PAPERS AND BOARDS FROM
HICKORY NEUTRAL SULFITE
SEMICHEMICAL PULPS

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In Cooperation with the University of Wisconsin
PAPERS AND BOARDS FROM HICKORY NEUTRAL

SULFITE SEMICHEMICAL PULPS

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Summary

Four species of hickory, mockernut, pignut, sand, and shagbark, were pulped by the neutral sulfite semichemical process to yields ranging from 85 to 56 percent. The wood reacted to digestion in a manner normal for North American hardwoods. The pulps were dark in color and varied appreciably in strength between species. Shagbark hickory pulps generally approached aspen pulps in quality. Pulps of fair to medium quality were obtained from the other woods.

A mixture containing 19 percent of bark was cooked to several yields. Although this mixture produced more pulp per cord of rough wood, some loss in strength was evident, and the chemical costs per ton of pulp were higher than when bark-free chips were cooked. The pulps were converted to a corrugated board of adequate strength and to a bond paper that was satisfactory except for a low opacity.

A shagbark hickory linerboard had satisfactory bursting strength and stiffness but did not match southern kraft liner in other properties. Glassine and greaseproof papers showed low permeability and satisfactory strength. A bond paper possessed excellent strength and good formation, but had the low opacity inherent in bleached neutral sulfite semichemical pulps.

1 Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

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Introduction

Hickory occurs in considerable amounts throughout much of the eastern United States. The wood is strong and very tough, but a large proportion of trees are not used because of low density or growth defects. This makes a considerable quantity of material available for pulping. The great density of the wood results in a large yield of fiber per cord of wood. The bark is difficult to remove, but it has been reported to be less deleterious to pulp quality than the bark of some other woods.²

From time to time, several hickories have been pulped by the neutral sulfite semichemical process at the Forest Products Laboratory. Corrugating board and linerboard, as well as bond, greaseproof, and glassine papers, were prepared. This report summarizes the results of these pulping and papermaking experiments.³

Three commercially significant species of hickory were investigated: (1) mockernut hickory, found in the Appalachian Range as well as in the Gulf States and in the Atlantic States south of Pennsylvania; (2) pignut hickory, occurring chiefly in the Appalachian Range, Indiana, Ohio, Kentucky, Tennessee, eastern Pennsylvania and southeastern New York; and (3) shagbark hickory, which occurs over nearly all of the Eastern United States, including the States just west of the Mississippi. A few pulps were also made from sand hickory a species of lesser commercial importance.

Experimental

Six shipments of wood were provided by the Southeastern Forest and Range Experiment Station, Forest Service, Asheville, N. C., for pulping experiments. The first shipment, cut in the Bent Creek Experimental Forest, Asheville, N. C., was considered to be typical of farm woodlot mockernut and pignut hickory. The second lot of mockernut and pignut hickory, obtained

³Results of pulping the first shipment of mockernut and pignut hickories were published in Forest Products Laboratory Report No. R1753, Pulps and Corrugating Paperboards from Farm Woodland Hickory (1949).
from the Biltmore Estate in Buncombe County, N. C., was taken from a sandy soil with southwestern exposure at an elevation of 2,000 feet. The shagbark and sand hickory were procured near Pickens, S. C. Additional information on the individual lots of wood is given in table 1. Because the shipments were small and contained few trees, minor differences in response to pulping or in the properties of the pulps are considered insignificant.

Wood was peeled and reduced to standard 5/8-inch chips. These were screened to reject fines and oversize material. In experiments where bark was included, chips made from peeled wood were mixed with pieces of bark that had been cut to appropriate size with a hatchet. This procedure insured an exact ratio of bark to wood in the digester charge.

The pulping agent was a technical grade of sodium sulfite, with sufficient sodium bicarbonate added to finish the cook with a slightly alkaline spent liquor. The details of the procedure varied between the several lots of wood, but the differences should not have significantly affected the nature of the pulps obtained. In the first two series the chips were impregnated with a concentrated liquor, and the excess liquor was withdrawn before the cooking was completed with direct steam. In the remaining series, the minimum amount of chemical was charged in a dilute solution, and the chips were cooked with indirect heating. A penetration period before cooking was included in the third series, but not subsequently. An outline of the three methods of cooking is given in table 2, with supplemental information on the individual digestions in tables 3 and 4.

Small-scale digestions are identified in the tables by a number followed by the letter "y." These were made in a stainless steel tumbling digester with a capacity of 0.8 cubic foot. Pulps in sufficient quantity for making papers and boards were cooked in a similar digester with a capacity of 13 cubic feet, and are identified by the letter "N."

Softened chips from the small digestions were pulped in an 8-inch, single-rotating disk refiner, while the larger digestions were fiberized in a commercial 36-inch, double-rotating disk refiner. Except as noted, material for making test sheets was pulped in the small 8-inch mill.

The fully bleached pulps were prepared in the usual sequence with chlorine, caustic soda, and hypochlorite, although four stages were used in one instance (table 7). The low-yield pulp from the bark-containing chips (digestion 5583-N) was cleaned by a single pass through a 3-inch centrifugal cleaner before it was bleached and converted to bond paper, but the other pulps were not cleaned.
Discussion

Wood

Hickory is one of the heavier woods, and the average density of these six lots of wood varied from 32.6 to 43.9 pounds per cubic foot on the basis of moisture-free weight and green volume (table 1). The first shipment of mockernut and pignut hickory had densities well below the range of 40 to 48 pounds per cubic foot commonly associated with maximum strength and toughness of the wood; the second shipment was considerably denser. The highest density in the group coincided with the most rapid growth, which is characteristic of hickory.

The average diameter of the logs also varied considerably among the shipments; the maximum was 24 and the minimum 4.4 inches for pignut and shagbark hickory. Growth rate and age were not obtained for the first lot of mockernut and pignut, because the logs had been split before they were shipped to the Laboratory.

Compared with other broadleaved species, the lignin content ranged from low to moderately high. Pentosans were average in amount, while the alpha cellulose content varied from 45 to as much as 51 percent.

The second shipment of mockernut and pignut hickory was remarkable because mockernut contained 13.6 and pignut 10.3 percent of alcohol-benzene soluble material. This large amount of extractives could explain much of the greater density of the wood in this shipment as compared with the first. Deciduous species are commonly reported to contain only a fraction of this amount. The second shipment also contained more substances soluble in 1-percent caustic soda and in hot water.

If the chemical analyses are recalculated to a basis of equal content of alcohol-benzene solubles, then the amount of lignin, alpha cellulose, and pentosans in the wood of the two shipments are found to be reasonably comparable. Recalculation on this basis, however, moderately increases the already large differences in material soluble in 1-percent caustic soda and hot water. High solubility in caustic soda is commonly associated with decay in wood, but no decay was apparent here.

Pulping

The hickory woods were intermediate in resistance to pulping within the general range of North American broadleaved species. As stated previously, the
three methods of cooking described in table 2 should give comparable pulps when applied to the same species. Although the digestions in each case were stopped when the concentration of sodium sulfite in the cooking liquor had decreased to 10 grams per liter, direct comparisons of the amount of sodium sulfite consumed cannot be made between all five series of pulps from the data in table 3.

In the first two series, an unknown and varying volume of direct steam was condensed during the cooking, so that the amount of unconsumed chemical in the spent liquor cannot be calculated. However, series IV and V can be compared directly, since 30 gallons of liquor of known concentration were charged per 100 pounds of wood in both series. Series III can also be compared with series IV and V in table 3 if 0.6 is deducted from the amount of sodium sulfite listed for series III in order to compensate for the greater volume of liquor charged. With this correction, the data show that the mixture of mockernut and pignut hickory, the shagbark hickory, and the sand hickory all consumed the same amount of sodium sulfite for a yield of 85 percent. The mockernut and pignut mixture required a little less than the others did for the lower yields of pulp, although the difference is not significant. According to the pH data, the quantity of sodium bicarbonate needed to neutralize the acids developed in cooking was average for hardwoods in general.

Table 4 shows the effect of replacing part of the wood chips with bark. The resulting mixture consisted of 81 parts of wood and 19 parts of bark on a moisture-free weight basis. For equal consumption of sodium sulfite, the mixture containing bark gave a yield several percent lower than the bark-free material. The margin increased as the cooking was extended, so that the difference was 2.5 percentage points at 75 percent yield and 3.7 percentage points at 60 percent yield. These yields, of course, are on the basis of the weight of material charged to the digester. On the basis of yield per cord of rough wood, more pulp is obtained if the wood is not peeled.

Bark cooked more rapidly than wood at medium high yields, but this was not so evident at lower yields of between 55 and 60 percent. In previous work in which hickory was cooked to 73 percent yield, the bark was also found to cook more rapidly than the wood.

Considerable energy was required to fiberize the chips that had received the least amount of cooking, but the requirement dropped rapidly as the cooking time was extended. Because of differences in the pattern of plates and other variables in the operation of the refiner, the various energy consumptions cannot be compared quantitatively. The expenditure ranged from above 30 to as low as 7 horsepower days for each ton of air-dry pulp.
Properties of Unbleached Pulps

The pulps were quite dark in color, reflecting the pigmentation of the wood. Although table 5 shows that these pulps gained 5 or 6 points in brightness on prolonged cooking, even the brightest could not be used in writing or printing papers without bleaching.

At the lower yields, shagbark hickory pulps were the strongest by a considerable margin, especially in resistance to tear; however, at 85 percent yield, the pulp made from the second shipment of mockernut and pignut hickory had the best overall quality. The pulps made of mockernut hickory were generally stronger than those of pignut, although at the lowest yield the differences were often insignificant. Sand hickory had low strength at high yield, but its relative position strengthwise was improved with more drastic cooking.

In strength, the lower yield shagbark hickory pulps ranked among the better hardwoods commonly pulped by the neutral sulfite semichemical process. In tearing resistance, this species was exceptionally good. Strength of the pulps made from mixed mockernut and pignut may be considered as reasonably good for pulp produced at moderate yields, and definitely better than that of the individual species made from the earlier shipment of low-density wood.

The effect on pulp properties of including bark with the wood is illustrated in table 6. At the higher yield of 72 to 74 percent, the mixture containing bark was moderately lower in strength than similar pulp from bark-free wood. The difference was of the same order as that reported in an earlier investigation of pignut hickory, although in the earlier work there was no loss in folding endurance.

On the other hand, the bark-containing pulp was as strong as the bark-free pulp in most categories when both were cooked to about 56 percent yield and was stronger in tearing resistance. Two reasons probably account for this fact: (1) The pulp containing bark was passed through a 3-inch centrifugal cleaner before it was beaten and tested (such cleaning improves the tearing strength of pulps in general, and sometimes improves other strength properties as well). (2) This pulp was defibered in the commercial refiner instead of in the 8-inch laboratory refiner which was used in the other instances.

If digestions are made to the same yield of pulp per ton of material charged to the digester, unbarked wood gives more pulp per cord of rough wood than if the material had been barked before charging. The unbarked wood also requires less sodium sulfite per ton of product. Offsetting this gain in amount of pulp and reduction in chemical requirement is the moderate loss in strength.
In order to obtain pulps of the same strength or bleachability, it is necessary to pulp the rough wood to a lower percentage yield and thus increase the chemical consumption per ton of product.

The data are insufficient to furnish a reliable balance between these considerations, because the figures are founded on a single experiment. However, calculations based on the strength data reported in table 5 are interesting, even if tentative. Bark-free test sheets made from pulp cooked to about 80 percent yield were equivalent in strength to the bark-containing mixture that had been cooked to 72.4 percent yield.

On this basis of equal strength, the unbarked wood gave 112 pounds of pulp for every 100 pounds of comparable pulp obtainable from a similar lot of barked wood. Since standard test sheets containing bark residues are commonly less dense than the equivalent bark-free sheets, as was the case here, the sheets containing bark would have made a better showing if all sheets were compared for strength at equal density.

To the value of the additional pulp obtainable from unbarked wood must be added the savings in barking costs; and from that sum the cost of the additional chemicals -- amounting to 90 pounds of sodium sulfite per ton of air-dry pulp -- must be subtracted. Several other minor adjustments must be included to obtain comparable cost figures, but the balance should favor the use of unbarked wood by several dollars a ton.

**Bleaching**

Bleaching tests were made to determine the chemical requirements and quality of bleached pulps from shagbark hickory and the mixture of mockernut and pig-nut hickory containing bark. The bleaching was done by the usual 3-stage process of chlorination, alkaline extraction, and hypochlorite, using amounts of chlorine necessary to produce brightness in the range of 84.4 to 86 percent. In the preparation of bleached shagbark hickory pulp (No. 2059, table 7), however, a 4-stage process with two chlorinations was used. The second chlorination was applied because it appeared that part of the chlorine applied in the first stage had escaped because of the shallow depth of the stock in the chlorinator. Comparison of the results of trial bleaches (Nos. 2056 and 2057 made on pulp chlorinated and extracted in the pilot plant, and beaker-scale bleaches 2054 and 2055) indicates that the amount lost was about 1 percent. It is unlikely that the replacement of this amount of chlorine in the additional stage in bleach 2059 had any particular effect on the quality of the bleached pulp.
The results of bleach 2055 show that the shagbark hickory pulp can be fully bleached with about 12 percent of chlorine in the usual 3-stage process. This agrees well with the normal chlorine requirement of hardwood neutral sulfite semichemical pulps -- that is, about 1.4 times their lignin content.

Although the yield of bleached pulp from the mixture of pignut, mockernut, and bark was much lower, the chlorine requirement was about the same as that of the shagbark hickory pulp -- that is, slightly over 12 percent. This is about 50 percent higher than the chlorine requirement normally expected for hardwood neutral sulfite pulps cooked to a yield of 56 percent. However, the chlorine requirement of the pulp from the mixture was not unusually high in relation to its Tingle number (10.2) or its lignin content as estimated from the Tingle number. Thus, it appears that the high bleach requirement in relation to yield of unbleached pulp was due to a high amount of chlorine-consuming material in the bark added to the wood mixture.

The shrinkage or bleaching loss of the two hickory pulps (about 19 and 22 percent) was larger than is usually expected, especially in the case of the pulp from the mixture containing bark. Consequently, the yields of bleached shagbark pulp based on wood were about 2 percent lower than normal and that of bleached pulp from the mixture was about 9 percent lower. Part of the shrinkage can be attributed to loss of fine material in the pilot-plant washer. However, most of the high shrinkage upon bleaching the pulp from the mixture was undoubtedly due to its high chlorine consumption.

The effect of bleaching on the strength of the two pulps is shown in table 8. The increases in strength, which averaged about 16 to 30 percent except in folding endurance, are typical of results generally obtained in bleaching hardwood neutral sulfite semichemical pulps. The high strength of these bleached pulps is also in agreement with results published by Haywood, which showed that bleached hickory neutral sulfite semichemical pulps were stronger than the corresponding gum, oak, or maple pulps.

The shives and small dark particles in the pulp from the mixture containing bark were removed satisfactorily by centricleaning. Consequently, the bleached pulp was essentially free of discolored particles. The dark shives and dirt in the shagbark pulp also appeared to be of a nature that would permit removal by centricleaning. With proper recycling in the cleaning operation, the loss of pulp should be less than 1 percent.

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Rept. No. 2088 -8-
Boards

Increased cooking gave corrugating boards with increased strength (table 9, machine runs 3084, 3085, 3086). A mixture of equal parts of pulps made from lower density mockernut and pignut hickory gave a board that was too soft and too weak to meet commercial requirements at a yield of 87.5 percent. Board made from pulps of medium yield (78.7 percent) corrugated well and was at least as strong as the average of some 13 commercial hardwood boards. Cooking to a yield of 67.2 percent gave a superior product.

A pulp prepared from a mixture of the higher density mockernut and pignut woods, with 19 percent of bark included, formed a board (table 9, machine run 4426) almost equal in properties to that from the bark-free lower-density woods at equal yield. The main exception was in tearing resistance. In flat crush and compression resistance, this bark-containing board was better than a similar board made on the same experimental paper machine with a commercial neutral sulfite semichemical aspen pulp furnish from which an excellent product had been produced in the mill. In other strength properties, the hickory board was equal to or better than the aspen board. The mixture containing bark had been cooked to a yield of 72.4 percent, which is below the 75 to 80 percent range commonly used in preparing pulp for corrugating board; still, the strength of the hickory board was sufficiently high to indicate that a satisfactory product could be obtained at a moderately greater yield.

Linerboard made from the mixture of mockernut and pignut hickory pulp containing bark was well below the accepted standard in bursting strength and much inferior to southern pine kraft linerboard in both tearing resistance and folding endurance. A similar board, formed from shagbark hickory pulp made at a yield of 67 percent, met the bursting strength specification but was still weak in tearing and folding quality. The ring crush resistance of these experimental linerboards indicated good stiffness.

Papers

The shagbark hickory pulp that had been cooked to a yield of 66.9 percent hydrated rapidly with beating and therefore was excellent stock for making greaseproof and glassine papers. The greaseproof sheet had good resistance to penetration by turpentine and castor oil and also had low air permeability, but was lower in strength than that of a commercial greaseproof paper used for comparison. Glassine paper made from the same pulp after it had been bleached compared favorably with a commercial softwood sulfite paper, especially in strength (table 10).
Some of the shagbark bleached pulp was converted into 20-pound bond paper. This paper had very good strength compared with a commercial No. 1 sulfite bond paper. However, its opacity, at 75.6 percent, was low. Since the experimental paper had more strength than necessary, its opacity could have been improved by increasing the amount of clay filler.

A similar bond paper was formed from the bleached pulp made from the mixture of mockernut and pignut hickory containing bark. With 5 percent of clay in the furnish, the opacity and folding endurance were below those of the commercial paper. The other strength characteristics of this paper were comparable and its brightness was superior to that of the commercial paper. Both of the experimental bond papers were clean and possessed the good formation typical of hardwood papers.

Results

1. Mockernut, pignut, sand, and shagbark hickory wood showed normal response to pulping by the neutral sulfite semichemical process. Chemical requirements were typical of those for broadleaved species. The pulps were dark in color. Test-sheet strength varied from moderate to very good.

2. Except at yields near 85 percent, shagbark hickory pulps were the strongest of the four, with unusually high resistance to tearing. In other strength properties, the shagbark pulps were not quite equal to aspen.

3. Mockernut, pignut, and shagbark hickory pulps were bleached readily by the conventional 3-stage process. A centrifugally cleaned pulp containing mockernut and pignut wood and large amounts of bark gave a strong clean product.

4. Good to excellent corrugating boards were made from bark-free chips and mixtures containing bark. A linerboard prepared from shagbark hickory met bursting strength specifications and had good stiffness, but did not compare with southern kraft linerboard in other properties.

5. Glassine and greaseproof papers made from shagbark hickory were excellent in resistance to penetration by castor oil and turpentine, while bond papers had high strength but low opacity. Bond paper made from a mixture of mockernut and pignut hickory containing bark was low in opacity and folding endurance, but had high brightness and was otherwise comparable with a No. 1 commercial sulfite bond paper.
Table 1.—Properties of hickory wood (*Carya* sp.) used in pulping experiments

<table>
<thead>
<tr>
<th>Species</th>
<th>Shipment No.</th>
<th>Physical properties</th>
<th>Chemical properties</th>
<th>Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Rate: Age: Density: Diameter of growth</td>
<td>Lignin: Holocellulose: Cellulose: Alpha: Total: Solubility in</td>
<td></td>
</tr>
<tr>
<td>Mockernut</td>
<td>2740</td>
<td>18.2: 65: 42.2: 7.2</td>
<td>22.8: 72.7: 51.1: 18.7: 2.3: 0.3: 14.8: 3.1</td>
<td></td>
</tr>
<tr>
<td>(C. tomentosa)</td>
<td>4089</td>
<td>19.4: 75: 40.9: 7.0</td>
<td>25.5: 73.2: 50.8: 17.5: 1.7: .2: 13.5: 2.0</td>
<td></td>
</tr>
<tr>
<td>Pignut</td>
<td>2740</td>
<td>19.4: 75: 41.3: 7.7</td>
<td>23.0: 68.8: 47.5: 16.2: 10.3: .3: 19.5: 7.7</td>
<td>.6</td>
</tr>
<tr>
<td>(C. glabra)</td>
<td>4089</td>
<td>19.4: 75: 41.3: 7.7</td>
<td>23.0: 68.8: 47.5: 16.2: 10.3: .3: 19.5: 7.7</td>
<td>.6</td>
</tr>
<tr>
<td>Sand</td>
<td>2935</td>
<td>31.8: 76: 40.9: 7.0</td>
<td>22.7: 68.5: 50.0: 16.6: 3.8: .4: 18.4: 6.7</td>
<td>1.0</td>
</tr>
<tr>
<td>(C. pallida)</td>
<td>2936</td>
<td>13.6: 29.3: 43.9: 4.4</td>
<td>21.4: 71.3: 48.4: 18.0: 3.4: .4: 17.6: 5.2</td>
<td>.6</td>
</tr>
<tr>
<td>Shagbark</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(C. ovata)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Determined volumetrically.
2 Based on oven dry weight and green volume.
3 Approximate value; logs were split before shipment.
Table 2.—Sequence of operations and general conditions used in cooking hickory by the neutral sulfite semichemical process

<table>
<thead>
<tr>
<th>Mockernut and pignut hickory (Shipment 2740) (Lower density woods)</th>
<th>Mockernut and pignut hickory (Shipment 4089) (Higher density woods)</th>
<th>Shagbark and sand hickory (Shipments 2935 and 2936)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Series I and II</strong></td>
<td><strong>Series III</strong></td>
<td><strong>Series IV and V</strong></td>
</tr>
<tr>
<td>Chips steamed 0.5 hour at 5-10 p.s.i.</td>
<td>Chips steamed 0.5 hour at 5-10 p.s.i.</td>
<td>Chips steamed 0.5 hour at 5-10 p.s.i.</td>
</tr>
<tr>
<td>Highly concentrated cooking liquor charged</td>
<td>Dilute cooking liquor charged</td>
<td>Dilute cooking liquor charged</td>
</tr>
<tr>
<td>One hour impregnation at 120° C.</td>
<td>0.5 hour to 120° C., 1 hour at 120° C., 1 hour to maximum temperature</td>
<td>2.5 hours to maximum temperature</td>
</tr>
<tr>
<td>Indirect heating</td>
<td>Cooked at maximum temperature</td>
<td>Cooked at maximum temperature</td>
</tr>
<tr>
<td>Free liquor removed</td>
<td>Indirect heating throughout</td>
<td>Indirect heating throughout</td>
</tr>
<tr>
<td>Temperature raised to maximum with direct steam as rapidly as possible (10-15 minutes)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooking completed with direct steam for short digestions, indirect steam for longer digestions</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.—Cooking conditions\(^1\) and yield in neutral sulfite semichemical pulping of hickory.

<table>
<thead>
<tr>
<th>Series, No.</th>
<th>Total Sodium</th>
<th>Sodium sulfite</th>
<th>Sodium bicarbonate</th>
<th>Sodium sulfite</th>
<th>Cooking time</th>
<th>Sodium liquor</th>
<th>pH of spent liquor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipment 1:</td>
<td>2740: 85</td>
<td>69.0</td>
<td>28.0</td>
<td>6.7</td>
<td>5.5</td>
<td>2:15</td>
<td>12.2</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>124.0</td>
<td>48.0</td>
<td>13.3</td>
<td>8.0</td>
<td>2:00</td>
<td>9.2</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>162.0</td>
<td>47.0</td>
<td>23.6</td>
<td>8.3</td>
<td>5:25</td>
<td>11.6</td>
</tr>
<tr>
<td>Shipment 2:</td>
<td>2740: 85</td>
<td>55.0</td>
<td>25.0</td>
<td>6.7</td>
<td>5.5</td>
<td>1:10</td>
<td>11.2</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>104.0</td>
<td>46.0</td>
<td>12.5</td>
<td>8.0</td>
<td>1:35</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>156.0</td>
<td>50.0</td>
<td>22.0</td>
<td>8.3</td>
<td>5:20</td>
<td>8.8</td>
</tr>
<tr>
<td>Shipment 3:</td>
<td>4089: 85</td>
<td>28.2</td>
<td>23.3</td>
<td>8.7</td>
<td>7.2</td>
<td>0:03</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>42.1</td>
<td>25.9</td>
<td>13.0</td>
<td>6.9</td>
<td>1:30</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>68.1</td>
<td>22.7</td>
<td>21.0</td>
<td>7.0</td>
<td>5:10</td>
<td>10.0</td>
</tr>
<tr>
<td>Shipment 4:</td>
<td>2936: 85</td>
<td>32.0</td>
<td>20.6</td>
<td>8.0</td>
<td>5.2</td>
<td>1:15</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>55.2</td>
<td>21.1</td>
<td>13.3</td>
<td>5.3</td>
<td>1:40</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>84.8</td>
<td>21.6</td>
<td>21.2</td>
<td>5.4</td>
<td>5:30</td>
<td>10.0</td>
</tr>
<tr>
<td>Shipment 5:</td>
<td>2935: 85</td>
<td>32.0</td>
<td>20.6</td>
<td>8.0</td>
<td>5.2</td>
<td>0:09</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>55.2</td>
<td>21.2</td>
<td>13.3</td>
<td>5.3</td>
<td>1:20</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>84.8</td>
<td>21.5</td>
<td>21.2</td>
<td>5.4</td>
<td>5:30</td>
<td>10.0</td>
</tr>
</tbody>
</table>

1. Procedure varied from series to series. See table 2. Cooking liquor charged per 100 pounds moisture-free material was: Series I, 42; Series II, 44; Series III, 37; Series IV and V, 30 gallons.

2. Moisture-free basis.

3. In Series III, IV, and V, the amounts of Na\(_2\)SO\(_3\) are adjusted to correspond to a concentration of 10 grams per liter in the spent liquor.
Table 4.—Effect of bark on the pulping of a mixture of equal parts of mockernut and pignut hickory (shipment 4069)

<table>
<thead>
<tr>
<th>Pulping conditions</th>
<th>Corrugating board pulp</th>
<th>Bleachable pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bark-free digestion</td>
<td>19 percent bark, digestion</td>
</tr>
<tr>
<td></td>
<td>1214y</td>
<td>5578N</td>
</tr>
<tr>
<td></td>
<td>Bark-free digestion</td>
<td>19 percent bark, digestion</td>
</tr>
<tr>
<td></td>
<td>1218y</td>
<td>5583N</td>
</tr>
<tr>
<td>Cooking liquor charged:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium sulfite</td>
<td>Gm. per l.</td>
<td>48.1</td>
</tr>
<tr>
<td>Sodium bicarbonate</td>
<td>Gm. per l.</td>
<td>25.9</td>
</tr>
<tr>
<td>Sodium sulfite</td>
<td>Lb. per 100 lb. material charged</td>
<td>13.0</td>
</tr>
<tr>
<td>Sodium bicarbonate</td>
<td>Lb. per 100 lb. material charged</td>
<td>6.9</td>
</tr>
<tr>
<td>Volume</td>
<td>Gal. per 100 lb. material charged</td>
<td>32</td>
</tr>
<tr>
<td>Maximum temperature</td>
<td>°C</td>
<td>170</td>
</tr>
<tr>
<td>Time at maximum temperature</td>
<td>Hr.:Min.</td>
<td>1:30</td>
</tr>
<tr>
<td>Spent cooking liquor - Alkalinity</td>
<td>pH</td>
<td></td>
</tr>
<tr>
<td>Sodium sulfite</td>
<td>Gm. per l.</td>
<td>10.4</td>
</tr>
<tr>
<td>Yield of pulp</td>
<td>Lb. per 100 lb. material charged</td>
<td>74.9</td>
</tr>
<tr>
<td>Pulp brightness</td>
<td>G.E. equivalent</td>
<td>46.2</td>
</tr>
</tbody>
</table>

1 Percent by weight, moisture-free basis.
2 Moisture-free basis.
3 The digester used for "N" digestions is known to cook more slowly than the digester used for "y" digestions.
Table 5.—Properties of history neutral sulfite semichemical pulps. Interpolated values

<table>
<thead>
<tr>
<th>Series/Total shipment yield</th>
<th>Physical properties of test sheets</th>
<th>Chemical properties of pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>Bursting strength at</td>
<td>Tearing resistance at</td>
</tr>
<tr>
<td></td>
<td>Freeness of</td>
<td>Freeness of</td>
</tr>
<tr>
<td></td>
<td>250 ml</td>
<td>250 ml</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I 2740</td>
<td>85</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>.38</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>.39</td>
</tr>
<tr>
<td>II 2740</td>
<td>85</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>.37</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>.47</td>
</tr>
<tr>
<td>III 400</td>
<td>85</td>
<td>.29</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>.43</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>.47</td>
</tr>
<tr>
<td>IV 2936</td>
<td>85</td>
<td>.16</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>.16</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>.20</td>
</tr>
<tr>
<td>V 2935</td>
<td>85</td>
<td>.10</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>.29</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>.39</td>
</tr>
</tbody>
</table>

1 Canadian Standard freeness.
2 Stem size: 25×40–500.
3 G.E. equivalent, obtained on Hunter reflectometer.
Table 6.—Effect of bark on the properties of hickory neutral sulfite pulp

<table>
<thead>
<tr>
<th>Physical properties of test sheets</th>
<th>Properties at pulp yield of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>74.9 percent:72.4 percent:57.3 percent:56.2 percent</td>
</tr>
<tr>
<td></td>
<td>(bark-free):(19 percent :bark-free):(19 percent bark)²</td>
</tr>
<tr>
<td>Digestion No.</td>
<td>1214y : 5578N : 1217y : 5583N</td>
</tr>
<tr>
<td>Bursting strength - 500 ml. freeness³</td>
<td>0.43 : 0.37 : 0.46 : 0.49</td>
</tr>
<tr>
<td></td>
<td>- 250 ml. freeness...Pts. per lb. per rm.: .64 : .55 : .75 : .77</td>
</tr>
<tr>
<td>Tearing resistance - 500 ml. freeness...Gm. per lb. per rm.: 1.08 : 1.02 : 1.28 : 1.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 250 ml. freeness...Gm. per lb. per rm.: 1.00 : .87 : 1.09 : 1.31</td>
</tr>
<tr>
<td>Breaking length - 500 ml. freeness........................Meters: 4,000 : 3,600 : 5,000 : 4,900</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 250 ml. freeness........................Meters: 5,900 : 5,200 : 6,900 : 6,600</td>
</tr>
<tr>
<td>Folding endurance - 500 ml. freeness......Double folds: 11 : 6 : 12 : 20</td>
<td></td>
</tr>
<tr>
<td>Density - 500 ml. freeness......................Gm. per cc.: .50 : .45 : .53 : .55</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 250 ml. freeness......................Gm. per cc.: .63 : .55 : .66 : .66</td>
</tr>
</tbody>
</table>

¹ Yield before cleaning. Cooked chips defibered in a commercial refiner and pulp centrifuged before making test sheets.

² Equal parts of mockernut and pignut hickory (shipment 4089). Percent of bark figured on moisture-free weight of wood and bark.

³ Canadian Standard freeness in all cases. Freeness and other test values are interpolated from standard beater test curves.

⁴ Ream size, 25x40—500.
Table 7.--Bleaching experiments on hickory neutral sulfite semichemical pulps

<table>
<thead>
<tr>
<th>Bleaching treatment and results</th>
<th>Shagbark</th>
<th>Mockernut and pignut</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digestion No. 5460N + 5461N</td>
<td>Yield 65.8 percent</td>
<td>Yield 56.2 percent</td>
</tr>
<tr>
<td>Lignin content 8.6 percent</td>
<td>Brightness 50.1 percent</td>
<td>Lignin content 8.0 percent</td>
</tr>
<tr>
<td>Brightness 50.1 percent</td>
<td>Brightness 34.1 percent</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bleach No.</th>
<th>2054</th>
<th>2055</th>
<th>2056</th>
<th>2057</th>
<th>2059</th>
<th>3400</th>
<th>3401</th>
<th>3402</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1, Chlorination</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amount applied, Percent</td>
<td>9.0</td>
<td>10.0</td>
<td>69.0</td>
<td>62.0</td>
<td>62.0</td>
<td>11.5</td>
<td>11.5</td>
<td>11.5</td>
</tr>
<tr>
<td>Amount consumed, Percent</td>
<td>8.9</td>
<td>9.9</td>
<td>68.9</td>
<td>61.9</td>
<td>61.9</td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
</tr>
<tr>
<td>Consistency, Percent</td>
<td>2.0</td>
<td>2.0</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Duration, Minutes</td>
<td>60</td>
<td>60</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

| Stage 2, Extraction | | | | | | | | |
| NaOH applied, Percent | 2.0 | 2.0 | 2.5 | 2.5 | 2.5 | 2.0 | 2.0 | 2.0 |
| Temperature, °C | 54 | 54 | 60 | 60 | 60 | 50 | 50 | 50 |
| Consistency, Percent | 10.0 | 10.0 | 11.2 | 11.2 | 11.2 | 10.2 | 10.2 | 10.2 |
| Duration, Minutes | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| pH range | | | | | | | | |
| 11.8-10.7 | 11.5-11.0 | 11.5-11.0 | 11.5-11.0 | 11.5-11.0 | 11.5-11.0 | 11.5-11.0 | 11.5-11.0 |

| Stage 3, Chemical | | | | | | | | |
| Kind | NaOCl : NaOCl : NaOCl : NaOCl : Cl₂ : Ca(OCl)₂ : Ca(OCl)₂ : Ca(OCl)₂ |
| Amount applied, Percent | 2.0 : 2.0 : 2.5 : 2.5 : 2.5 : 2.0 : 2.0 : 2.0 |
| Amount consumed, Percent | 1.9 : 1.8 : 3.0 : 3.9 : 1.0 : 1.0 : 1.3 : 1.8 |
| Temperature, °C | 32 : 32 : 35 : 36 : 25 : 37 : 37 : 34 |
| Consistency, Percent | 10.0 : 10.0 : 10.0 : 10.0 : 3.0 : 10.0 : 10.0 : 10.4 |
| pH range | | | | | | | | |
| 9.6-8.9 : 9.6-8.6 : 9.4-8.6 : 9.5-8.7 : (7) : 9.4-9.5 : 9.5-8.9 : 10.9-8.5 |

| Stage 4, Hypochlorite | | | | | | | | |
| Amount applied, Percent | | | | | | | | |
| Temperature, °C | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 37 |
| Consistency, Percent | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 |
| Duration, Minutes | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 |

| Bleached pulp | | | | | | | | |
| Brightness, Percent | 80.6 : 84.4 : 83.0 : 85.3 : 85.6 : 85.9 : 88.6 : 86.0 |
| based on wood, Percent | 83.6 : 83.6 : 83.6 : 83.6 : 83.6 : 83.6 : 83.6 : 83.6 |

1 Pulp from bleach No. 2059 and 3402 was used in experimental papers.
2 Amounts of chemicals are calculated on weight of unbleached pulp, moisture-free basis. Percentages of hypochlorite are in terms of available chlorine.
3 Moisture-free weight basis.
4 The digester charge contained 19 percent of bark. The pulp was centricleaned before bleaching.
5 Estimated from Tingle No. lignin relation.
6 Includes chlorine lost because of partial charge in the chlorinator.
7 Caustic soda was added after 20 minutes reaction to raise the pH to 9.5.
8 Moisture-free weight basis. Losses include fines removed by the washer but do not include cleaner rejects (bleach No. 3400, 3401, and 3402).

Rept. No. 2088
<table>
<thead>
<tr>
<th>Physical properties of test sheets</th>
<th>Pulp</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shagbark hickory</td>
<td>Mockernut and pignut hickory</td>
<td></td>
</tr>
<tr>
<td>Bursting strength - 450 ml. freeness$^2$ Pts. per lb. per rm.$^3$</td>
<td>0.70</td>
<td>0.81</td>
<td>0.55</td>
</tr>
<tr>
<td>- 250 ml. freeness...Pts. per lb. per rm.</td>
<td>0.96</td>
<td>1.15</td>
<td>0.77</td>
</tr>
<tr>
<td>Tearing resistance - 450 ml. freeness...Gm. per lb. per rm.</td>
<td>1.53</td>
<td>1.94</td>
<td>1.50</td>
</tr>
<tr>
<td>- 250 ml. freeness...Gm. per lb. per rm.</td>
<td>1.10</td>
<td>1.32</td>
<td>1.30</td>
</tr>
<tr>
<td>Breaking length - 450 ml. freeness...Meters</td>
<td>6,000</td>
<td>6,600</td>
<td>5,350</td>
</tr>
<tr>
<td>- 250 ml. freeness...Meters</td>
<td>7,900</td>
<td>8,200</td>
<td>6,600</td>
</tr>
<tr>
<td>Folding endurance - 450 ml. freeness...Double folds</td>
<td>50</td>
<td>110</td>
<td>38</td>
</tr>
<tr>
<td>- 250 ml. freeness...Double folds</td>
<td>220</td>
<td>460</td>
<td>175</td>
</tr>
<tr>
<td>Density - 450 ml. freeness...Gm. per cc.</td>
<td>.60</td>
<td>.63</td>
<td>.58</td>
</tr>
<tr>
<td>- 250 ml. freeness...Gm. per cc.</td>
<td>.73</td>
<td>.79</td>
<td>.66</td>
</tr>
</tbody>
</table>

$^1$Made from equal parts of mockernut and pignut hickory woods, including 19 percent of bark. Pulp given a single pass through a 3-inch centrifugal cleaner before testing and bleaching.

$^2$All freeness (Canadian Standard) and other test values are interpolated from standard beater test curves.

$^3$Ream size, 25x40--500.
Table 9.—Corrugating boards and linerboard from hickory neutral sulfite semi-chemical pulp

<table>
<thead>
<tr>
<th>Pulp or board</th>
<th>Machine</th>
<th>Pulp</th>
<th>Headbox</th>
<th>Weight per</th>
<th>Thickness</th>
<th>Density</th>
<th>Bursting strength</th>
<th>Tearing</th>
<th>Folding</th>
<th>Tensile</th>
<th>Endurance</th>
<th>Strength</th>
<th>Ring compression</th>
<th>Flat crush</th>
<th>Flat crush resistance</th>
<th>Flute direction</th>
<th>Ring compression resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent</td>
<td>ML.</td>
<td>lb.</td>
<td>Miles</td>
<td>gm. per cc</td>
<td>Pts.</td>
<td>Pts. per sq. ft.</td>
<td>per lb.</td>
<td>Double</td>
<td>lb. per inch</td>
<td>lb.</td>
<td>lb.</td>
<td>lb. per 36 in.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 percent mockernut</td>
<td>3084</td>
<td>87.5</td>
<td>455</td>
<td>27.5</td>
<td>10.7</td>
<td>0.49</td>
<td>25.3</td>
<td>0.26</td>
<td>0.75</td>
<td>3</td>
<td>24.2</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>50 percent pignut</td>
<td>3084</td>
<td>78.7</td>
<td>520</td>
<td>27.3</td>
<td>9.4</td>
<td>0.56</td>
<td>44.8</td>
<td>0.47</td>
<td>1.24</td>
<td>8.8</td>
<td>36.7</td>
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<tr>
<td>Shipment 3942</td>
<td>3086</td>
<td>67.2</td>
<td>410</td>
<td>27.2</td>
<td>8.9</td>
<td>0.59</td>
<td>63.5</td>
<td>0.66</td>
<td>1.60</td>
<td>151</td>
<td>39.1</td>
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</tr>
<tr>
<td>50 percent mockernut</td>
<td>4426</td>
<td>72.4</td>
<td>355</td>
<td>26.9</td>
<td>7.7</td>
<td>0.67</td>
<td>58.0</td>
<td>0.56</td>
<td>1.03</td>
<td>8.0</td>
<td>34.1</td>
<td></td>
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</tr>
<tr>
<td>50 percent pignut (19)</td>
<td>4428</td>
<td>72.4</td>
<td>300</td>
<td>25.3</td>
<td>7.6</td>
<td>0.64</td>
<td>47.4</td>
<td>0.55</td>
<td>0.99</td>
<td>121</td>
<td>34.7</td>
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<tr>
<td>Shipment 4089</td>
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<td>boards</td>
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<tr>
<td>Aspen furnish</td>
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<tr>
<td>50 percent mockernut</td>
<td>4427</td>
<td>72.4</td>
<td>300</td>
<td>55.6</td>
<td>28.9</td>
<td>0.72</td>
<td>87.0</td>
<td>0.55</td>
<td>1.13</td>
<td>116</td>
<td>62.1</td>
<td>138.9</td>
<td>123.4</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>50 percent pignut (19)</td>
<td></td>
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<tr>
<td>Shipment 4089</td>
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</tr>
<tr>
<td>Shagbark hickory</td>
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<tr>
<td>Shipment 2936</td>
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1 Specimen 0.5 by 6 inches.
2 A-flute corrugation.
3 Data from Rept. R1753.
4 Average of 13 boards.
5 Average of 8 samples.
6 Average of 2 samples.
7 Average of 3 commercial boards.
Table 10.—Powers of Hickory Neutral Sulfite Semi-chemical Pulps

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Seawater Pulp

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Mockerult and Picholine

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1 Unbleached pulp used for greaseproof paper; bleached pulp used for the others.
2 Schopper-Biegler.
3 0.5 to 3.0.
4 C.E. equivalent, obtained on Hunter reflectometer.
5 5 to 6.0 percent yield before bleaching.
6 Test negative or incomplete after 4 hours.
7 8 to 9 percent yield before cleaning and bleaching. Wood shipment 4689.