13[a c]; 8.4[b].	16 to 24[a]; 10 to 14[b c].
Yield (%) of bleached pulp	36 to 46		26.6 to 41.8[d]	35.2 to 47.5[d].

[a] Manufacture of Pulp and Paper, TAPPI, 3 (McGraw-Hill Book Co., 1927).
[b] Sutermeister, Chemistry of Pulp and Paper Making, 2d ed. (John Wiley and Sons, 1929).
[c] Easy bleaching.
[d] Assuming a 5 percent loss during bleaching.

The comparative data, as tabulated from authoritative sources, shows that straw pulp in many cases has advantages over wood; and some apparent disadvantages, the most noticeable of these being the relative amount of bleach required for straw in comparison with wood. It should be mentioned here that no attempts were made to bleach at a high consistency or at the increased temperatures which are in general practice in commercial plants, neither was there a comparison made with small-scale wood-pulp bleaching under identical conditions. The application of commercial bleaching methods and equipment to straw pulp would probably materially decrease the time of bleaching and bleach consumption and may affect yields as tabulated.

The capacity of a digester unit is low for straw in comparison with wood. Sutermeister gives the capacity of digesters at 4.445 [8] lb of wood pulp per cubic foot of digester space. The digester used in this experimental work produced 3.05 lb of straw pulp per cubic foot of digester space. The duration of the digestion must also be considered. Assuming a charging and discharging time of 1.5 hr, the capacity per cubic foot per hour for sulfate wood pulp is 1.48 to 0.59 lb, for soda pulp is 1.27 to 0.59 lb, for sulfite pulp is 0.56 to 0.17 lb, and for sulphate straw pulp is 0.55 lb. Modifications in digester design and methods of packing straw into the digester would materially increase straw-pulp capacity.

The amount of dirt in straws varies considerably with the method of gathering, baling, and storing, and with the weather conditions when the straw is gathered and baled. Some experimental work has been done on washing the straw with cold water previous to the water steeping. Prewashing removes the dirt almost entirely and greatly increases the effectiveness of the cooking and bleaching and improves the quality of the pulp produced. This effect is apparently due to the removal of water-soluble materials which, when present, hinder the chemical processes. Prewashing could very well be combined with shredding, thereby lowering the cost. The wet shredding process would eliminate the fines produced in the dry shredding operation.

V. SUMMARY AND CONCLUSIONS

1. Experimental work has shown that a strong bleached pulp can be produced from straws by using a modified sulfate process by the following procedure:

Water presteep at 100° C for 1 hr.

Chemical cook at 147° C for 3 hr with 1 to 2 percent of Na_2S and 9 to 10 percent of NaOH.

Wash.

Beating 90 min with 4 percent of chlorine added and allowing the stock to stand for 4 hr.

Screening through 0.004-in. slots and centrifugal cleaning.

Concentrating for further bleaching.

Final bleaching with 4 percent of chlorine for 16 hr and 2 percent additional for 24 hr.

Washing to remove excess chlorine.

Jordaning.

Paper formation.

2. Yields of 38 to 43 percent of strong, bleached pulp from wheat straw; 42 to 46 percent from rye straw; and 40 to 45 percent from oat straw, have been obtained.

3. Various grades of pulp can be produced by changing the amounts of the chemicals in the digestion process. Yields of 45 to 55 percent of unbleached pulps can be obtained.

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