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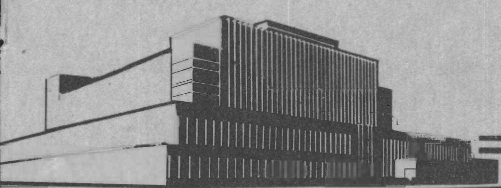

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

SUITABILITY OF SOME PACIFIC COAST WOODS FOR PRINTING PAPERS[1]

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SUMMARY

An investigation was made of the relative suitability of several Pacific coast softwoods and hardwoods in the manufacture of duplicating and offset printing papers. The woods tested were old-growth and second-growth Douglas-fir (Pseudotsuga menziesii) and black cottonwood (Populus trichocarpa), the more common species used in the Pacific Northwest for this type of paper, and western hemlock (Tsuga heterophylla), western redcedar (Thuja plicata), ponderosa pine (Pinus ponderosa), bigleaf maple (Acer macrophyllum), Pacific madrone (Arbutus menziesii), red alder (Alnus rubra), and tanoak (Lithocarpus densiflorus).

The density of the softwood species ranged from 22.3 pounds per cubic foot for western redcedar to 26.8 for western hemlock. The density of the hardwood species ranged from 20.1 pounds for black cottonwood to 35.6 for tanoak. Chemical analyses and fiber length measurements were made on the wood of each sample.

Sulfate pulps were experimentally produced individually from all the woods and from a mixture of equal parts of cottonwood and alder and a mixture of equal parts of old-growth Douglas-fir, second-growth Douglas-fir, hemlock, cottonwood, and alder. Pulps having permanganate numbers ranging from 15 to 20 for the softwoods and 10 to 15 for the hardwoods showed that trends in going from the lower to the higher permanganate numbers of the pulps were (1) a decrease in the chemical requirement for pulping, (2) higher yields of pulp, (3) an increase in the strength of the unbleached pulps, and (4) a higher chlorine requirement for bleaching the pulps.

Ponderosa pine was easier to pulp than old-growth Douglas-fir and was similar in pulping behavior to second-growth Douglas-fir. At a given permanganate number, ponderosa pine pulp had the best strength properties of any of the unbleached pulps tested. It was equal to old-growth Douglas-fir pulp in tearing resistance and much higher in bursting strength.

Sulfate pulps prepared for the papermaking trials were made at the standard permanganate number levels of 15 for the softwoods and 10 for the hardwoods. These pulps were bleached to a brightness of about 83 percent by a three-stage prehypochlorite bleaching process. The yields with this procedure were generally high, 95 percent or more, based on the weight of unbleached pulp.

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

Duplicating and offset papers were made of commercial pulps in combinations with the experimental pulps. Better formed duplicating papers were made when either second-growth Douglas-fir or western hemlock sulfate pulps were used to replace old-growth Douglas-fir pulp and the paper containing the second-growth Douglas-fir had higher strength--except in tearing resistance. Strength was improved by adding redcedar sulfate pulp to the furnish, but the amount that can be used is restricted because of the tendency of that pulp to increase resistance to oil penetration. Red alder sulfate pulp was substituted for cottonwood sulfate pulp without altering the porosity or oil receptivity of the paper, and there was an improvement in opacity and some strength properties. A mixture of the two woods cooked together was also satisfactory. Tanoak and madrone sulfate pulps used in place of cottonwood sulfate pulp gave more favorable air resistance and oil receptivity, but the madrone pulp caused a loss in strength.

The offset papers made with the second-growth Douglas-fir sulfate pulp were slightly more absorbent and those made with the hemlock sulfate pulp were stronger than the paper made with old-growth Douglas-fir pulp.

INTRODUCTION

The investigations described in this report were designed to evaluate the suitability of certain wood species available in the Pacific Coast States for the manufacture of printing papers. The species now used in the Northwest for this type of paper are mostly old-growth Douglas-fir and cottonwood. Other softwood and hardwood species are available in substantial amounts and might be used but basic information on their suitability for this purpose was needed.

It therefore was the purpose of the study to produce reference information on the pulping and bleaching characteristics of Douglas-fir (*Pseudotsuga menziesii*) (both old and second growth), redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), ponderosa pine (*Pinus ponderosa*), cottonwood (*Populus trichocarpa*), red alder (*Alnus rubra*), tanoak (*Lithocarpus densiflorus*), madrone (*Arbutus menziesii*), and bigleaf maple (*Acer macrophyllum*). Both duplicating and offset paper runs were made to characterize better the different species for use in high-quality paper.

WOOD PROPERTIES AND PREPARATION

The wood obtained for this work was considered to be representative of material available to pulpmills and papermills in the Pacific Northwest.

The wood used for the pulping experiments was comprised of pieces taken from all the bundles received. Sections were cut from representative sticks for the determination of wood density. The fiber dimensions of the five hardwood species were measured on samples taken from the disks that had been used for wood density determinations. For pulping, the wood was converted to chips, which were screened to remove undersize ones (smaller than 1/4 by 1/4 inch) and oversize (larger than 1-1/4 by 1-1/4 inches). The nominal chip length was 5/8 inch. The chemical constituents of the old-growth Douglas-fir, western hemlock, and the five hardwood species were determined on representative samples of the chips.

The densities of all the woods are given in table 1, the chemical compositions of certain species are given in table 2, and the fiber dimensions of the five hardwoods are given in table 3.

Density of the Woods

The density of the softwood species ranged from 22.3 pounds per cubic foot for western redcedar to 26.8 for western hemlock. Both old- and second-growth Douglas-fir had the same density of 26 pounds per cubic foot. The densities of these samples of Douglas-fir were 2 pounds (or 7 percent) lower than the average density of a number of samples of coast-type, old-growth Douglas-fir woods previously tested. The density of the ponderosa pine was only 0.5 pound lower than old-growth Douglas-fir (table 1). The density of the western redcedar was essentially the same as that previously found for a sample of white fir, which is included in table 1 for comparison. The average density of the three most plentiful of the softwoods--that is, the two types of Douglas-fir and the western hemlock--was 26.3 pounds per cubic foot.

The density of the five hardwoods ranged from 20.1 pounds per cubic foot for black cottonwood to 35.6 for tanoak. Bigleaf maple was closest to cottonwood in density. The density of the red alder was 12 percent higher and that of both madrone and tanoak were over 50 percent higher than the density of the cottonwood. From the standpoint of the weight of wood that could be put into a digester and the production of pulp per digester, red alder or a half-and-half mixture of cottonwood and alder would have a small advantage over cottonwood alone; tanoak would be much more effective than alder as a substitute for all or part of the cottonwood. The density of the sample of tanoak used in these experiments was 2 pounds per cubic foot lower than that of a sample of California tanoak previously tested. The average density of the most important hardwoods--the black cottonwood and red alder--was 22.4 pounds.

Chemical Composition of the Woods

For purposes of comparison, the chemical components of several woods tested previously are given in table 2. Values included were for second-growth Douglas-fir, western redcedar, ponderosa pine, white fir, tanoak, average of 4 Douglas-fir woods from the Pacific Northwest, average of 2 samples of red alder, and an average of 18 broad-leaved pulpwoods. The Douglas-fir used in these experiments was not greatly different in chemical composition from that of western hemlock, white fir, or other samples of Douglas-fir from the Pacific Northwest. Differences in values for lignin, cellulose, and extractives of the softwoods were considered too small to have a marked influence on pulping behavior.

The higher lignin and lower holocellulose content of the softwoods, in comparison with those components obtained for the hardwoods, gave a definite indication that the softwoods would require more drastic pulping conditions and give lower yields of pulp.

Black cottonwood was lower in lignin and higher in cellulose content than the red alder. The necessity to remove more lignin from the alder than from the cottonwood could account for the larger chemical requirement found later in pulping the alder. Also, the lower cellulose content of the alder might explain the comparatively lower weight yield of pulp from that wood. Except for pentosan content, the values for this red alder sample were quite close to those of other red alder woods tested previously. Bigleaf maple was similar to red alder in chemical composition and required pulping conditions more like the alder than the cottonwood. Pacific madrone was lower in cellulose content and higher in extractables than the other hardwood species. These properties of madrone seem to offer a logical explanation for the comparatively low weight yield of pulp obtained from this species. The tanoak was very similar to a tanoak from California in chemical composition. The chemical properties of black cottonwood and tanoak were close to those of the average of the 18 broad-leaved pulpwoods.

Fiber Dimensions

For the determination of fiber length, cell diameter, and cell wall thickness, one sample, 1/2 inch square on the end grain and 3/4 inch along the grain, was taken from each disk that was cut from the logs of the five hardwoods. The sampling point in each disk was on a circle, dividing the outer half of the cross sectional area from the inner half. Fiber length determinations were based on measurements of 50 whole fibers from each sample, except those for the black cottonwood and red alder, which were based on about 1,000 measurements.

Cell diameter and cell wall thickness were measured with the Gertner-Leitz transversing microscope on the transverse surface of the samples. Measurements were made of the cells within a distance of approximately 1 millimeter, and an average was computed. This was called a reading. Five such readings were obtained for each sample. The total number of readings for a species, therefore, depended on the number of disks cut of that species. Thus, the standard deviation and the minimum and maximum estimated ranges of mean were based on averages of 105 readings for black cottonwood, 115 for red alder, 20 for bigleaf maple, and 40 each for Pacific madrone and tanoak.

The fiber measurements and statistical computations therefrom are given in table 3.

The fibers of black cottonwood, red alder, and bigleaf maple were the longest at about 1.3 millimeters. The length of the tanoak fiber at 1.1 millimeters was about 85 percent of that of the three longest fibered species. Pacific madrone, with the shortest fiber length at 0.7 millimeter, was only 57 percent of the fiber length of the three longest fibered hardwoods. Though no general correlation was found between the fiber dimensions and the pulp strength of these hardwoods, an interesting observation showed that madrone with its comparatively short and thick fiber gave the weakest pulp of all.

The cell diameters of cottonwood, alder, maple, and madrone were nearly the same at about 22 microns. The cell diameter of tanoak was about three-fourths of that of the other four species. Therefore, the tanoak fiber was much thinner and somewhat shorter than the cottonwood, alder, and maple fibers, but its ratio of length to diameter was fairly close to the ratios of those three species and about twice that of the short-length madrone fiber.

Cell wall thickness varied from 2.45 microns for alder to 3.85 for madrone. The cell wall thickness of both cottonwood and tanoak was close to the midpoint of this range. A 22-percent-thinner cell wall for alder than for cottonwood was the only significant difference in cell dimensions found for these two species.

SULFATE PULPING EXPERIMENTS

Experimental sulfate pulps were produced individually from all of the woods, from a mixture of equal parts of cottonwood and alder, and from a mixture of equal parts of old-growth Douglas-fir, second-growth Douglas-fir, hemlock, cottonwood, and alder.

In general, pulps were made on a small scale at different permanganate number levels and compared to reveal trends in chemical requirements that influence pulping, pulp yield, and unbleached pulp strength. Three small-scale pulps with permanganate numbers ranging from 15 to 20 for the softwood and 10 to 15 for the hardwoods were made from the old- and second-growth Douglas-fir, western hemlock, black cottonwood, red alder, and the mixture of cottonwood and alder, with a sulfate cooking liquor of 16 percent sulfidity. Small-scale pulps at the lowest permanganate number levels were also made from the old-growth Douglas-fir and the cottonwood with a 22 percent-sulfidity cooking liquor.

Pulps prepared on a pilot-plant scale to furnish material for the papermaking trials were made at the standard permanganate number levels of 15 for the softwoods and 10 for the hardwoods.

Description of Pulping Experiments

To determine pulp yields and chemical requirements to make pulp, portions of chips equivalent to from 5 to 7 pounds of moisture-free wood were cooked in 0.8-cubic-foot digesters. After cooking for a predetermined time, the pulped chips were dumped from the digester, broken up, and washed. The washed pulp was screened through a 12-cut (0.012-inch slot width) flat screen, pressed to approximately 30 percent dryness, and sampled for the moisture determination. The yields of screened pulp and screenings were based on the weight of the original wood and calculated on a moisture-free basis.

The pilot-plant-scale cooks were made in digesters of 14-cubic-foot capacity. The equivalent of from 100 to 134 pounds of moisture-free chips were used for these digestions. At the end of the cooking period, the pulps were blown into a blow tank and washed thoroughly. The washed pulp was screened through 12-cut plates and then 8-cut plates of a flat screen. The screened pulp was run over a wet machine to remove water and bring its consistence to about 25 percent fiber content. Samples were taken for moisture determination and for strength development by the beater test method.

No spent (black) liquor was used for dilution in the cooking liquor. Calculation of the ratio of liquor to wood in the digester included the moisture in the chips charged. The initial concentration of cooking chemicals in the digester can be derived from the tabulated data by multiplying the percentage of active alkali used by 10 and dividing the product by the liquor-to-wood ratio of 4. For example, when 10 percent of active alkali was used, the initial concentration of chemicals calculated as sodium oxide was 25 grams per liter.

The selection of the ratio of chemical to wood for each of the pilot-plant-scale digestions was based primarily on the ratio that was found most suitable in small-scale digestions. The cooking conditions used in all of the pulping tests were basically those that were used in mill practice for pulping Douglas-fir and cottonwood, but some adjustments had to be made to obtain pulps with the desired permanganate numbers from the experimental digesters. (The permanganate number test is used as a measure of the chlorine requirement for bleaching.) For pulps of the same permanganate number, the small-scale digesters will usually require more cooking chemicals and give weaker pulps than pilot-plant-scale digesters.

Discussion of Sulfate Pulping Experiments

Small-Scale Pulping Tests

The small-scale digestion data tabulated in tables 4, 5, 6, and 7 are designated by X following the digestion number.

Old-growth Douglas-fir pulps.--Cooking conditions suitable to produce a Douglas-fir pulp with a permanganate number of about 15 were established first, and then the amount of active alkali charged was varied to give pulps at two higher permanganate number levels of about 17 and 19. The cooking data are in table 4. Except for the amount of active alkali, the cooking conditions found suitable to pulp Douglas-fir to a permanganate number of 15 were considered as standard for the other softwood species and were held constant for all of the digestions on the softwoods.

The active alkali required for the Douglas-fir pulps with permanganate numbers of about 15 and 19 was 21.0 and 16.3 percent, respectively. Pulp yield increased as the permanganate number increased. Yield of screened pulp on a moisture-free basis ranged from 39.9 to 42.7 percent as the permanganate number increased from 15 to 19. The percentages of active alkali charged and of pulp yield were intermediate for the Douglas-fir pulp made at the 17 permanganate number level.

The strength of the pulps became higher as the permanganate number and yield were increased. The pulp with a permanganate number of 19 was about 20 percent higher in bursting strength and 15 percent higher in tearing resistance than the pulp with a permanganate number of 15 (table 5). Douglas-fir pulps with permanganate numbers of 15 (digestions Nos. 3707X, 3717X, table 4) and 19 (digestion 3710X) made from sulfate cooking liquor with a sulfidity of 22 percent were compared with pulps of similar permanganate numbers made at 16 percent sulfidity. At the 15 permanganate number level (digestions 3688X, 3691X), the pulp yields were the same, though the chemical requirement to make pulp at 22 percent sulfidity was lower. At the 19 permanganate number level, the yield of screened pulp made at 22 percent sulfidity was higher than that at 16, though at both sulfidities, the same percentage of active alkali was required.

Second-growth Douglas-fir pulps.--Second-growth Douglas-fir was pulped to a permanganate number of 15.3 with 19.0 percent of active alkali. Two percent less active alkali were required to cook the second-growth Douglas-fir than to pulp old-growth Douglas-fir to the same permanganate number. The screened pulp yield of 42.7 percent for the second-growth Douglas-fir was 3 percent higher than that of the old-growth Douglas-fir pulp yield at permanganate number of 15.0. Second-growth Douglas-fir pulps cooked to the two higher permanganate number levels required 1 to 2 percent less active alkali than that used to pulp old-growth Douglas-fir to the same permanganate number. In general, screened pulp yields for the second-growth Douglas-fir ranged from 2 to 4 percent higher than old-growth Douglas-fir.

The strength of the second-growth Douglas-fir pulps increased as their permanganate numbers and yields went up (table 5). These pulps, however, do not show any appreciable increase in strength over the corresponding old-growth Douglas-fir pulps, except for consistently higher folding endurance.

Western hemlock pulp.--Western hemlock pulps with permanganate numbers of 15.3, 17.7, and 19.8 required 21.0, 19.0, and 17.0 percent, respectively, of active alkali. The western hemlock pulp with the lowest permanganate number required the same amount of active alkali and had the same yield of screened pulp as the similarly cooked old-growth Douglas-fir pulp. At the higher permanganate number level, the western hemlock pulps were also equal in yields to those of old-growth Douglas-fir pulps, but they required a little more active alkali in pulping (table 4).

The increase in strength of the western hemlock pulps between the lowest and highest permanganate numbers was 27 percent in bursting strength and 15 percent in tearing resistance (table 5). Corresponding changes in these properties were 20 and 15 percent for old-growth Douglas-fir and 29 and 22 percent for second-growth Douglas-fir. Except for tearing resistance, the strength properties of western hemlock pulps were higher than those of old-growth Douglas-fir pulps. Comparing hemlock and Douglas-fir under the same cooking conditions, yield, and permanganate number, the strength properties of the hemlock pulp were lower in tearing resistance by 35 percent but higher in bursting strength by 9 percent, in folding endurance by 27 percent, and in breaking length by 17 percent.

Western redcedar pulp.--The chemical requirement to pulp western redcedar at the permanganate number level of 15 was the same as that of second-growth Douglas-fir, western hemlock, and ponderosa pine, and slightly lower than that of old-growth Douglas-fir. The yield of 40 percent by weight for the redcedar pulp was similar to that obtained for the old-growth Douglas-fir and hemlock pulps of the same permanganate number (table 4). The yield on a volume basis, however, in which the comparatively low density of the redcedar was considered, was markedly lower than that for any of the other softwood pulps.

Western redcedar pulps are usually characterized by high bursting strength (table 5). In these experiments, the bursting strength of the redcedar pulp was about the same as that of the ponderosa pine pulp and 26 percent higher than that of the old-growth Douglas-fir pulp. On the other hand, redcedar pulp was 11 percent lower in tearing resistance than the old-growth Douglas-fir pulp (digestions 3688X, 3691X).

Ponderosa pine pulp.--The pulping behavior of the ponderosa pine was similar to that of second-growth Douglas-fir, but its yield by weight at the permanganate number level of 15 was lower. The yield of pine pulp in pounds of moisture-free pulp per cubic foot of solid wood was equal to that of hemlock pulps and old-growth Douglas-fir pulp. At the same permanganate number level, ponderosa pine pulp had the best strength properties of any of the small-scale unbleached pulps tested. It was equal in tearing resistance and much higher in bursting strength than old-growth Douglas-fir pulp (table 5).

The experiments on ponderosa pine consisted of pulping in small-scale digesters only. Bleaching and papermaking evaluations were not made on this wood.

Black cottonwood pulp.-- Cooking conditions suitable to produce a black cottonwood pulp with a permanganate number of about 10 and a cooking liquor of 16 percent sulfidity were established first. Then the amount of active alkali charged was varied to give pulps at the two higher permanganate number levels of about 12.5 and 15. Except for the amount of active alkali, the cooking conditions found suitable to pulp the cottonwood to a permanganate number of 10 were considered as standard for the other hardwood species. They were held constant for all of the hardwood digestions except one cook on red alder.

The making of black cottonwood pulps with permanganate numbers of 10.4 and 15.6 required the use of 16.0 and 11.5 percent, respectively, of active alkali. The corresponding yields of pulp were 53.2 and 56.2 percent by weight. Using the slightly lower amount of active alkali of 10.0 percent in digestion 3712X (table 6) gave inadequate pulping with an excessive amount of screening rejects of 12.6 percent and a low yield of screened pulp. Black cottonwood was the easiest to pulp, required the smallest amount of active alkali, and gave the highest weight yield of pulp of the hardwoods. The cottonwood pulps were stronger than any of the other hardwood pulps at the same permanganate level. In contrast to the other hardwoods, however, cottonwood could not be pulped to permanganate numbers much above 15 without reducing the yield of screened pulp and obtaining excessive amounts of screenings. In general, the strength of the cottonwood pulps increased as their permanganate numbers increased (table 7).

A cottonwood pulp made with 22-percent-sulfidity liquor at the 10 permanganate number level had the same chemical requirement and pulp yield as one made with liquor of 16 percent sulfidity at the same permanganate number level. The bursting strength and tearing resistance of these pulps also were about the same. The absence of any significant effect of changing sulfidity on cottonwood is typical for many hardwoods when they are pulped to low permanganate numbers.

Red alder pulp.--A much greater amount of active alkali was required to cook red alder than to pulp black cottonwood to the same permanganate number. Red alder pulps with permanganate numbers of 12.2 and 14.8 required 19.5 and 16.3 percent, respectively, of active alkali. Corresponding pulp yields were 45.3 and 49.3 percent. A lower active alkali of 13.2 percent gave a high yield of 52.2 percent of screened pulp, while still maintaining a low level of screening rejects of 0.3 percent (digestion 3755X, table 6). The permanganate number of this pulp was 17.7. When black cottonwood was pulped to this permanganate number, the high screening rejects of 12.6 percent were obtained (digestion 3712X, table 6). The constant pulping schedule used for these hardwood species would not give a red alder pulp with a permanganate number of 10, even with the use of a large amount of alkali. It was necessary to use an additional hour of cooking at maximum temperature to bring the permanganate number down to about 10 (digestions 3797X, 3800X). The cooking conditions found suitable to pulp red alder to a yield of 43 percent and a permanganate number of 10 were the same as those considered necessary for the softwood species. Red alder required 5 percent more active alkali and gave 19 percent less screened pulp than did black cottonwood cooked to the 10 permanganate number level. The red alder pulps were weaker, especially at the lowest permanganate number level, than the black cottonwood pulps. At the 15 permanganate number level, however, the alder pulp was equal in bursting strength and only 10 percent lower in tearing resistance than black cottonwood.

Cottonwood-alder mixture pulp.--A mixture of black cottonwood and red alder in equal parts by weight was pulped to the three permanganate number levels. The pulps with permanganate numbers of 10.6 and 15.2 required 19.0 and 13.0 percent of active alkali, respectively. Corresponding pulp yields were 49.6 and 54.3 percent. The chemical requirement to pulp the mixture was very close to the calculated quantity indicated by the separate pulping of the two woods. However, the yields of screened pulp were 1 to 2 percent higher than expected yields as calculated. The tendency of the mixture to give higher than the estimated yields was confirmed by the results of pilot-plant-scale digestions. The bursting and tearing strengths of the small-scale mixture pulps were equal to or slightly higher than the average of these strengths for the pulps of the individual woods.

Because of the tendency of cottonwood to give more screening rejects at a permanganate number level of 15 than the other hardwoods, pulping it alone to a higher level than 15 seems undesirable. However, the data seem to indicate that the alder-cottonwood mixture could be satisfactorily pulped to a permanganate number level above 15. As long as satisfactory pulping is obtained, pulping to the higher permanganate number should give better pulp yield and strength.

Bigleaf maple, Pacific madrone, and tanoak pulps.--Bigleaf maple, Pacific madrone, and tanoak were all pulped with 21.0 percent of active alkali to allow a comparison of their pulping characteristics. Maple was the most difficult to pulp, and its pulp had a yield of 44.6 percent and a permanganate number of 12.3 (table 6). Madrone pulped much easier than the maple, and its pulp was 2 points lower in permanganate number. Madrone gave the lowest yield on a weight basis of all the hardwoods tested, but its yield on a volume basis was about equal to that of red alder pulp and higher than that of maple pulp. Tanoak was the easiest of these three hardwoods to pulp. The pulp had the lowest permanganate number and the highest weight and volume yields. This sample of tanoak, however, gave lower yields by weight and volume than a sample of tanoak from California previously tested (table 6).

Pilot-Plant-Scale Pulping Tests

The pulps made in the pilot plant were produced primarily to furnish material for bleaching and papermaking experiments. With most of the woods, the pilot-plant-scale digestions required lesser amounts of active alkali and gave higher yields of pulp than did the small-scale cooks at the same permanganate number. The results of the pilot-plant-scale pulping tests are included in tables 4, 5, 6, and 7 (digestion numbers without suffix X).

A comparison of the pulping characteristics of old- and second-growth Douglas-fir, western hemlock, and western redcedar cooked on the pilot-plant-scale showed that the active alkali required to pulp these softwoods varied only slightly in the range of 16.0 to 16.5 percent. This has practical interest, because considerable advantage is gained in industrial practice to use essentially the same amounts of chemicals for all of the different woods being pulped. The various hardwoods differed markedly in the amount of chemical required in the pilot-plant-scale pulping. The range of active alkali was from 13 percent for cottonwood to 19 percent for bigleaf maple. Both Pacific madrone and tanoak required 17 percent and red alder needed 18 percent.

The yields of pulp ranged from 40 percent for western redcedar to 54 percent for cottonwood. The yield from second-growth Douglas-fir was considerably higher than that from either western hemlock or old-growth Douglas-fir. The yield of pulp from the mixture of five woods (table 4) was 47 percent. The yield for the cottonwood-alder mixture (table 6) was 52 percent and that from alder alone was 49 percent. Yields calculated on a volume basis, in which the density of the wood is taken into consideration, varied from 8.9 pounds of moisture-free pulp per cubic foot of solid green wood for western redcedar to 16.9 for tanoak. The volume yield of old-growth Douglas-fir, western hemlock, and black cottonwood was about 11 pounds per cubic foot.

For the hardwood pilot-plant-scale pulps, cottonwood had the highest strength (table 7). In a decreasing order of strength, the cottonwood-alder mixture of pulp was next to cottonwood; alder and maple were about the same; next in order was tanoak; Pacific madrone was much lower than the tanoak. For the softwood pilot-plant-scale pulps, bursting strength was highest for the western hemlock; then, in decreasing order, were pulps from western redcedar, old-growth Douglas-fir, and second-growth Douglas-fir (table 5). In tearing resistance for the softwood pulps, the order was exactly reversed as second-growth Douglas-fir pulp had the highest and western hemlock pulp the lowest values.

Increasing the sulfidity of the cooking liquors from 16 to 22 percent for both old-growth Douglas-fir and cottonwood pulps caused no significant change in pulp yield, bursting strength, or tearing resistance. The main effect of the higher sulfidity was to give higher folding endurances for the unbleached sulfate pulps.

RED ALDER NEUTRAL SULFITE SEMICHEMICAL PULPS

The cooking conditions used in the neutral sulfite pulping experiments on red alder are given in table 8. In the small-scale digestions (digestions 1553Y and 1554Y), the softened chips were passed through an 8-inch, single-rotating disk mill to convert them to pulp. A pulp with a yield of 64.4 percent was produced. The amount of sodium sulfite required to give a pulp of this yield was somewhat greater than that required for aspen and white oak.

The strength properties obtained on the unbleached pulp are given in table 7. The pulp had good strength, equal to or better than that obtained on typical hardwood species. At a freeness of 600 milliliters, the red alder neutral sulfite pulp had bursting strength and breaking length comparable to the cottonwood sulfate pulps, but it was lower in tearing resistance and folding endurance.

The concentration and amount of chemicals used and the digestion schedule followed for the red alder neutral sulfite pulp made in the pilot plant (digestion 5646) were based on the conditions used in the small-scale digestions. The softened chips were passed through a double-rotating disk mill to convert them to pulp. A pulp with a yield of 63.7 percent was produced. The strength of this pulp was slightly lower than that of the pilot-plant-scale red alder sulfate pulp with a permanganate number of 10.3 (table 7).

PULP BLEACHING

Bleaching experiments were carried out to determine the amounts of chemicals required to bleach the pulps to a brightness of about 83 percent and to provide bleached pulps for strength evaluation and papermaking experiments. Samples of commercial sulfate pulp were obtained for references in the small-scale pulping and bleaching experiments. These consisted of a Douglas-fir unbleached pulp (shipment No. 4481), Douglas-fir bleached pulp (shipment 4482), black cottonwood unbleached pulp (shipment 4484), and black cottonwood bleached pulp (shipment 4483). Valley beater tests were made on each of these, and the data are given in table 9.

The Bleaching Method

A three-stage prehypochlorite process was selected as a test method for comparing the various pulps. The name of the process derives from the use of a hypochlorite in the first stage. After the hypochlorite treatment, the first stage is completed with an elemental chlorine treatment without intermediate washing. The second and third stages are the usual caustic soda extraction and hypochlorite treatments. The prehypochlorite process was selected because results previously obtained with it at the Forest Products Laboratory in the bleaching of loblolly pine, Douglas-fir, and eucalyptus sulfate pulps showed it favorable to strength retention at a high-brightness level. Also, compared to the usual multistage process, which employs only chlorination in the first stage, savings up to 15 percent of total chlorine equivalent had been observed.

Previous work had indicated that the optimum proportions of the chlorine requirement for the prehypochlorite stage were 50 percent in the form of hypochlorite and 50 percent as elemental chlorine. For this study, preliminary trials made on two Douglas-fir pulps and one western hemlock pulp reaffirmed these proportions as being satisfactory for obtaining optimum disperse viscosity and brightness values. The data for certain bleaching experiments are presented in tables 10 and 11.

Bleaching of Softwood Sulfate Pulps

The softwood sulfate pulps generally had higher bleach requirements than the hardwood sulfate pulps of the same permanganate number, as was to be expected. Compared on the basis of total chlorine consumed with a commercial Douglas-fir sulfate pulp of permanganate number of 14.9, the second-growth Douglas-fir pulp of the same permanganate number had a lower bleach requirement, while the old-growth Douglas-fir pulp (bleach 4756) had a higher bleach requirement. The old- and the second-growth Douglas-fir sulfate pulps with permanganate numbers near 20 were essentially the same in bleach requirement, but at a permanganate number of about 15, the second-growth Douglas-fir had a somewhat lower bleach requirement.

It has been observed previously at the Forest Products Laboratory that wood species affect the relation between pulp bleach requirement and permanganate number. This observation was confirmed in this study. For example, when the bleach requirements were adjusted by interpolation to a permanganate number of 15 and a brightness of 83, the order of species with respect to increasing bleach requirements of the pulps was western hemlock, second-growth Douglas-fir, redcedar, and old-growth Douglas-fir.

Bleaching of Hardwood Sulfate Pulps

As mentioned in the foregoing, the bleach requirements of the hardwood sulfate pulps were, in general, lower than those of the softwood pulps for equal permanganate numbers. On the adjusted basis, cottonwood pulp had the lowest bleach requirement and red alder pulp the highest. Likewise, the red alder pulp had about the same bleach requirement as western hemlock, the easiest to bleach of the softwoods.

The red alder-cottonwood sulfate pulps were intermediate in bleach requirement between red alder and cottonwood, as would be expected.

When adjusted to a permanganate number of 10, the tanoak sulfate pulp was similar in bleach requirement to cottonwood pulp with the same permanganate number. The madrone and bigleaf maple sulfate pulps had somewhat higher bleach requirements, which were similar to red alder sulfate pulp of the same permanganate number.

Increasing the sulfidity of the cooking liquor from 16 to 22 percent did not change the bleach requirement of cottonwood sulfate pulp.

Bleaching of Pulp Made from a Mixture of Softwoods and Hardwoods

Sulfate pulp made from the mixture of five species (old- and second-growth Douglas-fir, western hemlock, cottonwood, and red alder) at a permanganate number of 16.3 was bleached with about the same amount of total chlorine equivalent as that expected by an average of the requirements of the individual species.

Bleaching of Red Alder Neutral Sulfite Semichemical Pulp

The red alder neutral sulfite semichemical pulp was bleached with a three-stage process consisting of chlorination, caustic soda extraction, and calcium hypochlorite. Since this pulp had a modified Tingle number[3] of 9.2 and was bleached to a brightness of 83.6 percent with 11.3 percent total chlorine equivalent, its response to bleaching was in the same range as that of hardwood semichemical pulps in general. These results also agreed with those obtained previously in the bleaching of red alder semichemical pulps.

Yields of Bleached Pulps

The yields of the bleached sulfate pulps ranged from about 91 to 95 percent or more based on the weight of unbleached pulp. The permanganate number of the pulp or the kind of wood appeared to have no significant effect on the percentage loss during the bleaching operation (table 10).

Strength of Bleached Pulps (General)

A summary of the strength data for the bleached pulps, for which bleaching data are given in table 10, is presented in table 11. The strength retention values are based on strength at 400 milliliters, Canadian Standard freeness. In general, the strength retention was somewhat higher for the small-scale bleaches than for the pilot-plant bleaches. The reasons for this have not been fully determined as yet.

The data indicated no relationship between strength retention and the sulfidity of the cooking liquor in the pulping of either old-growth Douglas-fir or cottonwood. On the average, strength retention was about the same for the old-growth Douglas-fir and for the cottonwood sulfate pulps, whether the sulfidity was 16 or 22 percent.

Strength of Bleached Softwood Sulfate Pulps

Strength retention was about the same for old- and second-growth Douglas-fir, and western hemlock sulfate pulps of permanganate numbers of about 15 and 20. The strength retention for western redcedar sulfate pulp, at a permanganate number of about 16, was approximately the same as for the other softwoods just mentioned.

The mill-made sulfate pulp of Douglas-fir that was bleached at the Forest Products Laboratory (bleach 4563, tables 10 and 11) had excellent strength retention of 96 percent. This value was higher than those of the experimental pulps.

In actual strength, the experimental old-growth Douglas-fir sulfate pulp of permanganate number of 14.0 (bleach 4753, table 11) and the second-growth Douglas-fir sulfate pulp of permanganate number of 19.8 (bleach 4735, table 11) were equal to the commercially

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[3]Tappi 36, No. 3: 123-126 (March 1953).

bleached Douglas-fir sulfate pulp (shipment 4482, table 9). The Douglas-fir pulps bleached in the pilot plant for papermaking experiments were not quite so strong as the commercial pulp in all strength properties, although some were higher in tearing resistance.

The bleached hemlock and redcedar pulps were generally lower in actual strength, particularly in tearing resistance, than the commercially bleached Douglas-fir sulfate pulp.

Strength of Bleached Hardwood Sulfate Pulps

Cottonwood pulp with the permanganate number of 15 had higher strength retention than the pulp of the permanganate number of 10, but this order was reversed for the red alder and cottonwood-red alder sulfate pulps. When bleached in the pilot plant, the cottonwood pulp with permanganate number of above 15 retained 93 percent of its strength, but the red alder pulp retained only 78 percent.

In strength retention, the experimental bleached cottonwood pulps averaged 86 percent, ranging from 79 to 93 percent. In actual strength, the experimental bleached pulps compared favorably with the commercial bleached pulp (shipment 4483, table 9).

The bleached tanoak sulfate, although lower in actual strength than cottonwood and red alder sulfate, had a good strength retention value of 89 percent in the pilot-plant bleach.

Bigleaf maple appeared to have strength properties similar to those of tanoak and had good strength retention of 93 percent.

Madrone, with the lowest actual strength of all the pulps, had a strength retention of 122 percent in the pilot-plant bleach, which means that bleaching increased the strength by 22 percent.

Strength of Bleached Sulfate Pulp Made from a Mixture of Five Woods

The sulfate pulp made from the mixture of five woods (equal parts by weight of old-growth Douglas-fir, second-growth Douglas-fir, cottonwood, red alder, and western hemlock) with a permanganate number of 16.3, when bleached in the pilot plant, had a strength retention of 84 percent. The bleached pulp was somewhat lower in most strength properties than the commercial Douglas-fir bleached pulp (shipment 4482, table 9).

Strength of Bleached Red Alder Neutral Sulfite Semichemical Pulp

The bleached red alder neutral sulfite semichemical pulp was equal in actual strength to the bleached red alder sulfate pulp of permanganate number of 15, and stronger than the sulfate pulp of permanganate number of 10. Upon bleaching, some increase in actual strength was obtained, which is typical of hardwood neutral sulfite semichemical pulps.

PAPERMAKING EXPERIMENTS

Duplicating and offset papers were produced from different experimental softwood and hardwood pulps on the Fourdrinier paper machine operating at a wire speed of 65 feet per minute. Preliminary runs were performed on each grade with commercially made pulps, varying the processing, filler content, and machine conditions to establish reference sheets with properties at least as good as typical sheets produced commercially. When a satisfactory reference sheet was obtained, the machine conditions and processing conditions so established were held as constant as possible in the subsequent runs to permit the best comparison of the various pulp furnishes. Generally, only one run was made from a specific experimental pulp or pulp blend, and the results should therefore be considered indicative in nature. All papers were tested for strength and other physical properties in accordance with TAPPI standards.

Three commercial bleached pulps were obtained for use in the papermaking experiments. Shipment 4574 was expected to be a bleached Douglas-fir sulfate pulp, but a fiber analysis showed it contained about 21 percent cottonwood fiber by weight. Shipment 4575 was a bleached cottonwood sulfate pulp. Shipment 4576 was a bleached deinked wastepaper stock that contained approximately equal proportions of hardwood and softwood fibers as determined by a fiber count. The species of fibers identified in the deinked paper stock were fir, white pine, hemlock, cottonwood, maple, and red alder. The strength values of these pulps are given in table 9.

Duplicating Paper Experiments

Preliminary Runs

A number of preliminary runs were made to establish conditions necessary to produce a duplicating paper with printing qualtities comparable to commercial paper. The furnish of commercial pulps used in the preliminary runs consisted of 44 percent of the bleached Douglas-fir pulp (shipment 4574), 46 percent of the bleached cottonwood pulp (shipment 4575), and 10 percent of old papers (shipment 4576).

The papers were surface sized by applying a starch mixture to both sides of the sheet at the size press of the paper machine. Various concentrations of the starch mixture were tried in the exploratory work, and it was found that a concentration of about 1.25 pounds of starch per gallon (plus small amounts of an enzyme and a wax emulsion) gave the optimum erasing characteristics and provided material that could be consistently applied to the surface of the paper with the size press equipment on the experimental machine. This concentration was selected for the runs in which the different pulp furnishes were compared.

On the basis of the preliminary trials, the following conditions were established for the reference run with the commercial pulp and for the subsequent runs involving the different experimental pulps:

(a) Moderate jordaning of the entire furnish
(b) Adding 28.5 percent of clay, 1 percent of titanium, and 1 percent of rosin size to the pulp furnish
(c) Surface sizing with the starch mixture at an approximate temperature of 160° F.
(d) Calendering three bottom nips with pressure equivalent to the weight of the calender rolls

Experimental Pulp Furnishes

As mentioned earlier, a fiber analysis on the commercial Douglas-fir pulp showed it contained 21 percent cottonwood fiber by weight. The furnish of the preliminary runs, therefore, actually consisted of about 35 percent of Douglas-fir fiber, 55 percent of cottonwood fiber, and 10 percent of deinked wastepaper. Therefore, in the runs with the experimental softwood pulps, the amounts of experimental and commercial cottonwood pulps were adjusted to make the furnishes nearly equal to that just described. No adjustment was made for the small amount of cottonwood fiber in the wastepaper.

In runs with the experimental hardwood pulps, however, the amount used--with one exception--was equal to the amount of commercial cottonwood pulp used in the reference run;

that is, 46 percent. Therefore, all the runs of duplicating paper containing experimental hardwood pulps also contained about 8 percent of cottonwood fiber introduced with the commercial Douglas-fir pulp. In one run, the hardwood content was increased to 75 percent to note the effect of larger amounts of hardwood fiber on sheet characteristics. The remaining components of this furnish consisted of 15 percent of the commercial fir pulp and 10 percent of deinked wastepaper.

Effect of Different Softwood Species

The effect of different softwood species in duplicating paper was studied by comparing papers made with old-growth Douglas-fir, second-growth Douglas-fir, western hemlock, and western redcedar bleached sulfate pulps. These four pulps were prepared at a sulfidity of 16 percent.

Data presented in table 12 show that paper made from both second-growth Douglas-fir and hemlock sulfate pulp is at least comparable in most strength properties to that made from old-growth Douglas-fir pulp, indicating that these could be substituted for old-growth Douglas-fir pulp in the production of good-quality mimeograph paper. The paper made from second-growth Douglas-fir (machine run No. 5349) had higher strength properties, except for tearing resistance, than the old-growth wood. Although the second-growth Douglas-fir sheet was not as bulky, it had air resistance, oil receptivity, and smoothness values comparable to that made with the old-growth pulp. The paper containing the hemlock pulp (machine run 5346) was equivalent to that containing the old-growth Douglas-fir in burst, tensile, folds, and castor oil penetration, but it was slightly less porous. While the paper made from the redcedar pulp (machine run 5350) had good strength properties, which in some instances were better than that containing old-growth Douglas-fir, it was more dense and more resistant to the penetration of oil. On the basis of oil receptivity, redcedar would therefore be the least desirable of the four softwoods for use in this kind of paper.

Effect of Different Hardwood Species

The effect of different hardwood species in duplicating paper was tested by comparing papers made with cottonwood, red alder, a mixture of equal parts of cottonwood and red alder pulped together, Pacific madrone, and tanoak. All had been cooked with liquor of the same sulfidity, approximately 16 percent, to a permanganate number of about 10. The data are given in table 13. The replacement of experimental cottonwood pulp with red alder pulp (machine runs 5351 and 5354) resulted in improved burst, tensile, fold, and opacity properties without altering desirable printing characteristics (measured by castor oil penetration, air resistance and smoothness). Machine run 5355, made from a combination of red alder and cottonwood, gave the highest burst and tensile properties of any papers in this hardwood series. In opacity, this paper ranked midway between the papers made with the individual cottonwood and red alder pulps. Tanoak and madrone were found to benefit air resistance and oil receptivity. The paper containing the tanoak (machine run 5356) had strength properties comparable to that containing the cottonwood pulp. The sheet containing madrone (machine run 5357) was comparable to the cottonwood sheet in all strength properties, except for lower tearing resistance.

Effect of Increasing the Amount of Hardwood Pulp

In machine run 5367, the hardwood content (cottonwood pulp made with a cooking liquor with a sulfidity of 22) was 75 percent. This paper (table 13) had castor oil penetration, air resistance, and smoothness values comparable to the paper made with about 46 percent of experimental hardwood pulp. It was, however, more opaque, which indicates that greater amounts of hardwood pulp in the furnish tend to increase the clay-holding characteristics of the sheet. This is shown by its higher ash content. The strength of the sheet with higher hardwood content was, as expected, less than the one containing the lower percentage, but this probably would not be considered too detrimental for this kind of paper.

Effect of Paper Quality of Sulfidity of Cooking Liquor

The effect on paper quality of the sulfidity of the liquor used in cooking the softwood was investigated for old-growth Douglas-fir. As shown by machine runs 5344 and 5348 in table 12, increasing the sulfidity of the cooking liquor from 16 to 22 percent resulted in a duplicating paper with better strength properties except for tearing resistance. These properties were obtained without altering such desirable printing characteristics as porosity and castor oil penetration. The higher sulfidity, however, had a slightly adverse effect on the opacity of the sheet.

An improvement in such strength properties as tensile, burst, and fold was realized when the sulfidity of the cooking liquor used to pulp the cottonwood was increased. Paper containing cottonwood pulp made with a sulfidity of 22 percent (machine run 5352) had considerably higher burst and fold values than paper (machine run 5351) produced from cottonwood pulp made with a sulfidity of 16 percent (table 13). It also had less tendency to lint. The higher sulfidity had very little effect on such printing properties as porosity and oil receptivity.

Effect on Paper Quality of Permanganate Number of the Hardwood Pulp

Both cottonwood and red alder were pulped to permanganate numbers of 10 and 15. The strength of the sheet containing cottonwood was improved with pulp cooked to the higher permanganate number (machine runs 5351 and 5353, table 13). The pulp with the higher permanganate number, however, gave a sheet that was more resistant to the passage of air and to the penetration of oil. The red alder, cooked to the higher permanganate number (machine run 5347), also produced a sheet more resistant to the passage of air and to the penetration of oil than the sheet made from pulp with a lower permanganate number (machine run 5354). In the case of the red alder, no change in strength properties was noted.

Papers From Red Alder Neutral Sulfite Semichemical Pulps

In two runs, the bleached red alder neutral sulfite semichemical pulp was substituted for the cottonwood sulfate pulp in the typical pulp furnish used to make duplicating papers. For machine run 5364, the processing and machine conditions were similar to those used for the other duplicating papers. This paper was more dense than the reference sheet and those made from the experimental hardwood sulfate pulps. It also possessed a higher resistance to the passage of air and to absorbency of oil, both of which are undesirable in this particular type paper. It had, however, good strength properties, and in some cases, better than those obtained with the hardwood sulfate pulps (table 13).

The stuff freeness for this sheet was somewhat lower than that recorded on runs containing the sulfate pulps, which perhaps affected adversely the properties that measure printing characteristics--oil receptivity and air resistance. Therefore, in the next run (machine run 5365), the jordaning treatment was eliminated, resulting in a paper with better printing qualities but still not as good as those obtained with the sulfate pulps.

Paper from a Mixture of Five Species Pulped Together

The sulfate pulp prepared from the mixture of old- and second-growth Douglas-fir, hemlock, red alder, and cottonwood was used as 58 percent of the furnish for machine run 5366, the remainder consisting of 32 percent of the commercial cottonwood pulp and 10 percent of the deinked wastepaper. The properties of this paper were good (table 12), comparable to those made with the individual softwood or hardwood pulps, thus indicating that these woods can be pulped together, if desired, to make duplicating paper.

Offset Paper Experiments

Preliminary Runs

A few preliminary offset paper runs were first made using the bleached mill pulps to establish conditions necessary to produce an offset paper with printing quality comparable to commercial paper. The pulp furnish consisted of 50 percent of the commercial Douglas-fir pulp, 30 percent of the commercial cottonwood pulp, and 20 percent of deinked wastepaper. It was determined after several trials that the Douglas-fir pulp should be processed to a freeness of 750 milliliters and then blended with the other components. The addition of 27 percent of clay and 3 percent of titanium resulted in a paper with adequate ash content and other properties meeting the specification for the offset paper. This paper (machine run 5360, table 14) was considered as the reference for the series.

The size formulation for the offset papers was approximately the same as that for the duplicating paper runs, except that the enzyme was omitted.

Offset Paper from Experimental Softwood Pulps

Offset paper runs were made in which different experimental softwood pulps were substituted for the commercial Douglas-fir pulp. Because the commercial pulp contained a portion of shorter hardwood fibers, as mentioned earlier, the amounts of the experimental softwood pulps were reduced to 40 percent of the furnish. The balance of the furnishes consisted of 40 percent of the commercial cottonwood pulp and 20 percent of old papers. In machine run 5361, old-growth Douglas-fir pulp was used. The furnish in machine run 5362 contained the western hemlock pulp, while the second-growth Douglas-fir pulp was used in machine run 5363 (table 14). For comparative purposes, table 14 also contains properties obtained on a sample of commercially made offset paper, as well as those of the reference sheet. The experimental old-growth Douglas-fir and western hemlock pulps gave offset papers with about the same oil receptivity, air resistance, and opacity values as the reference sheet. The old- and second-growth Douglas-fir papers, however, were not as smooth as either the reference paper or the paper containing hemlock. The paper with the second-growth Douglas-fir was more absorbent than the experimental offset papers. The hemlock pulp produced paper with higher strength properties, except for tensile strength, than either of the two experimental Douglas-fir pulps.

Table 1.--Density of some western woods

Species	Shipment No.	Density[1]
		Lb. per cu. ft.
SOFTWOODS		
Douglas-fir, old-growth[2]	4384	26.0
Douglas-fir, old-growth[3]	....	28.1
Douglas-fir, second-growth[2]	4465	26.2
Western hemlock[2]	4385	26.8
Western redcedar[2]	4467	22.3
Ponderosa pine	4464	25.5
White fir[4]	4149	22.7
HARDWOODS		
Black cottonwood	4463	20.1
Red alder	4462	24.6
Bigleaf maple	4405	21.7
Pacific madrone	4407	30.5
Tanoak	4404	35.6
Tanoak[4]	4153	37.5

[1]Based on moisture-free weight and green volume.

[2]Slabwood.

[3]Average of density values previously obtained on a number of samples of coast-type Douglas-fir.

[4]Wood from California, previously tested.

Table 2.--Chemical composition of some western woods

Species	Shipment No.	Lignin	Cellulose: Holo	Cellulose: Alpha	Pentosans	Solubility in--: Alcohol-benzene	Solubility in--: Ether	Solubility in--: 1 percent sodium hydroxide	Solubility in--: Hot water	Ash
		Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
SOFTWOODS										
Douglas-fir, old-growth	4384	27.9	64.5	51.4	7.2	3.9	0.8	15.0	4.1	0.7
Douglas-fir[1]	......	28.3	66.6	48.2	5.3	3.8	1.5	13.3	3.9	.3
Douglas-fir, second-growth[2]	2467	28.0	69.9	52.6	4.9	2.4	.7	9.7	2.4	.2
Western hemlock	4385	29.4	66.9	48.8	6.8	3.1	.5	11.4	3.8	.7
Western redcedar[2]	2132	31.8	......	38.0	9.0	14.1	2.5	21.0	11.0	.3
Ponderosa pine[3]	2814	25.1	67.7	45.0	10.2	5.6	4.1	13.4	2.9	.5
White fir[4]	4149	27.8	65.5	49.1	5.5	2.1	.3	12.7	5.2	.4
HARDWOODS										
Black cottonwood	4463	21.4	75.0	49.1	19.2	2.7	.7	18.0	2.6	.5
Red alder	4462	24.2	72.1	45.4	22.4	2.9	.7	16.6	2.9	.3
Red alder[5]	......	24.2	73.5	43.9	19.0	2.8	.4	15.8	2.8	.4
Bigleaf maple	4405	24.5	68.3	45.5	22.4	2.5	.7	18.2	2.3	.7
Pacific madrone	4407	21.0	65.0	44.2	22.7	4.6	.4	22.6	7.4	.7
Tanoak	4404	19.1	70.9	46.0	21.4	3.4	.6	20.1	4.0	.6
Tanoak[4]	4153	19.0	70.4	45.2	18.3	2.0	.1	18.9	5.1	.7
Average of 18 U.S. broad-leaved pulpwoods	......	22	75	47	19	2.8	.6	14	3.5	.5

[1] Values are the average of 4 samples from the Pacific Northwest previously tested.

[2] Douglas-fir from the vicinity of Oakridge, Oreg., redcedar from Vancouver Island, British Columbia, Canada. Both previously tested.

[3] Pine from western Idaho, previously tested.

[4] Wood from California, previously tested.

[5] The average of 2 samples previously tested.

Table 3.--Fiber dimensions of some western hardwoods

Dimension and unit of measure	Mean[1]	Minimum	Maximum	Standard deviation	Coefficient of variation	Estimated range of mean[2]	
						Minimum	Maximum
					Percent		
BLACK COTTONWOOD							
Cell diameter (μ)	22.40	16.15	30.71	2.74	12.2	21.87	22.93
Cell wall thickness (μ)	3.15	1.92	6.76	.71	22.5	3.01	3.29
Fiber length (mm.)	1.31	.54	2.24	.25	18.8	1.30	1.33
RED ALDER							
Cell diameter (μ)	20.90	14.73	25.15	1.90	9.1	20.53	21.27
Cell wall thickness (μ)	2.45	1.77	4.23	.35	14.3	2.39	2.52
Fiber length (mm.)	1.28	.58	2.15	.22	17.4	1.27	1.29
BIGLEAF MAPLE							
Cell diameter (μ)	22.07	19.34	24.40	1.55	7.0	21.35	22.79
Cell wall thickness (μ)	2.71	2.30	3.35	.26	9.5	2.59	2.83
Fiber length (mm.)	1.28	.69	1.98	.22	17.4	1.25	1.31
PACIFIC MADRONE							
Cell diameter (μ)	22.45	16.62	32.06	2.90	12.9	21.53	23.38
Cell wall thickness (μ)	3.85	2.77	4.66	.41	10.6	3.79	3.92
Fiber length (mm.)	.74	.42	1.11	.12	16.3	.73	.76
TANOAK							
Cell diameter (μ)	16.59	13.82	19.90	1.60	9.6	16.33	16.84
Cell wall thickness (μ)	3.04	2.49	3.81	.28	9.3	2.95	3.13
Fiber length (mm.)	1.10	.55	1.75	.20	18.0	1.08	1.11

[1]Arithmetic averages. Averages for cell diameter and cell wall thickness are based on 105 readings for black cottonwood, 115 readings for red alder, 20 readings for bigleaf maple, and 40 readings for Pacific madrone and tanoak. A reading was the average of the measurements on the number of cells within a distance of approximately 1 millimeter. Averages for fiber length are based on 50 measurements of whole fibers for each wood, except black cottonwood and red alder where 1,000 measurements were made.

[2]Based on 95 percent probability computed from variances around sample means.

Table 4.--Conditions[1] and results for sulfate pulping of some western softwoods

Digestion No.	Weight of wood charged (moisture free)	Chemicals charged: Amount (moisture-free wood basis): NaOH plus Na_2S	Chemicals charged: Amount (moisture-free wood basis): Active alkali	Chemicals charged: Sulfidity[3]	Chemicals consumed based on chemicals	Yield[2]: Screened pulp: By volume	Yield[2]: Screened pulp: By weight	Yield[2]: Screenings by weight	Permanganate number
	Lb.	Percent	Percent	Percent	Percent	Lb. per cu. ft.	Percent	Percent	
DOUGLAS-FIR, OLD-GROWTH									
3692X	6.0	19.9	15.5	16.0	85.2	11.4	43.9	0.2	22.7
3697X,3702X	6.0	20.9	16.3	16.0	80.8	11.1	42.7	.2	19.1
4282,4283,4284	120.0	21.2	16.5	16.0	81.0	10.7	41.3	.1	14.0
3693X,3698X	6.0	23.1	18.0	16.0	77.5	10.7	41.2	.1	17.0
3688X,3691X	6.5	27.0	21.0	16.0	71.6	10.4	39.9	.0	15.2
3710X	6.0	20.9	16.3	22.0	83.6	11.5	44.1	.1	19.2
4295,4301	120.0	21.2	16.5	22.0	82.4	10.7	41.1	.0	15.2
3707X,3717X	6.0	25.0	19.5	22.0	72.3	10.5	40.3	.0	15.2
DOUGLAS-FIR, SECOND-GROWTH									
3798X,3802X	6.0	19.3	15.0	16.0	87.4	12.1	46.3	.6	19.8
4291,4297	120.0	20.6	16.0	16.0	81.8	12.1	46.3	.1	14.9
3806X,3809X	6.0	21.8	17.0	16.0	82.1	11.6	44.3	.1	17.4
3810X,3814X	6.0	24.4	19.0	16.0	79.2	11.2	42.7	.1	15.3
WESTERN HEMLOCK									
3701X	6.0	19.3	15.0	16.0	83.2	12.0	44.6	.4	25.2
4280,4288,4289	116.0	20.9	16.3	16.0	81.2	11.3	42.1	.1	15.0
3699X,3704X	6.0	21.8	17.0	16.0	79.8	11.7	43.6	.1	19.8
3716X,3721X	6.0	24.4	19.0	16.0	76.7	10.8	40.3	.0	17.7
3695X,3703X	6.0	27.0	21.0	16.0	70.4	10.6	39.7	.0	15.3
MIXTURE (5 SPECIES)[4]									
4323,4325	120.0	19.3	15.0	16.0	86.5	11.7	47.4	.4	16.3
WESTERN REDCEDAR									
4310,4329	107.8	21.2	16.5	16.0	84.4	8.9	39.9	.2	16.3
3811X,3815X	6.0	24.4	19.0	16.0	78.6	8.9	40.0	.1	15.5
3799X	6.0	27.0	21.0	16.0	74.4	8.4	37.5	.1	13.2
PONDEROSA PINE									
3796X	6.0	19.3	15.0	16.0	85.7	11.6	45.5	.1	19.5
3805X,3808X	6.0	24.4	19.0	16.0	74.6	10.5	41.0	.0	15.0
3801X	6.0	27.0	21.0	16.0	74.8	10.0	39.1	.0	12.5

[1] All digestions were made in steam-jacketed, cylindrical, tumbling digesters heated indirectly with steam. The cooking conditions other than those shown were: Liquor-wood ratio, 4.0; time from 30° to 90° C., 0.5 hour; time from 90° to 175° C., 1.0 hour; time at 175° C., 3.0 hours.

[2] Yield by weight on a moisture-free basis. Yield by volume based on moisture-free weight of pulp, moisture-free weight of wood, and green volume of wood.

[3] Sulfidity based on active alkali (sodium hydroxide plus sodium sulfide--both calculated as sodium oxide).

[4] Mixture of equal parts by weight (moisture free) of old-growth Douglas-fir, second-growth Douglas-fir, western hemlock, black cottonwood, and red alder.

Table 5.--Strength properties of softwood experimental unbleached sulfate pulps[1]

Digestion No.	Sulfidity of pulping liquor	Permanganate number	Freeness (Canadian Standard)	Beating time	Bursting strength	Tearing resistance	Folding endurance (M.I.T.)	Breaking length	Sheet density
	Percent		Ml.	Min.	Pts. per lb. per rm.[2]	G. per lb. per rm.[2]	Double folds	M.	G. per cc.
				OLD-GROWTH DOUGLAS-FIR					
3697X,3702X	16	19.1	600	21	1.13	2.68	780	8,100	0.55
			400	34	1.25	2.19	840	9,200	.70
4282,4283, 4284	16	14.0	600	24	1.32	2.66	900	7,700	.63
			400	39	1.42	2.26	1,290	8,900	.73
3693X,3698X	16	17.0	600	20	1.07	2.49	640	8,400	.62
			400	30	1.18	2.17	680	8,700	.67
3688X,3691X	16	15.2	600	19	.93	2.17	440	7,500	.59
			400	31	1.04	1.91	660	8,300	.65
4295,4301	22	15.2	600	21	1.11	2.53	1,280	7,800	.66
			400	32	1.29	2.30	1,580	8,800	.72
3707X,3717X	22	15.2	600	18	.85	2.24	710	6,600	.60
			400	28	.94	1.85	770	7,000	.68
				SECOND-GROWTH DOUGLAS-FIR					
3798X,3802X	16	19.8	600	25	1.11	2.50	1,200	8,300	.66
			400	41	1.39	2.35	1,200	9,200	.70
4291,4297	16	14.9	600	21	1.16	2.63	1,210	8,400	.63
			400	33	1.33	2.56	1,670	9,100	.70
3806X,3809X	16	17.4	600	21	.96	2.39	730	8,000	.62
			400	40	1.20	2.01	800	9,100	.70
3810X,3814X	16	15.3	600	17	.97	2.35	600	7,400	.62
			400	34	1.08	1.92	810	8,600	.71
				WESTERN HEMLOCK					
4280,4288, 4289	16	15.0	600	23	1.56	1.90	1,570	9,300	.69
			400	39	1.76	1.50	1,980	10,700	.78
3699X,3704X	16	19.8	600	22	1.25	1.60	830	9,500	.70
			400	36	1.43	1.42	1,060	10,700	.79
3716X,3721X	16	17.7	600	20	1.07	1.63	710	8,200	.69
			400	35	1.26	1.33	1,170	9,100	.78
3695X,3703X	16	15.3	600	19	1.00	1.44	490	8,800	.66
			400	32	1.13	1.24	840	9,700	.79

Table 5.--Strength properties of softwood experimental unbleached sulfate pulps[1]--Continued

Digestion No.	Sulfidity of pulping liquor	Permanganate number	Freeness (Canadian Standard)	Beating time	Bursting strength	Tearing resistance	Folding endurance (M.I.T.)	Breaking length	Sheet density
	Percent		Ml.	Min.	Pts. per lb. per rm.[2]	G. per lb. per rm.[2]	Double folds	M.	G. per cc.
MIXTURE (5 SPECIES)[3]									
4323,4325	16	16.3	600	15	0.82	2.12	380	7,500	0.61
			400	33	1.29	1.66	1,150	8,900	.76
WESTERN REDCEDAR									
4310,4329	16	16.3	600	15	1.33	1.78	1,260	10,300	.69
			400	30	1.59	1.54	2,260	11,300	.79
3811X,3815X	16	15.5	600	20	1.19	2.05	880	8,300	.66
			400	33	1.31	1.70	1,080	9,400	.69
PONDEROSA PINE									
3805X,3808X	16	15.0	600	27	.81	2.12	270	5,600	.62
			400	29	1.36	1.98	1,250	9,500	.83

[1]Strength values for 600- and 400-milliliter freenesses are interpolated from beater test curves.

[2]Ream size was 500 sheets, each 25 by 40 inches.

[3]Mixture of equal parts by weight (moisture free) of old-growth Douglas-fir, second-growth Douglas-fir, western hemlock, black cottonwood, and red alder.

Table 6.--Conditions[1] and results for sulfate pulping of some western hardwoods

Digestion No.	Weight of wood charged (moisture free)	Chemicals charged: Amount (moisture-free wood basis): NaOH plus Na_2S	Chemicals charged: Amount (moisture-free wood basis): Active alkali	Chemicals charged: Sulfidity[3]	Chemicals consumed based on chemicals charged	Yield[2]: Screened pulp: By volume	Yield[2]: Screened pulp: By weight	Yield[2]: Screenings by weight	Permanganate number
	Lb.	Percent	Percent	Percent	Percent	Lb. per cu. ft.	Percent	Percent	
BLACK COTTONWOOD									
3712X	5.0	12.9	10.0	16.0	92.7	9.1	45.2	12.6	17.4
4315,4326	100.0	14.5	11.3	16.0	94.2	10.9	54.0	3.2	14.9
3723X,3727X	5.0	14.8	11.5	16.0	93.0	11.3	56.2	.8	15.6
3713X	5.0	15.4	12.0	16.0	90.5	11.2	55.7	.3	13.7
3720X,3722X	5.0	16.7	13.0	16.0	90.1	11.1	55.2	.1	12.4
4292,4302	101.5	16.7	13.0	16.0	86.7	10.9	54.0	.0	10.0
3715X	5.0	18.0	14.0	16.0	86.6	11.2	55.6	.0	11.3
3714X,3729X	5.0	20.6	16.0	16.0	82.2	10.7	53.2	.0	10.4
3735X	5.0	14.8	11.5	22.0	91.6	11.3	56.4	.4	14.9
4296,4300	100.0	16.7	13.0	22.0	87.8	10.8	53.8	.1	9.7
3730X,3739X	5.0	20.6	16.0	22.0	84.1	10.7	53.4	.1	10.1
RED ALDER									
4299,4303	100.0	16.7	13.0	16.0	92.5	12.6	51.1	.3	14.6
3755X	6.0	17.0	13.2	16.0	94.9	12.8	52.2	.3	17.7
3754X,3756X	6.0	20.9	16.3	16.0	87.6	12.1	49.3	.0	14.8
4304,4308	100.0	23.1	18.0	16.0	80.0	12.0	48.7	.0	10.3
3763X,3769X	6.0	25.1	19.5	16.0	79.9	11.1	45.3	.1	12.2
3797X,3800X	6.0	27.0	21.0	16.0	84.1	10.6	42.9	.0	10.2
MIXTURE (2 SPECIES)[4]									
3786X,3792X,3794X	5.0	16.7	13.0	16.0	92.3	12.1	54.3	.1	15.2
4311,4318	100.0	19.3	15.0	16.0	85.2	11.6	52.0	.1	10.2
3772X,3783X	5.0	20.6	16.0	16.0	86.3	11.6	52.1	.1	12.4
3771X,3789X	5.0	24.4	19.0	16.0	74.5	11.1	49.6	.0	10.6
BIGLEAF MAPLE									
4322	120.0	24.4	19.0	16.0	81.7	10.2	47.0	.1	10.0
3832X	5.5	27.0	21.0	16.0	77.5	9.7	44.6	.2	12.3
PACIFIC MADRONE									
3831X	7.0	21.8	17.0	16.0	....	12.7	41.6	2.9	12.5
4316,4320	113.0	21.8	17.0	16.0	82.6	12.9	42.2	.0	10.5
3827X	7.0	27.0	21.0	16.0	85.0	12.1	39.7	.2	10.3
TANOAK									
4313,4317	110.0	21.8	17.0	16.0	87.5	16.9	47.6	.0	11.7
3824X	6.0	23.1	18.0	16.0	89.9	16.9	47.4	.9	12.0
3829X	7.0	27.0	21.0	16.0	82.0	16.2	45.6	.2	9.3
[5]3259X	7.0	17.5	13.7	25.5	93.2	18.5	49.3	3.9	13.8
[5]3258X	7.0	18.8	14.7	25.5	92.2	19.0	50.6	2.1	12.9
[5]4158,4160	134.0	18.8	14.7	25.5	92.2	18.6	49.5	.5	10.8
[5]3256X	7.0	20.0	15.6	25.5	91.3	19.0	50.7	.8	12.4
[5]3257X	7.0	20.0	17.6	25.5	....	18.8	50.0	.3	11.2

[1]All digestions were made in steam-jacketed, cylindrical, tumbling digesters heated indirectly with steam. The cooking conditions other than those shown were: Liquor-wood ratio, 4.0; time from 30° to 90° C., 0.5 hour; time from 90° to 175° C. temperature, 1.0 hour; time at 175° C., 2.0 hours (digestions Nos. 3797X and 3800X only, 3.0 hours).

[2]Yield by weight on a moisture-free basis. Yield by volume based on moisture-free weight of pulp, moisture-free weight of wood, and green volume of wood.

[3]Sulfidity based on active alkali (sodium hydroxide plus sodium sulfide--both calculated as sodium oxide).

[4]Mixture of equal parts by weight (moisture free) of black cottonwood and red alder.

[5]Data on wood from California, previously tested. The maximum temperature of these digestions was 170° C., and time at maximum temperature, 1.5 hours.

Table 7.--Strength properties of hardwood experimental unbleached sulfate and neutral sulfite semichemical pulps[1]

Digestion No.	Sulfidity of pulping liquor	Permanganate number	Freeness (Canadian Standard)	Beating time	Bursting strength	Tearing resistance	Folding endurance (M.I.T.)	Breaking length	Sheet density
	Percent		Ml.	Min.	Pts. per lb. per rm.[2]	G. per lb. per rm.[2]	Double folds	M.	G. per cc.
				BLACK COTTONWOOD SULFATE PULP					
4315,4326	16	14.9	600	6	0.68	1.47	50	6,100	0.65
			400	20	1.31	1.38	670	10,300	.83
3723X,3727X	16	15.6	600	12	.78	1.30	150	6,600	.74
			400	28	1.19	1.28	1,170	10,800	.80
3720X,3722X	16	12.4	600	11	.63	1.35	30	6,400	.63
			400	27	1.08	1.33	540	10,300	.78
4292,4302	16	10.0	600	8	.58	1.27	60	5,900	.66
			400	30	1.25	1.31	960	10,900	.82
3714X,3729X	16	10.4	600	14	.50	1.12	20	5,500	.62
			400	37	.95	1.11	370	8,500	.77
4296,4300	22	9.7	600	6	.57	1.27	30	6,700	.65
			400	26	1.18	1.20	1,790	10,000	.80
3730X,3739X	22	10.1	600	14	.52	1.07	30	5,700	.64
			400	36	1.04	1.07	490	9,800	.77
				RED ALDER SULFATE PULP					
4299,4303	16	14.6	600	7	.54	1.58	50	5,300	.62
			400	23	1.36	1.32	620	10,900	.83
3754X,3756X	16	14.8	600	13	.56	1.42	20	3,600	.58
			400	42	1.22	1.15	730	8,300	.81
4304,4308	16	10.3	600	10	.43	1.30	20	4,700	.58
			400	34	1.03	1.19	450	9,100	.76
3763X,3769X	16	12.2	600	13	.41	1.06	10	4,800	.53
			400	44	.88	1.08	380	8,400	.74
3797X,3800X	16	10.2	600	12	.44	1.02	10	4,500	.45
			400	40	.74	.97	130	7,900	.76
				RED ALDER NEUTRAL SULFITE SEMICHEMICAL PULP					
1553Y,1554Y	....	....	600	11	.70	1.18	70	8,100	.64
			400	25	1.08	1.00	230	9,800	.72
5646	....	....	530	0	.56	1.21	20	5,600	.59
			400	8	.95	1.12	150	8,500	.73

Table 7.--Strength properties of hardwood experimental unbleached sulfate and neutral sulfite semichemical pulps[1]--Continued

Digestion No.	Sulfidity of pulping liquor	Permanganate number	Freeness (Canadian Standard)	Beating time	Bursting strength	Tearing resistance	Folding endurance (M.I.T.)	Breaking length	Sheet density
	Percent		Ml.	Min.	Pts. per lb. per rm.[2]	G. per lb. per rm.[2]	Double folds	M.	G. per cc.
COTTONWOOD-ALDER MIXTURE (EQUAL PARTS) SULFATE PULP									
3786X,3792X, 3794X	16	15.2	600	14	0.55	1.45	90	5,600	0.64
			400	37	1.28	1.25	1,500	10,200	.82
4311,4318	16	10.2	600	9	.53	1.40	30	6,000	.61
			400	31	1.06	1.24	740	9,900	.78
3772X,3783X	16	12.4	600	15	.42	1.32	10	4,900	.56
			400	46	.99	1.20	400	8,700	.80
3771X,3789X	16	10.6	600	16	.16	1.28	10	4,200	.58
			400	49	.92	1.05	300	8,100	.79
BIGLEAF MAPLE SULFATE PULP									
4322	16	10.0	600	9	.58	1.37	50	6,000	.63
			400	26	1.00	1.22	430	8,600	.77
PACIFIC MADRONE SULFATE PULP									
4316,4320	16	10.5	530	0	.09	.24	0	1,000	.47
			400	8	.20	.44	2	2,700	.56
TANOAK SULFATE PULP									
4313,4317	16	11.7	600	5	.33	1.00	5	3,700	.54
			400	23	.81	1.12	100	7,200	.75
[3]4158	26	10.8	600	11	.46	1.23	10	4,800	.60
			400	35	.82	1.24	120	7,500	.72

[1]Strength values for 600- and 400-milliliter freenesses are interpolated from beater test curves.

[2]Ream size was 500 sheets, each 25 by 40 inches.

[3]Data on wood from California, previously tested.

Table 8.--Neutral sulfite semichemical pulping conditions for red alder

Digestion No.	1553Y, 1554Y	5646
Weight of wood charged[1] ... lb.	7.0	124.7
Liquor charged:		
Volume per 100 pounds of wood[1] ... gal.	45.0	43.25
Concentration:		
Sodium sulfite ... gm. per l.	62.2	62.2
Sodium bicarbonate ... gm. per l.	15.5	16.5
Amount per 100 pounds of wood:[1]		
Sodium sulfite ... lb.	23.2	22.3
Sodium bicarbonate ... lb.	5.8	5.9
Digestion schedule:		
Presteaming ... hr.	0.5	0.5
Cooking temperature ... °C.	175	175
Rise to 175° C. ... hr.	2.5	2.5
Held at 175° C. ... hr.	4.6	5.75
Spent liquor:		
Sodium sulfite ... gm. per l.	9.9	8.0
Pulp yield ... percent	64.4	63.7

[1]Moisture-free basis.

Table 9.--Strength data[1] for commercial sulfate pulps and deinked old paper

Shipment No.	Freeness (Canadian Standard)	Beating time	Bursting strength	Tearing resistance	Folding endurance (M.I.T.)	Breaking length	Sheet density
	Ml.	Min.	Pts. per lb. per rm.[2]	G. per lb. per rm.[2]	Double folds	M.	G. per cc.
	DOUGLAS-FIR UNBLEACHED PULP, PERMANGANATE NUMBER 14.9						
4481	600	22	1.22	2.72	1,200	7,900	0.66
	400	37	1.33	2.17	1,340	9,200	.71
	DOUGLAS-FIR BLEACHED PULP, BRIGHTNESS 79.4 PERCENT						
4482	600	12	1.05	2.13	630	7,600	.61
	400	26	1.21	1.78	880	8,900	.71
	BLACK COTTONWOOD UNBLEACHED PULP, PERMANGANATE NUMBER 12.3						
4484	600	6	.54	1.32	35	5,500	.61
	400	22	1.23	1.26	690	10,000	.78
	BLACK COTTONWOOD BLEACHED PULP, BRIGHTNESS 84.1 PERCENT						
4483	600	8	.70	1.40	60	6,100	.61
	400	22	1.02	1.02	580	8,800	.77
	DOUGLAS-FIR BLEACHED PULP,[3] BRIGHTNESS 76.2 PERCENT						
4574	600	10	.92	2.09	600	7,000	.63
	400	22	1.38	1.56	1,300	9,900	.77
	BLACK COTTONWOOD BLEACHED PULP, BRIGHTNESS 77.2 PERCENT						
4575	600	2	.50	1.39	15	4,200	.54
	400	27	1.14	1.12	450	9,300	.78
	OLD PAPERS, DEINKED, BLEACHED, BRIGHTNESS 65.8 PERCENT						
4576	400	9	.41	.87	7	4,650	.63

[1]Strength values for 600- and 400-milliliter freenesses are interpolated from beater test curves.

[2]Ream size was 500 sheets, each 25 by 40 inches. All tests conducted on approximately 55-pound sheets.

[3]This pulp was estimated by microscopic examination to contain 21 percent of cottonwood fiber by weight.

Table 10.--Summary of selected bleaching tests on pulps made from some western woods

Bleach No.	Digestion No.	Permanganate number	Bleaching treatment[1]				Total chlorine		Bleached pulp	
			Stage 1		Stage 3		Applied	Consumed	Brightness	Yield
			Chlorine applied	Chlorine consumed	Chlorine applied	Chlorine consumed				
			Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
COMMERCIAL DOUGLAS-FIR SULFATE PULPS[2]										
4563	....	14.9	5.4	5.3	1.6	1.5	7.0	6.8	81.0	96.1
OLD-GROWTH DOUGLAS-FIR SULFATE PULPS										
4753	4282,4283,4284	14.0	6.5	5.6	1.1	.9	7.6	6.5	81.6	96.3
[3]4756	4282,4283,4284	14.0	6.2	5.7	1.5	1.4	7.7	7.1	82.3	95.4
4551	3697X,3702X	19.1	7.2	7.1	2.0	1.7	9.2	8.8	82.6	96.6
[3,4]4757	4295,4301	15.2	7.0	6.4	1.5	1.5	8.5	7.9	82.0	92.6
SECOND-GROWTH DOUGLAS-FIR SULFATE PULPS										
[3]4770	4291,4297	14.9	4.8	4.6	1.5	1.4	6.3	6.0	81.9	93.3
4735	3798X,3802X	19.8	7.8	7.6	1.8	1.6	9.6	9.2	82.4	97.0
WESTERN HEMLOCK SULFATE PULPS										
[3]4758	4280,4288,4289	15.0	5.0	4.3	.6	.6	5.6	4.9	83.0	97.5
4554	3699X,3704X	19.8	7.0	6.9	2.0	1.7	9.0	8.6	82.8	94.2
WESTERN REDCEDAR SULFATE PULPS										
[3]4793	4310,4329	16.3	5.6	5.3	2.5	2.3	8.1	7.6	81.0	91.4
BLACK COTTONWOOD SULFATE PULPS										
[3]4762	4292,4302	10.0	3.0	2.6	.8	.7	3.8	3.3	83.5	95.5
[3]4791	4315,4326	14.9	5.0	4.7	1.0	.9	6.0	5.6	84.2	91.8
[3,4]4766	4296,4300	9.7	3.0	2.7	.7	.6	3.7	3.3	82.7	93.7
RED ALDER SULFATE PULPS										
[3]4773	4304,4308	10.3	3.4	3.2	1.5	1.4	4.9	4.6	81.6	92.1
[3]4782	4299,4303	14.6	4.6	4.3	1.5	1.5	6.1	5.8	81.6	93.4
RED ALDER-BLACK COTTONWOOD (EQUAL PARTS) SULFATE PULPS										
[3]4777	4311,4318	10.2	3.0	2.7	1.2	1.1	4.2	3.8	81.7	91.8
4754	3786X,3792X,3794X	15.2	4.8	4.4	.9	.8	5.7	5.2	82.4	97.4

Table 10.--Summary of selected bleaching tests on pulps made from some western woods--Continued

Bleach No.	Digestion No.	Permanganate number	Bleaching treatment[1] Stage 1 Chlorine applied	Stage 1 Chlorine consumed	Stage 3 Chlorine applied	Stage 3 Chlorine consumed	Total chlorine Applied	Total chlorine Consumed	Bleached pulp Brightness	Bleached pulp Yield
			Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
				SULFATE PULPS FROM A MIXTURE OF 5 SPECIES[5]						
[3]4780	4323,4325	16.3	5.4	5.3	1.0	.9	6.4	6.2	83.6	95.4
				TANOAK SULFATE PULPS						
[3]4776	4313,4317	11.7	3.6	3.1	1.0	.9	4.6	4.0	83.5	94.3
				MADRONE SULFATE PULPS						
[3]4778	4316,4320	10.5	3.4	3.1	1.5	1.2	4.9	4.3	81.8	93.0
				BIGLEAF MAPLE SULFATE PULPS						
4779	4322	10.0	3.0	2.6	1.5	1.2	4.5	3.8	81.6	95.3
				RED ALDER NEUTRAL SULFITE SEMICHEMICAL PULPS						
[3]4795	5646N	[6]9.2	9.0	8.9	2.3	2.3	11.3	11.2	83.6	78.6

[1]In stage 1, calcium hypochlorite was applied at 8 percent consistence and 25° C. After it was consumed, chlorine was applied at 2 percent consistence and 25° C. without intermediate washing, except in pilot-plant bleaches where some washing occurred during transfer of the pulp between prehypochlorite and chlorination treatments. The total chlorine applied in stage 1 was divided approximately 50 percent to each step. In bleach No. 4795 only chlorine was applied in stage 1. Stage 2 was extraction for 1 hour with 2 percent caustic soda at 70° C., except in bleach No. 4795 where temperatures of 50° and 40° C., respectively, were used. In stage 3, calcium hypochlorite was applied at 10 percent consistence and 37° C. The pulps were washed after each complete reaction stage. The percentage of chemicals are based on weight of moisture-free pulp.

[2]Unbleached millmade pulp (shipment No. 4481).

[3]Bleached in pilot plant.

[4]Pulps made with liquor of 22 percent sulfidity.

[5]Equal mixture of old-growth Douglas-fir, second-growth Douglas-fir, western hemlock, black cottonwood, and red alder.

[6]Modified Tingle number.

Table 11.--Strength of selected bleached sulfate and neutral sulfite semichemical pulps from some western woods[1]

Bleach No.	Permanganate number of unbleached pulp	Freeness (Canadian Standard)	Beating time	Bursting strength	Tearing resistance	Folding endurance (M.I.T.)	Breaking length	Sheet density	Strength retention[2]: Bursting strength	Strength retention[2]: Tearing resistance	Strength retention[2]: Breaking length	Strength retention[2]: Average
		Ml.	Min.	Pts. per lb. per rm.[3]	G. per lb. per rm.[3]	Double folds	M.	G. per cc.	Percent	Percent	Percent	Percent
					DOUGLAS-FIR SULFATE PULP BLEACHED AT FOREST PRODUCTS LABORATORY							
4563	14.9	600	16	1.17	2.27	720	7,300	0.64	....	....	....	....
		400	28	1.27	1.98	990	9,250	.72	96	91	101	96
					OLD-GROWTH DOUGLAS-FIR SULFATE PULPS							
4753	14.0	600	14	1.15	2.30	470	7,750	.63	....	....	....	....
		400	25	1.28	1.78	990	8,200	.70	88	77	90	85
[4]4756	14.0	600	9	.74	2.78	325	5,000	.51	....	....	....	....
		400	22	1.01	2.30	670	6,500	.65	69	100	71	80
4551	19.1	600	15	.99	1.78	472	6,450	.67	....	....	....	....
		400	25	1.04	1.67	534	8,970	.71	83	77	98	86
[4,5]4757	15.2	600	8	.75	2.15	220	5,600	.61	....	....	....	....
		400	16	.89	1.70	470	6,400	.66	69	74	73	72
					SECOND-GROWTH DOUGLAS-FIR SULFATE PULPS							
[4]4770	14.9	600	13	.89	2.50	510	6,600	.64	....	....	....	....
		400	22	1.10	1.90	720	7,600	.71	83	74	84	80
4735	19.8	600	16	1.11	1.98	520	7,800	.61	....	....	....	....
		400	30	1.34	1.72	660	9,500	.70	96	73	103	91

(Sheet 1 of 4)

Table 11.--Strength of selected bleached sulfate and neutral sulfite semichemical pulps from some western woods[1]--Continued

Bleach No.	Permanganate number of unbleached pulp	Freeness (Canadian Standard)	Beating time	Bursting strength	Tearing resistance	Folding endurance (M.I.T.)	Breaking length	Sheet density	Strength retention[2] Bursting strength	Strength retention[2] Tearing resistance	Strength retention[2] Breaking length	Strength retention[2] Average
		Ml.	Min.	Pts. per lb. per rm.[3]	G. per lb. per rm.[3]	Double folds	M.	G. per cc.	Percent	Percent	Percent	Percent
						WESTERN HEMLOCK SULFATE PULPS						
[4]4758	15.0	600	7	0.95	2.15	470	5,200	0.59				
		400	19	1.12	1.45	685	7,700	.74	64	97	72	78
4554	19.8	600	16	1.03	1.40	500	7,950	.69				
		400	27	1.20	1.20	800	9,600	.77	84	84	90	86
						WESTERN REDCEDAR SULFATE PULP						
[4]4793	16.3	600	3	.86	2.15	130	5,400	.59				
		400	17	1.18	1.16	525	8,650	.79	74	75	77	75
						BLACK COTTONWOOD SULFATE PULPS						
[4]4762	10.0	600	0	.35	.96	7	3,270	.58				
		400	20	1.02	1.08	189	7,760	.82	82	83	71	79
[4]4791	14.9	600	0	.42	1.38	10	3,290	.58				
		400	16	1.20	1.40	850	9,000	.79	92	101	87	93
[4,5]4766	9.7	600	0	.40	1.13	8	3,370	.59				
		400	20	1.10	1.13	339	8,040	.81	86	94	80	87
						RED ALDER SULFATE PULPS						
[4]4773	10.3	600										
		400	16	.91	1.05	150	7,350	.77	88	88	81	86
[4]4782	14.6	600										
		400	16	1.04	1.18	450	7,600	.76	76	89	70	78

Table 11.--Strength of selected bleached sulfate and neutral sulfite semichemical pulps from some western woods[1]--Continued

Bleach No.	Permanganate number of unbleached pulp	Freeness (Canadian Standard)	Beating time	Bursting strength	Tearing resistance	Folding endurance (M.I.T.)	Breaking length	Sheet density	Strength retention[2]: Bursting strength	Strength retention[2]: Tearing resistance	Strength retention[2]: Breaking length	Strength retention[2]: Average
		Ml.	Min.	Pts. per lb. per rm.[3]	G. per lb. per rm.[3]	Double folds	M.	G. per cc.	Percent	Percent	Percent	Percent
						RED ALDER-BLACK COTTONWOOD (EQUAL PARTS) SULFATE PULPS						
[4]4777	10.2	600	0	0.33	1.08	5	3,260	0.54				
		400	23	1.09	1.10	500	8,500	.81	103	89	86	93
4754	15.2	600	8	.55	1.10	60	4,800	.62				
		400	33	1.24	1.08	1,100	9,100	.79	97	86	89	91
						SULFATE PULP FROM A MIXTURE OF 5 SPECIES[6]						
[4]4780	16.3	600	6	.89	1.85	325	5,100	.69				
		400	18	1.06	1.35	660	7,900	.75	82	81	89	84
						TANOAK SULFATE PULP						
[4]4776	11.7	400	13	.77	1.01	85	6,000	.71	95	90	83	89
						MADRONE SULFATE PULP						
[4]4778	10.5	400	3	.26	.50	2	3,300	.63	130	114	122	122
						BIGLEAF MAPLE SULFATE PULP						
4779	10	600	2	.40	1.12	10	3,100	.53				
		400	26	.92	1.10	220	8,300	.73	92	90	97	93

Table 11.--Strength of selected bleached sulfate and neutral sulfite semichemical pulps from some western woods[1]--Continued

Bleach No.	Permanganate number of unbleached pulp	Freeness (Canadian Standard)	Beating time	Bursting strength	Tearing resistance	Folding endurance (M.I.T.)	Breaking length	Sheet density	Strength retention[2]			
									Bursting strength	Tearing resistance	Breaking length	Average
		Ml.	Min.	Pts. per lb. per rm.[3]	G. per lb. per rm.[3]	Double folds	M.	G. per cc.	Percent	Percent	Percent	Percent
RED ALDER NEUTRAL SULFITE SEMICHEMICAL PULP												
[4]4795	[7]9.2	600										
		400	1	1.14	1.15	240	8,100	.76	120	103	95	106

[1]Strength values for 600- and 400-milliliter freenesses are interpolated from beater test curves.
[2]At 400-milliliter Canadian Standard freeness.
[3]Ream size was 500 sheets, each 25 by 40 inches.
[4]Bleached in pilot plant.
[5]Pulp made with 22 percent sulfidity cooking liquor.
[6]Equal parts of old-growth Douglas-fir, second-growth Douglas-fir, western hemlock, black cottonwood, and red alder.
[7]Modified Tingle number.

Table 12.--Test results on mimeograph papers made from black cottonwood and some western softwood pulps

Machine run No.	Bleached sulfate pulp furnish[1]: Species	Bleach No.	Sulfidity	Permanganate number	Sheet properties[2]: Ream weight (500 sheets): 25 by 40 inches	Ream weight (500 sheets): 17 by 22 inches	Thickness	Density	Bursting strength	Bursting strength	Average tearing resistance	Average tearing resistance	Average folding endurance (M.I.T.)	Average tensile strength	Castor oil penetration	Air resistance (Gurley)	Opacity	Smoothness (Bekk)	Brightness (G.E. equivalent)	Ash content
					Lb.	Lb.	Mils	G. per cc.	Pts.	Pts. per lb. per rm.[3]	G.	G. per lb. per rm.[3]	Double folds	Lbs. per in. width	Sec.	Sec. per 100 cc.	Percent	Sec.	Percent	Percent
	COMMERCIAL PAPER																			
(4)	....				52.5	19.6	4.4	0.66	30.9	0.58	62.7	1.18	65	23.3	52	16	89.4	13	75.7	13.4
	REFERENCE RUN																			
[5]5345	....				53.2	19.9	4.6	.64	23.3	.42	70.4	1.28	30	22.8	32	6	87.7	10	77.5	10.7
	EFFECT OF DIFFERENT SOFTWOOD SPECIES																			
5344	Old-growth Douglas-fir	4756	16	14.0	56.2	21.0	4.8	.65	19.0	.34	85.0	1.51	15	18.0	31	6	87.4	10	78.9	10.0
5349	Second-growth Douglas-fir	4770	16	14.9	55.5	20.8	4.5	.68	27.2	.49	74.2	1.31	31	24.0	29	6	86.4	11	75.7	11.0
5346	Western hemlock	4758	16	15.0	53.2	19.9	4.6	.64	19.9	.36	62.8	1.15	14	20.1	33	11	87.5	14	78.2	11.2
5350	Western redcedar	4793	16	16.3	53.8	20.1	4.3	.69	23.0	.42	64.2	1.18	14	22.0	61	11	87.5	16	78.3	11.4
5366	Mixture (5 species)[6]	4780	16	16.3	53.4	20.0	4.3	.69	26.5	.49	63.5	1.17	29	21.6	26	8	85.6	12	79.6	11.7
	EFFECT OF SULFIDITY																			
5344	Old-growth Douglas-fir	4756	16	14.0	56.2	21.0	4.8	.65	19.0	.34	85.0	1.51	15	18.0	31	6	87.4	10	78.9	10.0
5348	.........do.........	4757	22	15.2	54.2	20.3	4.5	.67	26.7	.49	68.0	1.25	39	21.5	29	6	85.6	9	75.1	10.9

[1]All furnishes except reference run and machine run 5366 contained 55 percent of commercial cottonwood pulp (shipment No. 4575), 10 percent of old papers (shipment No. 4576), and 35 percent of the various experimental softwood pulps.

[2]Papers were surface sized.

[3]Ream size was 500 sheets, 25 by 40 inches.

[4]A paper of Western manufacture. Shipment No. 4581.

[5]The furnish consisted of 44 percent of commercial Douglas-fir pulp (shipment No. 4574) that contained 21 percent of cottonwood fibers by weight, 46 percent of commercial cottonwood pulp (shipment No. 4575), and 10 percent of old papers (shipment No. 4576).

[6]Consisted of equal parts by weight of old-growth and second-growth Douglas-fir, western hemlock, red alder, and black cottonwood fibers. This mixture comprised 58 percent of the furnish with remainder consisting of 32 percent of commercial cottonwood pulp (shipment No. 4575) and 10 percent of old papers (shipment No. 4576).

Table 13.--Test results on mimeograph papers made from Douglas-fir and some western hardwood pulps

Machine run No.	Pulp furnish[1]				Sheet properties[2]															
	Species	Bleach No.	Sulfidity of cooking liquor	Permanganate number unbleached pulp	Ream weight (500 sheets) 25 by 40 inches	Ream weight (500 sheets) 17 by 22 inches	Thickness	Density	Bursting strength		Average tearing resistance		Average folding endurance (M.I.T.)	Average tensile strength	Castor oil penetration	Air resistance (Gurley)	Opacity	Smoothness (Bekk)	Brightness (G.E. equivalent)	Ash content
			Percent		Lb.	Lb.	Mils	G. per cc.	Pts.	Pts. per lb. per rm.[3]	G.	G. per lb. per rm.[3]	Double folds	Lb. per in. width	Sec.	Sec. per 100 cc.	Percent	Sec.	Percent	Percent
								COMMERCIAL PAPER												
(4)					52.5	19.6	4.4	0.66	30.9	0.58	62.7	1.18	65	23.3	52	16	89.4	13	75.7	13.4
								REFERENCE RUN												
[5]5345	....	......	....	....	53.2	19.9	4.6	.64	23.3	.42	70.4	1.28	30	22.8	32	6	87.7	10	77.5	10.7
								EFFECT OF DIFFERENT HARDWOOD SPECIES												
5351	Cottonwood	4762	16	10.0	51.3	19.2	4.1	.70	19.8	.38	66.6	1.30	12	18.1	24	6	85.7	15	79.4	11.3
5354	Red alder	4773	16	10.3	53.0	19.8	4.4	.67	23.5	.44	67.0	1.25	20	20.0	22	6	88.0	15	79.0	12.1
5355	Red alder and cottonwood	4777	16	10.2	53.6	20.1	4.3	.69	25.4	.47	66.4	1.23	22	21.8	27	6	86.7	15	76.8	11.2
5356	Tanoak	4776	16	11.7	53.0	19.8	4.5	.65	20.8	.39	66.4	1.25	11	19.4	16	4	87.3	14	77.9	11.4
5357	Madrone	4778	16	10.5	50.4	18.9	4.1	.68	20.9	.41	52.2	1.04	11	18.8	20	5	86.8	13	77.2	12.1
								EFFECT OF SULFIDITY												
5351	Cottonwood	4762	16	10.0	51.3	19.2	4.1	.70	19.8	.38	66.6	1.30	12	18.1	24	6	85.7	15	79.4	11.3
5352	Cottonwood	4766	22	9.7	53.0	19.8	4.2	.70	28.5	.54	65.2	1.25	45	23.3	27	7	85.4	15	77.6	11.0
								EFFECT OF PERMANGANATE NUMBER												
5351	Cottonwood	4762	16	10.0	51.3	19.2	4.1	.70	19.8	.38	66.6	1.30	12	18.1	24	6	85.7	15	79.4	11.3
5353	Cottonwood	4791	16	14.9	52.5	19.6	4.1	.71	22.9	.44	63.6	1.23	13	20.3	30	9	86.1	16	79.7	12.7
5354	Red alder	4773	16	10.3	53.0	19.8	4.4	.67	23.5	.44	67.0	1.25	20	20.0	22	6	88.0	15	79.0	12.1
5347	Red alder	4782	16	14.6	53.1	19.9	4.3	.68	22.5	.42	65.2	1.23	14	20.0	33	8	87.2	14	78.0	11.4
								EFFECT OF HARDWOOD CONTENT												
5351	Cottonwood	4762	16	10.0	51.3	19.2	4.1	.70	19.8	.38	66.6	1.30	12	18.1	24	6	85.7	15	79.4	11.3
[6]5367	Cottonwood	4766	22	9.7	52.2	19.5	4.1	.70	21.1	.40	52.4	1.00	12	19.0	26	9	87.4	13	78.9	13.0

Table 13.--Test results on mimeograph papers made from Douglas-fir and some western hardwood pulps--Continued

Machine run No.	Pulp furnish[1]				Sheet properties[2]															
	Species	Bleach No.	Sulfidity of cooking liquor	Permanganate number unbleached pulp	Ream weight (500 sheets) 25 by 40 inches	Ream weight (500 sheets) 17 by 22 inches	Thickness	Density	Bursting strength		Average tearing resistance		Average folding endurance (M.I.T.)	Average tensile strength	Castor oil penetration	Air resistance (Gurley)	Opacity	Smoothness (Bekk)	Brightness (G.E. equivalent)	Ash content
			Percent		Lb.	Lb.	Mils	G. per cc.	Pts.	Pts. per lb. per rm.[3]	G.	G. per lb. per rm.[3]	Double folds	Lb. per in. width	Sec.	Sec. per 100 cc.	Percent	Sec.	Percent	Percent
	COMPARISON BETWEEN SULFATE AND NEUTRAL SULFITE SEMICHEMICAL																			
5354	Red alder	4773	16	10.3	53.0	19.8	4.4	.67	23.5	.44	67.0	1.25	20	20.0	22	6	88.0	15	79.0	12.1
5364	Red alder[7]	4795	....	....	53.5	20.0	4.1	.72	27.3	.50	63.6	1.18	36	23.9	56	17	85.7	17	79.7	11.9
[8]5365	Red alder[7]	4795	....	....	53.8	20.1	4.3	.69	25.2	.47	65.8	1.24	27	20.8	33	11	86.0	13	79.6	11.2
	EFFECT OF PULPING SOFTWOOD AND HARDWOOD SPECIES TOGETHER																			
5366	Mixture (5 species)[9]	4780	16	16.3	53.4	20.0	4.3	.69	26.5	.49	63.5	1.17	29	21.6	26	8	85.6	12	79.6	11.7

[1]Bleached sulfate pulp unless otherwise noted. All furnishes except reference runs and machine run No. 5367 contained 46 percent of experimental hardwood pulp, 10 percent of old papers (shipment No. 4576), and 44 percent of commercial Douglas-fir pulp (shipment No. 4574) that also contained 21 percent cottonwood pulp by weight.

[2]Papers were surface sized.

[3]Ream size was 500 sheets, each 25 by 40 inches.

[4]A paper of Western manufacture. Shipment No. 4581.

[5]The furnish consisted of 44 percent of commercial Douglas-fir (shipment No. 4574, see footnote (1)),46 percent of commercial cottonwood pulp (shipment No. 4575), and 10 percent of old papers (shipment No. 4576).

[6]The furnish consisted of 75 percent of experimental cottonwood pulp, 15 percent of commercial Douglas-fir pulp (shipment No. 4574), and 10 percent of old papers (shipment No. 4576).

[7]Bleached neutral sulfite semichemical pulp.

[8]The stuff furnish received no jordan treatment. In all other runs jordaning was employed (load--16 amperes).

[9]Equal parts of old-growth Douglas-fir, second-growth Douglas-fir, western hemlock, black cottonwood, and red alder pulped together.

Table 14.--Properties of offset papers made from western softwood and hardwood sulfate pulps

Machine run No.	Fiber furnish[1]: Bleached sulfate pulp: Kind	Fiber furnish[1]: Bleached sulfate pulp: Amount	Fiber furnish[1]: Cottonwood bleached sulfate (shipment No. 4575)	Sheet properties[2]: Ream weight (500 sheets): 25 by 40 inches	Ream weight (500 sheets): 25 by 40 inches	Thickness	Density	Bursting strength	Bursting strength	Average tearing resistance	Average tearing resistance	Average folding endurance (M.I.T.)	Average tensile strength	Castor oil penetration	Air resistance (Gurley)	Opacity	Smoothness (Bekk)	Brightness (G.E. equivalent)	Ash content
		Percent	Percent	Lb.	Lb.	Mils	G. per cc.	Pts.	Pts. per lb. per rm.[3]	G.	G. per lb. per rm.[3]	Double folds	Lbs. per in. width	Sec.	Sec. per 100 cc.	Percent	Sec.	Percent	Percent
(4)				53.0	50.3	3.1	0.95	28.3	0.54	45.1	0.86	131	25.0	334	132	89.8	82	76.9	12.2
[5]5360	Douglas-fir (shipment No. 4574)[6]	50	30	52.3	49.7	3.2	.90	20.1	.38	48.5	.93	26	19.0	81	53	87.4	56	77.0	12.7
5361	Old-growth Douglas-fir (bleach No. 4756)	40	40	52.1	49.5	3.3	.87	18.0	.35	42.2	.81	13	18.1	82	58	86.9	49	76.8	12.7
5362	Western hemlock (bleach No. 4758)	40	40	51.4	48.8	3.1	.92	22.2	.43	46.4	.90	20	18.9	88	61	87.4	65	76.6	12.7
5363	Second-growth Douglas-fir (bleach No. 4770)	40	40	52.5	49.9	3.4	.85	20.5	.39	46.9	.89	12	20.0	64	37	87.1	39	76.3	12.2

[1]Contained 20 percent of old papers, deinked and bleached (shipment No. 4576).

[2]Papers were surface sized.

[3]Ream size was 500 sheets, each 25 by 40 inches.

[4]Commercial paper--western manufacture (shipment No. 4589).

[5]Reference standard.

[6]Contained by weight, 79 percent of mixed softwood fibers, mainly Douglas-fir, and 21 percent of cottonwood fibers.

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