THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

SEGREGATION OF WOOD CHIP/BARK MIXTURES USING LIQUID FLOTATION PROCEDURES

Project 2977

Report One

A Progress Report

to

MEMBERS OF GROUP PROJECT 2977

April 27, 1971

MEMBERS OF GROUP PROJECT 2977

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SUMMARY

Work on Project 2977 was initiated officially on October 1, 1970. The principal objectives of the program were to describe the flotation behavior of the bark and wood of selected tree species and use the information so obtained to work out ways to optimize bark segregation. Because of the developmental nature of the procedures being used in describing the flotation behavior of wood and bark, Lake States species were processed first. Southern and western species will be the next to be investigated. Progress of the research effort during the first six-months period is described in the paragraphs that follow.

A flotation device and flotation techniques were developed for use in characterizing the flotation behavior of wood and bark fractions of oak, maple, aspen, cottonwood, and birch. Pure fractions of wood and bark were employed in the flotation studies undertaken. Chip size, moisture content, and compression of the chips were the variables considered and water was used as the flotation medium.

Assuming a theoretical 75/25% wood/bark mixture and using the information on the flotation behavior of the pure fractions, "bark contamination factors" (BCF) were calculated. The BCF values provide an estimate of the amount of the original 25% bark that would remain as "contamination" in the recovered wood fraction and serve as an indicator of the effectiveness of the flotation system.

When quaking aspen bark and wood fractions were processed, chip size and moisture content had only a minor influence on the flotation behavior. The wood chips floated and a large percentage of the bark sank. The best predicted

segregation, based on BCF values, was obtained using "on 1/4-inch" chips at 45% moisture content. Under these conditions the estimated bark contamination was 0.1%.

Bur oak, when processed, also demonstrated good segregation possibilities but behaved, when at 45% moisture content, in a manner the reverse of aspen. The wood of oak sank and the bark floated. Both moisture content and chip size influenced the flotation behavior with moisture content being the more important. Based upon the calculated BCF information, the most satisfactory segregation could be expected to be obtained by using "on 3/4-inch" chips at 45% moisture content. A BCF of only 0.5% resulted when this approach to segregation was used.

The flotation characteristics of white birch, although more complicated than the previously described species, can be used to effect satisfactory wood/bark segregation. The wood when processed at 20% moisture floated with very little loss due to sinking chips. The bark is composed of two quite different fractions, inner bark and outer bark, that usually separate upon chipping. The outer bark floats and the inner bark sinks. When processing bark/wood mixtures, it appears that the outer bark will need to be removed by some procedure such as air flotation or screening. The remaining mixture of wood and inner bark can then be handled exactly like aspen. Calculations of the bark contamination factor indicate that if a mixture of "on 1/4-inch" chips is processed at 20% moisture by first removing the curled papery outer bark and then floating the wood and inner bark, approximately 98% of the wood would be recovered. The bark contamination using this approach would be reduced from 25% to approximately 0.5%.

The flotation behavior of the bark and wood of sugar maple and eastern cottonwood was also investigated. Although the two species did not behave in the same manner, results indicate neither species can be segregated using the simple water flotation procedure and variables employed in the preliminary work. The results obtained defined the problems involved and indicate that the use of such procedures as air entrapment, wetting agents, etc., may be useful in establishing a satisfactory wood segregation system.

INTRODUCTION

Background information presented to cooperating companies when Project 2977 was established stressed that "recent predictions of increases in raw material requirements, woods labor problems and increasing pressure by the public to create less disturbance to man's environment has made it evident that pulp and paper industries must develop radically new and more efficient raw material harvesting systems." Basically, the approach that appears to offer the most promise is one being pursued by the American Pulpwood Association which involves developing a procedure that allows chipping at the stump and the bulk handling of the chips from the woods to the mill. Such a procedure would make possible the utilization of small-sized trees and the use of a greater portion of the total tree. In addition, it has been predicted that greatly reduced harvesting and transportation costs would result and shorter rotations would be possible.

Techniques which need to be mastered before the several benefits associated with "chipping at the stump" can be realized include: (1) perfection of functional harvester-chippers, (2) reduction of wood/bark adhesion on chip samples during the dormant season, (3) development of methods of segregating chip/bark mixtures.

The first problem area mentioned above is presently being worked on by loggers, woodland organizations, engineers and equipment manufacturers. The variation in the approaches being used to solve the problem is as great as the number of organizations involved. The spectrum of innovations approximately equals the diversity of the plans of attack. Whether the plans and innovations call for conventional harvesting of logs or pulpwood, better utilization of the residue, or for processing the tree into chips at the stump, the question of how to segregate the bark from the wood and fully utilize the wood fiber present must eventually be faced.

The second factor, wood/bark adhesion, becomes important somewhere along the line in most of the harvesting techniques being proposed. Bark adhering to wood chips during the dormant season is a cause for concern whether dealing with logging residue, debarking residue or trees chipped in total at the stump. The problem of bark adhesion to wood has been examined by a number of investigators and is presently under investigation in Project 2929 by other researchers at The Institute of Paper Chemistry.

The third technique mentioned, "segregation of chip/bark mixtures," is the subject of this investigation. This is a problem that has intrigued men for many years but only recently has the economics of the situation encouraged a determined attempt to resolve it. With rising costs, a steadily decreasing availability of woods laborers and predicted wood shortages, every incentive exists to provide means of utilizing wood chips prepared at the stump. Development of means to segregate wood from bark chips in mixtures is a major step in that direction.

Early work by Vroom, et al. (1) described the treatment of barking wastes by wet disintegration, hydraulic centrifuging and screening to separate fibrous materials from the nonfibrous fraction. His work was further improved by Brandts, et al. (2) by adding semidry screening and air classification to the technique. Blanchard (3) developed "a machine for separating bark from wood chips" and assigned the patent for it to the Hosmer Machine and Lumber Co., Inc. The working of the machine was subsequently described by the Paper Trade Journal (4), and Blackford (5-6) of the Hosmer Machine and Lumber Co., Inc. The segregation procedure came to be known as the "Hosmer debarking process." The machine works by compressing the chip mixture between rollers. Some bark sticks to the rollers and is doctored off. The bark passing through "crumbles or splays apart" and is segregated from the wood chips ("wood rebounds to its original shape") by screening. The machine is claimed to work on most tree species.

Wood/bark segregation by air flotation work is presently underway at the Forest Engineering Laboratory at Houghton, Michigan under the direction of John Erickson.

While some work has been done on the removal of bark from wood chips by flotation, much of it is preliminary in nature and the results are described in a very general manner. An earlier (1956) patent by Scheid (7) described an "apparatus for preparation of wood chips" that was used on bigtooth and quaking aspen. The patent, initially by-passed in literature reviews for this project because of its name, employs a concept similar to one perceived by Institute researchers for the segregation of wood and bark chips. Another apparatus of note along these lines is described by Lea, et al (8). His is a "flotation apparatus and recovery and utilization of wood fines from mill wastes." The development of the Vac-sink (9-10) process by Battelle Memorial Institute through the sponsorship of several southern companies is among the earliest of commercially applied processes and has been used only on southern pine to date. Preliminary bark removal using water flotation for birch in Finland was described by Liiri (11-12) in 1960 and 1961. He found the sinking of the chips varied, depending on whether the original timber was or was not floated. Lloyd, et al. (13) described a process for hardwoods which crushed the bark, screened out the crumbled outer bark and floated the remaining chips to segregate the inner bark chips from the wood chips.

Bark removal through liquid flotation, which is the main objective of this project, was initiated at the Institute in the early 1960's when Dr. Roland Kremers, working with enzymes and dilute acids to separate bark from wood [Haas and Kremers (14)] discovered that aspen bark sunk in water while the wood floated. An Institute project was initiated some time later to further study the phenomena on a seasonal basis. The work culminated in a publication by Einspahr, *et al*. (15) and the proposal for this project.

When it was decided that this project would be undertaken at a budget under that originally proposed as minimum, some modifications were necessary that would reduce costs and still give the sponsoring companies the information desired. With the above in mind, the objectives of this project were established to: (1) develop a testing technique and tools to describe the "aspen flotation system," (2) use that technique to describe the flotation behavior of bark and wood of species specified by project cooperators, and finally, (3) from the description obtained, try to modify the flotation system to give satisfactory results for the specified species.

EXPERIMENTAL METHODS AND MATERIALS

Depending on the mill, the process and the end product, the acceptable level of bark contamination lies somewhere between virtually no bark in the wood to as high as 10%. For a practical approach to the problem it was decided that 1 to 3% was a reasonable bark contamination percentage and that further reduction of bark would be considered a problem specific to the particular mill. Since the aspen flotation system falls within these limits (1-3%) and cooperating companies indicated more concern for other species, it was decided further work in improving the aspen flotation system was unnecessary at this point.

The basis for evaluation of the flotation tests was considered and it was decided that evaluations could best be made by isolating, as far as practical, the several variables influencing the flotation procedure. Chip size and moisture content were chosen as the two factors most likely to influence the test. It was decided to run the flotation tests on extremes of these factors. Additionally, it was decided that testing "bark only" and "wood only" as pure fractions would improve the descriptive procedure and the ease of understanding of the results. While admittedly this would preclude observation on interaction of bark and wood in mixtures, it was felt the understanding which might result could offer better solutions to the ultimate optimization of the system. Also, in an optimum system, a mixture of wood and bark chips should be processed in a manner which allows individual reaction of a particle to the flotation medium.

TREE SPECIES SAMPLED

Correspondence enclosed with the proposal asked for indications of interest as to tree species to investigate. On the basis of cooperator interest, a list of candidate tree species was compiled. Included in the list were the six hardwoods and four coniferous (softwood) species listed as follows:

sugar maple (Acer saccharum Marsh.)

white birch (Betula papyrifera Marsh.)

shagbark hickory [Carya ovata (Mill.) K. Koch]

white spruce [Picea glauca (Moench) Voss]

slash pine (Pinus elliottii Engelm.)

eastern cottonwood (Populus deltoides Bartr.)

quaking aspen (Populus tremuloides Michx.)

bur oak (Quercus macrocarpa Michx.)

Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco]

western hemlock [Tsuga heterophylla (Rafn.) Sarg.]

The first series of experiments was run using Lake States grown quaking aspen, sugar maple, white birch, eastern cottonwood, and bur oak. All five species were available in native stands near Appleton, Wisconsin. The sampling and descriptions of the species used are given in the following section.

FIELD SAMPLING PROCEDURES

In early November two trees of locally grown quaking aspen were cut and brought into the Institute for chipping and use in the development of a testing procedure and equipment for describing the "aspen flotation system." Two trees each of white birch, sugar maple, and bur oak were sampled in mid-November. Finally, in the first week of December, the cottonwood stems were cut and prepared for chipping. All trees were located near Appleton in farm wood lots. The trees were cut into three 100-inch bolts and two half-inch disks were taken from four locations in each tree (stump height, 100, 200, and 300-inch positions).

The disks from the 100-inch level were used to determine the moisture content of the wood and bark on a green weight basis. Duplicate specific gravity determinations of wood and bark were made of the remaining sampling positions (stump, 200 and 300 inches). Specific gravity determinations were made on a green volume, ovendry weight basis using a water displacement technique.

Trees range in age from 14 years for the eastern cottonwood to over 70 years for the bur oak. The descriptions of the trees in terms of age, dimensions, moisture content when cut, and density of both wood and bark are given in Table I.

TABLE I

SAMPLE TREE DESCRIPTIONS

Material	Age, years	Height, feet	Diam. at 4.5 Ft., inches	Moisture Content at Time Cut, % of fresh wt.	Av. Sp. Gr., g./cc. Wood	Av. Sp. Gr., g./cc. Bark
Quaking aspen	39	60	9.0	42.5	0.346	0.503[a]
	39	60	8.5	41.7	0.368	0.503[a]
Sugar maple	48	54	10.5	40.1	0.603	0.575
	63	54	9.0	39.3	0.572	0.550
White birch	49	55	9.5	39.6	0.532	0.529
	44	63	11.7	43.3	0.502	0.554
Eastern cottonwood	16	60	8.0	58.3	0.362	0.369
	16	60	10.0	58.3	0.385	0.408
Bur oak	79+	45	9.6	38.7	0.640	0.384
	45	54	13.2	38.4	0.651	0.374

[a]Technical difficulties arising during bark specific gravity for aspen necessitated a rerun, using bark-chips from the aggregate chips of both trees. The figure given is an average of five aggregate bark-chip samples.

PREPARATION OF SAMPLE

The newly cut wood was presented in the form of ca. 4-ft. bolts. Some of these were too great in diameter to enter the chute of the chipper so they were split as necessary. Each species was handled separately and the chipper was carefully cleaned between uses.

The chipper is a 41-in., 4-knife machine made by Carthage Machine Co., and the newly sharpened knives were set to deliver chips of a nominal 3/4-inch length. All of the bolts constituting one sample were chipped together and the chips were well mixed before processing.

A representative sample of chips from each wood species was screened on a 24-in. Sweco vibratory screen fitted with 3/4, 1/2, and 1/4-in. mesh screens. The chips were charged to the top (3/4-in. mesh) screen where the obviously oversized material was picked off manually. The screen delivers the sized material continuously, so four streams were recovered, i.e.: (1) on 3/4-in., (2) through 3/4- and on 1/2-in. mesh, (3) through 1/2- and on 1/4-in. mesh, and (4) through 1/4-in. mesh. The data concerning this preliminary work are given in Table II. The differences in the proportions of the various sizes of chips noted for the species involved may be related to the resistance of the wood to the impact of the chipper blade.

TABLE II

PRELIMINARY CHIP SIZE CLASSIFICATIONS

	Species				
	Aspen	Maple	Birch	Cottonwood	Oak
Oversize, %	2.8	7.1	1.1	2.3	3.6
On 3/4-in., %	54.8	29.0	19.3	10.2	20.8
On 1/2-in., %	37.8	35.5	61.3	64.0	54.5
On 1/4-in., %	10.3	26.5	14.7	19.9	17.6
Through 1/4-in., %	3.3	0.9	3.6	3.6	3.5

The general requirements of the flotation work defined the amounts of bark and wood of each size needed. Since it was decided that both relatively large and relatively small particle sizes would be tested, the fractions retained on the 3/4-in. mesh and the 1/4-in. mesh were set aside for study. Each was hand sorted and the moisture-free weight of the wood-free bark and the bark-free wood components was determined. These data were used to calculate the amount of unscreened chips which had to be processed to provide all of the samples needed for testing. The oversized chip fraction accumulated in the screening operation was oven dried, weighed, and discarded. The same was true of the fines which passed the 4-mesh (1/4-in. opening) screen. The fraction which passed the 3/4-in. opening screen and was retained on the 2-mesh (1/2-in. opening) screen was set aside, although there are no immediate plans for using this material. The large (on 3/4 in.) and small (on 1/4 in.) chips were handled identically. The entire amounts accumulated on these screens in the screening operation for each wood species were well mixed and quartered to produce a sample weighing approximately 5 kilograms, moisture free. This was stored in a polyethylene bag in the cold room, with dilute formaldehyde-soaked blotter paper enclosed as a preservative. The rest of the chips remaining from this operation were hand sorted to obtain a minimum of 600 g. moisture-free bark (no wood) and 1200 g. moisture-free wood (no bark). These samples were stored in the cold room in the manner described above. After this was accomplished, the following materials were available for testing for each wood species:

(1) large (on 3/4 inch) wood chips

(2) large (on 3/4 inch) bark chips

(3) small (on 1/4 inch) wood chips

(4) small (on 1/4 inch) bark chips

Some of each sample was sacrificed for determination of moisture-free solids content. The ovendry equivalent of the samples needed were then quartered out, put in separate polyethylene bags, adjusted to the appropriate moisture content by either drying or adding moisture, and allowed 24 hours to equilibrate.

EXPERIMENTAL PROCEDURE

A convenient set of terms to describe the various fractions which could be separated from a single sample during exposure to the test conditions was required. Therefore, in all of the experiments described below, the term "first floaters" will mean any material skimmed from the water surface after the preliminary soak and agitation and "first sinkers" such material as could not be removed by skimming because of its location on or near the bottom of the test vessel. Similarly, "second floaters" will be the term used to describe the skimmings from the second water soak and "second sinkers" the material not so removed.

The flotation test utilized a clear acrylic vessel 45.5 cm. in height made from a piece of 26.7-cm. i.d. tubing having 0.64-cm. walls (see Fig. 1). Appleton city tap water adjusted to 20°C. was used to fill the vessel to a height of 38 cm. and the top was closed with a device which pushed the chips to a position at least 6 cm. beneath the surface of the water. A 4-blade paddle actuated by a manually operated crank kept the chips agitated during the 5-min. period used in the first soak. At the end of this time, the top was removed and any material which floated was skimmed off (first floaters). The vessel was now emptied on a muslin-covered box and the sunken fraction (first sinkers) was recovered. This was placed in a tared 8-lb. kraft bag and properly identified as to wood species, size of particle (i.e., 3/4- or 1/4-in. nominal), moisture content at the start of the test, and whether wood or bark. The vessel was refilled with water and a hand-operated, rubber-rolled laundry wringer was mounted above it. The roll tension was arbitrarily set, then not changed. A small stream of water was played on the roll nip and the first floaters were fed through the wringer back into the water. This operation took as long as 2 minutes to perform. The cover-stirrer was then set in place and the chips were immersed and agitated for an additional 3 minutes. Again, the separation between the portions either sinking or floating was made and the second floaters and second sinkers were placed in properly identified, tared paper sacks. When testing was completed, all of the sacks were placed in an oven maintained at 105°C. and dried until the weight was stabilized. A schematic diagram of the operation is shown in Fig. 2. The test was performed in duplicate, with a change of operators made between tests.

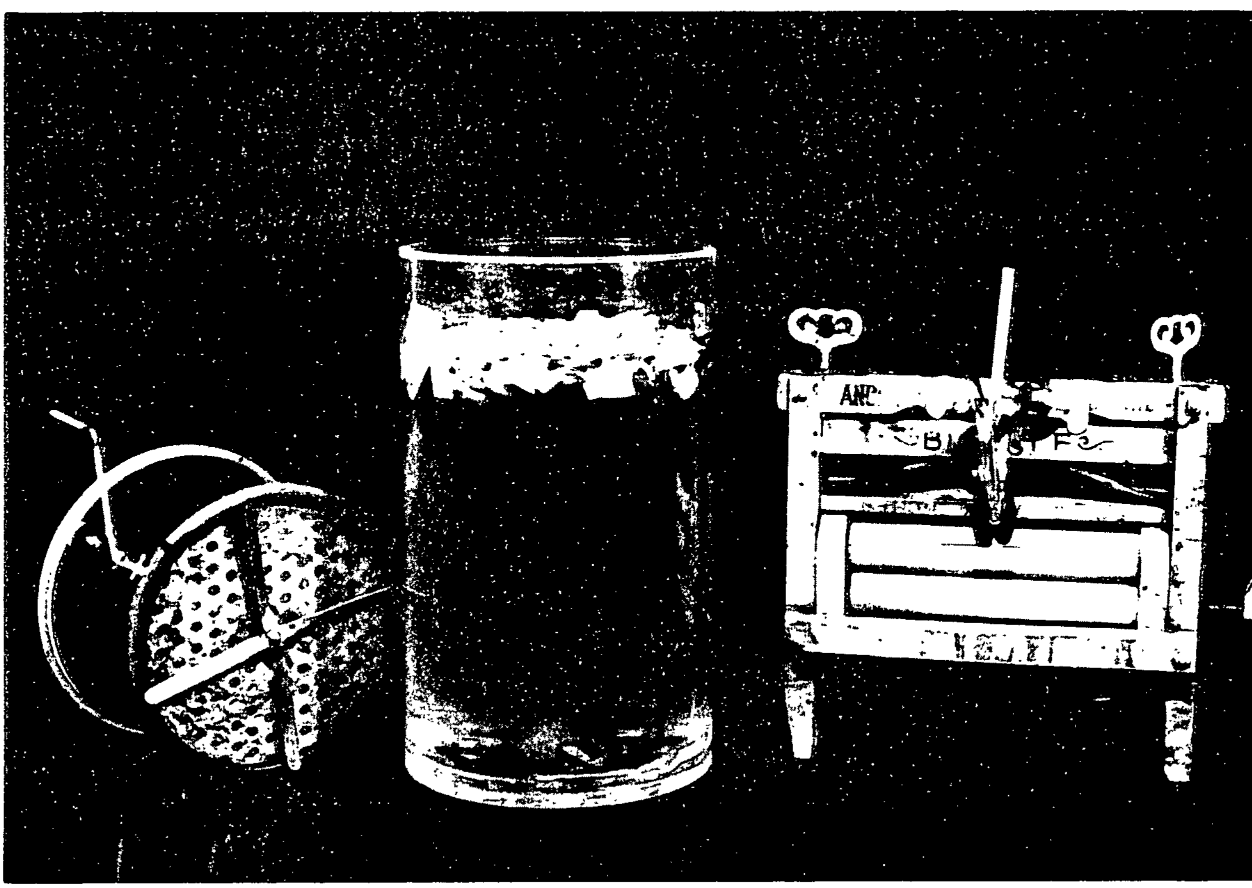

Figure 1. Shown Above is the Flotation Apparatus Used in the Flotation Tests. From Left to Right the 4-Bladed Agitator, the Flotation Vessel, the Chip Compressor

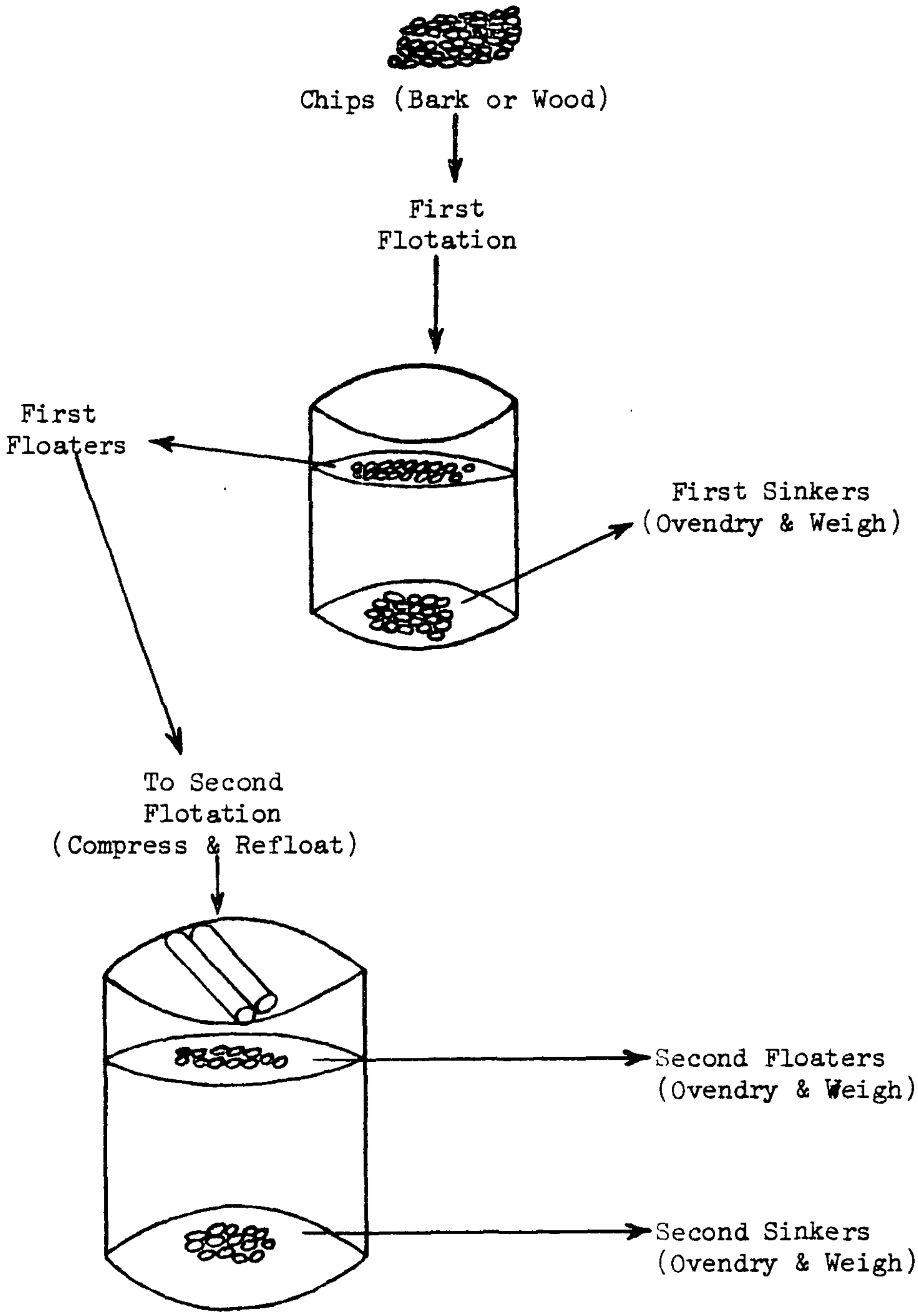

Figure 2. A Schematic Diagram of the Flotation Testing Procedure

The data were compiled for the various flotations, the averages for the duplicated runs determined and these values listed in tables by species. This information is included and used in later sections of this report when discussing the reaction to flotation of the wood and bark chips for each of the tree species.

As was stated earlier, "pure bark" and "pure wood" samples were tested to facilitate the description of the process and the interpretation of the data. A complete study must take into account how a wood-bark chip mixture might behave. To accomplish this, the data available on pure fractions were used to interpret, by means of a mathematical formula, the percentage of bark that would remain as "contamination" in the recovered wood. The term used to describe the results of computing this mathematical formula is "bark contamination factor" (BCF). The BCF was computed for the largest portion of wood which could be recovered from a theoretical wood-bark chip mixture after flotation. In most cases the wood is recovered as the floating portion but in some cases (oak, for example), the wood is recovered as the sunken portion. The manner in which the BCF is computed is given in Appendix I.

The contamination reflected by the BCF is related to the percentage of bark in the mixture to be processed. This could vary from 10% for large round wood to more than 50% for milling residues. For the purposes of this report, a theoretical mixture of 25% bark was used. This is more nearly the percentage of bark found in the total stem and thus gives a BCF slightly higher than anticipated for present-day merchantable limits.

RESULTS OF FLOTATION EXPERIMENTS

QUAKING ASPEN (Populus tremuloides Michx.)

Because of previous experience with quaking aspen bark/wood chip segregation, the aspen material was processed first in order to accomplish any final adjustment of the planned experimental techniques. As it worked out, no further refinements were necessary.

The average specific gravity of the wood and bark for each species was listed previously in Table I. The ranges and averages for specific gravity determinations for the aspen samples used are as follows:

(1) bark – 0.431-0.528; average 0.503

(2) wood – 0.328-0.415; average 0.357

These data for specific gravity of aspenwood and bark, based on ovendry weight/green volume, are average for bark and low for wood compared to the values reported by other researchers and listed in Table VIII of the Appendix. As the data show, the bark is heavier than the wood but both are less than the density of water. From this one might deduce that both bark and wood for aspen would float on water but that is not the case. Generally, as the flotation tests showed, the bark sinks and the wood floats.

The summary data for the aspen flotation work are shown in Table III. It should be remembered, when observing the data, that the tests were run as either pure bark or pure wood. In all tests run, 96% or more of the aspenwood floated while 17.5% or less of the aspen bark floated. Figure 3 illustrates the results of the tests run using bark and wood samples at 45% moisture content.

The wood tests indicated no appreciable differences in flotation of wood due to differences in chip size. Increasing the moisture content of the wood chips from 20 to 45% also gave no appreciable flotation change. The percentage of wood floating was so high that first and second sinker comparisons are unnecessary.

TABLE III

ASPEN FLOTATION RESULTS[a]

	Wood	Bark	BCF[b]	Wood	Bark	BCF[b]
Chip Size		"on 1/4 inch"			"on 3/4 inch"	
		20% Moisture Content				
First Flotation						
First sinkers	0.2	76.1	--	0.2	45.2	--
First floaters	98.8	23.9	7.4	98.8	54.8	18.3
Second Flotation						
Second sinkers	0.0	14.5	--	0.2	41.4	--
Second floaters	98.8	9.4	3.0	99.6	13.4	4.3
		45% Moisture Content				
First Flotation						
First sinkers	1.2	95.4	--	0.9	78.7	--
First floaters	98.8	4.6	1.5	99.1	21.3	6.7
Second Flotation						
Second sinkers	2.5	4.8	--	0.3	16.2	--
Second floaters	96.3	0.8	0.1	98.8	5.1	1.7

[a]Results for wood and bark were determined from pure fractions and are expressed as percentages of the original sample which was approximately 200 grams for wood and 100 grams for bark. Values shown are averages for duplicate determinations.

[b]Bark contamination factor (BCF) is the percentage of bark remaining in the "recovered wood" (largest wood fraction) after processing a theoretical wood-bark chip mixture of 25% bark and 75% wood. The values are listed as "sinkers" or "floaters," depending on where the largest wood fraction is located. BCF values listed in the second flotation are composites of first and second flotation results. See Appendix I for an example of the computation.

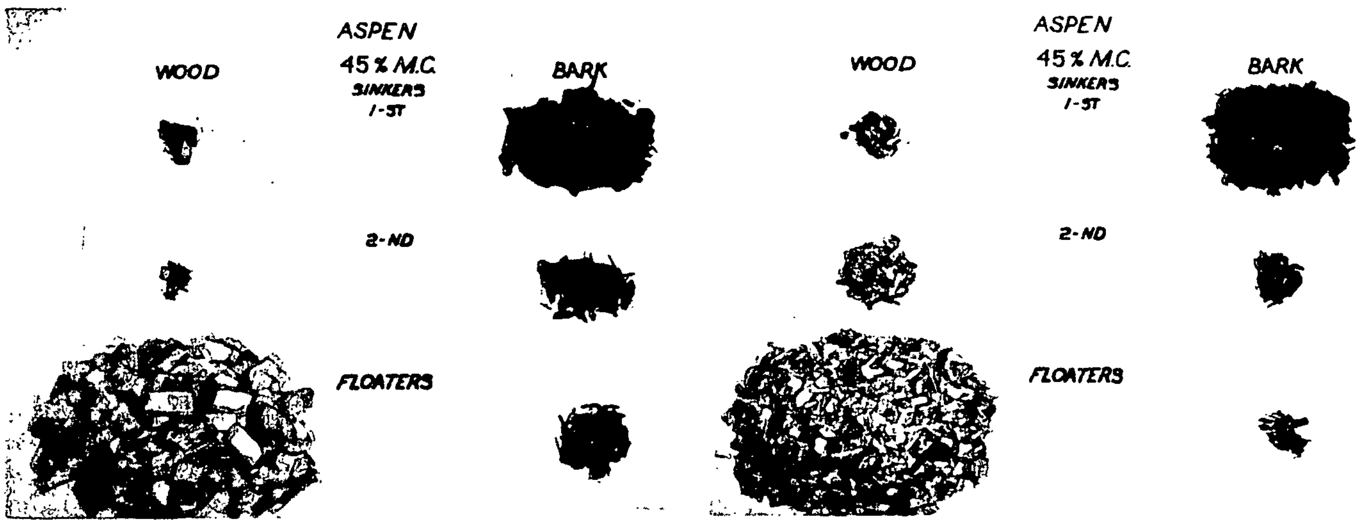

Figure 3. Represented Pictorially Above are the Results of One of the Best Aspen Wood-Bark Chip Flotation Segregation Tests. Represented is (Left) 98.8% Wood Recovery with 1.7% BCF for "on 3/4-Inch" Chips and (Right) 96.3% Wood Recovery with 0.1% BCF for "on 1/4-Inch" Chips. Both Size Chips Were Processed at 45% Moisture Content

The bark tests indicated a higher percentage of moisture in the bark will result in more bark sinking. There is some indication smaller bark chips will sink more readily than larger bark chips; however, moisture content has a greater effect than chip size. Compression and refloating of the bark chips (first floaters) remaining after the five-minute first flotation increased the total percentage of bark sinking so that less than 14% of the bark remained from the 20% moisture content samples and less than 2% from the 45% moisture content samples.

The "bark contamination factor" (BCF) column in the table was computed from the wood and bark data to determine the percentage of bark in the largest wood fraction assuming the bark and wood were mixed. The fact that the bark contamination factor (BCF) values obtained for aspen are similar to the actual contamination results obtained by Einspahr, et al. (15) offers some assurance as to the validity of this computation. The mixture percentages used to determine the BCF was 75% wood chips and 25% bark chips. It is important to keep this in mind because the BCF changes with changes in the ratio of wood to bark in the original mixture, e.g., a reduction of bark in the original mixture to from 25 to 15% for the "on 3/4-inch" 20% moisture content sample would decrease the BCF after the second flotation from 4.3 to 2.3%. The contamination figures computed indicate that "on 1/4-inch" chips at 20% moisture and both size chips at 45% moisture can be processed and bark removed from the samples leaving less than 3% bark contamination.

SUGAR MAPLE (Acer saccharum Marsh.)

The test procedures for sugar maple were the same as used with quaking aspen. However, the results for sugar maple are not as clear cut as those for aspen. The summary of the data for the flotation tests run is presented in Table IV. Figure 4 gives a pictorial illustration of the test results related to wood and bark samples at 20% moisture content.

The range and average of the specific gravity determinations for sugar maple wood and bark are as follows:

(1) bark – 0.494 to 0.597; average 0.563

(2) wood – 0.558 to 0.615; average 0.588

The specific gravities listed are similar to those reported by other researchers and presented in Table VIII of the Appendix. As the data indicate, the specific gravity for the sugar maple wood and bark were similar.

Flotation tests with sugar maple wood indicated that the moisture content of the sample controlled whether it would sink or float. At 45% moisture content, 85% of both large and small chips sank. At 20% moisture content, the reverse was true, i.e., 85% of the wood floated. Neither chip size nor compression and a second flotation seemed to affect the results appreciably.

TABLE IV

SUGAR MAPLE FLOTATION RESULTS[a]

	Wood	Bark	BCF[b]	Wood	Bark	BCF[b]
Chip Size	"on 1/4 inch"			"on 3/4 inch"		
	20% Moisture Content					
First Flotation						
First sinkers	7.6	33.7	--	1.5	3.0	--
First floaters	92.4	66.3	19.3	98.5	97.0	24.7
Second Flotation						
Second sinkers	5.0	13.5	--	2.2	5.0	--
Second floaters	87.4	52.8	16.8	96.3	92.0	24.2
	45% Moisture Content					
First Flotation						
First sinkers	86.1	67.3	20.7	93.2	68.2	19.6
First floaters	13.9	32.7	--	6.8	41.8	--
Second Flotation						
Second sinkers	4.3	3.1	20.6	1.3	3.2	20.1
Second floaters	9.6	29.6	--	5.5	38.6	--

[a]Results for wood and bark were determined from pure fractions and are expressed as percentages of the original sample which was approximately 200 grams for wood and 100 grams for bark. Values shown are averages for duplicate determinations.

[b]Bark contamination factor (BCF) is the percentage of bark remaining in the "recovered wood" (largest wood fraction) after processing a theoretical wood-bark chip mixture of 25% bark and 75% wood. The values are listed as "sinkers" or "floaters," depending on where the largest wood fraction is located. BCF values listed in the second flotation are composites of first and second flotation results. See Appendix I for an example of the computation.

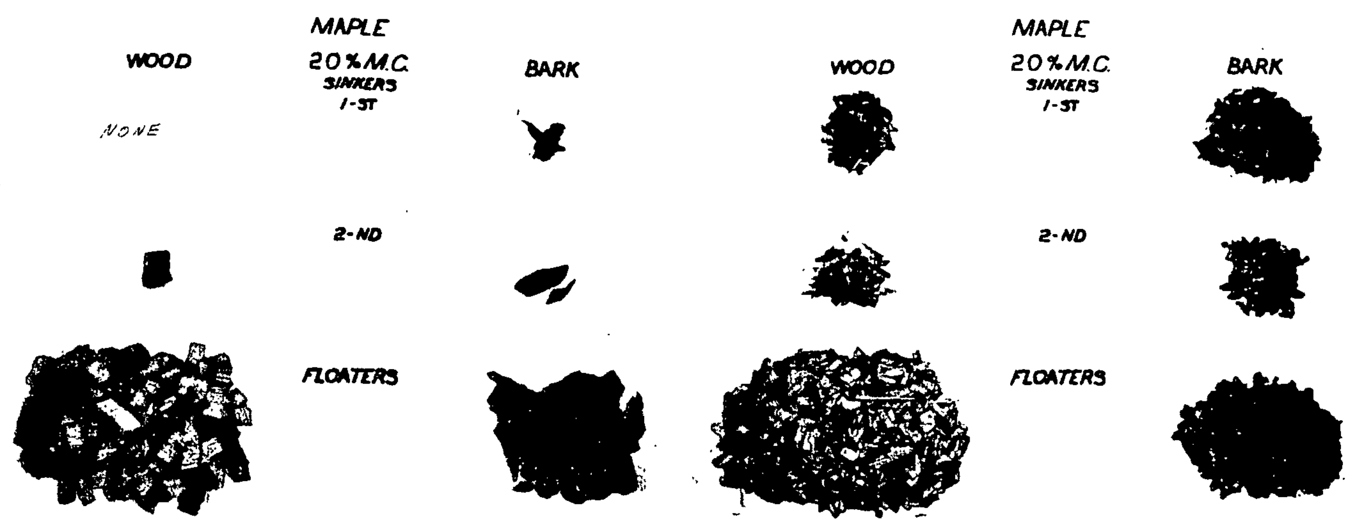

Figure 4. Illustrated Above are the Results of the Best Sugar Maple Wood-Bark Chip Flotation Segregation Tests. Testing 20% Moisture Content Chips Showed a Recovery of 96.3% "on 3/4-Inch" Wood Chips (Left) with a BCF of 24.2% and a 87.4% Recovery of "on 1/4-Inch" Wood Chips (Right) with a BCF of 16.8%. None of the Maple Tests Gave Satisfactory Segregation

The flotation tests run on sugar maple bark revealed that the bark chips respond to flotation in a manner similar to the wood chips. At a 20% moisture content about one-half of the "on 1/4-inch" chips and 90% of the "on 3/4-inch" chips floated. At the 45% moisture content about 70% of both size bark chips sank.

The bark contamination factor (BCF) was determined two ways for the maple tests. At 20% moisture the majority of the wood floated so the BCF was computed in the same manner as the aspen. The best results were obtained with the "on 1/4-inch" chips where 87.4% of the wood was recovered with a BCF of 16.8%. At 45% moisture the majority of the wood sank so a slightly different interpretation was used (see Appendix I for example). The best results were obtained in the first flotation of the "on 3/4-inch" 45% moisture chips where 93.2% of the wood was recovered through sinking with a BCF of 19.6%. The second flotation resulted in the recovery through sinking of 1.3% more wood but at an BCF increased to 20.1% due to more bark sinking than wood in the second flotation. The data suggest that the bark is not affected as much as the wood by moisture content. This will be taken into account in additional work to improve sugar maple wood-bark chip segregation.

WHITE BIRCH (Betula papyrifera Marsh.)

The wood characteristics of white birch are very similar to those of maple but the birch bark is quite different from maple bark. When the white birch was chipped the unique characteristics of birch bark were very obvious. As can be seen in Fig. 5, the outer bark tended to separate from the inner bark and form a dry paperlike curl.

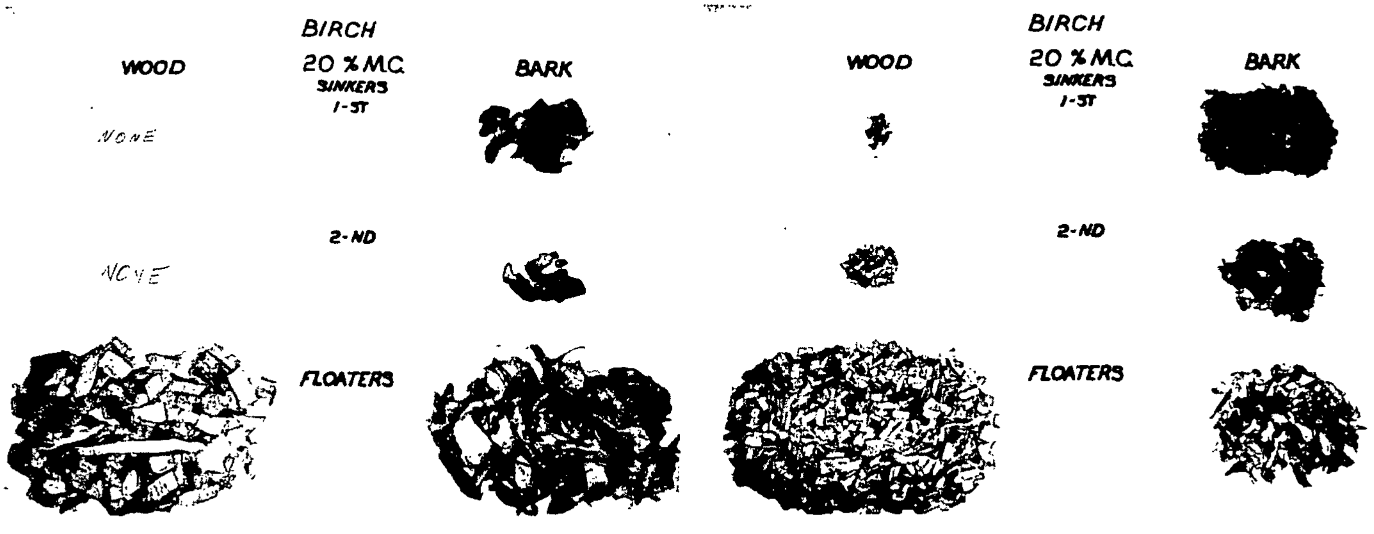

Figure 5. Results of the Better White Birch Flotation Tests Pictured Above Focus on the Segregation Problem. Elimination of the Outer Bark from the "on 3/4-Inch" Bark Chip Floaters (Left) and "on 1/4-Inch" Bark Chip Floaters (Right) Would Result in BCF Values of 4.0 and 0.5%, Respectively, with over 98% Wood Recovery

The range and average specific gravity determinations for the white birch used are as follows:

(1) bark — 0.512 to 0.559; average 0.542

(2) wood — 0.484 to 0.543; average 0.517

These values are in general agreement with those of other researchers presented in Table VIII of the Appendix. The description of the original trees is given in Table I, in the section "Experimental Methods and Materials." The results of the flotation tests are given in Table V.

TABLE V

WHITE BIRCH FLOTATION RESULTS[a]

Chip Size	Wood "on 1/4 inch"	Bark "on 1/4 inch"	BCF[b] "on 1/4 inch"	Wood "on 3/4 inch"	Bark "on 3/4 inch"	BCF[b] "on 3/4 inch"
20% Moisture Content						
First Flotation						
First sinkers	0.7	67.2	--	0.3	12.7	--
First floaters	99.3	32.8	10.0	99.7	87.3	22.6
Second Flotation						
Second sinkers	1.0	13.7	--	0.2	6.7	--
Second floaters	98.3	19.1	6.1	99.5	80.6	21.3
45% Moisture Content						
First Flotation						
First sinkers	31.2	87.2	--	26.6	26.2	--
First floaters	68.8	12.8	5.8	73.4	73.8	25.1
Second Flotation						
Second sinkers	10.7	1.0	--	4.5	1.3	--
Second floaters	58.1	11.8	6.3	68.9	72.5	26.0

[a]Results for wood and bark were determined from pure fractions and are expressed as percentages of the original sample which was approximately 200 grams for wood and 100 grams for bark. Values shown are averages for duplicate determinations.

[b]Bark contamination factor (BCF) is the percentage of bark remaining in the "recovered wood" (largest wood fraction) after processing a theoretical wood-bark chip mixture of 25% bark and 75% wood. The values are listed as "sinkers" or "floaters," depending on where the largest wood fraction is located. BCF values listed in the second flotation are composites of first and second flotation results. See Appendix I for an example of the computation.

The tests run on the wood chip samples indicate little change in flotation results due to chip size; however, there were influences due to moisture content. Better than 98% of the wood chips floated at the 20% moisture content while only 58% "on 1/4-inch" and 69% "on 3/4-inch" floated at 45% moisture content.

The flotation results for bark showed there were differences due to chip size. At 20% moisture the second floaters amounted to 80.6% of the "on 3/4-inch" bark chips and only 19.1% of the "on 1/4-inch" bark chips. At 45% moisture the second floaters amounted to 72.5% of the "on 3/4-inch" bark chips and 11.8% of the "on 1/4-inch" bark chips. As Fig. 5 adequately illustrates, the majority of the bark floating is the paperlike outer bark. The floating sample was composed of: (1) 78% outer bark, (2) 7% inner bark, and (3) 15% whole (inner and outer) bark of which 42% was outer bark. Neither bark chip size nor moisture content were found to have any influence on the composition of the bark fraction which remained floating.

The bark contamination factor (BCF) figures show improved segregation for the second flotation of samples at 20% moisture content. While contamination of the large chips is quite high, 21% to 26% as opposed to 6% for the "on 1/4-inch" chips, the fact that the majority of the contaminating chips are outer bark focuses attention on the problem to resolve.

EASTERN COTTONWOOD (<u>Populus deltoides</u> Bartr.)

Of the materials tested and included in this report, eastern cottonwood offered the greatest surprise. Because it is related generically to aspen and possesses similar wood qualities, it was felt the flotation results would be very similar to those of aspen. This was not the case as the flotation test results will show.

The range and average specific gravities determined for the eastern cottonwood samples used are as follows:

(1) bark — 0.342 to 0.427; average 0.392

(2) wood — 0.344 to 0.384; average 0.372

The wood and bark specific gravities listed are similar to values reported by other researchers (Table VIII of the Appendix). The basic difference between eastern cottonwood and aspen, as far as these data are concerned, is in the specific gravity of the bark (0.503 for aspen and 0.392 for eastern cottonwood). The flotation test results for cottonwood, shown in Table VI, indicate 91% of the wood floats at 45% moisture content regardless of chip size and at 20% moisture content 99% to 100% floats regardless of size. See Fig. 6.

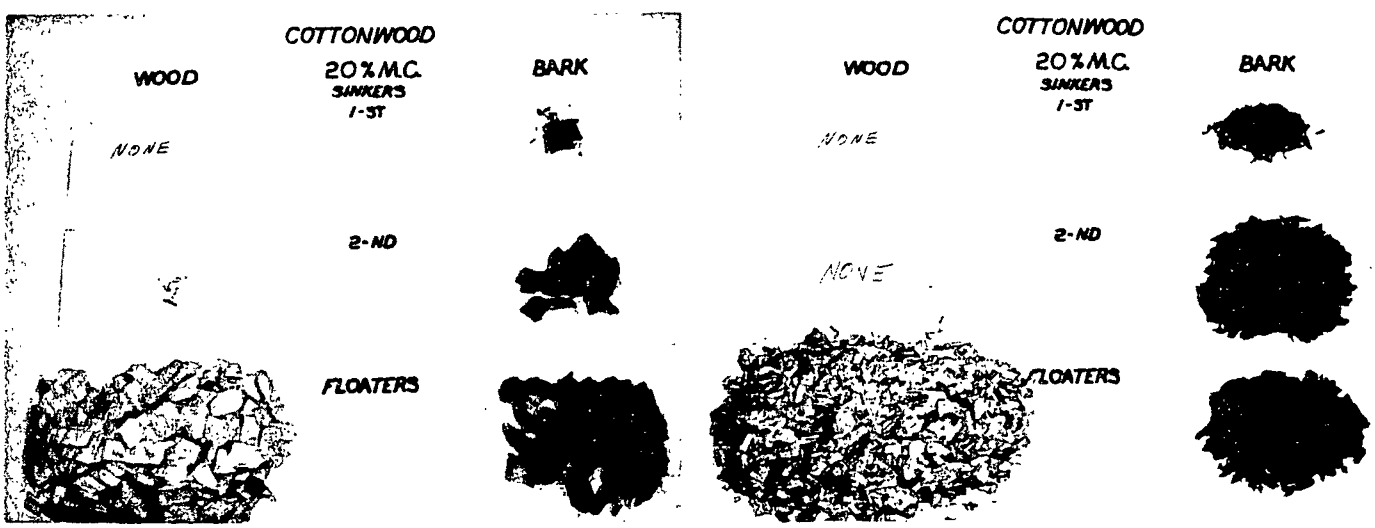

Figure 6. The Segregated Fractions of a 20% Moisture Content Eastern Cottonwood Flotation Test. As can be seen, Higher Amounts of "on 1/4-Inch" Bark Chips (Right) Sank than "on 3/4-Inch" Bark Chips (Left)

TABLE VI

EASTERN COTTONWOOD FLOTATION RESULTS[a]

Chip Size	Wood	Bark	BCF[b]	Wood	Bark	BCF[b]
	"on 1/4 inch"			"on 3/4 inch"		
	20% Moisture Content					
First Flotation						
First sinkers	0.3	14.4	--	0.0	1.0	--
First floaters	99.7	85.6	22.3	100.0	99.0	24.8
Second Flotation						
Second sinkers	0.2	49.8	--	0.0	19.4	--
Second floaters	99.5	35.8	10.7	100.0	79.6	21.0
	45% Moisture Content					
First Flotation						
First sinkers	5.3	19.7	--	5.9	3.2	--
First floaters	94.7	80.3	22.0	94.1	96.8	25.5
Second Flotation						
Second sinkers	3.5	53.9	--	3.2	38.2	--
Second floaters	91.2	26.4	8.8	90.9	58.6	17.7

[a]Results for wood and bark were determined from pure fractions and are expressed as percentages of the original sample which was approximately 200 grams for wood and 100 grams for bark. Values shown are averages for duplicate determinations.

[b]Bark contamination factor (BCF) is the percentage of bark remaining in the "recovered wood" (largest wood fraction) after processing a theoretical wood-bark chip mixture of 25% bark and 75% wood. The values are listed as "sinkers" or "floaters," depending on where the largest wood fraction is located. BCF values listed in the second flotation are composites of first and second flotation results. See Appendix I for an example of the computation.

There were differences in the bark flotation tests due to chip sizes and moisture content. The data show that "on 1/4-inch" bark chips at 45% moisture gave the highest percentage of sinkers. At 20% moisture, the amount of bark sinking was 64.2% for "on 1/4-inch" bark chips and 20.4% for "on 3/4-inch" bark chips. At 45% moisture 73.6% of the "on 1/4-inch" and 41.4% of the "on 3/4-inch" bark chips sank.

Assuming a bark-wood ratio of 25/75 in a chip mixture the bark contamination factor (BCF) averages 8 to 11% for 1/4-inch chips and 18 to 21% for 3/4-inch chips. A decrease in bark contamination was observed in all tests between the first- and second-flotations with a final BCF of 8% for the 1/4-inch chips at 45% moisture content being the lowest value obtained for a single test.

BUR OAK (*Quercus macrocarpa* Michx.)

The white oak group consists of a number of oak species which are relatively easily distinguished from each other by leaf and fruit characteristics but very difficult, at best, to tell apart by wood characteristics. Bur oak is a locally grown representative of this group which was chosen for testing. The range and average specific gravity for the test samples used varied as follows:

(1) bark — 0.397 to 0.355; average 0.379

(2) wood — 0.670 to 0.625; average 0.646

The wood specific gravity is similar to that reported by other researchers and listed in Table VIII of the Appendix. No bark specific gravity information was available.

The wood flotation test results listed in Table VII show that the flotation of this white oak varies with a change in moisture content. At 45% moisture (see Fig. 7) better than 94% of the wood sank in the first flotation regardless of chip size. An amount of wood less than 1% sank on the second flotation. At 20% moisture 15.7% of the "on 1/4-inch" chips and 10.5% of the "on 3/4-inch" chips sank during the first flotation. After the second flotation 64.3% of the "on 1/4-inch" chips and 78.8% of the "on 3/4-inch" chips remained floating.

TABLE VII

BUR OAK FLOTATION RESULTS[a]

Chip Size	Wood	Bark	BCF[b]	Wood	Bark	BCF[b]
	"on 1/4 inch"			"on 3/4 inch"		
			20% Moisture Content			
First Flotation						
First sinkers	15.7	3.0	--	10.5	0.5	--
First floaters	84.3	97.0	27.7	89.5	99.5	27.0
Second Flotation						
Second sinkers	20.0	13.8	--	10.7	2.5	--
Second floaters	64.3	83.2	30.1	78.8	97.0	29.1
			45% Moisture Content			
First Flotation						
First sinkers	94.8	12.7	4.3	96.6	1.5	0.5
First floaters	5.2	87.3	--	3.4	98.5	--
Second Flotation						
Second sinkers	0.8	17.3	9.5	0.3	5.5	2.4
Second floaters	4.4	70.0	--	3.1	93.0	--

[a] Results for wood and bark were determined from pure fractions and are expressed as percentages of the original sample which was approximately 200 grams for wood and 100 grams for bark. Values shown are averages for duplicate determinations.

[b] Bark contamination factor (BCF) is the percentage of bark remaining in the "recovered wood" (largest wood fraction) after processing a theoretical wood-bark chip mixture of 25% bark and 75% wood. The values are listed as "sinkers" or "floaters," depending on where the largest wood fraction is located. BCF values listed in the second flotation are composites of first and second flotation results. See Appendix I for an example of the computation.

The bark flotation tests uniformly showed a strong tendency for the bark to float. Bark flotation was influenced by moisture content. After the first flotation 97.0-99.5% of bark at 20% moisture floated and 87.3-98.5% of the bark at 45% moisture floated. In each case, more of the "on 3/4-inch" bark floated than the "on 1/4-inch" bark.

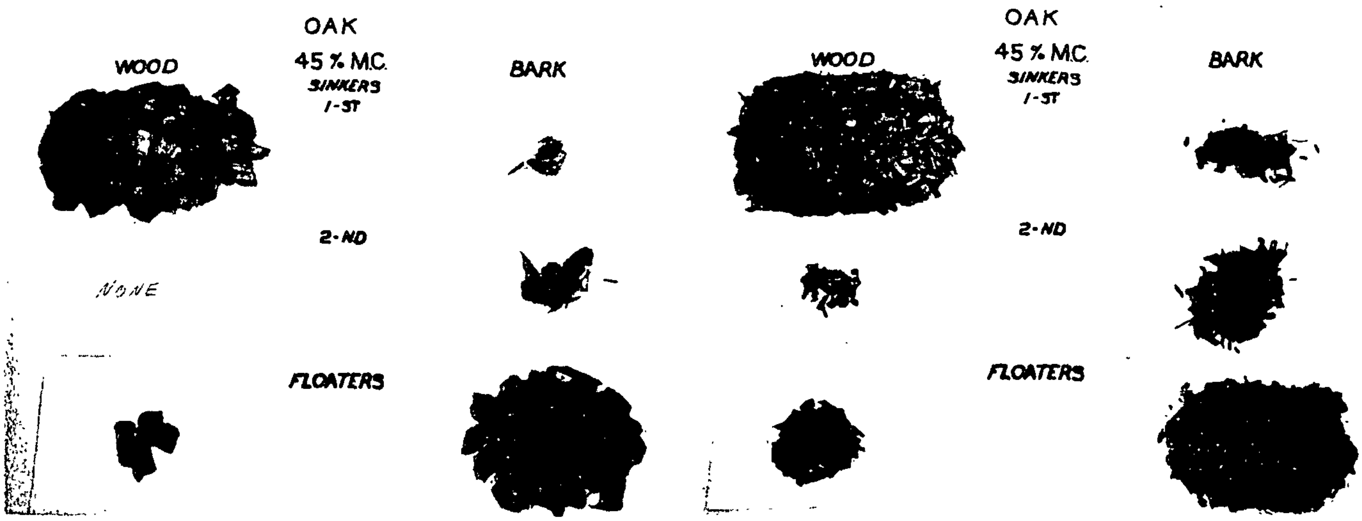

Figure 7. Pictured Above are the Results from one of the Flotation Tests on Bur Oak Chips of 45% Moisture Content. For "on 3/4-Inch" Wood Chips (Left) 96.6% Were Recovered as Sunken Chips with an Estimated BCF of 0.5% and 94.8% of the "on 1/4-Inch" Wood Chips (Right) Recovered as Sunken Chips with an Estimated BCF of 4.3%

Before reviewing the bark contamination factor (BCF), it should be noted that two different interpretations of BCF are involved. At 20% moisture the BCF was figured with floating wood while at 45% moisture the BCF was figured with sinking wood. At 20% moisture no effective segregation took place. In fact, there is an increase in percentage of bark in the wood due to the fact that more wood was lost than bark. If the BCF was computed for sinking wood, the bark contamination would be slightly improved but the percentage of wood recovered would be too low. At 45% moisture much more satisfactory results can be seen. About 95% of the wood is recovered after the first float with 0.5% BCF in the "on 3/4-inch" chips and 12.7% BCF in the "on 1/4-inch" chips. The second flotation adds less than 1% wood in each size class and too much bark, 5-17%, to make the second flotation worthwhile. From these data it appears that segregation of white oak bark and wood chips can best be accomplished using large chips at 45% moisture content.

DISCUSSION

For reasons stated earlier, the flotation work for this first phase of the project employed pure fractions of bark or wood to facilitate data interpretation. To obtain comparable results using chip mixtures, it would be necessary to control the thickness of the mat of chips on the water or to sufficiently agitate the chips to allow individual particles to react to water flotation without interference from other particles. It is felt that data for pure fractions will be of more aid in decision making than that obtained from an arbitrarily chosen wood/bark mixture.

Temperature of the water and dwell time of chips in water were factors controlled but not tested in these studies. Changes in these factors would very likely effect significant modification of the flotation behavior of some species. The temperatures and dwell time used were chosen as reasonable to attain under present mill conditions. The effect of the temperature of the flotation media and dwell time are factors to be considered in the optimization work yet to be done on certain problem species.

Two factors were varied in the flotation tests, material moisture content and particle size. Throughout the flotation tests on the five species, the ability of a particle to take up water seemed to determine whether the particle would sink or float. In general, it can be said that particles at 45% moisture tended to sink sooner than particles at 20% moisture. Similarly, 1/4-inch particles tended to sink sooner than 3/4-inch particles. The flotation results showed a large variability within both of the above statements depending on species and type of material (wood or bark). Segregation of the components of a wood-bark chip mixture in certain species can be controlled by regulating moisture content and particle size.

The flotation data collected for the five species tested indicate satisfactory (0-3% bark contamination factor) segregation could be made with the described system for two species, aspen and bur oak (a white oak). In the case of aspen, the bark sank and the wood floated. Processing of chips at 45% moisture content should give optimum segregation. Near acceptable results could be obtained using 20% moisture content samples. At either moisture content, compression and/or refloating of the chips is necessary to reduce the bark contamination to less than 3%.

In the case of bur oak, the wood sank and the bark floated. Processing chip samples at 45% moisture content should give acceptable segregation while processing 20% moisture content samples will not. Use of larger chip size also should result in cleaner segregation, less than 1% equivalent bark contamination after the first float, with bur oak. One flotation is sufficient for bur oak; the second flotation resulted in a recovery of less than 1% additional wood and a significant increase in bark contamination.

The observations on the white birch samples indicated the main problem is to eliminate the paperlike outer bark from the wood chips. The wood and outer bark float while the inner bark sinks. In general, the data indicated a better segregation and higher percentage of wood recovery could be obtained by processing chip mixtures at 20% than at 45% moisture content. It is felt that a number of possibilities are available which would reduce the bark contamination factor to under 3%. Removal of the outer bark of birch from the mixture would make birch compatible with the aspen and allow treatment of chip mixtures of the two species.

Neither the maple nor the eastern cottonwood showed good segregation possibilities with the basic flotation test used. The results of the flotation tests adequately defined the problem areas so that reasonable solutions to the segregation problem and a resulting acceptable bark contamination factor value seem possible. With the eastern cottonwood it is a matter of treating the chips in such a way that more bark is encouraged to sink. The maple offers a bit more challenge in that the wood can be made to either sink or float depending on the moisture content and, as a result, a greater number of possible solutions to the segregation problems seem to exist.

PLANS

The objectives of this project and the plan of attack define the scope of the work proposed for the next few months. The initial flotation experiments were sufficiently successful with aspen and bur oak to preclude the need for further immediate technique improvement with these species. This means work during the next six-months period will concentrate on modifications which will improve the wood-bark chip segregation via flotation of eastern cottonwood, sugar maple, and white birch.

Modifications under consideration for the flotation-segregation of the abovementioned species include: the use of wetting agents, the use of air entrapment techniques, changes in dwell time and medium temperatures, and, for the white birch, air classification to segregate the outer bark from the other particles. Successful modifications with the three "problem" species will be tested with aspen or bur oak, whichever is appropriate, to determine compatibility of the modifications with species mixes.

Near the end of this next report period (Aug.-Sept.) processing will begin for the remaining species: shagbark hickory, white spruce, slash pine, Douglas-fir, and western hemlock. The basic flotation experiments will be conducted with these species and the flotation behavior characterized. Upon defining problem areas, the necessary modifications will be investigated using approaches similar to those described above.

ACKNOWLEDGMENTS

The program involved has been a team approach involving ideas, talent, advice, and patience from personnel of the Division of Natural Materials and Systems and the Division of Materials and Engineering Processes. The authors would particularly like to acknowledge the assistance of Al Schumacker and Rick Shea for their help in collecting and preparing the logs and their perseverance and patience in sorting chips, Robert Fumal for his help and patience in preparing and sorting the chips and running the flotation tests, and Mrs. Marianne Harder for her all around assistance with specific gravity determinations, preparation of data and assistance with the report.

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APPENDIX I

BARK CONTAMINATION FACTOR DEFINITION AND EXAMPLES

Bark Contamination Factor (BCF) is a computed value, using the flotation behavior of pure bark and pure wood, to indicate the approximate percentage of bark chips in the wood chips after segregating the two. The theory used in developing the flotation tests on pure fractions of either wood or bark is that in any flotation system each particle will be treated in such a way, with some sort of agitation, that the particle will be allowed to react to the flotation media without significant interference from other particles.

The BCF is computed by determining the percentage of bark (by ovendry weight) in the mixture to be processed. This will vary, depending on a number of factors peculiar to the organization processing the chips. For instance, it could be as low as 10% in large-sized wood or higher than 50% for milling residues. For the purposes of this report a mixture of 25% bark was assumed.

BCF of the wood fraction was computed using the largest wood fraction (sinking or floating) wherever it turned up after the first flotation. The steps and two examples are given below:

Steps	Examples for Majority of Wood: Floating Aspen, 1/4-inch 45% M.C.	Sinking Oak, 3/4-inch 45% M.C.
1. Determine ratio wood to bark in mixture to be processed	75/25	75/25
To determine BCF in wood after first flotation:		
2. Multiply percentage of wood in original mixture times percentage of wood after first flotation	75 x 98.8 = 7410	75 x 96.6 = 7245

Steps	Examples for Majority of Wood: Floating Aspen, 1/2-inch 45% M.C.	Examples for Majority of Wood: Sinking Oak, 3/4-inch 45% M.C.
3. Multiply percentage of bark in original mixture times percentage of bark in fraction corresponding to (2) above	25 x 4.6 = 115.0	25 x 1.5 = 37.5
4. Add results of (2) + (3)	7410 + 115 = 7525	7245 + 37.5 = 7282.5
5. To determine BCF % after first flotation, divide percentage of bark, (3), by total wood and bark, (4)	(115/7525)100 = 1.5%	(37.5/7282.5) = 0.5%
To determine BCF in wood after second flotation:		
6. Multiply percentage of wood in original mixture times the largest percentage of wood (sinking or floating) after first and second flotation	75 x 96.3 = 7222.5	75 x 96.9 = 7267.5
7. Multiply percentage of bark in original mixture times percentage bark corresponding to (6)	25 x 0.4 = 10	25 x 7.0 = 175.0
8. Add results of (2) + (3)	7222.5 + 10 = 7232.5	7267.5 + 175 = 7442.5
9. To determine BCF % from first and second flotation results combined, divide percentage of bark, (7), by total wood and bark, (8)	(10/7232.5)100 = 0.1%	(175/7267.5)100 = 2.4%

TABLE VIII

WOOD AND BARK SPECIFIC GRAVITIES AND REFERENCES[a]

Species	Type Sample	Einspahr (16)	Hale (17)	Lamb (18)	Martin (19)	Wood Handbook (20)	Isenberg (21)	Other
		g./cc. by green volume — ovendry weight						
Quaking aspen	Wood	0.40		0.39		0.35	0.40	0.39[b]
	Total bark	0.44-0.63	0.46-0.54	0.45				
	Inner bark			0.40				0.37[c]
	Outer bark			0.49				0.54[c]
Sugar maple	Wood			0.61		0.56	0.60	0.59[d,e]
	Total bark			0.53	0.65-0.69			
	Inner bark			0.67	0.68-0.77			
	Outer bark			0.47				0.57-0.77[f]
White birch	Wood			0.51		0.48	0.50	
	Total bark		0.48-0.56	0.52				
	Inner bark			0.52				0.63[c]
	Outer bark			0.52				0.66[c]
Eastern cottonwood	Wood	0.40				0.37	0.40	0.32-0.46[g,h]
	Total bark							
	Inner bark							
	Outer bark							0.30-0.44[g]
Bur oak	Wood					0.58	0.60	
	Total bark							
	Inner bark							0.81-0.88[f,i]
	Outer bark							0.62-0.82[f,i]

[a]The original references for the above values are listed in the literature cited under the number shown in parentheses. Those listed in the "Other" column are as follows: b = Valentine (22), c = Smith (23), d = Sajdok (24), e = Paul (25), f = Martin and Crist (26), g = Posey (27), and h = Farmer (28).

[i]White oak (*Quercus alba*) values.