FNR 155

Forestry &
Natural Resources

Furniture Manufacturing

Seasoning of Wood

By C. A. Eckelman

Introduction

As it comes from the mill freshly cut and green, wood contains excess moisture which must be re
is suitable for most articles of manufacture. The process of removing this moisture is referred to a
constitutes one of the most important steps in converting raw wood into finished products. Green
contain very sizeable amounts of water. Rietz (1957) points out that a southern pine log 16 feet l
inches in diameter may contain 70 gallons of water; a white oak log 16 feet long and 18 inches i
inch sapwood may contain 126 gallons or 1,050 pounds of water. This latter figure represents 56
total weight of the log!

Seasoning is a costly and time consuming process and would not be employed except in specia
there were valid reasons why it is required. A few of the more important reasons (Rietz, 1957) ar
reduces gross weight and thereby subsequent shipping and handling costs, imparts dimensiona
increases most strength properties, increases fastener holding power and thereby joint strength,
electrical resistance, improves paintability and glueability, and finally, improves the thermal prop
addition to these advantages, drying wood below the fiber saturation point renders it impervious
degradation so long as it is not re-wetted. Attack by wood destroying fungi, in particular, is preve

Effect of Seasoning on Wood Properties

Whether artificially seasoned or left to dry naturally in place, wood in service will ultimately assu
content level that is consistent with the relative humidity of its surroundings, i.e., it will adsorb or
from or to the atmosphere until the vapor pressure of the water in the wood just balances the par
the water vapor in the surrounding air. This equilibrium value, or equilibrium moisture content, va
as well as service conditions and may easily range from 4 percent for furniture in a heated house
timber in covered but unheated buildings.

Removal of so-called free water, or sap, from cell cavities has little effect on wood other than to li
removal of "imbibed", or "hygroscopic", moisture from the cell walls materially affects its physical
properties. Free water is removed first during seasoning since energy needed to break hygrosco
utilized evaporating free water from the wood surface. The moisture content level at which all free

removed from the cell cavities but none of the hygroscopic moisture from the cell walls is referre saturation point." For most species the fiber saturation point exists at a moisture content level of percent (where moisture content is expressed as a percentage of the oven dry weight of the woo

Shrinking and Swelling

When dried below the fiber saturation point, wood becomes dimensionally unstable and its volu length become a function of its moisture content. This functional relationship is different along ea natural axes of wood. Table 1 (Rasmussen, 1961) gives average shrinkage values for a number woods along the radial, tangential, and longitudinal axes based on dimensions when green. As c tangential shrinkage is greatest, ranging from about 4 to 14 percent as wood dries from the gree condition. Comparable values for radial and longitudinal directions are 2 to 8 and 0.1 to 0.3 perc Since wood in most of its uses will eventually come to an equilibrium moisture content considera fiber saturation point, it will, if placed in service while green, shrink as it dries. Such shrinkage is often unacceptable.

Bender (1964) points out that in the furniture industry, shrinking and swelling cause: "sticking dr sunken glue-joints in veneered particleboard panels; loosening of dowelled, mortised, and variou joints; splitting of solid wood components such as chair seats; end splits in the cores of veneere which are not end-banded; warping of doors and other panel components which are not firmly h frame; and development of fine cracks and checks on the surface of highly finished veneered pa (1955) states that in building construction "shrinkage may cause loosening of fastenings and set building with resulting plaster cracks, uneven floors, and unsightly openings around moldings. S studs, sheathing and siding decreases weathertightness of walls, loosens fastenings, and reduc mechanical strength and stiffness of walls."

Table 1. Total shrinkage values of domestic woods.

Species	Shrinkage to 0 percent moisture content		Species	Shrinkage to 0 percent moisture content	
SOFTWOODS	**Radial**	**Tangential**	**HARDWOODS**	**Radial**	**Tangential**
Baldcypress	3.8	6.2	Alder, red	4.4	7.3
Cedar:			Ash:		
Alaska	2.8	6.0	Black	5.0	7.8
Atlantic-white	2.9	5.4	Green	4.6	7.1
Eastern redcedar	3.1	4.7	White	4.9	7.8
incense	3.3	5.2	Aspen:		
Northern white	2.2	4.9	Bigtooth	3.3	7.9

Port-Orford	4.6	6.9	Quaking	3.5	6.7
Western redcedar	2.4	5.0	Basswood, American	6.6	9.3
Douglas-fir:			Beech, American	5.5	11.9
Coast	4.8	7.6	Birch:		
Interior north	3.8	6.9	Paper	6.3	8.6
Interior south			Sweet	6.5	9.0
Interior west	4.8	7.6	Yellow	7.3	9.5
Fir:			Butternut	3.4	6.4
Balsam	2.9	6.9	Cherry, black	3.7	7.1
California red	4.5	7.9	Cottonwood		
Grand	3.4	7.5	Black	3.6	8.6
Noble	4.3	8.3	Eastern	3.9	9.2
Pacific silver	4.4	9.2	Elm:		
Subalpine	2.6	7.4	American	4.2	9.5
White	3.3	7.0	Rock	4.8	8.1
Hemlock:			Hackberry	4.8	8.9
Eastern	3.0	6.8	Hickory	7.4	11.4
Western	4.2	7.8	Magnolia, southern	5.4	6.6
Larch, western	4.5	9.1	Maple:		
Pine:			Bigleaf	3.7	7.1
Eastern pine	2.1	6.1	Red	4.0	8.2
Jack	3.7	6.6	Silver	3.0	7.2
Lodgeple	4.3	8.3	Sugar	4.8	9.9
Ponderosa	3.9	6.2	Oak:		
Pine:			Nothern red	4.0	8.6
Red	3.8	7.2	Northern white	5.6	10.5
Southern:			Southern red	4.7	11.3
Loblolly	4.8	7.4	Southern white (chestnut)	5.3	10.8
Longleaf	5.1	7.5	Pecan	4.9	8.9
Shortleaf	4.6	7.7	Sweetgum	5.3	10.2

Slash	5.4	7.6	Sycamore, American	5.0	8.4
Sugar	2.9	5.6	Tanoak	4.9	11.7
Western white	4.1	7.4	Tupelo:		
Redwood:			Black	5.1	8.7
Old growth	2.6	4.4	Water	4.2	7.6
Young growth	2.2	4.0	Walnut, black	5.5	7.8
Spruce:			Willow, black	3.3	8.7
Engelmann	3.8	7.1	Yellow-poplar	4.6	8.2
Red	3.8	7.8			
Sitka	4.3	7.5			
White	4.7	8.2			

Mechanical Properties

Reduction of moisture content below the fiber saturation point with but few exceptions increases the mechanical strength properties of the wood. Cell walls become more compact, fibers thereby become stronger and stiffer, and strength properties accordingly increase (Wangaard, 1950). Molecularly, reduction of moisture content below the fiber saturation point promotes hydrogen bridge cross-bonding between adjacent cellulose chains in regions of low spatial order which are primarily responsible for fiber stiffness and rigidity (Wakeham, 1955). The moisture content level at which the mechanical properties of a number of species begin to change is given in Table 2, (Anon 5, 1974). As can be seen, these levels are slightly below the fiber saturation point. The Wood Handbook (Anon. 1, 1955) gives the following values, Table 3, for average increase or decrease in strength properties for a one percent moisture content change. Two of the most critical properties, modulus of rupture and shear parallel to the grain, increase four and three percent respectively for each percent decrease of moisture content below the fiber saturation point. One strength

Table 2. Moisture con
change due to drying

Species
Ash white
Birch, yellow
Chestnut, Ar
Douglas-fir
Hemlock, we
Larch, weste
Pine, loblolly
Pine, logleaf
Pine, red
Redwood
Spruce, red
Spruce, Sitk
Tamarack

property that does not increase with decreased moisture content, however, is toughness. Toughn measure of the ability of the wood to absorb shock or impact loads and is a function of both strer Drying wood makes it less pliable, and hence toughness is reduced.

Table 3. Moisture content at which properties change due to drying for selected species.

	Change per 1-percent change in moisture content (percent)
Static bending:	
Fiber stress at proportional limit	5
Modulus of rupture	4
Modulus of elasticity	2
Work to proportional limit	8
Work to maximum load	0.5
Impact bending, height of drop causing complete failure	0.5
Compression parallel to grain:	
Fiber stress at proportional limit	5
Maximum crushing strength	6
Compression perpendicular to grain, fiber stress at proportional limit	5..5
Shear parallel to grain, maximum shearing strength	3
Tension perpendicular to grain, maximum tensile strength	1..5
Hardness:	
End	4
Side	2..5

Electrical Resistance

The electrical resistance of wood also increases as it dries below the fiber saturation point. Table 1951) gives the average electrical resistance in megohms (megohm = 1 million ohms) measured between two pairs of needle electrodes 1 ¼ inches apart driven 5/16 inches into the wood. Unde conditions and at a seven percent moisture content, black walnut has a resistance of 51,300 meg twenty-five percent its resistance drops to 0.38 megohms - a sizeable reduction! Above the fiber however, the relationship between resistivity and moisture content is unpredictable. Wet wood co electricity readily. The resistance of wet wood to the passage of electricity, for example, is actuall for pure water. The functional relationship of resistivity to moisture content is of particular interes wood seasoning since several resistance type moisture meters utilize this property. Since resista little above twenty-five percent moisture content and tends toward infinity below seven percent, s perform well only between these limits.

Table 4. Average electrical resistance along the grain

Species																
	Electrical rsistance in megohms, when percent moisture content is -															
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Softwoods:																
Cypress, southern	12,600	3,980	1,410	630	265	120	60	33	18.6	11.2	7.1	4.6	3.09	1.78	1.26	0.9
Douglas-fir	22,400	4,780	1,660	630	265	120	60	33	18.6	11.2	7.1	4.6	3.09	2.14	1.51	1.1

(coast type)																
Fir, California red	31.600	6,760	2,000	725	315	150	83	48	28.8	18.2	11.8	7.6	5.01	3.31	2.29	1.5
Fir, white	57,600	15,850	3,980	1,120	415	180	83	46	26.9	16.6	11.0	6.6	4.47	3.02	2.14	1.5
Hemlock, western	22,900	5,620	2,040	1,445	400	185	98	51	28.2	16.2	10.0	6.0	3.89	2.52	1.58	1.0
Larch, western	39,800	11,200	3,980	850	560	250	120	63	33.9	19.9	12.3	7.6	5.02	3.39	2.29	1.6
Pine, eatern white	20,900	5,620	2,090	1,320	405	200	102	58	33.1	19.9	12.3	7.9	5.1	3.31	2.19	1.5
Pine, longleaf	25,000	8,700	3,160	1,410	575	270	135	74	41.7	24.0	14.4	8.9	5.76	3.72	2.46	1.6
Pine, ponderosa	39,800	8,910	3,310	1,350	645	300	150	81	44.7	25.1	14.8	9.1	5.62	3.55	2.34	1.6
Pine, shortleaf	43,600	11,750	3,720	645	560	255	130	69	38.9	22.4	13.8	8.7	5.76	3.80	2.63	1.8
Pine, sugar	22,900	5,250	1,660	615	280	140	76	44	25.7	15.9	10.0	6.6	4.36	3.02	2.09	1.4
Redwood	22,400	4,680	1,550	830	250	100	45	22	12.6	7.2	4.7	3.2	2.29	1.74	1.32	1.9
Spruce, Sitka	22,400	5,890	2,140	250	365	165	83	44	25.1	15.5	9.8	6.3	4.27	3.02	2.14	1.5
Hardwoods:																
Ash, commercial white	12,000	2,190	690	180	105	55	28	11	8.3	5.0	3.2	2.0	1.32	0.89	0.63	0.5
Basswood	36,300	1,740	470	1,290	85	45	27	16	9.6	6.2	4.1	2.8	1.86	1.32	0.93	0.6
Birch	87,000	19,950	4,470	110	470	200	96	53	30.2	18.2	11.5	7.6	5.13	3.55	2.51	1.7
Elm, American	18,200	2,000	350	340	45	20	12	7	3.9	2.3	1.5	1.0	0.66	0.48	0.42	0.4
Hickory, true		31,600	2,190	2,750	115	50	21	11	6.3	3.7	2.3	1.5	1.00	0.71	0.52	0.4
Khaya	44,600	16,600	6,310	2,040	1,260	630	340	180	105.0	60.2	35.5	21.9	14.10	9.33	6.16	4.1
Magnolia	43,700	12,600	5,010	870	910	435	205	105	56.2	29.6	16.2	9.1	5.25	3.09	1.86	1.1
Mahogany, American	20,900	6,760	2,290	690	380	180	85	43	22.4	12.3	7.2	4.4	2.69	1.66	1.07	0.7
Maple, sugar	72,400	13,800	3,160	630	250	105	53	29	16.6	10.2	6.8	4.5	3.16	2.24	1.62	1.2
Oak, commercial red [2]	14,400	4,790	1,590	415	265	125	63	32	18.2	11.3	7.3	4.6	3.02	2.09	1.45	0.9
Oak, commercial white	17,400	3,550	1,100	80	170	80	42	22	12.6	7.2	4.3	2.7	1.70	1.15	0.79	0.6
Shorea [3]	2,890	690	220	815	35	15	9	5	2.8	1.7	1.1	0.7	0.45	0.30	0.21	0.1
Sweetgum	38,000	6,460	2,090	1,820	345	160	81	45	25.7	15.1	9.3	6.0	3.98	2.63	1.78	1.2
Tupelo, black	31,700	12,600	5,020	1,890	725	275	120	58	27.4	13.0	6.9	3.7	2.19	1.38	0.95	0.6

2															
Walnut, black	51,300	9,770	2,630	890	355	155	78	41	22.4	12.9	7.8	4.9	3.16	2.14	1.48	1.0
Yellow-poplar 2	24,000	8,320	3,170	1,260	525	250	140	76	43.7	25.2	14.5	8.7	5.76	3.81	2.64	1.9

Strength of Mechanical Fasteners

Wet wood will not make as strong a joint with mechanical fasteners as will dry wood. Furthermor
which occurs as the wood dries will cause the joints to become loose. Timbers used in heavy co
particular, are often not dried before they are put into service. Drying large timbers requires an e
of time, and often the seasoning defects which occur in the drying process more than offset the i
strength gained by drying. Thus when bolts are used with large timbers, it is necessary to period
nuts as the wood dries. Joints made with other fasteners such as nails and screws in wet wood
the holding power of joints made with seasoned material. One reference (Rietz, 1957) states tha
with green lumber and allowed to season indoors one month before being tested were found to
as rigid as similar panels made of seasoned material and tested immediately. The same source
boxes made of green lumber will dry in service, and the resulting shrinkage results in loss of nail
and consequent loss in strength of the box. Tests showed that boxes made with green material
to a ten percent moisture content may have only one-fourth the strength of similar boxes made

Glue Bonds

The ability of wood to form glue bonds is dependent on its moisture content. For some glues, the
content of the wood must be quite low before a good bond can be formed. Thus, cold-setting ure
better bond with wood at eight to ten percent than at five to six while hot pressed urea-formaldeh
form bonds at a moisture content of two to twenty-six percent (Brown, Panshin, and Forsaith, 19
which dry by evaporation of moisture will vary in their moisture requirements, but in general the
should be low. If large internal stresses are to be avoided in bonded assemblies, the moisture co
after it is bonded should be at an equilibrium moisture content consistent with the atmosphere s
Since glues which dry by loss of moisture add water to the wood, the initial moisture content of th
be below the equilibrium moisture content if the final moisture content of the wood is not to excee
moisture content.

The strength and durability of a glue bond are also dependent on the moisture content. Strong b
animal or vegetable glues at a low moisture content are weakened if the moisture content of the
adhesives of natural origin are destroyed if the moisture content rises to a point where molds ca
adhesives, such as melamine, will form truly waterproof bonds, and these maintain a high propo
strength at any moisture content.

Resistance to Decay

One of the most important reasons for seasoning wood is to reduce its susceptibility to fungal att
responsible for three types of infestation in wood—molds, blue-stain, and decay (Rasmussen, 1
which has been well seasoned can be stored indefinitely in protected and covered sheds without
damage, but green wood cannot. Sapwood, in particular, is vulnerable to attack, especially in mil
weather. Of the three types of fungi, molds are perhaps the least serious, but even light attacks c
has been found that infections from molds and sapstains markedly increase the permeability of

(1952), for example, found that southern pine heavily infected with Trichoderma viride absorbed more preservative oil during a cold soaking treatment than did uninfected wood. The infected wo about 4 times more water during a simulated rain shower than did uninfected wood. Such wood, the weather, soaks up excessive amounts of rain so that it supports decay and as a consequenc seriously damaged.

Molds develop, for the most part, on the surface of the wood although the mycelium may penetra mold is seen as a fluffy or cottony growth on the surface which may range in color from white thr of gray to black. It may also appear as a blue-green, green yellowish, or reddish powder. Discolo wood is due to the spores which are abundantly produced (Boyce, 1961). Mold has little effect o properties of the wood but is usually objectionable because of its appearance (Hunt and Garratt, be allowed in material to be used in food containers, however. Generally, the mold can be brush the surface of the wood so that the value of the wood is little reduced. In kiln drying timber specie low initial drying temperatures and high humidities, molds may grow so luxuriantly that they are air passageways between boards. This is a particular problem in kilns which are improperly desi operating imperfectly so that cold spots develop. Rasmussen (1956), for example, cites a case i occurred in drying a charge of green, 3-inch thick white oak bending stock—a cold zone with a t 3oF. below that desired resulted in development of mold so thick that the air passageways betwe of lumber were practically closed. When temperatures are raised, the molds are finally killed, but the mold may cause the wood to surface check owing to uneven drying. Mold growth in kilns is the common black mold (Mucor spp. and Phizopus spp.). Lumber is most frequently infected by (Penicillium, Trichoderma, and Glioclodium opp.) and also Aspergillus spp. which cause black d (Boyce, 1961).

Blue stain is another fungal defect which like molds may seriously reduce the value of wood eve not seriously weaken it. The stain appears as a blue-gray discoloration which is most obvious on section and less so on a longitudinal section (Kollman, 1936). It is known the world over and ma sapwood of practically all timber, but conifers are more susceptible than are hardwoods. White a red gum and yellow poplar are listed as being especially susceptible (Boyce, 1961). Blue stain is mycelium of several fungi which belong to the genera Ceratocystis among others. Ceratocystis s frequent cause of blue stain in logs and lumber in the United States.

Wood may be infected by spores carried by the wind. In warm humid weather, they germinate a hypha which penetrate the cell walls or pit pores in search of food (Henderson, 1951). Blue stai utilize the contents of the cell cavities rather than the cell walls themselves as in the case of woo fungi. Consequently, the mycelium develop for the most part in the wood rays and parenchyma where most of the food which they utilize is stored. The heartwood is not affected. Although the h utilize the cell walls, they are able to attack it to a limited extent, and the ray cells may be serious hypha develop in vessels, tracheids, and other cells (Boyce, 1961). Hypha pass from one cell to pit openings although they may also form bore holes. This characteristic is of considerable diag distinguishing blue stain from other fungi under the microscope.

The moisture content of the wood is a critical factor in the development of blue stain. Green and wood are not attacked. Boyce (1961) points out that blue stain may occasionally partially infect t some species such as ponderosa pine, sitka spruce, and southern pines, and may even develo heartwood of some living trees such as northern white cedar. It may also develop in the heartwoo are dying. At 30 percent moisture content, the growth of the fungus is greatly retarded, and belo growth practically ceases. Optimum moisture content for growth lies between 33 and 74 percent content, and above 143 percent all growth ceases. Optimum temperatures lie between 75 and 9 to 110 °F. and below 40 to 45 °F. all growth practically ceases (Henderson, 1951). The above va for C. coerulea on Scotch pine. Conditions for other species will vary, but in general, optimum te appear to lie between 75 to 85 °F. and a moisture content of 20 percent is set for the lower limit c

The strength properties of wood are usually not seriously affected by blue stain, and infected wo for most purposes if its appearance is not objectionable. Losses in bending strength for stained c commonly below 5 percent but may occasionally reach 10 percent. Toughness is seriously affec and may be reduced by 30 percent. Tests have shown that staining of hardwoods produces simi reductions in strength (Campbell, 1959).

The most damaging of the three types of fungi are those which cause decay. The weakening effe wood is far out of proportion to any loss of weight noted in the wood. Furthermore, even a slight i enough to make the wood brash or brittle so that it is apt to break suddenly under load (Scheffer,

Wood may be infected either by air-borne spores or by coming into contact with infected materia the fungus sends out thread-like hypha which penetrate the wood in all directions. These hypha extracellular enzymes which depolymerize the various cell wall components into water soluble m fragments (Cowling, 1961). These fragments diffuse back to the hypha where they are assimilat metabolized by the fungus. Fungi are usually described as being either a brown rot type or a whi depending on the nature of the constituents in the wood which they attack. Brown rot fungi attac the wood and leave the brown colored lignin. White rots on the other hand, attack the lignin prim the cellulose which gives a whitish color to the wood. There are a great many fungi which cause common fungus responsible for brown rot is Poria Monticola; a common fungus causing white ro versicolor (Cowling, 1961). An extensive list of wood-destroying fungi is given by Duncan and L Excellent illustrations of discoloration and decay in living northern hardwood trees are given by (1969).

At least a small amount of free water is necessary for diffusion of the extracellular enzymes away partial degradation products to the hypha. Thus, dried wood is protected against attack so long (Cowling, 1963).

Factors Complicating Seasoning

If all trees were alike and no variation existed in wood composition and structure, seasoning coul reduced to a simple standard procedure. Wood is quite variable, however, and consequently a u drying conditions is needed for nearly every species. Two major factors complicate the drying pr uniform moisture content in the material to be dried and lack of a uniform rate at which it dries.

Initial Moisture Content

The moisture content of green wood is not a constant value. It varies among species, within spec individual trees. Individual species differ greatly in moisture content. Average moisture contents 1961) of green soft woods and hardwoods are given in Table 5. Extreme high and low values for 162 percent for black cottonwood and 31 percent for osage orange. Maximum and minimum valu are 149 percent for red cedar and 35 percent for Atlantic white cedar respectively. Using data ex Markwardt and Wilson, (1935) Brown et al. (1952) found the average moisture content of all Nor hardwood species to be about 80 percent with a standard deviation of 28 percent compared to a percent and standard deviation of 33 percent for softwoods.

Moisture distribution in an individual living tree may also be quite varied and hence the position i
which a log is cut will have a bearing on its moisture content. Brown et al. (1952) state that root w
than branch wood, branch wood wetter than stem wood, and lower stem wood wetter than that fr
stem. Rietz (1957) writes that the heartwood of a number of green redwood trees examined decr
moisture content from 160 percent at the stump to 60 percent at a height of about 100 feet. He p
contrast, however, that the moisture content of sapwood increased, but only slightly, with height.

Variation in trees of the same species also exists, and material cut from logs of several trees of a
may show considerable variation in moisture content. Lumber cut from a single tree of almost an
also vary in moisture content depending on whether it is cut from sapwood or heartwood. In gene
difference in moisture content between sap and heartwood in hardwoods than in softwoods. Omi
species in Table 5 for which both sap and heartwood values are not given, for hardwoods the av
content of sapwood is 86.6 percent compared to 89.1 percent for heartwood. In softwoods compa
148.9 percent for sapwood and 58.5 percent for heartwood. The average moisture content of sap
softwood group (148.9 percent) is thus greater than the average moisture content in the hardwo
percent) whereas with respect to heartwood the opposite is true -- 54.5 percent for the softwood
89.1 percent for the hardwoods. It is also notable that the sapwood of Western red cedar (249 pe
pine (219 percent), redwood (210 percent), and incense cedar (210 percent) all attain moisture c
excess of 200 percent, whereas black cottonwood (162 percent) and water tupelo (150 percent) l
the only hardwood species listed which equal or exceed even 150 percent.

Another factor which adds to the complications caused by differences of moisture content is the
drying rate of heartwood and sapwood of even the same species. For example, the sapwood of r
easily and quickly whereas the heartwood dries much more slowly and with a greater degree of
Furthermore, there is also a difference in the rate at which the heartwood of different species drie
heartwood of oak is very difficult to dry as is also that of redwood, whereas the heartwood of bass
dried easily. In general, however, it will be found that hardwoods are more difficult to dry than sof

Table 5: Average moisture content of green wood by species							
Species	Moisture content [1]		Species		Moisture content [1]		
Common Name	Heartwood	Sapwood	Mixed heartwood and sapwood	Common Name	Heartwood	Sapwood	Mixed heartwood and sapwood
SOFTWOODS	Pct.	Pct.	Pct.	HARDWOODS	Pct.	Pct.	Pct.
Baldcypress	121	171	Alder, red	Alnuss rubra		97	
Cedar:				Ash:			
Alaska	32	166		Black	95		
Atlantic white		35		Green		58	
Eastern redcedar	33			White	46	44	

Incense	40	213		Aspen:			
Northern white			55	Bigtooth	95	113	
Port-Orford	50	98		Quaking			
Western redcedar	58	249		Basswood			
Douglas-fir [2]				American	81	133	
Coast	37	115		Beech			
Interior north	37	130		American	55	72	
Interior south	30	130		Birch:			
Interior west	30	140		Paper	89	72	
Fir:				Sweet	75	70	
Balsam	120	140		Yellow	74	72	
California red			108	Butternut			104
Grand	91	136		Cherry, black	58		65
Noble	34	115		Cottonwood:			
Pacific silver	55	164		Black	162	146	
Subalpine			47	Eastern	160	145	
White	98	160		Elm:			
Hemlock:				American	95	92	
Eastern	97	119		Rock	44	57	
Western	85	170		Hackberry	61	65	
Larch, werstern	54	119		Hickory	71	51	
Pine:				Magnolia	80	104	
Eastern white			68	southern			
Jack			70	Maple:			
Lodgepole	41	129		Bigleaf	77	138	
Ponderosa	40	148		Red			70

Red	32	134		Silver	58	97	
Pine:				Sugar	65	72	
Southern:				Oak:			
Loblolly	33	110		Northern red	80	69	
Longleaf	31	106		Northern white	64	78	
Shortleaf	32	105		Southern red	83	75	
Slash	30	100		Southern white (chestnut)	72		
Sugar	98	219		Pecan	71	62	
Western white	62	148		Sweetgum	79	137	
Redwood:				Sycamore	114	130	
Old-growth	86	210		American			
Young-growth	100	200		Tanoak			89
Spruce:				Tupelo:			
Engelmann	51	173		Black	87	115	
Red			55	Water	150	116	
Sitka	41	142		Walnut, black	90	73	
White			55	Willow, black			139
				Yellow-poplar	83	106	

Material Size

Variation in size of material being dried also complicates the seasoning procedure since thick lu
dried much more slowly to avoid defects than thin stock of the same species. As an example (M
in one series of tests, 4/4 hickory was kiln dried in 12 days whereas 8/4 stock required 22 to 41
these and other variations and also because these variations depend to a large extent upon the
of the stock being dried which in turn is continuously changing, drying procedures have never b
reduced to a simple systematic set of rules. Operator skill and experience has been and will likel

an important factor in the efficient drying of lumber.

Methods of Seasoning Wood

Air Drying

Of the methods available for seasoning wood, air drying is the oldest and simplest. Air dried luml
exterior use, and green timber is also frequently allowed to partially air dry prior to kiln drying. Si
effectiveness of the drying process depends upon weather conditions which control the drying ra
moisture content which can be reached, air drying has been replaced by kiln drying in many area
important process. Most air seasoned material is dried in flat piles with stickers placed between l
it is essential to have rapid drying to prevent sap stain, end piling may be used. In humid areas t
necessary if a dry kiln is not available. Such end racking promotes good air circulation and cons
drying which eliminates the staining problem but often causes end surface checking and warping
Another method of piling once used to promote rapid drying was edge piling (Tiemann, 1938).

Although it is generally thought that air drying is a gentle method of seasoning timber, it is often s
depending on the time of the year and the species involved. Material cut from the oaks, sycamore
and other woods which have large rays will surface check readily and consequently thick materia
trees is given special treatment. To eliminate rapid end drying, the ends are frequently coated wi
such as paraffin or tar to retard evaporation, but often this is not enough protection, and it is nece
the material in what are known as semi-kilns in which the drying rate is still more retarded. Semi-
nothing more than covered sheds in which the material is piled, but they may often be large encl
which low heat and controlled humidity are used to slow the drying process. In semi-kilns where
is maintained at 110 °F. to 120 °F. and fans are used to circulate the air, green stock may be drie
percent moisture content in 3 months (Henderson, 1951).

Air seasoning has been extensively treated in the literature. Among those publications which cov
some detail are papers by Fullaway and Hill (1928), Mathewson (1930), Peck (1956), and Rietz
(1971).

Kiln Drying

Kiln drying of lumber is perhaps the most effective and economical method available. Drying rate
be carefully controlled and defect losses reduced to a minimum. Length of drying time is also gre
is predictable so that dry lumber inventories can often be reduced. Where staining is a problem,
often the only reasonable method that can be used unless chemical dips are employed.

Kilns are usually divided into two classes—progressive and compartment (Thelen, 1923). In the
timber enters at one end and moves progressively through the kiln much as a car moves through
Temperature and humidity differentials are maintained throughout the length of the kiln so that th
is progressively dried as it moves from one end to the other. Progressive kilns may be further su
natural draft kilns in which heated air is allowed to rise through the material by natural convectio
draft kilns in which fans are employed to force the air through the wood (Rasmussen, 1955).

Compartment kilns differ from progressive kilns in that the timber is loaded into the kiln and rema
throughout the drying process. Compartment kilns are usually smaller than progressive kilns, an
their construction the temperature and humidity conditions within them can be closely controlled

they are often used to dry expensive material or woods which are difficult to dry. Circulation may
or natural just as with progressive kilns. Drying conditions cannot be controlled as closely in natu
compartment kilns, however, as in forced draft kilns, and the rate of drying is also slower. For the
built today are of the forced draft type and many of the old natural draft types have been converte

Dehumidification Drying

Although dehumidification drying is relatively new compared to conventional kiln drying, it is now
significant numbers of manufacturers. Reasons for its popularity include low capital investment r
conventional kilns and simplicity of operation. The process is based on refrigeration technolgy w
reliable and cost efficient.

A refrigeration-based dehumidifer is used to remove water from the kiln chamber. Heat generate
dehumidifier is returned to the kiln to provide the energy needed for evaporation of moisture from
refrigeration units will not operate efficiently at high temperatures, maximum temperature are limi
°F. although most units operate at lower temperatures. Electric strip heaters or small capacity ele
steam boilers may be used to bring the kiln to these higher temperatures. Drying conditions are
than those used in conventional steam kilns so that drying times may be somewhat longer. Beca
conditions, there is less tendency for drying degrade, and shrinking and warping are reduced. In
the course of drying is enhanced since operators are able to move freely in and out of the kiln at
commonly used. There is no provision for relieving drying stresses, however, unless steam can
into the kiln.

Special Methods

There are many other methods available for drying wood, but for various reasons, chiefly econon
has ever achieved the popularity of air seasoning or kiln drying. Among these "special" methods
seasoning (McMillen, 1960); high frequency di-electric heating (McMillen and James, 1961); res
emersion in hot liquid metal; boiling in oily liquids (McMillen, 1956a); infra-red radiation (Anon. 2
drying (Anon. 3, 1956); vapor drying (Anon. 4), solvent seasoning (McMillen, 1956b); high temp
solar radiation (Peck, 1962) and forced air drying with unheated (Stevens, 1965) and heated air
Torgeson, 1959). A few of these methods are of commercial importance; some are apparently im
at present are uneconomical. Whether these methods are impractical and uneconomical today s
eliminate them from our thinking, however. Many improvements in wood seasoning are yet to be
only by inquisitive thinking into newer and less perfected ways of drying that improvements in th
can be achieved.

Objectives of Seasoning

Regardless of the method used the objectives of any seasoning process are to dry the material t
moisture content with a minimum amount of degrade in a minimum amount of time with a minimu
operating expenses and equipment. These objectives are not all compatible with one another, ar
be sacrificed to satisfy another. The conditions of each situation must necessarily determine the
emphasis placed on each objective. Thus rate of drying must often be retarded to allow the wood
minimum of degrade. If walnut is being dried, this is almost certainly true. If cordwood were bein
firewood, however, drying defects would make little difference, and drying the wood in a minimur
minimum cost would be the only considerations.

References

1. Anon. 1, 1955. Wood Handbook, U.S. Department of Agriculture, Handbook N
Washington, D.C.

2. Radiation, U.S. Forest Products Laboratory Report 1665-6, Madis

3. Anon. 3, 1956. Special Methods of Seasoning Wood: Vacuum Drying, U.S. Forest Pro
Report 1665-5, Madison, Wisconsin.

4. Anon. 4. Special Methods of Seasoning Wood: Vapor Drying, U.S. Forest Products L
1665-3, Madison, Wisconsin.

5. Anon. 5, 1974. Wood Handbook. U.S. Department Agr. Handbook No. 72,

6. Bender, F., 1964. Dimensional Stabilization of Wood, Canadian Dept. of Forestry F
Ottawa.

7. Boyce, J.S., 1961. Forest Pathology. McGraw-Hill, New York.

8. Brown, H.P., A.J. Panshin and C.C. Forsaith, 1952. Textbook of Wood Technology, M
Company, New York.

9. Campbell, R.N., December 15, 1959. Fungus Sap-Stains of Hardwoods.

10. Cowling, E.B., 1961. Comparative Biochemistry of the Decay of Sweetgum Sapwood b
Brown-Rot Fungi. U.S. Department Agr. Tech. Bul. No. 1258.

11. Cowling, Ellis, 1963. "Structural Features of Cellulose that Influence its Susceptibi
Hydrolysis. Advances in Enzymatic Hydrolysis of Cellulose and Related Materials, Edi
Reese, Pergamon Press, New York.

12. Duncan, C.G. and F.F. Lombard, 1965. Fungi Associated with Principal Decays in th
U.S. Forest Serv. For. Prod. Lab. Rept. No. WO-4.

13. Fullaway, S.V. and C.L. Hill, 1928. The Air Seasoning of Western Softwood Lumber. U
Bul. 1425.

14. Henderson, H.L., 1939. The Air Seasoning and Kiln Drying of Wood. J.B. Lyon Co., A

15. Hunt, George M. and George A. Garratt, 1953. Wood Preservation. McGraw-Hill Boo

16. Kimball, K.E. and O.W. Torgeson, 1959. A Small Lumber Drying Unit Employing a Po
for Heat and Air Circulation, U.S. Forest Products Laboratory Report 1799, Madi

17. Kollmann, F., 1936. Technologies des Holzes. Julius Springer Pub

18. Lindgren, Ralph M., 1952. Permeability of Southern Pine as Affected by Mold ar

Infection. Proc. Am. Wood-Preservers' Assoc., Vol. 48.

19. Markwardt, L.J. and T.R.C. Wilson, 1935. Strength and Related Properties of Woo
United States, U.S. Department Agriculture Technical Bulletin 479.

20. Mathewson, J.S., 1930. The Air Seasoning of Wood. U.S. Dept. of Agr.

21. Mathewson, J.S., 1954. High-Temperature Drying: Its Application to the Drying o
Products Research Society Reprint 553, Madison, Wisconsin.

22. McMillen, J.M., 1956a. Special Methods of Seasoning Wood: Boiling in Oily Liq
Products Laboratory Report 1665, Madison, Wisconsin.

23. McMillen, J.M., 1956b. Special Methods of Seasoning Wood: Solvent Seasoning, U.S
Laboratory Report 1665-2, Madison, Wisconsin.

24. McMillen, J.M., 1956c. Seasoning Hickory Lumber and Handle Blanks, Hickory Task
4, U.S. Department of Agriculture, Southeastern Forest Experiment Station, Ashville,

25. McMillen, J.M., 1960. Chemical Seasoning, U.S. Forest Products Laboratory Report
Madison, Wisconsin.

26. McMillen, J.M. and W.L. James, 1961. Hi-Frequency Dielectric Heating, U.S. Forest Pro
Report 1665-7, Madison, Wisconsin.

27. Peck, E.C., 1955. Moisture Content of Wood in Use, U.S. Forest Products Laborat
Madison, Wisconsin.

28. Peck, E.C., 1956. Air Drying of Lumber. U.S. Forest Products Lab. R

29. Peck, E.C., 1962. Drying 4/4 Red Oak by Solar Heat, Forest Products Journ

30. Drying, U.S. Forest Products Laboratory Report 1900-1, Madison, Wisconsin.

31. Rasmussen, E.F., 1955. Types of Ventilated Lumber Dry Kilns. U.S. Forest Product
1900-2.

32. Rasmussen, E.F., 1956. Need for Uniformity of Temperature in a Forced-Air-Circul
Compartment Dry Kiln. U.S. Forest Prod. Lab. Rept. No. 1669.

33. Rasmussen, E.F., 1961. Dry Kiln Operators Manual, U.S. Department of Agricultural Ha
U.S.G.P.O., Washington, D.C.

34. Rietz, R.C., 1957. Importance of Dry Lumber, U.S. Forest Products Laboratory
Madison, Wisconsin.

35. Rietz, R.C. and R.H. Page, 1971. Air Drying of Lumber: A guide to Industry Practices.
of Agr. Handbook No. 402.

36. Scheffer, T.C., 1973. Microbiological Degradation and the Causal Organisms. In "W
and its Prevention by Preservative Treatments" Vol. 1, edited by D.D. Nichols, Syracuse
Syracuse.

37. Shigo, A.L. and E.H. Larson, 1969. A Photo Guide to the Patterns of Discoloration an
Northern Hardwood Trees. USDA Forest Research Paper NE-127.

38. Stevens, W.C., 1965. Forced Air Drying Tests, Timber Trades Jo

39. Thelen, Rolf, 1923. Kiln Drying Handbook U.S. Dept. of Agr. Bull. No. 1136.

40. Tiemann, Harry D. 1938. Lessons in Kiln Drying. Southern Lumberman. Na

41. Wakeham, H., 1955. Mechanical Properties of Cellulose and its Derivatives; High
Cellulose and Cellulose Derivatives, Part 3, p. 1304. Interscience Publicati

42. Wangaard, F.F., 1950. The Mechanical Properties of Wood, p. 183, John Wiley and

Purdue University + Department of Forestry & Natural Resources + 1159 Forestry Bldg. + West Lafayette, IN. 47907