SULPHATE PULPING OF DOUGLAS-FIR, WESTERN HEMLOCK, PACIFIC SILVER FIR, AND WESTERN REDCEDAR LOGGING AND SAWMILL WASTE

February 1947

INFORMATION REVIEWED AND REAFFIRMED
March 1956

No. R1641
Pulping experiments were made at the Forest Products Laboratory to determine the suitability of logging and sawmill wastes from four major western species (Douglas-fir, Western hemlock, Pacific silver fir, Western redcedar, and various mixtures of these) for the production of strong kraft and bleachable sulfate pulps. Although higher yields of kraft pulps, based on moisture-free weights, were obtained from Western hemlock and Pacific silver fir than from Douglas-fir, the Douglas-fir excelled all the others in yield per unit volume of wood. The lowest yield of kraft and bleachable sulfate pulps, on both a volume and weight basis, was obtained from Western redcedar, but both the kraft and bleachable sulfate pulps from this species excelled all others in several of the most important strength properties, with the exception of tearing strength. Because of these characteristics, proper blending of the fibers of Western redcedar with those from species that excel principally in tearing strength, such as Douglas-fir, should be helpful in the production of pulps of balanced quality. In general, the results of the pulping experiments indicated that no difficulty should be experienced in cooking various mixtures of these four western species by the sulfate process and that logging and sawmill waste obtained from them is suitable for the production of good quality kraft and bleachable sulfate pulps.
Introduction

Utilization of the vast quantities of cull material, woods waste, and sawmill waste has long been a challenge to progressive lumber manufacturers of the Northwest as well as to the U. S. Forest Service. A profitable utilization that pays the cost of removal of this material from the woods will at the same time promote improvements in forest management. Although unfit for lumber manufacture for various reasons, a large part of this waste material comes from perfectly sound trees and, therefore, should find profitable uses in various wood conversion industries. The pulp and paper industry offers a possible outlet for large quantities of these types of waste material.

The Forest Products Laboratory at Madison, Wisconsin, recently investigated the possibilities of these waste materials for the production of strong kraft and bleachable sulfate pulps for use in high-quality papers. The wastes consisted of several species including Douglas-fir (Pseudotsuga taxifolia), Western hemlock (Tsuga heterophylla), Pacific silver fir (Abies amabilis), and Western redcedar (Thuja plicata).

Previous to this, the Laboratory had made rather extensive pulping trials on roundwood of Douglas-fir (1,2,3) and Pacific silver fir (4) to determine the effects on yield and pulp quality both of the more important cooking variables and of certain structural characteristics due to the growth conditions of the tree. A limited amount of work had been done on the sulfate pulping of Western hemlock (5), but only a small number of scout pulping trials had been made a number of years ago on Western redcedar (5). The Laboratory had also studied the bleaching of Douglas-fir (6) sulfate pulps by multistage bleaching methods and had produced experimentally several grades of papers from both the kraft and the bleached sulfate pulps.

For the present investigation, however, the Laboratory wished to extend the available information to logging and milling wastes representative of such material both as individual species and as it occurs in mixtures of species at sawmills. In general, a natural mixture of these species would consist of approximately 40 percent Douglas-fir, 22.5 percent Western hemlock, 22.5 percent Pacific silver fir, and 15 percent Western redcedar.

Description of the Raw Material

The wood was shipped to the Laboratory from a western sawmill in the form of chips of the general size commonly used for sulfate pulping. Because of their relatively high moisture content (35 to 50 percent) when received, it was apparent they had lost little water in transit. In addition to the chips, transverse sections of a log of each species representative of the material available at that time at the sawmill were furnished for examination and measurement of density and certain growth characteristics.

Upon arrival at the Laboratory the chips of a given species were thoroughly mixed and run over the Laboratory chip screen. All material passing the

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1-1/4- by 1-1/4-inch upper screen and remaining on the 5/16- by 5/16-inch lower screen of the chip screen was used for the pulping experiments. There was only a relatively small percentage of oversized pieces and fines which were rejected.

A representative sample of the chips of each species was taken for chemical analysis and, before the digester was charged, each batch of chips was sampled for its moisture content, so that chemical concentrations, liquor volumes, and pulp yields could be calculated on the moisture-free weight of wood charged.

The physical data obtained from the disks and the chemical analyses of the chips are recorded in table 1 in the order of decreasing density of the wood. The growth rate of the individual disks of Douglas-fir varied from 18.9 to 35.6 rings per inch, average 25.8 rings per inch; Western hemlock from 10.1 to 14.7 rings per inch, average 11.7 rings per inch; Pacific silver fir from 8.1 to 10.0 rings per inch, average 8.8 rings per inch; and Western redcedar from 7.2 to 9.4 rings per inch, average 8.1 rings per inch. The Douglas-fir was by far the slowest growth material of any of the species submitted and it also had the greatest density. The Western redcedar had the lowest density, which was noticeably reflected in the pulp yield per unit volume of wood.

The heartwood content of the Western redcedar was highest, varying from 82 to 91 percent by volume, average 85 percent; that for the Douglas-fir disks was second, varying from 78 to 84 percent, average 82 percent; then Pacific silver fir from 54 to 81 percent, average 66 percent; and finally Western hemlock, 33 to 72 percent, average 54 percent.

The four species varied considerably in chemical composition. These variations are noticeably reflected in yield and strength properties of the resulting pulps. For example, the low total and alpha-cellulose and the high lignin and extractives contents of Western redcedar presage the low pulp yields obtained on a weight basis. These chemical characteristics coupled with the low density of this wood resulted in abnormally low and probably uneconomical pulp yields on a cord or unit volume basis. In general, the analytical data obtained on the other three species are in line with average data previously obtained at the Laboratory on wood from various localities in Washington and Oregon. The chemical analysis did not indicate the presence of decay in any of the lots of chips, and except for the Western redcedar, there was nothing to indicate abnormal pulp yields.

A point of interest in regard to the chemical composition of a number of western conifers is their low pentosan content, 7 to 9 percent, in comparison with the spruces and pines of the East, and the yellow pines of the South, which have a pentosan content of from about 12 to 14 percent.

**Sulfate Pulping Experiments**

Two types of sulfate pulping procedures were used, one for the purpose of producing strong kraft pulps of higher yield and the other for the production of bleachable pulps of somewhat lower yield. For the kraft type of digestions all species were reduced under the same cooking conditions, which were so chosen from past experience as to be generally suitable for the production of
this type of pulp both in high yield and with high strength properties. The conditions employed, while similar to those commonly used in kraft mill operations, differed in that dilution to the predetermined point was accomplished by the addition of water rather than sulfate spent or "black" liquor.

The bleachable sulfate digestions differed from the kraft-type digestions in that a higher ratio of chemical-to-wood and a higher concentration of chemicals in the cooking liquors were employed for the bleachable sulfate digestions than for the kraft-type digestions. Pulps with two degrees of softness, or bleachability, were made by increasing the time of digestion at maximum temperatures 3/4 hour in one digestion over that of another.

**Digestion Procedure**

All digestions were made on the equivalent of 100 pounds of moisture-free chips in a 14-cubic foot steam-jacketed, tumbling-type digester heated indirectly with steam. A linear temperature-increase schedule was followed allowing 1-1/4 hours to bring the temperature of the digester from 30° C. to 150° C. and 1/2 hour from 150° C. to the maximum temperature (170° C.) where it was held for 1-1/2 hours for the kraft digestions and for one type of the bleachable sulfate digestions and for 2-1/4 hours for the other type of bleachable sulfate digestions.

The sulfidity of the cooking liquors, when calculated on their active alkali content (\(\text{NaOH} + \text{Na}_2\text{S}\) calculated as \(\text{Na}_2\text{O}\)) was 30 percent for all the digestions.

The quantity of active chemicals (calculated as \(\text{NaOH}\) and \(\text{Na}_2\text{S}\)) charged per hundred pounds of moisture-free wood was 20 pounds (15.62 pounds of \(\text{Na}_2\text{O}\)) for the kraft digestions and 27.5 pounds (21.47 pounds of \(\text{Na}_2\text{O}\)) for the bleachable sulfate digestions. The total initial concentration of active alkali (\(\text{NaOH}\) and \(\text{Na}_2\text{S}\)) in the cooking liquors, including the moisture in the chips, was 50 grams per liter (equivalent to 39.05 grams per liter of \(\text{Na}_2\text{O}\)) for the kraft digestions and 60 grams per liter (equivalent to 46.35 grams per liter of \(\text{Na}_2\text{O}\)) for the bleachable sulfate digestions. Since indirect steam heating was employed, no further dilution occurred as a result of the cooking operation. The total volume of liquor charged, including the moisture in the chips per hundred pounds of moisture-free wood, was 48 gallons (6.42 cu. ft.) for the kraft digestion and 55 gallons (7.35 cu. ft.) for the bleachable sulfate digestions, making the liquor-wood ratios 4 to 1 and 4.6 to 1, respectively.

Upon completion of the cooking schedules, the pulps were blown at reduced pressure and washed with hot water, screened through an 8-cut (slot openings 0.008 inch width) flat screen, run over the Laboratory wet machine, where they were sampled for their moisture contents, and finally weighed for the determination of the yield.

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All calculations of chemicals charged, liquor volumes, and pulp yields were based on the moisture-free weight of chips charged. Bleach consumption and the results of chemical analysis, on the contrary, are reported on the weight of moisture-free pulp tested.

The results obtained from the kraft pulping experiments together with similar data on some commercial pulps are reported in table 2 and those for the production of bleachable sulfate pulps are reported in table 3.

**Methods of Testing the Pulps**

The freeness of the unbleached pulps was determined by the Schopper-Riegler method. The strength properties of the unbleached pulps were determined on test sheets prepared after processing in a 1-1/2-pound standard beater according to TAPPI Standard T-200m-40, which specified 6,500-gram weight on the bed-plate lever for kraft pulps. The unbleached pulps were also chemically analyzed for cellulose, alpha-cellulose, lignin, and pentosan contents and for the chlorine consumption and permanganate number according to TAPPI standard procedures. The single-stage calcium hypochlorite bleach requirement test of the pulps was made by treating a 15-gram sample with 25 percent of its moisture-free weight of bleaching powder solution (equivalent to 8.75 percent chlorine) at 40°C. for such a time as was necessary to exhaust the chlorine. The brightness of the unbleached and bleached pulps was determined with a Hunter reflectometer calibrated in accordance with TAPPI method T-217sm-42.

**Results and Discussion of Pulping Experiments**

**Kraft-type Pulps**

Yield of Kraft Pulps.—As shown in table 2, the yields of moisture-free kraft pulp for the four species, when compared on the weight basis, were about the same (ranging from 47 to 49 percent) for Douglas-fir, Western hemlock, and Pacific silver fir, but, owing to the high lignin and extractives and the low cellulose contents of Western redcedar, the yield of moisture-free kraft pulp from this species was about 10 percent lower (39.5 percent, based on moisture-free wood). Although the percentage yield by weight of kraft pulp from Douglas-fir is about 2 percent lower than those of Western hemlock and Pacific silver fir, the higher density of the Douglas-fir wood more than compensates for the difference, and the net result is a slightly higher yield of pulp per cubic foot of solid wood. Since both the density of Western redcedar and the percentage yield of pulp by weight are considerably lower, the yield of kraft pulp per cubic foot of solid wood from this species is approximately 36 percent less than the average of the yields from the other species. Pulp yields per unit of digester space would, of course, vary in the same proportion. The economical utilization of Western redcedar by kraft pulping would appear questionable were it not for the excellent strength properties of the pulp. The yield of kraft pulp obtained from the 50-50 mixture of Western hemlock and Pacific silver fir chips was about the same as those obtained from pulp- ing the two species separately.
Chemical Composition of the Kraft Pulps.--The chemical analytical data reported in table 2 indicate that all the experimental kraft pulps were given approximately the same degree of cooking as the commercial kraft pulps made from Southern yellow pine, jack pine, and Scotch pine, but were probably not reduced to quite the same degree as the sample of commercial black spruce kraft.

Small differences in lignin, cellulose, and permanganate number, however, tend to indicate that Pacific silver fir reduced a little more readily under the conditions employed than the other three species. On the other hand, Western redcedar, because of its high extractives and high lignin contents, has a higher alkali requirement and, therefore, under equal cooking conditions is reduced to pulps of higher bleach requirements than any of the other species. Brightness values of test sheets obtained from single-stage bleachability tests and the permanganate numbers indicate the same trend and show roughly the bleach requirements of the kraft pulps. As of the wood of these Western species, the pentosan content of the several pulps was low. Furthermore, the pentosan contents were low in comparison with the values obtained for the commercial kraft pulp samples on which this constituent was determined.

Physical Properties of the Kraft Pulps.--The Schopper-Riegler freeness and the physical properties of the test sheets were obtained on the experimental and commercial kraft pulps after definite time intervals of processing in the test beater. Curves were prepared by plotting the physical properties and beating time against the freeness. The values given in table 2 were interpolated from the curves at given freeness values.

Since the differences in the chemical composition of the experimental kraft pulps are small, any differences in their physical properties may likely be attributable to some physical or morphological characteristic of the fibers rather than to degree of cooking. This conjecture is based on past experience where the proportion of springwood and summerwood was determined on log cross sections. It was not possible to make this measurement on the chips submitted for tests in this work. Since springwood fibers are different from those of summerwood, (2), (7), (8), (9), variations in the ratio of these two components in the chips furnished may account for some of the differences in the physical properties and quality of the pulps obtained from the experimental cooks. For instance, the diameter of the lumen and possibly the wall thickness of the springwood and summerwood fibers of the several species may account for some of the differences in the physical properties of the pulps. If, as in the tables, the four species are arranged in the order of their densities, it is interesting to note that several of the strength properties of the kraft pulps vary with the density of the wood. With the exception of tearing resistance, which behaves in the reverse order of the other physical properties, the strength properties of the pulps as well as the densities of the test sheets increase as the order of the densities of the woods decrease. Previous experiments (2), (7), (8), on a number of species including Northern and Southern pines, Douglas-fir, and others have shown the same trends in pulp properties with wood density. The effect is probably actually caused by variation in the springwood-summerwood ratio. The density of the wood of conifers has been observed to increase markedly with increase in the summerwood content (10). Therefore, in the observed relationship between pulp strength and density, the density itself is probably a secondary factor.
The fact that, when compared at a given degree of beating, the pulps obtained from the low density Western redcedar excelled all others in bursting, tensile, and folding strengths and in sheet density as well, but were lower in tearing strength strongly suggests that the sample of this species either contained a preponderance of springwood fibers or that the summerwood fibers were thinner-walled than those of the other species.

Fiber measurements on Western redcedar (11) indicate that both the springwood and the summerwood fibers of this species have thinner walls than any of the other three species. It can be expected that thin-walled summerwood fibers would tend to behave like springwood fibers in their effect on pulp properties.

In comparing the experimental Western redcedar kraft pulp with the commercial Western redcedar sample (table 2, 9445-T) the experimental pulp may be seen to excel the commercial pulp in all the physical properties. In fact, the experimental Western redcedar kraft pulp, except for tearing resistance, compared favorably in strength with those of the commercial kraft pulps shown in table 2.

Western redcedar might be used to good advantage to improve the quality of kraft pulps from other Western species. For instance, it might be added to Douglas-fir which is lacking in those qualities in which Western redcedar excels but possesses other properties, especially tearing strength, that are lacking in Western redcedar. It would seem, therefore, that proper blending of the fibers of these two species would have excellent possibilities for the production of a kraft product of balanced physical properties.

The experimental Douglas-fir kraft pulp (table 2, cooks 2684-85) obtained from logging and millwaste chips was about equal in strength properties to other experimental pulps of this species made previously (2), (3) from roundwood. The pulp, as mentioned previously, was characteristically high in tearing strength but mediocre in other physical properties. Nevertheless, its strength properties were about equal to those of the commercial sample of Southern kraft.

The experimental Kraft pulps made from Western hemlock and Pacific silver fir and also that from the mixture of equal weights of these two species had better strength properties, excepting resistance to tear, than the Douglas-fir kraft pulp. In these experiments most of the strength properties of the Pacific silver fir slightly exceeded those of the Western hemlock; only the tearing resistance was slightly lower. The experimental Kraft pulps from both these species compared favorably in most respects with those made commercially from Southern yellow pine (sample 9057-T), the 80-20 mixture of Western hemlock and white fir (sample 8685-T), and the sample of dried Scandinavian Kraft pulp (sample 7954-T). They were about equal in folding endurance, and somewhat better in tearing strength than the commercial Kraft pulps from Northern jack pine and black spruce (samples 8981-T and 9312-T, respectively).
Bleachable Sulfate Pulps

The data on bleachable sulfate pulps are reported in table 3. Results are shown for pulping experiments on the four individual species and for several mixtures. The experiments on the single species not only indicate their individual behavior, but the pulp properties show their contribution to the physical properties of pulps made from mixtures.

Yield of Bleachable Sulfate Pulps.--As a result of pulping with a liquor of higher chemical content (21.47 percent Na₂O) than that used for the kraft digestions (15.62 percent Na₂O), the pulp yields were decreased by about 4 or 5 percent, except for Western redcedar, which was only 1 percent lower. The small difference for Western redcedar may be attributed to the high content of extractives of this species. These react readily with the cooking chemicals and possibly account largely for the lower yield compared to the other species. The additional chemicals used in the bleachable pulp digestions, being available for reaction with the most resistant wood constituents were only slightly more effective in lowering the yield. Increasing the time of digestion at maximum temperature (170°C) from 1-1/2 hours to 2-1/4 hours resulted in a further decrease of about 3 to 4 percent in the yield of moisture-free pulp from each species without much change in the percentage of screenings (0.2 percent at most).

Chemical Composition of Bleachable Sulfate Pulps.--The chemical compositions of the bleachable sulfate pulps (table 3) compared with those of the kraft pulps (table 2) indicate that a considerable improvement in purity (higher cellulose and lower lignin contents and lower bleach requirements) resulted from the more drastic digestion conditions. The pentosan contents of the bleachable pulps were only slightly lower than those of the kraft pulps. The Western redcedar pulps had a higher pentosan content than any of those from the other three species.

The bleachable pulps prepared by the longer cooking schedule are also of noticeably higher purity and have lower bleach requirement than those cooked for the shorter period. The total cellulose contents of the pulps cooked by the shorter schedule averaged 95.1 percent for all species and those for the longer period averaged 96.1 percent. The average of the lignin contents of the pulps was decreased from 3.2 percent to 2.0 percent and that of the permanganate numbers from 16.8 to 14.0 percent by the longer cooking schedule.

As was pointed out in discussing the physical properties of the kraft pulps, certain of the strength properties of the bleachable sulfate pulps also can, to some extent, be correlated with the density of the wood. For example, tearing strength decreased with decrease in the order of the density of the four species and Western redcedar having the lowest wood density produced the pulps having the highest bursting, tensile, and folding strengths. However, under the more drastic cooking conditions employed for making the bleachable pulps, the physical properties of the pulps become more difficult to correlate with any property of the wood itself.
An increase in the time of digestion at maximum temperature (of digestions 2703 and 2700, table 3) caused a decrease in practically all the strength properties of the pulps from Douglas-fir, but showed very little difference in the pulps from Western redcedar (of digestions 2698 and 2699) and the 50-50 mixture of Western hemlock and Pacific silver fir (of digestions 2695 and 2697). The change in the cooking conditions, however, caused a noticeable decrease in the bleach requirements of the pulps from all the species as evidenced by the lower permanganate numbers and the higher brightness values of the pulps bleached by the single-stage hypochlorite test method.

Conclusions

The experimental data obtained from the pulping of Douglas-fir, Western hemlock, Pacific silver fir, and Western redcedar show that these four species can be cooked together without difficulty by the sulfate process and that logging and sawmill waste is suitable for the production of kraft and bleachable sulfate pulps of good quality. The kraft pulps obtained from all four species were at least the equal in strength to the sample of Southern commercial kraft tested, with the possible exception of the low tensile strength of the Douglas-fir kraft. The kraft pulps made from Western hemlock and Pacific silver fir were superior in tearing strength and equal in other strength properties to that of a commercial kraft pulp made from a mixture of 80 percent Western hemlock and 20 percent white fir. However, they were lower in bursting and tensile strengths, about equal in folding endurance, and higher in tearing resistance than commercial Northern kraft pulps made from jack pine and black spruce. Except for tearing resistance, the experimental Western redcedar kraft pulp was superior to any of the commercial Northern, Southern, or Western kraft pulps tested. Confirming previous findings on Douglas-fir, the kraft pulp made from this species was higher in tearing resistance but lower in most other strength properties than any of the commercial pulps listed.

The bleachable pulps retained considerable strength even though they were produced with a higher percentage of chemical. Again the bleachable sulfate pulp from Western redcedar excelled those made from the other three species in all strength properties, except tearing resistance. As would be expected, the longer cooking schedule reduced the strength properties of the bleachable sulfate pulps, but not to such a degree as to render this method unfeasible should ultimate savings in bleach consumption and strength retained by fully bleached pulps warrant such a procedure. The strength characteristics of Western redcedar and Douglas-fir pulps suggest that proper blending of the fibers of these species should have excellent possibilities for the production of a kraft product of balanced physical properties.


Table 1.—Growth characteristics, and density, of four western species and chemical analyses of sawdust and wood waste.

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<thead>
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<th>Species</th>
<th>Tests on log cross sections</th>
<th>Chemical analysis of chips</th>
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<tr>
<td></td>
<td>Diameter</td>
<td>Age</td>
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<tr>
<td>Douglas-fir (Pseudotsuga taxifolia)</td>
<td>12096</td>
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<td>Western hemlock (Tsuga heterophylla)</td>
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<td>Pacific silver fir (Abies amabilis)</td>
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<tr>
<td>Western redcedar (Thuja plicata)</td>
<td>1232</td>
<td>24.5</td>
</tr>
</tbody>
</table>

1 The waste material was received in the form of pulpwod chips.
2 Moisture-free weight per cubic foot, green volume.
<table>
<thead>
<tr>
<th>Species</th>
<th>Treatment</th>
<th>Wood</th>
<th>Sawdust</th>
<th>Shredded</th>
<th>Grind</th>
<th>Woodchips</th>
<th>Shredded</th>
<th>Grind</th>
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<td>90%</td>
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</tbody>
</table>

**Note:**
- All measurements were made at 21% moisture content, except for sampling of woodchips which was done at 15% moisture content.
- Sawdust, shreds, and grinds were dried at 130°C in a vacuum oven for 24 hours.
- Volatile matter, calculated as 106°C, based on the original sample weight.
- Loss on ignition, calculated as the difference between the original and dried sample weights.
- Woodchips were dried at 130°C in a vacuum oven for 24 hours.
- Woodchips were dried at 130°C in a vacuum oven for 24 hours.

**References:**
- A report by the Forest Research Laboratory, Oregon State University.