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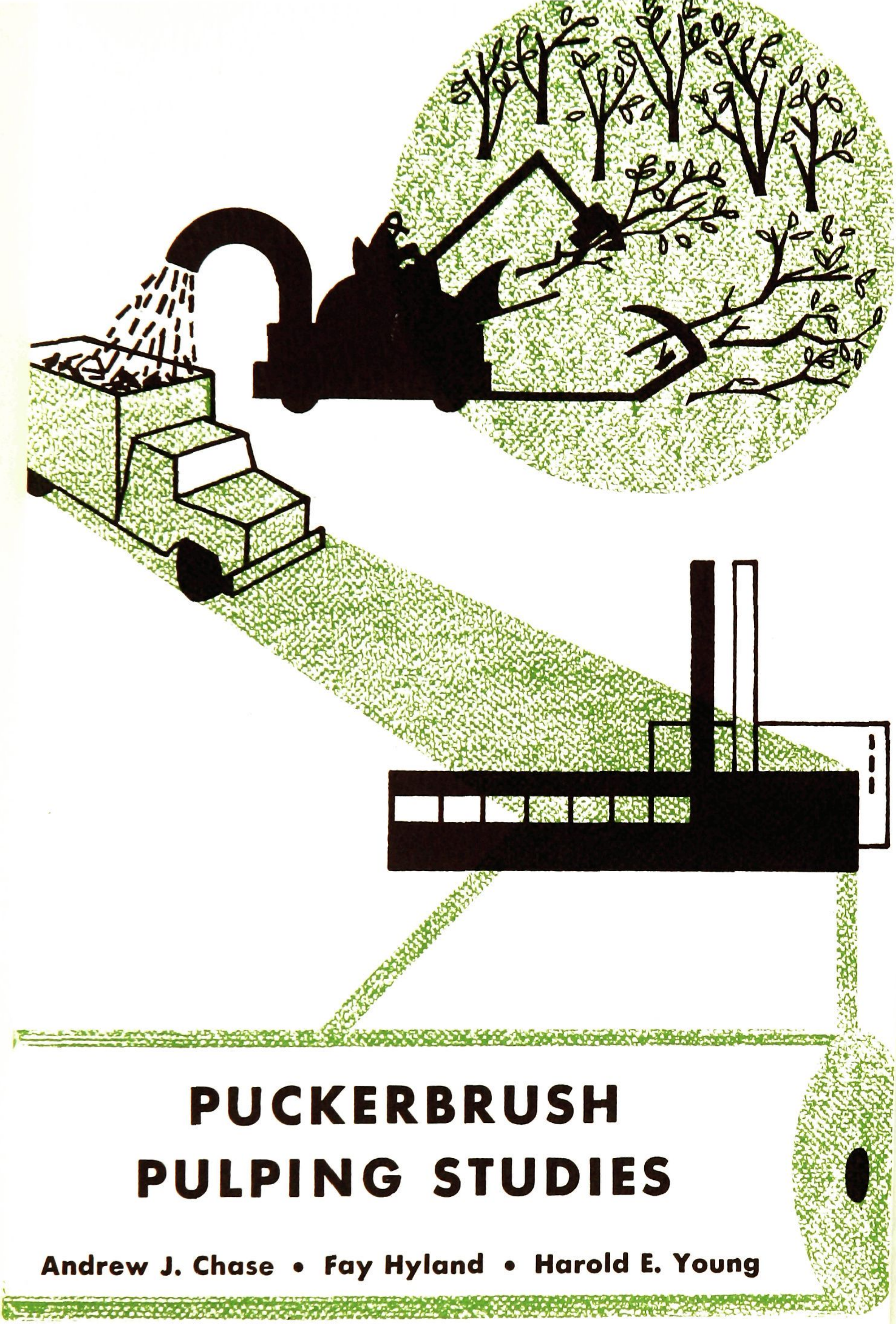

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PUCKERBRUSH PULPING STUDIES

Andrew J. Chase,[1] Fay Hyland[2] and Harold E. Young[3]

Abstract

A study was made of the potential of weed trees and shrubs, called "puckerbrush", native to the state of Maine as a source of fiber for the paper industry.

Six species, gray birch, red maple, pin cherry, aspen, alder, and willow were used in the study. All components of each species were studied separately. These included stemwood, branches, roots and stump. In addition, two mixtures of components of each species were studied. These were Composite 1, a representative mixture of stem, branches, roots and stump, and Composite 2, a mixture of stem and branches. All components were treated with the bark intact; stemwood was also treated with the bark removed.

The sulfate process was used in the pulping study. The sulfate cooks were made in stainless steel digesters using indirect steam heat. A compartment basket arrangement made it possible to cook several different samples simultaneously without the resulting pulps becoming mixed together.

The bleaching study consisted of several different sequences of the basic treatments, chlorination, caustic extraction, hypochlorite, and chlorine dioxide.

Optimum pulping conditions that were established were active chemical to wood ratio 0.2, sulfidity 25%, cooking temperature 345°F, time at temperature ½ hour, initial concentration of white liquors 25 to 30 grams per liter (as Na_2O). Under these conditions the screened yield of unbleached pulp ranged from 37% for alder to 45% for red maple with the yields for the other species falling within this range. These values are for Composite 2 mixture of each species.

For all species the stemwood without bark produced the highest cook yield, and the branches (except for red maple and willow) gave the lowest yield. For these two species, the stump and root component produced the lowest yield.

Further study will be required to determine the optimum bleaching process and conditions. The highest brightness obtained for puckerbrush pulp in this study was for gray birch stemwood without bark. A value of 84.6 G.E. brightness was realized using the sequence chlorination, caustic extraction, chlorination, extraction, hypochlorite,

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chlorine dioxide. A 60% excess of chlorine, over that indicated by the Kappa Number measurement, was used in this bleach sequence with all the excess being added in the second chlorination stage. The overall yield of bleached pulp, while not definitely established for all species, was on the low side, ranging from 30 to 35%. This can be improved by debarking the weeds before pulping and also by optimizing the bleaching conditions.

The TAPPI standard beater test was made on all components of all species; beating or refining characteristics were studied and bulk, burst, tear, and tensile test measurements were made on hand sheets. In general, the results compared very favorably with those common to commercial sulfate pulp from full sized deciduous trees. No one species was superior in all respects. However, gray birch, pin cherry, aspen and red maple were definitely better than alder and willow. The latter two are apparently excessively damaged by beating. The ranges of values obtained for various physical characteristics were:

Breaking length, 7000 to 15000 meters
Burst factors, 30 to 100
Tear factors, 60 to 100

Maximum strength values were attained generally after 30 minutes of beating, except for the willow which usually started to deteriorate early in the beating cycle.

Stemwood produced the strongest pulp with the best yield. Branch pulp was generally superior to stump and root pulp in burst and tensile strength, but was inferior in tear.

A comprehensive study of fiber dimensions was made, including length, cell and lumen diameters and cell wall thickness. Compared with fibers from normal sized hardwood trees, those of puckerbrush are shorter (0.5 to 0.75 mm.) and have thinner walls (1.7 to 3.3 microns).

No consistent correlation between fiber dimensions and paper strength could be established for all species. However, the species with the shortest fibers and relatively thick cell walls (willow) did produce the poorest pulp. The longest fiber species, gray birch and aspen, produced the best pulps, particularly in tensile strength. This general trend of long-fiber and high strength is in agreement with established fact.

This study has established that at least four puckerbrush species, gray birch, red maple, pin cherry and aspen can be pulped by the sulfate process to produce a good grade of pulp that is at least equal to standard commerical pulps in strength characteristics. Pulping can be done with the bark intact and yields of unbleached pulp will range from 35 to 45%, the value being determined by the species being pulped and the proportion of bark to wood. Bleached pulp can be produced with G.E. brightnesses in excess of 80 points and with an *overall* yield of 30 to 35%. There is some evidence that the pulped bark contributes little to the important properties of the final product and that it does increase the difficulty of bleaching the pulp.

Further, and as yet uncompleted, studies have given preliminary indications that a good grade of high yield (65 to 75%) pulp can be produced from some puckerbrush species. For this type of pulp it is probable that pulp and pulped bark can be separated, if necessary or desirable, by mechanical operation.

Introduction

The study reported in this paper represents a logical supplement to previous work conducted at the University of Maine concerning the pulping of non-merchantable parts of the tree (1-6) and to the general philosophy that there is potentially useful fiber in all woody plants and that the potential should be evaluated.

In the late 1950's, studies were started at the University of Maine that led to the complete tree and complete forest concepts. These ideas pertain to utilization of the entire tree, rather than the bole only, as a source of fiber, and the exension of the fiber source to include the entire forest. Implied in these concepts are sound principles of forest management.

Encouraging results were obtained from the pulping of tree parts that are normally wasted, and from the pulp obtained from several kinds of puckerbrush (7). In particular, the quality of pulp obtained in the earlier studies on successional species of shrubs and trees was sufficiently high that the idea of woody fiber production and utilization was conceived. This plan involves the production of puckerbrush on 5- to 10-year rotations and the use of wood and bark from all parts of the plants as a source of fiber. There are large amounts of this type of plant in nearly all areas of the world and it may represent a potential raw material that can be produced and used domestically by countries that do not have adequate supplies of the standard fiber sources.

There have been extensive studies, in several countries, on the utilization of grasses and non-woody plants as sources of fiber. A notable example is the work that has been done and is continuing at the U. S. Department of Agriculture's Northern Utilization Research and Development Division.

The use of waste material from lumbering operations and from various wood-using industries as a fiber source for the paper industry is by no means a novelty. The use of sawdust and sawmill waste has attained significance, particularly in the western part of the United States.

A comprehensive literature survey on the complete tree concept is being prepared by J. L. Keays, research scientist at the forest products laboratory of the department of fisheries and forestry, Canadian Forestry Service. This review includes some 2000 references, a testimony to the wide interest in the search for more efficient use of our potential source of wood fiber.

The study whose initial results are presented in this paper may be the first that is devoted in a very comprehensive manner to the puckerbrush of a specific region.

Objectives

The major purposes of this investigation were:
(1) to determine whether acceptable pulps could be produced from puckerbrush native to the state of Maine, using the sulfate pulping process and pulping conditions typical of those used in pulping chips from trees and, (2) to determine the physical properties of paper hand sheets made of the pulps.

Other objectives were: determination of *optimum* sulfate pulping conditions, determination of *optimum* bleaching conditions, evaluation of bleached pulp properties and measurement of fiber dimensions.

Experimental Procedure

(A) *Preparation of sample for pulping.* The field crew that harvested the samples also delivered them to the pulping laboratory, chipped them, and did the preliminary chip screening.

Six puckerbrush species were used. They were speckled alder (*Alnus rugosa* (Du Roi) Spreng.), gray birch (*Betula populifolia* Marsh.), red maple (*Acer rubrum* L.), pin cherry (*Prunus pensylvanica* L. f.), quaking aspen (*Populus tremuloides* Michx.), slender willow (*Salix gracilis* Anderss.) Six samples were prepared from the various parts of each of the species. These were: stem without bark, stem with bark, branches with bark, stump and roots with bark, Composite 1, and Composite 2. Composite 1 was a mixture of stem, branches, stump and roots, all with bark, containing the same proportions of each as existed in the tree. Composite 2 contained only stem and branches, both with bark, again in the same proportions as existed in the tree. It should be noted that all species were pulped with the bark intact, with the exception of samples of stemwood from each species which were pulped in both barked and unbarked conditions.

A laboratory size 4-knife Carthage chipper was used in the chipping operation. In some cases, because of the small size of the samples, it was necessary to tie them into bundles to realize an adequate job of chipping.

Chip screening was done with the Williams chip classifier as described in TAPPI Standard Method T-16. In some cases, the large size fraction from the screening was rechipped.

All chips, except the largest which were discarded, were dried under ambient conditions by spreading them on the laboratory floor and allowing at least two weeks for equilibrium moisture content to be attained. The dried chips were re-screened and the 7/8, 5/8, and 3/8 inch fractions were used in subsequent pulping operations. In the case of the branches, the 3/16 inch fraction was also saved for pulping because it represented a significant part of the total chip product from this portion of the tree.

It should be explained that the "chips" from the smallest parts of the puckerbrush, the branches, bore no physical resemblance to the standard chip common to commercial pulping operations. Generally, they maintained their cylindrical form, and varied in length from 1/2 to 6 inches.

(B) *Cooking Procedure.* The sulfate process was used for all cooks. The digester used for the series of cooks on the six species previously described was a laboratory size stainless steel vessel having a capacity of 15 to 20 pounds of chips (dry basis). Heat was supplied to the digester by continuous circulation of the cooking liquor through an external steam-heated exchanger. The cooking cycle was controlled at desired time-temperature conditions by means of a Honeywell Data Trak Programmer—Vutronik indicating control station set-up.

In order that several species (or several parts of single species) could be cooked simultaneously, a stainless steel basket containing eight compartments was used. The cylindrical basket and cover were made of type 316 stainless steel perforated with 1/8 inch holes on 3/16 inch centers to allow adequate circulation of cooking liquor without any mixing of chips of different species. It was a very convenient operation to load the basket and then insert it into the digester. It was constructed to conform to the inside dimensions of the digester with only enough clearance to allow for easy insertion and removal.

Cooking (white) liquor was made in separate batches for each cook. Chemically pure sodium hydroxide and sodium sulfide were used so it was necessary only to weigh the required amount of each on the basis of the specified chemical-to-wood ratio, sulfidity, and weight of chips, and dissolve in enough water to just cover the chips when they were placed in the digester. Because of differences in chip packing density and in weight of chips cooked, there was some variation in the amount of dilution water used. Thus, the liquor-to-wood ratio and cooking liquor concentration varied over a narrow range, but the sulfidity and active alkali-to-wood ratio were constant for all cooks in this series.

At the end of a cook, steam flow was stopped and digester pressure was relieved. Black liquor was pumped to the sewer, the cover and bottom plate were removed from the digester and cold water was circulated through the basket of chips for approximately ½ hour. The basket was then removed from the digester and each compartment was emptied separately into a screen box where the cooked chips were again washed until the washings contained no discernible black liquor. The washed chips were transferred to a Morden Slushmaker where they were defibered for five minutes. Conditions of time and consistency for this defibering operation were maintained the same for all pulps because this particular operation has an effect on the percent of rejects realized from a cook.

The defibered pulp was transferred to a fifty-five gallon drum that served as a feed tank for the Bird vibratory pulp screen. Dilution water was added, consistency samples were taken and from this measurement unscreened pulp yields were determined.

After screening, the accepted pulp was again diluted for consistency and screened pulp yield measurements. In most cases the amount of reject pulp was small enough that all of it was oven dried and then weighed to determine percent reject pulp. Samples of the acceptable fiber were saved for physical and chemical tests, and in a few cases, for bleaching.

Some cooks were made in a small digester. The smaller equipment was used in those instances in which optimum cooking conditions were being determined and it was necessary to produce only enough pulp for yield and Kappa Number measurements. This digester had a capacity of two or three pounds of chips and contained a 2-compartment basket so that two different samples could be treated simultaneously. Care was taken to have as nearly as possible the same conditions as existed in the larger digester.

(C) *Bleaching Procedure.* Bleach demand of the pulps was determined by making Kappa Number determinations, converting tc Permanganate Number using the relationship,

$$\text{Permanganate Number} = \frac{\text{Log Kappa \#} - 0.837}{0.0323}$$

and then using the relationship between Permanganate Number an bleach demand.

Several combinations of chlorination, alkaline extraction, hypc chlorite and chlorine dioxide treatments were used.

The first bleaching runs were made on 600 gram samples. Chlor nations were made in a covered stainless steel container at room tempe ature. Extractions, hypochlorite and chlorine dioxide treatments were made in plastic bags. Elevated temperatures were maintained by submerging the bags in a hot water bath, and mixing was accomplished by periodic kneading of the bags during the treatment. The pulp samples were washed after each bleaching stage, using tap water. Finally, bleached yields were measured and samples of the bleached pulps were taken for measurement of G.E. brightness, viscosity, and alpha cellulose.

A series of bleaching runs was also made on smaller (20 gram) pulp samples to determine optimum bleaching conditions. All treatments were made in glass jars. Mixing was accomplished by periodic shaking of the jars and in order to attain adequate mixing, it was necessary to use relatively low consistencies (5%) in the extraction, hypochlorite, and chlorine dioxide stages. Distilled water was used in all washing stages. G.E. brightness tests were made on the final bleached pulps.

(D) *Pulp Test Procedures.* In all cases where a TAPPI Standard Method was applicable, it was used. Following is a résumé of the testing procedures.

Chip screening,	TAPPI Standard Method	T- 16
Kappa Number,	" " "	T-236
Permanganate Number,	" "	T-214
Cu (EN). Viscosity	"	T-230
Alpha cellulose,	" "	T-203

Standard beater tests were made on both unbleached and bleached pulps according to the following procedures.

Freeness of pulp,	TAPPI Standard Method	T-227
Beater processing of pulp,	" " "	T-200
Forming hand sheets,	" " "	T-205
Physical testing of hand sheets,	" " "	T-220

The physical tests included burst, tear, and tensile strength measurements. In some cases, because of the characteristics of some of the pulps and because of available testing equipment, it was necessary to make slight changes in the standard test procedures.

(E) *Microscopic Analysis of Fibers.* The specimens used in the fiber study were samples of unbleached, unbeaten pulp from each of the various parts of the six species. These samples were in the form of dried pulp pads and the procedure for preparing and analyzing for microscopic analysis follows.

Each pulp pad was soaked in water for several days, with frequent changes in water. It was then carefully defibered and shaken in the liquid until a uniform slurry resulted. The excess water was then slowly drained off and replaced with 5% aqueous formalin. The specimens were then stored in labeled bottles. Samples of the fibers were removed from the bottles, placed on microscope slides, and examined with a calibrated compound microscope.

The following measurements were made, and reported in ocular division units, for each species: fiber length, fiber diameter, lumen width, and wall thickness. One hundred measurements were made for fiber length, using 100x magnification. *Broken pieces* under 14 ocular units (180.6 microns) in length were not recorded. Twenty-five measurements were made for fiber width, lumen diameter and wall thickness, using 400x magnification.

In preparing the slides the fiber samples were drawn randomly from the slurry, placed on a standard microscope slide, and covered with a No. 1 cover glass. Care was taken to include only a relatively few fibers in each mount. The mounting medium was the 5% formalin storage fluid. A mechanical stage was used to avoid duplicating measurements of any specific fiber.

After measurements were completed, simple number averages were calculated and these values were converted to dimensions, in microns, by multiplying by the appropriate conversion factor. The conversion factors were 12.9 for the 100x measurements and 3.3 for the 400x measurements. The data were also analyzed for distribution of fiber dimensions within each sample.

Results and Discussion

(A) *Initial Cooks.* This series of sulfate cooks was made with only one purpose in mind, namely, to determine whether reasonable yields of acceptable pulp could be obtained under cooking conditions that had been used in prior studies on pulping of non-merchantable parts of the tree and of puckerbrush species. These cooking conditions, except for liquor concentration and liquor to wood ratio, are not unusual in any way when compared with typical industrial figures. They are shown in Table 1.

Table 1
Conditions for Initial Cooks (Sulfate Process)

Chemical-to-wood ratio	$0.25 \frac{\#\text{Active Alkali (As } Na_2O)}{\#\text{Dry wood}}$
Sulfidity of cooking liquor	25%
Conc. of cooking liquor	26 to 31g/1 (as Na_2O)
Cooking liquor-to-wood ratio	$7.8/_1$ to $9.8/_1$
Maximum temperature	345 ± 3° F
Time to temperature	40 ± 5 min.
Time at temperature	120 min.
Total time	2 ¾ hours (approx.)
Weight of wood	16 to 19.5 #'s

There were variations in liquor to wood ratio, hence in liquor concentration. This was caused by differences in the packing density of the chips and the necessity for using varying amounts of dilution water to assure chip coverage. In general these variations were small.

Using these conditions the following species were pulped: alder, gray birch, aspen, red maple, pin cherry and willow. As described in Procedure, for each *species* the following *components* were pulped: stem without bark, stem with bark, branches with bark, stump and roots (combined) with bark, Composite 1 with bark, and Composite 2 with bark.

Each cook involved the simultaneous treatment of all six components of a single species. Thus, six cooks were made in this initial part of the pulping study; in all cases, the 8-compartment basket was completely filled with wood, the two spare compartments being filled with whichever component was present in excess. In most cases this was stemwood with bark.

The screened yields and Kappa Numbers for the pulps produced in this series are shown in Table 2. The weight percent compositions of Composites 1 and 2, as charged to the digester, are shown, for each of the six species, in Table 3.

The effect that bark has on cook yield is easily recognized by comparing yields for stemwood with and without bark (Table 2). In all cases the wood without bark gave the higher yield, the *difference in percent yields* ranging from a low of 1.3 for aspen to a high of 10.3 for willow. This is to be expected inasmuch as the bark itself would show a very low yield by the sulfate process. In the absence of any data it may be speculated that different proportions of bark to wood in the different species would account, in part, for the variation in yield differences between stemwood with and without bark.

The branch component generally produced the lowest yield, while the stump and root component gave yields intermediate between those of the stemwood and the branches. The lower yields for the branches and stump and roots can be attributed, in part, to a higher proportion of bark to wood than is the case for the stemwood. This is especially true for the branch component. Some differences in morphological and chemical characteristics between stemwood and the other components could also account for the lower cook yield of the latter.

Yields from Composites 1 and 2 were between those of the stemwood and those of the other components. If yields for the composites are *estimated* by summing weighted averages of yields of the various components, the results show good agreement with *actual* yields. This could be an indicator that simultaneous cooking of all components of a species has no significant effect on the yield of any single component. Table 4 presents a comparison of actual and estimated yields.

Values of the Kappa Numbers (Table 2), which are generally within the range 15-30, indicate well-cooked pulps. Screen rejects, which are not shown in the results, were also very low, in the 0.5 to 1.0% range, another indication of complete cooking.

Table 2

Cook Yield and Kappa Number

Species	Screened Yield (%)						Kappa Number					
	SWOB	SWB	BR	SR	COMP.1	COMP.2	SWOB	SWB	BR	SR	COMP.1	COMP.2
Alder	43.8	37.8	27.3	35.6	34.7	35.3	20.3	28.0	33.2	37.1	32.8	29.3
Gray Birch	45.6	41.9	32.4	34.5	37.9	38.1	22.1	23.2	24.7	30.4	24.0	21.5
Aspen	44.6	43.3	35.0	39.1	41.4	42.7	10.2	13.2	19.5	17.9	15.9	14.8
Maple	48.4	41.8	34.1	30.3	37.6	42.2	11.8	14.4	21.8	25.7	17.2	15.1
Cherry	50.9	41.7	35.4	45.6	41.9	40.9	16.0	12.8	15.5	14.8	14.2	12.6
Willow	49.5	39.2	36.1	34.9	38.2	38.4	14.0	15.9	18.7	23.1	18.4	16.8

SWOB = Stems without bark

SWB = Stems with bark

BR = Branches with bark

SR = Stump and roots with bark

Comp. 1 = Composite 1

Comp. 2 = Composite 2

Table 3
Compositions of Composites 1 and 2
(Wgt. %)

Species	Composite 1			Composite 2	
	SWB	BR	SR	SWB	BR
Alder	40	30	30	60	40
Gray Birch	55	20	25	75	25
Aspen	60	15	25	80	20
Maple	65	10	25	85	15
Cherry	60	15	25	80	20
Willow	55	25	20	70	30

Table 4
Cook Yields
Actual and Estimated Values

SPECIES	Composite 1 % Yield		Composite 2 % Yield	
	Actual (Table 2)	Estimated	Actual (Table 2)	Estimated
Alder	34.7	34.0	35.3	34.1
Gray Birch	37.9	38.1	38.1	39.5
Aspen	41.4	42.7	41.1	41.6
Maple	37.6	38.2	42.2	40.7
Cherry	41.9	41.7	40.9	40.4
Willow	38.2	37.6	38.4	38.2

Pulps from the branch and stump and root components generally had the higher Kappa Numbers. This may be explained by the higher proportion of bark to wood in these components and the fact that the residue from the pulping of bark contains significant percentages of oxidizable materials.

TAPPI Standard beater tests were made on all pulp samples. The responses of the various species to treatment by the standard beater are shown in Figs. 1 through 6. The same information is contained in Tables 1A through 6A in the appendix.

The "standard" pulp shown in Fig. 1 was made from commercial hardwood chips obtained from the wood room of Diamond International's pulp mill in Old Town, Maine. It was produced under the same cooking conditions and in the same equipment as were the puckerbrush species pulps and was used as a control sample for purposes of comparison.

The responses to beating of four species, red maple, pin cherry, aspen, and gray birch were similar, and this was true for all components of the species except the branches. The magnitudes of the freenesses of these four species were different but the rates of freeness decrease with beating, were essentially similar. The highest freenesses were exhibited

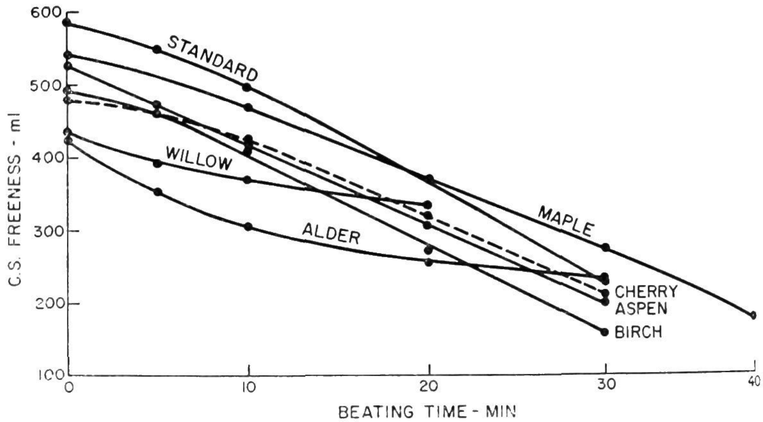

FIGURE 1. Freeness vs Beating Time (Stem Without Bark)

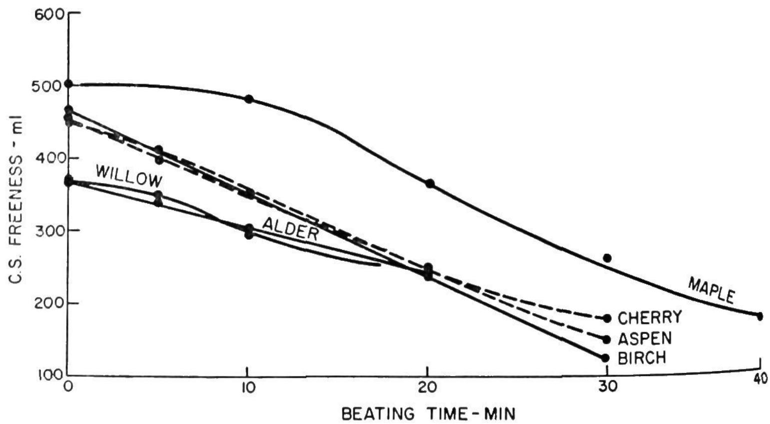

FIGURE 2. Freeness vs [illegible]

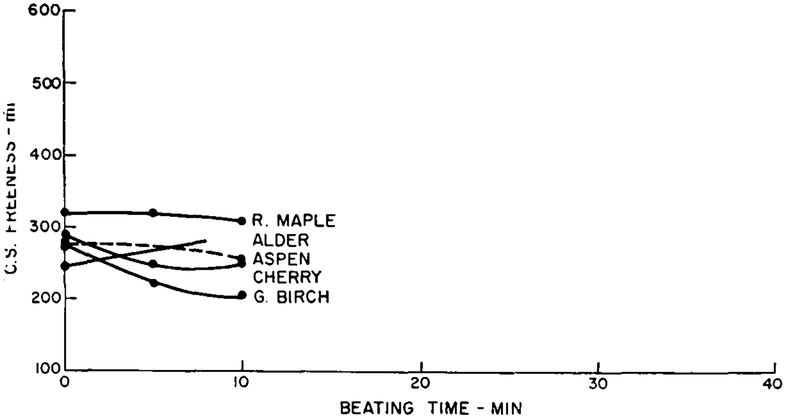

FIGURE 3. Freeness vs Beating Time (Branches)

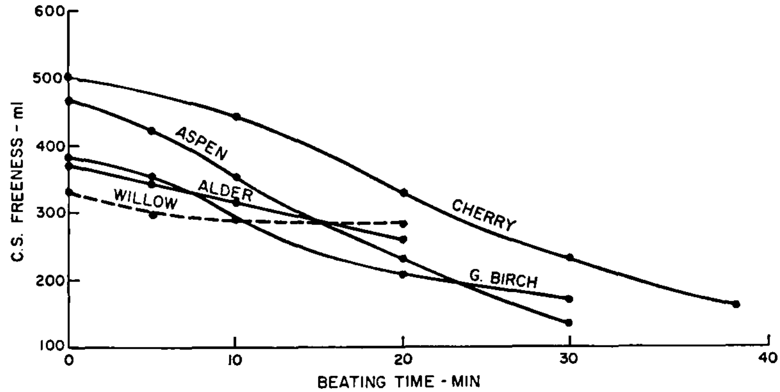

FIGURE 4. Freeness vs Beating Time (Stump and Roots)

by the pulps from stemwood without bark, as would be expected. The lower freenesses of pulps from the other components can be attributed to the presence of extremely low freeness bark materials and the different physical characteristics, particularly fiber length, of these components. This is most clearly evident in the case of the branch pulp (Fig. 3) which exhibited very low freenesses and which started to give false freeness readings after short beating intervals of 5 to 10 minutes.

The willow and alder pulps (all components) had the lowest freenesses and were most sensitive to the action of the beater. Generally, after 10 to 20 minutes of beating, it was not possible to get true freeness readings on these pulps.

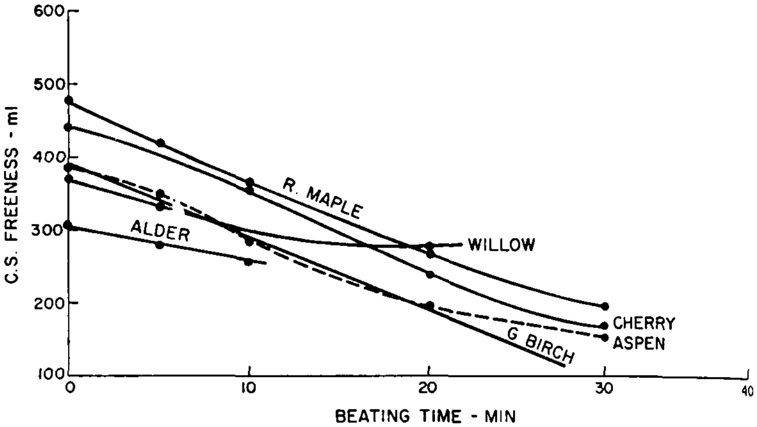

FIGURE 5. Freeness vs Beating Time (Composite1)

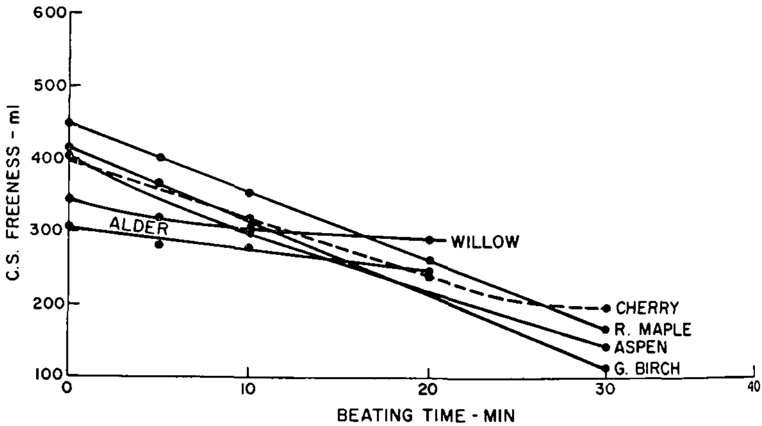

FIGURE 6. Freeness vs Beating Time (Composite 2)

Hand sheets were tested for burst, tear and tensile strengths. Bull was calculated for each of the pulp samples. The results of these test are shown in Figs. 7 through 21, and in the appendix, Tables 7A througl 30A.

It should be noted that the physical characteristics are shown as function of freeness rather than beating time in Figs. 7 through 21. In asmuch as the freeness values in these figures were obtained by inter polation from the smoothed curves of freeness versus beating time (Figs 1-6), no data points are shown.

Figs. 7-11 show the development of bursting strength with beating Gray birch and pin cherry pulps are generally superior to the others i this characteristic. Willow is the weakest by far

The stem without bark pulps were generally the strongest in bursting strength although some exceptions to this may be noted by comparing the curves of Figs. 7-11.

It appears that none of the pulps had attained their maximum bursting strength by the beating treatment but the *rate* of strength development was decreasing materially toward the end of the cycle.

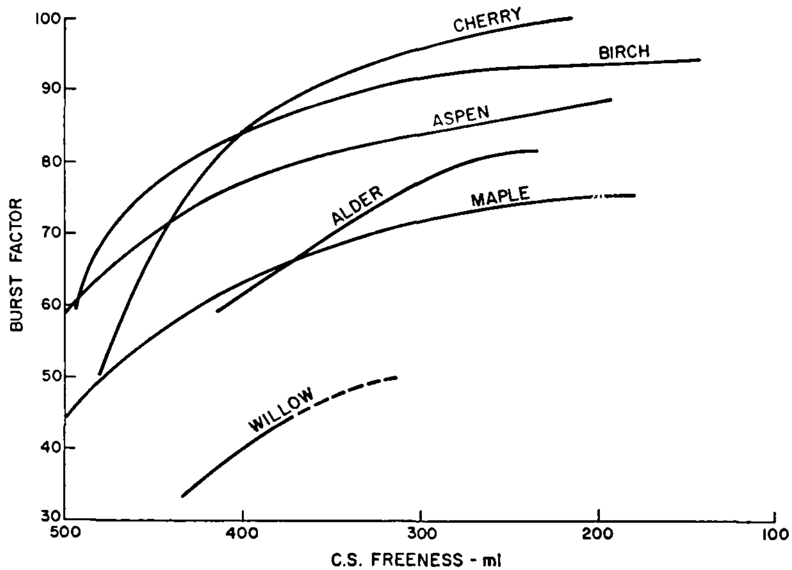

FIGURE 7. Burst Factor vs Freeness (Stem Without Bark)

Figs. 12-16 show tearing strength as a function of pulp freeness. In some cases there is a slight increase in tear strength in the early stages of beating; in other cases the increase is gradual and a maximum is reached nearer the midpoint of the beating cycle. In general the tearing strength is not affected to a great extent by beating.

Gray birch and pin cherry pulps show greater strength in tear than do the other pulps, and again, willow is inferior to all the other species. The strongest component, in tear, was the stem without bark for gray birch and pin cherry species. For the other species no particular component is consistently the strongest and the tearing strengths for all are in the range 70 to 90, willow pulp excepted.

Tensile strength, expressed as breaking length, is shown as a function of freeness in Figures 17-21. The development of tensile strength with beating follows that of bursting strength quite closely. One difference is noted. For some species the maximum value of tensile strength was attained during the latter stages of the beating cycle. This is most evident for the stem with bark component (Fig. 18) and the Composites 1 and 2 (Figs. 20 and 21).

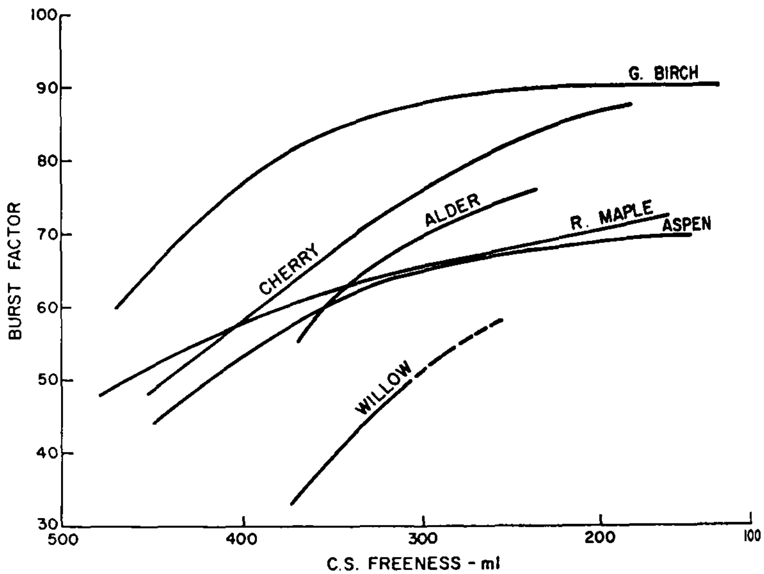

FIGURE 8. Burst Factor vs Freeness (Stem With Bark)

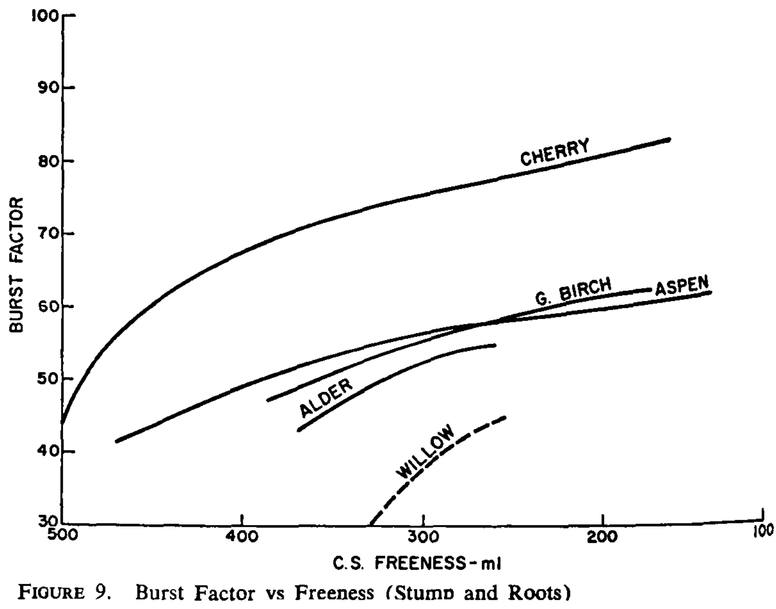

FIGURE 9. Burst Factor vs Freeness (Stump and Roots)

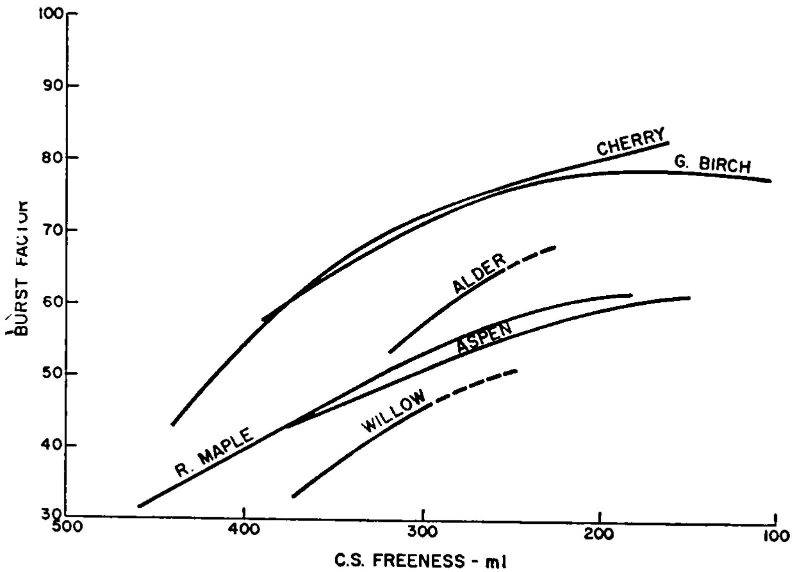

FIGURE 10. Burst Factor vs Freeness (Composite 1)

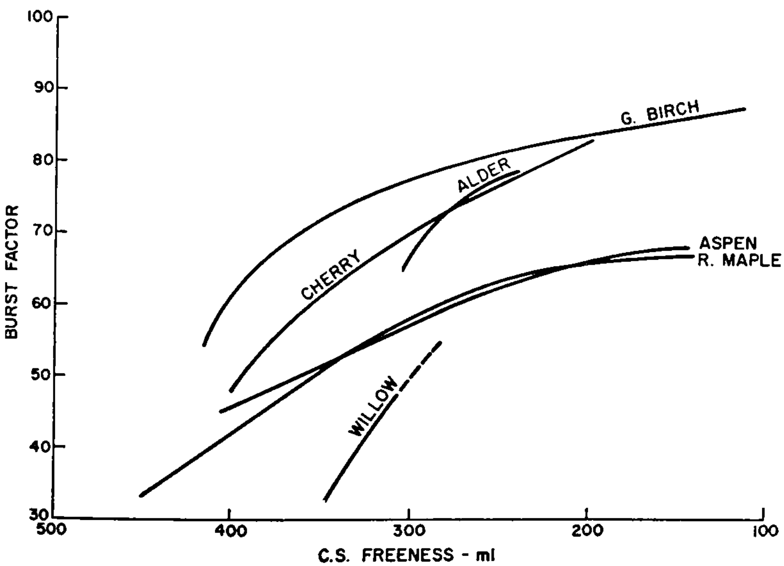

FIGURE 11. Burst Factor vs Freeness (Composite 2)

Again, the gray birch and pin cherry pulps are superior to the other species, although aspen replaces gray birch in the ratings for two of the components, stem without bark and stump and roots. Willow showed the lowest tensile strength of all species.

The strength characteristics for the *branch component* of all species are shown in Tables 7A through 24A in the appendix. They were not plotted versus freeness because of the very short beating times, 5 to 10

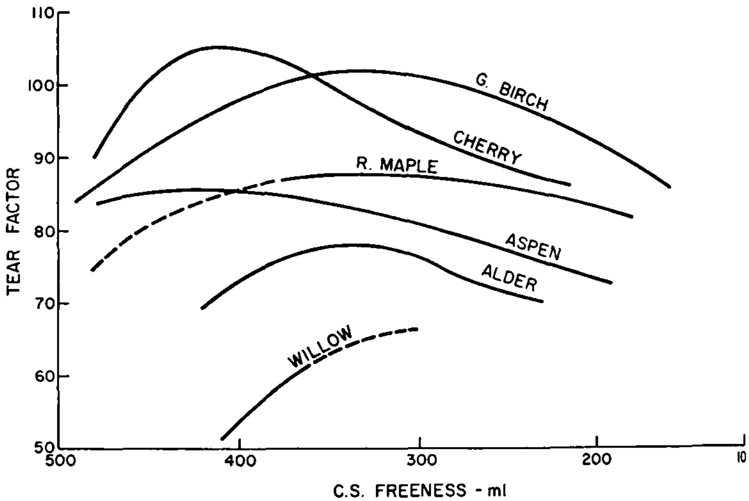

FIGURE 12. Tear Factor vs Freeness (Stem Without Bark)

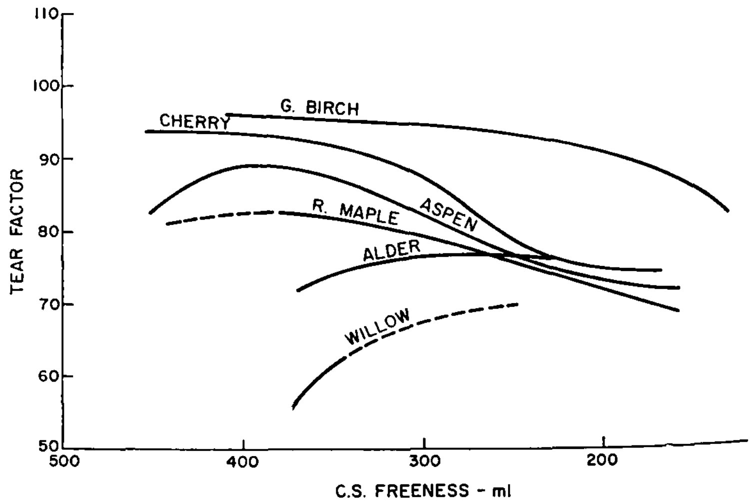

FIGURE 13. Tear Factor vs Freeness (Stem With Bark)

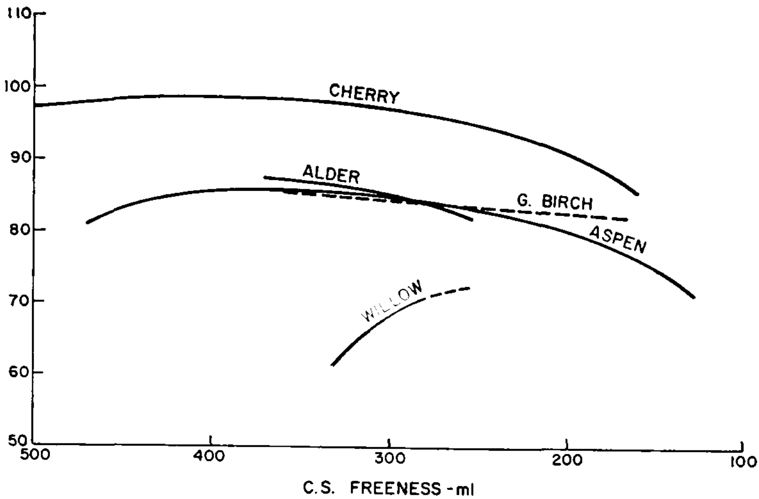

FIGURE 14. Tear Factor vs Freeness (Stump and Roots)

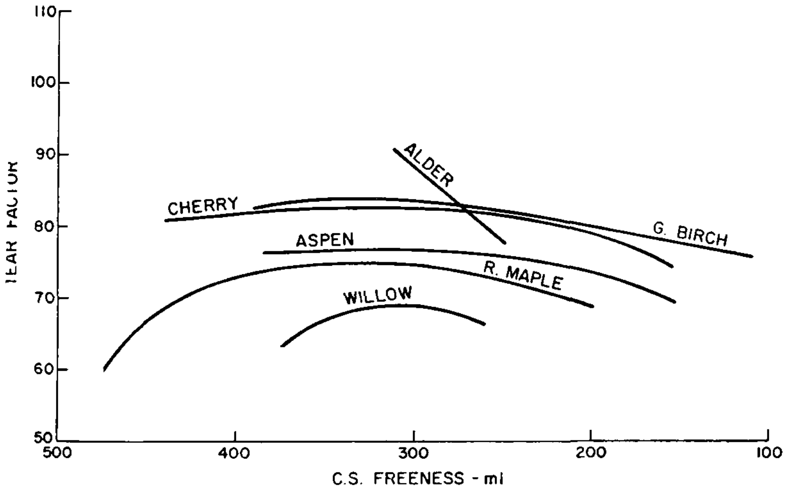

FIGURE 15. Tear Factor vs Freeness (Composite 1)

minutes, hence the scarcity of data points. A comparison of the physical properties of the branch pulp with those of the other components leads to the following conclusions. Bursting strength is intermediate between that of the stemwood pulp and that of the stump and root pulp. The same is true in the case of tensile strength. However, in tearing strength, the branch pulp is inferior to the other components.

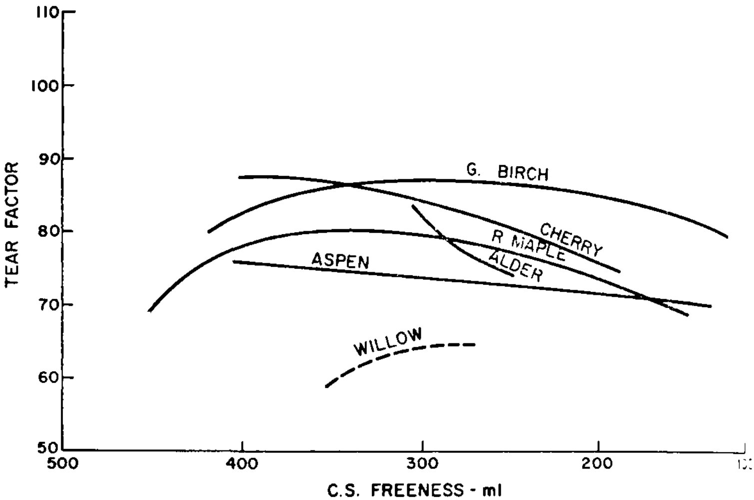

Figure 16. Tear Factor vs Freeness (Composite 2)

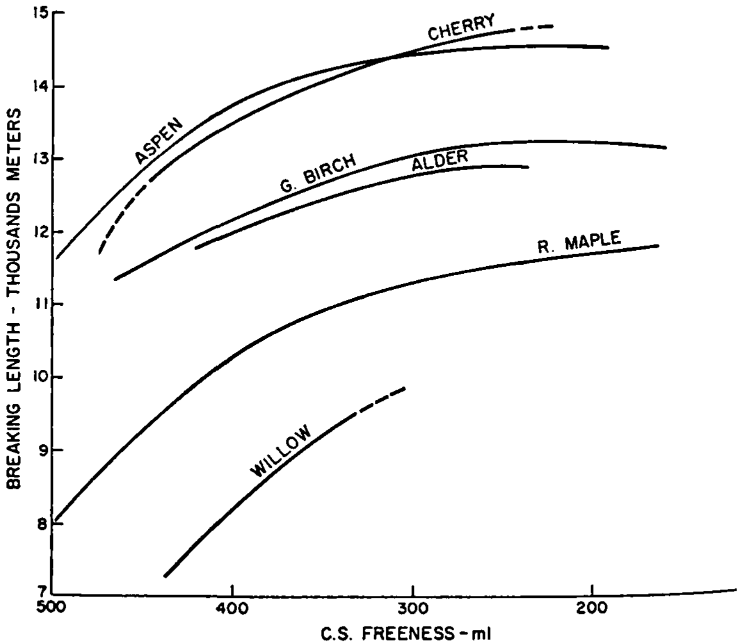

Figure 17. Breaking Length vs Freeness (Stem Without Bark)

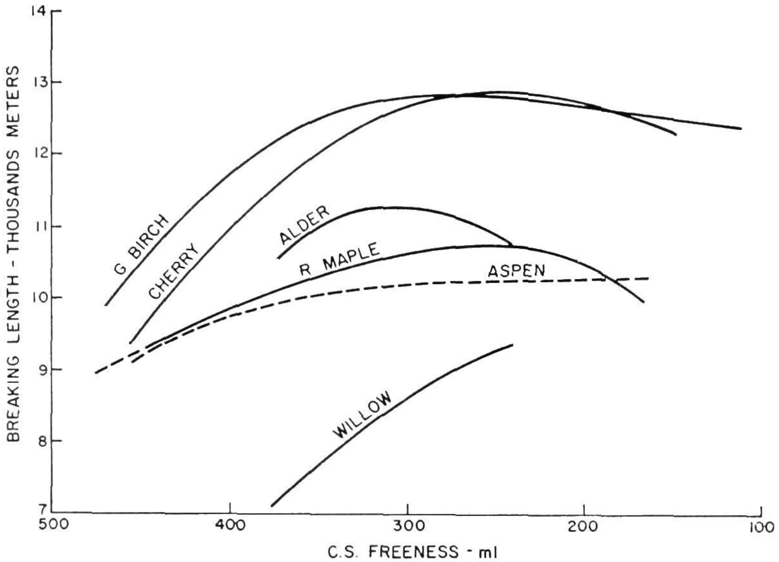

FIGURE 18. Breaking Length vs Freeness (Stem With Bark)

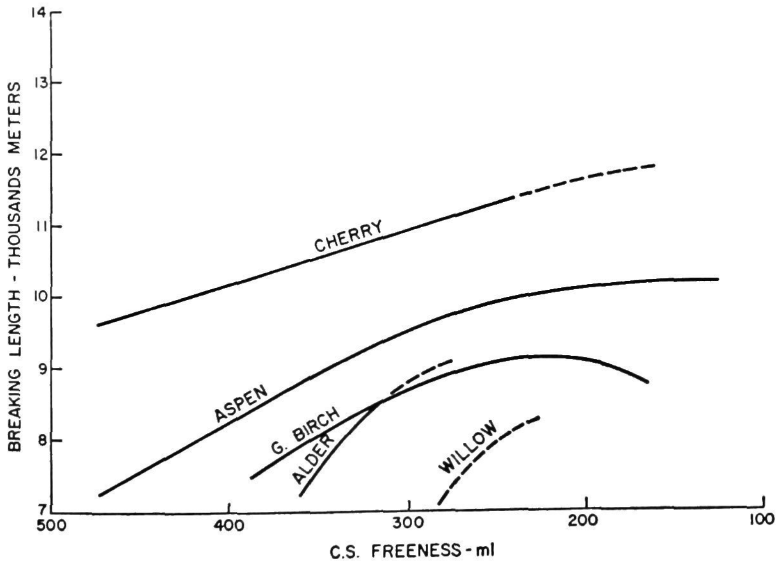

FIGURE 19. Breaking Length vs Freeness (Stump and Roots)

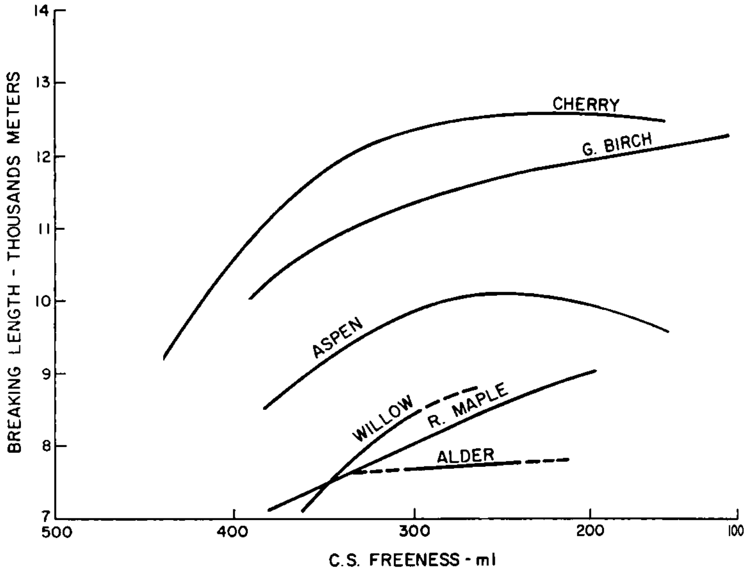

FIGURE 20. Breaking Length vs Freeness (Composite 1)

Tables 25A through 30A of the appendix present data on hand sheet bulk. A general conclusion on the basis of these data is, the one component without bark, i.e., the stemwood shows the lowest bulk for all species. This could be because of the presence of the more bulky bark in the pulp plus any adverse effects it would have on fiber bonding. In general, aspen produced the bulkiest paper and pin cherry, the least bulky.

The levels of strength exhibited by the pulps produced in this phase of the study compare favorably with those of commercial pulps produced from commercial hardwood chips by the sulfate process. Of course, wide ranges of values were realized, from those of the physically inferior willow pulp to those of the strongest pin cherry and gray birch pulps.The components which showed the most promise with respect to strength properties were those which normally would be the easiest to harvest and prepare for pulping, namely the stemwood with or without bark, and Composite 2 (stem and branches, both with bark).

The encouraging results that were obtained in this initial work led to further study.

(B) *Pulping and Bleaching of Composite 2 of Three Puckerbrush Species.*

Composite 2 of three puckerbrush species, gray birch, aspen, and red maple, were pulped under the same conditions as those in (A), and a portion of each [illegible] bleached. TAPPI Standard beater

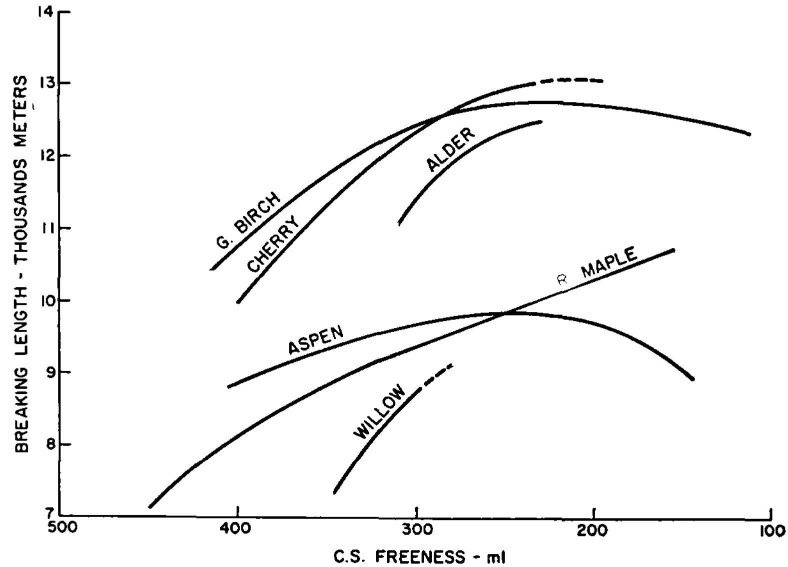

FIGURE 21. Breaking Length vs Freeness (Composite 2)

tests were made on both the unbleached and bleached pulps. In addition, commercial hardwood chips were pulped and the resulting pulp was carried through the bleaching and beating operations to serve as a standard of comparison for evaluating the puckerbrush species. The commercial chips contained no bark, whereas the composition of Composite 2 of the three puckerbrush species was the same as shown in Table 3.

Screened yields of the pulps were determined. Kappa Numbers were determined and converted to chlorine demand.

A 4-stage bleaching sequence, chlorination, caustic extraction, hypochlorite, and chlorine dioxide was used. Bleach yields were measured so that *overall* bleached pulp yields, based on dry wood charged to the digester, could be estimated. The bleached pulps were tested for G.E. brightness, cupriethylene diamine viscosity, and alpha cellulose content.

Conditions of the bleaching operations are shown in Table 5. Results of tests on the unbleached and bleached pulps are shown in Table 6.

The results of the bleaching were not encouraging. Shrinkage during bleaching was high, resulting in a very low yield of bleached pulp. It is concluded that the low yield can be attributed to several factors. First, the pulps appeared to be somewhat over-cooked. The cook yields and Kappa Numbers, being on the low side, substantiate this conclusion. Second, bark components contained in the unbleached pulp are readily attacked and solubilized in the bleaching operation, thu accounting for high bleach shrinkage. Third, small losses of fiber durin the bleaching operations, particularly in the washes between stages, ca create significant percentage losses in small scale bleaching. The firs and third factors certainly are capable of improvement.

Table 5

Bleaching Conditions

VARIABLE	STAGE			
	Chlorination	Extraction	Hypochlorite	Chlorine Dioxide
Percent of Chlorine demand added	60	–	20	20
Consistency (%)	3	10	10	10
Temperature (°F)	75°	160°	100°	160°
pH	2 – 3	11 – 12	11 – 12	-
Time (hr.)	1	1	2	2

Pulp was washed after each stage.

Table 6

Test Results, Bleached and Unbleached Pulps

TEST	SPECIES*			
	Standard	Aspen	Gray Birch	Maple
Cook Yield (%)	46.5	40.3	40.8	42.1
Rejects (%)	0.3	0.1	0.1	0.1
Screened Yield (%)	46.2	40.2	40.7	42.0
Kappa Number	14.5	13.9	17.7	13.6
Cl_2 demand (%)	4.75	4.46	6.24	4.30
Bleach Shrinkage (%)	15.3	17.8	15.4	19.7
Overall Yield (%) (Cook plus bleach)	39.1	33.1	34.5	33.9
G. E. Brightness	82.8	77.4	79.6	78.8
$Cu(EN)_2$ Viscosity (Cp)	19.4	24.3	14.7	14.6
Alpha Cellulose (%)	91.0	92.3	89.1	88.7

* Composite 2 of each of the species, aspen, birch, maple.

The G.E. brightness values were not as high as might be expected ·r hardwood pulps having such low unbleached Kappa Numbers. Inasuch as the standard pulp did bleach to an 83 brightness, 4 to 5 points gher than any of the puckerbrush pulps, it is assumed that some bark .aterial, with high resistance to removal by bleaching with chlorine ɔmpounds, is the offender in the puckerbrush species.

Further evidence that the pulps may have been over-cooked are ıe relatively low viscosity values. Generally the cupriethylene diamine iscosity of a normal sulfate pulp is something greater than 30.

The results of beater tests on the bleached and unbleached pulps re shown in Tables 31A-34A and Figures 22-31.

Comparison of the beating characteristics of the red maple, gray ›irch, and aspen pulps produced in this second series of cooks with hose of the first cooks shows good agreement (see Figs. 6 and 22). There are some differences noted between the two series with respect to he initial (unbeaten) freenesses, but the rate of freeness decrease with ɔeating is essentially the same for both series.

The effect of bleaching on beating characteristics may be noted by comparing Figs. 22 and 23. Generally the bleached pulps were slower beating, probably as a result of the removal of hemicellulosic materials

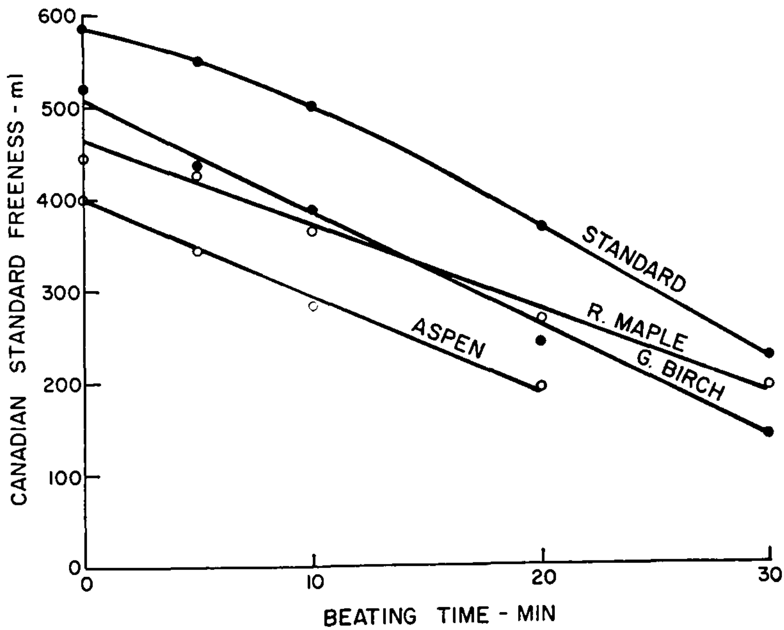

FIGURE 22. Freeness vs Beating Time (Unbleached Pulps)

by the bleaching chemicals. This is usually the effect that is noted unless the pulp is degraded by too severe chemical treatment in the bleaching operation.

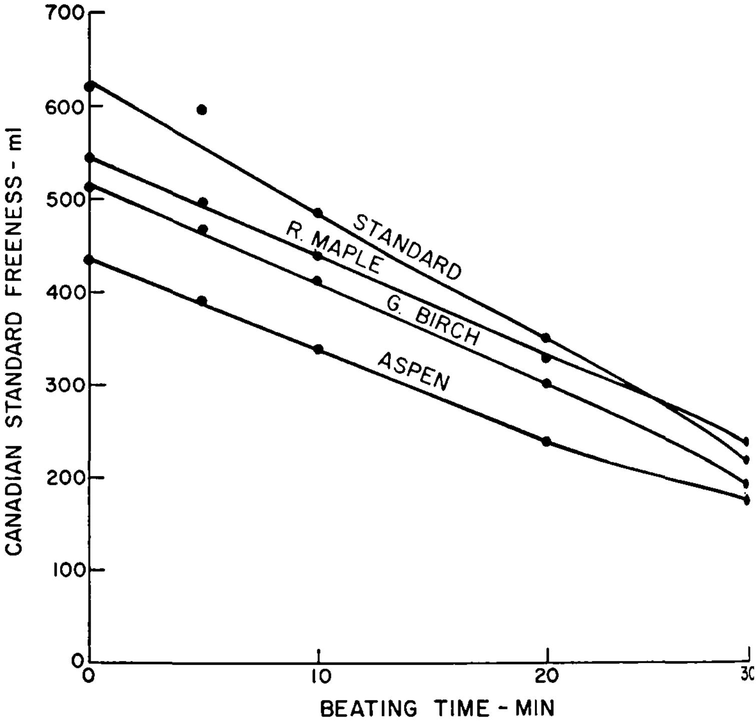

FIGURE 23. Freeness vs Beating Time (Bleached Pulps)

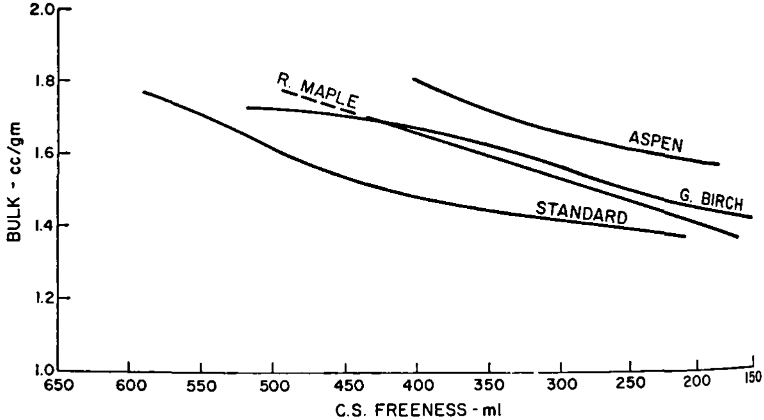

FIGURE 24. Bulk vs Fre[illegible]

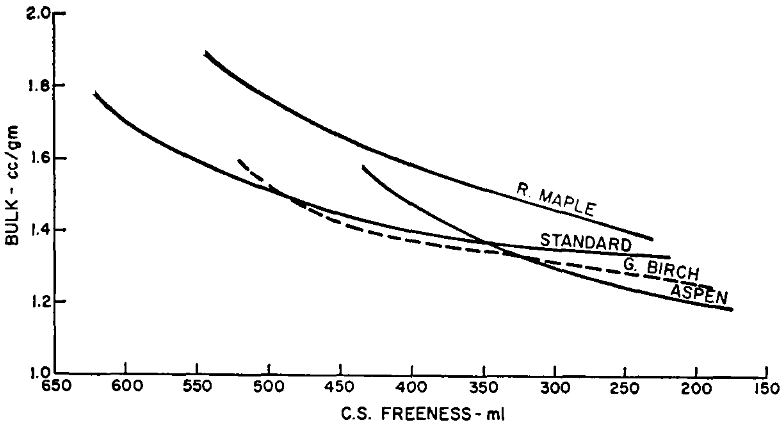

FIGURE 25. Bulk vs Freeness (Bleached Pulps)

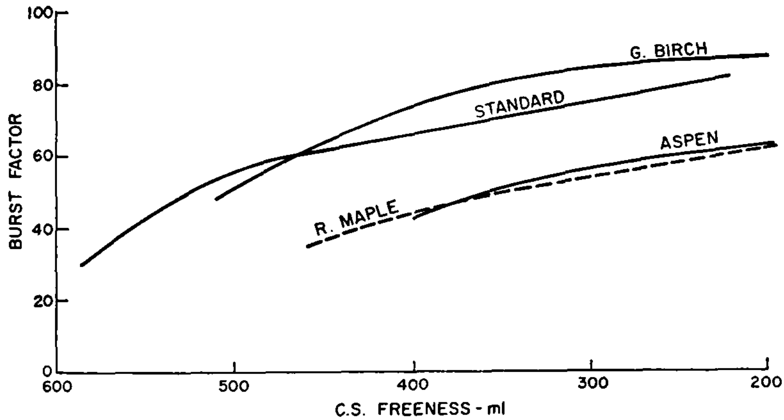

FIGURE 26. Burst Factor vs Freeness (Unbleached Pulps)

The results in Figs. 26-31 show that the bleached pulps were generally stronger than the unbleached, most significantly in tear and burst strengths.

Fig. 32 is a plot of tear factor versus breaking length for the gray birch and standard pulps in both the bleached and unbleached states. The results show that there is definitely an optimum freeness level or time of beating for each pulp which will give the maximum combinations of tear and tensile strengths. If this maximum is exceeded, there is a rather drastic drop in tearing strength as tensile strength continues to increase. This can be explained by the concurrent effects

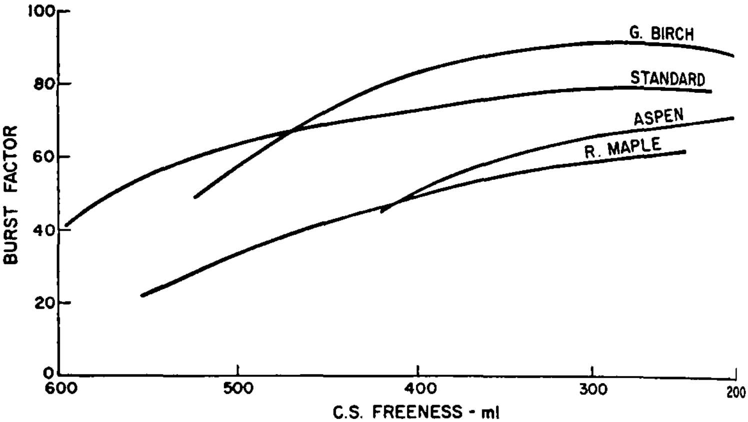

FIGURE 27. Burst Factor vs Freeness (Bleached Pulps)

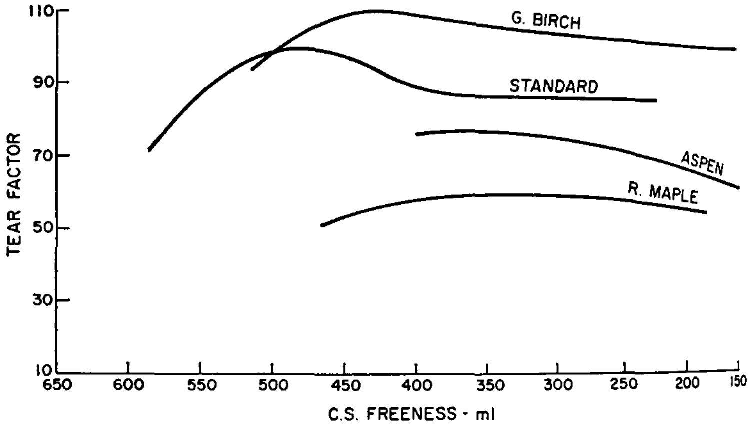

FIGURE 28. Tear Factor vs Freeness (Unbleached Pulps)

of increased bonding and fiber shortening. Both contribute to a decrease in tear strength, whereas the former improves tensile strength.

(C) *Optimizing Cooking Conditions.* At this point in the study it had been established that a good grade of hardwood kraft pulp could be obtained from puckerbrush. The strength characteristics compared favorably with those of commercial hardwood pulps. However, the yields were comparatively low and the pulps were difficult to bleach.

A series of cooks was made to determine optimum conditions, the criteria being yield, and degree of cooking as indicated by the Kappa Number. The cooks were made in the smaller stainless steel digester previously mentioned in this report. Factors that were varied were chemical-to-wood ratio, sulfidity, and time at maximum temperature.

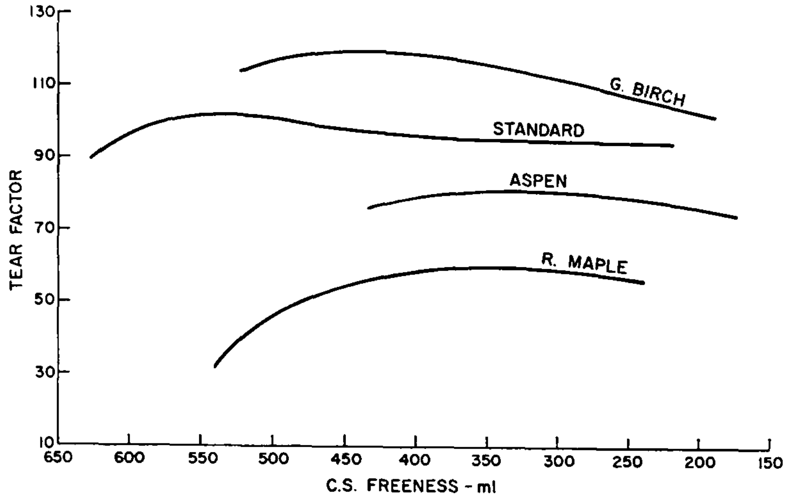

FIGURE 29. Tear Factor vs Freeness (Bleached Pulps)

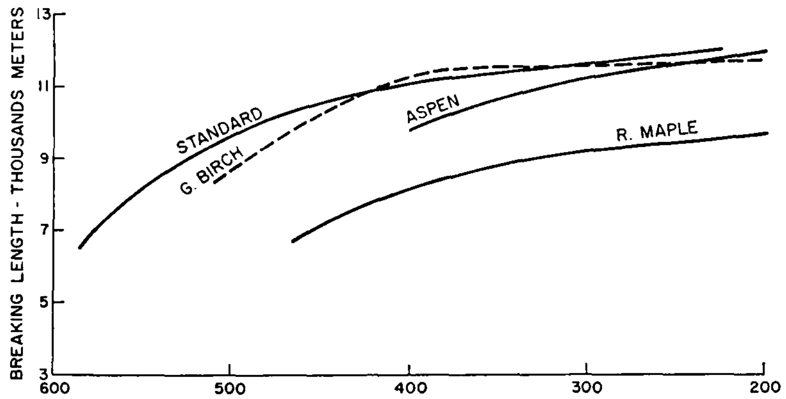

FIGURE 30. Breaking Length vs Freeness (Unbleached Pulps)

Maximum temperature for all cooks was 345°F, liquor-to-wood ratio was 7 to 9.5 depending on the packing density of the chips, and total chemical concentration of the white liquor at the start of a cook was 38 grams per liter (2.3 #/ft^3) as Na_2O.

Gray birch stemwood with bark, and gray birch branches were chosen for this phase of the study because gray birch had generally produced the best pulp in the previous cooks. Nine cooks were made and the conditions and results are shown in Table 7.

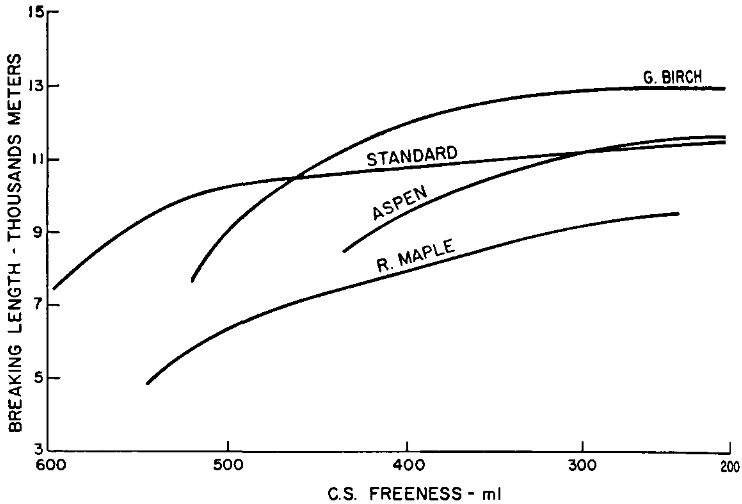

Figure 31. Breaking Length vs Freeness (Bleached Pulps)

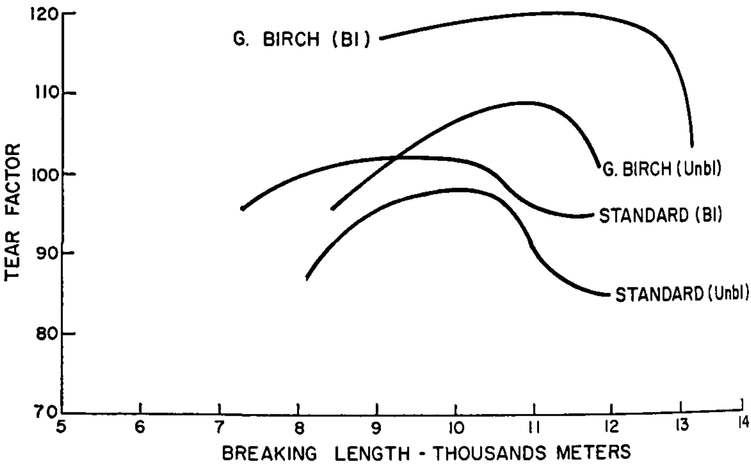

Figure 32. Tear Factor vs Breaking Length

The general objective for this series of cooks was to establish a combination of realistic cooking conditions that would produce a pulp at a yield not less than 45% and a Kappa Number not greater than 30. This refers to the gray birch stemwood.

It was decided, on the basis of results obtained, that the conditions of cook #5 (Table 7) most nearly met the objectives which had been set. The conditions of this cook, when compared with those used in the

Table 7

Effect of Cooking Variables on Yield and Kappa Number

Cook #	1	2	3	4	5	6	7	8	9
Species	Standard Chips	Gray Birch	Runs 2 through 9 were Gray Birch.						
Active Alkali-to-Wood Ratio	0.25	0.25	0.20	0.20	0.20	0.20	0.15	0.20	0.20
Sulfidity (%)	25	25	25	25	25	25	25	20	20
Time at Temperature (hours)	2	1	2	1	½	0	2	2	½
Yield (%) Stemwood	46.9	42.8	43.7	45.2	47.7	51.2	48.2	42.9	50.0
Rejects (%) Stemwood	—	—	0.2	1.4	6.2	28.0	8.4	0.8	9.6
Kappa Number Stemwood	12.8	18.9	20.4	21.2	29.4	43.6	40.4	20.7	35.9
Yield (%) Branches	—	33.2	32.6	32.3	34.2	39.5	39.7	33.7	38.4
Rejects (%) Branches	—	—	0.1	0.8	1.6	6.6	4.5	0.6	4.0
Kappa Number Branches	—	27.7	26.4	29.4	33.9	53.6	46.0	28.5	41.8

Max. Temperature = 343 - 345° F
Liquor-to-Wood Ratio = 7 - 9.5
Chemical Concentration = 39 g.p.l. (as Na_2O)
2.3 #/ft^3 (as Na_2O)

first phase of the pulping study, show a decrease in the chemical-to-wood ratio, from 0.25 to 0.20, and a substantial decrease in cooking time at maximum temperature, 2 hours to ½ hour. Continuing the comparison, but for results obtained, it is seen (Tables 2 and 7) that the yield of stemwood pulp is increased from 41.9 to 47.7%, and the Kappa Number from 23.2 to 29.4 by the new cooking conditions. The 6.2% rejects that are shown for cook 5 would be reduced considerably under commercial pulping conditions because they were actually "soft" rejects and the high value resulted mainly from the defibering conditions that were arbitrarily established for this study. This would, of course, result in further improvement in cook yield. The Kappa Number of 29.4 compares very favorably with that experienced under commercial pulping conditions and it represents a pulp which is well-cooked, but certainly not over cooked to the point of fiber degradation.

It is interesting to note that the branchwood reacted much the same as did the stemwood to the variations in cooking conditions, although the level of yields is much lower for the branches, and the Kappa Numbers are higher. These effects can be attributed to the higher proportion of bark to wood, and a higher percentage of oxidizable materials in the branchwood pulp.

Using the conditions established in cook 5, Table 7, Composite 2 of four species, gray birch, alder, aspen, and red maple, were pulped in separate cooks, using the larger digester. Yields and Kappa Numbers were determined for each of the pulps. Beater tests were run and hand sheets were made and tested. The results are shown in Table 8. The purpose of this series of cooks was to determine what effects the new cooking conditions would have on yields and properties of pulps from these four prevalent puckerbrush species.

For ease of comparison of results obtained under the new cooking conditions with those obtained in the first cooks, the earlier results are shown in parentheses in Table 8.

Increases in yield obtained when stemwood was pulped under the new conditions did not materialize in the case of Composite 2, although there were slight increases for all species except aspen. One reason for this may be that proportionally there is more bark in Composite 2 than in the stemwood, inasmuch as there are branches present.

Kappa Numbers were higher for all species and this result is in agreement with what was expected on the basis of results shown in Table 7.

It is seen that the new pulping conditions produced pulps with improved strength properties. The differences are not significant in some cases but the trend is toward increased strength. Pulp freenesses also

Table 8

Properties of Composite 2 of Four Species: Gray Birch, Alder, Aspen, and Red Maple Pulped Under Conditions of Cook #5, Table 7

Beating Time (min.)		0	5	10	20	30
Cook Yield (%)	Gray Birch	39.9 (38.1)				
	Alder	37.0 (35.3)				
	Aspen	41.3 (42.7)				
	Red Maple	45.0 (42.2)				
Kappa Number	Gray Birch	29.6 (21.5)				
	Alder	37.8 (29.3)				
	Aspen	32.2 (14.8)				
	Red Maple	25.9 (15.1)				
C. S. Freeness (ml)	Gray Birch	522 (418)	442 (368)	365 (306)	232 (197)	107 (106)
	Alder	392 (302)	343 (282)	312 (—)	200 (248)	— (—)
	Aspen	417 (402)	369 (332)	333 (313)	222 (213)	175 (145)
	Red Maple	481 (451)	417 (401)	367 (353)	252 (261)	182 (167)
Bulk (cc/gm)	Gray Birch	1.9 (1.78)	1.9 (1.62)	1.9 (1.63)	1.8 (1.54)	1.7 (1.58)
	Alder	1.68 (1.42)	1.59 (1.32)	1.56 (1.30)	1.56 (—)	— (—)
	Aspen	1.99 (1.79)	1.93 (1.74)	— (1.70)	1.87 (1.58)	1.81 (1.55)
	Red Maple	1.82 (1.75)	1.74 (1.62)	1.66 (1.54)	1.61 (1.42)	1.51 (1.36)
Burst Factor	Gray Birch	45 (54)	69 (70)	79 (76)	82 (83)	88 (88)
	Alder	61 (64)	76 (71)	85 (75)	94 (78)	— (—)
	Aspen	46 (44)	57 (54)	61 (58)	72 (65)	80 (68)
	Red Maple	36 (33)	48 (43)	59 (50)	71 (62)	81 (67)
Tear Factor	Gray Birch	76 (80)	93 (88)	92 (85)	89 (86)	73 (85)
	Alder	63 (84)	72 (80)	92 (76)	89 (75)	— (—)
	Aspen	66 (76)	71 (75)	73 (71)	71 (—)	71 (71)
	Red Maple	65 (69)	91 (79)	97 (79)	84 (78)	78 (71)
Breaking Length (meters)	Gray Birch	10620 (10380)	12330 (11580)	13730 (12260)	14170 (12790)	14210 (12940)
	Alder	10970 (11220)	12050 (12330)	12590 (12070)	12850 (12309)	—— (——)
	Aspen	9560 (8780)	10830 (9360)	10950 (10670)	12450 (9820)	11740 (10740)
	Red Maple	7960 (6960)	9320 (8300)	10530 (8800)	11860 (9670)	11930 (9010)

Values in parentheses are results obtained in first phase of the work.
They were copied from Tables 1A—35 in the appendix

were generally higher, although the response to beating did not appear to change materially.

A portion of the gray birch pulp was bleached using the bleaching conditions shown in Table 5. The bleach yield, overall yield, and G.E. brightness were measured. A standard beater test was run on a sample of the bleached pulp. The results are shown in Table 9.

Again, as in previous bleaching results, there was a considerable shrinkage as a result of the operation and the overall yield was a low 32%. The brightness value of 73.3 is approximately 6 points lower than was previously experienced on pulp from gray birch Composite 2. It is believed that this present value is not accurate and resulted from coloring materials in the water used for pulp washing.

Bleaching resulted in a decrease in freeness of the gray birch pulp. Effects on strength properties were slight and no consistent trend was noted. One exception was the bulk, which decreased significantly as a result of the bleaching.

(D) *Study of Bleaching Conditions.* Several bleaching sequences were used in an effort to produce at least an 80 brightness pulp without abnormal damage to the fiber. The bleaching conditions and resulting brightness values are shown in Table 10. No other tests were made on the bleached pulps.

Three pulps were prepared for the bleach study, using the optimum pulping conditions that had been established previously. The pulps were prepared from Composite 2 of gray birch, gray birch stemwood without

Table 9

Properties of Gray Birch Pulp
Pulped Under Conditions of Cook #6, Table 7

Beating Time (min.)		0	5	10	20	30
C.S. Freeness (ml.)	Unbleached	522	442	365	232	107
	Bleached	485	431	348	208	133
Bulk (cc/gm)	Unbleached	1.9	1.9	1.9	1.8	1.7
	Bleached	1.5	1.4	1.3	1.3	1.3
Burst Factor	Unbleached	45	69	79	82	88
	Bleached	50	76	86	84	89
Tear Factor	Unbleached	76	93	92	89	73
	Bleached	69	95	90	81	72
Breaking Length (meters)	Unbleached	10620	12330	13730	14170	14210
	Bleached	11210	13640	14560	14550	13730

Cook Yield (%)	39.1	Overall Yield (%)	32.0
Kappa Number	29.6	G. E. Brightness	73.3
Bleach Yield (%)	81.6	Bleach Sequence	CEHD

bark, and commercial hardwood chips. The latter two were prepared as standards for purposes of comparison.

The first two bleach runs were made on gray birch Composite 2 pulp, using a 4-stage sequence, with 60% of the chlorine demand being used in the chlorination stage (C) and the remaining 40% being divided equally between the hypochlorite (H) and chlorine dioxide stages (D).

A brightness of 80.3 was realized for Run 1. This is much better than the 73.3 value that was obtained previously and the difference can be attributed to an improvement in the color condition of the water used in the pulp washing stages.

In run 2, the percent addition of chlorine was increased by 25%. Inasmuch as the additional chemical did not increase brightness, it was decided to try different sequences of bleaching stages. In runs 3 and 4 the same percent of chemical was used as in run 1 (100%) but it was divided among a different number and sequence of stages. Six stages, two being chlorine dioxide, were used in run 3, and five stages, two being hypochlorite, in run 4. No improvement in brightness, over that obtained in the four-stage treatment, was realized.

In run 5, the percent addition of chlorine was increased by 60% over that indicated by the Kappa Number as being required. The additional chemical was added as a second chlorination stage. This resulted in the highest brightness yet attained for a puckerbrush species pulp, 82.2 points. Further work will be required to determine whether it is the additional chemical, the sequence of addition, or both, that control the brightness development. It is suspected that the chlorine demand, as indicated by the Kappa Number, is too low, and must be increased by some minimum factor, particularly for puckerbrush species that are pulped with the bark intact. The results of run 6 offer some support to this hypothesis. Here the pulp from gray birch stemwood *without bark* attained a brightness of 84.6.

The pulp from a commercial blend of hardwood chips bleached to an 86.6 brightness using the 60% excess chlorine addition, thus providing more evidence that the puckerbrush may be more difficult to bleach than is pulp from the wood of full size trees.

(E) *Fiber Morphology Study.* In the final phase of this study a complete analysis was made of the important dimensions of the fibers of puckerbrush species. The procedure used in measuring these dimensions was described in the experimental procedure section of this report. The results are shown in Table 11.

The strength characteristics of paper are dependent to a large degree on the dimensions and intrinsic strength of the wood fibers of which it is composed. Many studies have been made attempting to

Table 10

Results of Bleach Study

Run #	Wood Species Cook Yield Kappa Number	Percent of Cl_2 Demand Used	Bleaching Stages	Percent of Cl_2 Demand Used in Stage	G. E. Brightness
1	Gray Birch Composite 2 39.1% 29.6	100	C E H D	60 — 20 20	80.3
2	"	125	C E H D	60 — 20 20	79.3
3	"	100	C E H D E D	60 — 20 10 — 10	80.0
4	"	100	C E H H D	60 — 10 10 20	79.7
5	"	160	C E C E H D	60 — 60 — 20 20	82.2
6	Gray Birch Stems Without Bark, 47.5% 23.9	160	"	"	84.6
7	Commercial Hwd. Chips, 46.7% 25.1	160	"	"	86.6

develop meaningful relationships between the strength of paper and the criteria mentioned. There have been few such correlations developed. However, it is an established fact that strength properties, particularly tearing strength, increase with increasing fiber length. Also fiber flexibility, which would be enhanced by fibers having a low ratio of cell wall thickness to lumen diameter, tends to contribute to paper strength. The reason for this is the increased degree of contact, and greater opportunity for fiber-fiber bonding, where the fibers conform to their neighbors during water removal in the forming of a sheet.

Table 11

Fiber Dimensions

Species	Length (mm.)	Cell Diameter (microns)	Lumen Diameter (microns)	Cell Wall Thickness (microns)
Aspen Stem w/o bark	0.73	27.5	23.5	2.0
Aspen Stem with bark	0.69	26.6	23.1	1.7
Aspen Branches	0.51	23.4	17.2	2.0
Aspen Stump & Roots	0.77	30.3	26.6	1.9
Aspen Composite 1	0.62	28.0	23.6	2.1
Aspen Composte 2	0.60	26.7	23.1	1.8
Alder Stem w/o bark	0.64	23.9	19.0	2.3
Alder Stem with bark	0.57	23.1	18.0	2.6
Alder Branches	0.48	18.4	13.6	2.4
Alder Stump & Roots	0.68	28.9	23.3	2.8
Alder Composite 1	0.56	21.9	17.3	2.2
Alder Composite 2	0.55	21.5	16.9	2.2
Gray Birch Stem w/o bark	0.73	22.6	16.4	3.1
Gray Birch Stem with bark	0.72	20.5	15.0	2.7
Gray Birch Branches	0.61	18.0	13.2	2.4
Gray Birch Stump & Roots	0.68	24.7	19.8	3.0
Gray Birch Composite 1	0.67	21.5	15.6	2.9
Gray Birch Composite 2	0.64	21.2	15.3	2.9
Red Maple Stem w/o bark	0.62	20.0	13.4	3.3
Red Maple Stem with bark	0.64	20.2	13.6	3.3
Red Maple Stem Branches	0.51	17.3	11.8	2.7
Red Maple Stump & Roots	0.61	27.6	21.9	3.3
Red Maple Composite 1	0.62	21.3	15.8	2.7
Red Maple Composite 2	0.63	18.2	13.8	2.9
Pin Cherry Stem w/o bark	0.64	18.6	12.5	3.1
Pin Cherry Stem with bark	0.57	19.1	13.0	3.0
Pin Cherry Branches	0.50	15.3	9.8	2.7
Pin Cherry Stump & Roots	0.69	24.4	18.4	3.0
Pin Cherry Composite 1	0.58	20.8	15.5	2.7
Pin Cherry Composite 2	0.58	18.7	13.5	2.6
Willow Stem w/o bark	0.47	17.0	10.9	3.0
Willow Stem with bark	0.56	16.5	10.9	2.9
Willow Branches	0.46	15.4	10.0	2.7
Willow Stump & Roots	0.50	22.1	16.7	2.9
Willow Composite 1	0.50	17.6	12.4	2.7
Willow Composite 2	0.48	15.3	9.7	2.8
Standard Pulp	0.84	22.1	13.5	4.3

The puckerbrush fibers are generally shorter, and have a greater lumen-to-wall thickness ratio, than the fibers from diciduous trees.

Aspen stemwood has the best combination of fiber length, and lumen-to-cell wall ratio of the six puckerbrush species. It should be the most flexible of the lot and it is one of the two having the longest fibers, gray birch being the other. It does excel in some respects, particularly in tensile strength, but overall it is somewhat weaker than either the gray birch and pin cherry.

Willow has the shortest fibers and the highest cell wall-to-lumen diameter ratio and as might be expected, it produces the weakest pulp.

The wall thickness of the gray birch, red maple and pin cherry fibers are greater than those of the willow and they are longer and have a larger lumen diameter. Inasmuch as they are much superior to the willow in strength characteristics, it is apparent that no single dimension, but rather a combination of dimensions, is the criterion.

Several such combinations were calculated for the stemwood fibers of all six species and they are shown in Table 12. Included in the table are strength properties from Figures 7, 12 and 17, at a freeness of 300. The derived property combinations are defined at the bottom of the table. The "total length factor" was determined from Fig. 33 and represents the *relative* total lengths of 100 fibers. It is proportional to the area under any curve shown in Fig. 33. Thus, gray birch would have the greatest total length factor and willow, the lowest.

The lack of any consistent relationships between fiber dimension combinations and physical properties indicates that other important factors are contributing to the strength characteristics. Probably one of the most important of those factors, and one that has not been determined in this study, is the inherent strength of the fiber iself. This might explain, in part, the reason that aspen fibers which, according to the results in Table 12, excel in length, flexibility, and total length factor, do not produce the strongest paper in general.

Biomass Studies

Introduction

Foresters commonly use the term "bush" to mean natural forests of commercial tree species in Africa, Australia, Canada and portions of the United States. In the State of Maine, U. S. A., the term "puckerbrush" is commonly used to mean thickets of alder and willow, young aspen birch and red maple or similar stands that are generally less than thirty feet in height. This term seems to be equally appropriate for dense young softwood stands. In the world there are millions of acres of non-commercial woody shrub and tree stands to which the term puckerbrush may aptly be used to differentiate such stands from natural forest stands of species that are commercially important.

Rodin and Bazilevich (8, 9), Whittaker and Woodwell (10, 11) and Young (12, 13) have summarized most of the world literature on biomass studies of individual trees and forest stands that has been published in the past thirty years. The literature indicates that generally satisfactory means have been established for sampling the components of individual trees but many authors have indicated dissatisfaction with their sampling methods for forest stands. Inasmuch as a forest stand

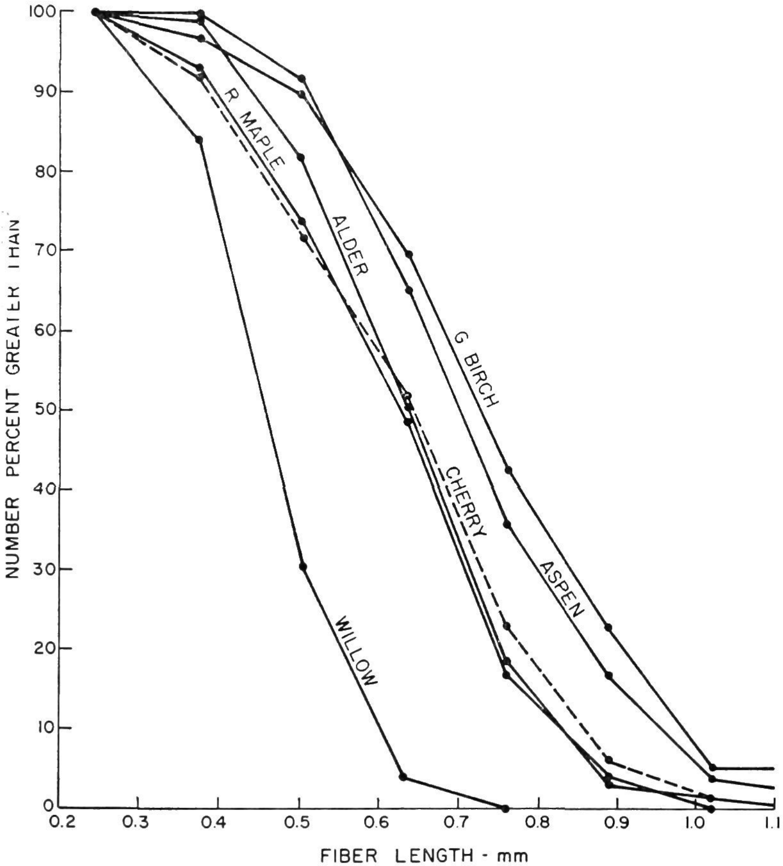

FIGURE 33. Fiber Length Distribution (Stem Without Bark)

consists of more than one tree on some specified area, such biomass studies are more time consuming and therefore encourage considerable sub-sampling to keep the field work within reasonable time limits in terms of the information desired.

The literature does not disclose any biomass studies of forest stands that are statistically sound and economical in terms of time. Therefore, a study of biomass sampling methods for puckerbrush stands is appropriate and timely for there is increasing interest in this segment of the plant world. This study will report on two different sampling methods that have been field tested in Maine.

Table 12

Paper Strength Properties and Fiber Characteristics

Species	Fiber Length (mm)	Fiber Flexibility	Fiber Solids-Length Factor	Total* Length Factor	Burst Factor	Breaking Length (meters)	Tear Factor
Gray Birch	0.73	73	34	1	92	13100	101
Pin Cherry	0.64	67	35	4	97	14500	93
Red Maple	0.62	67	34	5	72	11300	88
Aspen	0.73	85	20	2	84	14500	81
Alder	0.64	81	22	3	78	12800	76
Willow	0.47	64	28	6	50	9900	66

$$\text{Fiber Flexibility} = \left(\frac{\text{Lumen Diameter}}{\text{Cell Diameter}}\right)(100)$$

$$\text{Fiber Solids — Length Factor} = \left(\frac{\text{Cell Wall Cross-Section Area}}{\text{Cell Cross-Section Area}}\right)(\text{Fiber Length})\ (100)$$

Total Length Factor = Relative Total Lengths of 100 Fibers. See Fig. 33

* 1 means longest, 6 shortest.

Methods

Puckerbrush stands range from 2-50 feet in average height, include 1-10 species per acre and have from 200-20,000 or more stems per acre. The primary objective of a biomass study of a forest stand is to obtain reliable estimates on a per acre basis of the fresh and dry weight for each component of the shrub or tree for each species present. Inasmuch as this type of study requires destructive sampling, the time required in the field and laboratory is directly related to the number of plant components recognized, the number of woody plants present and the area of the sample plot. The objective of the sampling investigations, therefore, must be to establish sampling and sub-sampling procedures that will yield estimates within the limits of accuracy established by the research worker. Then finally acceptable sampling procedures should minimize the destructive sampling which is so very time consuming.

1969 Methods

Two major considerations in the planning stage were: (1) estimates of dry matter of all vegetation above- and below-ground were to be made and (2) sub-sampling errors would be eliminated by drying all of the vegetation on the plot. With these considerations in mind the basic plot was to be square and as many meters on each side as the stand was meters high to the nearest full meter. Thus, for a stand five meters high the plot would be 5 by 5 meters consisting of five sub-plots each 1 by 5 meters. On each sub-plot the data were to be recorded by one meter squares. Statistical analysis of the major sub-plots would be performed to see if fewer strips would give satisfactory results.

The field work on the square meter sub-plots of the first sub-plot strip of the first basic plot required more than two days for a two-man field crew. Therefore the basic plot was reduced from the square dimensions to a single strip of square meter sub-plots as long as the trees on the plot were high in meters to the nearest meter. Each square meter sub-plot was delineated in the field by a ⅜" steel chain with 30-penny nails in the corner as measured with a meter stick. For each species on the sub-plot the material was separated into above- and below-ground portions. The above-ground portion for the perennials was separated into leaves, branches (material smaller than ¼") and stem (material larger than ¼") after drying. As a general practice the material from all of the sub-plots of a plot was brought to the laboratory at one time, weighed in the fresh condition and then placed in a drying room at 80° C for at least two days and sometimes longer. All remaining earth and stones were removed from the material after taking it from the drying room. The components were separated before weighing for each species.

1970 Methods

The sampling procedures of 1969 were so time consuming and the plot was so small that considerable thought was given to alternative methods. If the annuals were omitted, the study would be limited to woody vegetation and would not be complete in an ecological sense. If the below-ground material were omitted, the study would be limited but information on below-ground material was simultaneously being collected for a pulping study. If sub-sampling procedures were employed, the field and laboratory work per plot would be considerably less. These were the three major factors in the time required per plot and the plot size in 1969.

To expand the basic plot for 1970 the annuals and the below-ground portions were eliminated and sub-sampling procedures were included. The basic plot would be 25 by 25 feet (1/70th-acre) regardless of the average height of the stand. Surveying pins were to be used to mark the plot corners and a plastic line with a metal corner marked in 25′ segments was used to locate the plot. Both diagonals were measured with a specially marked piece of plastic line to insure accuracy of plot size. The two-man field crew then placed the Fairbanks Morse counter beam scales (350 pound maximum with 50 pounds on the beam with quarter pound limits) on a level spot adjacent to and outside of the plot boundary nearest to the road.

The procedure for each species on the plot was as follows:

1. Three trees were selected as the tallest, medium and shortest. A small Homelite chainsaw was used to sever the stems at a three-inch stump. The entire above-ground portion of the three trees was then weighed in a large rigid plastic container of known weight.
2. The length of each was measured and the annual rings counted at the stump end to estimate average age and height for the species.
3. The branches (material less than ⅜″) were clipped from the three stems (material larger than ⅜″). The branches and stems were then separately weighed to estimate the proportion of each in the above-ground material.
4. All of the trees of the species were severed and weighed in the plastic container in a series of weighings depending on the mass of material present.
5. A random sample of branches was clipped from the pile and placed in a flexible plastic container along with several stem disks.
6. In the laboratory the leaves were stripped from the branches and then the branches and leaves were separately weighed to estimate the proportion of each in the branch component.
7. The stem disks, a random sample of leaves and a random sample of branches without leaves were weighed and placed in an oven at

105°C for at least 24 hours at which time they were re-weighed to estimate the moisture content.

Analytical Procedures

1969 Data

No effort was made to differentiate between species or to separate the above- and below-ground portions for the annuals. By inspection the variation in the dry weight between sub-plots of a single plot was so great that no attempt was made to analyze the sub-plots statistically. The woody shrubs and trees had initially been separated into components by species by sub-plots. The species were combined by components (leaves, stems and stumps and roots) within a sub-plot and the sub-plots of each plot were combined to estimate the components on a per-acre basis.

1970 Data

All of the above-ground portion of the woody shrubs and trees were weighed in successive loads in the rigid plastic container. Therefore the fresh weight of the aerial portion is relatively free of error.

Three sub-sampling routines were used to estimate the dry matter in the leaf, branch and stem components of each species on an acre basis. The proportion of branches with leaves of the aerial portion as estimated (step 2 of procedure) was applied to the total fresh weight of the plot to estimate the amount of branches with leaves and stems on the plot. The proportion of leaves and branches without leaves (step 6 of procedure) was applied to the estimate of the fresh weight of branches with leaves to estimate the fresh weight of leaves and branches without leaves on the plot. By this procedure the actual fresh weight of the plot was cast into separate estimates of the fresh weight of leaves, branches without leaves and stems and these were multiplied by 69.696 and divided by 2,000 to place the estimates on an acre basis in tons. Estimates of the percent of dry matter in each component (step 7 of procedure) were then applied to prepare the estimates of the dry matter of each component per acre for the species. Finally the species were combined by components to estimate the dry matter of each per acre.

Results

1969

Nine stands ranging from 2-5 meters in height were sampled by two young men during a four-week period. The results are shown in Table 13. From the limited amount of data it appears that the mass of annuals decreases as the stand becomes fully stocked with woody vegetation. The leaf mass per acre seems to be relatively constant regardless of species composition or size. The total dry biomass per acre for these young stands ranged from 10.6-31.8 tons per acre with the dry matter pro-

Table 13

Pilot Biomass Study of Weed Tree Species and Woody Shrub Communities - 1969

	Meadow-sweet	Dogwood Meadow-sweet	Alder	Alder	Grey Birch	White Birch	Willow	Aspen	Aspen
Number of square meter subplots	2	2	3	3	3	3	5	5	3
Approximate height above ground in meters	1	2	2	3	3	3	5	5	5
Approximate age	4	8	4	6	12	6	11	7	7
All figures below are dry weight in tons per acre									
Annuals	2.7	2.0	4.4	3.4	3.2	2.5	1.0	0.8	2.5
Trees and Shrubs:									
Leaves	2.0	1.9	1.7	3.0	2.8	3.6	2.2	1.6	1.8
Stems and Branches	8.0	10.9	3.1	7.7	12.8	16.4	22.8	11.8	9.3
Roots	6.0	4.0	1.4	2.4	4.0	5.6	5.8	2.7	2.3
Total Biomass	18.7	18.8	10.6	16.5	22.8	28.1	31.8	16.9	15.9

luction of stems and branches ranging from 0.8-2.7 tons per acre per year.

1970

During a 13-week period two young men obtained data on 61 plots in 50 different stands representing at least 15 species combinations. They did either one or two plots a day with travel time an important factor, as the plots were distributed in central and northern Maine. About one-quarter of that time was spent on another related project.

Because so few have examined biomass data, a selected portion is displayed in Table 14 to give some notion of the actual plots. The data for the 61 plots is summarized as follows:

Factor	Range	Average
Individual average stand age	2 59 years	
Individual average stand height	3 - 45 feet	
Estimated dry matter (wood and bark) per acre above ground	2.9 55.3 tons	
Dry matter production (wood and bark) per year in fully stocked stands	0.4 2.0 tons	1.2 tons
Dry matter production (wood and bark) per linear foot of height in fully stocked stands	0.4 - 1.5 tons	0.8 tons

Only eight of the plots were in stands that had been regenerated by coppicing. Four were on an experimental area of the Penobscot Experimental Forest, U. S. Forest Service, in Bradley and Eddington townships, Maine. These had been clear cut six years previously and ranged from 1.4-2.0 tons of dry matter per acre per year. The other four were on an esker northeast of Orono, Maine in open-grown stands 19-26 years old that ranged from 0.6-1.2 tons per acre per year.

The average height of the sample trees on the plot was 7.9 feet below the height of the tallest sample tree. The range of difference in height from the average to the tallest was 1-20 feet.

The field data were collected over a three-month period during which time the moisture content of the wood vegetation probably changed. To ascertain if any seasonal changes were apparent, the estimated dry matter in the stems and branches without leaves was calculated as a percent of the total above-ground fresh weight of the plot. There was no observable seasonal trend. The average percentage was 52.2 ranging from 42.2-69.1. As a rule of thumb the dry weight of

Table 14

Selected plot Data of Dry Matter Production Study Collected in 1970 Field Season

Plot No.	Dominant Species	Other Species	Ave. Hgt. Feet	Ave. Age	Dry Matter tons/acre Stems & Branches	Dry Matter tons/acre per year	Production tons/acre per ft. hgt.	Leaves tons/acre
3	Aspen	Red Maple, Beech	35	20	33.13	1.66	0.95	0.84
9	Willow		11	9	10.03	1.11	0.91	1.00
10	Alder		9	5	8.46	1.69	0.94	1.93
15	Aspen, Grey Birch	Red Maple	45	41	52.42	1.28	1.16	0.95
17	Meadowsweet		3	2	2.91	1.46	0.97	1.22
23	Sugar Maple, Beech, Yellow Birch		43	49	55.29	1.13	1.29	1.27
26	Pin Cherry	Striped Maple, Grey Birch, Aspen	20	15	14.31	0.95	0.70	1.57
31	Aspen		17	6	10.58	1.76	0.62	1.52
33	Paper Birch, Aspen	Beech, Yellow Birch, Maple	34	24	23.12	0.96	0.68	1.57
35	Aspen, Red Maple		15	6	8.62	1.44	0.57	1.75
44	Sugar Maple, Beech		20	18	19.29	1.07	0.97	1.40
54	Beech		26	26	34.87	1.34	1.34	0.79
55	Paper Birch	Sugar Maple	22	22	13.32	0.61	0.61	0.83
58	Yellow Birch		29	25	26.45	1.06	0.91	0.98
60	Alder		18	20	13.84	0.69	0.77	1.00

the stems and branches without leaves is approximately half the fresh weight of the same material with leaves.

Three of the stands sampled in 1969 were re-sampled in 1970 primarily to learn the effect of increased plot size on the per acre estimates. In all three cases the acre tonnage was less.

Discussion

Biomass sampling of forest stands presents two formidable fundamental questions. How accurately do we need or want to know the dry weight of each component by species on the plot? How accurately do we need or want to know the dry weight of components by species or by combined species for a particular forest stand? These must be resolved for the destructive nature of the basic biomass studies is so much more time consuming for forest stands than similar studies for individual trees species.

If the plot data were devoid of error, each forest stand would have sufficient variation that from 6-30 plots would be required to obtain an error of estimate of the mean that did not exceed 10 percent at 19:1 odds when all components and all species were combined. If it is essential to have the information by species or by component within species, or by component when all species are combined, then the number of plots in a single forest stand might be increased by factors of 3-10. Under such conditions a single two-man field crew might spend an entire summer field season in a single forest stand. For certain scientific objectives this can be justified, but it is unlikely that this would be feasible for an applied study.

Within the plot as described for 1970 there are three levels of subsampling. Are three trees per species extending over the range of tree sizes adequate to determine average height, average age and proportion of branches with leaves to stem? This was not tested, but it is likely that if six sets of three trees had been selected the results would have demonstrated a range of at least 10% from the smallest to the largest of the six sets. Is it important to estimate this error?

In plot number 20 six sets of random samples of branches with leaves and six sets of stem disks were brought to the laboratory. The proportion of leaves and branches were determined by weighing them separately for each set. The proportion of branches without leaves ranged from 37.1-51.4%. All of this material was dried in the oven and then re-weighed to determine the moisture content which was 57.1-61.4% for the leaves, 42.0-51.8% for the branches without leaves and 37.2-43.8% for the stem disks. Is it sufficiently important to know the errors of sub-sampling to take this many additional samples? If so, then if the three sub-sampling routines are increased sixfold in order to calculate the error of estimate, it is extremely unlikely that more than one plot would be field sampled in one day even if the field crew were expanded to three people.

In some instances it took a half day for the field crew to get to a particular area where a series of plots was to be measured. It is well to point out that contacting forest managers and forest land owners for permission to do destructive sampling and actually locating the plots involves more time and effort than may be apparent. From a fixed location a two-man field crew did one or two plots a day, depending on the size of the trees, including 25 miles travel distance to and from the plot and the essential laboratory work. If the sub-sampling were increased sixfold for each of the three routines and if ten plots were essential for each forest stand, then a minimum of ten crew days with three men in the crew would be required to reliably estimate the above-ground portion of a particular forest stand. If it becomes necessary to sample the under-ground portion of the forest stand with similar error requirements, then the field and laboratory time would be at least doubled for forest stands with trees no larger than four inches in diameter at breast height.

Because there is so little biomass data for puckerbrush stands, the decision was made to employ the sampling procedures outlined in the methods section. By so doing some information was obtained in a number of plots representing a variety of species composition, size classes and regional distribution rather than a precise estimate of a very few forest stands.

Although the 1970 plot data yielded smaller tonnage per acre than the 1969 plot data there is still no certainty as to the proper plot size for puckerbrush stands of different size classes. It is conceivable that 50 by 50 foot plots might have been more accurate. The important point to recognize is that we need a number of biomass sampling studies to determine the proper plot size and shape for biomass studies of forest stands. Such investigations should be conducted in the present and near future as there is evidence accumulating that biomass is a more meaningful way to quantitatively describe an ecosystem.

Summary and Conclusions

Two sampling procedures were tested in successive years. In 1969 all of the vegetation above- and below-ground was weighed fresh and dry from small plots. This is an extremely time consuming process that probably should be used only on small-scale, sophisticated, basic ecological studies. In 1970 three sub-sampling routines were employed on only the above-ground portion of larger plots. These methods introduce greater error, but permit larger plots and more plots as a means of uantitatively describing puckerbrush stands. These methods, probably ith some refinements, are probably applicable to applied studies.

Puckerbrush stands in central and northern Maine appear to be roducing about 1.2 tons of dry wood and bark per acre per year on he stems and branches regardless of species composition or age, providng the stand is fully stocked. For convenience this can be expressed as about 0.8 tons of dry matter per linear foot for the average height of the stand above ground.

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APPENDIX

1A – 6A.	C. S. Freeness (ml.) vs Beating
7A – 12A.	Burst Factor vs Beating Time
13A – 18A.	Tear Factor vs Beating Time
19A – 24A.	Breaking Length (meters) vs Beating Time
25A – 30A.	Bulk (cc/gm) vs Beating Time
31A – 35A.	C. S. Freeness vs Beating Time (Composite 2)

for

Gray Birch, Red Maple, Aspen, Pin Cherry, Alder and Willow

Table 1A

C.S. Freeness (ml) vs Beating Time

Alder Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	422	355	303	255	231	
Stem with bark	371	341	305	240	—	
Branches	245	268	—	—	—	
Stump and Roots	370	342	315	260	—	
Composite 1	304	278	258	—	—	
Composite 2	302	282	282	248	—	

Table 2A

C.S. Freeness (ml) vs Beating Time

Gray Birch Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	492	464	400	272	155	
Stem with bark	468	396	352	234	122	
Branches	277	224	207	—	—	
Stump and Roots	383	353	290	207	170	
Composite 1	387	349	284	198	77	
Composite 2	418	368	306	197	106	

Table 3A

C. S. Freeness (ml) vs Beating Time

Aspen Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	527	479	410	301	199	215
Stem with bark	446	411	351	245	148	—
Branches	269	268	256	—	—	—
Stump and Roots	467	423	352	233	132	—
Composite 1	388	349	293	192	153	—
Composite 2	402	332	313	213	145	—

Table 4A

C. S. Freeness (ml) vs Beating Time

Red Maple Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	542	—	472	361	269	180
Stem with bark	502	—	481	362	262	170
Branches	316	314	307	—	—	—
Stump and Roots	742	—	—	—	—	—
Composite 1	475	417	365	270	197	—
Composite 2	451	401	353	261	167	—

Table 5A

C. S. Freeness (ml) vs Beating Time

Pin Cherry Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	480	—	421	314	215	—
Stem with bark	452	—	351	242	182	—
Branches	287	247	252	—	—	—
Stump and Roots	504	—	441	332	233	162
Composite 1	442	—	355	237	167	—
Composite 2	406	—	317	237	197	—

Table 6A

C. S. Freeness (ml) vs Beating Time

Willow Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	436	392	370	335		
Stem with bark	367	351	296	252		
Branches	308	—	—	—		
Stump and Roots	330	297	286	278		
Composite 1	367	333	290	280		
Composite 2	343	322	299	290		

Table 7A

Burst Factor vs Beating Time

Alder Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	59	69	75	82	82	
Stem with bark	55	63	69	76	77	
Branches	63	68	71	—	—	
Stump and Roots	43	47	51	55	57	
Composite 1	56	62	65	69	—	
Composite 2	64	71	75	78	—	

Table 8A

Burst Factor vs Beating Time

Gray Birch Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	59	74	84	93	95	
Stem with bark	60	75	84	90	91	
Branches	52	62	68	—	—	
Stump and Roots	47	51	55	60	63	
Composite 1	58	67	70	80	78	
Composite 2	54	70	76	83	88	

Table 9A

Burst Factor vs Beating Time

Aspen Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	50	65	75	83	89	90
Stem with bark	44	52	59	68	70	—
Branches	39	44	46	—	—	—
Stump and Roots	41	47	53	59	62	—
Composite 1	41	47	52	60	62	
Composite 2	44	54	58	65	68	

Table 10A

Burst Factor vs Beating Time

Red Maple Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	29	—	52	66	74	76
Stem with bark	31	—	48	61	68	72
Branches	40	46	51	—	—	—
Stump and Roots	22	26	—	—	—	—
Composite 1	29	37	45	57	62	—
Composite 2	33	43	50	62	67	—

Table 11A

Burst Factor vs Beating Time

Pin Cherry Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	50	—	78	94	103	—
Stem with bark	48	—	68	82	88	—
Branches	56	63	69	—	—	—
Stump and Roots	40	—	62	72	80	83
Composite 1	43	—	65	78	84	—
Composite 2	48	—	67	78	83	—

Table 12A

Burst Factor vs Beating Time

Willow Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	33	40	46	57		
Stem with bark	32	42	49	61		
Branches	39	46	—	—		
Stump and Roots	30	35	42	45		
Composite 1	33	40	46	54		
Composite 2	34	41	48	56		

Table 13A

Tear Factor vs Beating Time

Alder Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	69	78	76	71	71	
Stem with bark	72	71	77	76	65	
Branches	71	75	71	—	—	
Stump and Roots	88	88	85	83	84	
Composite 1	90	84	80	76	—	
Composite 2	84	80	76	75	—	

Table 14A

Tear Factor vs Beating Time

Gray Birch Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	84	88	98	100	86	
Stem with bark	108	96	95	93	82	
Branches	82	78	81	—	—	
Stump and Roots	96	86	83	—	84	
Composite 1	83	81	84	79	76	
Composite 2	80	88	85	86	80	

Table 15A

Tear Factor vs Beating Time

Aspen Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	87	83	87	80	74	72
Stem with bark	82	89	—	76	72	—
Branches	82	78	81	—	—	—
Stump and Roots	81	80	86	83	73	—
Composite 1	76	76	—	80	69	
Composite 2	76	75	71	—	71	

Table 16A

Tear Factor vs Beating Time

Red Maple Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	59	—	90	87	87	82
Stem with bark	64	—	89	82	76	70
Branches	62	64	59	—	—	—
Stump and Roots	56	59	—	—	—	—
Composite 1	60	71	67	74	69	—
Composite 2	69	79	79	78	71	—

Table 17A

Tear Factor vs Beating Time

Pin Cherry Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	90	—	105	95	91	—
Stem with bark	93	—	92	78	75	—
Branches	70	66	66	—	—	—
Stump and Roots	97	—	102	98	95	86
Composite 1	81	—	90	86	83	—
Composite 2	88	—	83	81	76	—

Table 18A

Tear Factor vs Beating Time

Willow Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	45	52	62	70		
Stem with bark	55	69	66	70		
Branches	56	57	—	—		
Stump and Roots	61	68	71	71		
Composite 1	63	70	67	68		
Composite 2	60	60	67	62		

Table 19A

Breaking Length (meters) vs Beating Time

Alder Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	11780	12330	12800	12450	12890	
Stem with bark	10550	11010	11570	10640	10380	
Branches	10300	10440	11190	—	—	
Stump and Roots	6870	7800	8550	—	9460	
Composite 1	7710	—	7760	9890	—	
Composite 2	11220	12330	12070	12390	—	

Table 20A

Breaking Length (meters) vs Beating Time

Gray Birch Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	9350	11320	12130	13160	13150	
Stem with bark	9870	11550	12540	12820	12510	
Branches	9590	10230	10580	—	—	
Stump and Roots	7550	8000	8600	9160	8810	
Composite 1	9960	10980	10340	11990	12450	
Composite 2	10380	11580	12260	12790	12490	

Table 21A

Breaking Length (meters) vs Beating Time

Aspen Species

omponent of Species	Beating Time (min.) 0	5	10	20	30	40
tem	10580	11940	13530	14440	14510	14320
tem with bark						
ranches	8260	8890	9480	——	——	——
tump and Roots	7190	8030	8920	9970	10190	——
omposite 1	8510	8960	10060	9930	9630	——
omposite 2	8780	9360	10670	9820	9010	——

Table 22A

Breaking Length (meters) vs Beating Time

Red Maple Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	6670	——	8780	10730	11330	11770
Stem with bark	6390	——	8930	10220	10800	10230
Branches	7600	7610	8330	——	——	——
Stump and Roots	3910	4190	——	——	——	——
Composite 1	5280	6810	7220	8100	9140	——
Composite 2	6960	8300	8800	9670	10740	——

Table 23A

Breaking Length (meters) vs Beating Time

Pin Cherry Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	9780	——	13210	14210	15030	——
Stem with bark	9380	——	12040	12920	12670	——
Branches	10210	10920	11040	——	——	——
Stump and Roots	6980	——	9620	10750	11040	12150
Composite 1	9180	——	11680	12620	12530	——
Composite 2	9980	——	12050	13110	13840	——

Table 24A

Breaking Length (meters) vs Beating Time

Willow Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	7180	8330	8820	9470		
Stem with bark	7010	7910	8500	9390		
Branches	7730	8670	——	——		
Stump and Roots	5380	6050	6530	7290		
Composite 1	6720	7840	8590	9570		
Composite 2	7350	8130	8700	9600		

Table 25A

Bulk (cc/gm) vs Beating Time

Alder Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	1.34	1.30	1.26	1.17	1.16	
Stem with bark	1.61	1.52	1.44	1.38	1.28	
Branches	1.46	1.45	1.37	——	——	
Stump and Roots	1.66	0.51	1.49	1.41	1.32	
Composite 1	1.54	1.48	1.44	1.36	——	
Composite 2	1.42	1.32	1.30	1.34	——	

Table 26A

Bulk (cc/gm) vs Beating Time

Gray Birch Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	1.48	1.48	1.43	1.24	1.20	
Stem with bark	1.63	1.62	1.56	1.38	1.36	
Branches	1.61	1.50	1.44	——	——	
Stump and Roots	1.78	1.71	1.65	1.54	1.50	
Composite 1	1.76	1.68	1.59	1.52	1.44	
Composite 2	1.78	1.62	1.63	1.54	1.48	

Table 27A

Bulk (cc/gm) vs Beating Time

Aspen Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	1.44	1.38	1.33	1.20	1.22	1.16
Stem with bark	1.87	1.78	1.66	1.60	1.54	——
Branches	2.00	1.91	1.87	——	——	——
Stump and Roots	1.93	1.79	1.70	1.64	1.62	——
Composite 1	1.94	1.83	1.59	1.53	1.49	——
Composite 2	1.79	1.74	1.70	1.58	1.55	——

Table 28A

Bulk (cc/gm) vs Beating Time

Red Maple Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	1.64	——	1.46	1.32	1.24	1.18
Stem with bark	1.74	——	1.54	1.46	1.36	1.28
Branches	1.56	1.49	1.40	——	——	——
Stump and Roots	1.94	1.80	——	——	——	——
Composite 1	1.80	1.68	1.56	1.45	1.32	——
Composite 2	1.75	1.62	1.54	1.42	1.36	——

Table 29A

Bulk (cc/gm) vs Beating Time

Pin Cherry Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	1.49	——	1.25	1.20	1.18	——
Stem with bark	1.49	——	1.28	1.26	1.18	——
Branches	1.42	1.32	1.28	——	——	——
Stump and Roots	1.67	——	1.47	1.34	1.26	1.21
Composite 1	1.60	——	1.34	1.29	1.20	——
Composite 2	1.48	——	1.32	1.23	1.22	——

Table 30A

Bulk (cc/gm) vs Beating Time

Willow Species

Component of Species	Beating Time (min.) 0	5	10	20	30	40
Stem	1.69	1.60	1.48	1.31		
Stem with bark	1.77	1.62	1.44	1.32		
Branches	1.68	1.56	——	——		
Stump and Roots	1.88	1.72	1.61	1.46		
Composite 1	1.74	1.64	1.58	1.45		
Composite 2	1.78	1.66	1.59	1.38		

Table 31A

C.S. Freeness vs Beating Time

(Composite 2)

Species		Beating Time (min.) 0	5	10	20	30
Standard	Unbleached	586	549	497	366	224
	Bleached	620	594	482	352	220
Aspen	Unbleached	402	344	282	192	—
	Bleached	434	384	340	238	176
Gray Birch	Unbleached	519	437	391	243	143
	Bleached	515	468	412	300	192
Red Maple	Unbleached	444	424	368	266	194
	Bleached	542	497	438	327	240

Table 32A

Bulk (cc/gm) vs Beating Time

(Composite 2)

Species		Beating Time (min.) 0	5	10	20	30
Standard	Unbleached	1.78	1.72	1.59	1.46	1.38
	Bleached	1.79	1.68	1.52	1.38	1.34
Aspen	Unbleached	1.82	1.69	1.66	1.59	1.53
	Bleached	1.59	1.45	1.36	1.26	1.20
Gray Birch	Unbleached	1.73	1.70	1.67	1.49	1.42
	Bleached	1.63	1.38	1.38	1.32	1.26
Red Maple	Unbleached	1.90	1.70	1.60	1.50	1.40
	Bleached	1.90	1.80	1.60	1.50	1.40

Table 33A

Burst Factor vs Beating Time

(Composite 2)

Species		Beating Time (min.) 0	5	10	20	30
Standard	Unbleached	30	41	56	69	83
	Bleached	28	44	64	76	80
Aspen	Unbleached	43	50	56	64	67
	Bleached	45	53	63	69	75
Gray Birch	Unbleached	47	65	77	87	90
	Bleached	49	69	82	92	90
Red Maple	Unbleached	35	42	48	57	64
	Bleached	22	35	43	57	63

Table 34A

Tear Factor vs Beating Time

(Composite 2)

Species		Beating Time (min.) 0	5	10	20	30
Standard	Unbleached	66	87	99	86	85
	Bleached	89	99	101	96	95
Aspen	Unbleached	76	78	71	66	60
	Bleached	77	79	82	80	75
Gray Birch	Unbleached	94	109	107	103	98
	Bleached	113	120	118	113	103
Red Maple	Unbleached	51	57	58	59	54
	Bleached	32	50	53	61	57

Table 35A

Breaking Length (meters) vs Beating Time

(Composite 2)

Species		Beating Time (min.) 0	5	10	20	30
Standard	Unbleached	6560	8150	9650	11,400	12,150
	Bleached	5890	7790	10,340	11,010	11,810
Aspen	Unbleached	9760	10,880	11,300	12,140	11,920
	Bleached	8480	9930	10,680	11,690	11,980
Gray Birch	Unbleached	8380	10,300	11,560	11,670	11,940
	Bleached	7670	10,410	11,850	13,000	13,240
Red Maple	Unbleached	6890	7590	8640	9430	9900
	Bleached	4850	6520	7360	8880	9610