SOME EXPERIMENTS IN SODIUM SULFITE PULPING

August 1948

No. R1728

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison 5, Wisconsin
In Cooperation with the University of Wisconsin

SOME EXPERIMENTS IN SODIUM SULFITE PULPING[1]

By

J. N. McGOVERN, Chemical Engineer
and
E. L. KELLER, Chemist

Forest Products Laboratory,[2] Forest Service
U. S. Department of Agriculture

Abstract

Pulping with sodium sulfite (Na_2SO_3), one of the earliest-mentioned chemical pulping processes, has not been used commercially to any extent despite the high quality of the pulp, mainly because of chemical-recovery complications. Recently renewed interest in the process, due perhaps to the possibility of employing it for little-used wood species, has made timely the presentation of results of some experiments in sodium sulfite pulping at the Forest Products Laboratory, Madison 5, Wis. These experiments were as follows:

1. Black spruce chips were pulped with sodium sulfite buffered with sodium sulfide, and the effects on pulp yield and on quality of variations in pulping time, temperature, and liquor concentration were determined.

2. The black spruce sodium sulfite pulps were compared with acid sulfite and sulfate pulps from the same kind of chips, and were found to be produced in 15-percent-lower yield, to be nearly as bright as the acid sulfite pulps (unbleached), to be as strong or stronger than the sulfate pulps, and to require 25 percent more chemical on a sodium oxide base and much longer pulping times than the sulfate pulps.

3. Sodium sulfite pulps were also prepared from white spruce, Engelmann spruce, balsam fir, aspen, and black maple. The results from the softwood pulps were all similar, whereas the hardwood pulps were produced in appreciably higher yields and brightnesses, but were considerably weaker than the softwood pulps. The hardwood sodium sulfite pulps, however, after some beater processing, compared favorably in strength with softwood acid sulfite pulp..

---

[1] Presented at the annual meeting of the Technical Section, Canadian Pulp & Paper Assn., Montreal, Q., Jan. 28-30, 1948; published in Pulp & Paper Mag. of Canada, Aug. 1948.

[2] Maintained at Madison 5, Wis., in cooperation with the University of Wisconsin.

4. Jack pine chips were pulped with sodium sulfite buffered with sodium bicarbonate in producing pulps in yields varying from 48 to 78 percent. Maximums in bursting, tearing, and tensile strengths were obtained in pulps made in yields of 55 to 60 percent, but the decreases in these strengths up to 78 percent yield were only 25 percent of the maximum values. The highest folding-endurance values were shown by the lowest-yield pulp. A high-yield (56.5 percent) sulfate pulp from the same chips had the same strengths as the neutral sodium sulfite pulp made in the same yield except for folding endurance, which was twice as high for the sulfate pulp.

Introduction

The idea of using sodium sulfite (Na_2SO_3) in the neutral or slightly alkaline condition to produce a chemical pulp from wood is credited to Cross in 1880 (8).[3] In 1886 (9), Cross and Bevan published a "Classification of the Chemical Processes of Disintegrating Wood," which included, as a specific process, pulping with "Water Together with Neutral Sulfites." A neutral pulping process was apparently proposed by Cross to avoid the serious difficulties from corrosion encountered in acid sulfite pulping. The high temperatures and pressures required for neutral sulfite pulping, however, prohibited its application in the digesters of the construction of that time. The subsequent development of acid-resistant digester linings removed the need for a neutral pulping agent.

Except for occasional patents relating to sodium sulfite pulping,[4] it was not until more than 40 years after Cross' invention that a definite interest in the process was again shown. By this time the limitations of digester construction had largely been overcome, and the demand for pulps of higher and higher quality had turned the attention of the pulp industry to the previously recognized excellence of sodium sulfite pulps. These pulps were generally considered to equal sulfate pulps in strength and acid sulfite pulps in unbleached brightness and bleachability (a satisfactory method for bleaching sulfate pulps was not available at that time). During the 1920's several American mills started commercial pulping with sodium sulfite according to the Keebra process (2, 7), and Drewsen mentioned his work and application in the same field (11). The procedures used, however, for recovering the large amounts of chemical used in the process were somewhat complicated and not entirely satisfactory, and operation of the process was gradually

---

[3] Underlined figures in parentheses refer to Literature Cited on page 10 of this report.

[4] Because excellent reviews of the literature on sodium sulfite pulping have been given by Hausen (13), Rue (17), Haffner and Kobe (12), Sutermeister (19), and Schellhorn (18), and the general aspects of sodium sulfite have recently been considered by Wells (20) and Murdock (15), no attempt is made to cover the literature in this report.

discontinued.[5] Further, the subsequent development of methods for bleaching sulfate pulps practically made sodium sulfite pulps unnecessary.

In the last few years an interest in sodium sulfite pulping has reappeared, possibly due to a desire to obtain greater pulp values from the little-used species, such as the hardwoods and Douglas-fir, than seemingly can be obtained from pulps prepared by conventional methods (6, 12).

So far as the technology of sodium sulfite pulping is concerned, Cross (10) established the main principles involved, namely, that high temperatures and large amounts of chemicals are required, but gave few details of the process. Since that time there have been relatively few published studies giving basic data needed for the successful application of the process, outside of the information to be found in patents and descriptive articles. The chief basic studies appearing in the literature have been as follows:

1. Aspen and blackgum sawdusts have been pulped under certain variations of temperature, time, and chemical concentration and compositions, and yields and chemical compositions of the pulps have been determined (1, 3, 4, 16).

2. White spruce, Western hemlock, and slash pine have been pulped with sodium sulfite and sodium bisulfite and mixtures thereof, and pulp yields and properties have been determined (5).

3. Shortleaf pine has been pulped with sodium sulfite, buffered with various agents because wood acids formed during pulping, especially from hardwoods, cause sodium sulfite liquors to become acid unless provision is made to maintain the liquor in the neutral or slightly alkaline condition, and the yield, bleachability, and strengths of the pulp have been determined (6). A sodium sulfide buffered liquor has been also applied to numerous hardwoods and softwoods in determining its effects on pulp bleachability and strength (6).

4. Douglas-fir has been pulped, the pulp yield, bleachabilities, and strengths have been determined under various conditions of temperature and ratios of sodium oxide to sulfur dioxide in the cooking liquor and sodium oxide to the wood in establishing the optimum conditions for pulping this species. Southern pine, Western hemlock, cottonwood, and aspen have also been pulped under the established conditions (12).

---

[5] The semichemical pulping process employing sodium sulfite buffered with sodium bicarbonate or carbonate, which started in the late 1920's, has shown a remarkable expansion in recent years. In semichemical pulping, wood chips are softened and partially delignified by cooking in the sodium sulfite liquor, and the pulping is completed mechanically, usually in an attrition mill. Because of the relatively small amount of chemicals used and the high pulp yields obtained, recovery of the chemicals has generally not been necessary for economical operation. This process has been found particularly applicable to hardwood species.

5. The effect of the presence of sodium thiosulfate in the sodium sulfite cooking liquor on pulp properties has been determined in connection with the formation of this chemical in preparing the cooking liquor following certain proposed chemical-recovery processes (14, 18).

The experiments reported here were conducted at the Forest Products Laboratory on certain variables of the sodium sulfite pulping process and on several species in connection with developing pulps for special paper products. These experiments included a study of the effects on pulp yield and properties of time, temperature, and liquor concentration in pulping black spruce with sodium sulfite buffered with sodium sulfide and a study of the effect of pulp yield on properties of jack pine pulps made with sodium sulfite buffered with sodium bicarbonate. Also included in the report, are a comparison of black spruce sodium sulfite, sulfate, and acid sulfite pulps and a comparison of several hardwood and softwood pulps prepared by sodium sulfite processes and conventional processes.

PULPING WITH SODIUM SULFITE BUFFERED WITH SODIUM SULFIDE

Varying Time, Temperature, and Liquor Concentration in Pulping Black Spruce

In these experiments typical black spruce (Picea mariana) from the Algoma District, Ontario, Canada, was pulped with a sodium sulfite liquor buffered with sodium sulfide. The effects of varying (a) pulping time, (b) pulping temperature, and (c) concentration of sodium sulfite in the pulping liquor on pulp yield and properties were determined. The digestions of 5/8-inch chips were made in duplicate in a stainless-steel-lined, tumbling digester equipped with a steam jacket and having a capacity of 13 cubic feet. The cooking liquor was made by adding separately to the digester sodium sulfite and sodium sulfide solutions prepared from technical-grade chemicals. The cooking liquor at the start of the digestion had a pH value of approximately 11.0. The pH value dropped to about 9.0, however, shortly after the start of the digestion and remained near this lower value to the end of the digestion. The digestion conditions employed are given in table 1. Upon completion of the digestions the pulps were discharged into a blowpit and washed. The pulps were then screened over a flat diaphragm screen with 0.008-inch slots and lapped on a wet machine for the yield determination. The screening rejects were dried directly. The pulps were tested for bleachability as measured by permanganate number, strength, and chemical composition, according to TAPPI standard methods.

The digestions were all conducted with an excess of sodium sulfite in the cooking liquor. In the experiments on effect of pulping time and temperature, nearly twice the chemicals required for pulping were present. In the experiments on effect of liquor concentration, the excess varied roughly from 50 to 100 percent of the actual chemical requirements.

(a) Effect of Pulping Variables on Pulp Yield and Chemical Composition

Pulping time (Series I, table 1).--The general effects of increasing the total pulping time from 7.25 to 11.5 hours, other conditions being the same, were, of course, to decrease total yield, screenings, permanganate number, and pulp lignin content, and to increase chemical consumption and the total and alpha cellulose content of the pulps. The nature of some of these changes within the range of the experiments are shown in figure 1. The change in chemical composition of the pulp with increasing pulping time is interesting. The delignification reaction proceeded at a uniform rate up to the point of about 99 percent lignin removal, corresponding to about 0.5 percent lignin in the pulp, and then practically ceased. During the period of delignification within the present experiments, only small amounts of total and alpha cellulose were removed and the contents of these constituents in the pulps increased at the expense of the lignin. When delignification virtually stopped, however, the rates of cellulose removal became appreciable and pulp yield decreased at a faster rate than previously, which indicated overcooking and degradation of the cellulose. During this period of degradation, the cellulose contents of the pulp increased somewhat, probably because hemicelluloses were being removed at a faster rate than the cellulose. It should be stated that nearly 37 percent of the total cellulose and 27 percent of the alpha cellulose present in the wood had been removed in pulping to the highest yield under consideration in these experiments.

Pulping temperature (Series II, table 1).--The main effect of increasing the pulping temperature from 170° to 185° C., in pulping to the same permanganate number, was to reduce greatly the pulping time. Only 2.3 hours were required at a pulping temperature of 185° C., in comparison with 8 hours at 170° C., to remove approximately 98 percent of the lignin in the wood. (The total digestion times were 7.3 and 13 hours, respectively.) The yield data were not sufficient to determine any definite effect. The chemical compositions of the pulps made at the different temperatures were practically the same, which indicated that the relative rates of total and alpha cellulose and lignin solution were the same at the various temperatures. Slightly less chemical was consumed in pulping at 185° C. in comparison with 170° C. This decrease may have meant that the pulping was somewhat more efficient at the higher temperature.

Pulping liquor concentration (Series III, table 1).--The general effects of increasing the concentration of sodium sulfite in the pulping liquor from 98 to 177 grams per liter, in pulping to the same permanganate number, was to reduce appreciably the pulping time, to increase chemical consumption, and to decrease somewhat (at the highest concentration) the total and alpha cellulose contents of the pulp. The total digestion time at the highest concentration was 8.5 hours in comparison with 10.5 hours at the lowest concentration. The chemical consumption increased approximately 25 percent when pulping with the strongest as compared with the weakest pulping liquor. The pulp made with the strongest pulping liquor appeared to have lower total and alpha cellulose contents than those made with weaker liquors, a fact that indicates a possibly more drastic action on the pulp at high concentrations of cooking liquor than at lower concentrations.

(b) Effect of Pulping Variables on Pulp Strength

All of the black spruce sodium sulfite pulps were very strong, in which respect they were comparable to sulfate pulps (as will be discussed later). Variations in the pulping conditions affected pulp strength only in a minor way, for the most part.

Pulping time (Series I, table 2).--The bursting and tensile strengths showed a tendency toward maximum values at the medium pulping times in the medium to hard pulps (permanganate numbers of 11 to 16). The tearing strength appeared to increase somewhat with pulping time, and was highest in the softest pulp. The folding endurance of pulps did not change according to any trend with degree of pulping.

Pulping temperature (Series II, table 2).--There appeared to be no trend in pulp strength with temperature of pulping within the limits of the experiments.

Pulping liquor concentration (Series II, table 2).--Although differences in pulp strength were found between pulps made with varying concentrations of sodium sulfite in the pulping liquor, there appeared to be no trend within the limit of the experiments.

Comparison of Sodium Sulfite Pulps with Calcium Acid Sulfite and Sulfate Pulps from Black Spruce

Conventional calcium-base sulfite and sulfate pulps were made from the same shipment of black spruce as was used for the alkaline sodium sulfite experiments described above. Yield, brightness, chemical composition, and strength data for the three kinds of pulps may be found in table 3. Data are given in table 3 for two sodium sulfite pulps to enable comparison with the sulfite and sulfate pulps at the same permanganate number. The chief points of interest about the sodium sulfite pulps are their brightness, nearly that of sulfite pulp; their strength, equal to or greater than that of the sulfate pulp; and their relatively low yield. The yield of sodium sulfite pulp was approximately 15 percent lower than that of the sulfite or sulfate pulps, a serious drawback in these days of wood shortages and high wood costs. The amount of chemical on a sodium oxide base used in producing the sodium sulfite pulp was 25 percent more than that used for the sulfate pulp. Further, the use of a cooking liquor with a high concentration of sodium sulfite (and a resulting large excess of chemical over that required for pulping) in order to accelerate the pulping to a rate permitting relatively short pulping times, could possibly result in two to three times as much chemical on a soda base going to the recovery system in sodium sulfite pulping as in sulfate pulping, if some scheme of reuse of the spent sodium sulfite liquor were not employed. Finally, the sodium sulfite digestions, although made at the elevated temperature of 180° C., required somewhat longer digestion times than the acid sulfite digestions and greatly longer times than the sulfate digestions.

Comparison of Softwood, Aspen, and Black Maple Sodium Sulfite Pulps

Three varieties of spruce, balsam fir, and two northern hardwoods were pulped under similar conditions with sodium sulfite buffered with sodium sulfide. The digestion results and pulp data may be found in table 4. The white (Picea glauca) and Engelmann (Picea Engelmannii) spruce and balsam fir (Abies balsamea) appeared to give somewhat higher yields of pulp than the black spruce, but the strengths of all the pulps were in the same range as those of the black spruce pulp. The Engelmann spruce pulp was possibly higher in tearing strength than the others. The quaking aspen (Populus tremuloides) was pulped somewhat more easily than the black spruce, as was shown by the slightly shorter cooking time, lower permanganate number, and lower concentration of sodium sulfite used in the pulping liquor, although the chemical consumption was approximately the same for the two woods. The black maple (Acer nigrum) was pulped more difficultly than the aspen, although the differences may have been largely due to the relatively low concentration of sodium sulfite in the cooking liquor. The high screenings value for the maple digestion, an indication of nonuniform pulping, may also have been a result of this low concentration. The yields of the hardwood pulps were substantially higher than that of the black spruce pulp. The yield of black maple pulp was exceptionally high, but the yield of aspen pulp was lower than that usually obtained in acid sulfite and sulfate pulping to the same lignin content. The unbleached hardwood pulps showed brightness values as high as or higher than might be expected from the corresponding unbleached sulfite pulps. The strengths of the hardwood sodium sulfite pulps were greatly below those of the corresponding black spruce and other softwood pulps. On the other hand, the strengths of the hardwood sodium sulfite pulps after processing to 550-cubic-centimeter freeness (Schopper-Riegler) were practically the same as the strengths of spruce acid sulfite pulp (table 3). Unprocessed or slightly processed hardwood pulps, however, were considerably weaker than spruce acid sulfite pulp at the same high freeness value. The strengths of the hardwood sodium sulfite pulps check with those previously reported (6) for aspen and maple.

PULPING WITH SODIUM SULFITE BUFFERED WITH SODIUM BICARBONATE

Pulping with sodium sulfite buffered with sodium bicarbonate is generally called neutral sodium sulfite pulping. The cooking liquor at the start of the digestion has a pH value of 8.0 to 8.5. During the course of the digestion the pH value of the pulping liquor drops somewhat, so that the final value is nearly neutral, 7.2 to 7.6. This type of pulping liquor is used extensively in semichemical pulping.

Varying Yield in Pulping Jack Pine

In these experiments, jack pine slabs (Pinus banksiana) from wood cut in the region north of Lake Superior were pulped with a sodium sulfite liquor buffered with sodium bicarbonate to produce pulp varying from 48.4 to 78.4 percent. The digestions were made of 5/8-inch chips in the same digester as described previously. The pulping liquor was made from technical-grade sodium sulfite and sodium bicarbonate. Pulping was done according to a two-stage process as follows: The chips were steamed in the digester at atmospheric pressure for 0.5 hour. The steamed chips were then impregnated for 1 hour at 120° C. with neutral sodium sulfite liquor. The excess liquor not absorbed by the chips was then removed and fortified for a subsequent impregnation. The digestion was then conducted with the chemicals left in the chips and digester. The digestion conditions may be found in table 5.

All of the partially or fully pulped chips were fiberized in a commercial-size disk fiberizer to a freeness value near 850 cubic centimeters (Schopper-Riegler). The pulps were then screened over a flat diaphragm screen with 0.012-inch slots and lapped on a wet machine. The yields were determined by fiberizing an aliquot of the unfiberized material in a 5-pound beater and determining the loss of soluble matter on fiberizing. The pulps fiberized in the Bauer mill were tested for strength and chemical composition according to standard methods. The results may be found in table 6.

Chemical Consumption and Pulping Time

The total amount of chemical (sodium sulfite plus sodium bicarbonate) consumed in the pulping varied from 53.3 percent of wood weight for the pulp of lowest-yield (48.4 percent) to 22.0 percent for the pulp of highest-yield (78.4 percent). The relatively high concentration of sodium sulfite in the spent liquor (table 5) indicated that the actual chemical requirements were about 10 percent less than found in these experiments. In comparison with sulfate pulping to the same lignin content, the neutral sodium sulfite pulping, as conducted in these experiments and as calculated on a sodium oxide base, consumed about 45 percent more chemical.

The time at the pulping temperature of 170° C. varied from 14 hours (converted from 180° C.) for the lowest-yield pulp to 3.0 hours for the highest-yield pulp. The variation appeared to be linear within this range.

Chemical Composition

The neutral sodium sulfite pulps were analyzed for lignin, holocellulose, and alpha cellulose. The chemical-composition data and the percentages of the several constituents removed during pulping (table 6) were plotted against pulp yield, and the resulting curves may be found in figures 2 and 3. In proceeding from the highest- to the lowest-yield pulps, the lignin content decreased and the holocellulose and alpha cellulose contents increased in a nearly linear direction (fig. 2). The percentage of each constituent removed

during pulping increased with a decrease in yield (fig. 3). There was a tendency for less alpha cellulose than hemicellulose to be removed with decreasing yield, as indicated by the ratios of alpha cellulose to holocellulose contents from the data in table 6. There was also a tendency for relatively less lignin than nonlignin (including holocellulose) to be removed, as indicated by the ratios of lignin removed to lower yield from the data in table 6. Appreciable amounts of both holocellulose and alpha cellulose, in addition to the considerable amount of lignin, were removed in pulping to the yield of 77.4 percent, the highest yield for which data were available.

Pulp Strength

The strengths of test sheets from the various pulps processed to 800-cubic-centimeter and 550-cubic-centimeter freeness (Schopper-Riegler) according to the standard beater test, were plotted against pulp yield. The resulting curves may be found in figure 4. The pulps appeared to show maximum values in bursting, tearing, and tensile strengths at pulp yields of 55 to 60 percent. The decreases in these maximum-strength properties in increasing the yield to the highest value of 78.4 percent, were of the rather moderate order of 25 to 30 percent. The folding endurance, on the other hand, was highest in the lowest-yield pulp and was about three times as high as in the highest-yield pulp.

The fact that the jack pine neutral sodium sulfite pulps made in yields of 75 to 80 percent were quite strong, is interesting because of the indicated possibility of producing high-yield pulps for use in paper and board products requiring relatively higher-strength pulps. Experiments at the Forest Products Laboratory have indicated that jack pine sulfate pulps produced in yields near 75 percent, on the other hand, may be only one-third or less as strong as pulp produced in 50-percent yield, except in tearing strength, for which property the loss in strength is relatively small.

Comparison of Jack Pine Neutral Sulfite and Sulfate Pulps

A high-yield sulfate pulp was made from the same kind of jack pine chips as were used in the neutral sodium sulfite pulping experiments previously described. The yield of sulfate pulp was 56.5 percent, or in the range of yields in which the neutral sodium sulfite pulps showed maximum values in most of their strength properties. The strength properties of the sulfate pulp and of a neutral sodium sulfite pulp at the same yield are given in table 6. The data for the neutral sodium sulfite pulp were interpolated from the relationships between yield and chemical composition in figures 2 and 3 and strength properties in figure 4. The high-yield sulfate and neutral sodium sulfite pulps are indicated in table 6 as not differing appreciably in bursting, tearing, and tensile strengths. The sulfate pulp, however, had nearly twice the folding endurance of the neutral sulfite pulp. The folding-endurance data may be considered to show that the sulfate pulp is a softer and more resilient pulp than the more brittle neutral sodium sulfite pulp. Although the strength values, except for folding endurance, are approximately at the maximum that

can be expected from the neutral sodium sulfite pulp under the pulping conditions employed, it is likely that the strength properties of the sulfate pulp would be increased to a certain extent by pulping to a somewhat lower yield.

LITERATURE CITED

1. Aronovsky, S. I., and Gortner, R. A. Ind. Eng. Chem. 25, No. 11: 1260-1265 (Nov. 1933).
2. Bradley, Linn, and McKeefe, E. R. Paper Trade Jour. 88, No. 8: 131-133 (Feb. 21, 1929).
3. Bray, M. W., and Eastwood, P. R. Paper Trade Jour. 90, No. 25: 57-60 (June 19, 1930).
4. Bray, M. W., and Eastwood, P. R. Paper Trade Jour. 93, No. 17: 38-42 (Oct. 22, 1931).
5. Chidester, G. H., and Billington, P.S. Paper Trade Jour. 104, No. 6: 39-42 (Feb. 11, 1937).
6. Chidester, G. H., and McGovern, J. N. Paper Trade Jour. 108, No. 6: 31-32 (Feb. 9, 1939).
7. Clark. J. D. Paper Trade Jour. 83, No. 22: 43-45 (Nov. 25, 1926).
8. Cross, C. F. British Patent 4984 (1880).
9. Cross, C. F., and Bevan, E. J. Forestry Exhibition Reports, Edinburgh (1886) No.20(in Cross&Bevans,Cellulose,Longmans,Greene&Co.,New York, p.209) (1903).
10. Cross and Bevan (Cross, C. F., Bevan, E. J., and Beadle, C.), Cellulose, Longmans, Greene & Co., New York, p. 98, 210 (1903).
11. Drewsen, P. Paper Trade Jour. 83, No. 24: 41-42 (Dec. 8, 1926).
12. Haffner, L. C., and Kobe, K. A., Paper Trade Jour. 111, No. 9: 93-98 (Aug. 29, 1940).
13. Hausen, J. Paper Trade Jour. 84, No. 9: 51-60 (Mar. 3, 1927).
14. Kobe, K. A., and Hanson, John M. Paper Trade Jour. 117, No. 2: 25-26 (July 8, 1943).
15. Murdock, H. R. Paper Trade Jour. 124, No. 4: 51-52 (Jan. 23, 1947).
16. Rawling, F. G., and Staidl, J. A. Paper Trade Jour. 81, No. 8: 49-51 (Aug. 20, 1925).
17. Rue, J. D. Paper Trade Jour. 81, No. 16: 54-56 (Oct. 15, 1925).
18. Schellhorn, F. S. Paper Trade Jour. 119, No. 23: 39-46 (Dec. 7, 1944).
19. Sutermeister, Edwin. Chemistry of Pulp and Paper Making, 3rd edition, New York, Wiley (1941).
20. Wells, S. D. Paper Trade Jour. 119, No. 21: 107-108 (Nov. 23, 1944).

Table 1.--Experimental conditions and results of digestions of black spruce with sodium sulfite buffered with sodium sulfide

Digestion number	Sodium sulfite concentration in cooking liquor[1]	Maximum temperature	Time at maximum temperature	Total time	Pressure[2]	Chemical consumption[3]	Total yield	Screenings	Permanganate number	Color of pulp	Chemical composition			
											Lignin	Cross and Bevan cellulose	Alpha cellulose	Total pentosans
	Gm. per liter	° C.	Hours	Hours	P.s.i.	Percent	Percent	Percent		Parts blue[4]	Percent	Percent	Percent	Percent
Series I. Effect of pulping time														
5029-31	175.5	180	2.25	7.25	143	39.3	43.2	3.2	22.8	52	3.8	91.4	75.8	9.7
5028-30	177.0	180	3.5	8.5	142	44.8	42.5	.9	16.4	52	2.0	92.7	75.4	9.2
5024-25	174.0	180	5.0	10.0	142	47.0	41.2	.5	11.4	56	.5	95.3	79.6	9.1
5026-27	178.5	180	6.5	11.5	144	50.9	38.6	.4	7.6	58	.5	96.8	80.0	9.3
Series II. Effect of pulping temperature														
5034-38	177.5	170	8.0	13.0	110	45.3	45.6	1.4	16.3	54	1.4	92.7	78.5	9.2
5028-30	177.0	180	3.5	8.5	142	44.8	42.5	.9	16.4	52	2.0	92.7	75.4	9.2
5037-39	178.0	185	2.83	7.33	162	43.4	44.8	4.8	16.5	52	1.5	92.9	79.0	9.3
Series III. Effect of sodium sulfite concentration														
5042-43	98.5	180	5.5	10.5	150	35.3	42.0	1.2	17.0	54	2.0	94.1	78.4	9.5
5044-45	139.0	180	4.25	9.25	152	42.1	41.6		16.3	56	1.3	95.4	80.2	10.0
5028-30	177.0	180	3.5	8.5	142	44.8	42.5	.4	16.4	52	2.0	92.7	75.4	9.2

[1] Includes water in wood, but not 2.5 percent (wood basis) of sodium sulfide added separately during charging of cooking liquor.
[2] No relief.
[3] Calculated as sodium sulfite and including sodium sulfide.
[4] Ives photometer.

Table 2.--Strength properties of black spruce sodium sulfite pulp

Digestion number	Digestion conditions: Sodium sulfite concentration in cooking liquor	Digestion conditions: Maximum temperature	Digestion conditions: Total time	Test beater strength properties -- 25 x 40 - 500 ream: Bursting strength: Freeness[2] -- cc. 800	Bursting strength: Freeness[2] -- cc. 550	Tearing strength: Freeness[2] -- cc. 800	Tearing strength: Freeness[2] -- cc. 550	Tensile strength: Freeness[2] -- cc. 800	Tensile strength: Freeness[2] -- cc. 550	Folding endurance[1]: Freeness[2] -- cc. 800	Folding endurance[1]: Freeness[2] -- cc. 550
	Gm. per liter	° C.	Hours	Pts. per lb. per ream	Pts. per lb. per ream	Gm. per lb. per ream	Gm. per lb. per ream	P.s.i.	P.s.i.	Double folds	Double folds
Series I. Effect of pulping time											
5029-31	175.5	180	7.25	1.78	1.92	1.62	1.18	8,800	12,650	1,045	1,200
5028-30	177.0	180	8.5	1.86	1.91	1.77	1.49	10,350	12,400	1,150	1,200
5024-25	174.0	180	10.0	1.77	1.94	1.96	1.52	9,650	12,850	1,150	1,500
5026-27	178.5	180	11.5	1.68	1.86	2.03	1.54	9,150	12,000	1,350	1,250
Series II. Effect of pulping temperature											
5034-38	177.5	170	13.0	1.84	1.91	2.04	1.48	9,400	12,550	1,285	1,625
5028-30	177.0	180	8.5	1.86	1.91	1.77	1.49	10,350	12,400	1,150	1,250
5037-39	178.0	185	7.33	1.90	2.04	2.14	1.58	9,675	12,000	1,280	1,380
Series III. Effect of sodium sulfite concentration											
5042-43	98.5	180	10.5	1.81	2.00	1.88	1.49	8,950	11,750	1,000	1,100
5044-45	139.0	180	9.25	1.91	1.96	1.80	1.38	9,300	12,300	1,325	1,250
5028-30	177.0	180	8.5	1.86	1.91	1.77	1.49	10,350	12,400	1,150	1,200

[1] Schopper instrument used.

[2] Schopper-Riegler freeness.

Table 3.--Comparison of calcium acid sulfite, sodium sulfite, and sulfate pulps from black spruce

Type of pulp	Acid sulfite[1]	Sodium sulfite[2]	Sodium sulfite[3]	Sulfate[4]
Total yield, percent	50.2	42.5	43.2	49.8
Screenings, percent	.5	.9	3.2	.2
Permanganate number	15.0	16.5	22.8	22.0
Color, percent blue on Ives photometer	60	54	52	31
Chemical composition:				
Lignin, percent	1.1	1.6	3.8	4.2
Cross and Bevan cellulose, percent	93.1	93.6	91.4	93.5
Alpha cellulose, percent	76.6	78.3	75.8	75.9
Total pentosans, percent	6.0	9.5	9.7	9.8
Solubility in 1 percent caustic soda, percent	8.7	4.3	3.8	--
Pulp strength -- 25x40-500 ream:				
Bursting strength at 800 cc.[5], pts. per lb. per ream	1.10	1.86	1.78	1.59
Bursting strength at 550 cc., pts. per lb. per ream	1.22	1.97	1.92	1.75
Tearing strength at 800 cc., gm. per lb. per ream	1.22	1.93	1.62	1.78
Tearing strength at 550 cc., gm. per lb. per ream	.86	1.48	1.18	1.36
Tensile strength at 800 cc., lb. per sq. in.	8,800	9,500	8,800	9,350
Tensile strength at 550 cc., lb. per sq. in.	11,300	12,200	12,650	12,650
Folding endurance[6] at 800 cc., double folds	450	1,200	1,045	1,300
Folding endurance at 550 cc., double folds	775	1,300	1,200	1,300

[1] Digestions 5005, 5006.

[2] Digestions 5028, 5030, 5034, 5037, 5038, 5039, 5042, 5043, 5044, 5045.

[3] Digestions 5029, 5031.

[4] Digestions 2607, 2614, 2646.

[5] Schopper-Riegler freeness.

[6] Schopper instrument used.

Table 4.--Comparison of sodium sulfite (sodium sulfide buffered) pulps from several species

Property	Wood species					
	Black spruce	White spruce	Engelmann spruce	Balsam fir	Quaking aspen	Black maple
Digestion numbers	5044-45	3948	3949	5022-23	5092	5093
Sodium sulfite concentration of cooking liquor.....gm. per liter	139.0	133.5	133.5	128.0	119.0	95.5
Maximum temperature.....°C.	180	181	181	180	181	181
Time at maximum temperature.....hours	4.25	5.0	5.0	5.0	4.0	4.0
Total digestion time.....hours	9.25	10.0	10.0	10.0	8.5	8.5
Chemical consumption.....percent of wood	44.8	44.1	.....	44.9	43.9	45.8
Total pulp yield.....percent	41.6	43.8	44.4	44.2	46.0	54.4
Screenings.....percent	.5	.....	.2	.2	.4	5.4
Permanganate number	16.3	.....	11	13.3	11.7	17.9
Color.....percent blue on Ives photometer	56	42	52	55	66	65
Chemical composition:						
Lignin.....percent	1.3	1.5	.2	1.1	2.1	3.5
Cross and Bevan cellulose.....percent	95.4	96.0	97.7	94.8	94.2	92.7
Alpha cellulose.....percent	80.2	83.6	84.6	80.6	78.4	76.0
Total pentosans.....percent	10.0	.....	9.6	8.2	15.2	16.0
Solubility in 1 percent caustic soda...percent	3.7	.....	.....	.....	4.3	5.8
Pulp strength -- 25 x 40 - 500 ream						
Bursting strength at 800 cc.[1] .....pts. per lb. per ream	1.91	1.73	1.81	1.80	.60	.62
Bursting strength at 550 cc. .....pts. per lb. per ream	1.96	1.80	1.80	1.94	1.17	1.16
Tearing strength at 800 cc. .....gm. per lb. per ream	1.80	1.83	2.04	1.85	1.05	1.05
Tearing strength at 550 cc. .....gm. per lb. per ream	1.38	1.45	1.60	1.35	1.00	1.10
Tensile strength at 800 cc. .....lb. per sq. in.	9,300	8,500	9,000	10,500	4,000	1,900
Tensile strength at 550 cc. .....lb. per sq. in.	12,300	11,600	12,100	13,900	11,100	8,600
Folding endurance at 800 cc.[2].....double folds	1,325	1,150	1,600	1,350	50	40
Folding endurance at 550 cc.....double folds	1,250	1,150	1,600	1,700	630	710

[1]Schopper-Riegler freeness.

[2]Schopper instrument used.

Z M 76967 F

Table 5.--Experimental conditions and yields for neutral sodium sulfite digestions of jack pine

Digestion number	Impregnation conditions[1]				Cooking conditions			Total digestion time	Yield of pulp
	Liquor concentration		Chemicals absorbed		Time at 170° C.	Pressure[2]	Spent liquor		
	Sodium sulfite	Sodium bicarbonate	Sodium sulfite	Sodium bicarbonate			Sodium sulfite		
	Gm. per liter	Gm. per liter	Gm. per liter	Gm. per liter	Hours	Lb. per sq.in.	Gm. per liter	Hours	Percent
5244	148.5	30.8	43.3	10.0	[3]7.0	148	24.2	10.0	48.4
5241	141.3	34.4	35.5	8.4	10.2	120	24.0	13.2	62.1
5245	121.1	30.9	27.3	8.4	6.0	121	26.8	9.2	69.6
5242	100.0	25.0	19.9	5.6	3.0	123	25.7	6.2	77.4
5258-59	89.3	22.7	16.9	5.0	3.5	128	13.8	6.7	78.0

[1] Impregnation at 120° C. for 1 hour for all digestions.

[2] Pressure not relieved.

[3] 180° C.

Table 6.--Chemical composition and physical properties of jack pine neutral sodium sulfite pulps and strength properties of a jack pine sulfate pulp

Property	Digestions with sodium sulfite -- sodium bicarbonate						Sulfate digestion
Digestion number	5244	5241	5245	5242	5258-59	(1)	2936
Pulp yield, percent	48.4	62.1	69.6	77.4	78.0	56.5	565
Pulp brightness, percent	45.9	36.8	41.7	42.7	38.4	.....	.....
Chemical composition:							
Lignin in pulp, percent	4.1	10.4	14.1	16.0	.....	8.0	.....
Lignin removed, percent of wood	92.8	77.0	64.0	51.6	.....	84.0	.....
Holocellulose in pulp, percent	88.6	82.2	76.8	73.5	.....	84.2	.....
Holocellulose removed, percent of wood	38.8	27.0	23.6	18.6	.....	33.0	.....
Alpha cellulose in pulp, percent	73.3	65.0	60.3	58.0	.....	68.0	.....
Alpha cellulose removed, percent of wood	32.2	22.8	19.8	14.2	.....	27.5	.....
Strength properties -- 25 x 40_2 - 500 ream							
Bursting strength at 800 cc.[2] pts. per lb. per ream	1.15	1.05	1.06	.72	.91	1.15	1.22
Bursting strength at 550 cc. pts. per lb. per ream	1.41	1.44	1.31	1.08	1.07	1.47	1.44
Tearing strength at 800 cc. gm. per lb. per ream	1.50	1.90	1.60	1.60	1.20	1.85	1.90
Tearing strength at 550 cc. gm. per lb. per ream	1.15	1.25	1.20	.95	.90	1.32	1.55
Tensile strength at 800 cc. lb. per sq. in.	7,500	5,800	6,000	4,000	4,200	7,000	8,600
Tensile strength at 550 cc. lb. per sq. in.	9,600	10,200	7,900	6,500	6,900	10,500	9,500
Folding endurance[3] at 800 cc. double folds	900	520	400	400	270	700	1,500
Folding endurance at 550 cc. double folds	1,900	720	780	200	560	1,150	2,000

[1] Interpolated from plots of data for 5244, 5241, 5245, 5242, and 5258-9 (figs. 2 and 4).

[2] Schopper-Riegler freeness.

[3] MIT instrument used.

Z M 76968 F

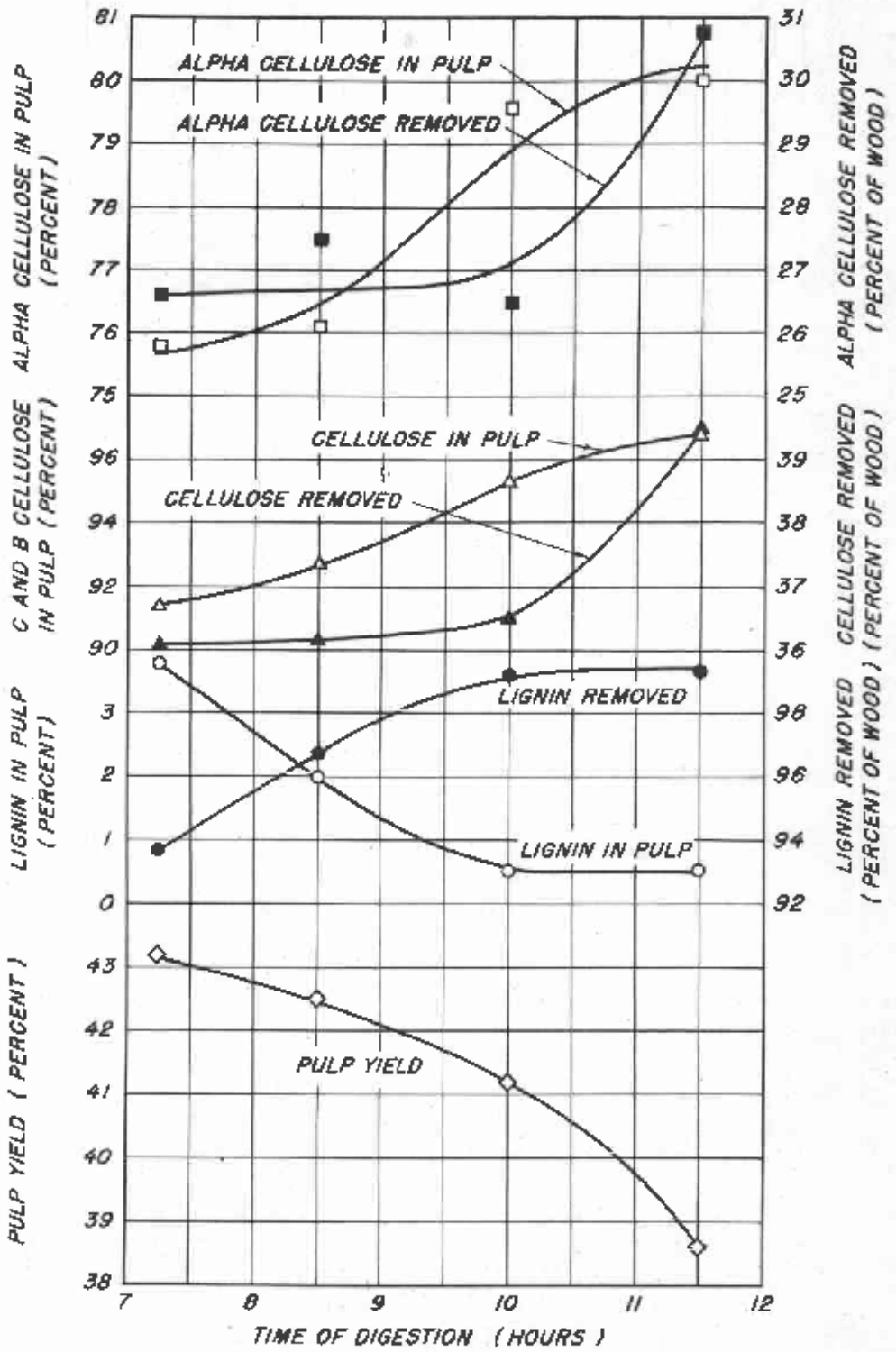

Figure 1.--Relations between yield and chemical composition of black spruce sodium sulfite pulps and time of digestion.

Z M 77363 F

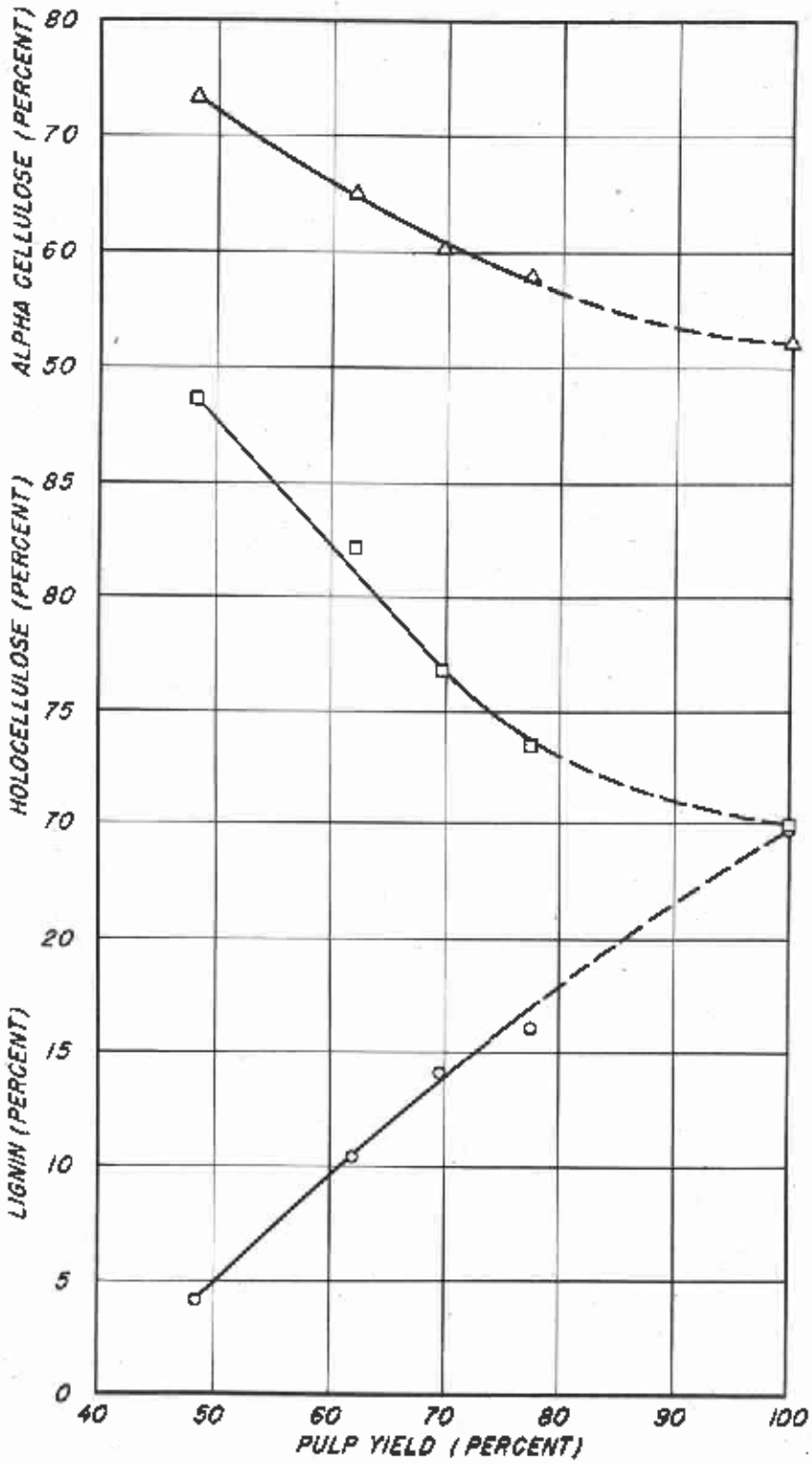

Figure 2.--Relations between chemical constituents of jack pine neutral sulfite pulps and pulp yield.

2 X 77385 F

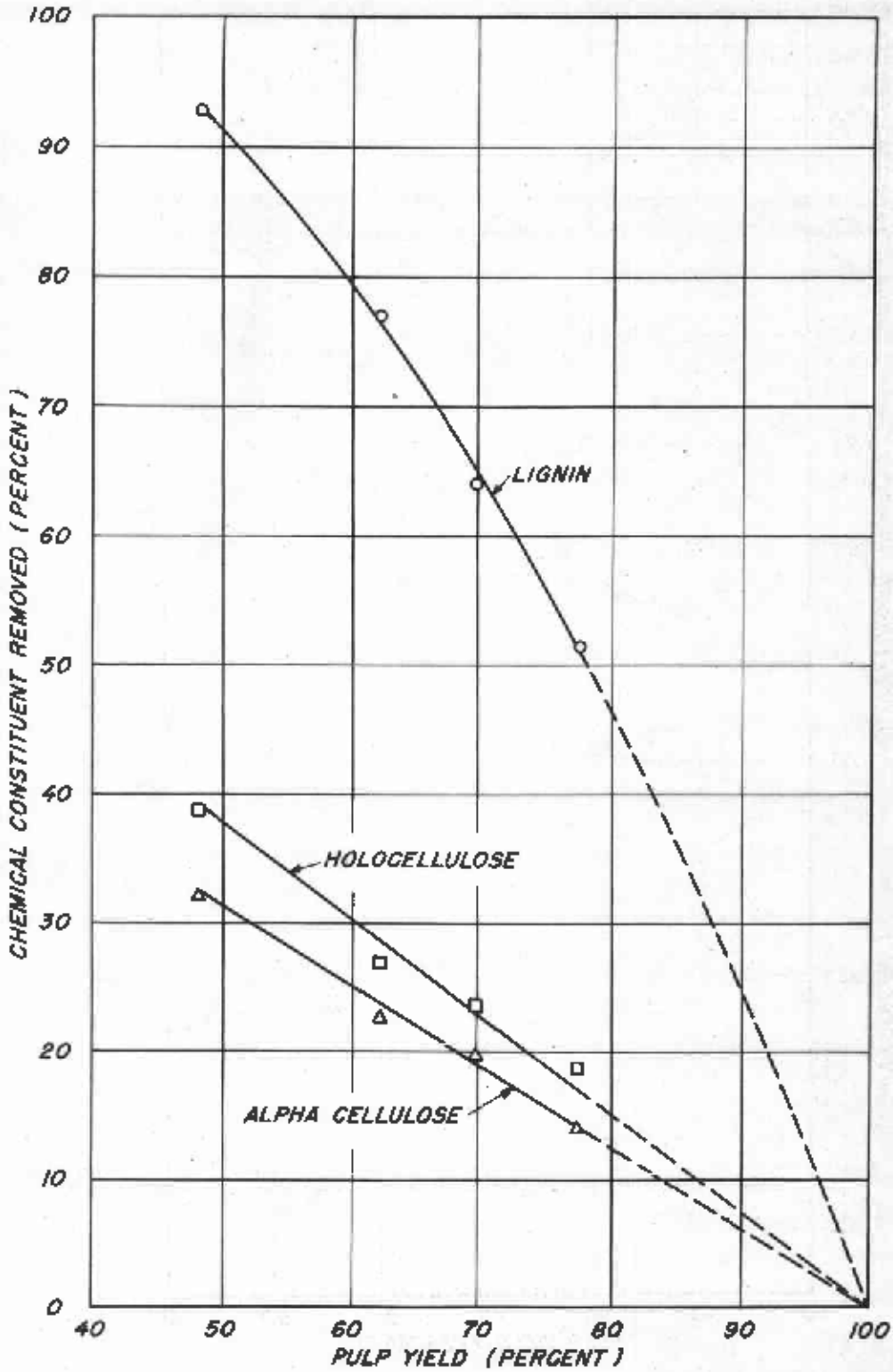

Figure 3.--Relations between chemical constituents removed in neutral sulfite pulping of jack pine and pulp yield.

Z M 77384 F

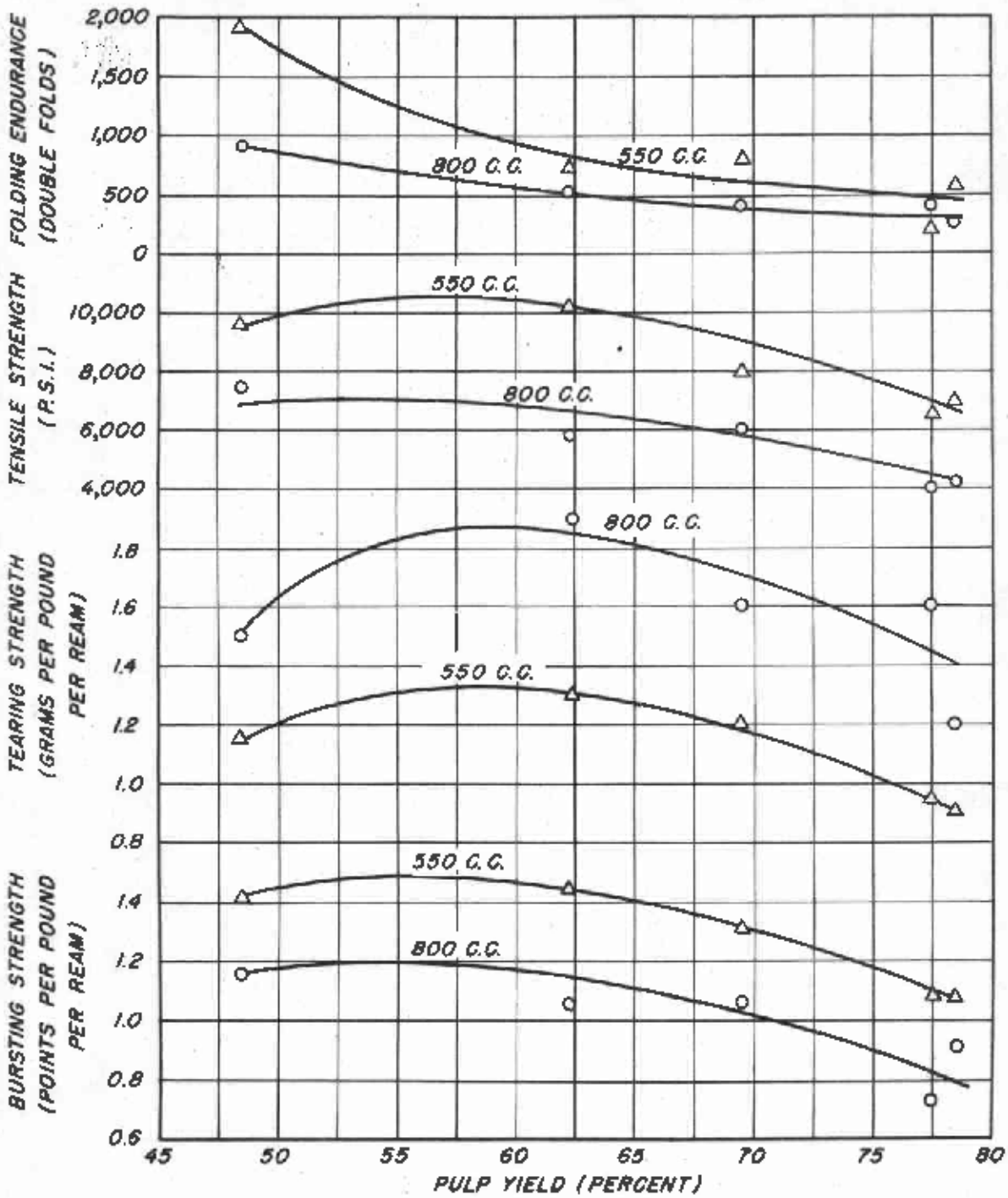

Figure 4.--Strengths of jack pine sodium sulfite pulps at two freeness values.

Z M 77386 F