

BARK AND ITS POSSIBLE USES

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Bark Structure

Bark comprises the outer part of woody stems and branches (5,6).² Anatomically it includes all the tissues outside the cambium. Although the term bast is sometimes used as the equivalent of bark, or inner bark, it should more correctly apply only to the lignified fibers that are commonly found in many barks as well as other fibrous materials.

Bark formation is initiated by the cambium, which lays down xylem on the woody side and phloem, the primary bark tissue, on the bark side. Phloem tissue contains phloem parenchyma, bast fibers, companion cells, and the very important sieve cells or sieve tubes. These sieve elements are the main channel for the downward movement of sap and nutrients from the leaves contra to the upward rise of water from the roots in the xylem. This layer of physiologically active tissue adjacent to the cambium is known as the inner bark and is generally relatively thin and light colored. As subsequent layers of phloem are laid down year by year, the outer layers become crushed and compressed, and the sieve elements and similar structures are collapsed. This tissue then ceases to take part in active physiological processes and is transformed into the relatively inert, dark-colored outer bark that comprises the bulk of most tree barks.

The structure of bark is further complicated by the presence of a second cambial layer within the bark, called the phellogen or cork cambium. Periderm, or cork, is produced by this cork cambium and contributes appreciably to the structure of the outer bark. The innermost layer of periderm is normally considered as the boundary between the inner and outer bark. A number of other types of auxiliary tissues are also found in bark.

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²Underlined numbers in parentheses refer to literature cited at the end of this report.

This oversimplified description is given merely to indicate that bark is a highly complex, heterogeneous material composed of a thin, physiologically active inner layer and a complex, relatively inert outer layer, whose main functions are to protect the cambium and prevent loss of water. Some barks, such as spruce, are relatively thin and contain a high proportion of inner bark. Other barks, such as Douglas-fir and redwood, are quite thick and thus contain a very high percentage of outer bark.

Bark Utilization

Centralized debarking of trees, especially pulpwood and sawlogs, has resulted in recent years in the more efficient utilization of wood substance and in the accumulation of huge tonnages of relatively wood-free bark at central industrial locations. Bark comprises about 9 to 15 percent of the log, by volume (table 1) (13), or slightly more by weight on a dry basis. There are roughly 225 pounds of bark per cord, or 1/4 ton for each thousand board feet log scale. Total United States production of bark may be around 20 million tons. Since one of the major costs in processing any natural material is the cost of collection, bark, for which collection costs have already been paid, has become increasingly attractive as a potential raw material.

Bark has a long history of utility ranging from the Indian's birch bark canoes to the tapa cloth of the South Pacific. Cork, fiber, tannins, dyes, gums, resins, latexes, foodstuffs, flavorings, fish and arrow poisons, antibiotics, and medicinals are all bark products. Among some of the varied products obtained from bark might be mentioned the flavoring, cinnamon; the powerful aphrodisiac used by natives, yohimbine; the antimalarial, quinine; the cocktail ingredient, Angostura bitters; and the root beer flavoring, sassafras. The tremendous range of products obtainable from bark is a reflection not only of the complexity of bark itself, but also of the extreme differences between barks of different species. A most interesting utilization of bark is the isolation of chemical extracts with physiological properties. Unfortunately, barks containing this type of extract are largely limited to tropical species--our domestic temperate zone species are disappointingly deficient in this respect.

Fortunately, the tremendous literature on bark utilization has been reviewed and surveyed by a number of people. Two excellent recent bibliographies (11, 14) provide a thorough index to the literature on bark, so that extensive references will not be given here. The most recent information on bark and extractives can be obtained from references published in the Annual Review of Chemical Conversion (Utilization) each February in the Forest Products Journal (15). Among the general reviews, the report of a conference of the

Northeastern Wood Utilization Council (1) might be considered outstanding, while the recent review by Sayward (16) is one of the most up to date. It might also be mentioned that the April 1959 issue of the Forest Products Journal was devoted to bark and had several articles of interest.

Low-Grade Utilization

The complexity of bark and the extreme variation in chemical and physical properties between barks has already been pointed out. Thus, any high-grade utilization scheme will of a necessity require large amounts of clean bark from a single species. Frequently this is not the case--the bark will be obtained as a mixture of species or in amounts insufficient for economical commercial processing to high-grade products. Even when the bark is processed to high-grade products, there will always be a residue. These factors indicate that initial commercial development should concentrate on schemes that can utilize bark independently of its physical and chemical properties.

Initial outlets for bark can well be identical to those of other wood waste. Thus, the bark may be used as a fuel. Recent years have seen the development of improved multiple-fired burners together with heavy-duty presses that are capable of obtaining positive fuel value even from water-soaked bark. The recovered value of the bark is low, but at least some value is being obtained. Ten tons of completely dry bark will, on the average, have a gross heating value equivalent to some 7 tons of coal. Table 2 (7) contains data on ash content and heat of combustion of some barks.

Another outlet is in charcoal. Demand for charcoal for recreational use has increased sharply. Slabs, high in bark content, form an important portion of the raw material for this charcoal. Bark is normally assumed to have a high ash content. This is not necessarily true. Clean bark has an ash content only slightly higher than that of wood. Bark does, however, readily pick up dirt, both windborne while the tree is still standing and during felling and dragging. Nevertheless, a moderately higher ash content is not disadvantageous for charcoal used in the home barbecue. The charcoal from bark is more friable and contains a higher percentage of fines than that from wood. These factors are undesirable in lump charcoal but would be advantageous if bark charcoal were incorporated into briquettes, since grinding costs would be lower than for wood charcoal. Recent equipment innovations should be applicable to the continuous carbonization of suitably ground bark.

Bark can also be pressed into briquettes for use as a fireplace fuel. This is commonly done with other wood wastes, and various kinds of fireplace logs have been marketed throughout the country. Bark has found only limited use in this form because it usually contains excessive amounts of water. When

dried, however, it may be equal and perhaps superior to other wood waste in fireplace logs. Binders and sizing would probably not be needed. Some companies have investigated the possibility of adding various chemicals to produce colored flames. Although the idea appears quite attractive, in practice the cost of mixing in the chemicals, the necessity of keeping the various colors somewhat separated to prevent them from obscuring one another, and the corrosive and other deleterious effects of the chemicals have limited this feature.

Another outlet for bark is in various types of building fiberboards and particle boards, and many publications have dealt with this possibility. Various barks have been incorporated into almost every type of board. The practice has been more prevalent in foreign countries, and opinions on the value of this form of utilization range from highly enthusiastic to mildly skeptical. Particularly significant is the fact that wood chipped for these board materials may not need to be debarked if certain production difficulties can be tolerated. In general, bark has less fiber than wood, so that strength is somewhat lowered. Many softwood barks, however, are relatively rich in resins and waxes, and this can obviate the need for sizing. Indeed, the higher extractive content of bark may also be an aid in binding the particles together. The Oregon Forest Products Research Center has prepared boards from Douglas-fir bark alone, with no sizing or adhesive, merely by pressing the bark under heat and overlaying the resultant sheet with paper or veneer.

Minor amounts of bark can be tolerated in certain types of paper, although in general this is not particularly advantageous. However, bark fibers such as from the inner bark of paper mulberry have been used for many generations for handmade paper.

Use of Bark in the Soil

It is perhaps as a soil conditioner that bark finds one of its most attractive low-grade outlets. Transportation of bark is expensive, however, so that this form of utilization is limited within a 50- to 150-mile radius of the plant. Location near a city opens up the possibilities of preparing a balanced soil conditioner fertilizer or a mulch for the home gardener, as well as preparing a substitute for the nurseryman's peat moss. In general, the nurserymen and farmers have preferred to buy raw bark at the lowest price possible and then alter it themselves as needed. Location near farming areas opens up a large-scale potential market, and in cattle or poultry raising areas the marketing of bark as a bedding should be advantageous.

The fertilizer value of bark is, for all practical purposes, zero. Nevertheless, the benefits that it can confer on poor soils as a soil conditioner are appreciable. This is especially so in sandy or clayey soils, where bark can improve the tilth, structure, and aeration of heavy soils; increase water absorption and penetration; conserve moisture through weed control and reduced evaporation; maintain uniformity of the soil; improve granulation of surface soils; reduce soil erosion; and build up organic matter and humus in soil, with concurrent benefit to the soil microflora.

Although there are some very good publications on the use of bark in the soil (1,4,8,16), there are many more publications on the use of sawdust and other wood wastes in the soil (2,3). Bark should be almost completely analogous to other wood wastes, with only three differences. Bark is darker in color than other wood waste—a positive factor when the bark is used as a mulch, since it is more pleasing to the eye. Bark also decomposes more slowly in the soil—a positive factor, since the nitrogen-depletion factor discussed below is lessened. Finally, bark is richer in extractives. This may be a negative factor, but it has not yet been completely assessed. Treated Douglas-fir bark is, however, quite effective in controlling red stele disease when used as a mulch around strawberries (4). Subsequent comments will apply equally to bark and other wood wastes.

The older literature is filled with reports on the toxic effects of wood waste in the soil. We now know that this is almost entirely due to the nitrogen-depletion problem. Reports of actual toxicity due to extractive chemicals present in wood or bark are extremely rare. When wood waste is added to the soil, it rapidly begins to decompose, especially if the wood waste is finely divided and rich in sapwood. The micro-organisms that decompose this wood waste require nitrogen. Since wood waste has practically no nitrogen or other fertilizer elements, the micro-organisms will rob nitrogen from the growing plants if necessary. This situation is temporary. The nitrogen is not lost, but merely temporarily removed by the micro-organisms. This problem can be met in several different ways--by prior use of the wood waste as a mulch, by prior use of the wood waste as an animal bedding, by addition of mineral nutrients along with the wood waste, or by prior composting of the wood waste, preferably with added nutrients.

Addition of nitrogen and other mineral nutrients along with the wood waste is not too attractive. Excessive amounts of nitrogen are needed, and the system is difficult to control. The other ways of meeting the nitrogen-depletion problem, however, are all excellent. Bark makes a fine mulch. Since it decomposes only slowly on the surface of the ground, there is no nitrogen-depletion problem. For either the home gardener or the nurseryman, bark should be able to compete with peat moss. As an animal bedding, bark should be equivalent to other wood waste, although excessive fines might be

undesirable. After use as a bedding for cattle or poultry, the bark is sufficiently fortified to be used directly in the soil.

Composting appears most attractive. A new journal, Compost Science, includes many articles of interest along this line. The composting can, of course, be accelerated by addition of nitrogen and other mineral nutrients. These can be added either in the form of chemical fertilizers or by adding green materials, brewery waste, sewerage sludge, fish waste, manure, or other nitrogen-containing wastes. Composting with added nutrients has four important advantages. The nitrogen-depletion problem is solved, the product can be marketed as a combined soil conditioner and fertilizer, any possible toxicity is removed in the composting process, and the composting process is greatly accelerated.

Another approach to the nitrogen-depletion problem has involved chemical treatment of the wood waste to render it resistant to decay. Decayed wood consists mainly of a mixture called humus. A closely related material, humin, is produced when wood waste is treated with acid at high temperatures, sometimes with added formaldehyde. This product, however, is strictly a soil conditioner. It still contains no nitrogen or other fertilizer elements.

Still another approach that has been tried is the ammoniation of bark (4). Bark contains many chemical groups that will combine with ammonia. In the soil, some of this ammonia is released to the plants rapidly, and some is released only slowly over a longer period of time. Another scheme is the use of bark fibers in trickling filters for secondary treatment of sewerage effluent.

An interesting related use of bark is as an orchid rooting medium. Several companies are marketing bark for this purpose. Bark should also be a suitable growing medium for mushrooms, and ground bark is finding some use for covering school playgrounds.

Physical Upgrading of Bark

As already mentioned, bark is a highly heterogeneous material that varies widely from species to species. In order to isolate physical fractions of

value from bark, it is probably necessary to start with a single species. Then, by various treatments such as grinding, milling, chemical treatment, screening, water flotation, and even firing from a fiber-exploding gun, various physical fractions can be obtained that usually correspond to different cell types present in the bark. Both redwood and Douglas-fir are now processed industrially in this manner.

One of the most valuable fractions is the cork. The Mediterranean cork oak is our main commercial source of cork, and its bark consists almost entirely of cork. Most barks contain cork, which, although not so predominant as in cork oak, nevertheless can often be separated as discrete particles. Cork granules are commercially produced at present by physically fractionating Douglas-fir bark. Formerly, a large outlet for these cork granules was in bottle caps. Although this market has largely been lost to synthetic materials, the preparation of cork composition floor tiles looks quite attractive. The Oregon Forest Products Research Center has carried out some promising research in this direction.

Another fraction commonly produced is fibrous. These fibers may be either short, tough, brittle, needlelike bast fibers, such as are obtained from Douglas-fir, or longer, more flexible fibers, as in redwood or cedar. These fibers find outlets in pulp, building fiberboards, filters, as a sealant in oil well preparations, and as a reinforcing filler in ceramics, concrete, molded products, and the like. The use of the highly fibrous redwood bark in insulation, as a furniture stuffing, and even in combination with wool for felt hats is well known.

A final fraction that will almost always be produced in the physical upgrading of bark is an amorphous powder. Douglas-fir bark dust and redwood dust are commercial sources of such fractions which have found use in phenolic molding compounds; as an adhesive extender; as an anticaking agent for, among other things, insecticides and fertilizers; as an extender in flooring, thermoplastic resins, and rubber products; and even as an ingredient in foundry sands. Douglas-fir bark powder can be used alone as a thermosetting, water-resistant adhesive for plywood, since it flows under heat and pressure, but more commonly it is used as an extender in phenolic-resin glues. Since the bark powder actually undergoes chemical reaction during hot pressing, it is more than an inert filler.

The use to which any one physical fraction from bark can be put depends on the exact chemical and physical properties of the fraction. The bark of each species is different, and a utilization scheme must be developed individually for each particular bark. Greatest promise is shown, however, by those barks which are particularly rich in cork or fiber. Incidentally, physical fractionation of bark is usually accompanied by chemical fractionation, so

that specific physical fractions are often far superior to whole bark for further chemical fractionation.

Chemical Upgrading of Bark

Barks generally are much richer in both quantity and complexity of extrac-tives than the corresponding woods. A large number of pure organic chemi-cals can be isolated from barks, among which are flavanoids, alkaloids, carbohydrates, inositols, terpenoids, glycosides, saponins, esters, steroids, fats, lignans, and complex phenols. Various chemical fractions, such as tannins, waxes, balsams, essential oils, gums, mucilages, resins, latexes, and dyestuffs, which may or may not consist of a relatively pure chemical entity, also are often isolated.

In general, the isolation of pure organic chemicals from bark is economical only if other chemical and physical fractions of value are isolated at the same time. Factors such as plant size, ability of the market to absorb the products at a profitable price, competition from other chemicals, and main-tenance of a proper balance between products need careful evaluation. Although many pure chemicals could be isolated from domestic tree barks, to date no pure organic compound has yet achieved a profitable large-volume market in this country. Quercetin, a flavanoid made from the dihydro-quercetin in Douglas-fir bark, comes closest to this ideal and can be used in pharmacology, in dyestuffs, as an antioxidant, as an ultraviolet screen in sunburn creams, and as a chemical intermediate.

Crude fractions, on the other hand, have definitely found a market. The largest of these are the tannins, which are generally condensed (polymerized) polyphenols. Tanoak, oak, chestnut, mangrove, hemlock, eucalyptus, red-wood, sumac, spruce, Douglas-fir, and even pine barks have all been pro-cessed for tannin. Even though some of these domestic tannins are satis-factory for tanning leather, wattle bark and quebracho wood, both imported, are the main source of natural tannins today. Significant in their ability to capture the main market for leather tanning are their availability in large quantities at a low price and uniform and reproducible high quality.

Bark tannins, such as from western hemlock, redwood, and Douglas-fir, find a large market in other outlets, however. One of these is in oil well drilling muds; large quantities are used to thin the muds. They act as a deflocculent and control the viscosity and gel strength of drilling muds. Some 50,000 tons of mud thinners are used yearly. This field has recently been reviewed (12).

Another major outlet for bark tannins is in adhesives, particularly for plywood and particle board. Noteworthy is the development of a cold-setting, waterproof adhesive from western hemlock bark (10). Since the cost is much less than that for resorcinol-formaldehyde glues, this type of use appears particularly attractive. Both of these major uses for tannins have been the subject of many recent publications, and a large number of patents have been granted. Of significance is the fact that these polyphenolic fractions can be extracted from bark in an especially high yield with alkaline reagents, sometimes containing pulping additives. Tree barks are remarkably soluble in alkali; often over 50 percent of the bark will go into solution. By varying the extraction conditions as well as the purification and treating steps, a wide variety of different polyphenolic products can be prepared to fit almost any specification. Work in this field has been greatly helped by research into the chemistry of these complicated extracts (9).

Other uses for these polyphenolic extracts are as a dispersant, binder, deflocculent in ceramic clays, antioxidant, sequestering agent in boiler feed water, flotation agent in ore beneficiation, and stabilizer in asphalt emulsions as well as in the vat dyeing of nylon and the desulfurization of gasoline.

Waxes are another field of interest. Carnauba wax and beeswax are now largely imported. The corky fraction of many softwood barks is, however, rich in wax. Refined and chemically processed waxes from Douglas-fir bark may be superior to the waxes presently in use, and could lead to a multi-million pound market for this material. A comprehensive market survey on the wax extracted with nonpolar solvents from Douglas-fir bark has been made, but no commercial production along these lines has been initiated. Wax polishes and carbon paper are two attractive commercial possibilities.

Although the literature is full of publications on bark chemistry, very little is really known about the subject. For the majority of bark species, not one single pure chemical compound has been isolated, and for many species nothing has been reported on the chemistry. It is therefore no wonder that the chemical utilization of bark is at a relatively primitive stage. Tables 3 to 6 (7) contain general information on the extractives, carbohydrates, and lignin of a series of pulpwood barks.

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Table 1.--Bark volume

Wood	Diameter of tree	Number of growth rings	Bark volume based on wet log volume
	<u>Inches</u>		<u>Percent</u>
Spruce	4.2	62	12.06
	8.7	112	9.26
Fir (true)	4.5	38	10.0
	8.4	65	9.4
Birch, white	3.9	46	14.5
	8.3	68	9.5
Birch, yellow	4.2	74	10.1
	9.3	92	9.3
Beech	4.2	63	6.9
	8.9	125	6.1
Maple, sugar	4.1	67	13.5
	7.8	114	18.0

Table 2.--Heat of combustion of barks

Species	Ash ¹	Moisture	Calories per	British thermal units
		content	gram ²	per pound ²
	Percent	Percent		
Fir, balsam	2.3	6.5	4,923	8,861
Larch, western	1.6	6.7	4,558	8,204
Spruce, Engelmann	2.5	5.5	4,644	8,359
Spruce, black	2.0	6.5	4,581	8,246
Pine, jack	1.7	6.6	4,867	8,761
Pine, lodgepole ³	2.0	5.6	5,661	10,190
Pine, slash	.6	6.4	5,001	9,002
Pine, sugar	.6			
Hemlock, eastern	1.6	6.2	4,890	8,802
Boxelder	6.2			
Maple, sugar	6.3	6.0	4,056	7,301
Alder, red	3.1	5.8	4,415	7,947
Birch, yellow	1.7	5.2	5,042	9,076
Birch, paper	1.5	4.8	5,241	9,434
Pecan	7.5			
Sweetgum	5.7	6.2	4,139	7,450
Blackgum	7.2	6.0	4,409	7,936
Sycamore, American	5.8	6.4	4,113	7,403
Cottonwood, swamp	4.0			
Aspen, quaking	2.8	5.5	4,685	8,433
Oak, white ⁴	10.7	6.5	3,886	6,995
Oak, red	5.4	4.4	4,461	8,030
Willow, black	6.0	6.7	3,982	7,168
Elm, American	9.5	6.7	3,845	6,921

¹Based on weight of oven-dry wood.

²Values are for samples of the indicated moisture content.

³High heat of combustion probably due to high content of benzene extractives.

⁴Low heat of combustion probably due to high ash content.

Table 3.--Various extractions of barks (Percentages
based on weight of oven-dry unextracted
bark)

Species	Material dissolved by successive extractions with--					
	Material soluble in 1 percent sodium ¹ hydroxide	Benzene	95 percent alcohol	Hot water	1 percent sodium hydroxide	
	Percent	Percent	Percent	Percent	Percent	
Fir, balsam	49.4	13.2	3.3	2.7	30.6	
Larch, western ²	43.6	1.3	14.8	3.8	22.7	
Spruce, Engelmann ²	64.0	5.2	25.9	10.9	22.2	
Spruce, black	51.6	5.0	14.6	4.4	28.0	
Pine, jack	62.6	8.0	12.4	3.0	41.3	
Pine, lodgepole	72.9	28.7	10.9	5.6	29.8	
Pine, slash	48.5	3.4	10.6	3.7	28.9	
Pine, sugar ²	62.7	1.5	21.7	3.2	36.0	
Hemlock, eastern ²	51.7	2.8	21.2	3.3	24.6	
Boxelder	39.7	2.4	6.3	6.2	23.7	
Maple, sugar	28.3	1.2	3.9	2.4	19.2	
Alder, red	37.8	2.3	3.9	3.7	27.5	
Birch, yellow	46.9	4.3	10.8	2.3	28.4	
Birch, paper	42.9	9.4	10.5	2.5	25.1	
Pecan	50.9	.8	18.4	5.4	25.3	
Sweetgum	48.3	1.5	17.7	7.4	21.3	
Blackgum	39.4	2.5	4.6	5.3	27.8	
Sycamore, American	33.4	2.1	6.0	3.6	22.0	
Cottonwood, swamp	35.0	1.9	8.0	4.8	20.2	
Aspen, quaking	41.8	4.0	11.6	4.7	22.0	
Oak, white	38.2	2.7	4.4	5.8	26.5	
Oak, northern red	39.8	4.8	7.9	3.6	22.3	
Willow, black	35.3	1.6	3.8	4.8	23.8	
Elm, American	45.2	.5	10.1	6.0	27.0	

¹An appreciable percentage of this extract was reprecipitated on acidification.

²Barks with highest tannin content.

Table 4.--Reducing sugars produced by hydrolysis of bark with 72 percent sulfuric acid
(Percentage, as glucose, based on weight of oven-dry, unextracted bark)

Species	Reducing sugars from--		
	Unextracted	Extractive-	Alkali-
	bark	free bark	extracted bark ¹
	Percent	Percent	Percent
Fir, balsam	46.6	45.3	32.9
Larch, western	46.6	46.0	38.0
Spruce, Engelmann	42.9	34.3	24.2
Spruce, black	47.9	44.8	32.3
Pine, jack	30.6	28.8	21.1
Pine, lodgepole	38.3	32.9	19.2
Pine, slash	29.7	29.8	26.4
Pine, sugar	22.1	19.8	16.1
Hemlock, eastern	34.9	33.3	29.1
Boxelder	40.6	37.8	30.0
Maple, sugar	35.4	34.3	31.1
Alder, red	38.6	38.0	30.3
Birch, yellow	32.5	31.8	26.0
Birch, paper	32.2	30.1	21.8
Pecan	33.5	30.7	23.3
Sweetgum	35.6	33.5	26.4
Blackgum	29.6	27.2	22.4
Sycamore, American	40.9	39.0	31.1
Cottonwood, swamp	41.0	39.2	34.1
Aspen, quaking	41.4	39.7	34.9
Oak, white	27.8	28.2	21.2
Oak, northern red	32.4	31.7	28.3
Willow, black	42.9	43.4	35.4
Elm, American	37.0	35.4	27.0

¹—Extractive-free bark extracted with 1 percent sodium hydroxide.

Table 5.--Composition of reducing sugars from hydrolysis
with 72 percent sulfuric acid (Percentages
based on total reducing sugar)

Species	Glucose	Galactose	Mannose	Arabinose	Xylose
	Percent	Percent	Percent	Percent	Percent

EXTRACTIVE-FREE BARKS

Fir, balsam	64	5	12	9	7
Larch, western	69	4	11	6	9
Spruce, Engelmann	61	5	9	13	9
Spruce, black	64	6	7	11	9
Pine, jack	64	7	6	10	11
Pine, lodgepole	50	7	6	26	8
Pine, slash	63	7	7	7	15
Pine, sugar	69	6	8	7	9
Hemlock, eastern	67	3	13	8	7
Boxelder	65	3	2	7	20
Maple, sugar	63	3	1	6	25
Alder, red	54	3	1	6	34
Birch, yellow	54	3	1	8	32
Birch, paper	53	2	1	6	36
Pecan	69	4	1	11	11
Sweetgum	60	3	3	11	20
Blackgum	60	4	1	8	24
Sycamore, American	59	4	1	4	30
Cottonwood, swamp	61	4	1	5	26
Aspen, quaking	60	2	1	5	30
Oak, white	60	4	2	7	24
Oak, northern red	53	3	1	6	35
Willow, black	69	3	1	6	18
Elm, American	70	4	2	9	11

ALKALI-INSOLUBLE BARK RESIDUES¹

Larch, western	74	4	9	4	9
Pine, slash	67	6	7	5	15
Hemlock, eastern	76	2	10	5	7
Maple, sugar	69	2	1	4	24
Birch, paper	55	2	1	5	37
Sweetgum	71	2	1	5	21

¹Residues from the 1 percent sodium hydroxide extraction of extractive-free bark.

Table 6.--"Lignin"¹ and methoxyl of "lignin" and of bark

Species	"Lignin" from extractive-free bark:		"Lignin" from alkali-extracted bark		Methoxyl in unextracted bark
	Yield ²	Methoxyl ³	Yield ²	Methoxyl ³	
	Percent	Percent	Percent	Percent	Percent
Fir, balsam	27.7	8.5	15.0	12.7	3.30
Larch, western	30.0	8.9	19.6	10.7	3.14
Spruce, Engelmann	17.9	7.2	8.7	9.7	2.90
Spruce, black	25.3	8.2	14.4	10.0	3.20
Pine, jack	42.2	4.7	14.4	10.1	3.07
Pine, lodgepole	14.8	5.1	5.4	8.1	1.99
Pine, slash	49.9	6.3	26.1	10.2	3.95
Pine, sugar	49.9	3.9	20.1	8.2	2.45
Hemlock, eastern	35.8	8.0	20.1	10.5	3.61
Boxelder	30.1	11.1	22.8	12.4	4.03
Maple, sugar	37.3	11.2	27.4	11.9	5.05
Alder, red	40.9	7.9	28.5	9.2	3.85
Birch, yellow	40.6	7.6	26.3	9.2	3.46
Birch, paper	37.8	8.4	22.7	12.1	4.04
Pecan	24.9	7.5	16.0	9.5	2.69
Sweetgum	25.3	10.7	18.7	12.9	3.37
Blackgum	38.3	10.3	25.0	12.5	4.97
Sycamore, American	26.6	15.0	21.3	16.8	5.53
Cottonwood, swamp	33.4	12.0	27.2	13.7	5.36
Aspen, quaking	31.2	10.3	21.0	13.6	4.75
Oak, white	31.8	7.3	20.9	9.3	3.28
Oak, northern red	34.8	9.1	23.3	11.3	4.32
Willow, black	29.0	9.2	20.9	12.0	3.74
Elm, American	27.5	6.9	16.9	9.7	2.91

¹The acid-insoluble residue from bark by the 72 percent sulfuric acid method. This fraction should consist of bark lignin plus insoluble corky substances. Ash was not determined in "lignin" residue.

²Yield based on oven-dry, unextracted bark.

³Yield based on weight of the corresponding oven-dry "lignin" residue.