CHEMISTRY OF WOOD
V. The Results of Analysis of Some American Woods

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V. The Results of Analysis of Some American Woods[1]

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American forests are rapidly becoming depleted of certain species of woods. The industries using these particular species are turning with increased interest to the use of other woods with similar physical and chemical properties. Where such similar essential characteristics occur in two or more woods, it is possible in many cases to substitute one for the other. In considering different woods for the same use, certain properties might be classified as primary and others as secondary. If the primary properties are satisfactory, and the secondary are not, it may be possible by various treatments to render the woods suitable for the required purpose. This is strikingly illustrated in the paper industry in which some woods are given the soda treatment, some the sulphate treatment, and still others the sulphite process treatment in order to obtain pulp for paper.

If data were available on the chemical composition of more of the important American woods, it is believed that the wood-using industries could in some cases use woods in new processes, and in other instances utilize woods now considered of little value. With this in mind further work was done at the Forest Products Laboratory on the study of the chemical composition of some American woods, a project which was begun by A. W. Schorger[2] and continued by S. A. Mahood and D. E. Cable.[3]

Experimental

In selecting the woods for this comparative analysis an attempt was made to take some of the more useful woods which would at the same time confirm or disapprove the general belief (1) that there is a relation between the density and the ligno-cellulose content of wood, and (2) that there is a relation between the susceptibility to decay and the cellulose

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[1] Published in Jour. Indus. & Eng. Chem., Nov. 1922.

[2] Ibid., Vol. 9, No. 6, 1917.

[3] Ibid., Vol. 12, No. 9, 1920; Vol. 14, 1922.

content of different species. With these two seemingly possible conditions in mind, woods with extremely high densities, such as hickory, others with extremely low densities, such as balsa, and some with intermediate specific gravity were selected. These woods are as follows:

Species	Where obtained
Ponderosa pine (Pinus ponderosa)	Coconino County, Arizona
Yellow cedar (Chamaecyparis nootkatensis)	Sinohomish County, Washington
Incense cedar (Libocedrus decurrens)	Fresno County, California
Tanbark oak (Quercus densiflora)	Trinity County, California
Redwood (heartwood) (Sequoia sempervirens)	Shipment from Pacific Lumber Co., California
Mesquite (Prosopis juliflora)	Shipment from Board of Commissioners of Agriculture and Forestry, Div. of Forestry, Honolulu, Hawaii
Balsa (Ochroma lagopus)	Shipment from American Balsa Co., New York
Shellbark hickory (Hicoria ovata)	Harrisonburg County, Virginia

The results obtained from the analysis of the eight woods are given in Table 1. In the analytical work, which followed the methods described by the former investigators, all samples except incense cedar and mesquite were run in duplicate. The results tabulated are the average of the two determinations. The data relative to redwood are not exactly comparable with the results obtained on the other species shown in Table 1, as the sapwood showed decay, and the heartwood only could be analyzed.

Discussion of Results

Ash Content

The ash in the hardwoods runs considerably higher than in the conifers. Balsa, which weighs about 7 pounds per cubic foot, has an unusually high ash content as compared with the other species listed in the table. Estimated on a ton basis, balsa would be a good source for potash, provided its ash is high in potassium. Measured on a cord basis, however, the yield of potash is lower than in other hardwoods.

Table 1 - Analysis of woods

Results in percentage of oven-dry (105°C) samples).

Species	Sample	Moisture	Ash	Solubility in: Cold water	Solubility in: Hot water	Solubility in: 1% NaOH	Solubility in: Ether	Acetic acid	Methoxy	Pentosan	Methyl pentosan	Cellulose	Lignin	In cellulose: Pentosan	In cellulose: Methyl pentosan	In cellulose: Alpha cellulose	In cellulose: Beta cellulose	In cellulose: Gamma cellulose
Western yellow pine (Pinus ponderosa)	141	5.32	0.43	5.58	5.67	9.63	22.08	0.92	4.55	8.06	1.68	56.22	26.75	9.50	2.13	69.18	----	30.82
	142	8.28	0.42	2.97	3.40	6.52	16.58	1.24	4.02	9.96	1.24	57.72	25.85	8.97	1.97	66.17	5.52	28.31
	143	6.89	0.55	4.62	6.33	9.45	23.16	1.03	4.51	5.88	1.81	58.89	26.29	4.20	1.90	57.65	6.54	35.80
	144	5.19	0.44	3.17	4.89	6.48	19.37	1.18	4.87	5.52	1.77	56.82	27.72	4.63	1.90	55.40	19.02	25.58
	Mean	6.42	0.46	4.09	5.05	8.52	20.30	1.09	4.49	7.36	1.62	57.41	26.65	6.82	1.98	62.10	10.86	30.13
Yellow cedar (Chamaecyparis nootkatensis)	161	3.54	0.33	1.66	2.89	2.67	13.80	1.66	5.42	8.86	3.97	51.45	33.21	8.60	2.03	62.88	11.10	26.02
	162	5.19	0.35	3.03	3.46	3.34	14.49	1.62	5.60	8.52	3.57	54.04	31.27	8.09	1.91	62.96	10.99	26.05
	163	4.87	0.62	2.47	2.86	2.08	12.69	1.55	5.05	6.72	2.97	54.78	30.43	6.65	1.65	59.37	11.64	28.97
	164	5.91		2.74	3.23	2.11	12.67	1.54	4.92	7.37	3.17	55.17	30.27	5.86	1.54	65.52	10.51	23.97
	Mean	4.89	0.43	2.47	3.11	2.55	13.41	1.59	5.25	7.87	3.42	53.86	31.32	7.30	1.78	62.68	11.06	26.25
Incense cedar (Libocedrus decurrens)	165	5.32	0.38	3.09	4.87	3.33	17.37	0.96	6.34	11.07	1.20	39.94	38.14	9.53	2.13	48.47	15.42	36.11
	166	4.63	0.27	2.53	3.62	4.69	13.81	1.04	6.29	9.99	1.60	44.10	37.73	7.90	1.71	41.42	12.77	45.81
	167	5.42	0.38	5.31	7.64	4.30	21.89	0.73	6.09	10.70	1.26	40.76	37.17	9.83	2.13	50.90	6.82	42.28
	Mean	5.12	0.34	3.64	5.38	4.31	17.69	0.91	6.24	10.65	1.35	41.60	37.68	9.08	1.99	46.92	11.67	41.06
Redwood (Heartwood) (Sequoia sempervirens)	168	9.64	0.22	7.31	9.77	1.00	20.06	1.03	5.27	7.93	2.77	48.67	34.18	7.40	2.09	78.81	2.95	18.24
	169	9.71	0.20	7.40	9.94	1.14	19.94	1.13	5.16	7.67	2.74	48.83	34.25	----	----	----	----	----
	Mean	9.68	0.21	7.36	9.86	1.07	20.00	1.08	5.21	7.80	2.75	48.45	34.21	7.40	2.09	78.81	2.95	18.24
Tanbark oak (Quercus densiflora)	151	4.10	0.78	4.14	5.25	0.74	22.59	5.70	5.34	20.02	----	59.46	23.29	25.22	----	56.50	18.81[a]	25.64
	152	3.95	0.81	4.32	6.15	0.73	25.30	5.70	6.19	20.00	----	56.50	20.07	25.46	---	56.91	2.95	41.14
	153	3.26	0.82	4.22	5.92	0.80	23.91	4.40	5.35	19.13	----	57.27	25.20	30.30	---	58.15	22.62[a]	19.23
	154	3.36	0.91	3.72	5.08	0.98	22.93	5.13	6.09	19.22	----	58.95	24.86	22.32	---	57.82	18.27[a]	24.21
	Mean	3.66	0.83	4.10	5.60	0.80	23.96	5.23	5.74	19.59	----	58.03	24.85	22.82	---	56.77	19.92	23.03
Mesquite (Prosopis juliflora)	171	4.53	0.57	12.55	15.27	2.20	28.72	1.52	5.68	14.04	0.59	44.79	30.27	17.99	1.07	76.00	1.73	22.27
	172	6.10	0.58	13.50	15.77	---	30.09	1.70	5.69	13.99	0.69	45.25	30.13	17.99	1.21	76.71	2.56	20.73
	173	6.15	0.49	12.68	15.56	2.33	29.60	2.53	5.29	13.85	1.18	45.87	31.28	17.57	----	76.40	3.06	21.54
	174	5.20	0.50	11.74	13.77	2.37	25.69	2.37	5.66	13.95	0.34	45.97	30.22	17.44	0.96	76.83	3.04	20.13
	Mean	5.49	0.54	12.62	15.09	2.30	28.52	2.03	5.55	13.96	0.70	45.48	30.47	17.75	0.31	76.48	2.35	21.17
Balsa (Cohrona lagopus)	175	6.50	2.15	1.85	2.84	1.27	20.37	5.75	5.71	17.51	0.88	54.04	26.52	19.99	1.35	75.64	0.27	24.08
	176	6.44	2.09	1.68	2.74	1.19	20.36	5.85	5.65	17.79	0.83	54.24	26.47	---	---	---	---	---
	Mean	6.47	2.12	1.77	2.79	1.23	20.37	5.80	5.69	17.65	0.86	54.15	26.50	19.99	1.35	75.64	0.27	24.08
Hickory (Shellbark) (Hicoria ovata)	177	9.60	0.65	4.71	5.41	0.65	18.65	2.60	5.61	18.58	0.92	55.60	23.83	21.33	1.64	75.27	2.64	22.09
	178	7.39	0.74	4.86	5.73	0.62	19.44	2.42	5.65	19.46	0.87	56.85	23.04	22.45	1.19	77.38	3.01	18.61
	Mean	8.49	0.69	4.78	5.57	0.63	19.04	2.51	5.63	19.02	0.90	56.22	23.44	21.89	1.41	76.32	2.82	20.35

[a] Trouble filtering

ZM1540F

Cold-Water Soluble Content

The outstanding features of the cold-water solubility determinations are shown in connection with mesquite and balsa. The former has an exceptionally high cold-water soluble content, due to the mesquite gum. The latter has a low cold-water soluble content because it contains very little tannin or gum. The redwood runs fairly high in water soluble material, undoubtedly because of the large amount of tannin.

Hot-Water Soluble Content

The hot-water soluble content is from approximately 1 to 2.5 percent higher than the cold-water soluble content. The products dissolved by water are principally tannins and carbohydrates.

Ether Soluble Content

The general idea prevails that the ether soluble content is higher in conifers than in the hardwoods. Exceptions, however, are redwood among the conifers and mesquite and balsa among the hardwoods. As would be expected, ponderosa pine has the highest ether extract in this series of woods.

One Percent NaOH Soluble Content

The alkali soluble extract consists primarily of tannins, resin acids, and carbohydrates with slight traces of cellulose and lignin. The alkali soluble material in ponderosa pine and redwood averages above that of the other conifers. This is due to the high resin content of the former and the large percentage of tannin of the latter. Tanbark oak and mesquite among the hardwoods show a high percentage of alkali soluble material.

Methoxy Content

It will be noted that on the average the softwoods run slightly lower in methoxy content than the hardwoods. The one exception is incense cedar, which, on account of its exceedingly high methoxy content, might be expected to compare favorably with hardwoods for the production of methyl alcohol by destructive distillation. It has been found, however, that the conifers as a rule produce scarcely 30 percent as much methyl alcohol as the hardwoods, even though their methoxy content is about 85 percent of that in the broad-leaved species. Consequently, a very poor yield of methyl alcohol from incense cedar is not surprising. The above chemical constants are discussed more fully in connection with acetic acid content, as shown in Table 2.

Table 2.--Percentages of acetic acid, methoxy, and methyl alcohol in various woods

Species	Acetic acid		Methoxy and methyl alcohol	
	Acid hydrolysis	Destructive distillation	Zeisel method for methoxy	Destructive distillation for methyl alcohol
Birch	4.30	6.80 [1]	6.07	1.54 [1]
Maple	4.46	5.26 [1]	7.25	1.76 [1]
Tanbark oak	5.23	6.89 [1]	5.74	1.72 [1]
Hickory	2.51	5.05 [2]	5.63	2.08 [2]
Redwood	1.08		5.21	
Incense cedar	.91		6.24	

[1] U. S. Dept. of Agr. Bulletin 508.

[2] U. S. Dept. of Agr. Bulletin 129.

A higher yield of acetic acid is obtained in all cases by destructive distillation than by acid hydrolysis. The reverse is true in regard to methoxy and methyl alcohol.

Pentosan Content

As in acetic acid content, there is also a marked difference in the percentage of pentosans, presumably xylan and araban, in the softwoods and hardwoods. The analyses of the eight species examined show that the pentosan content of coniferous woods is about 50 percent of that found in broad-leaved species. The average for the former is 8.4 percent, for the latter 17.5 percent.

Methyl Pentosan Content

The percentage of methyl pentosans is considerably higher in softwoods than in hardwoods. Tanbark oak is the only one of all the species which contains no methyl pentosans. The quantity of pentosans and methyl pentosans obtained confirm the conclusions of Schorger[2] and of Mahood and Cable.[2]

Cellulose Content

No marked difference in the cellulose content of hardwoods and softwoods appears to exist in the eight species analyzed. Of the hardwood

mesquite is low in cellulose and of the softwoods, incense cedar and redwood have a low percentage of cellulose when compared with ponderosa pine and yellow cedar. Cellulose was prepared according to the directions outlined in the Journal of Industrial & Engineering Chemistry, Vol. 9, 1917, p. 556, and is the residue left after the alternate chlorination and sodium sulphite extraction had been carried out until the sodium sulphite filtrate remained colorless.

That the cellulose thus obtained differs in individual species is apparent from the pentosan content of the cellulose from the various woods.

Calculated on the oven-dry weight of the wood, the cellulose isolated from the softwoods is from 4.5 to 5.0 percent higher than the pentosan free cellulose; in the hardwoods it is from 8.5 to 13.3 percent higher. This is considering the pentosans and methyl pentosans collectively. If it were possible to extract the pentosans and nothing more from cellulose of various woods obtained by the Cross and Bevan method, one might argue that the residual material should be the same. How such a separation can be accomplished cannot be answered by consulting our present methods of analysis. Even if a clean-cut separation of the pentosans from the rest of the cellulose were made, the remaining residues from the various woods seem to differ in some respects. This can be illustrated by using some of the data in Table 1 to obtain a different relationship as shown in Table 3. Column 2 shows the percent of pentosans which resist the treatment for determining cellulose. The hardwood cellulose contains a much higher percent of pentosans than the softwood cellulose. It was thought that a complete extraction of these bodies from the cellulose could be accomplished by using 17.5 percent NaOH as is done in separating alpha from beta and gamma cellulose. If the figures in column 4 are subtracted from the corresponding numbers in column 1, the values of beta and gamma cellulose in the various woods are obtained. In other words, the results in column 5 represent the percent of material extracted from cellulose with 17.5 percent NaOH. Now, if the pentosans exist as such in the cellulose, one would expect a complete extraction of such bodies with 17.5 percent NaOH, especially when it is noted that a large amount of hexosans is also dissolved with the treatment. In column 6 is found the percent of hexosans extracted over and above the percent of pentosans present. On this basis, the percents of hexosans dissolved in the first four woods agree favorably. In the tanbark oak also the amount of hexosans extracted is high. In the remaining five species the percent of extract in excess of the pentosans present is low compared with the species mentioned above.

To determine whether all the pentosans are removed from the remaining cellulose by a 17.5 percent NaOH treatment, samples of alpha cellulose of ponderosa pine, western white pine, tanbark oak, mesquite, balsa and some purified cotton cellulose were subjected to the regular pentosan determination. The results given in column 7 were obtained. Calculating these results on the oven-dry basis of the original wood as indicated in column 8, and comparing these figures with the

Table 3.--Distribution of pentosans

Results in percentages of oven-dry weight of wood

Species	Cellulose in wood	Cellulose pentosans in wood	Pentosan free cellulose in wood	Alpha cellulose in wood	Beta + gamma cellulose in wood	Hexosans in beta + gamma cellulose	Pentosans in alpha cellulose	Alpha cellulose pentosans in wood	Cellulose pentosans retained in alpha cellulose
Ponderosa pine	57.41	5.06	52.35	35.65	21.76	16.70	1.82	0.65	12.8
Western white pine	59.71	4.34	55.37	38.57	21.14	16.80	2.05	.79	18.2
Yellow cedar	53.86	4.89	48.97	33.76	20.10	15.21			
Incense cedar	41.60	4.60	37.00	19.52	22.08	17.48			
Redwood	48.45	4.60	43.85	38.10	10.35	5.75			
Tanbark oak	58.03	13.24	44.79	32.94	25.09	11.85	9.51	3.13	23.6
Eucalyptus	57.62	13.49	44.13	39.66	17.96	4.47			
Mesquite	45.48	8.48	37.00	35.61	9.87	1.39	3.48	1.24	14.6
Balsa	54.15	11.56	42.59	40.96	13.19	1.63	2.63	1.07	9.2
Hickory	56.22	13.10	43.12	42.92	13.30	.20			
Cotton (purified cellulose) percent pentosan found								1.03	

corresponding ones in column 2, one may see that a considerable part of the pentosans found in the original wood is still retained in the alpha cellulose. This is shown on a percentage basis in column 9 of Table 3. From these figures it is apparent that the alpha cellulose isolated from the various sources is not the same chemically as is claimed by some investigators who have worked with too limited a number of samples.

It is realized that some will argue that the furfural found by distilling the alpha cellulose with 12 percent HCL might have been due to a breaking down of some hexoses formed by hydrolysis. It is claimed[4] that such sugars produce small amounts of furfural under the above conditions. According to the above reference, the percent of furfural available from such a source is considerably lower than the figures of this table show.

Another source of furfural may be oxycellulose.[5] It is possible that some of this form of cellulose may be present when preparing the material according to the Cross and Bevan method. If the furfural found when working with alpha cellulose in this research came from oxycellulose, then it should be possible to hydrolyze the alpha cellulose to a hexose quantitatively. If, however, the furfural came from pentosans present in the alpha cellulose, then it should be possible to identify some pentose derivatives after hydrolyzing the alpha cellulose with acid. This work will be done later.

From the data presented in this paper it appears as though the celluloses prepared from the different sources are not identical. It is, perhaps, possible to reduce two or more of them to the same stable nucleus by alternate alkali and acid treatments. Whether this should be done or not depends upon just how cellulose should be defined. To the writer it seems that such a reduction is carrying the treatment to an extreme. By such a process it is possible to reduce two or more definite individual compounds to the same nucleus. For instance, benzoic acid and phthalic acid on treatment with lime produce benzene. Methyl benzene and ethyl benzene on oxidation give benzoic acid. In like manner it might be possible to change two or more definite kinds of cellulose to the same stable complex. The pentosans which withstand the vigorous treatment to which they are subjected in the Cross and Bevan process must without a doubt be closely bound with the cellulose molecule if not really incorporated in it. If one refers to the work of Johnsen and Hovey[6] in which they discuss the relative merits of the original and modified methods of Cross and Bevan for preparing cellulose, he will see that their work confirms what has been found by the writer. On page 44 of their report is found the following data:

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[4] Browne, Handbook of Sugar Analysis, p. 453.

[5] Browne, Handbook of Sugar Analysis, p. 376.

[6] Paper, Vol. 21, No. 23 (1917-18), p. 36.

Table 4.--Comparison of cellulose obtained in Cross and Bevan's original and modified methods

Species	Cellulose percent		Furfural in cellulose percent	
	Original method	Modified method	Original method	Modified method
Balsam fir	54.45	51.50	5.43	4.39
Aspen	60.95	57.25	11.88	10.16

By recalculation and rearrangement of this data, the following results are obtained:

Table 5.--Furfural and pentosans of original wood in the cellulose prepared by the two methods of Cross and Bevan. Percentages are based on weight of the original wood.

Species	Original method	Modified method	Loss in cellulose	Loss in furfural	Loss in pentosans	Loss in hexosans
Balsam fir	54.45	51.50	2.95	0.63	0.98	1.97
Aspen	60.95	57.25	3.70	1.43	2.23	1.47

If the furfural in column 4 comes from pentosans, then the figures in column 5 indicate the amount of pentosans extracted. By subtracting the data in column 5 from the corresponding items in column 3, the substances other than pentosans (hexosans) are indicated. In each case there is a considerable amount of such substances removed from the cellulose. Until a uniform method of isolating cellulose is decided upon, the material which different investigators prepare from the same source will undoubtedly have varying characteristics, when subjected to chemical tests. If such a complex substance as cellulose prepared by a uniform method from different sources is not identical, there ought not be any cause for concern, for it might be possible that more than one kind of the substance does exist.

Lignin Content

There is no marked distinction in the lignin content of hardwoods and softwoods. If ponderosa pine and mesquite are eliminated from the eight species analyzed it then appears as though, on the average, that the softwoods have a higher lignin content than the hardwoods. However, a larger number of species must be analyzed before a definite conclusion can be drawn.

Contrary to some experimental data, it is quite generally accepted that the methoxy group is entirely associated with the lignin. If this were the case, either of the following conditions should obtain: (1) The lignin content should be proportional to the methoxy content in the various species, or (2) the composition of the lignin in different species must vary.

A case in which the total methoxy content of the wood is recovered from the isolated lignin is found in a paper by Dore[7] on "The Distribution of Certain Chemical Constants of Wood over Its Proximate Constituents." In this paper it was found that the methoxy content of redwood is 5.60 percent. By determining the methoxy content of the redwood lignin, Dore was able to recover the entire methoxy found in the original wood.

In another paper by the same author[8] on "The Approximate Analysis of Hardwoods," is found some data which show that in live oak the methoxy is only partially associated with the lignin. The methoxy content of the original oven-dry live oak was found to be 5.80 percent. Of this amount 3.72 percent was associated with the live oak lignin. The remaining 2.08 percent methoxy was found to be otherwise associated or at most loosely associated with the lignin. This, then, is an example in which more than 1/3 of the total methoxy content of the original wood is not found in the isolated lignin. That the methoxy is not entirely associated with the lignin in hardwoods and firmly bound to the lignin in softwoods seems to be shown by the above example. Whether this condition is true of hardwoods and softwoods generally is a study which will be taken up at the Forest Products Laboratory in the future. As is shown in Table 1 the methoxy content is not proportional to lignin. The proportion between the two chemical constants does not even hold in a series of woods belonging to either the hardwood or softwood classes.

It is of interest to use the data on redwood and live oak and calculate the methoxy content of the redwood and live oak lignins. Following are the results:

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[7] Jour. Indus. & Eng. Chemistry, May 1920, p. 475.

[8] Ibid., Oct. 1920, p. 986.

Table 6.--Distribution of methoxy group based upon the oven-dry weight of wood

Species	CH_3O content oven-dry wood percent	CH_3O content oven-dry wood in lignin percent	Lignin content of oven-dry wood percent	CH_3O content of lignin percent
Redwood	6.25	6.28	34.5	18.17
Live oak	5.80	3.72	21.14	17.59

From the above table it appears that the composition of lignin in the two species is quite uniform from the standpoint of methoxy content. If this uniformity of the methoxy content of lignin holds in all woods, then the methoxy not associated with the lignin must vary. This is another project which will be investigated in connection with percent of total methoxy associated with the lignin, to which reference was made above.

It is an experimental fact that softwoods do not react the same as hardwoods from the standpoint of methyl alcohol yield, when subjected to destructive distillation. If the softwoods have all of the methoxy associated with the lignin, and the hardwoods only partially, as the very limited amount of data show, it may explain why the broad-leaved species give higher yields of wood alcohol. It is possible that the methoxy not combined with lignin is more easily obtained as methyl alcohol than the methoxy associated with lignin. Under such conditions, the greater share of methyl alcohol in hardwoods would be derived from methoxy not associated with the lignin. In softwoods it would originate from the lignin methoxy entirely.

Pentosans and Methyl Pentosans in Cellulose

Approximately 50 percent of the pentosans and methyl pentosans of the original wood are retained in the cellulose. The hardwood cellulose is higher in pentosans, and lower in methyl pentosans, than softwood cellulose. The relationship between these pentose-producing bodies in the hardwood and softwood celluloses is very similar to that found in the original species.

Alpha, Beta, and Gamma Cellulose

This determination is of interest to the manufacturers of soda and sulphate pulps and cellulose derivatives, who wish a high yield of stable or alpha cellulose.

The conifers have a higher gamma cellulose content than the deciduous class.

Density and Ligno-Cellulose Content

Hickory, one of the extremely dense woods, has a ligno-cellulose content of 79.66 percent. Yellow cedar and ponderosa pine, two light woods, have a ligno-cellulose content of 85.18 and 84.06 percent, respectively. Balsa, which weighs about 7 pounds per cubic foot, has a ligno-cellulose content of 80.65 percent. Thus, it appears that no direct relationship exists between density and the ligno-cellulose content of woods. The density seems to depend upon the structure, that is, the compactness of the cells and the quantity of incrustaceous material.

Cellulose Content and Resistance to Decay

Balsa, on account of its extreme lightness, is used in the manufacture of life-saving apparatus and insulating material. The wood must be treated chemically to protect it against water soaking and decay. Its extreme susceptibility to decay is claimed to be due to a very high cellulose content. The results found in its analysis show that the cellulose content of balsa is not above the average of other woods. Therefore, the ease with which balsa decays seems to be due to some other specific property.

Analyses of Woods

Table 7 includes the data on the species referred to in this report as well as that previously published by the Forest Products Laboratory on the comparative chemical composition of woods. The results are derived from the three sources indicated in the footnotes.

By consulting the directions of Schorger and Mahood for preparing the wood sample for determining cellulose, it will be noted that a change was made by the latter. The directions of Mahood were followed in the cellulose determinations given in this paper.

Summary

Hardwoods show a higher acetic acid content than softwoods by the acid hydrolysis process.

Hardwoods average about 100 percent higher in pentosan content than softwoods.

Softwoods have a higher methyl pentosan content than hardwoods.

The methoxy content of softwoods is approximately 85 percent of that found in hardwoods.

The cellulose isolated from the different species varies in furfural-producing substances. Cellulose retains about 50 percent of the furfural-yielding bodies in the original wood.

Beta cellulose content is higher in softwoods than in hardwoods.

Apparently the acetic acid content obtained by acid hydrolysis is lower than that obtained by destructive distillation.

The analyses of eight species of woods not previously determined are given.

Table 7 - Analysis of woods.

Results in percentage of oven-dry (105°C samples).

Species	Sample	Moisture	Solubility in: Ash	Cold water	Hot water	1% Ether	1% NaOH	Acetic acid	Methoxy	Pentosan	Methylpentosan	Cellulose	Lignin	In cellulose: Pentosan	Methylpentosan	Alpha cellulose	Beta cellulose	Gamma cellulose
Western yellow pine (Pinus ponderosa)	141	5.32	0.43	5.58	5.67	9.63	22.08	0.92	4.55	8.06	1.68	56.22	26.75	9.50	2.13	69.18	---	30.82
	142	8.28	0.42	2.97	3.40	6.52	16.58	1.24	4.02	9.96	1.24	57.72	25.85	8.97	1.97	66.17	5.52	28.31
	143	6.89	0.55	4.62	5.33	9.45	23.16	1.03	4.51	5.88	1.81	58.88	26.25	4.20	1.90	57.65	6.54	35.80
	144	5.19	0.44	3.17	4.69	6.48	19.37	1.18	4.97	5.52	1.77	56.82	27.72	4.63	1.90	55.40	19.02	25.58
	Mean	6.42	0.46	4.09	5.05	8.52	20.30	1.09	4.49	7.35	1.62	57.41	26.65	6.82	1.98	62.10	10.56	30.13
Yellow cedar (Chamaecyparis nootkatensis)	161	5.54	0.33	1.66	2.89	2.67	13.80	1.66	5.42	8.86	3.97	51.45	33.21	8.60	2.03	62.88	11.10	26.02
	162	5.19	0.35	3.03	3.46	3.34	14.49	1.62	5.60	8.52	3.57	54.04	31.27	8.09	1.91	62.96	10.99	26.05
	163	4.87	0.62	2.47	2.86	2.08	12.69	1.55	5.05	6.72	2.97	54.78	30.43	6.65	1.65	59.37	11.64	28.97
	164	5.91		2.74	3.23	2.11	12.67	1.54	4.92	7.37	3.17	55.17	30.27	5.86	1.54	55.52	10.51	33.97
	Mean	4.89	0.43	2.47	3.11	2.55	13.41	1.59	5.25	7.87	3.42	53.86	31.32	7.30	1.78	62.68	11.06	26.25
Incense cedar (Libocedrus decurrens)	165	5.32	0.38	3.09	4.87	3.33	17.37	0.96	6.34	11.07	1.20	39.94	38.14	9.53	2.13	48.47	15.42	36.11
	166	4.63	0.27	2.63	3.62	4.69	13.81	1.04	6.29	9.99	1.60	44.10	37.73	7.90	1.71	41.42	12.77	45.81
	167	5.42	0.38	5.31	7.64	4.90	21.89	0.73	6.09	10.70	1.26	40.76	37.17	9.83	2.15	50.90	6.82	42.28
	Mean	5.12	0.34	3.64	5.38	4.31	17.69	0.91	6.24	10.65	1.35	41.60	37.68	9.08	1.99	46.92	11.67	41.06
Redwood (heartwood) (Sequoia sempervirens)	168	9.64	0.22	7.31	9.77	1.00	20.06	1.03	5.27	7.95	2.77	48.67	34.18	7.40	2.09	78.81	2.95	18.24
	168	9.71	0.20	7.40	9.94	1.14	19.94	1.13	5.16	7.67	2.74	48.23	34.25	----	----	----	----	----
	Mean	9.68	0.21	7.36	9.86	1.07	20.00	1.08	5.21	7.80	2.75	48.45	34.21	7.40	2.09	78.81	2.95	18.24
Western white pine[1] (Pinus monticola)	1	6.18	0.21	2.60	3.35	4.00	13.97	1.21	4.38	6.75	3.41	58.53	27.22	4.47	1.59	70.58	18.16	11.26
	2	7.68	0.20	1.73	2.87	4.42	12.70	0.94	4.59	7.19	3.25	62.29	24.15	5.68	2.97	64.34	10.69	24.97
	3	7.00	0.18	3.92	7.25	3.98	15.92	1.37	4.96	6.48	3.33	59.40	27.55	5.19	1.68	74.29	9.17	16.54
	4	7.15	0.19	4.40	4.78	4.63	16.51	1.09	4.41	7.46	2.80	58.61	26.82	5.96	1.56	49.27	27.27	23.46
	Mean	7.00	0.20	3.16	4.49	4.26	14.78	1.03	4.66	6.97	3.22	59.71	26.44	5.38	1.96	64.61	16.32	19.06
Longleaf pine[2] (Pinus palustris)	11		0.40	7.75	8.20	6.70	24.62	0.70	5.00	7.33	3.48	55.33		8.38	1.26			
	12		0.34	5.60	6.03	6.70	21.07	0.93	4.90	7.52	3.29	57.53		7.19	1.39			
	13		0.35	5.40	6.78	2.65	18.89	0.62	5.26	7.57	3.87	61.41		7.39	1.03			
	20		0.38	6.05	7.57	9.23	24.87	0.79	5.03	7.43	3.67	59.67		7.90	0.96			
	Mean		0.37	6.20	7.15	6.32	22.36	0.76	5.06	7.46	3.50	58.48		7.71	1.16			
Douglas fir[2] (Pseudotsuga taxifolia)	1		0.40	3.79	6.62	0.94	15.82	0.93	4.81	6.03	4.24	61.97		5.56	1.26			
	2		0.37	3.16	6.07	1.00	16.76	1.01	5.17	6.30	4.64	57.00		----	----			
	3		0.35	2.94	6.36	1.11	15.12	1.13	4.88	6.00	4.38	63.08		----	----			
	5		0.38	4.25	6.96	1.02	16.72	1.07	4.92	5.73	4.38	63.82		5.12	1.15			
	Mean		0.38	3.54	6.50	1.02	16.11	1.04	4.95	6.02	4.41	61.47		5.34	1.20			
Western larch[2] (Larix occidentalis)	1		0.21	10.45	12.57	0.72	22.07	0.61	5.08	11.15	2.47	58.25		9.12	1.40			
	2		0.32	11.00	12.40	0.74	21.93	0.91	4.91	11.04	2.83	58.71		8.41	1.22			
	3		0.22	8.16	10.08	0.93	19.44	0.76	5.08	10.22	3.14	60.91		9.67	1.24			
	4		0.16	12.83	15.30	0.83	25.11	0.55	5.05	10.78	2.80	53.31		9.55	0.90			
	Mean		0.23	10.61	12.59	0.81	22.14	0.71	5.03	10.80	2.81	57.80		8.94	1.19			
White spruce[2] (Picea canadensis)	1		0.33	1.28	1.88	1.95	11.33	1.58	5.31	10.78	3.08	62.61		10.26	0.83			
	2		0.29	0.92	2.26	0.90	11.58	1.57	5.26	10.31	3.52	63.29		9.29	0.68			
	3		0.30	1.45	2.52	0.97	12.75	1.49	5.29	10.04	3.95	60.43		----	----			
	4		0.32	0.82	1.88	1.63	10.63	1.75	5.32	10.42	3.64	61.09		9.33	0.66			
	Mean		0.31	1.12	2.14	1.36	11.57	1.59	5.30	10.39	3.55	61.85		9.63	0.72			
Tanbark oak (Quercus densiflora)	151	4.10	0.78	4.14	5.28	0.74	22.59	5.70	5.34	20.02	[illegible]	59.40	23.29	23.22	[illegible]	55.50	[illegible]	25.64
	152	3.95	0.81	4.32	5.15	0.73	25.33	5.70	6.19	20.00	---	56.50	26.07	25.46	---	55.91	[illegible]	41.14
	153	3.26	0.82	4.22	5.92	0.80	23.91	4.40	5.35	19.13	---	57.27	25.20	20.30	---	58.15	[illegible]	19.25
	154	3.36	0.91	3.72	5.08	0.98	22.93	5.13	6.09	19.22	---	58.95	24.86	22.32	----	57.82	[illegible]	24.21
	Mean	3.66	0.83	4.10	5.60	0.80	23.96	5.23	5.74	19.59	----	58.03	24.85	22.82	----	56.77	19.92	23.05
Mesquite (Prosopis juliflora)	171	4.53	0.57	12.55	15.27	2.20	28.72	1.53	5.68	14.04	0.59	44.79	30.27	17.99	1.07	76.00	1.73	22.27
	172	6.10	0.58	13.50	15.77	----	30.08	1.70	5.69	13.99	0.69	45.28	30.13	17.99	1.21	76.71	2.56	20.73
	173	6.15	0.49	12.68	15.56	2.33	29.60	2.53	5.29	15.85	1.18	45.87	31.28	17.57	----	76.40	2.00	21.54
	174	5.20	0.50	11.74	13.77	2.37	25.69	2.37	5.66	13.95	0.34	45.97	30.22	17.44	0.96	76.83	3.04	20.13
	Mean	5.49	0.54	12.62	15.09	2.30	28.52	2.03	5.55	13.96	0.70	45.48	30.47	17.75	0.81	76.48	2.25	21.17
Balsa (Ochroma lagopus)	175	6.50	2.15	1.85	2.84	1.27	20.37	5.75	5.71	17.51	0.88	54.04	26.52	19.99	1.35	75.64	0.27	24.08
	176	6.44	2.09	1.68	2.74	1.19	20.36	5.85	5.65	17.79	0.83	54.24	26.47	----	----	----	----	----
	Mean	6.47	2.12	1.77	2.79	1.23	20.37	5.80	5.68	17.65	0.86	54.15	26.50	19.99	1.35	75.64	0.27	24.08
Hickory (shellbark) (Hicoria ovata)	177	9.60	0.65	4.71	5.41	0.65	18.65	2.60	5.61	18.58	0.92	55.60	23.65	21.33	1.64	75.27	2.64	22.09
	178	7.39	0.74	4.86	5.73	0.62	19.44	2.42	5.65	19.06	0.67	56.85	23.04	22.45	1.19	77.38	3.01	19.61
	Mean	8.49	0.69	4.78	5.57	0.63	19.04	2.51	5.63	18.82	0.80	56.22	23.44	21.89	1.41	76.32	2.82	20.85
Eucalyptus (Eucalyptus globulus)[3]	1	6.99	0.23	2.65	4.41	0.54	16.57	2.31	7.11	21.41	1.97	59.67	24.04	20.35	3.92	67.85	2.11	31.04
	2	6.55	0.20	4.93	6.96	0.52	18.42	1.97	6.37	20.66	2.14	58.53	25.24	21.62	2.44	69.75	0.00	31.25
	3	6.87	0.27	5.31	8.26	0.60	17.90	1.51	6.87	17.90	2.74	56.45	25.07	20.10	2.24	68.99	0.00	31.01
	4	5.90	0.24	5.79	8.27	0.59	21.40	1.62	6.56	20.39	2.48	55.83	26.74	21.76	1.26	----	----	----
	Mean	6.58	0.24	4.67	6.98	0.56	18.57	1.85	6.73	20.09	2.33	57.62	25.07	20.96	2.46	68.86	0.70	31.10
Basswood (Tilia americana)[3]	1		0.80	2.04	3.84	1.50	23.43	5.78	6.23	19.82	3.72	62.92		24.48	1.19			
	2		0.74	1.63	2.94	1.14	21.61	6.14	6.05	19.54	3.85	62.41		23.54	1.46			
	3		0.96	3.14	5.66	3.59	26.93	5.46	6.11	20.37	3.68	54.66		26.61	1.62			
	4		0.94	1.23	3.22	0.89	21.46	5.41	5.91	19.14	4.16	63.13		21.89	1.45			
	5		0.86	2.55	4.67	2.68	25.38	6.18	5.72	20.79	3.23	63.08		24.86	2.00			
	Mean		0.86	2.12	4.07	1.96	23.76	5.79	6.00	19.93	3.73	61.24		24.28	1.54			
Yellow birch (Betula lutea)[3]	1		0.58	2.88	4.21	0.55	20.02	3.99	6.12	24.26	3.18	60.49		28.40	1.11			
	2		0.57	2.58	3.87	0.67	20.20	4.39	6.03	25.40	3.12	61.08		29.96	1.32			
	3		0.54	3.15	4.66	0.54	19.51	3.81	6.19	23.00	2.25	61.82		26.55	1.04			
	4		0.37	2.06	3.15	0.63	19.65	5.02	5.92	25.86	2.21	61.85		----	----			
	Mean		0.52	2.67	3.97	0.60	19.85	4.30	6.07	24.63	2.69	61.31		28.30	1.16			
Sugar maple (Acer saccharum)[3]	1		0.46	2.60	4.27	0.29	16.98	4.26	7.22	21.10	2.50	60.78		21.60	1.04			
	2		0.61	2.73	4.22	0.22	17.20	4.25	7.23	21.90	2.14	61.67		25.02	1.05			
	3		0.40	2.94	4.78	0.30	18.04	4.60	7.25	22.21	2.05	60.20		25.85	1.00			
	4		0.38	2.33	4.15	0.20	18.35	4.74	7.28	21.62	2.85	60.48		25.20	0.77			
	Mean		0.44	2.65	4.36	0.25	17.64	4.46	7.25	21.71	2.39	60.78		24.48	0.96			

[1] Jr. Ind. & Eng. Chem. Vol. No.

[2] Jr. Ind. & Eng. Chem. Vol. 9, No. 3 (1917).

[3] Trouble filtering

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