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Synopsis

Sulfate pulping experiments on Douglas-fir (Pseudotsuga taxifolia) and aspen (Populus tremuloides) have shown that standard 5/8-inch chips can be completely reduced to pulp in an extremely short time by allowing preheated cooking liquors to flow continuously through a digester charge during the entire cooking period. Since the maximum digestion temperature is attained in from 15 to 20 minutes and since the concentration of chemicals in the cooking liquor remains practically constant throughout the digestion period, the pulping of the wood chips is performed in a shorter time than is consumed in the customary batch process. Further, the large volume of liquor passing through the chips causes a rapid removal of soluble lignin reaction products and pulp discoloring substances from the sphere of reaction; lighter-colored unbleached pulps of easier-bleaching characteristics, lower pentosan and higher alpha cellulose contents than those obtained by ordinary sulfate pulping methods result.

With a concentration of 90 grams per liter and a maximum temperature of 170° C., Douglas-fir kraft pulp was produced in as short a total cooking period as 35 minutes and bleachable sulfate pulp in 50 minutes. Aspen was pulped even more easily. At a concentration of 45 grams per liter and a temperature of 170° C., a 50-percent yield of easy-bleaching sulfate pulp of relatively high alpha cellulose content (88.6 percent) was obtained from aspen in 35 minutes total cooking time. The cooking time could be further reduced by the use of higher temperatures, concentrations, and rates of flow than those given. While the use of a continuous flow of liquors in pulping indicates means for reducing cooking time and for producing pulps of higher purity with respect to alpha cellulose, pentosan contents, and bleachability than present commercial methods, its practical application largely depends upon utilization of active chemicals remaining in the cooking liquor after passing through the digester.

Introduction

Concentration of chemicals in the cooking liquor has been shown to be an important variable affecting the rate of pulping by the sulfate process (7). It is evident that a continuously decreasing concentration as the cooking proceeds in a commercial operation will have an adverse effect on the progress of the pulping reaction. Although injection of chemical during cooking has been suggested as a means of maintaining a constant concentration during the entire period of digestion, a continuous flow of preheated liquors through the digester would appear to offer certain advantages. First, the use of cooking liquors heated to the maximum cooking temperature prior to introduction into the digester practically eliminates the need for a temperature rise period. Second, preheating the cooking liquor facilitates absorption of chemicals by the chips by increasing the removal of air from the chips and digester and by increasing the movement of chemicals into the chips by the forces of capillarity and diffusion (6, 8). Third, maintenance of a constant concentration throughout the entire cooking period by this means combines the advantages of pulping with relatively large liquor ratios and of removing from the sphere of reaction the spent liquors and byproducts of digestion as rapidly as they are formed. Finally, this method of cooking affords better control of the process and also a means of studying certain variables of the sulfate process under constant conditions. Data thus obtained should be of value in determining effects under various continuous-flow conditions; for example, those existing in the countercurrent process described by Haslam and Ryan (3) and others (4, 10, 11).

The data here presented show the effects of some of the variables of a continuous liquor flow alkaline pulping method, including chemical concentration, pulping time, sulfidity, and rate of flow on yield and pulp quality and on rate of delignification. Comparisons are also made between the results from the continuous liquor flow and the customary batch methods of alkaline pulping.

Materials

Five-eighths-inch chips prepared from Douglas-fir (tree 3, bolts 7, 9, 10, and 11, shipment 1528) thoroughly mixed, were pulped in this study. For comparison additional digestions were made on chips from another tree (tree 4, bolt 10) of the same shipment and from aspen wood of shipment 1537. Physical and chemical properties of the woods are given in table 1.

Because of its high lignin content, prior pulping experiments by the batch method on this shipment (1528) of Douglas-fir gave rather unsatisfactory results (1, 2), but, for comparison of the two pulping methods, the same sample of wood was used in the present experiments.

Experimental Procedure

The digestion equipment used in these experiments is diagrammatically shown in figure 1. It consists of a steam-jacketed autoclave, C, of 0.5-cubic-foot capacity, connected by means of a jacketed steam pipe, B, to a 14-cubic-foot steam-jacketed pressure vessel, A. Approximately 75 gallons of sulfate cooking liquor of known composition were charged to tank, A. The liquor, heated to approximately 180° C., was passed through the steam-jacketed pipe, B, to the autoclave, C, charged with chips. The spent liquors from the autoclave were passed through a cooler, D, where they could be sampled before discharging to the sewer.

In all digestions employing a continuous flow of preheated liquors, the maximum temperature, 170° C., was attained in approximately 20 minutes, where it was maintained throughout the entire cooking period. For the customary batch digestions made for comparison, the temperature increase period was 1-1/2 hours. The steam jackets on the delivery pipe and autoclaves were connected in series so that the temperature of the contents of the autoclave could never exceed that of the incoming cooking liquor.

Four series of digestions of varying cooking times were made on Douglas-fir chips from tree 3 with sulfate cooking liquors of the following concentrations: 90, 52.5, 45, and 30 grams per liter. The sulfidity in each case was 33.9 percent. The rate of flow of cooking liquor throughout the digestion period was approximately 1/4 gallon per minute, which permitted a sufficiently large volume of cooking liquor to pass through the digester, so that the desired concentration was maintained fairly constant during the cooking period.

Comparable digestions were made on Douglas-fir chips of tree 4 and also on aspen chips; in the latter instance, the concentration was held at 45 grams per liter.

In addition, a limited number of experiments were made to determine the effect of sulfidity and rate of flow.

Method of Testing the Pulps

The strength properties of the pulps were determined on test sheets prepared after processing according to Technical Association of the Pulp and Paper Industry method T200m-40, for definite intervals in a 1-1/2-pound standard test beater provided with a 6,500-gram weight on the bedplate. Bleaching tests were made on the pulps by treating 15-gram samples by a single-stage method with known amounts of bleaching powder solutions. The color of the bleached and unbleached pulps was determined

by an Ives tint photometer. Samples of the unbleached pulps were analyzed for their cellulose, alpha cellulose, lignin, and pentosan content and for their chlorine-absorbing power according to standard methods of the Forest Products Laboratory. In addition, permanganate numbers of the various pulps were determined according to method T214m-37 of the Technical Association of the Pulp and Paper Industry (9).

Discussion of Results

Effect of Concentration

In accordance with previous experience, the rate of pulping increased as the concentration of chemical in the cooking liquor was increased. However, for concentrations in excess of 52.5 grams per liter the change in rate of pulping was not in proportion to the increase in concentration. In all cases studied, the rate of the reaction greatly exceeded that of the conventional batch process where the concentration of the cooking liquors decreases as the reaction proceeds. Kraft-type pulps were produced in 35 minutes under the conditions employed. Easy-bleaching sulfate pulps were produced in relatively short cooking periods, only 1 hour and 50 minutes being required for even the concentration of 30 grams per liter. The relationship between yield of pulp and time of digestion for several concentrations of chemicals in the cooking liquor is shown in figure 2.

The data in table 2 show that, except for thoseproduced at the highest concentration (90 grams per liter), pulps of equal yield were quite similar in strength, bleach requirement, and chemical properties. Digestions made with a concentration of 90 grams per liter in the cooking liquor resulted in pulps of inferior strength properties.

As indicated in figures 3, 4, 5, and 6 the permanganate numbers of the pulps are criteria of their yield, bleach requirement, strength, and chemical composition. The data plotted in figure 3 show that, except for the pulps produced at the highest concentration, the total yield of pulp is a straight-line function of the permanganate number. Figure 4 also shows straight-line relationships between lignin content of the pulps and their permanganate and Roe chlorine numbers, respectively. The data recorded in table 2 and shown graphically in figures 5 and 6 indicate relationships between the permanganate number and the bursting and tearing strengths of the pulps. Except for extremely raw pulps, an increase in the permanganate number corresponded to an increase in the bursting strength. At both 700 and 550 Schopper-Riegler freeness values, maximum bursting strengths were obtained when the permanganate numbers were 20 or above. (Fig. 5.) The tearing strength reached a maximum value at a permanganate number of approximately 13. (Fig. 6.)

The Douglas-fir sulfate pulps were characteristically high in tearing strength. According to the data in table 2, pulp produced from the same sample of chips by the customary batch process (digestions 1266, 1267, and 1268) were not different in strength properties from that (digestion 1301) made by continuous liquor flow. However, the color, bleach requirement, and chemical characteristics, notably the lower pentosan content, definitely indicated higher purity of the pulp produced with continuous liquor flow. In addition, for the same bleach requirement, a continuous flow of liquor produced higher yields of pulp than the usual batch method.

Since, as previously mentioned, the wood from tree 3 was high in lignin and difficult to reduce, several pulping tests were made on wood taken from another tree of this shipment (tree 4, bolt 10), which had a relatively low lignin and a high cellulose content. Although this material pulped more easily than that of tree 3, no noticeable differences in strength, bleach requirement, or chemical characteristics of the pulps resulted. (See table 3.)

Additional pulping tests made on aspen by continuous liquor flow indicated similar trends. (Table 4.) The aspen chips were readily reduced. They gave good yields of pulp of high alpha cellulose and of low pentosan contents and of low bleach requirement. The data contrasted with results obtained by the customary batch process on aspen are reported in table 4, where it is shown, in comparing pulps of equal yield, that pulps of lower pentosan content, lower chlorine requirement, higher alpha cellulose content, and better strength properties were obtained in a much shorter cooking time with a continuous flow of liquor than by the ordinary batch process.

Effect of Varying the Sulfidity

As shown in table 5, increasing the sulfidity of cooking liquors of the same alkali content increased the rate of pulping, especially with Douglas-fir. The effect brought about by this change, however, appears to vary with the species. The pulps obtained from aspen with 10.2 and 33.9 percent sulfidity differed much less in yield, strength, bleach requirement, and chemical characteristics than those obtained from Douglas-fir. Pulps of lower yield and of higher purity were obtained from Douglas-fir (tree 3) by increasing the sulfidity from 10.2 to 20.4 percent and from 20.2 to 33.9 percent. Douglas-fir kraft pulp produced with a cooking liquor of 33.9 percent sulfidity (digestion No. 1301) was superior in strength characteristics to comparable pulps obtained with liquors of lower sulfidity. The lower strength properties of the latter pulps may be attributed to their high lignin content or "rawness." The easy-bleaching pulp obtained with liquor of 33.9 percent sulfidity was as good, if not better, in all strength properties than comparable pulps obtained with liquors of lower sulfidities, although the yield and bleach requirements of the high sulfidity pulp were lower than those obtained with

liquors of lower sulfidity. However, unlike the kraft pulps, the easy-bleaching pulps did not vary greatly in their strength and bleaching characteristics.

Effect of Rate of Flow

The data recorded in table 6 showing the effect of rate of flow on time of digestion indicate that increasing the rate of flow increased the rate of pulping for the short cooking periods. (Cf. digestions 1323 and 1316.) However, for the longer cooking periods (cf. digestions 1324 and 1318) where low yields were obtained, increasing the rate of flow showed little difference in yield but the pulps resulting from a more rapidly flowing liquor were higher in total and alpha cellulose contents and lower in lignin, in pentosans, and in chlorine requirements than those obtained from a slower flowing liquor.

Even when relatively large volumes of liquors carrying proportionally large quantities of chemicals were passed continuously through the digester, the actual amount of chemicals consumed was calculated to be approximately the same as for the normal ratios of chemical to wood employed in the batch method. More complete consumption of the chemicals in the spent liquors might be effected by using a battery of digesters, allowing the liquors to pass from one to the other in a countercurrent manner until the active alkali is practically exhausted. (It has been claimed by Jenke (4) that the amount of chemicals necessary to be replaced in a countercurrent system need not exceed that of the batch process.) Another alternative is that the spent liquor from a continuous flow operation might be refortified and used again in digesters operated by the batch process.

Conclusions

The use of a continuous flow of preheated liquors at constant concentration produced both kraft and easy-bleaching pulps in much shorter time than the customary batch process. Pulps of higher purity, higher strength, higher alpha cellulose content, and lower bleach requirement can be made by this method. Although the economic feasibility of pulping by such a method depends upon complete consumption of the chemicals in subsequent digestions, application of the continuous flow principle offers possibilities of increasing production by decreasing the time of digestion.

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Table 1.--Physical and chemical properties of Douglas-fir pulpwood from shipment 1526 and aspen pulpwood from shipment 1537

Species	Tree, log and section	Physical data: Relative height above stump	Diameter	Age	Rate of growth	Specific gravity: Density: O.D. weight per green volume	Dryness of wood	Proportion by volume: Heartwood	Summer wood	Bark by weight[2]	Chemical data: Cellulose	Alpha-cellulose	Lignin	Pentosans: Total	In cellulose	Solubility in --: Alcohol-benzene	Ether	1 percent NaOH	Hot water
		Percent	Inches	Years	Rings per inch	Lb. per cu. ft.	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Douglas-fir	3-9	50	13.9	42	6.1	0.439	27.4	58.0	58.9	29	9.2	56.6	43.1	29.2	8.7	5.9	3.4	0.9	14.4	4.4
Do.....	4-10	50	12.7	37	5.8	.400	25.0	56.8	59.8	29	10.9	62.8	48.0	25.5	7.5	5.7	2.6	.9	13.1	3.3
Aspen[3]	.....	.....	7.3	36	10.4	.362	22.6	72.4	21.9	.....	.....	66.3	48.6	17.4	18.1	22.7	2.8	1.5	16.6	2.4

[1]Logs were 4 feet long and numbered consecutively beginning with the butt log.
[2]Some bark was lost in transit and handling.
[3]Average of six logs selected for pulping.

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Table 3.--Sulfate pulping of Douglas-fir (Pseudotsuga taxifolia) by a continuous liquor-flow method. Comparison of yield and quality of pulps obtained from tree 3, bolts 7, 9, 10 and 11 and tree 4, bolt 10

Digestion	Cooking and yield data[1]: Tree	Duration at maximum temperature, 170° C.	Yield of moisture-free pulp: Screened	Screenings	Total	Interpolated beater strength data on unbleached pulp. Tests made at 72° F. and 65 percent relative humidity: Freeness (Schopper)	Time of treatment	Bursting strength	Tearing strength	Folding endurance	Tensile strength	Solution fraction	Bleach requirement: Standard bleaching powder added to pulp	Ives readings: Red	Green	Blue	Chemical characteristics: Cellulose: Total	Alpha	Lignin	Total pentosans	Roe number	Permanganate number
No.	No.	Hours	Percent	Percent	Percent	Cc.	Minutes	Points	Points	Double folds	Lb. per sq. inch	Ratio	Percent	Parts	Parts	Parts	Percent	Percent	Percent	Percent		
1300	3	1/4	36.3	16.7	53.0	700	66	0.84	2.9	1,350	5,800	0.43	0	44	31	23	88.4	76.0	9.1	4.6	8.8	33.9
						550	86	.95	2.3	1,750	6,700	.47	25	64	48	35						
1315	4	1/4	49.1	2.8	51.9	700	77	.89	2.6	1,100	5,600	.42	0	42	28	21	86.9	75.8	9.4	4.8	8.7	.....
						550	100	.97	2.2	1,400	6,600	.46	25	59	42	29						
1301	3	1/2	46.8	.3	47.1	700	60	.88	3.2	1,800	5,000	.43	0	49	36	30	92.3	80.6	5.1	4.0	5.0	22.4
						550	80	1.02	2.8	2,050	6,000	.46	25	79	68	56						
1316	4	1/2	47.3	.1	47.4	700	53	.87	3.4	1,300	5,400	.41	0	50	35	27	91.8	79.7	4.9	4.8	5.3	21.9
						550	72	.98	2.7	1,200	7,000	.47	25	75	62	50						
1302	3	1	42.9	.1	43.0	700	58	.85	3.6	1,760	4,600	.42	0	58	46	36	95.5	84.0	2.3	3.4	2.3	13.4
						550	78	.94	3.1	1,710	5,400	.45	25	92	87	82						
1317	4	1	44.4	.0	44.4	700	48	.87	2.9	1,200	5,200	.43	0	58	44	36	95.1	83.5	2.2	4.0	2.4	13.2
						550	66	.94	2.6	1,900	6,600	.48	25	87	82	82						
1303 1304	3	1-1/2	40.6	.0	40.6	700	49	.81	3.1	940	5,000	.42	0	61	50	41	96.8	84.9	1.0	2.9	1.9	9.3
						550	68	.89	2.7	1,120	6,300	.46	20	92	88	85						
1318	4	1-1/2	42.4	.0	42.4	700	47	.77	3.1	880	5,400	.41	0	60	48	40	95.8	83.9	1.4	3.7	1.0	8.8
						550	66	.86	2.4	1,200	6,500	.45	20	87	82	84						

[1]The cooking conditions other than those given are as follows:
Temperature increase period - 1/3 hour
Maximum digestion temperature - 170° C.
Rate of flow of cooking liquor - 1/4 gallon per minute
Sulfidity of cooking liquor - 33.9 percent
Ratio of caustic soda to sodium sulfide - 2:1
Total concentration of chemicals in cooking liquor - 45.0 grams per liter.

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Table 2.--Sulfate pulping of Douglas-fir (Pseudotsuga taxifolia) by a continuous liquor-flow method. Effect of concentration on yield and pulp quality (tree 1, shipment 1528)

Digestion No.	Cooking and yield data[1]: Total concentration of chemical (Gm. per liter)	Duration at maximum temperature 170° C. (Hours)	Yield of moisture-free pulp: Screened (Percent)	Screenings (Percent)	Total (Percent)	Interpolated beater strength data on unbleached pulp. Tests made at 72° F. and 65 percent relative humidity: Freeness (Schopper) (Gs.)	Time of treatment (Minutes)	Bursting strength (Points)	Tearing strength (Points)	Folding endurance[2] (Double folds)	Tensile strength (Lb. per sq. in.)	Solidification (Ratio)	Bleach requirement: Standard bleaching powder added to pulp (Percent)	Ives readings: Red (Parts)	Green (Parts)	Blue (Parts)	Chemical characteristics: Cellulose: Total (Percent)	Alpha (Percent)	Lignin (Percent)	Total pentosans (Percent)	Roe number	Permanganate number	Ash (Percent)
1289	90	1/4	47.4	0.4	47.8	870	0	0.24	2.3	5	1,014	0.22	0	49	37	28	94.4	82.9	4.6	3.0	4.6	22.0	0.7
						700	56	.82	2.6	1,300	5,000	.40	20	80	67	55							
						550	76	.90	2.2	1,230	6,000	.44	25	84	75	64							
						880	0	.24	2.4	1	680	.21	0	55	42	36							
1290	90	1/2	43.4	.1	43.5	700	46	.73	2.7	730	4,800	.41	10	75	65	55	95.6	83.8	2.3	2.2	2.5	14.2	.7
						550	65	.80	2.2	800	5,200	.44	20	89	83	78							
1291	90	1	36.6	.0	36.6	880	0	.28	2.6	6	1,600	.22	0	58	47	42	97.4	84.0	.8	1.6	1.0	7.6	.8
						700	40	.68	2.1	340	4,400	.39	10	88	84	78							
						550	54	.68	1.7	225	5,200	.44	15	88	85	83							
						860	0	.31	2.7	10	1,115	.22	0	66	56	51							
1292	90	1-1/2	33.2	.0	33.2	700	24	.55	1.7	70	3,600	.35	5	87	84	77	97.6	82.2	.3	1.2	.4	4.4	.6
						550	37	.58	1.2	90	4,900	.46	7	87	84	81							
1338	52.5	1/4	48.1	1.0	49.1	880	0	.20	2.1	1	764	.23	0	43	31	23	90.4	77.8	7.8	4.0	7.9	30.2	.....
						700	81	.90	2.6	1,380	5,600	.41	25	89	82	27							
						550	89	1.00	1.9	1,275	7,000	.45											
1294	52.5	1/2	45.4	.3	45.7	880	0	.26	2.2	11	1,050	.24	0	50	37	29	95.5	80.5	4.6	3.3	4.6	19.7	1.2
						700	61	.85	3.3	620	5,300	.41	20	83	68	57							
						550	82	.95	2.8	540	6,700	.43	25	88	76	64							
1295	52.5	1	40.6	.0	40.6	880	0	.23	2.3	5	1,160	.23	0	62	48	40	97.7	80.4	1.8	2.7	2.2	10.8	.7
						700	49	.80	3.0	710	5,400	.39	10	85	77	78							
						550	66	.89	2.6	800	5,700	.41	20	92	90	86							
1296	52.5	1-1/2	39.8	.0	39.8	870	0	.24	2.5	5	1,020	.25	0	64	51	44	97.5	65.2	.4	2.2	1.1	7.1	1.1
						700	46	.76	3.0	1,100	4,600	.44	10	93	89	82							
						550	61	.82	2.5	1,100	5,700	.49	25	94	93	86							
1300	45.0	1/4	36.3	16.7	53.0	885	0	.17	1.7	0	740	.24	0	44	31	23	88.4	76.0	9.1	4.6	8.8	33.9	1.1
						700	66	.84	2.9	1,350	5,800	.43	20	61	43	31							
						550	86	.95	2.3	1,750	6,700	.47	25	84	48	35							
1301	45.0	1/2	46.8	.3	47.1	870	0	.25	2.4	6	1,037	.25	0	49	36	30	98.3	80.6	5.1	4.0	5.0	22.4	1.0
						700	60	.88	3.2	1,800	5,000	.43	20	76	59	47							
						550	80	1.02	2.8	2,050	6,000	.46	25	79	68	56							
1302	45.0	1	42.9	.1	43.0	880	0	.23	2.2	3	1,025	.25	0	58	46	36	95.5	84.0	2.3	3.4	2.3	13.4	1.0
						700	58	.85	3.6	1,760	4,600	.42	20	85	82	76							
						550	78	.94	3.1	1,710	5,400	.45	25	92	87	82							
1303	45.0	1-1/2	40.9	.0	40.9	870	0	.24	2.4	4	1,083	.26	0	61	50	41	96.0	84.3	1.0	2.5	1.9	9.1	1.1
						700	46	.82	3.0	900	5,000	.42	10	85	79	69							
						550	63	.89	2.6	1,100	6,200	.46	20	92	87	84							
1304	45.0	1-1/2	40.3	.0	40.3	875	0	.20	1.9	0	1,007	.25	0	61	50	40	97.5	85.5	.9	3.2	1.9	9.4	1.1
						700	52	.80	3.1	980	5,000	.42	10	85	78	70							
						550	72	.88	2.7	1,140	6,400	.46	20	92	89	85							
1305	45.0	2	39.1	.0	39.1	875	0	.23	2.3	1	1,205	.25	0	66	54	48	97.6	85.4	.2	3.0	.6	6.8	.9
						700	40	.74	2.9	680	4,800	.43	10	88	86	81							
						550	55	.79	2.3	780	5,800	.47	15	93	91	86							
1297	30.0	1/4	.0	58.4	58.4	890	0	.10	1.1	0	375	.20	0	37	26	16	80.6	69.0	16.8	5.9	9.6	.....	1.8
						700	82	.78	2.2	880	4,600	.39											
						550	102	.90	1.8	1,080	5,600	.44											
[3]1298	30.0	1/2	44.3	8.6	52.9	890	0	.19	1.7	1	685	.21	0	45	30	23	89.0	76.0	9.0	5.4	8.1	34.6	1.1
						700	67	.92	2.5	500	5,600	.41	20	58	41	29							
						550	87	1.04	2.1	700	6,800	.46	25	84	47	34							
1299	30.0	1	45.8	.2	46.0	870	0	.22	2.2	2	893	.25	0	50	37	29	93.7	80.8	4.3	4.6	4.4	29.7	.7
						700	55	.88	3.4	2,000	4,800	.41	20	80	68	57							
						550	77	.98	3.0	2,500	6,200	.44	25	87	77	67							
1306	30.0	1-1/2	42.8	0	42.8	880	0	.21	2.1	0	990	.25	0	58	45	38	96.4	85.1	1.9	4.3	2.1	12.6	1.0
						700	51	.80	3.6	1,450	5,100	.45	20	91	85	79							
						550	69	.86	2.8	1,980	6,200	.46	25	92	88	85							
1307	30.0	2-1/2	40.6	.0	40.6	880	0	.22	2.3	0	1,150	.26	0	65	53	44	97.2	84.9	.5	3.6	.4	7.7	1.2
						700	50	.79	3.5	1,080	4,600	.42	10	89	86	79							
						550	67	.89	2.7	1,600	5,400	.47	15	93	89	86							
[4]1266	49.6	1-1/2	46.4	1.5	47.9	880	0	.17	1.6	1	790	.25	0	35	21	18	92.5	78.1	5.6	6.4	6.1	28.9	.....
1267						700	69	.96	2.8	1,200	5,850	.46	25	89	55	40							
1268						550	90	1.09	2.3	1,400	7,300	.45											

[1] All digestions were made in a 3.7 gallon, steam-jacketed, spherical autoclave.
The cooking conditions other than those shown are as follows:
Ratio of caustic soda to sodium sulfide, 2 to 1, respectively, equivalent to a sulfidity of 33.9 percent.
Temperature increase period 20 minutes.
Maximum digestion temperature - 170° C.
Rate of flow of cooking liquor - 1/4 gallon per minute.

[2] Folding tests run at 50 percent relative humidity.

[3] All strength tests made at 50 percent relative humidity.

[4] Digestion made by the batch process under the same conditions as the others except as follows:
Total chemicals added per 100 pounds oven-dry wood - 19.83 pounds
Volume of cooking liquor (including moisture chips) - 48.0 gallons
Temperature increase period - 1-1/2 hours.

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Table 4.--Sulfate pulping of aspen (Populus tremuloides) (Ohlrogge 1537). Comparison of batch and continuous liquor-flow methods

Digestion	Cooking and yield data[1]						Interpolated beater strength data on unbleached pulp. Tests made at 72° F. and 65 percent relative humidity							Bleach requirement				Chemical characteristics					
	Shipment	Duration at maximum temperature 170° C.	Yield of moisture-free pulp				Freeness (Schopper)	Time of treatment	Burating strength	Tearing strength	Folding endurance	Tensile strength	Solidification	Standard bleaching powder added to pulp	Ives readings			Cellulose		Lignin	Total pentosans	Roe number	Permanganate number
			Screenings	Screenings	Total										Red	Green	Blue	Total	Alpha				
No.	No.	Hours	Percent	Percent	Percent		Co.	Minutes	Points	Points	Double folds	Lb. per sq. inch	Ratio	Percent	Parts	Parts	Parts	Percent	Percent	Percent	Percent		
1308	1536	1/4	50.2	0.3	50.5		860	0	0.19	0.5	1	1,840	0.31	0	64	52	46						
1311							700	72	.72	1.4	200	6,600	.53	10	91	85	82	96.3	88.6	1.3	11.8	0.9	9.5
							550	112	.85	1.2	520	8,400	.61	15	94	91	87						
2 931							865	0	.20	.5	1	1,505	.34	0	54	42	36						
932	P-1329	1-1/2	55.9	.1	56.0		700	69	.84	1.2	320	7,000	.52	15	93	88	84	97.0	84.5	.6	16.8	1.7	.....
933							550	111	.98	1.1	570	9,400	.80	20	94	90	87						
							855	0	.16	.5	1	1,180	.28	0	65	53	50						
1312	1536	1/2	48.4	.0	48.4		700	85	.60	1.2	75	5,700	.49	10	93	91	85	97.6	91.6	.9	9.6	.0	6.2
							550	140	.66	1.1	165	7,300	.56	15	93	91	88						
2 892							850	0	.17	.5	1	1,110	.31	0	54	45	40						
893	P-1329	4-1/2	47.1	.0	47.1		700	80	.53	.8	9	4,360	.43	15	93	88	82	97.5	78.6	1.4	15.8	1.6	.....
894							550	.....	.....	.....	.....	.....	.....	20	92	90	85						
							850	0	.15	.4	1	1,170	.29	0	67	58	53						
1309	1536	3/4	47.2	.0	47.2		700	73	.56	1.0	48	5,200	.49	5	90	86	83	98.0	92.2	.6	9.7	.4	4.9
							550	121	.60	.9	80	6,400	.57	8	94	92	88						
1310							850	0	.15	.5	1	1,150	.28	0	68	60	53						
1313	1536	1	46.1	.0	46.1		700	86	.57	1.1	49	4,600	.48	6	92	88	85	97.5	91.4	.6	8.8	.0	4.0
							550	138	.59	.9	75	5,600	.56	9	93	91	88						
							850	0	.15	.5	0	1,128	.27	0	75	66	62						
1314	1536	1-1/2	43.1	.0	43.1		700	78	.54	1.0	34	5,200	.47	3	90	88	84	97.1	92.3	.3	6.6	.0	2.7
							550	128	.54	.8	46	5,700	.54	7	94	90	89						

[1] The cooking conditions other than those given are as follows:

Continuous liquor flow
- Time to maximum temperature - 1/3 hour
- Maximum temperature ..... - 170° C.
- Rate of flow of liquor..... - 1/4 gallon per minute
- Sulfidity..... - 33.9 percent
- Ratio of NaOH to Na_2S..... - 2:1
- Total concentration[2]..... - 45.0 grams per liter

[2] Batch process
- Time to maximum temperature ..... - 1-1/2 hours
- Maximum temperature ..... - 170° C.
- Sulfidity ..... - 33.9
- Ratio of NaOH to Na_2S..... - 2:1
- Total concentration[2]..... - 50.0 grams per liter
- Pounds of chemical per 100 pounds of wood... - 20.0
- Volume of liquor per 100 pounds of wood..... - 48.0

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Table 5.--Sulfate pulping of Douglas-fir (*Pseudotsuga taxifolia*) and aspen (*Populus tremuloides*) by a continuous liquor-flow method. Effect of sulfidity on yield and pulp quality

Digestion	Cooking and yield data[1]									Interpolated beater strength data on unbleached pulp. Tests made at 72° F. and 65 percent relative humidity							Bleach requirement				Chemical characteristics					
	Tree	Concentration of chemical	Sulfidity	Free alkali content	Duration at maximum temperature 170° C.	Yield of moisture-free pulp: Screened	Yield of moisture-free pulp: Screenings	Yield of moisture-free pulp: Total	Freeness (Schopper)	Time of treatment	Bursting strength	Tearing strength	Folding endurance	Tensile strength	Solid fraction	Standard bleaching powder added to pulp	Ives readings: Red	Ives readings: Green	Ives readings: Blue	Cellulose: Total	Cellulose: Alpha	Lignin	Total pentosans	Roe number	Permanganate number
No.	No.	Gm. per liter	Per cent	Gm. per liter	Hours	Percent	Per cent	Per cent	Cc.	Minutes	Points	Points	Double strokes	Lb. per sq. in.	Ratio	Percent	Parts	Parts	Parts	Per cent	Per cent	Per cent	Per cent		
Douglas-fir																									
1301	3	45.0	33.9	37.7	1/2	46.8	0.3	47.1	700	60	0.88	3.2	1,600	5,000	0.43	0	49	36	30	92.3	80.6	5.1	4.0	5.0	22.4
									550	80	1.02	2.8	2,050	6,000	.46	25	79	68	56						
1329	3	41.8	20.4	37.7	1/2	47.8	.7	48.5	700	65	.78	2.8	1,080	4,400	.41	0	42	29	22	89.6	78.3	7.3	4.5	7.2	23.5
									550	86	.85	2.3	1,200	5,800	.46	25	64	49	33						
1325	3	39.7	10.2	37.7	1/2	49.0	2.2	51.2	700	67	.78	2.6	840	4,600	.39	0	40	27	20	87.4	74.9	10.3	4.6	8.5	24.0
									550	87	.86	1.9	1,050	5,600	.44	25	58	40	29						
1303 1304	3	45.0	33.9	37.7	1-1/2	40.6	.0	40.6	700	49	.81	3.1	940	5,000	.42	0	61	50	41	96.8	84.9	1.0	2.9	1.9	9.3
									550	68	.89	2.7	1,120	6,000	.46	20	92	86	85						
1330	3	41.8	20.4	37.7	1-1/2	41.4	.0	41.4	700	41	.79	2.7	670	5,400	.42	0	58	46	39	96.0	83.3	1.6	3.3	1.6	10.5
									550	57	.82	2.0	700	6,400	.45	20	84	80	80						
1326	3	39.7	10.2	37.7	1-1/2	43.4	.0	43.4	700	43	.76	3.3	1,070	4,200	.40	0	55	42	35	96.3	83.7	2.5	3.3	2.1	14.3
									550	63	.85	2.5	1,200	6,000	.46	20	87	82	79						
Aspen																									
1308 1311	....	45.0	33.9	37.7	1/4	50.2	.3	50.5	700	72	.72	1.4	200	6,000	.53	0	64	52	46	96.3	88.6	1.3	11.8	.9	9.5
									550	112	.85	1.2	520	8,400	.61	15	94	91	87						
1327	....	39.7	10.2	37.7	1/4	50.8	.8	51.6	700	84	.67	1.3	150	5,800	.52	0	62	50	44	94.9	88.2	1.8	11.6	1.8	11.7
									550	134	.81	1.1	375	8,200	.61	15	84	78	80						
1310 1313	....	45.0	33.9	37.7	1	46.1	.0	46.1	700	86	.57	1.1	49	4,600	.49	0	68	60	53	97.5	91.4	.6	8.8	.0	4.0
									550	138	.59	.9	75	5,800	.56	6	92	88	85						
1328	....	39.7	10.2	37.7	1	46.3	.0	46.3	700	83	.57	1.1	63	5,200	.50	0	71	62	57	98.6	93.2	.3	8.5	.3	4.1
									550	133	.61	.9	96	6,500	.58	6	83	78	82						

[1] The cooking conditions other than those given are as follows:
Temperature increase period - 1/3 hour
Maximum digestion temperature - 170° C.
Rate of flow of cooking liquor - 1/4 gallon per minute

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Table 6.--Sulfate pulping of Douglas-fir (Pseudotsuga taxifolia) by a continuous liquor-flow method. Effect of rate of flow of cooking liquor on yield and pulp quality (tree 4, shipment 1528)

Digestion	Cooking and yield data[1]					Interpolated beater strength data on unbleached pulp. Tests made at 72° F. and 65 percent relative humidity							Bleach requirement				Chemical characteristics					
	Rate of flow of liquor	Duration at maximum temperature 170° C.	Yield of moisture-free pulp: Screened	Yield of moisture-free pulp: Screenings	Yield of moisture-free pulp: Total	Freeness (Schopper)	Time of treatment	Burst factor	Tear factor	Folding endurance	Tensile strength	Solid fraction	Standard bleaching powder added to pulp	Ives readings: Red	Ives readings: Green	Ives readings: Blue	Cellulose: Total	Cellulose: Alpha	Lignin	Total pentosans	Roe number	Permanganate number
No.	Gal. per min.	Hours	Percent	Percent	Percent	Cc.	Minutes	Points	Points	Double folds	Lb. per sq. inch	Ratio	Percent	Parts	Parts	Parts	Percent	Percent	Percent	Percent		
1315	1/4	1/4	49.1	2.8	51.9	700	77	0.89	2.6	1,100	5,600	0.42	0	42	28	21	86.9	75.8	9.4	4.8	8.7	23.8
						550	100	.97	2.2	1,400	6,600	.46	25	59	42	29						
1323	1/10	1/2	43.3	7.3	50.6	700	53	.90	2.9	1,700	5,200	.41	0	43	30	23	90.7	77.8	7.1	5.6	7.4	30.3
						550	71	.98	2.3	1,960	6,700	.48	25	70	54	42						
1316	1/4	1/2	47.3	.1	47.4	700	53	.87	3.4	1,300	5,400	.41	0	50	35	27	91.8	79.7	4.9	4.8	5.3	21.9
						550	72	.98	2.7	1,200	7,000	.47	25	75	62	50						
1317	1/4	1	44.4	.0	44.4	700	48	.87	2.9	1,200	5,200	.43	0	58	44	36	95.1	83.5	2.2	4.0	2.4	13.2
						550	66	.94	2.6	1,900	6,600	.48	25	87	82	82						
1324	1/10	1-1/2	42.5	.0	42.5	700	54	.90	2.8	1,200	5,100	.42	0	54	42	34	95.0	82.1	1.9	4.3	2.2	13.3
						550	75	.96	2.2	1.120	6,600	.47	25	86	81	83						
1318	1/4	1-1/2	42.4	.0	42.4	700	47	.77	3.1	880	5,400	.41	0	60	48	40	95.8	83.9	1.4	3.7	1.0	8.8
						550	66	.86	2.4	1,200	6,500	.45	20	87	82	84						

[1]The cooking conditions other than those given are as follows:
- Temperature increase period - 1/3 hour
- Maximum digestion temperature - 170° C.
- Sulfidity of cooking liquor - 33.9 percent
- Ratio of caustic soda to sodium sulfide - 2:1
- Total concentration of chemicals in cooking liquor - 45.0 grams per liter

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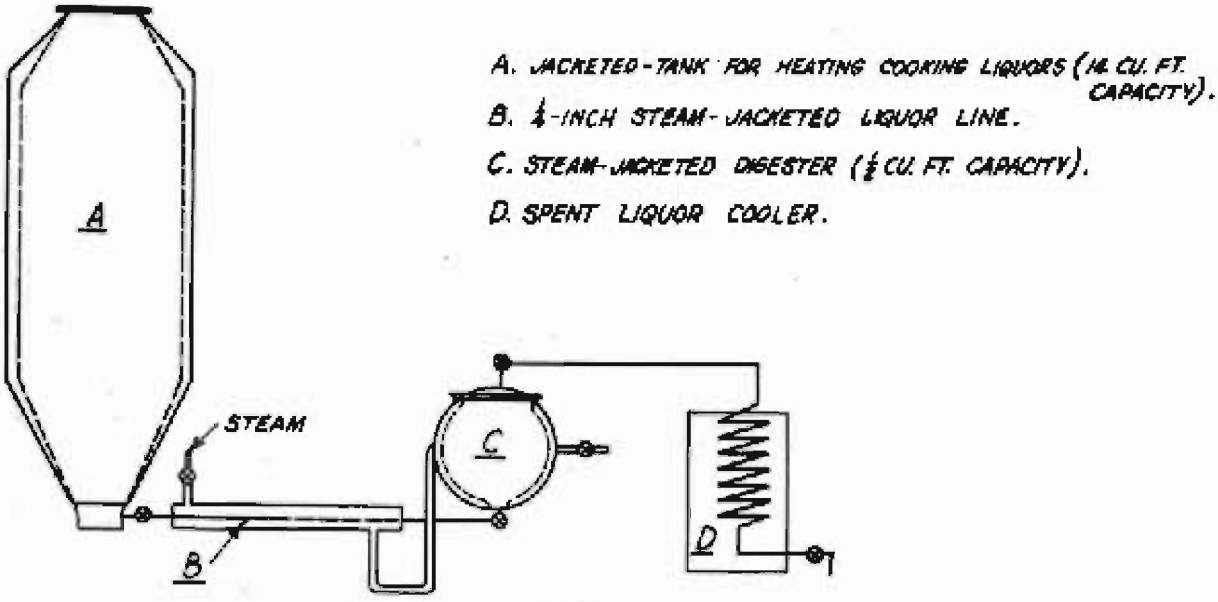

FIG. 1
DIAGRAM OF LABORATORY EQUIPMENT FOR PULPING BY THE CONTINUOUS LIQUOR-FLOW METHOD

M 40120 F

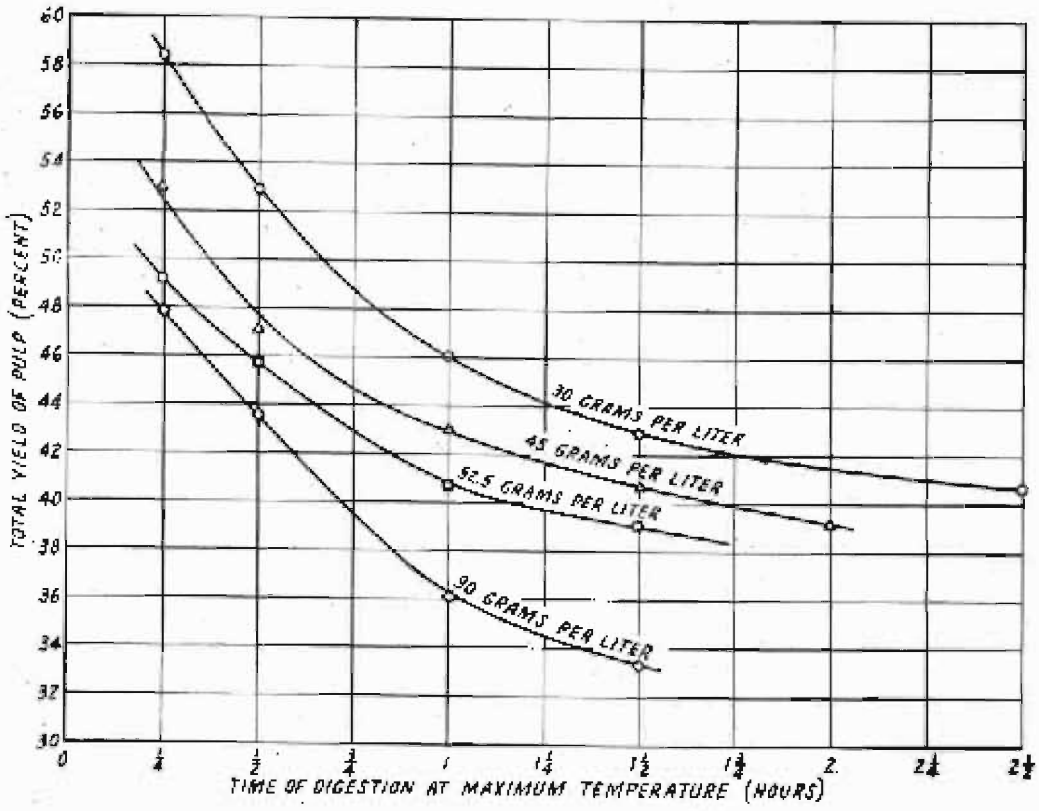

FIG. 2
RELATIONSHIP OF YIELD OF SULFATE PULP TO TIME OF DIGESTION AT MAXIMUM TEMPERATURE, 170°C. FOR SEVERAL CONCENTRATIONS OF CHEMICALS IN COOKING LIQUOR

M 40121 F

Z M 41900 F

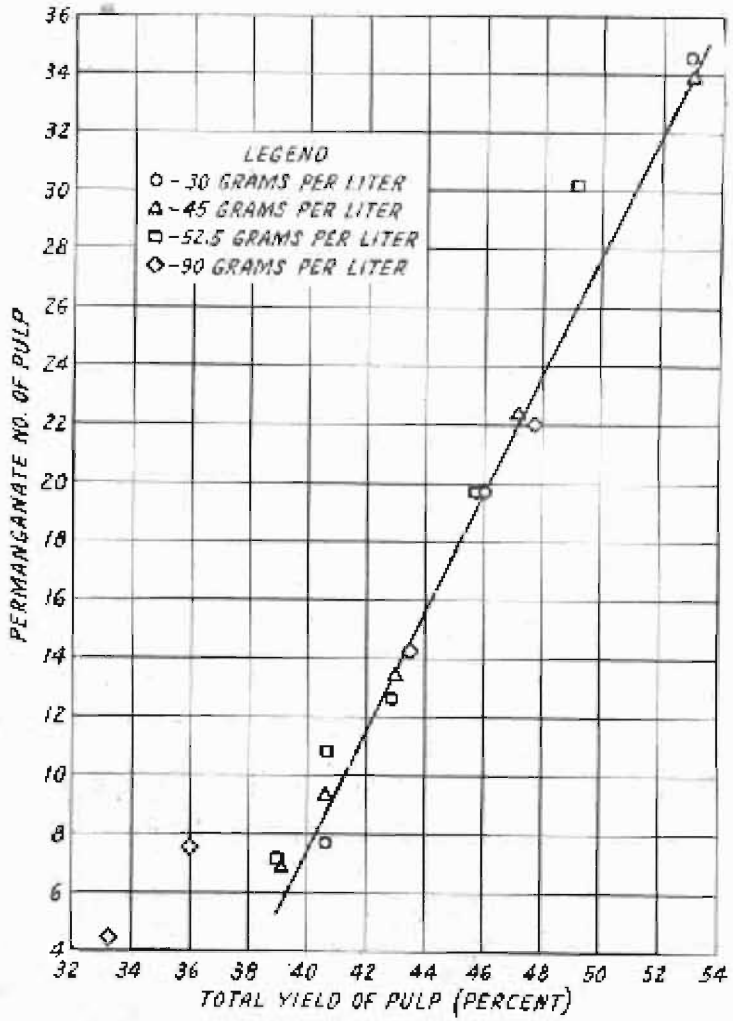

FIG. 3
RELATIONSHIP OF PERMANGANATE NO. TO
TO TOTAL YIELD OF SULPHATE PULP

Z M 41901 F

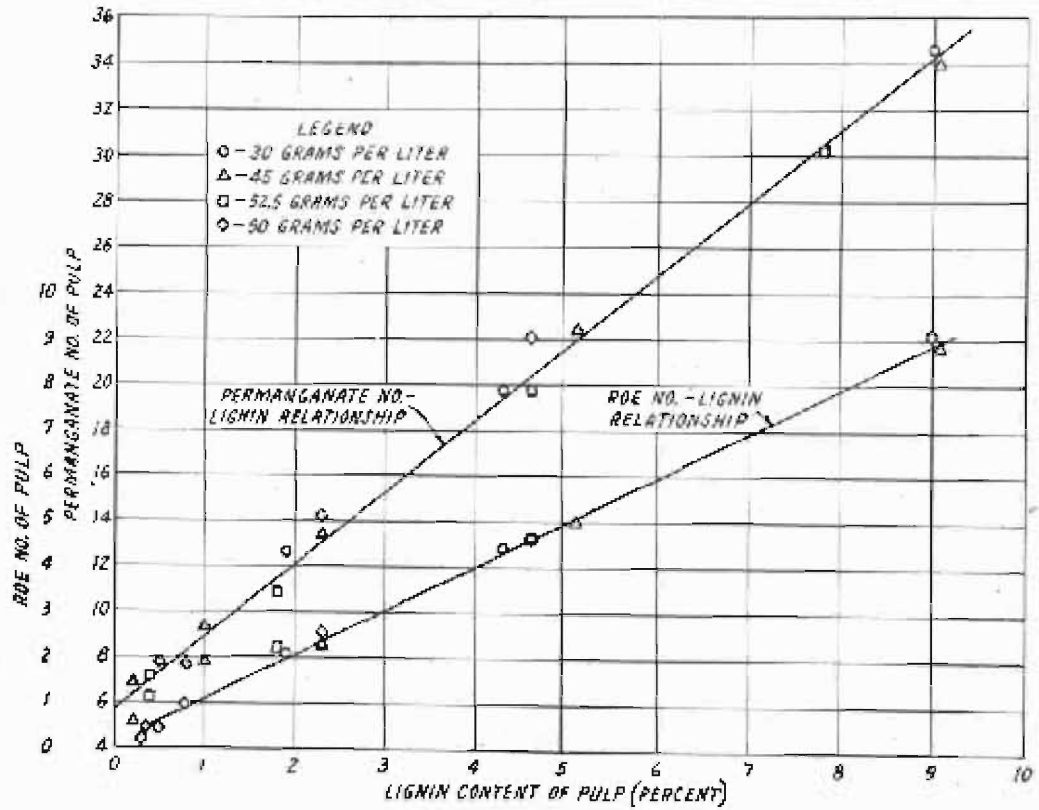

FIG. 4
RELATIONSHIP OF PERMANGANATE NO. AND ROE NO. TO
LIGNIN CONTENT OF SULFATE PULP

M 40123 F

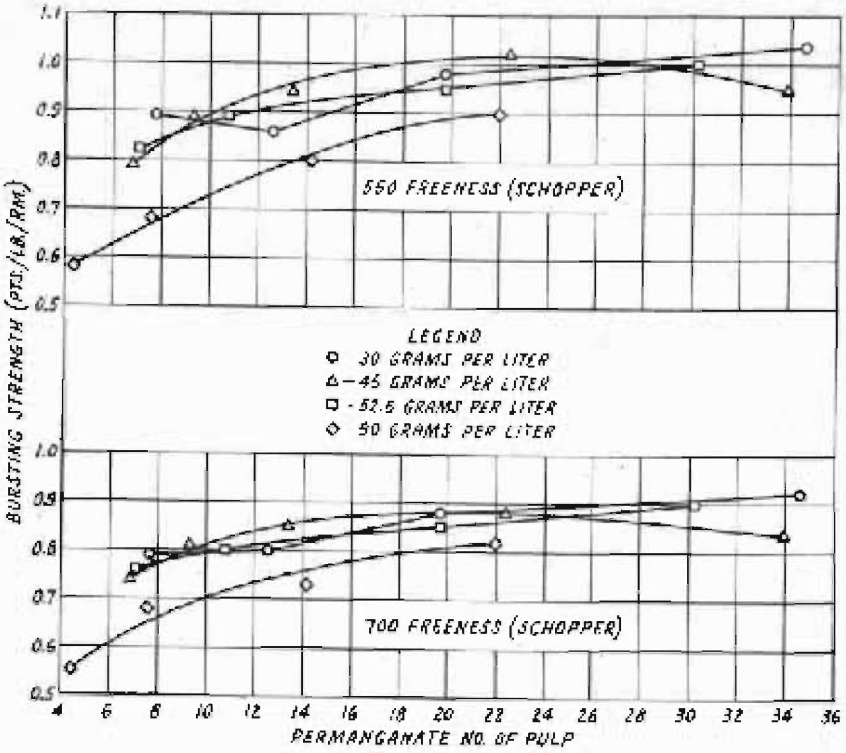

FIG. 5
RELATIONSHIP OF PERMANGANATE NO. TO THE BURSTING STRENGTH OF SULFATE PULP AT 700 AND 550 cc. SCHOPPER FREENESS

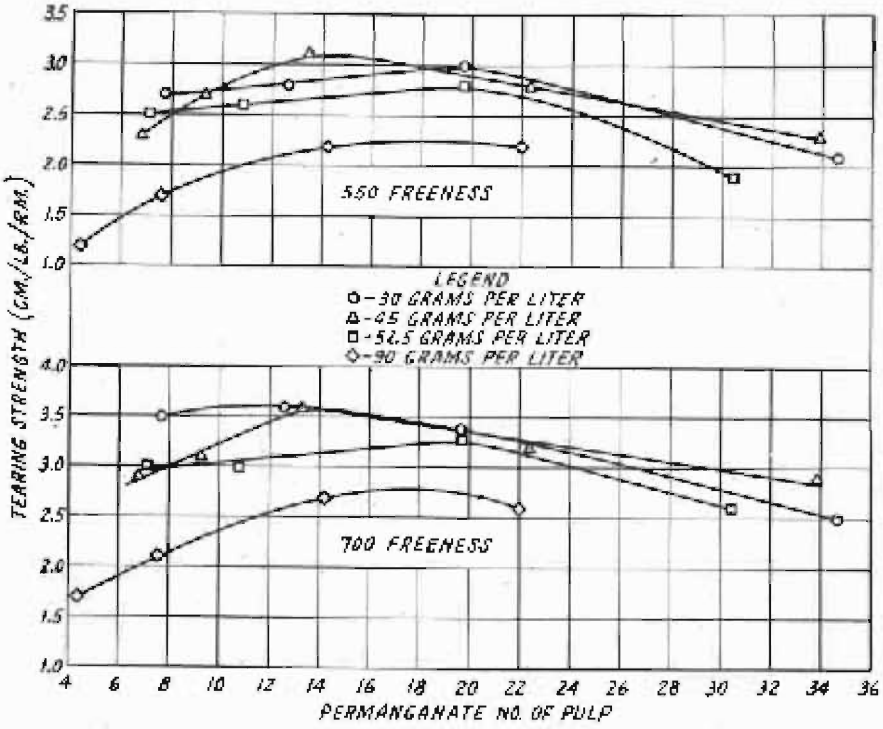

FIG. 6
RELATIONSHIP OF PERMANGANATE NO. TO THE TEARING STRENGTH OF SULFATE PULP AT 700 AND 550 cc. SCHOPPER FREENESS