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DENSITY, FIBER LENGTH, AND YIELDS OF PULP FOR VARIOUS SPECIES OF WOOD

The yield of pulp obtained from a given species of wood is influenced greatly by the kind and severity of the pulping process used. The highest yield, of course, is obtained by strictly mechanical processes that reduce practically all of the wood to a fibrous pulp. The lowest yield is obtained from drastic chemical digestion that gives pulp consisting of nearly pure cellulose fibers. Within these extremes in yield lie pulps with all the gradations in quality needed for use in the many kinds of pulp and paper products that are manufactured.

There are three relatively standard chemical processes for making wood pulp; the sulfite, the sulfate, and the soda processes. The yield of pulp (expressed as a percentage by weight on the moisture-free basis) obtained by digesting wood by one of these chemical processes is dependent to a large extent on the chemical composition of the wood. Since the principal chemical components of the normal sound wood of most species do not vary much in amount, the percentage yield of pulp obtained by a given process does not vary greatly from one species to another. The chemical composition of wood and consequently the yield of chemical pulp generally varies more between softwoods (coniferous woods) and hardwoods (broadleaf woods) as classes than between the individual woods within these classes.

The yield of pulp expressed on a volume basis, such as the pounds of pulp per cubic foot of wood or per cord of wood is affected by the variations in the percentage yield and also in the variations in those structure and growth characteristics of the wood that influence its density and weight per cord.

Because of the many and interacting variations in wood properties and pulping conditions, the yield of pulp obtained from a given wood cannot be stated without qualifications, and a single average value for a species

and process cannot be given. The typical values given in the following tables may, however, be considered to be suitable for general estimating purposes. The percentage yields given in tables 1 and 2 for the three principal chemical pulping processes are those that might be expected in the production of pulp of papermaking grade. Lower yields would be expected in the production of pulp to be used for the manufacture of viscose and other cellulose derivatives, owing to the more severe chemical treatment in their preparation.

The yields of semichemical pulp and groundwood pulp are not included in tables 1 and 2. The yields obtained by these processes are relatively independent of the kind of wood used. The semichemical processes may be operated under a much wider range of conditions than the more standardized chemical processes, and the yields of pulp, as indicated in tables 3 and 4, may vary from about 55 to about 95 percent. In calculating the values given in tables 3 and 4, a yield of 95 percent for groundwood pulp has been used for all species, and the 5 percent loss has been assumed to consist of 3.5 percent water-soluble material and 1.5 percent screenings.

The calculated yields of pulp per cord of wood given in table 3 and the cords of wood required per ton of pulp given in table 4 may differ from those obtained in commercial operation for a number of reasons, some of which are pointed out in the footnotes. On the basis of pulpwood and wood-pulp statistics, the U. S. Tariff Commission reported in 1938 the average of cords of wood required to make one ton of air-dry pulp by the principal processes was: Sulfite pulp, 1.965 cords; sulfate pulp, 1.786 cords; soda pulp, 1.813 cords; and groundwood pulp, 0.973 cord.

A notable difference between softwoods and hardwoods is observed in their fiber length. In general, softwoods produce longer fibered pulps than hardwoods and are preferred for most kinds of paper for this reason. The fiber length, among other structural characteristics of fibers, has an influence on the strength and other properties of the pulp and of the paper in which the pulp is used. Tables 1 and 2 contain reported values for the average fiber length of a number of the species.

Table 1.--Typical values of average fiber length, density, and yields of chemical pulp for various softwood¹

Species	Average fiber length	Density ²	Yield of chemical pulp ²		Species	Average fiber length	Density ²	Yield of chemical pulp ²	
			Sulfite ^{1,2}	Sulfate ³				Sulfite ^{1,2}	Sulfate ³
	Mm.	Lb. per cu. ft.	Percent	Percent		Mm.	Lb. per cu. ft.	Percent	Percent
Spruce (<i>Picea</i> sp.)					Hemlock (<i>Tsuga</i> sp.)				
White (<i>P. glauca</i>)	3.50	23	48	50	Western (<i>T. heterophylla</i>)	4.00	25	46	47
Black (<i>P. mariana</i>)	3.50	25	48	50	Eastern (<i>T. canadensis</i>)	3.50	24	44	45
Red (<i>P. rubens</i>)	3.70	24	48	50	Carolina (<i>T. caroliniana</i>)	3.10	30	48	45
Blue (<i>P. pungens</i>)	2.80	23	48	43	Mountain (<i>T. mertensiana</i>)	3.70	26		45
Angelmann (<i>P. engelmanni</i>)	3.50	20	48	47					
Norway (<i>P. abies</i>)		30	48	48	Fir (<i>Abies</i> sp.)				
Sitka (<i>P. sitchensis</i>)	5.50	24	48	47	Alpine (<i>A. lasiocarpa</i>)	3.15	21	48	48
					Balsam (<i>A. balsamea</i>)	3.50	21	47	50
Pine (<i>Pinus</i> sp.)					California red (<i>A. magnifica</i>)	3.25	23	48	
Loblolly (<i>P. taeda</i>)	4.00	29	45	48	ica				
Longleaf (<i>P. palustris</i>)	4.00	29	45	48	Noble (<i>A. procera</i>)	4.00	22	48	47
Shortleaf (<i>P. echinata</i>)	4.00	29	45	48	Grand (<i>A. grandis</i>)	5.00	24	49	48
Slash (<i>P. caribaea</i>)	4.00	29	45	47	Pacific silver (<i>A. amabilis</i>)	3.55	24	49	42
Sand (<i>P. clausa</i>)	2.85	29	46	47	White (<i>A. concolor</i>)	3.50	22	48	48
Pond (<i>P. rigida</i>)	3.55	29	43	48					
Virginia (<i>P. virginiana</i>)	2.80	26	43	48	Douglas-fir (<i>Pseudotsuga taxifolia</i>)	4.50	29	48	40
Jack (<i>P. banksiana</i>)	3.50	24	45	48					
Red (<i>P. resinosa</i>)	3.70	27	45	48	Larch (<i>Larix</i> sp.)	3.50	31	42	35
White, eastern (<i>P. strobus</i>)	3.70	20		48	Eastern (tamarack) (<i>L. laricina</i>)	5.00	27	42	48
					Western (<i>L. occidentalis</i>)				
White, western (<i>P. monticola</i>)	4.40	23	45	48					
Lodgepole (<i>P. contorta</i>)	3.50	25	45	48					
Ponderosa (<i>P. ponderosa</i>)	3.60	24	45	48					
Sugar (<i>P. lambertiana</i>)	4.10	23	45	48					
Pinon (<i>P. edulis</i>)	2.00	31	40	45					
Limber (<i>P. flexilis</i>)	2.95	23		48					
Monterey (<i>P. radiata</i>)	2.60	29	45	48					
					Port-Orford (<i>C. lawsoniana</i>)	2.60	26	45	45
					ana				
					Atlantic (<i>C. thyoides</i>)	2.10	20		45
					Redcedar, eastern (<i>Juniperus virginiana</i>)	2.80	27		45
					Redcedar, western (<i>Juniperus plicata</i>)	3.80	19	43	40
					Redwood (<i>Sequoia sempervirens</i>)	7.00	23		38
					Baldcypress (<i>Taxodium distichum</i>)	6.00	27	46	48

¹Considerable variation between samples of the same species can be expected.

²Moisture-free weight, green volume.

³Yields of moisture-free, screened pulp based on weight of moisture-free wood. Screenings, which may amount to about 0.5 percent, are frequently refined and returned to the pulp system or converted into lower grade products and therefore are not always actually lost.

⁴Bleachable pulp of papermaking grade.

⁵Yields given for sulfite pulp made from the pines, Douglas-fir, and the larches are based on use of young wood essentially free from heartwood or on the use of a modification of the standard lime-base process.

⁶Kraft-type, wrapping, and board grade; bleachable pulp may be 2 to 3 percent lower than the values given.

Table 3.--Weight, in pounds, of moisture-free pulp produced per cord of rough logs for various kinds and percentage yields of pulp, and densities of wood¹

Density: of wood ²	Wood per: cord ²	Yield of chemical pulp ⁴										Yield of semichemical pulp ⁴										Yield of ground- wood: pulp ⁴	
		35	38	40	41	42	43	44	45	46	47	48	49	50	55	60	65	70	75	80	85	90	95
19	1,575:	520:	565:	610:	625:	640:	655:	670:	685:	700:	710:	725:	740:	815:	890:	965:	1,040:	1,115:	1,185:	1,260:	1,335:	1,410:	1,430
20	1,660:	545:	595:	640:	655:	670:	685:	705:	720:	735:	750:	765:	780:	860:	935:	1,015:	1,095:	1,170:	1,250:	1,330:	1,405:	1,485:	1,505
21	1,745:	575:	625:	675:	690:	705:	720:	740:	755:	770:	785:	805:	820:	900:	985:	1,065:	1,150:	1,230:	1,310:	1,395:	1,475:	1,560:	1,580
22	1,825:	600:	655:	705:	720:	740:	755:	775:	790:	810:	825:	840:	860:	945:	1,030:	1,115:	1,205:	1,290:	1,375:	1,460:	1,545:	1,635:	1,660
23	1,910:	630:	685:	735:	755:	775:	790:	810:	825:	845:	860:	880:	900:	990:	1,080:	1,170:	1,260:	1,350:	1,435:	1,525:	1,615:	1,705:	1,735
24	1,990:	655:	710:	760:	785:	805:	825:	845:	860:	880:	900:	920:	935:	1,030:	1,125:	1,220:	1,310:	1,405:	1,500:	1,595:	1,685:	1,780:	1,810
25	2,075:	685:	740:	790:	820:	840:	860:	880:	900:	920:	935:	955:	975:	1,075:	1,170:	1,270:	1,365:	1,465:	1,560:	1,660:	1,760:	1,855:	1,885
26	2,160:	710:	770:	825:	855:	875:	895:	915:	935:	955:	975:	995:	1,015:	1,115:	1,220:	1,320:	1,420:	1,525:	1,625:	1,725:	1,830:	1,930:	1,960
27	2,240:	740:	800:	865:	895:	905:	930:	950:	970:	990:	1,010:	1,035:	1,055:	1,160:	1,265:	1,370:	1,475:	1,580:	1,685:	1,795:	1,900:	2,005:	2,035
28	2,325:	765:	830:	895:	925:	940:	960:	985:	1,005:	1,030:	1,050:	1,070:	1,095:	1,205:	1,310:	1,420:	1,530:	1,640:	1,750:	1,860:	1,970:	2,080:	2,110
29	2,405:	795:	860:	925:	955:	975:	995:	1,020:	1,040:	1,065:	1,085:	1,110:	1,135:	1,245:	1,360:	1,475:	1,585:	1,700:	1,810:	1,925:	2,040:	2,150:	2,185
30	2,490:	820:	890:	955:	985:	1,010:	1,030:	1,055:	1,080:	1,100:	1,125:	1,150:	1,170:	1,290:	1,405:	1,525:	1,640:	1,760:	1,875:	1,990:	2,110:	2,225:	2,260
31	2,575:	850:	920:	995:	1,015:	1,040:	1,065:	1,090:	1,115:	1,140:	1,160:	1,185:	1,210:	1,330:	1,455:	1,575:	1,695:	1,815:	1,935:	2,060:	2,180:	2,300:	2,335
32	2,655:	875:	950:	1,025:	1,050:	1,075:	1,100:	1,125:	1,150:	1,175:	1,200:	1,225:	1,250:	1,375:	1,500:	1,625:	1,750:	1,875:	2,000:	2,125:	2,250:	2,375:	2,410
33	2,740:	900:	980:	1,055:	1,085:	1,110:	1,135:	1,160:	1,185:	1,210:	1,235:	1,265:	1,290:	1,420:	1,545:	1,675:	1,805:	1,935:	2,060:	2,190:	2,320:	2,450:	2,485
34	2,820:	930:	1,010:	1,090:	1,115:	1,140:	1,170:	1,195:	1,220:	1,250:	1,275:	1,300:	1,330:	1,460:	1,595:	1,725:	1,860:	1,990:	2,125:	2,260:	2,390:	2,525:	2,560
35	2,905:	955:	1,040:	1,095:	1,120:	1,150:	1,175:	1,205:	1,230:	1,260:	1,285:	1,310:	1,340:	1,505:	1,640:	1,775:	1,915:	2,050:	2,185:	2,325:	2,460:	2,595:	2,635
36	2,990:	985:	1,070:	1,125:	1,155:	1,180:	1,210:	1,235:	1,265:	1,295:	1,320:	1,350:	1,380:	1,545:	1,685:	1,820:	1,970:	2,110:	2,250:	2,390:	2,530:	2,670:	2,710
37	3,070:	1,010:	1,100:	1,155:	1,185:	1,215:	1,245:	1,270:	1,300:	1,330:	1,360:	1,385:	1,415:	1,590:	1,735:	1,880:	2,025:	2,170:	2,310:	2,455:	2,600:	2,745:	2,790
38	3,155:	1,040:	1,130:	1,185:	1,215:	1,245:	1,275:	1,305:	1,335:	1,365:	1,395:	1,425:	1,455:	1,640:	1,790:	1,940:	2,090:	2,240:	2,390:	2,540:	2,690:	2,840:	2,885
39	3,235:	1,065:	1,160:	1,220:	1,250:	1,280:	1,310:	1,340:	1,370:	1,400:	1,430:	1,460:	1,495:	1,700:	1,860:	2,020:	2,180:	2,340:	2,500:	2,660:	2,820:	2,980:	3,035
40	3,320:	1,095:	1,185:	1,250:	1,280:	1,310:	1,345:	1,375:	1,405:	1,435:	1,470:	1,500:	1,530:	1,750:	1,920:	2,100:	2,280:	2,460:	2,640:	2,820:	3,000:	3,180:	3,245

¹The product of the percentage yield (divided by 100), the density, and 85 cubic feet of wood per cord (see footnote 3) corrected for the following additional losses representative of commercial practice: For chemical and semichemical pulps, 2 percent loss of wood in barking, 2 percent loss of wood in chipping, and 2 percent loss of fiber in washing the pulp. The additional losses used in computing the groundwood pulp figures were: 2 percent loss of wood in barking and 2.5 percent loss of fiber in the white water. The results are expressed to the nearest 5 pounds. Commercial production is usually based on air-dry pulp having an assumed moisture content of 10 percent. To convert the moisture-free values given in the table to air-dry values, multiply by 1.11. The pounds of pulp obtained per cord of bark-free logs are from 1.15 to 1.20 times the amount for a cord of logs with the bark on.

²Pounds of moisture-free wood per cubic foot, green volume. The density of wood is influenced by the amounts of springwood and summerwood, the amount of heartwood, the rate of growth, age, location of wood in the tree, and other factors.

³Pounds moisture-free wood in a standard cord (128 cubic feet) of rough logs. Figures in this column are the product of the density and the cubic feet of solid wood per cord expressed to the nearest 5 pounds. The factor of 85 cubic feet of solid wood per cord used is based on an average volume of 65 percent wood and 35 percent bark and air space in a freshly stacked pile of rough 4-foot logs with average diameter inside bark per cord ranging from 7 to 10 inches and with number of logs ranging between 45 and 100 per cord. The factor will vary with length, diameter, crook, knottiness, bark thickness, size of pile, and closeness of piling from as low as 75 to as high as 95 or more cubic feet per standard cord. The solid-volume content of a cord of bark-free logs is from 1.15 to 1.20 times (depending on bark thickness) that for a cord of logs of the same average diameter with the bark on.

⁴Percent of moisture-free wood.

Table 4.--Cords of rough logs required per ton of moisture-free pulp for various kinds and percentage yields of pulp, and densities of wood¹

Density: of wood ²	Yield of chemical pulp ²																Yield of semichemical pulp ²																Yield of ground- wood pulp ²
	35	38	40	41	42	43	44	45	46	47	48	49	50	55	60	65	70	75	80	85	90	95	95										
19	3.845	3.540	3.360	3.280	3.200	3.125	3.055	2.985	2.920	2.855	2.815	2.760	2.705	2.655	2.615	2.580	2.545	2.510	2.475	2.440	2.405	2.370	2.335	2.300	2.265	2.230	2.195	2.160	2.125	2.090	2.055	1.400	
20	3.670	3.360	3.200	3.125	3.055	2.985	2.920	2.855	2.780	2.720	2.665	2.615	2.565	2.525	2.485	2.445	2.405	2.365	2.325	2.285	2.245	2.205	2.165	2.125	2.085	2.045	2.005	1.965	1.925	1.885	1.845	1.330	
21	3.480	3.200	3.055	2.965	2.900	2.835	2.780	2.705	2.650	2.595	2.550	2.505	2.460	2.420	2.380	2.340	2.300	2.260	2.220	2.180	2.140	2.100	2.060	2.020	1.980	1.940	1.900	1.860	1.820	1.780	1.740	1.265	
22	3.335	3.055	2.920	2.835	2.780	2.705	2.650	2.580	2.530	2.470	2.425	2.380	2.325	2.280	2.240	2.200	2.160	2.120	2.080	2.040	2.000	1.960	1.920	1.880	1.840	1.800	1.760	1.720	1.680	1.640	1.600	1.205	
23	3.175	2.920	2.780	2.720	2.650	2.580	2.530	2.470	2.425	2.365	2.325	2.275	2.220	2.020	1.850	1.710	1.585	1.480	1.395	1.310	1.240	1.175	1.105	1.035	0.970	0.915	0.860	0.815	0.770	0.730	0.690	0.665	
24	3.055	2.815	2.665	2.595	2.550	2.485	2.425	2.365	2.325	2.275	2.220	2.175	2.140	2.100	2.060	2.020	1.980	1.940	1.900	1.860	1.820	1.780	1.740	1.700	1.660	1.620	1.580	1.540	1.500	1.460	1.420	1.105	
25	2.920	2.705	2.565	2.500	2.440	2.380	2.325	2.275	2.220	2.175	2.140	2.095	2.050	2.010	1.970	1.930	1.890	1.850	1.810	1.770	1.730	1.690	1.650	1.610	1.570	1.530	1.490	1.450	1.410	1.370	1.330	1.060	
26	2.815	2.595	2.470	2.395	2.340	2.285	2.235	2.185	2.140	2.095	2.050	2.010	1.970	1.930	1.895	1.860	1.825	1.790	1.755	1.720	1.685	1.650	1.615	1.580	1.545	1.510	1.475	1.440	1.405	1.370	1.335	1.020	
27	2.705	2.500	2.365	2.310	2.260	2.210	2.160	2.110	2.060	2.020	1.980	1.940	1.900	1.860	1.825	1.790	1.755	1.720	1.685	1.650	1.615	1.580	1.545	1.510	1.475	1.440	1.405	1.370	1.335	1.300	1.265	0.985	
28	2.615	2.410	2.285	2.235	2.175	2.130	2.085	2.035	1.990	1.940	1.905	1.870	1.825	1.780	1.740	1.700	1.660	1.620	1.580	1.540	1.500	1.460	1.420	1.380	1.340	1.300	1.260	1.220	1.180	1.140	1.100	0.960	
29	2.515	2.325	2.210	2.150	2.105	2.050	2.010	1.960	1.920	1.880	1.845	1.800	1.760	1.720	1.680	1.640	1.600	1.560	1.520	1.480	1.440	1.400	1.360	1.320	1.280	1.240	1.200	1.160	1.120	1.080	1.040	0.930	
30	2.440	2.245	2.140	2.085	2.030	1.980	1.940	1.895	1.850	1.820	1.780	1.740	1.700	1.660	1.620	1.580	1.540	1.500	1.460	1.420	1.380	1.340	1.300	1.260	1.220	1.180	1.140	1.100	1.060	1.020	0.900	0.885	
31	2.355	2.175	2.060	2.010	1.970	1.925	1.880	1.835	1.795	1.755	1.725	1.690	1.655	1.620	1.585	1.550	1.515	1.480	1.445	1.410	1.375	1.340	1.305	1.270	1.235	1.200	1.165	1.130	1.095	1.060	0.970	0.855	
32	2.285	2.105	2.000	1.950	1.905	1.860	1.820	1.780	1.740	1.700	1.665	1.630	1.595	1.560	1.525	1.490	1.455	1.420	1.385	1.350	1.315	1.280	1.245	1.210	1.175	1.140	1.105	1.070	1.035	1.000	0.940	0.850	
33	2.220	2.040	1.940	1.895	1.845	1.800	1.760	1.725	1.690	1.655	1.620	1.585	1.550	1.515	1.480	1.445	1.410	1.375	1.340	1.305	1.270	1.235	1.200	1.165	1.130	1.095	1.060	1.025	0.990	0.955	0.890	0.805	
34	2.150	1.980	1.885	1.835	1.795	1.755	1.715	1.675	1.640	1.600	1.570	1.540	1.505	1.470	1.435	1.400	1.365	1.330	1.295	1.260	1.225	1.190	1.155	1.120	1.085	1.050	1.015	0.980	0.945	0.910	0.875	0.780	
35	2.095	1.925	1.825	1.785	1.740	1.700	1.660	1.625	1.585	1.555	1.525	1.495	1.465	1.435	1.405	1.375	1.345	1.315	1.285	1.255	1.225	1.195	1.165	1.135	1.105	1.075	1.045	1.015	0.985	0.955	0.920	0.760	
36	2.030	1.870	1.780	1.730	1.695	1.655	1.620	1.580	1.545	1.515	1.480	1.450	1.425	1.395	1.365	1.335	1.305	1.275	1.245	1.215	1.185	1.155	1.125	1.095	1.065	1.035	1.005	0.975	0.945	0.915	0.885	0.740	
37	1.980	1.820	1.730	1.690	1.645	1.605	1.570	1.535	1.500	1.470	1.445	1.415	1.385	1.355	1.325	1.295	1.265	1.235	1.205	1.175	1.145	1.115	1.085	1.055	1.025	0.995	0.965	0.935	0.905	0.875	0.750	0.715	
38	1.925	1.770	1.690	1.645	1.605	1.570	1.535	1.500	1.465	1.435	1.405	1.375	1.345	1.315	1.285	1.255	1.225	1.195	1.165	1.135	1.105	1.075	1.045	1.015	0.985	0.955	0.925	0.895	0.865	0.835	0.700	0.670	
39	1.880	1.725	1.640	1.600	1.560	1.525	1.495	1.460	1.430	1.400	1.370	1.340	1.310	1.280	1.250	1.220	1.190	1.160	1.130	1.100	1.070	1.040	1.010	0.980	0.950	0.920	0.890	0.860	0.830	0.800	0.690	0.665	
40	1.825	1.690	1.600	1.560	1.525	1.485	1.455	1.425	1.395	1.365	1.335	1.305	1.275	1.245	1.215	1.185	1.155	1.125	1.095	1.065	1.035	1.005	0.975	0.945	0.915	0.885	0.855	0.825	0.795	0.765	0.675	0.665	

¹Based on 83 cubic feet of solid wood for standard cord of unbarked logs (see footnote 3, table 3). Allowances made for manufacturing losses are listed in footnote 1, table 3. To convert to cords of rough logs per ton of air-dry pulp, multiply these values by 0.9. The cords of bark-free logs per ton of moisture-free pulp are from 0.834 to 0.870 times that with the bark on (depending, in inverse order, on the bark thickness).

²Pounds, moisture-free wood per cubic foot, green volume.

³Percent of moisture-free wood.