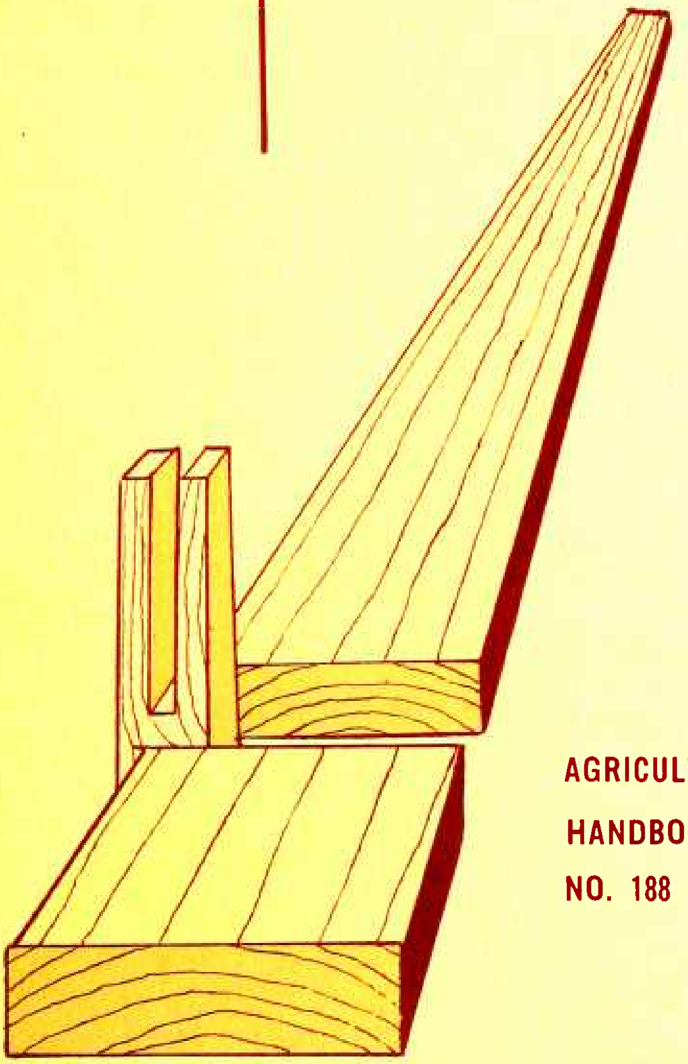
DRY KILN OPERATOR'S MANUAL



AGRICULTURE HANDBOOK NO. 188

U.S. DEPARTMENT OF AGRICULTURE • FOREST SERVICE

DRY KILN OPERATOR'S MANUAL

Agriculture Handbook No. 188

by
EDMUND F. RASMUSSEN,
Engineer

FOREST PRODUCTS LABORATORY,
FOREST SERVICE,
U.S. DEPARTMENT OF AGRICULTURE

(*Maintained at Madison, Wisconsin, in cooperation with the University of Wisconsin*)

Growth Through Agricultural Progress

1961
March

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.
Price $1

ACKNOWLEDGMENT

In the writing of this manual, the author received much valued assistance and information from other staff members of the Forest Products Laboratory, other units of the Forest Service, and companies and individuals active in the lumber industry. The very magnitude of this help makes individual acknowledgment to all who contributed impractical.

Special acknowledgment is made to Raymond C. Rietz for overall planning and supervision of the project; and to Edward C. Peck, John M. McMillen, Harvey H. Smith, and A. C. Knauss for their helpful assistance, respectively, in preparing the sections of the manuscript on storage of wood, kiln schedules, kiln samples, and drying defects. (Rietz, Peck, and McMillen are members of the Forest Products Laboratory staff; Smith is a technologist with the Pacific Southwest Forest and Range Experiment Station; and Knauss is on the staff of the Pacific Northwest Forest and Range Experiment Station.)

In addition, the author gratefully acknowledges the contribution of information, advice, and guidance received from the many manufacturers of dry kilns, control instruments, and auxiliary equipment, and from consulting engineers and dry kiln operators.

CONTENTS

INTRODUCTION

The modern dry kiln is a unique product of research and development. It represents the only practical means now in wide use for rapid, high-volume seasoning of lumber to conditions essential for maximum serviceability in housing, farm structures, furniture, vehicles, ships and boats, sporting goods, and many other wood products. In its development, Forest Service research begun more than half a century ago has been a major factor.

A well-designed dry kiln, properly operated, can in a few days or weeks transform green lumber fresh from the forest into a dry, stable material essential for successful industrial enterprises in today's highly competitive markets. The more critical the seasoning requirements, the more firmly the dry kiln becomes established as an integral part of the lumber mill, the millwork plant, the furniture factory. For many wood products, kiln-dried lumber is indispensable.

Well-seasoned lumber has many advantages for producers and users alike. Removal of excess moisture reduces weight and, thereby, shipping and handling costs. Proper seasoning confines shrinking and swelling to inconsequential amounts under all but extreme conditions of use. Properly seasoned wood can be cut to precise dimensions and machined more easily and efficiently; wood parts are more readily and securely fitted and fastened together with nails, screws, bolts, and adhesives; warping, splitting, checking, and other harmful effects of uncontrolled drying are largely eliminated; paint, varnish, and other finishes are more effectively applied and maintained; and decay hazards are eliminated if the wood is subsequently treated or protected from excessive moisture regain.

Efficient kiln-drying of lumber is therefore of key importance in the utilization of our forest resources. On the one hand, it helps to assure continued markets for wood products by increasing their service life and contributing to consumer satisfaction. On the other, it in effect helps to conserve supplies of wood, and thereby our timber resources, by extending service life and usefulness of the product. Both are essential in attaining wise use of timber, which has long been an accepted tenet of United States forest conservation policy.

Because adequate supplies of well-seasoned lumber are essential alike to producers and consumers of wood products, research in the drying of wood has been conducted by the Forest Products Laboratory ever since it was founded in 1910. This program includes both fundamental research on the physical processes by which wood gives off and takes on moisture and applied research on means of accelerating and controlling these processes.

The fruits of much of the Laboratory's research have been directly applied in the design, construction, and operation of dry kilns. United States patents obtained by the Laboratory are available for public use. Industry uses basic drying schedules that have been developed for many of the commercially important wood species. Demonstrations conducted from time to time by Laboratory personnel attract hundreds of kiln operators. The purpose of these demonstrations is to show how research findings can be put to use to achieve fast, high-quality kiln-drying of lumber.

This manual presents knowledge of kiln-drying principles that will be of most direct usefulness to owners and operators of dry kilns. Unless stated otherwise, the techniques described can be applied in the drying of lumber, dimension stock, cooperage stock, and many special items such as gunstock, bowling pin, and shoe-last blanks. This manual is also intended as a text on the theory and practice of kiln-drying, and it should prove of value to students of wood technology, dry kiln manufacturers, and producers of wood products in general.

The full benefits of modern dry kilns can be gained only when certain prerequisites are observed. Mill management must recognize the importance of efficient operation to quality of product, and operators must be well trained and encouraged to apply the best techniques. Quality should not be sacrificed for quantity in the production of kiln-dried stock best suited for the products being made. Also, adequate attention must be paid to proper maintenance of kilns and auxiliary equipment.

Insofar as possible, the use of proprietary terms has been avoided in this manual. Where necessary to describe a given type of equipment or procedure, however, such use was authorized by the owner of the proprietary interest. The use of these proprietary terms, or the illustration of proprietary products, does not constitute an endorsement by the Forest Products Laboratory or the U.S. Department of Agriculture.

Certain dry kilns and equipment described and illustrated herein may have features protected under the patent laws of the United States. The use of such descriptions and illustrations by the Laboratory cannot be construed as giving or implying any protection to others from legal action for infringement of patent rights.

Terms used in this manual to describe dry kilns and their component parts, drying characteristics of wood, and kiln operational procedures are generally accepted and used throughout the industry. There are, however, some exceptions. For the purpose of clarification, and to help an inexperienced kiln operator to become familiar with terms used in kiln drying, a glossary of terms is included (p. 177).

CHAPTER 1. PROPERTIES OF WOOD RELATED TO DRYING

Considerably more than 100 commercially important species of trees grow in the United States. The wood they produce varies greatly in its drying characteristics. Since there are also many variations in other characteristics of the wood of these species, it is necessary for the kiln operator to have a sound working knowledge of these characteristics to do an effective job of kiln-drying. This chapter is concerned with such variability.

The most commonly used commercial names for lumber and the corresponding species names accepted by the Forest Service (*4*)[1] for the trees from which it is cut are given in the following list. The list was adapted from the Standard Nomenclature of Domestic Hardwoods and Softwoods adopted in 1952 by the American Society for Testing Materials. While the commonly used lumber names are generally satisfactory for the buying and selling of lumber, they sometimes cover lumber from a number of species that differ in their moisture content when green, their shrinkage, or their seasoning characteristics. Therefore, in the tables and indexes of drying schedules given elsewhere in this manual, the woods are arranged alphabetically by the common species names accepted by the Forest Service.

[1] Italic numbers in parentheses refer to Literature Cited, p. 21.

HARDWOODS

Commercial name for lumber	*Common tree name*	*Botanical name*
Alder:		
Red alder	red alder	*Alnus rubra*
Apple	apple	*Malus* spp.
Ash:		
Black ash [1]	black ash	*Fraxinus nigra*
Oregon ash	Oregon ash	*F. latifolia*
Pumpkin ash	pumpkin ash	*F. profunda*
White ash	blue ash	*F. quadrangulata*
	green ash	*F. pennsylvanica*
	white ash	*F. americana*
Aspen [2]	bigtooth aspen	*Populus grandidentata*
	quaking aspen	*P. tremuloides*
Basswood [3]	American basswood	*Tilia americana*
	white basswood	*T. heterophylla*
Beech	beech	*Fagus grandifolia*
Birch [4]	gray birch	*Betula populifolia*
	paper birch	*B. papyrifera*
	river birch	*B. nigra*
	sweet birch	*B. lenta*
	yellow birch	*B. alleghaniensis*
Box elder	boxelder	*Acer negundo*
Buckeye	Ohio buckeye	*Aesculus glabra*
	yellow buckeye	*A. octandra*
Butternut	butternut	*Juglans cinerea*
Cherry	black cherry	*Prunus serotina*
Chestnut	American chestnut	*Castanea dentata*
Cottonwood	balsam poplar	*Populus balsamifera*
	black cottonwood	*P. trichocarpa*
	eastern cottonwood	*P. deltoides*
	plains cottonwood	*P. sargentii*
	swamp cottonwood	*P. heterophylla*
Cucumber	cucumbertree	*Magnolia acuminata*
Dogwood	flowering dogwood	*Cornus florida*
	Pacific dogwood	*C. nuttallii*

[1] Black ash is known commercially in some consuming centers as brown ash, and is also sometimes designated as such in specifications.
[2] Aspen lumber is sometimes designated as popple.
[3] For some commercial uses where a white appearance is a requirement, the sapwood of American basswood (*Tilia americana*) is specified under the designation "white basswood." This commercial-use designation should not be confused with the species (*T. heterophylla*) having the common name white basswood.
[4] The principal lumber species is yellow birch. It may be designated either sap birch (all sapwood) or red birch (all heartwood) or it may be unselected. Sweet birch is sold without distinction from yellow birch. Paper birch is a softer wood used principally for turnings and novelties and is widely known as white birch. The remaining birches are of minor commercial importance.

HARDWOODS—Continued

Commercial name for lumber	*Common tree name*	*Botanical name*
Elder, *see* Box elder		
Elm:		
Rock elm	cedar elm	*Ulmus crassifolia*
	rock elm	*U. thomasii*
	September elm	*U. serotina*
	winged elm	*U. alata*
Soft elm [5]	American elm	*U. americana*
	slippery elm	*U. rubra*
Gum [6]	sweetgum	*Liquidambar styraciflua*
Hackberry	hackberry	*Celtis occidentalis*
	sugarberry	*C. laevigata*
Hickory [7]	mockernut hickory	*Carya tomentosa*
	pignut hickory	*C. glabra*
	sand hickory	*C. pallida*
	shagbark hickory	*C. ovata*
	shellbark hickory	*C. laciniosa*
Holly	American holly	*Ilex opaca*
Ironwood	eastern hophornbeam	*Ostrya virginiana*
Locust	black locust	*Robinia pseudoacacia*
	honeylocust	*Gleditsia triacanthos*
Madrone	Pacific madrone	*Arbutus menziesii*
Magnolia	southern magnolia	*Magnolia grandiflora*
	sweetbay	*M. virginiana*
Maple:		
Hard maple [8]	black maple	*Acer nigrum*
	sugar maple	*A. saccharum*
Oregon maple	bigleaf maple	*A. macrophyllum*
Soft maple [8]	red maple	*A. rubrum*
	silver maple	*A. saccharinum*
Mulberry	red mulberry	*Morus rubra*
Myrtle, *see* Oregon myrtle		
Oak:		
Red oak	black oak	*Quercus velutina*
	blackjack oak	*Q. marilandica*
	California black oak	*Q. kelloggii*
	cherrybark oak	*Q. falcata* var. *pagodaefolia*
	laurel oak	*Q. laurifolia*
	northern pin oak	*Q. ellipsoidalis*
	northern red oak	*Q. rubra*
	Nuttall oak	*Q. nuttallii*
	pin oak	*Q. palustris*
	scarlet oak	*Q. coccinea*
	Shumard oak	*Q. shumardii*
	southern red oak	*Q. falcata*
	turkey oak	*Q. laevis*
	willow oak	*Q. phellos*
White oak	Arizona white oak	*Q. arizonica*
	blue oak	*Q. douglasii*
	bur oak	*Q. macrocarpa*
	California white oak	*Q. lobata*
	chestnut oak	*Q. prinus*
	chinkapin oak	*Q. muehlenbergii*
	Emory oak	*Q. emoryi*
	Gambel oak	*Q. gambelii*
	Mexican blue oak	*Q. oblongifolia*
	live oak	*Q. virginiana*
	Oregon white oak	*Q. garryana*
	overcup oak	*Q. lyrata*
	post oak	*Q. stellata*
	swamp chestnut oak	*Q. michauxii*
	swamp white oak	*Q. bicolor*
	white oak	*Q. alba*
Oregon myrtle	California-laurel	*Umbellularia californica*
Osage orange	Osage-orange	*Maclura pomifera*

[5] Soft elm lumber is sometimes designated as white elm. A special type of slowly grown material is sometimes designated commercially as gray elm. Slippery elm is called red elm is some localities, although that term is also used for two other elms.

[6] Usually designated either as red gum or as sap gum, as the case may be, or as gum or sweetgum when not selected for color. (For black gum, *see* tupelo, footnote 9.)

[7] The impossibility of distinguishing between hickory and pecan lumber for accurate species identification is recognized. Three of the four major *Carya* species in the pecan group (which see) have the word "hickory" in their name.

[8] When hard maple or soft maple is specified to be white, the specification generally is interpreted as being a requirement for sapwood, although it sometimes may take on the special meaning of being all sapwood with a minimum of natural color.

HARDWOODS—Continued

Commercial name for lumber	*Common tree name*	*Botanical name*
Pecan [7]	bitternut hickory	*Carya cordiformis*
	nutmeg hickory	*C. myristicaeformis*
	water hickory	*C. aquatica*
	pecan	*C. illinoensis*
Persimmon	common persimmon	*Diospyros virginiana*
Poplar	yellow-poplar	*Liriodendron tulipifera*
Sassafras	sassafras	*Sassafras albidum*
Silverbell	Carolina silverbell	*Halesia carolina*
Sycamore	American sycamore	*Platanus occidentalis*
Tanoak	tanoak	*Lithocarpus densiflorus*
Tupelo [9]	black tupelo	*Nyssa sylvatica*
	Ogeechee tupelo	*N. ogeche*
	swamp tupelo	*N. silvatica* var. *biflora*
	water tupelo	*N. aquatica*
Walnut	black walnut	*Juglans nigra*
Willow	black willow	*Salix nigra*
	peachleaf willow	*S. amygdaloides*
SOFTWOODS		
Cedar:		
Alaska cedar	Alaska-cedar	*Chamaecyparis nootkatensis*
Incense cedar	incense-cedar	*Libocedrus decurrens*
Port Orford cedar	Port-Orford-cedar	*Chamaecyparis lawsoniana*
Eastern red cedar	eastern redcedar	*Juniperus virginiana*
	southern redcedar	*J. silicicola*
Western red cedar	western redcedar	*Thuja plicata*
Northern white cedar	northern white-cedar	*T. occidentalis*
Southern white cedar	Atlantic white-cedar	*Chamaecyparis thyoides*
Cypress [10]	baldcypress	*Taxodium distichum*
	pondcypress	*T. distichum* var. *nutans*
Fir:		
Balsam fir [11]	balsam fir	*Abies balsamea*
	Fraser fir	*A. fraseri*
Douglas fir [12]	Douglas-fir	*Pseudotsuga menziessii*
	———	*P. menziesii* var. *glauca*
Noble fir	noble fir	*Abies procera*
White fir	California red fir	*A. magnifica*
	grand fir	*A. grandis*
	noble fir	*A. procera*
	Pacific silver fir	*A. amabilis*
	subalpine fir	*A. lasiocarpa*
	white fir	*A. concolor*
Hemlock:		
Eastern hemlock	Carolina hemlock	*Tsuga caroliniana*
	eastern hemlock	*T. canadensis*
Mountain hemlock	mountain hemlock	*T. mertensiana*
West coast hemlock	western hemlock	*T. heterophylla*
Juniper:		
Western juniper	alligator juniper	*Juniperus deppeana*
	Rocky Mountain juniper	*J. scopulorum*
	Utah juniper	*J. osteosperma*
	western juniper	*J. occidentalis*
Larch:		
Western larch	western larch	*Larix occidentalis*
Pine:		
Jack pine	jack pine	*Pinus banksiana*
Lodgepole pine	lodgepole pine	*P. contorta*
Norway pine	red pine	*P. resinosa*
Ponderosa pine	ponderosa pine	*P. ponderosa*
Sugar pine	sugar pine	*P. lambertiana*
Idaho white pine	western white pine	*P. monticola*
Northern white pine	eastern white pine	*P. strobus*
Longleaf yellow pine [13]	longleaf pine	*P. palustris*
	slash pine	*P. elliottii*

[9] The impossibility of distinguishing between black tupelo (blackgum), swamp tupelo, and water tupelo lumber for accurate species identification is recognized.

[10] Cypress includes types designated as red cypress, white cypress, and yellow cypress. Red cypress is frequently classified and sold separately from the other types.

[11] Balsam fir lumber is sometimes designated either as eastern fir or as balsam.

[12] Douglas fir may be specified either as Coast Region Douglas fir or as Inland Region Douglas fir, but if the particular type is not so specified or is not otherwise indicated through the grade specifications, either or both types will be allowed.

[13] The commercial requirements for longleaf yellow pine lumber are that not only must it be produced from trees of the botanical species of *Pinus elliottii* and *P. palustris*, but each piece in addition must average either on one end or the other not less than six annual rings per inch and not less than one-third summerwood. Longleaf yellow pine lumber is sometimes designated as pitch pine in the export trade.

SOFTWOODS—Continued

Commercial name for lumber	Common tree name	Botanical name
Southern yellow pine	loblolly pine	*Pinus taeda*
	longleaf pine	*P. palustris*
	pitch pine	*P. rigida*
	shortleaf pine	*P. echinata*
	slash pine	*P. elliottii*
	Virginia pine	*P. virginiana*
Redwood	redwood	*Sequoia sempervirens*
Spruce:		
Eastern spruce	black spruce	*Picea mariana*
	red spruce	*P. rubens*
	white spruce	*P. glauca*
Engelmann spruce	blue spruce	*P. pungens*
	Engelmann spruce	*P. engelmannii*
Sitka spruce	Sitka spruce	*P. sitchensis*
Tamarack	tamarack	*Larix laricina*
Yew:		
Pacific yew	Pacific yew	*Taxus brevifolia*

Hardwoods and Softwoods

Trees are divided into two classes, hardwoods and softwoods. The hardwoods, such as birch, elm, maple, and the oaks, have broad leaves. Some softwoods or conifers, such as the cedars, have scalelike leaves, while others, such as the pines, Douglas-fir, and the spruces, have needlelike leaves.

The terms "hardwood" and "softwood" are not directly associated with the hardness or softness of the wood. In fact, such hardwood trees as cottonwood and yellow-poplar have softer wood than such softwoods as longleaf pine and Douglas-fir.

Gross Structural Features of Wood

A cross section of an oak tree is shown in figure 1. The outer part of the tree is the outer bark (*C*). Just beneath is a layer called the inner bark (*B*), and beneath it is the cambium (*A*).

Sapwood

Sapwood (fig. 1, *D*) plays an important part in a tree's living processes. In general, only the last few outside layers of the sapwood are alive. The rest of the sapwood carries moisture from the roots to the leaves and stores food for the tree. It usually has a higher moisture content than the heartwood.

Heartwood

During the life of a tree, sapwood gradually changes into heartwood (fig. 1, *E*). As it does so, it becomes less permeable. Since moisture movement is thus retarded considerably, heartwood dries more slowly than sapwood. Heartwood usually surface checks and honeycombs more readily than sapwood, hence requires milder drying conditions. It is usually darker in color and also more resistant to decay than sapwood. Since the color change may require several years, a band of heartwood may have the same color as the sapwood next to it, yet not dry so easily because it is less permeable.

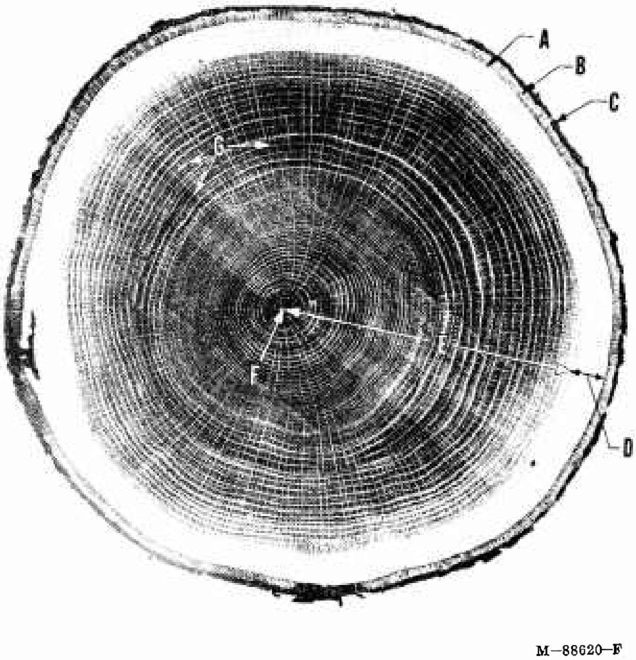


FIGURE 1.—Cross section of an oak tree: *A*, Cambium layer (microscopic) is inside of inner bark and forms wood and bark cells. *B*, Inner bark is moist and soft, carries prepared food from leaves to all growing parts of tree. *C*, Outer bark or corky layer is composed of dry dead tissue, gives general protection against external injuries. *D*, Sapwood is the light-colored wood beneath the bark; it carries sap from roots to leaves. *E*, Heartwood (inactive) is formed by a gradual change in the sapwood; it gives the tree strength. *F*, Pith is the soft tissue about which the first wood growth takes place in the newly formed twigs. G, Wood rays are strips of cells that extend radially within the tree and serve primarily to store and transport food.

Pith

The pith of a tree (fig. 1, *F*) is laid down by the growing tip. It is usually very small and of no practical importance in the drying of wood. The juvenile wood immediately around the pith, however, differs in some ways from most of the wood in the tree, and it is almost impossible to dry such wood without drying defects.

Annual Growth Rings

Diameter growth of a tree in temperate climates is represented by rings that usually can be easily seen on the end of a log as concentric circles about the pith. The closer the annual rings are to the pith, the greater their degree of curvature. Each annual growth ring is composed of springwood and summerwood (in some places known as early wood and late wood). The inner part, which is formed early in the growing season, is called springwood, and the outer part, formed later, is called summerwood. When lumber is cut from a log, the annual rings are cut across in one direction or another and form a pattern on the broad faces of the boards. Typical patterns are shown in figure 2.

Wood Rays

Wood rays appear as ribbonlike strands on the face of a quartersawed board (fig. 2, *A*). Because they are relatively weak, surface, end, and honeycomb checks usually occur in or next to them. Such woods as oak and beech, which have large rays, require special care during the early stages of drying in order to minimize surface and end checking.

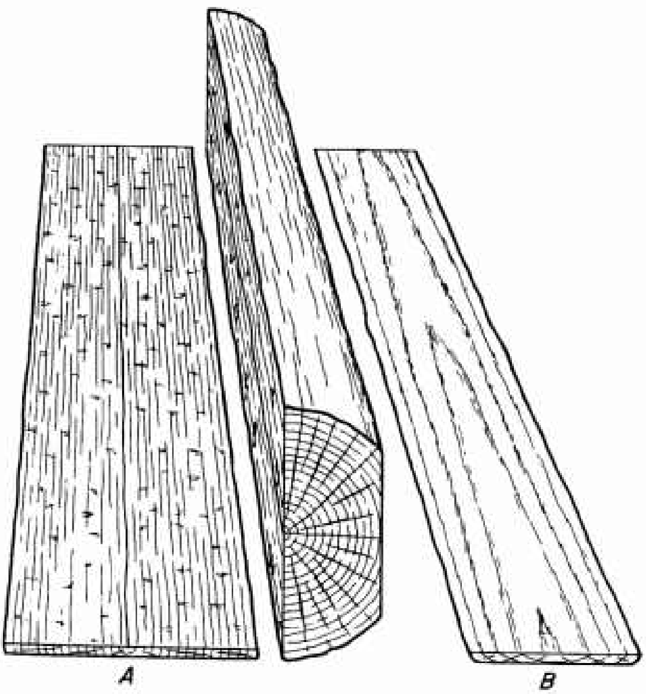


FIGURE 2.—*A*, A quartersawed board shows the edge of the annual rings on its broad face; *B*, a plainsawed board shows the side of the rings.

Grain and Texture

The physical characteristics of various woods that have some bearing on drying are loosely termed "grain" and "texture." Several terms are used in describing grain. The terms "fine-grained" and "coarse-grained" refer to ring pattern, either the prominence of the summerwood band or the width of the rings. When used in connection with wood cells, grain refers only to the direction of the cells or fibers. In straight-grained wood, the fibers run generally parallel to the length of the board, and in cross-grained wood they run at an angle. The terms "end grain" and "side grain" are also commonly used in discussing moisture loss and seasoning defects. A cross section of a log or board has an end-grain surface. Any other section, radial, tangential, or intermediate, has a side-grain surface.

Texture usually refers to the diameter of individual cells. Fine-textured wood has small cells; coarse-textured wood has large cells. If all the cells of a softwood or all the pores of a hardwood are of approximately the same size, the wood is usually called "uniform-textured." Coarse-textured woods usually dry faster than fine-textured woods. Uniform-textured woods in general are less likely to develop drying defects than are nonuniform-textured woods. The word "texture" should not be used in describing hardness of wood.

Variations in Structure

Lumber commonly contains variations in wood structure, such as knots, spiral grain, tension wood, and compression wood.

Cross grain in lumber may result either from the way in which the log is sawed (diagonal grain) or from spiral grain that occurred in the growing tree. When spiral grain alternately runs in one direction and another in successive groups of growth rings, interlocked grain results. Lumber containing diagonal, spiral, or interlocked grain shrinks more in length than does straight-grained lumber. Such lumber may bow, crook, and twist during drying.

Knots are sections of tree branches appearing in boards. Because of shrinkage, some kinds of knots may drop out during drying; more often, however, they are loosened or checked during drying and drop out of the boards during handling or machining. These are called "incased" knots; they result from dead branches around which trunk wood later grew. Intergrown knots, caused by living branches intergrown with trunk wood, are much less likely to drop out of dried lumber.

Compression wood occurs in softwoods mainly on the lower side of leaning trees but sometimes in other parts of the tree trunk. Because this wood shrinks more longitudinally than normal wood, boards that contain compression wood may bow, crook, and twist during drying. If this warping is restrained, the compression wood may rupture and form cross-breaks in the lumber.

Tension wood occurs in hardwoods, mainly on the upper side of leaning trees but sometimes in other parts of the trunk. Lumber containing this wood will shrink more longitudinally than will normal wood, causing warp during drying.

Further information on wood structure is available elsewhere (*2*, *9*).

Wood-Moisture Relations

All wood in growing trees contains considerable quantities of water, commonly called sap. Although sap contains some materials in solution, from the drying standpoint it is considered to be plain water. Most of this water should be removed in order to obtain satisfactory service from the wood in use. All wood gains or loses moisture in an attempt to reach a state of balance with the conditions under which it is stored or used. This state of balance depends upon the relative humidity and temperature of the surrounding air. Therefore, some knowledge of wood-moisture relations is helpful in understanding what happens to wood during drying, storage, fabrication, and use.

Water is held by wood in two ways, as "free water" in the cell cavities and as "bound water" in the cell walls. The free water does not affect the properties of wood other than weight. The bound water, however, does affect many properties of wood, and is more difficult to remove in drying.

Moisture Content

The amount of moisture in wood is spoken of as its moisture content, and is expressed as a percentage of the ovendry weight of the wood.

The universally accepted method of determining the moisture content of wood is the ovendrying method, or oven test. This method, described in chapter 6, is used to calculate moisture content from weight values obtained from a section of wood before and after it has been ovendried. Other methods of determining the moisture content of wood are described in chapter 3.

The amount of water in green wood varies greatly. One wood may contain as little as 30 percent; another may contain 200 percent or more. Large variations may occur not only between species but also within the same species and even in the same tree. Sapwood usually contains more water than heartwood. In some species the butt logs of the tree may contain more water than the top logs. One example of this is redwood.

Contrary to a popular belief, the amount of water in green wood does not vary greatly with the season of the year in which the trees are cut. Some species of wood contain zones of unusually high moisture content, commonly called water pockets. This water moves out very slowly during the drying process. Woods such as eastern white pine, noble fir, western hemlock, and sweetgum frequently contain water pockets. Moisture content values for green wood of various species are given in table 1.

The Fiber Saturation Point.—This is defined as the point at which the cell walls are saturated, but no free water remains in the cell cavities. Moisture content of the individual cell walls at the fiber saturation point is approximately 30 percent for all woods. The term "fiber saturation point" pertains to the moisture content of the walls of a cell and not to the whole piece of wood. For example, if the average moisture content of a whole piece of wood is at 30 percent, some of the cell cavities will contain free water.

The fiber saturation point is important in the drying of wood for the following reasons: (1) more heat is required to move water from a cell wall than from a cavity; (2) a wood cell will not shrink until it reaches the fiber saturation point; and (3) large changes in the physical and mechanical properties of wood begin to take place at the fiber saturation point.

Equilibrium Moisture Content.—Any piece of wood gives off or takes on moisture until the amount it contains is in balance with that in the surrounding atmosphere. The amount of moisture in the wood at the point of balance is called the equilibrium moisture content. Assuming constant temperature, the ultimate moisture content that a given piece of wood will attain depends entirely upon the relative humidity of the air surrounding it. This relationship is illustrated in figure 3, which shows, for example, that wood kept in air constantly at 141° F. and 65 percent relative humidity will eventually come to equilibrium at a moisture content of about 10 percent. Equilibrium moisture content is designated by the letters EMC.

To assure proper control of drying conditions in a kiln, both temperature and relative humidity must be accurately measured. Two thermometers are used for this purpose. One measures temperature in the usual way. The bulb of the other is kept wet with a wicklike cover, from which water evaporates at a rate deter-

TABLE 1.—*Average moisture content of green wood*

SOFTWOODS

Species	Moisture content [1]		
	Heartwood	Sapwood	Mixed heartwood and sapwood
	Percent	*Percent*	*Percent*
Baldcypress	121	171	
Cedar:			
Alaska-	32	166	
Atlantic white-			35
Eastern redcedar	33		
Incense-	40	213	
Northern white-			55
Port-Orford-	50	98	
Western redcedar	58	249	
Douglas-fir:			
Coast type	37	115	
Intermediate type	34	154	
Rocky Mountain type	30	112	
Fir:			
Balsam			117
California red			108
Grand	91	136	
Noble	34	115	
Pacific silver	55	164	
Subalpine			47
White	98	160	
Hemlock:			
Eastern	97	119	
Western	85	170	
Larch, western	54	119	
Pine:			
Eastern white			68
Lodgepole	41	120	
Ponderosa	40	148	
Red	32	134	
Southern yellow:			
Loblolly	33	110	
Longleaf	31	106	
Shortleaf	32	122	
Sugar	98	219	
Western white	62	148	
Redwood:			
Old-growth	86	210	
Second-growth			127
Spruce:			
Black	34	128	
Engelmann	51	173	
Sitka	41	142	
Tamarack	49		

HARDWOODS

Species	Heartwood	Sapwood	Mixed heartwood and sapwood
Alder, red		97	
Apple	81	74	
Ash:			
Black	95		
Green		58	
White	46	44	
Aspen	95	113	
Basswood, American	81	133	
Beech, American	55	72	

TABLE 1.—*Average moisture content of green wood*—Continued

HARDWOODS—Continued

Species	Moisture content [1]		
	Heartwood	Sapwood	Mixed heartwood and sapwood
	Percent	*Percent*	*Percent*
Birch:			
Paper	89	72	
Sweet	75	70	
Yellow	74	72	
Buckeye, yellow			141
Butternut			104
Cherry, black	58		
Chestnut, American	120		
Chinkapin, golden			134
Cottonwood, black	162	146	
Dogwood, flowering			62
Elm:			
American	95	92	
Cedar	66	61	
Rock	44	57	
Hackberry	61	65	
Hickory:			
Bitternut	80	54	
Mockernut	70	52	
Pignut	71	49	
Red	69	52	
Sand	68	50	
Water	97	62	
Holly, American			82
Hophornbeam, eastern			52
Laurel, California			65
Locust, black			40
Madrone, Pacific			81
Magnolia	80	104	
Maple:			
Silver (soft)	58	97	
Sugar (hard)	65	72	
Oak:			
California black	76	75	
Live			50
Northern red	80	69	
Southern red	83	75	
Southern swamp	79	66	
Water	81	81	
White	64	78	
Willow	82	74	
Osage-orange			31
Persimmon, common			58
Sweetgum	79	137	
Sycamore, American	114	130	
Tanoak			89
Tupelo:			
Black	87	115	
Swamp	101	108	
Water	150	116	
Walnut, black	90	73	
Willow, black			139
Yellow-poplar	83	106	

[1] Based on ovendry weight.

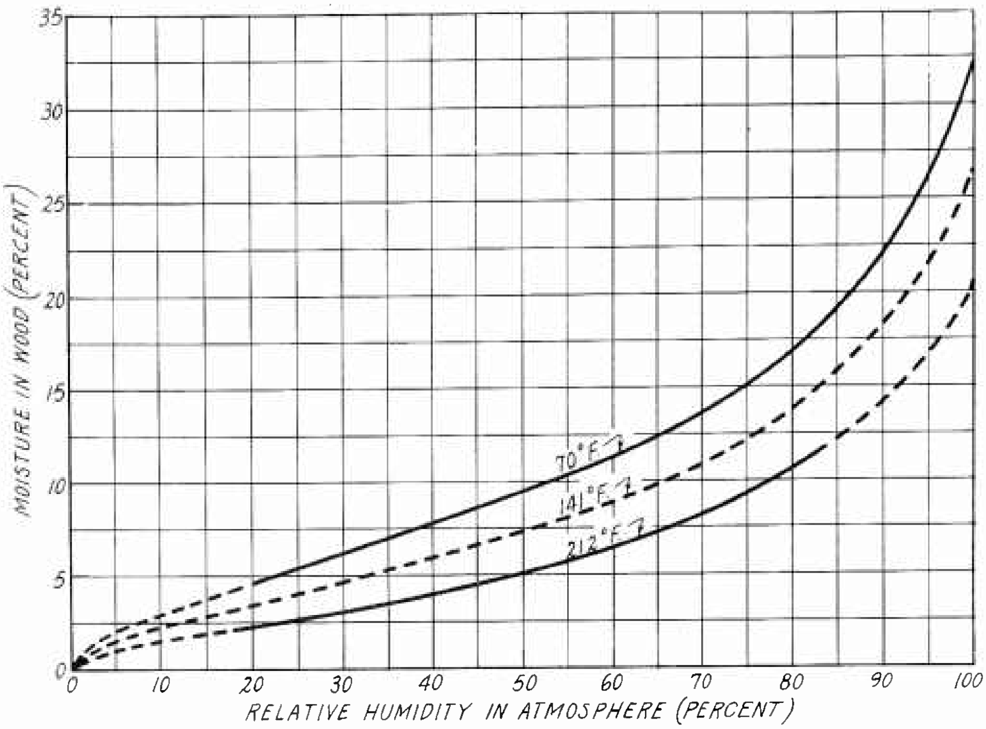


Figure 3.—Relation of the equilibrium moisture content of wood to the relative humidity of the surrounding atmosphere at three temperatures.

mined by the dryness of the air around it. This evaporation has a cooling effect that increases as evaporation speeds up. Thus, the dryer the air, the greater the cooling effect, and the lower the temperature recorded by the wet-bulb thermometer. The difference between the dry-bulb and wet-bulb temperatures—called the wet-bulb depression—is thus a measure of the relative humidity in the air.

In kiln-drying, it is more convenient to convert wet-bulb depressions at given dry-bulb temperatures directly into EMC values. The EMC values for various dry-bulb temperatures and wet-bulb depressions commonly used in kiln drying are shown in table 2.

For example, assume that the dry-bulb temperature in a kiln is 150° F. and the wet-bulb temperature 130°. The wet-bulb depression, that is, the difference between these two temperatures, is 20°. Wet-bulb depression values are shown across the top of table 2, and dry-bulb temperatures on the extreme left of the table. To find the EMC at the assumed conditions, (1) locate the 20° wet-bulb depression column, (2) follow this column downward until it intersects the 150° dry-bulb temperature line, and (3) read the EMC value, 8 percent, given at this intersection in italic type.

How Wood Dries

Water in wood normally moves from zones of higher to zones of lower moisture content (*1*). This fact supports the familiar statement that "wood dries from the outside in," which means that the surface of the wood must be drier than the interior if moisture is to be removed. In drying, the surface fibers of the heartwood of most species attain moisture equilibrium with the surrounding atmosphere almost as soon as drying begins, and at this time a moisture gradient begins to develop. The surface fibers of sapwood also tend to reach a state of balance with the surrounding drying atmosphere early in the drying process, if the air circulation is fast enough to evaporate the water as rapidly as it comes to the surface of the wood. If the air circulation is too slow, however, a longer time is required for the surfaces of sapwood to attain equilibrium. To reduce drying time, the initial wet-bulb depression in the kiln should be as large as possible without causing serious end or surface checking.

Moisture in wood moves as liquid or vapor through several kinds of passageways. These consist of the cavities of fibers and vessels, wood ray cells, pit chambers and their pit membrane

Table 2.—*Relative humidity*[1] *and equilibrium moisture content*[2] *values occurring at various dry-bulb temperatures and wet-bulb depressions*

Temperature dry bulb (°F.)	Wet-bulb depression (°F.)																																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	32	34	36	38	40	45	50
30	89	78	67	57	46	36	27	17	6	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	*15.9*	*12.9*	*10.8*	*9.0*	*7.4*	*5.7*	*3.9*	*1.6*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
35	90	81	72	63	54	45	37	28	19	11	3	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	*16.8*	*13.9*	*11.9*	*10.3*	*8.8*	*7.4*	*6.0*	*4.5*	*2.9*	*0.8*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
40	92	83	75	68	60	52	45	37	29	22	15	8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	*17.6*	*14.8*	*12.9*	*11.2*	*9.9*	*8.6*	*7.4*	*6.2*	*5.0*	*3.5*	*1.9*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
45	93	85	78	72	64	58	51	44	37	31	25	19	12	6	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	*18.3*	*15.6*	*13.7*	*12.0*	*10.7*	*9.5*	*8.5*	*7.5*	*6.5*	*5.3*	*4.2*	*2.9*	*1.5*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
50	93	86	80	74	68	62	56	50	44	38	32	27	21	16	10	5	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	*19.0*	*16.3*	*14.4*	*12.7*	*11.5*	*10.3*	*9.4*	*8.5*	*7.6*	*6.7*	*5.7*	*4.8*	*3.9*	*2.8*	*1.5*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
55	94	88	82	76	70	65	60	54	49	44	39	34	28	24	19	14	9	5	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	*19.5*	*16.9*	*15.1*	*13.4*	*12.2*	*11.0*	*10.1*	*9.3*	*8.4*	*7.6*	*6.8*	*6.0*	*5.3*	*4.5*	*3.6*	*2.5*	*1.3*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	9	5	1	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	*19.9*	*17.4*	*15.6*	*13.9*	*12.7*	*11.6*	*10.7*	*9.9*	*9.1*	*8.3*	*7.6*	*6.9*	*6.3*	*5.6*	*4.9*	*4.1*	*3.2*	*2.3*	*1.3*	*0.2*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
65	95	90	84	80	75	70	66	61	56	52	48	44	39	36	32	27	24	20	16	13	8	6	2	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	*20.3*	*17.8*	*16.1*	*14.4*	*13.3*	*12.1*	*11.2*	*10.4*	*9.7*	*8.9*	*8.3*	*7.7*	*7.1*	*6.5*	*5.8*	*5.2*	*4.5*	*3.8*	*3.0*	*2.3*	*1.4*	*0.4*	---	---	---	---	---	---	---	---	---	---	---	---	---	---
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	22	19	15	12	9	6	3	---	---	---	---	---	---	---	---	---	---	---	---
	---	*20.6*	*18.2*	*16.5*	*14.9*	*13.7*	*12.5*	*11.6*	*10.9*	*10.1*	*9.4*	*8.8*	*8.3*	*7.7*	*7.2*	*6.6*	*6.0*	*5.5*	*4.9*	*4.3*	*3.7*	*2.9*	*2.3*	*1.5*	*0.7*	---	---	---	---	---	---	---	---	---	---	---	---
75	95	91	86	82	78	74	70	66	62	58	54	51	47	44	41	37	34	31	28	24	21	18	15	12	10	7	4	1	---	---	---	---	---	---	---	---	---
	---	*20.9*	*18.5*	*16.8*	*15.2*	*14.0*	*12.9*	*12.0*	*11.2*	*10.5*	*9.8*	*9.3*	*8.7*	*8.2*	*7.7*	*7.2*	*6.7*	*6.2*	*5.6*	*5.1*	*4.7*	*4.1*	*3.5*	*2.9*	*2.3*	*1.7*	*0.9*	*0.2*	---	---	---	---	---	---	---	---	---
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35	32	29	26	23	20	18	15	12	10	7	5	3	---	---	---	---	---	---	---
	---	*21.0*	*18.7*	*17.0*	*15.5*	*14.3*	*13.2*	*12.3*	*11.5*	*10.9*	*10.1*	*9.7*	*9.1*	*8.6*	*8.1*	*7.7*	*7.2*	*6.8*	*6.3*	*5.8*	*5.4*	*5.0*	*4.5*	*4.0*	*3.5*	*3.0*	*2.4*	*1.8*	*1.1*	*0.3*	---	---	---	---	---	---	---
85	96	92	88	84	80	76	73	70	66	63	59	56	53	50	47	44	41	38	36	33	30	28	25	23	20	18	15	13	11	9	4	---	---	---	---	---	---
	---	*21.2*	*18.8*	*17.2*	*15.7*	*14.5*	*13.5*	*12.5*	*11.8*	*11.2*	*10.5*	*10.0*	*9.5*	*9.0*	*8.5*	*8.1*	*7.6*	*7.2*	*6.7*	*6.3*	*6.0*	*5.6*	*5.2*	*4.8*	*4.3*	*3.9*	*3.4*	*3.0*	*2.4*	*1.7*	*0.9*	---	---	---	---	---	---
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41	39	36	34	31	29	26	24	22	19	17	15	13	9	5	1	---	---	---	---
	---	*21.3*	*18.9*	*17.3*	*15.9*	*14.7*	*13.7*	*12.8*	*12.0*	*11.4*	*10.7*	*10.2*	*9.7*	*9.3*	*8.8*	*8.4*	*8.0*	*7.6*	*7.2*	*6.8*	*6.5*	*6.1*	*5.7*	*5.3*	*4.9*	*4.6*	*4.2*	*3.8*	*3.3*	*2.8*	*2.1*	*1.3*	*0.4*	---	---	---	---
95	96	92	89	85	82	79	75	72	69	66	63	60	57	55	52	49	46	44	42	39	37	34	32	30	28	26	23	22	20	17	14	10	6	2	---	---	---
	---	*21.3*	*19.0*	*17.4*	*16.1*	*14.9*	*13.9*	*12.9*	*12.2*	*11.6*	*11.0*	*10.5*	*10.0*	*9.5*	*9.1*	*8.7*	*8.2*	*7.9*	*7.5*	*7.1*	*6.8*	*6.4*	*6.1*	*5.7*	*5.3*	*5.1*	*4.8*	*4.4*	*4.0*	*3.6*	*3.0*	*2.3*	*1.5*	*0.6*	---	---	---
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54	51	49	46	44	41	39	37	35	33	30	28	26	24	22	21	17	13	10	7	4	---	---
	---	*21.3*	*19.0*	*17.5*	*16.1*	*15.0*	*13.9*	*13.1*	*12.4*	*11.8*	*11.2*	*10.6*	*10.1*	*9.6*	*9.2*	*8.9*	*8.5*	*8.1*	*7.8*	*7.4*	*7.0*	*6.7*	*6.4*	*6.1*	*5.7*	*5.4*	*5.2*	*4.9*	*4.6*	*4.2*	*3.6*	*3.1*	*2.4*	*1.6*	*0.7*	---	---
105	96	93	90	87	83	80	77	74	71	69	66	63	60	58	55	53	50	48	46	44	42	40	37	35	34	31	29	28	26	24	20	17	14	11	8	---	---
	---	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.0*	*13.2*	*12.6*	*11.9*	*11.3*	*10.8*	*10.3*	*9.8*	*9.4*	*9.0*	*8.7*	*8.3*	*7.9*	*7.6*	*7.3*	*6.9*	*6.7*	*6.4*	*6.1*	*5.7*	*5.4*	*5.2*	*4.8*	*4.6*	*4.2*	*3.6*	*3.1*	*2.4*	*1.8*	---	---
110	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	52	50	48	46	44	42	40	38	36	34	32	30	28	26	23	20	17	14	11	4	---
	---	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.1*	*13.3*	*12.6*	*12.0*	*11.4*	*10.8*	*10.4*	*9.9*	*9.5*	*9.2*	*8.8*	*8.4*	*8.1*	*7.7*	*7.5*	*7.2*	*6.8*	*6.6*	*6.3*	*6.0*	*5.7*	*5.4*	*5.2*	*4.8*	*4.5*	*4.0*	*3.5*	*3.0*	*2.5*	*1.1*	---
115	97	93	90	88	85	82	79	76	74	71	68	66	63	61	58	56	54	52	50	48	45	43	41	40	38	36	34	32	31	29	26	23	20	17	14	8	2
	---	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.1*	*13.4*	*12.7*	*12.1*	*11.5*	*10.9*	*10.4*	*10.0*	*9.6*	*9.3*	*8.9*	*8.6*	*8.2*	*7.8*	*7.6*	*7.3*	*7.0*	*6.7*	*6.5*	*6.2*	*5.9*	*5.6*	*5.4*	*5.2*	*4.7*	*4.3*	*3.9*	*3.4*	*2.9*	*1.7*	*0.4*
120	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60	58	55	53	51	49	47	45	43	41	40	38	36	34	33	31	28	25	22	19	17	10	5
	---	*21.3*	*19.0*	*17.4*	*16.2*	*15.1*	*14.1*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.0*	*9.7*	*9.4*	*9.0*	*8.7*	*8.3*	*7.9*	*7.7*	*7.4*	*7.2*	*6.8*	*6.6*	*6.3*	*6.1*	*5.8*	*5.6*	*5.4*	*5.0*	*4.6*	*4.2*	*3.7*	*3.3*	*2.3*	*1.1*
125	97	94	91	88	86	83	80	77	75	73	70	68	65	63	61	59	57	55	53	51	48	47	45	43	41	39	38	36	35	33	30	27	24	22	19	13	8
	---	*21.2*	*18.9*	*17.3*	*16.1*	*15.0*	*14.0*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.0*	*9.7*	*9.4*	*9.0*	*8.7*	*8.3*	*8.0*	*7.7*	*7.5*	*7.2*	*7.0*	*6.7*	*6.5*	*6.2*	*6.0*	*5.8*	*5.5*	*5.2*	*4.8*	*4.4*	*4.0*	*3.6*	*2.7*	*1.6*
130	97	94	91	89	86	83	81	78	76	73	71	69	67	64	62	60	58	56	54	52	50	48	47	45	43	41	40	38	37	35	32	29	26	24	21	15	10
	---	*21.0*	*18.8*	*17.2*	*16.0*	*14.9*	*14.0*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.0*	*9.7*	*9.4*	*9.0*	*8.7*	*8.3*	*8.0*	*7.8*	*7.6*	*7.3*	*7.0*	*6.8*	*6.6*	*6.4*	*6.1*	*5.9*	*5.6*	*5.3*	*4.9*	*4.6*	*4.2*	*3.8*	*3.0*	*2.0*
140	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64	62	60	58	56	54	53	51	49	47	46	44	43	41	40	38	35	32	30	27	25	19	14
	---	*20.7*	*18.6*	*16.9*	*15.8*	*14.8*	*13.8*	*13.2*	*12.5*	*11.9*	*11.4*	*10.9*	*10.4*	*10.0*	*9.6*	*9.4*	*9.0*	*8.7*	*8.4*	*8.0*	*7.8*	*7.6*	*7.3*	*7.1*	*6.9*	*6.6*	*6.4*	*6.2*	*6.0*	*5.8*	*5.4*	*5.1*	*4.8*	*4.4*	*4.1*	*3.4*	*2.6*
150	98	95	92	90	87	85	82	80	78	76	74	72	70	68	66	64	62	60	58	57	55	53	51	49	48	46	45	43	42	41	38	36	33	30	28	23	8
	---	*20.2*	*18.4*	*16.6*	*15.4*	*14.5*	*13.7*	*13.0*	*12.4*	*11.8*	*11.2*	*10.8*	*10.3*	*9.9*	*9.5*	*9.2*	*8.9*	*8.6*	*8.3*	*8.0*	*7.8*	*7.5*	*7.3*	*7.1*	*6.9*	*6.7*	*6.4*	*6.2*	*6.0*	*5.8*	*5.4*	*5.2*	*4.9*	*4.5*	*4.2*	*3.6*	*2.9*
160	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	64	62	60	58	57	55	53	52	50	49	47	46	44	43	41	38	35	33	31	25	21
	---	*19.8*	*18.1*	*16.2*	*15.2*	*14.2*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.6*	*10.1*	*9.7*	*9.4*	*9.1*	*8.8*	*8.5*	*8.2*	*7.9*	*7.7*	*7.4*	*7.2*	*7.0*	*6.8*	*6.7*	*6.4*	*6.2*	*6.0*	*5.8*	*5.5*	*5.2*	*4.9*	*4.6*	*4.3*	*3.7*	*3.2*
170	98	95	93	91	89	86	84	82	80	78	76	74	72	70	69	67	65	63	62	60	59	57	55	53	52	51	49	48	47	45	43	40	38	35	33	28	24
	---	*19.4*	*17.7*	*15.8*	*14.8*	*13.9*	*13.2*	*12.4*	*11.8*	*11.3*	*10.8*	*10.4*	*9.9*	*9.6*	*9.2*	*9.0*	*8.6*	*8.4*	*8.0*	*7.8*	*7.6*	*7.3*	*7.2*	*6.9*	*6.7*	*6.6*	*6.4*	*6.2*	*6.0*	*5.7*	*5.5*	*5.2*	*4.9*	*4.6*	*4.4*	*3.7*	*3.2*
180	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	67	65	63	62	60	58	57	55	54	52	51	50	48	47	45	42	40	38	35	30	26
	---	*18.9*	*17.3*	*15.5*	*14.5*	*13.7*	*12.9*	*12.2*	*11.6*	*11.1*	*10.6*	*10.1*	*9.7*	*9.4*	*9.0*	*8.8*	*8.4*	*8.1*	*7.8*	*7.6*	*7.4*	*7.2*	*7.0*	*6.8*	*6.5*	*6.4*	*6.2*	*6.0*	*5.8*	*5.7*	*5.4*	*5.2*	*4.8*	*4.6*	*4.4*	*3.8*	*3.3*
190	98	96	94	92	90	88	85	84	82	80	78	76	75	73	71	69	68	66	65	63	62	60	58	57	56	54	53	51	50	49	46	44	42	39	37	32	28
	---	*18.5*	*16.9*	*15.2*	*14.2*	*13.4*	*12.7*	*12.0*	*11.4*	*10.9*	*10.5*	*10.0*	*9.6*	*9.2*	*8.9*	*8.6*	*8.2*	*7.9*	*7.7*	*7.4*	*7.2*	*7.0*	*6.8*	*6.6*	*6.4*	*6.2*	*6.0*	*5.9*	*5.7*	*5.5*	*5.3*	*5.0*	*4.8*	*4.5*	*4.4*	*3.8*	*3.3*
200	98	96	94	92	90	88	86	84	82	80	79	77	75	74	72	70	69	67	66	64	63	61	60	58	57	55	54	53	52	51	48	46	43	41	39	34	30
	---	*18.1*	*16.4*	*14.9*	*14.0*	*13.2*	*12.4*	*11.8*	*11.2*	*10.8*	*10.3*	*9.8*	*9.4*	*9.1*	*8.8*	*8.4*	*8.1*	*7.7*	*7.5*	*7.2*	*7.0*	*6.9*	*6.6*	*6.4*	*6.2*	*6.0*	*5.9*	*5.7*	*5.6*	*5.4*	*5.2*	*4.9*	*4.7*	*4.5*	*4.3*	*3.8*	*3.3*
210	98	96	94	92	90	88	86	85	83	81	79	78	76	75	73	71	70	68	67	65	64	63	61	60	59	57	56	54	53	52	50	47	45	43	41	36	32
	---	*17.7*	*16.0*	*14.6*	*13.8*	*13.0*	*12.2*	*11.7*	*11.1*	*10.6*	*10.0*	*9.7*	*9.2*	*9.0*	*8.7*	*8.3*	*8.0*	*7.6*	*7.4*	*7.1*	*6.9*	*6.8*	*6.5*	*6.3*	*6.1*	*5.9*	*5.8*	*5.5*	*5.4*	*5.3*	*5.1*	*4.8*	*4.6*	*4.4*	*4.2*	*3.7*	*3.2*

[1] Relative humidity values in roman type.
[2] Equilibrium moisture content values in italic type.

openings, resin ducts of certain softwoods, other intercellular spaces, and transitory cell-wall passageways (*2*). Most of the moisture lost by wood during drying moves through cell cavities and the small openings in the cell walls. Moisture moves in these passageways in any direction, longitudinally as well as laterally. Lighter woods in general dry more rapidly than do the heavier woods.

Forces That Move Water

When wood is drying, several forces may be acting simultaneously to move water. These forces are as follows:

1. Capillary action, which causes free water to flow, for the most part, through cell cavities and small openings in the cell wall.
2. Differences in relative humidity in the wood that cause water vapor to move through various passageways by diffusion.
3. Differences in moisture content that move the bound water through the small passageways in the cell wall by diffusion.

When green wood starts to dry, evaporation of water from the surface cells sets up capillary forces that exert a pull on the free water in the zones of wood beneath the surface, and a flow results. This is similar to the movement of water in a wick. Much of the free water in sapwood moves in this manner.

Movement of moisture by diffusion results from differences in relative humidity and moisture content between the surface and the interior, or between any two zones of the wood. Moisture in wood moves to the surface by simultaneous diffusion of vapor and bound water. In comparison with capillary movement, diffusion is a slow process.

Longitudinal diffusion is about 10 to 15 times faster than lateral—that is, radial or tangential—diffusion. Radial diffusion, perpendicular to the growth rings, is somewhat faster than tangential diffusion, parallel to the rings. Although longitudinal diffusion is 10 to 15 times as fast as lateral diffusion, it is of practical importance only when short items are being dried.

Most of the moisture is removed from wood by lateral diffusion during drying. The rate of lateral diffusion depends to a large extent upon the permeability of the cell walls and upon their thickness. Thus permeable woods dry faster than impermeable woods. Generally, the rate of diffusion decreases rapidly as the specific gravity of the wood increases.

Moisture diffuses more rapidly in sapwood than in heartwood. This is probably due to the fact that extractives plug the small cell wall openings in the heartwood.

Because moisture moves more freely in sapwood than heartwood, both by diffusion and by capillary flow, sapwood generally dries faster than heartwood under the same drying conditions. The heartwood of some species, however, may reach the final desired moisture content in a shorter drying time than the sapwood, because its initial moisture content may be much lower than that of the sapwood.

Factors That Influence Drying Rate

The rate at which moisture moves in wood is dependent upon the relative humidity of the surrounding air, the steepness of the moisture gradient, and the temperature of the wood. The lower the relative humidity, the greater the capillary flow. Low relative humidity also stimulates diffusion by lowering the moisture content, at the surface, thereby steepening the moisture gradient. If the relative humidity is too low during the early stages of the drying of green wood, excessive end and surface checking may result. The higher the temperature of the wood, the faster will be the rate at which the moisture moves from the wetter interior to the drier surfaces. If the temperature is too high, however, collapse, honeycombing, or reduction in strength may result.

Specific Gravity and Weight of Wood

Specific gravity is one of the physical properties of wood that are guides to ease of drying. In general, the heavier the wood, the slower the drying rate and the greater the likelihood of developing defects during drying. Specific gravity is defined as the ratio of the weight of a body to the weight of an equal volume of water. Usually the specific gravity of wood is based on the volume of the wood when green and its weight when ovendry. Thus, if the specific gravity of a specimen of green wood is 0.5, the ovendry weight of the wood substance in a cubic foot of the green wood is one-half the weight of a cubic foot of water. The higher the specific gravity of wood, the greater is the amount of ovendry wood found in a unit volume of green wood. Thus, at the same moisture content the woods of higher specific gravity contain more water. The specific gravity of a number of species is given in table 3.

Weight of wood depends on its specific gravity and its moisture content. Calculated weights are given in table 4. The values for weights per thousand board feet in columns 2 and 3 apply to a thousand feet, surface measure, of boards exactly 1 inch thick (actual board feet) and not to a thousand board feet, lumber scale. These weights were determined by multiplying the weight per cubic foot at the given moisture contents by 83.3, the number of cubic feet in a thousand board feet. Since these weights are based on actual board feet—a thousand lineal feet of lumber exactly 1 inch thick and 12 inches wide—they must be adjusted upward for rough lumber and downward for dressed. For example, the adjustment factor for a 1- by 8-inch board dressed to $^{25}/_{32}$ inch in thickness and $7\frac{1}{2}$ inches in width is arrived at as follows:

$$\frac{{}^{25}/_{32} \times 7\frac{1}{2}}{1 \times 8} = 0.7324$$

Values in columns 2 and 3 of table 4 multiplied by 0.7324 give the weights of a thousand board feet of dressed 1- by 8-inch lumber. Similarly, for any dressed size a factor can be worked out and the weight per thousand board feet calculated. The adjustment for rough lumber is made in a like manner, the actual rough size being divided by the nominal size (*9*).

The weight per thousand board feet (actual) at any moisture content below 30 percent can be determined by applying the correction factors in column 4 of table 4. For example, the weight of a thousand board feet of coast type Douglas-fir at a moisture content of 21 percent would be 14.3 pounds more than that shown in column 2;

TABLE 3.—*Specific gravity of wood*

Species	Average specific gravity [1]
SOFTWOODS	
Baldcypress	0.42
Cedar:	
Alaska-	.42
Atlantic white-	.31
Eastern redcedar	.44
Incense-	.35
Northern white-	.29
Port-Orford-	.40
Western redcedar	.31
Douglas-fir:	
Coast type	.45
Intermediate type	.41
Rocky Mountain type	.40
Fir:	
Balsam	.34
California red	.37
Grand	.37
Noble	.35
Pacific silver	.35
Subalpine	.31
White	.35
Hemlock:	
Eastern	.38
Western	.38
Larch, western	.51
Pine:	
Eastern white	.34
Lodgepole	.38
Ponderosa	.38
Red	.40
Southern yellow:	
Loblolly	.47
Longleaf	.54
Shortleaf	.46
Sugar	.35
Western white	.36
Redwood:	
Old-growth	.38
Second-growth	.30
Spruce:	
Black	.38
Engelmann	.32
Red	.38
White	.37
Sitka	.37
Tamarack	.49
HARDWOODS	
Alder, red	0.37
Apple	.61
Ash:	
Black	.45
Green	.53
White	.55
Aspen	.35
Basswood, American	.32
Beech, American	.56
Birch:	
Paper	.48
Sweet	.60
Yellow	.55
Buckeye, yellow	.33
Butternut	.36
Cherry, black	.47
Chestnut, American	.40
Chinkapin, golden	.42
Cottonwood, black	.32
Dogwood, flowering	.64
Elm:	
American	.46
Cedar	.59
Rock	.57
Slippery	.48
Hackberry	.49
Hickory	.65
Hickory, pecan:	
Bitternut	.60
Nutmeg	.56
Pecan	.60
Water	.61
Hickory, true:	
Mockernut	.64
Pignut	.66
Shagbark	.64
Shellbark	.62
Holly, American	.50
Hophornbeam, eastern	.63
Laurel, California	.51
Lemonwood	.82
Locust, black	.66
Madrone, Pacific	.58
Magnolia	.46
Maple:	
Silver (soft)	.44
Sugar (hard)	.56
Oak:	
California black	.51
Live	.81
Red [2]	.54
Water	.56
White	.60
Willow	.56
Osage-orange	.76
Persimmon, common	.64
Sweetgum	.46
Sycamore, American	.46
Tanoak	.56
Tupelo:	
Black	.46
Water	.46
Walnut, black	.51
Willow, black	.34
Yellow-poplar	.40

[1] Based on weight when ovendry and volume when green.
[2] Average of northern and southern red oak.

555315 O—61——2

TABLE 4.—*Calculated weights of wood*

SOFTWOODS

Species	Weight per 1,000 board feet (actual board feet)		Correction factor per 1,000 board feet for each 1 percent change in moisture content [1]
	At 20 percent moisture content	At 8 percent moisture content	
	Pounds	*Pounds*	*Pounds*
Baldcypress	2, 790	2, 620	14. 3
Cedar:			
Alaska-	2, 700	2, 530	14. 3
Atlantic white-	2, 020	1, 920	8. 6
Eastern redcedar	2, 870	2, 680	15. 7
Incense-	2, 190	2, 020	14. 3
Northern white-	1, 880	1, 730	12. 9
Port-Orford-	2, 580	2, 410	14. 3
Western redcedar	2, 010	1, 870	11. 4
Douglas-fir:			
Coast type	2, 930	2, 760	14. 3
Intermediate type	2, 710	2, 570	11. 4
Rocky Mountain type	2, 620	2, 430	15. 7
Fir:			
Balsam	2, 270	2, 200	5. 7
California red	2, 420	2, 270	12. 6
Grand	2, 420	2, 275	12. 1
Noble	2, 320	2, 180	11. 4
Pacific silver	2, 390	2, 275	9. 3
Subalpine	1, 940	1, 775	13. 6
White	2, 270	2, 150	10. 0
Hemlock:			
Eastern	2, 480	2, 330	12. 9
Western	2, 530	2, 390	11. 4
Larch, western	3, 350	3, 180	14. 3
Pine:			
Eastern white	2, 190	2, 020	14. 3
Lodgepole	2, 490	2, 350	11. 4
Ponderosa	2, 440	2, 290	12. 9
Red	2, 680	2, 530	12. 9
Southern yellow:			
Loblolly	3, 080	2, 930	12. 9
Longleaf	3, 550	3, 360	15. 7
Shortleaf	3, 030	2, 880	12. 9
Sugar	2, 240	2, 075	13. 8
Western white	2, 380	2, 260	10. 0
Redwood, old-growth	2, 450	2, 280	14. 3
Spruce:			
Black	2, 460	2, 320	11. 4
Engelmann	2, 070	1, 930	11. 4
Sitka	2, 400	2, 260	11. 4
Tamarack	3, 205	3, 025	15. 0
HARDWOODS			
Alder, red	2, 450	2, 330	10. 0
Apple	4, 090	3, 970	10. 0
Ash:			
Black	3, 000	2, 860	11. 4
Green	3, 470	3, 280	15. 7
White	3, 630	3, 460	14. 3
Aspen	2, 310	2, 190	10. 0
Basswood, American	2, 200	2, 125	6. 4
Beech, American	3, 750	3, 600	12. 9
Birch:			
Paper	3, 280	3, 180	8. 6
Sweet	4, 000	3, 830	14. 3
Yellow	3, 680	3, 530	12. 9

See footnote at end of table.

TABLE 4.—*Calculated weights of wood*—Continued

HARDWOODS—Continued

Species	Weight per 1,000 board feet (actual board feet)		Correction factor per 1,000 board feet for each 1 percent change in moisture content [1]
	At 20 percent moisture content	At 8 percent moisture content	
	Pounds	*Pounds*	*Pounds*
Buckeye, yellow	2, 160	2, 070	7. 1
Butternut	2, 340	2, 200	11. 4
Cherry, black	3, 090	2, 900	15. 7
Chestnut, American	2, 600	2, 460	11. 4
Chinkapin, golden	2, 750	2, 610	11. 4
Cottonwood, black	2, 080	1, 980	8. 6
Dogwood, flowering	4, 340	4, 225	9. 3
Elm:			
American	3, 060	2, 960	8. 6
Cedar	3, 890	3, 720	14. 3
Rock	3, 770	3, 560	17. 1
Hackberry	3, 190	3, 020	14. 3
Hickory	4, 340	4, 200	11. 4
Holly, American	3, 380	3, 240	11. 4
Hophornbeam, eastern	4, 240	4, 070	14. 3
Laurel, California	3, 370	3, 180	15. 7
Locust, black	4, 220	3, 890	27. 1
Madrone, Pacific	3, 860	3, 720	11. 4
Magnolia	3, 020	2, 870	12. 9
Maple:			
Silver (soft)	2, 880	2, 730	12. 9
Sugar (hard)	3, 770	3, 620	12. 9
Oak:			
Northern red	3, 730	3, 540	15. 7
Southern red	3, 480	3, 340	11. 4
White	3, 970	3, 800	14. 3
Osage-orange	4, 910	4, 575	27. 9
Persimmon, common	4, 290	4, 140	12. 9
Sweetgum	3, 080	2, 960	10. 0
Sycamore, American	3, 030	2, 890	11. 4
Tupelo:			
Black	3, 080	2, 960	10. 0
Water	2, 980	2, 830	12. 9
Walnut, black	3, 320	3, 080	20. 0
Willow, black	2, 340	2, 240	8. 6
Yellow-poplar	2, 580	2, 430	12. 9

[1] Applies only to moisture values of 30 percent or less.

at a moisture content of 7 percent, 14.3 pounds less than that shown in column 3.

Shrinkage of Wood

When wood is dried below the fiber saturation point, it shrinks. When it has dried to 15 percent moisture content, about one-half of the total possible shrinkage has taken place; when dried to 8 percent moisture content, nearly three-fourths of the maximum possible amount has taken place. Figure 4 indicates how Douglas-fir shrinks with loss of moisture. While these curves are not straight, shrinkage is generally thought of as a straight line relationship (*5*, *6*).

Average Shrinkage Values

Table 5 gives average shrinkage values for various species of wood. These values are given in percentages of the green dimension. Wood shrinks about 1½ or 2 times as much parallel to the annual growth rings (tangentially) as it does across the rings (radially). The shrinkage along the grain (longitudinally) is very little (0.20 percent or less) in normal wood. The combined effects of radial and tangential shrinkage are shown in figure 5.

Shrinkage values in table 5 can be converted into useful units of measurement. Each 3 percent of shrinkage, either radially or tangentially, is roughly equivalent to a decrease in width or

TABLE 5.—*Shrinkage values of wood, based on its dimensions when green*

SOFTWOODS

Species	Dried to 20 percent moisture content [1]		Dried to 6 percent moisture content [2]		Dried to 0 percent moisture content	
	Radial shrinkage	Tangential shrinkage	Radial shrinkage	Tangential shrinkage	Radial shrinkage	Tangential shrinkage
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Baldcypress	1.3	2.1	3.0	5.0	3.8	6.2
Cedar:						
Alaska-	.9	2.0	2.2	4.8	2.8	6.0
Atlantic white-	1.0	1.8	2.3	4.3	2.9	5.4
Eastern redcedar	1.0	1.6	2.5	3.8	3.1	4.7
Incense-	1.1	1.7	2.6	4.2	3.3	5.2
Northern white-	.7	1.6	1.8	3.9	2.2	4.9
Port-Orford-	1.5	2.3	3.7	5.5	4.6	6.9
Western redcedar	.8	1.7	1.9	4.0	2.4	5.0
Douglas-fir:						
Coast type	1.7	2.6	4.0	6.2	5.0	7.8
Intermediate type	1.4	2.5	3.3	6.1	4.1	7.6
Rocky Mountain type	1.2	2.1	2.9	5.0	3.6	6.2
Fir:						
Balsam	1.0	2.3	2.3	5.5	2.9	6.9
California red	1.3	2.4	3.2	5.8	4.0	7.2
Grand	1.1	2.5	2.7	6.0	3.4	7.5
Noble	1.5	2.7	3.6	6.6	4.5	8.2
Pacific silver	1.5	3.3	3.7	7.8	4.6	9.8
Subalpine	.9	2.5	2.1	5.9	2.6	7.4
White	1.1	2.4	2.6	5.7	3.2	7.1
Hemlock:						
Eastern	1.0	2.3	2.4	5.4	3.0	6.8
Western	1.4	2.6	3.4	6.3	4.3	7.9
Larch, western	1.4	2.7	3.4	6.5	4.2	8.1
Pine:						
Eastern white	.8	2.0	1.8	4.8	2.3	6.0
Lodgepole	1.5	2.2	3.6	5.4	4.5	6.7
Ponderosa	1.3	2.1	3.1	5.0	3.9	6.3
Red	1.5	2.4	3.7	5.8	4.6	7.2
Southern yellow:						
Loblolly	1.6	2.5	3.8	5.9	4.8	7.4
Longleaf	1.7	2.5	4.1	6.0	5.1	7.5
Shortleaf	1.5	2.6	3.5	6.2	4.4	7.7
Sugar	1.0	1.9	2.3	4.5	2.9	5.6
Western white	1.4	2.5	3.3	5.9	4.1	7.4
Redwood:						
Old-growth	.9	1.5	2.1	3.5	2.6	4.4
Second-growth	.7	1.6	1.8	3.9	2.2	4.9
Spruce:						
Black	1.4	2.3	3.3	5.4	4.1	6.8
Engelmann	1.1	2.2	2.7	5.3	3.4	6.6
Red	1.3	2.6	3.0	6.2	3.8	7.8
Sitka	1.4	2.5	3.4	6.0	4.3	7.5
Tamarack	1.2	2.5	3.0	5.9	3.7	7.4
Yew, Pacific	1.3	1.8	3.2	4.3	4.0	5.4
HARDWOODS						
Alder, red	1.5	2.4	3.5	5.8	4.4	7.3
Apple	2.0	3.5	4.7	8.4	5.9	10.5
Ash:						
Black	1.7	2.6	4.0	6.2	5.0	7.8
Green	1.5	2.4	3.7	5.7	4.6	7.1
White	1.6	2.6	3.8	6.2	4.8	7.8
Aspen:						
Bigtooth	1.1	2.6	2.6	6.3	3.3	7.9
Quaking	1.2	2.2	2.8	5.4	3.5	6.7
Basswood, American	2.2	3.1	5.3	7.4	6.6	9.3

See footnotes on following page.

TABLE 5.—*Shrinkage values of wood, based on its dimensions when green*—Continued

HARDWOODS—Continued

Species	Dried to 20 percent moisture content [1]		Dried to 6 percent moisture content [2]		Dried to 0 percent moisture content	
	Radial shrinkage	Tangential shrinkage	Radial shrinkage	Tangential shrinkage	Radial shrinkage	Tangential shrinkage
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Beech, American	1. 7	3. 7	4. 1	8. 8	5. 1	11. 0
Birch:						
Paper	2. 1	2. 9	5. 0	6. 9	6. 3	8. 6
Sweet	2. 2	2. 8	5. 2	6. 8	6. 5	8. 5
Yellow	2. 4	3. 1	5. 8	7. 4	7. 2	9. 2
Buckeye, yellow	1. 2	2. 7	2. 9	6. 5	3. 6	8. 1
Butternut	1. 1	2. 1	2. 7	5. 1	3. 4	6. 4
Catalpa, northern	. 8	1. 6	2. 0	3. 9	2. 5	4. 9
Cherry, black	1. 2	2. 4	3. 0	5. 7	3. 7	7. 1
Chestnut, American	1. 1	2. 2	2. 7	5. 4	3. 4	6. 7
Cottonwood, black	1. 2	2. 9	2. 9	6. 9	3. 6	8. 6
Dogwood, flowering	2. 5	3. 9	5. 9	9. 4	7. 4	11. 8
Elm:						
American	1. 4	3. 2	3. 4	7. 6	4. 2	9. 5
Rock	1. 6	2. 7	3. 8	6. 5	4. 8	8. 1
Slippery	1. 6	3. 0	3. 9	7. 1	4. 9	8. 9
Hackberry	1. 6	3. 0	3. 8	7. 1	4. 8	8. 9
Hickory:						
Mockernut	2. 6	3. 7	6. 2	8. 8	7. 8	11. 0
Pignut	2. 4	3. 8	5. 8	9. 2	7. 2	11. 5
Shagbark	2. 3	3. 3	5. 6	8. 0	7. 0	10. 0
Shellbark	2. 5	4. 2	6. 1	10. 1	7. 6	12. 6
Holly, American	1. 6	3. 3	3. 8	7. 9	4. 8	9. 9
Hophornbeam, eastern	2. 8	3. 3	6. 8	8. 0	8. 5	10. 0
Laurel, California-	1. 0	2. 8	2. 3	6. 8	2. 9	8. 5
Locust, black	1. 5	2. 4	3. 7	5. 8	4. 6	7. 2
Madrone, Pacific	1. 9	4. 1	4. 5	9. 9	5. 6	12. 4
Magnolia, southern	1. 8	2. 2	4. 3	5. 3	5. 4	6. 6
Mahogany	1. 2	1. 7	2. 9	4. 0	3. 6	5. 0
Maple:						
Black	1. 6	3. 1	3. 8	7. 4	4. 8	9. 2
Red	1. 3	2. 7	3. 2	6. 6	4. 0	8. 2
Silver	1. 0	2. 4	2. 4	5. 8	3. 0	7. 2
Sugar	1. 6	3. 2	3. 9	7. 6	4. 9	9. 5
Oak:						
Black	1. 5	3. 2	3. 6	7. 8	4. 5	9. 7
Bur	1. 5	2. 9	3. 5	7. 0	4. 4	8. 8
California black	1. 2	2. 2	2. 9	5. 3	3. 6	6. 6
Chestnut	1. 8	3. 2	4. 4	7. 8	5. 5	9. 7
Live	2. 2	3. 2	5. 3	7. 6	6. 6	9. 5
Oregon white	1. 4	3. 0	3. 4	7. 2	4. 2	9. 0
Pin	1. 4	3. 2	3. 4	7. 6	4. 3	9. 5
Northern red	1. 3	2. 7	3. 2	6. 6	4. 0	8. 2
Scarlet	1. 5	3. 2	3. 7	7. 8	4. 6	9. 7
Southern red	1. 5	2. 9	3. 6	7. 0	4. 5	8. 7
Swamp chestnut	1. 7	3. 6	4. 2	8. 6	5. 2	10. 8
Swamp red	1. 8	3. 5	4. 4	8. 5	5. 5	10. 6
Water	1. 4	3. 1	3. 4	7. 4	4. 2	9. 3
White	1. 8	3. 0	4. 2	7. 2	5. 3	9. 0
Willow	1. 7	3. 2	4. 0	7. 7	5. 0	9. 6
Persimmon, common	2. 6	3. 7	6. 3	9. 0	7. 9	11. 2
Sweetgum	1. 7	3. 3	4. 2	7. 9	5. 2	9. 9
Sycamore, American	1. 7	2. 5	4. 1	6. 1	5. 1	7. 6
Tupelo:						
Black	1. 5	2. 6	3. 5	6. 2	4. 4	7. 7
Water	1. 4	2. 5	3. 4	6. 1	4. 2	7. 6
Walnut, black	1. 8	2. 6	4. 4	6. 2	5. 5	7. 8
Willow, black	. 9	2. 7	2. 1	6. 5	2. 6	8. 1
Yellow-poplar	1. 3	2. 4	3. 2	5. 7	4. 0	7. 1

[1] These shrinkage values have been taken as 1/3 of the shrinkage to the ovendry condition as given in the last 2 columns of this table.
[2] These shrinkage values have been taken as 4/5 of the shrinkage to the ovendry condition as given in the last 2 columns of this table.

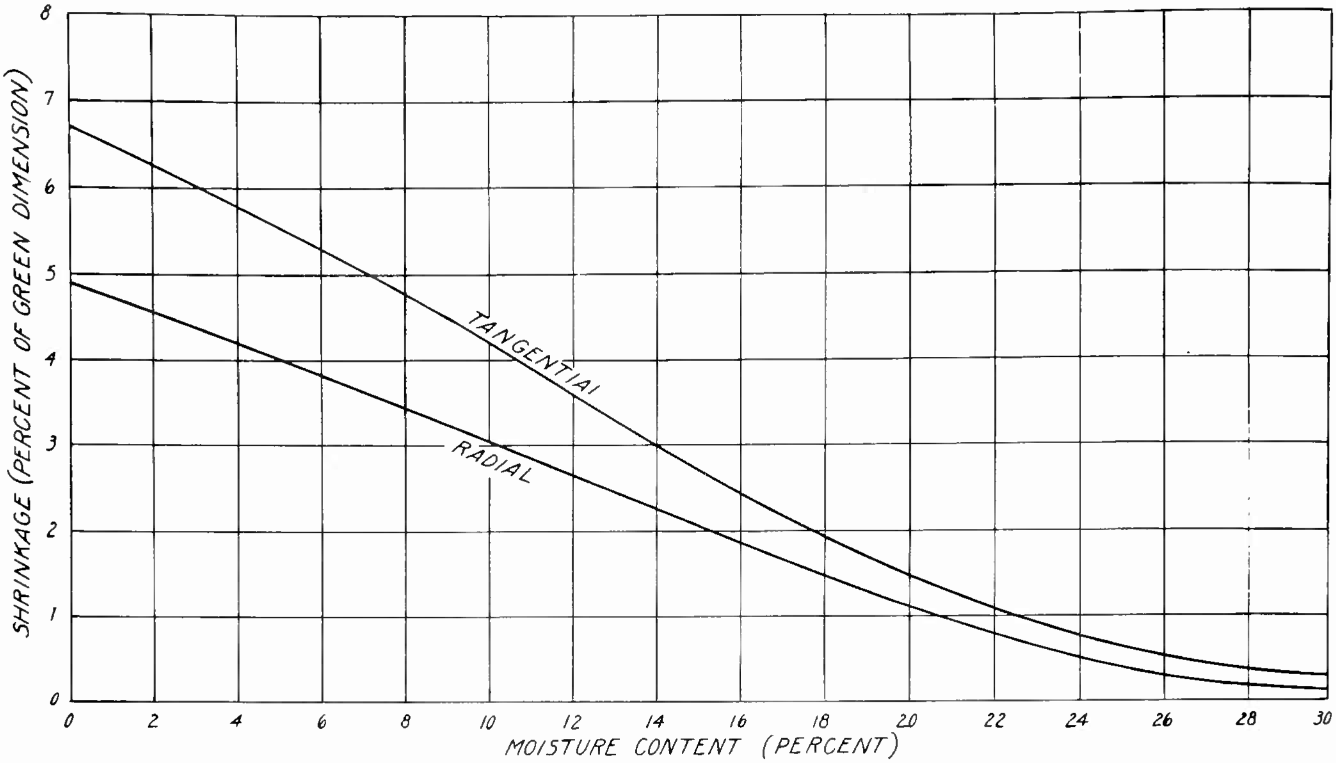


FIGURE 4.—Typical relation of moisture content to shrinkage of Douglas-fir. Although the curves are not straight lines, for practical shrinkage calculations they may be considered as such.

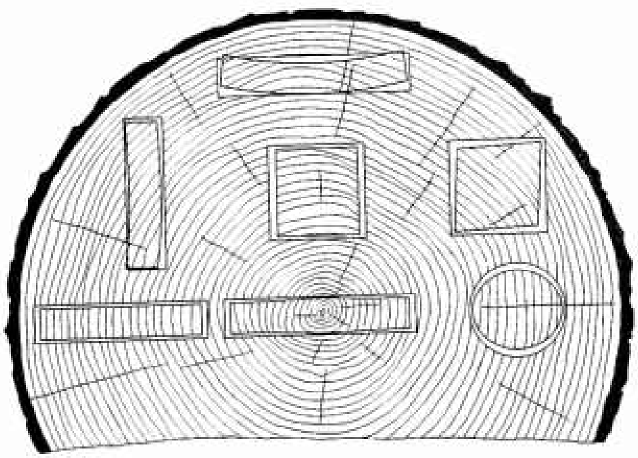


FIGURE 5.—Characteristic shrinkage and distortion of flats, squares, and rounds as affected by the direction of annual growth rings. The dimensional changes shown are somewhat exaggerated.

thickness of $\frac{1}{32}$ inch per inch. For example, the tangential shrinkage of western hemlock at 6 percent moisture content is 6.3 percent (table 5). Therefore, the shrinkage per inch of width in a flat-sawed board would be

$$\frac{6.3}{3} \times \frac{1}{32} = \frac{2}{32} \text{ or } \frac{1}{16} \text{ inch (approximate)}$$

This shrinkage is for 1 inch. For an 8-inch-wide flat-sawed board, this value would become $8 \times \frac{1}{16} = \frac{8}{16}$ or $\frac{1}{2}$ inch.

Knowing the total shrinkage of a species at 0 percent moisture content, the percentage of shrinkage at any moisture content below 30 percent can be calculated. Since shrinkage curves are reasonably close to straight lines from 30 percent (the fiber saturation point) to 0 percent moisture content, each 1 percent change in moisture content below 30 percent is equal to $\frac{1}{30}$ of the total shrinkage. For example, the total tangential shrinkage of western hemlock dried to 0 percent moisture content is 7.9 percent (table 5). At 25 percent moisture content its tangential shrinkage would be $\frac{5}{30}$ of 7.9 percent, or about 1.3 percent; at 12 percent its tangential shrinkage would be $\frac{18}{30}$ of 7.9, or about 4.7 percent.

Shrinkage Variability

Shrinkage differs not only with respect to the length, width, and thickness of a piece and among species, but even in material cut from the same species and from the same tree. The overall shrinkage of wood also is influenced by drying conditions. Generally, the higher the temperature and relative humidity during the initial stages of drying, the greater the shrinkage.

On the average, hardwoods shrink more than softwoods. Although, in general, the woods of high specific gravity have the greater shrinkage, there are exceptions. Basswood, a light wood, has a high shrinkage, while black locust, a heavy wood, has a moderate shrinkage. The amount of shrinkage and the difference between radial and tangential shrinkage have a direct bearing on the seasoning defects that occur during drying.

Effects of Shrinkage

Shrinkage is responsible for decrease in dimension, loss of footage, warping, end and surface checking, splitting, honeycombing, collapse, and casehardening. All of these are discussed in detail in chapter 9, "Drying Defects."

Electrical Properties of Wood

The most important electrical properties of wood are its dielectric properties and its resistance to the passage of an electric current. These properties are utilized in electric meters designed to determine the moisture content of wood (*3*, *7*).

The direct current electrical resistance of wood varies greatly with moisture content (table 6), especially below the fiber saturation point, increasing very greatly as the moisture content decreases. It also varies with species, is greater across the grain than along it, and is affected by temperature. The resistance is not greatly influenced by differences in specific gravity. Commercial moisture meters of the resistance type are often calibrated for one species of wood, but correction tables for other species are supplied by the manufacturers. Since these meters are usually calibrated for use at 70° F., the readings require correction if used at other temperature (fig. 6).

Meters that use the dielectric properties of wood, dielectric constant and power factor, are known as radio frequency power-loss moisture meters. With this type of instrument, electrodes are pressed against the wood, and radio frequency power is applied. The electrodes do not mar or damage the wood. The amount of power absorbed depends upon the wood's moisture content. The meter is calibrated directly in terms of moisture content for one species, and values from zero to the fiber saturation point are indicated on its dial. Correction tables for other species are provided by the instrument makers.

Color of Wood

As a tree grows, the white or straw-colored sapwood gradually changes to heartwood, and with this change there is usually a marked change in color (*8*, *9*). Holly, basswood, cottonwood,

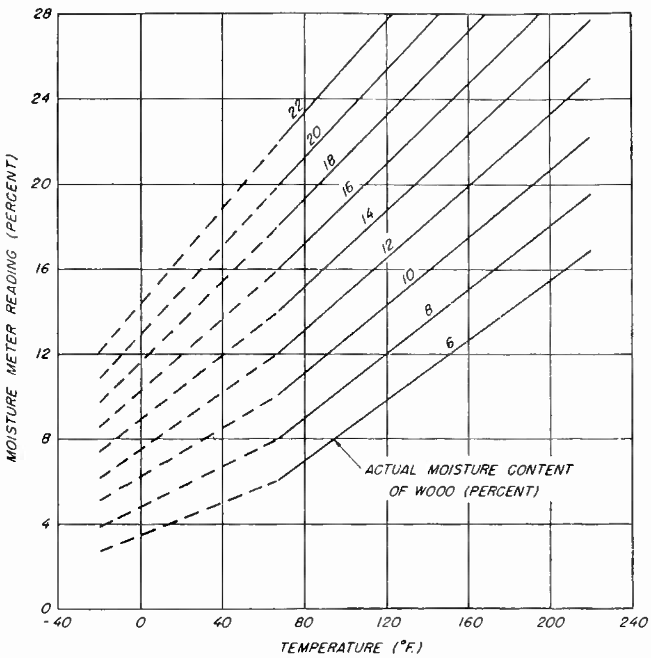


FIGURE 6.—Temperature correction chart for resistance-type moisture meters.

and magnolia, however, are examples of hardwoods in which the wood undergoes little or no change in color. Spruces and true firs are examples of softwoods that do not change color materially.

The temperatures used in kiln-drying tend to darken wood. Dry kiln operators are usually little concerned with color changes that might take place in heartwood during drying, but they are concerned with those that occur in sapwood.

Beneficial color changes may be brought about by steaming green wood before drying it. Walnut, for example, is steamed in vats to darken the sapwood before it is dried. At one time sap gum was steamed to produce a salmon color that the using industries preferred and paid a premium to get. European beech is often steamed before it is dried in order to improve its color appearance.

Chemical stain can occur when green sapwood of some species is kiln-dried. The sapwood of hickory tends to turn pinkish when kiln-dried; very low initial temperatures must be used if its whiteness is to be preserved. Paper birch sapwood turns brownish when kiln-dried, and many plants prefer air-drying for that reason.

Perhaps one of the most troublesome color changes in wood is brown stain that occurs in ponderosa pine, the true white pines, and some other softwoods. It is usually most conspicuous at or near the surface, but it may be present throughout the wood. The stain is most pronounced on end- and flat-grained surfaces. The

TABLE 6.—*Average electrical resistance along the grain, for selected species, as measured at 80° F. between two pairs of needle electrodes 1¼ inches apart and driven to a depth of 5/16 inch*

Species	Electrical resistance in megohms, when percent moisture content is—																		
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
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. 91	0. 66	0. 51	0. 42
Douglas-fir (coast type)	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. 10	. 79	. 60	. 46
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. 58	1. 15	. 83	. 63
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. 55	1. 12	. 86	. 62
Hemlock, western	22, 900	5, 620	2, 040	850	400	185	98	51	28. 2	16. 2	10. 0	6. 0	3. 89	2. 52	1. 58	1. 05	. 72	. 51	. 37
Larch, western	39, 800	11, 200	3, 980	1, 445	560	250	120	63	33. 9	19. 9	12. 3	7. 6	5. 02	3. 39	2. 29	1. 62	1. 20	. 87	. 66
Pine, eastern white	20, 900	5, 620	2, 090	850	405	200	102	58	33. 1	19. 9	12. 3	7. 9	5. 01	3. 31	2. 19	1. 51	1. 05	. 74	. 52
Pine, longleaf	25, 000	8, 700	3, 160	1, 320	575	270	135	74	41. 7	24. 0	14. 4	8. 9	5. 76	3. 72	2. 46	1. 66	1. 15	. 79	. 60
Pine, ponderosa	39, 800	8, 910	3, 310	1, 410	645	300	150	81	44. 7	25. 1	14. 8	9. 1	5. 62	3. 55	2. 34	1. 62	1. 15	. 87	. 69
Pine, shortleaf	43, 600	11, 750	3, 720	1, 350	560	255	130	69	38. 9	22. 4	13. 8	8. 7	5. 76	3. 80	2. 63	1. 82	1. 29	. 93	. 66
Pine, sugar	22, 900	5, 250	1, 660	645	280	140	76	44	25. 7	15. 9	10. 0	6. 6	4. 36	3. 02	2. 09	1. 48	1. 05	. 75	. 56
Redwood	22, 400	4, 680	1, 550	615	250	100	45	22	12. 6	7. 2	4. 7	3. 2	2. 29	1. 74	1. 32	1. 05	. 85	. 71	. 60
Spruce, Sitka	22, 400	5, 890	2, 140	830	365	165	83	44	25. 1	15. 5	9. 8	6. 3	4. 27	3. 02	2. 14	1. 58	1. 17	. 91	. 71
Hardwoods:																			
Ash, commercial white	12, 000	2, 190	690	250	105	55	28	14	8. 3	5. 0	3. 2	2. 0	1. 32	. 89	. 63	. 50	. 44	. 40	. 40
Basswood	36, 300	1, 740	470	180	85	45	27	16	9. 6	6. 2	4. 1	2. 8	1. 86	1. 32	. 93	. 69	. 51	. 39	. 31
Birch	87, 000	19, 950	4, 470	1, 290	470	200	96	53	30. 2	18. 2	11. 5	7. 6	5. 13	3. 55	2. 51	1. 78	1. 32	. 95	. 70
Elm, American	18, 200	2, 000	350	110	45	20	12	7	3. 9	2. 3	1. 5	1. 0	. 66	. 48	. 42	. 40	. 40	. 40	. 40
Hickory, true	------	31, 600	2, 190	340	115	50	21	11	6. 3	3. 7	2. 3	1. 5	1. 00	. 71	. 52	. 44	. 40	. 40	. 40
Khaya [1]	44, 600	16, 200	6, 310	2, 750	1, 260	630	340	180	105. 0	60. 2	35. 5	21. 9	14. 10	9. 33	6. 16	4. 17	2. 82	1. 99	1. 44
Magnolia	43, 700	12, 600	5, 010	2, 040	910	435	205	105	56. 2	29. 5	16. 2	9. 1	5. 25	3. 09	1. 86	1. 17	. 74	. 50	. 32
Mahogany, American	20, 900	6, 760	2, 290	870	380	180	85	43	22. 4	12. 3	7. 2	4. 4	2. 69	1. 66	1. 07	. 72	. 49	. 35	. 26
Maple, sugar	72, 400	13, 800	3, 160	690	250	105	53	29	16. 6	10. 2	6. 8	4. 5	3. 16	2. 24	1. 62	1. 23	. 98	. 75	. 60
Oak, commercial red [2]	14, 400	4, 790	1, 590	630	265	125	63	32	18. 2	11. 3	7. 3	4. 6	3. 02	2. 09	1. 45	. 95	. 80	. 63	. 50
Oak, commercial white	17, 400	3, 550	1, 100	415	170	80	42	22	12. 6	7. 2	4. 3	2. 7	1. 70	1. 15	. 79	. 60	. 49	. 44	. 41
Shorea [3]	2, 890	690	220	80	35	15	9	5	2. 8	1. 7	1. 1	. 7	. 45	. 30	. 21	. 16	. 12	. 09	. 07
Sweetgum	38, 000	6, 460	2, 090	815	345	160	81	45	25. 7	15. 1	9. 3	6. 0	3. 98	2. 63	1. 78	1. 26	. 87	. 63	. 46
Tupelo, black [2]	31, 700	12, 600	5, 020	1, 820	725	275	120	58	27. 6	13. 0	6. 9	3. 7	2. 19	1. 38	. 95	. 63	. 46	. 33	. 25
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. 02	. 72	. 51	. 38
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. 91	1. 39	1. 10	. 85

[1] Known in the trade as "African mahogany."
[2] The values for this species were calculated from measurements on veneer.
[3] A Philippine hardwood, identified as tanguile or some similar species.

occurrence and control of brown stain are discussed in chapter 9.

For interior woodwork and furniture that is to receive natural finish, a type of discoloration called sticker stain can become a serious problem. Sticker stain generally occurs during air-drying and appears after planing as blackish or brownish streaks across the faces of boards where they were in contact with the stickers. In redwood, however, the sticker markings are light colored. Although it is generally limited to sapwood, it occasionally occurs in heartwood. It is a chemical stain and should not be confused with sap (blue) stain that is caused by fungi.

Literature Cited

(1) BAKER, WILLIAM J.
1956. HOW WOOD DRIES. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1642, 9 pp. [Processed.]

(2) BROWN, H. P., PANSHIN, A. J., AND FORSAITH, C. C.
1949. TEXTBOOK OF WOOD TECHNOLOGY. VOL. 1. STRUCTURE, IDENTIFICATION, DEFECTS, AND USES OF THE COMMERCIAL WOODS OF THE UNITED STATES. 652 pp., illus. New York.

(3) JAMES, W. L.
1954. ELECTRICAL MOISTURE METERS FOR WOOD. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1660, 18 pp., illus. [Processed.]

(4) LITTLE, ELBERT L., JR.
1953. CHECK LIST OF NATIVE AND NATURALIZED TREES . . . U.S. Dept. Agr., Agr. Handbook 41, 472 pp.

(5) PECK, E. C.
1953. SHRINKING AND SWELLING OF WOOD IN USE. U.S. Forest Serv. Forest Prod. Lab. Rpt. 736, 18 pp., illus. [Processed.]

(6) PECK, EDWARD C.
1957. HOW WOOD SHRINKS AND SWELLS. Forest Prod. Jour. 7: 235–244, illus.

(7) TOMBACH, HAROLD.
1954. THE ELECTRIC MOISTURE METER FOR WOOD. South. Lumberman 188 (2347): 63–64, 66–68, 70, illus.

(8) U.S. FOREST SERV. FOREST PRODUCTS LABORATORY.
1956. WOOD: COLORS AND KINDS. U.S. Dept. Agr., Agr. Handbook 101, 36 pp., illus.

(9) ———
1955. WOOD HANDBOOK. U.S. Dept. Agr., Agr. Handbook 72, 528 pp., illus.

CHAPTER 2. KILN TYPES AND FEATURES

A dry kiln consists of one or more chambers, rooms, or tunnels in which air can be circulated around the wood being dried. The temperature and relative humidity of this air can be manually or automatically maintained by controlling the dry- and wet-bulb temperatures.

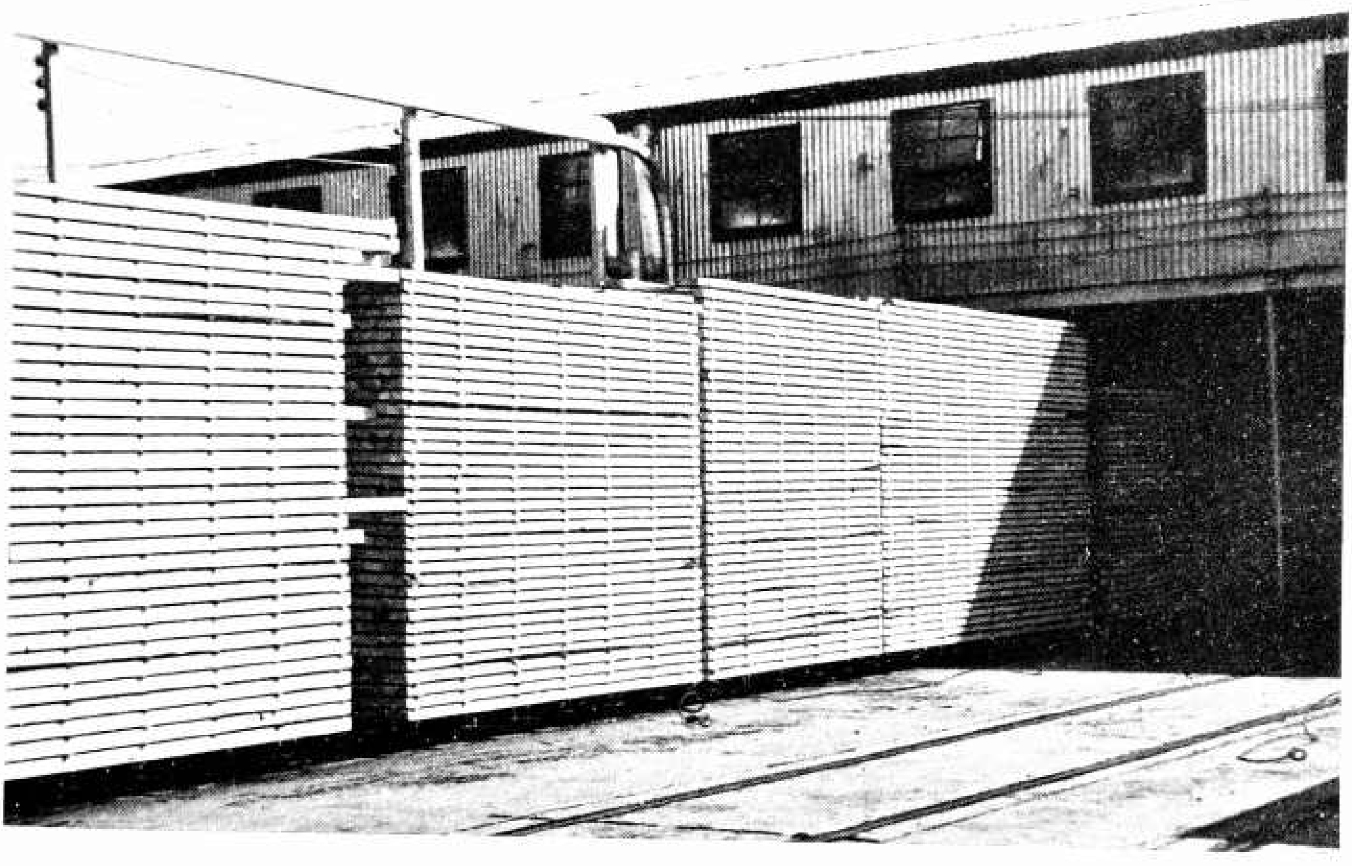
The design of a kiln has an important bearing on its operation and drying efficiency. A properly designed and operated kiln will dry most species of lumber or other wood products to any specified moisture content between 3 and 15 percent in a reasonably short time without appreciable losses due to seasoning defects.

Kilns designed to dry wood are classified in this manual as either compartment or progressive kilns, on the basis of their construction and operation. Both classes include natural-circulation and forced-circulation kilns of the ventilated type.

Compartment kilns are loaded fully at one time; the entire charge remains stationary throughout the drying period, and temperature and relative humidity are kept as uniform as possible throughout the kiln. The dry- and wet-bulb temperatures are changed from time to time as the wood dries. Compartment kilns have doors at one or both ends or along the sides. A few kilns have removable roofs through which the lumber is put in and taken out.

In a progressive kiln, the charge consists of a number of truckloads of wood, each at a different stage of drying. Progressive kilns have doors at both ends. The wettest stock is on the truckload nearest the loading, or "green," end of the kiln; the driest near the unloading, or "dry," end. Whenever a truckload of dry lumber is removed from the unloading end of the kiln, the remaining trucks are moved toward the unloading end, and a truckload of green or partially dry lumber is rolled into the kiln at the loading end. The drying conditions usually are less severe at the loading than at the unloading end. This is accomplished mainly by putting more heating coils at the unloading end of the kiln, where a higher dry-bulb temperature is desired.

Most dry kilns are of the track type. The wood is stacked on trucks that are rolled into and out of the kiln on tracks (fig. 7). Kilns of the track-



ZM–105938–F

FIGURE 7.—Lumber stacked on trucks of a track-type kiln.

less type are loaded and unloaded with lift trucks or overhead cranes and are commonly called package-loaded kilns.

Compartment Kilns

Natural-Circulation Compartment Kilns

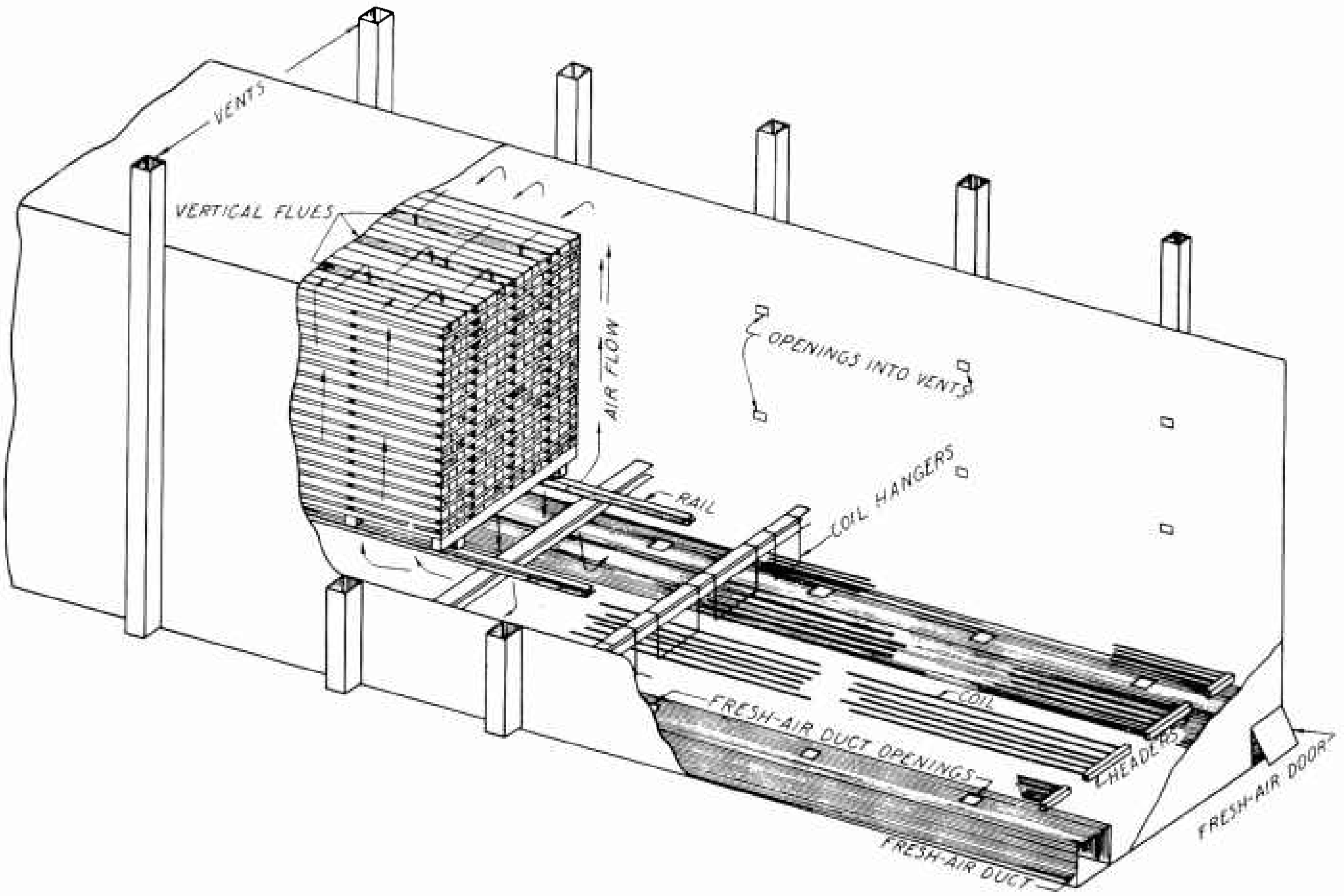
In a natural-circulation compartment kiln (fig. 8), the air circulates through the loads of lumber by natural means; the air heated by the coils rises and that cooled by the wood falls. Fresh, cool air enters the kiln through fresh-air ducts that usually extend the full length of the kiln below the heating coils. Hot, moist air is removed from the kiln through roof or wall ventilators.

During the first stages of drying green or partially air-dried stock in a single-track, end-piled kiln (fig. 8), the heated air moves upward from the heating coils through the spaces between the loads and the kiln walls. When this air reaches the ceiling of the kiln, it begins to move downward through flues or openings built into the loads, cooling as it falls. The downward movement continues until the air reaches the heating coils, where it is reheated, mixed with fresh air that enters the kiln through the fresh-air ducts, and recirculated in the kiln. During this stage of drying, the side coils are turned on and the center coils off.

When the stock has dried to an average moisture content of about 10 to 20 percent, the side coils are turned off and the center coils on. This reverses the direction of air movement; the heated air moves upward through the load and downward along the side walls. This reversal of air circulation tends to reduce the moisture content of the boards in the center and lower parts of the load, which usually dry more slowly during the initial stages of drying.

End-piled, natural-circulation kilns can be constructed with one or more loading tracks. In multiple-track kilns of this type, additional heating coils are placed below and between the tracks.

In a cross-piled, natural-circulation kiln, the loads of lumber are separated so that air can circulate between them as well as between the



ZM-59503-F

FIGURE 8.—A natural-circulation, steam-heated, single-track, end-piled compartment kiln. Vents for exhausting moist, hot air may be on the roof or, as shown, in the walls. Arrows indicate air movement during the early stages of drying, when the side coils are on and the center coils off.

ends of the loads and the kiln walls. Flues should be provided in the loads of lumber to facilitate circulation.

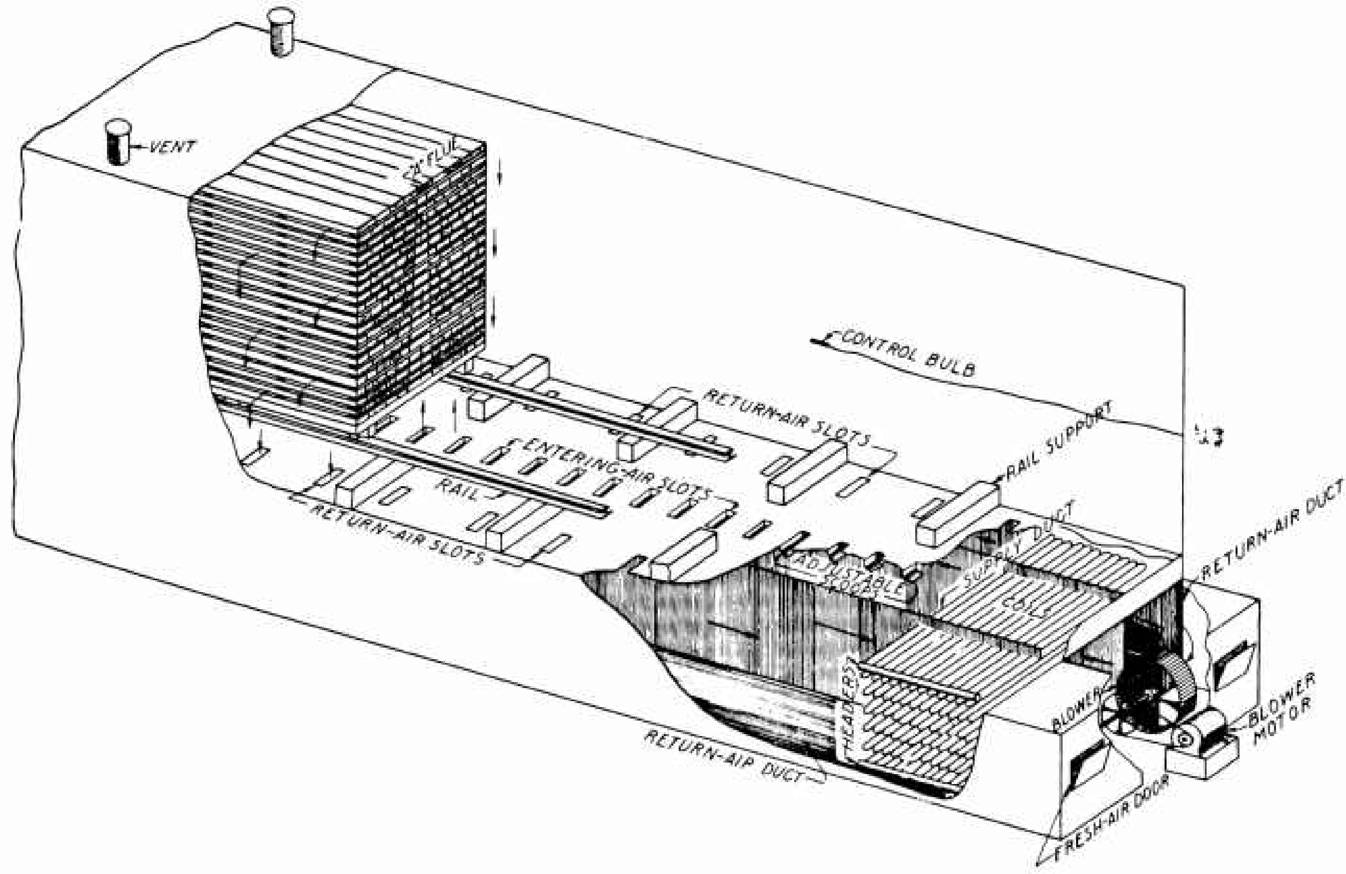
Forced-Circulation Compartment Kilns

Air is circulated within all types of kilns to (1) carry heat from the steam coils or other types of heaters to the lumber, (2) mix the air, and (3) carry away the moisture evaporated from the wood. To perform these functions more efficiently than is possible in a natural-circulation kiln, a number of forced-circulation compartment kilns have been developed that differ mainly in the arrangement of fans or blowers. Forced-circulation compartment kilns, on this basis, are of two general types—external-blower and internal-fan.

External-Blower Kilns.—Some types of external-blower compartment kilns are shown in figures 9, 10, and 11. In the type shown in figure 9, the air ducts are located below track level and run the length of the kiln. There are two return-air ducts, one on each side of a supply duct. A blower located at one end of the kiln blows the air through the heating coils and into the supply duct located directly under the center of the loads of lumber. Along the top of this supply duct is a series of slots with adjustable air scoops that pick up the air and direct it through the slots and thence into an A-shaped flue built into each load of lumber.

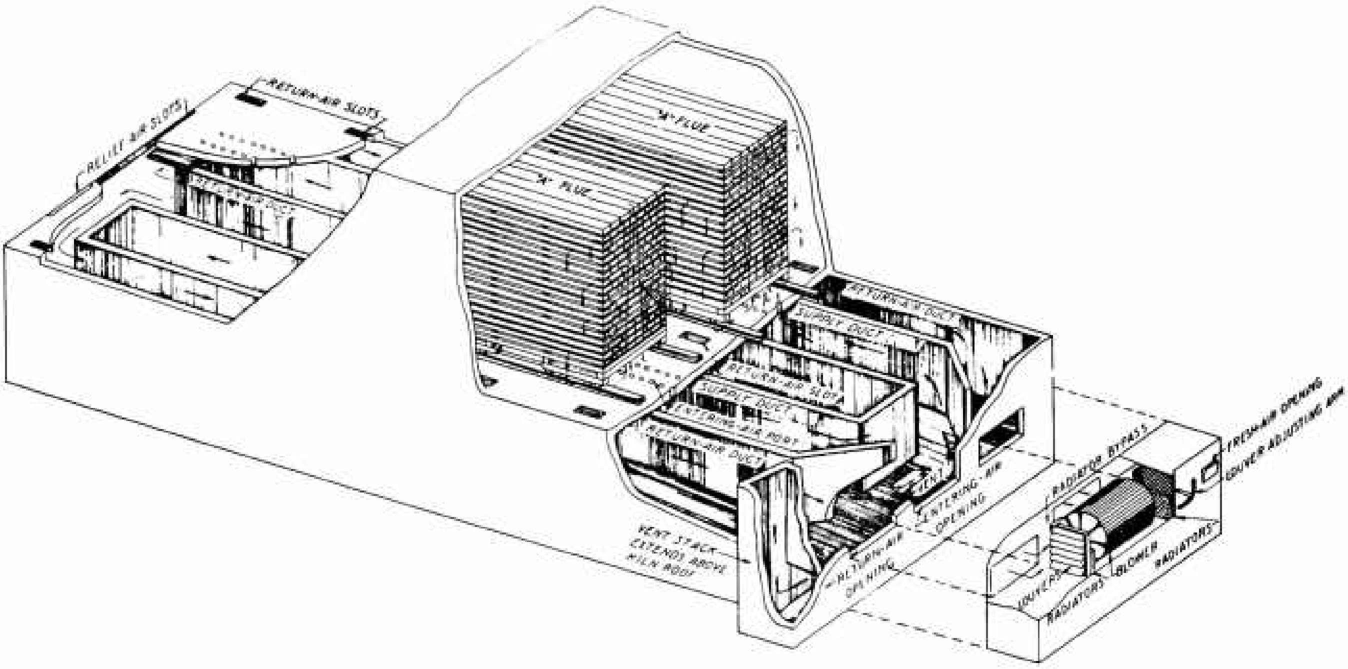
From this A flue, the air moves outward to each side of the load, then downward. Most of the air leaving the load of lumber enters the return-air ducts through slots, while the rest is drawn under the load and mixed with the air being blown into the A flue from the supply duct. The air that enters the return-air ducts travels back to the blower and coils to be reheated and again blown into the kiln. The top of the A flue in each load of lumber is closed to prevent the air from short circuiting over the loads.

Hot, moist air is expelled from the kiln through roof vents, while fresh air enters the kiln through doors in the blower housing. Steam spray is injected into the kiln to maintain the desired wet-bulb temperature. The steam sprays are usually located in the return-air ducts between the heating coils and the blower.



ZM–59501–F

FIGURE 9.—External-blower, single-track, compartment kiln with A-shaped flue in the load. Air moves through the load in only one direction during the drying period. Throughout the structure, air is under slight pressure; hence structure can be vented on the leaving-air side of the load or on the low-pressure side of the blower.



ZM—59502—F

FIGURE 10.—External-blower, double-track, compartment dry kiln with A-shaped flues in the loads. Air circulates in same direction at all times. Vent is located in entering-air supply duct.

In the type of double-track blower kiln shown in figure 10, the blower is located below track level at the end of the kiln. There are two supply ducts and three return-air ducts. The center return-air duct is sealed near the blower end of the kiln so that the returning air in this duct travels to the opposite end of the kiln and returns to the blower through the two return-air ducts located on either side of the kiln.

The blower forces air into a main supply duct, which is divided just inside the kiln into two ducts that run under the center of each track. Along the tops of these ducts are entering-air ports. The air is blown upward through these ports into an A flue built into each load, moves across the load, and then downward through slots in the floor to the return-air ducts. Only part of the air leaving the load enters the return-air ducts; the rest is drawn under the load, mixed with the air entering the A flues from the entering-air ports, and recirculated through the lumber. The air in the return ducts passes through heating units, then through the blower, and back into the main supply duct. The amount of air coming from the entering-air ports is regulated by adjusting a relief air slot located at the closed end of the supply ducts.

Hot, moist air is discharged from the kiln through an adjustable vent damper located on the floor of the main supply duct. Fresh-air openings are located in the blower housing. Steam spray is injected into the kiln, when required, through nozzles located in the blower housing on the low-pressure side of the blower.

A trackless type of external-blower compartment kiln is shown in figure 11. The packages of lumber are loaded into the kiln with a forklift truck. A space of 12 to 18 inches is left between the tiers of packages. The blower is located at one end of the kiln above the drying compartment. Heat and spray units are located in the blower housing. A main supply-air duct connected to the blower is located between the top of the drying compartment and the kiln roof. Transverse supply-air ducts are connected to the bottom of the main supply-air duct directly over alternate spaces between the tiers of packages. Return-air ducts, which connect to the blower, are located in the kiln walls.

The heated air moves from the blower through the main supply-air duct, and is discharged through nozzles downward into the space between alternate tiers of packages. From this space the air moves across the boards of the stickered packages. It then passes into the return-air ducts in the walls and back to the blower, to be reheated and blown back into the kiln.

Internal-Fan Kilns.—Fans of internal-fan compartment kilns can be placed in various locations in relation to the kiln charge (fig. 12). When natural-circulation kilns are remodeled, the fans are usually placed in the pit below track level. Most new kilns, however, are built with overhead fans.

ZM–105946–F

FIGURE 11.—External-blower compartment kiln loaded with packaged lumber arranged in tiers. Heated air enters the chamber through nozzles in ceiling.

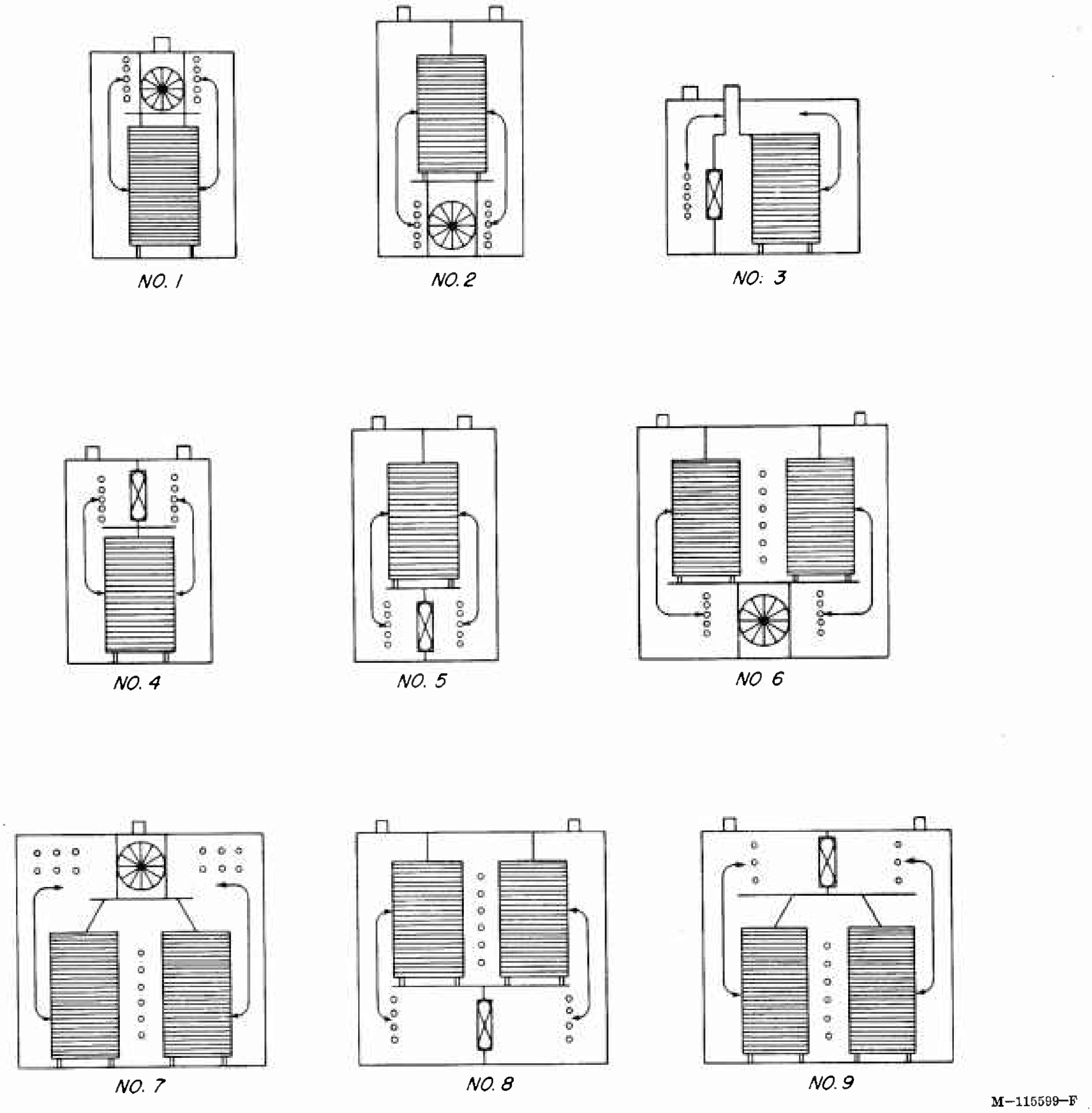
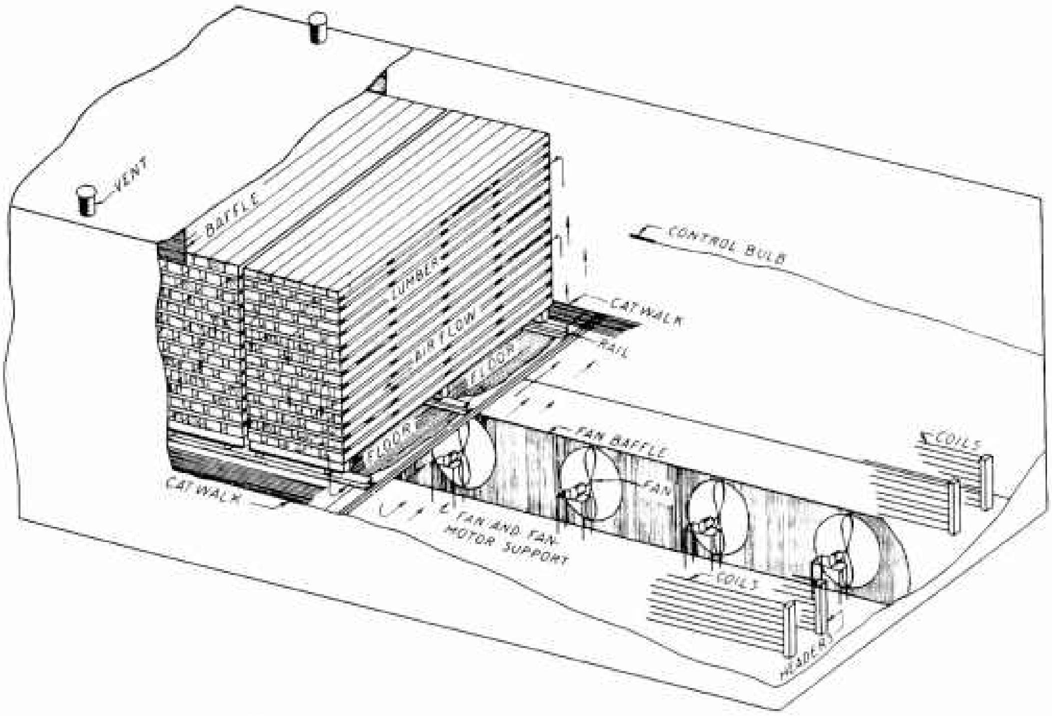


FIGURE 12.—Some plans for location of fans above, below, or alongside lumber charges in internal-fan kilns.

Internal-fan kilns with direct-connected fan motors are shown in figures 13, 14, and 15. Figure 13 shows a cross-piled, direct-connected, internal-fan, reversible-circulation kiln, the fans of which are located below track level. This design is frequently used when cross-piled, natural-circulation kilns are remodeled. A solid floor is constructed over the fans and the coils between the outside rails. Catwalks, gratings of metal or wood, are usually installed between the outside rails and the walls.

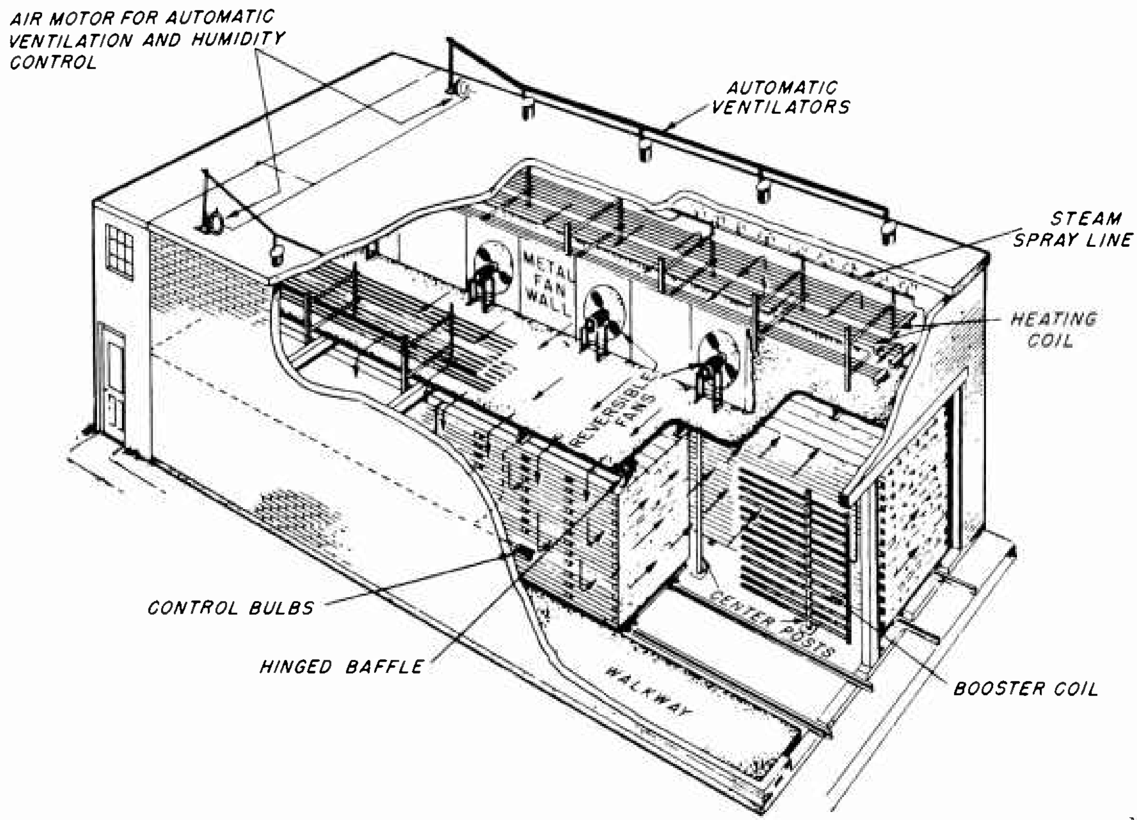
Air is blown across the heating coils, which extend the full length of the kiln. It then moves upward through the catwalk into the space between the kiln wall and the ends of the loads of lumber. Ceiling baffles prevent the air from short circuiting over the tops of the loads. The boards in each course of lumber should be placed at least 2 inches apart, so that the air can move through the load. A steam spray line usually extends the length of the kiln below track level. Roof vents permit hot, moist air to leave the kiln and cool, dry air to enter. Kiln conditions usually are automatically controlled. Circulation can be reversed manually or automatically by means of switches that change the direction of rotation of the fans.

The kiln shown in figure 14 is a double-track, internal-fan, reversible-circulation kiln with end-piled loads. The fans and coils are above the



ZM–59505–F

FIGURE 13.—Compartment kiln with internal fans directly connected to individual motors. Open-piled loads placed crosswise in kiln. Air flows against stickers and through spaces between edges of boards. Vent on high-pressure side of fan becomes fresh-air inlet when direction of circulation is reversed.



M–105906–F

FIGURE 14.—Double-track compartment kiln with internal fans directly connected to motors. Lumber piles are loaded endwise, and boards are stacked edge to edge. Air flows parallel to stickers.

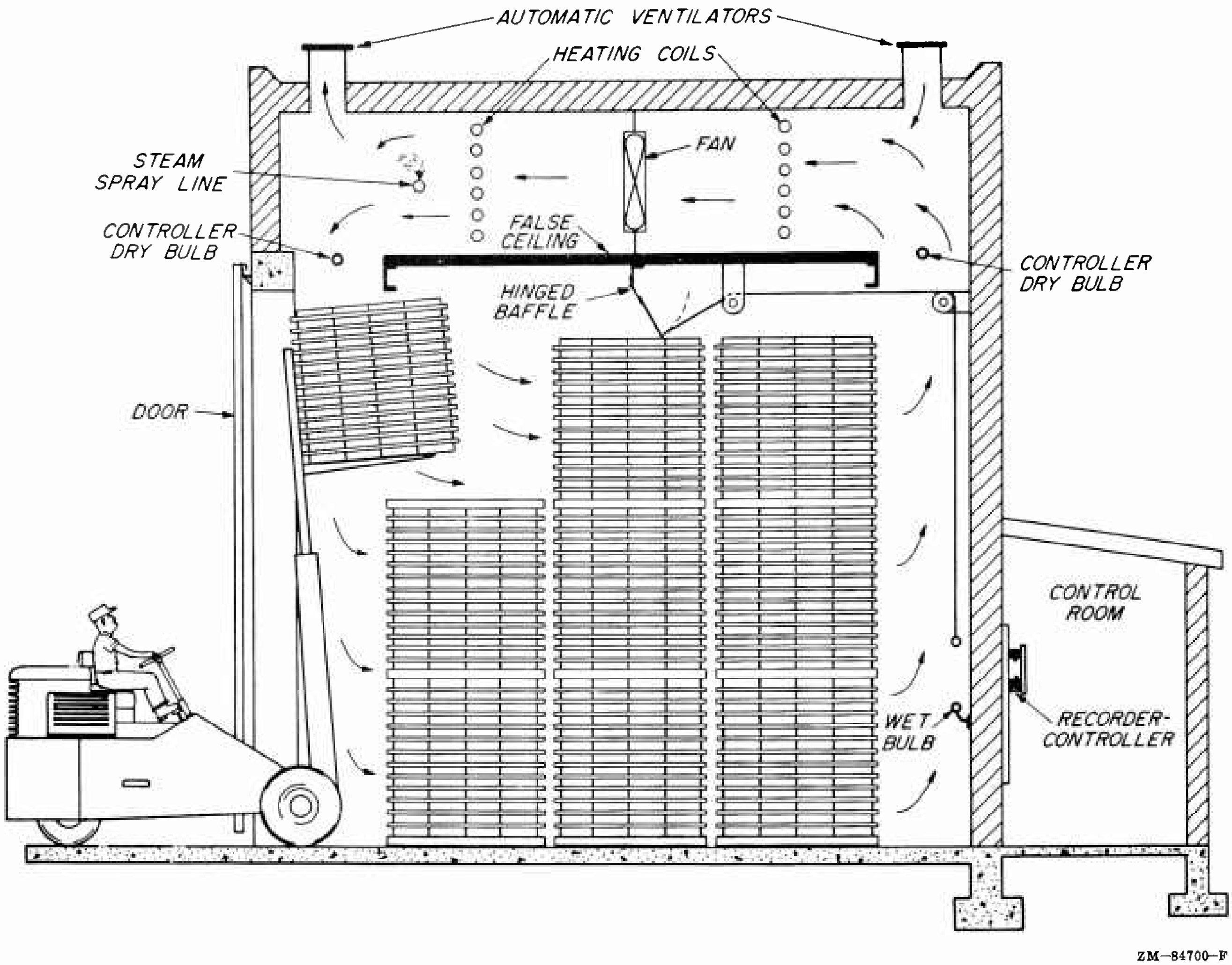


FIGURE 15.—Package-loaded compartment dry kiln with internal fans directly connected to motors.

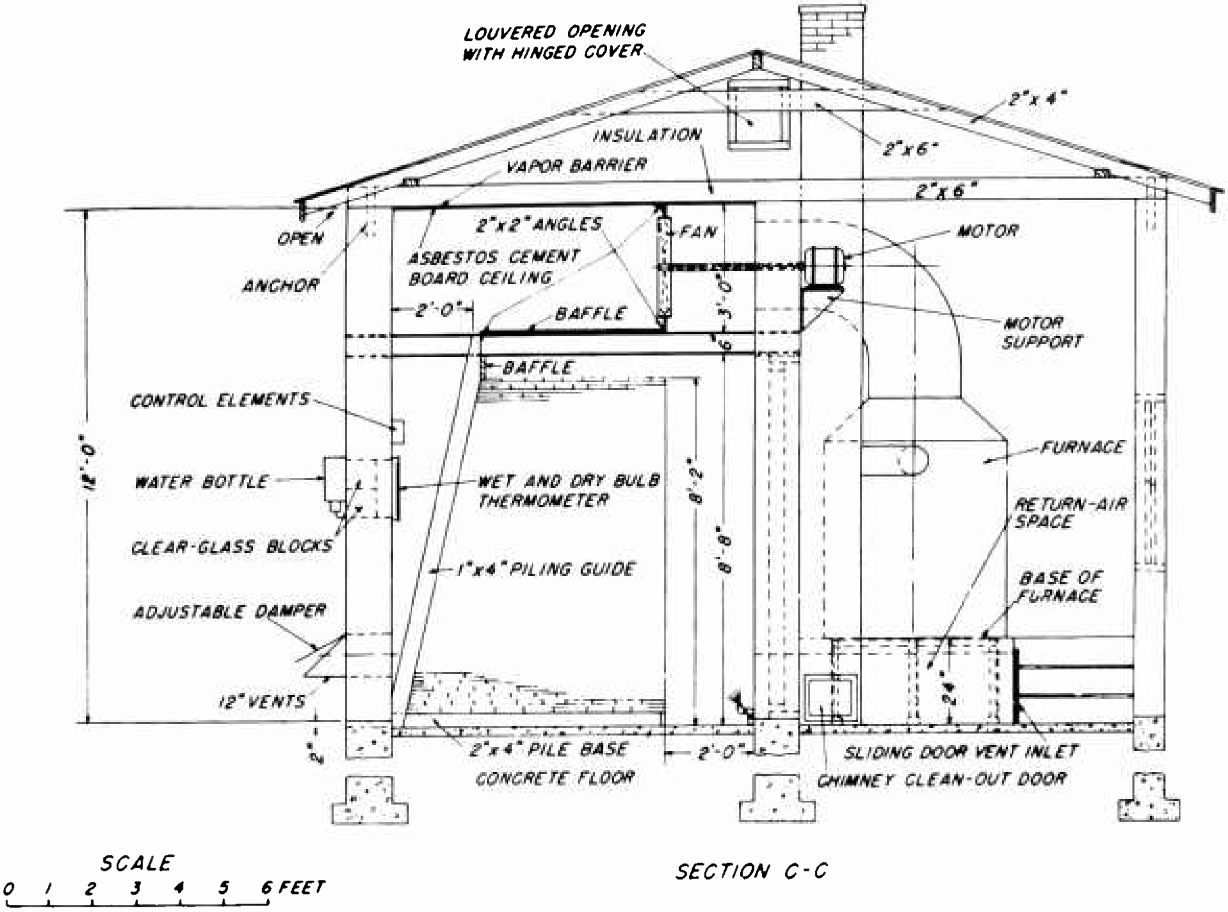
loads. Hinged baffles prevent the air from short circuiting over the top of the loads, and walkways or baffles on the kiln floor prevent short circuiting under the loads. The air moves through the heating coils, which extend the length of the kiln, and then downward in the space between the kiln wall and the load. It then moves across the loads and upward to return to the fans. The illustration shows booster coils located between the tracks to raise the temperature of the air after it has passed through the first track load of lumber. A steam spray line extending the length of the kiln is also shown. Hot, moist air leaves the kiln and cool, dry air enters it through the roof vents. Kiln conditions usually are automatically controlled.

A package-loaded, trackless kiln with direct-connected internal fans and reversible circulation is shown in figure 15. This kiln operates in the same way as the internal-fan, end-piled kiln shown in figure 14. Baffles that extend from the bottom to the top of the drying chamber on each wall are needed to prevent the short circuiting of air past the ends of the packages. Baffles are also required between the false ceiling (fan floor) and the top of the lumber charge.

Short-shaft, internal-fan kilns have shafts of varying lengths connecting the fans to the motors, which are located outside the kiln. The motors can be connected directly or with belts to the fan shafts. The fans can be located alongside, above, or below the loads. Baffles prevent the air from short circuiting around the loads. Kiln conditions usually are automatically controlled.

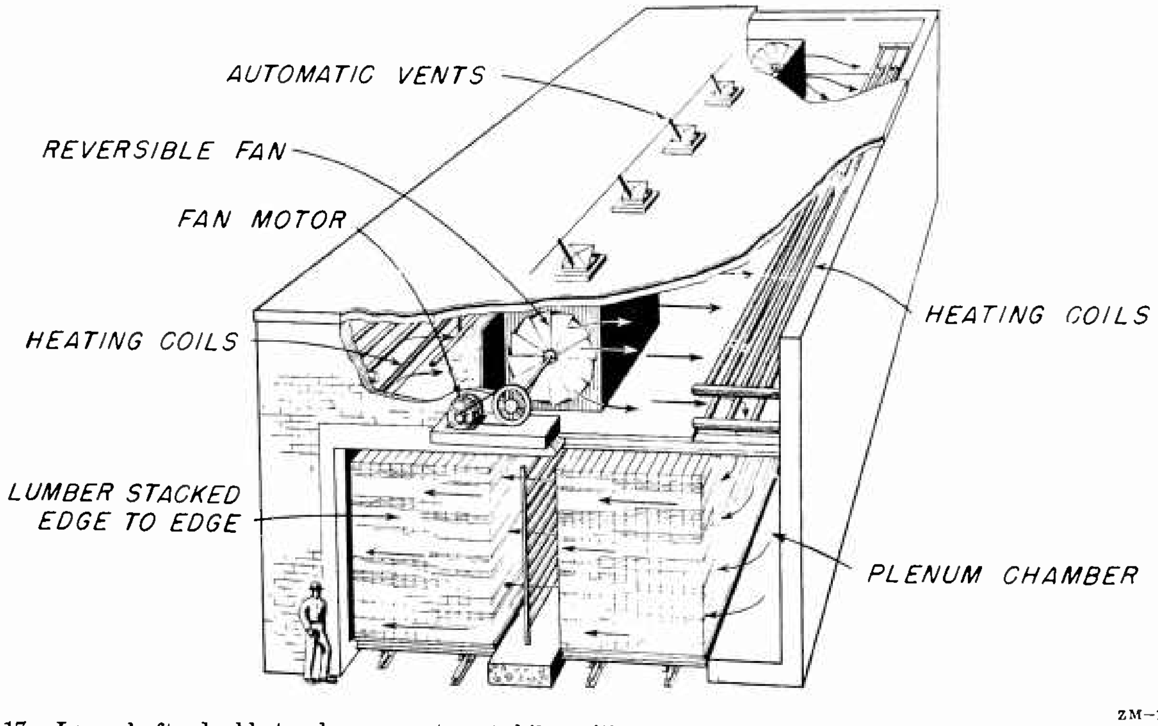
A short-shaft, internal-fan kiln design is illustrated in figure 16. The heating system is an ordinary house furnace using gas, oil, coal, or wood for fuel. The fans in this kiln should not be reversed.

A double-track, long-shaft, internal-fan kiln with reversible circulation is shown in figure 17. It has alternate right-hand and left-hand fans mounted on the shaft. This arrangement, together with the fan baffles, forces the air across the kiln and prevents lengthwise drifting. Baffles between the fan floor and the top of the load,



ZM-82167-F

FIGURE 16.—Internal-fan, short-shaft, end-piled compartment kiln with furnace for heating air.



ZM-105908-F

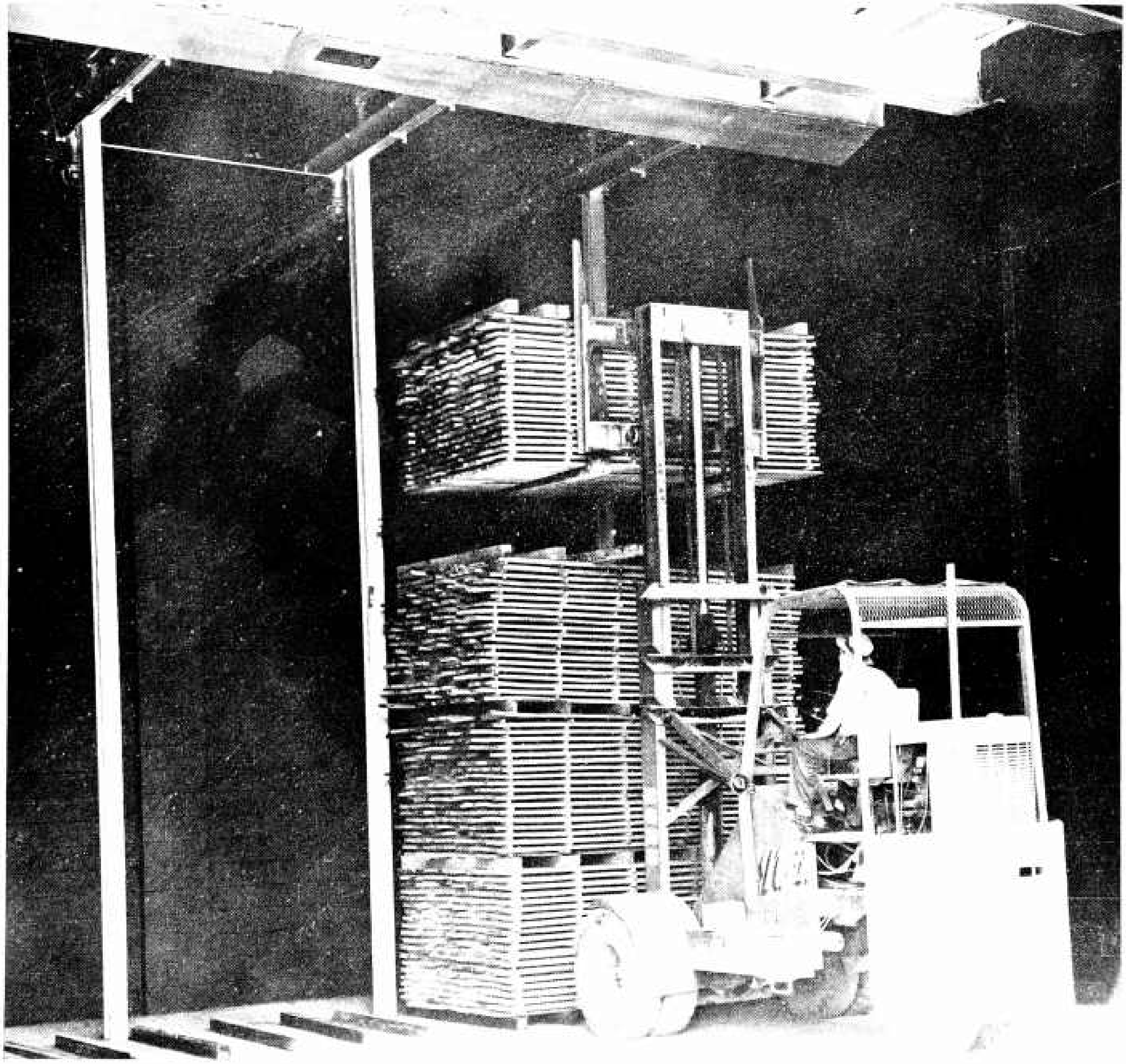
FIGURE 17.—Long-shaft, double-track, compartment kiln with alternately opposing internal fans. Vents are over fan shaft between fans. Vent on high-pressure side of fan becomes fresh-air inlet when direction of circulation is reversed.

together with a combination walkway and baffle on the kiln floor, prevent the air from short circuiting below and above the loads. Roof ventilators permit hot, moist air to escape from the kiln, and cold, dry air to enter it. Kiln conditions usually are automatically controlled. A spray line supplies steam for control of relative humidity, and a booster coil reduces the temperature drop between the two tracks of lumber.

A package-loaded, trackless kiln of the long-shaft, internal-fan, reversible-circulation type is shown in figure 18. The fan-baffling system is the same as that used in the double-track, long-shaft kiln shown in figure 17.

Progressive Kilns

Like compartment kilns, progressive kilns can be classified into two broad types, natural-circulation and forced-circulation kilns.



M–106138–F

FIGURE 18.—Loading a trackless compartment kiln with packages of lumber.

Natural-Circulation Progressive Kilns

The heating system in natural-circulation progressive kilns is designed to produce higher dry-bulb temperatures at the dry end of the chamber than at the green end (fig. 19). Fresh air enters the kiln through a duct located on the floor of the pit at the dry end. It rises through the heating coils and moves upward through flues or openings in the loads of lumber in the dry end of the kiln. The air then moves along the tops of the loads of lumber toward the green end, flows downward through the loads into the pit, and then returns to the dry end of the kiln to begin a new cycle. Moisture is added to the kiln atmosphere, when necessary, by means of steam sprays. The hot, moist air is expelled from the kiln through ventilators. These kilns are designed for both cross-piled and end-piled loads.

Forced-Circulation Progressive Kilns

Fans or blowers are used to circulate heated air through the loads in forced-circulation progressive kilns.

External-Blower Kiln.—A progressive kiln of the external-blower type, sometimes called a "wind-tunnel" dryer, is shown in figure 20. In this kiln, air is moved through a heating coil and blown into the dry end of the chamber by an external blower. The air travels the entire length of the chamber, becoming cooler as it passes through the loads of lumber, and is discharged from the kiln at the green end of the chamber. Loads of cross-piled lumber progress from the green end to the dry end of the kiln. When dry, they are removed from the kiln on a transfer way. The air is prevented from short circuiting around the loads of lumber by hinged or canvas baffles suspended from the ceiling and swung in from both walls.

Internal-Fan Kilns.—Internal-fan, progressive kilns are usually similar to the internal-fan compartment kiln shown in figure 17. To be operated progressively, the internal-fan kiln must have split heating systems so that the temperature in each zone can be controlled independently. The temperature at the green end is held lower than that at the dry end.

General Construction Features

Dry kilns are constructed of many different kinds of materials (*2*),[1] including wood, brick,

[1] Italic numbers in parentheses refer to Literature Cited, p. 47.

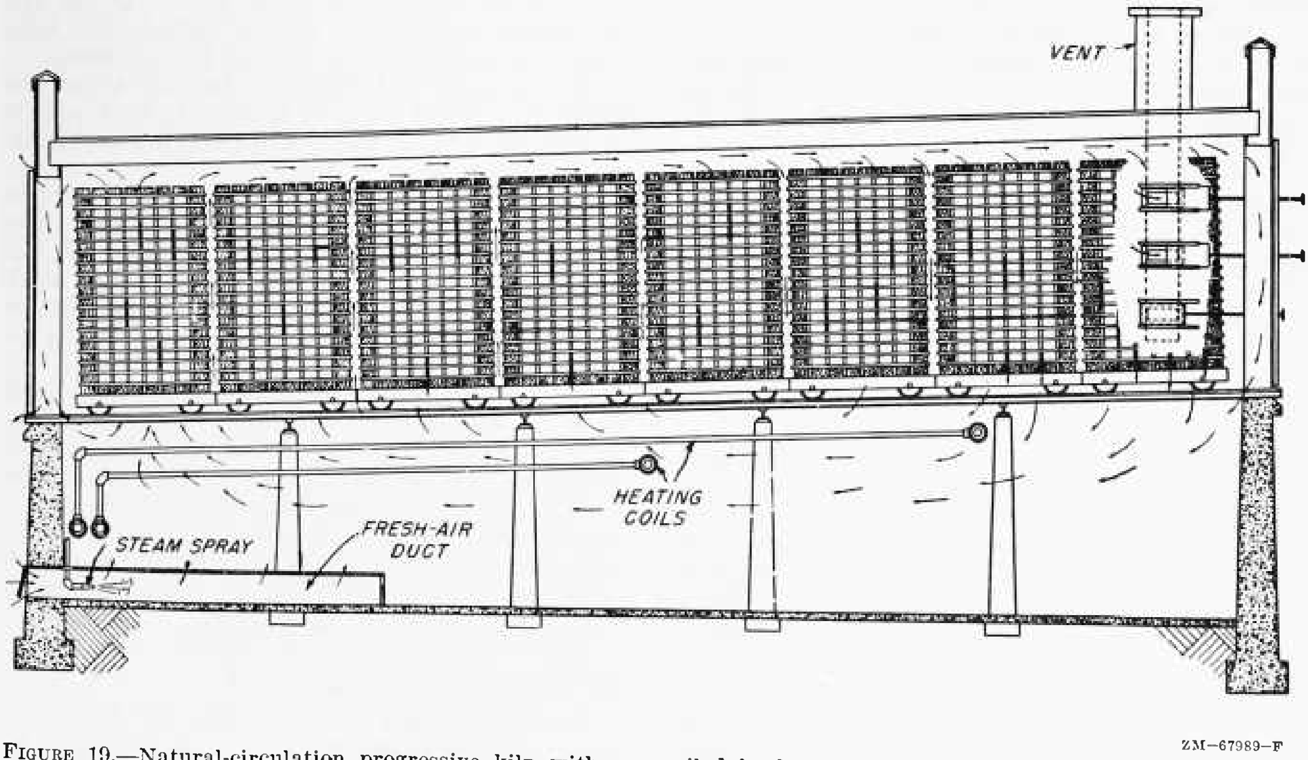


FIGURE 19.—Natural-circulation progressive kiln with cross-piled load. Vent is located at loading (green) end of the kiln and the fresh-air inlet at unloading (dry) end on pit floor.

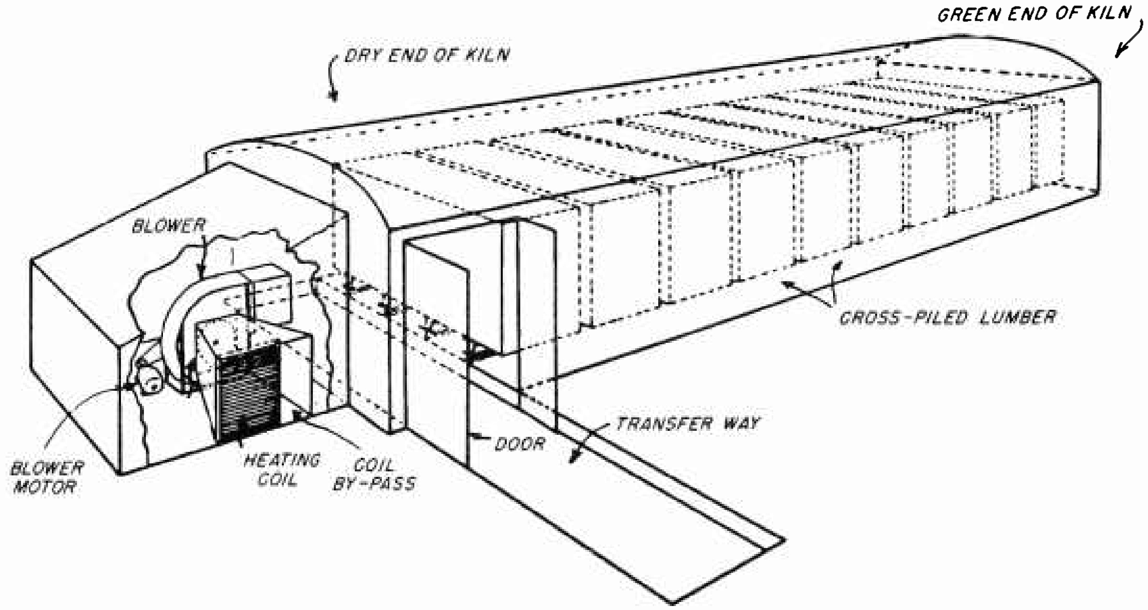


FIGURE 20.—External-blower progressive kiln with cross-piled loads. Air drawn into heater from the outside is blown through the loads of lumber. Cool, moist air is discharged at the green end of the dryer.

tile, concrete, cement blocks with gravel or lightweight aggregate, asbestos-cement boards, and sheet metal. Kiln size varies considerably. Most kilns are large enough to accommodate single- or double-loading tracks; some have as many as four tracks. In general, the height of a kiln with underload fans is about 12 feet from track level to ceiling. Kilns equipped with overload fans are about 17 feet high from track to ceiling. Trackless, package-loaded kilns may have a drying chamber as high as 28 feet.

The width of a kiln depends primarily on the number of tracks installed and the method used to pile the lumber. A single-track kiln with end-piled lumber is usually 12 to 16 feet wide, while a single-track kiln with cross-piled lumber is generally 18 to 22 feet wide. Kilns for end-piled lumber are usually built about 10 feet wider for each additional track. Package-loaded, trackless kilns may be as wide as 38 feet. Kiln lengths may range from 20 to 225 feet.

Heat is usually supplied by heat exchangers, such as steam coils, unit heaters, or smoke pipes. In kilns of the forced-circulation type, the heating systems may be above the loads, below the track level, or on the side of the kiln, depending upon the location of the fans or blowers. In natural-circulation kilns the heating system must always be located below track level.

Kilns in which heating coils and fans are below the tracks usually are constructed with the tracks about 4 to 6 feet above the pit floor, depending on the size of the fans and coils. The floor must be high enough above grade level to prevent water from seeping into the kiln and interfering with wet-bulb temperature control; kilns built on low ground near a body of water are especially exposed to this hazard. The control or instrument room is usually attached to one end or wall, below track level. If the fan or blower motors are located outside the kiln, they also are generally housed in this room.

If the coils and fans are located above the load, the control room is frequently built at one end of the kiln on the level of the fan and heating compartment.

Most kilns are constructed with ventilators to expel hot, moist air and draw in cool air. The ventilators are generally located on the roof, but in some external-blower kilns a ventilator stack and a fresh-air intake are attached to the blower housing. Ventilators can be either manually or automatically operated.

A kiln may be built with doors at one or both ends, or on one side, depending on which layout is most convenient for handling the lumber. When the doors are located at both ends, the tracks are usually installed with a slight downgrade from the front (loading) to the back (unloading) end, so that the trucks can be moved more easily. This is especially important when trucks are moved by manpower.

Heating System

Heat is required in a dry kiln for four purposes: (1) to warm the wood and the water in the wood; (2) to evaporate moisture from the wood; (3) to warm the fresh air entering the kiln; and (4) to replace the heat lost by radiation through the kiln structure. Sources of heat are of two general classes—direct and indirect.

Direct Heating.—In direct-heated kilns the hot gases produced by burning gas, oil, sawdust, or other fuels are mixed with the air that is circulated through the loads of lumber. In some direct-heated kilns, these products are forced into ducts and then discharged into the drying chamber. In other types of direct-heated kilns, the open flames of gas or oil burners heat metal radiating surfaces (heat exchangers). Fans mounted directly over the heat exchanger move the hot air through the loads of lumber (fig. 21).

Indirect Heating.—In indirect-heated kilns various sources of heat—hot gases and air, electricity, and steam—are used. The heat exchangers can be located either inside or outside the drying chamber. The exchangers, in turn, heat the air being circulated through the loads of lumber.

Steam is commonly used at various pressures as a source of heat in dry kilns. Since the temperature of steam varies with its pressure, more radiating surface is required to obtain a given temperature if the kiln is operated at low steam pressures than if it is operated at high steam pressures.

Radiating Surfaces

Several types of radiating surfaces are used in dry kilns, including pipe coils, unit heaters, hot gas pipes, and electric strip heaters.

Pipe coils used in steam-heated kilns are of several types—plain-header coils, single-return-bend header coils, multiple-return-bend header coils, booster coils, and ceiling coils.

The plain header coils, both horizontal and vertical (fig. 22), are frequently used as heating units. They may be of any length, although short coils are more efficient and produce more uniform temperatures along their length than do long coils. They consist of varying numbers (runs) of pipe connected directly to a feed header at one end and attached to short springer pipes at the other end. The springer pipes are in turn connected to a drain header. The coil pipes are usually from 1 to 2 inches in diameter and the springer pipes are usually of smaller diameter. This provides flexibility in the springer section, so that unequal thermal expansion of the runs will not crack the headers. The coils should be installed with a downward pitch from the feed header to the springer section. The pitch usually varies from 1/8 to 1/4 inch per foot of coil length, depending upon the steam pressure used and the space available for the coils.

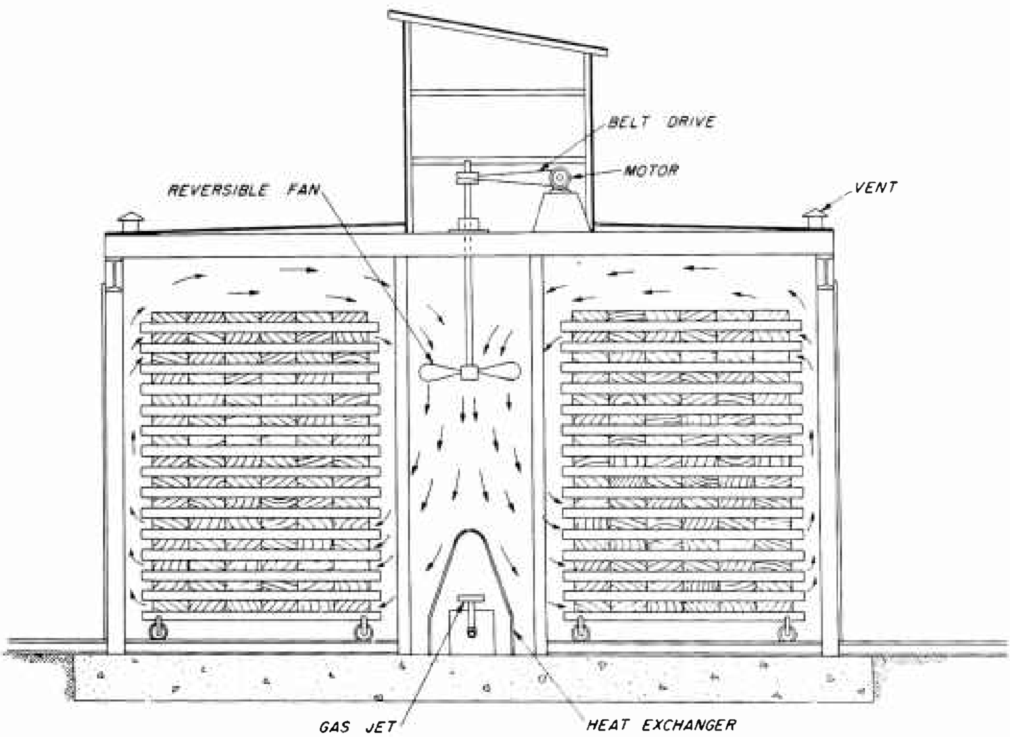
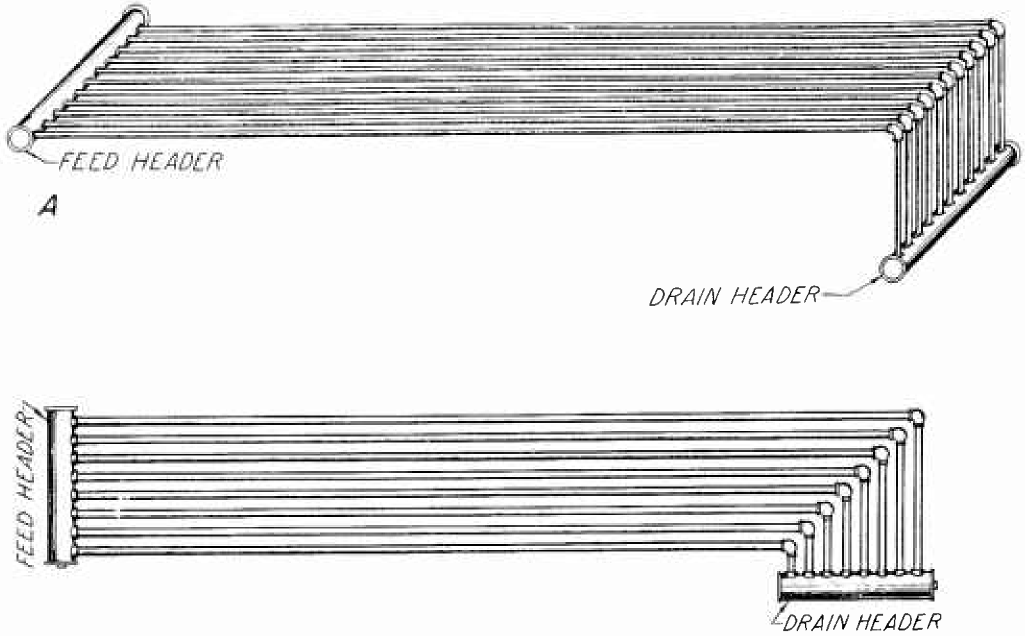


Figure 21.—Double-track, end-piled, internal-fan compartment kiln heated directly with natural gas.



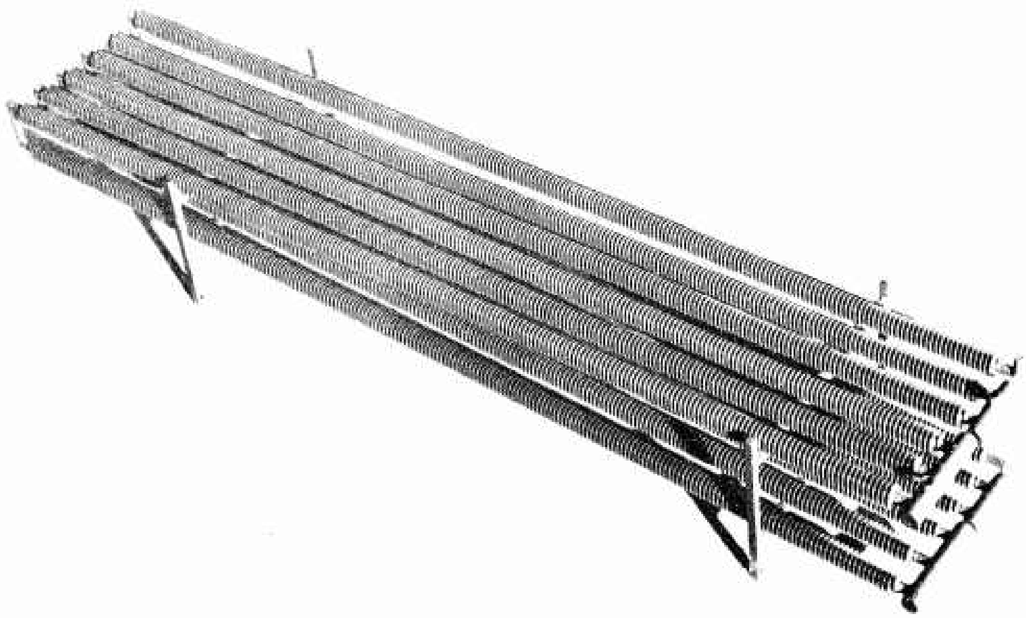
ZM–60739–F

FIGURE 22.—*A*, Horizontal, and *B*, vertical plain header coils.

The runs can be of either plain or fin-type pipe. Fin pipe is plain pipe or copper tubing equipped with thin metal strips or disks (fig. 23). These fins increase the radiating surface of the pipe about 5 to 8 times.

Header coils with a single-return bend (figs. 23 and 24) are highly efficient if they are the proper size to produce uniform temperatures along their entire length. The feed and drain headers are of various sizes, so that almost any number of runs of pipe of either fin (fig. 23) or plain (fig. 24) pipe can be used. Although pipes vary in size, they generally are from 1 to 2 inches in diameter. The runs should pitch downward from the feed to the return-bend header and from the bend to the drain header about $\frac{1}{8}$ to $\frac{1}{4}$ inch per foot of length, depending upon the steam pressure used and the coil space available.

Vertical coils located between the tracks of a multiple-track, end-piled, forced-circulation kiln are called booster coils (figs. 14 and 17). As the



ZM–106142–F

FIGURE 23.—Heating coil made with fin pipe.

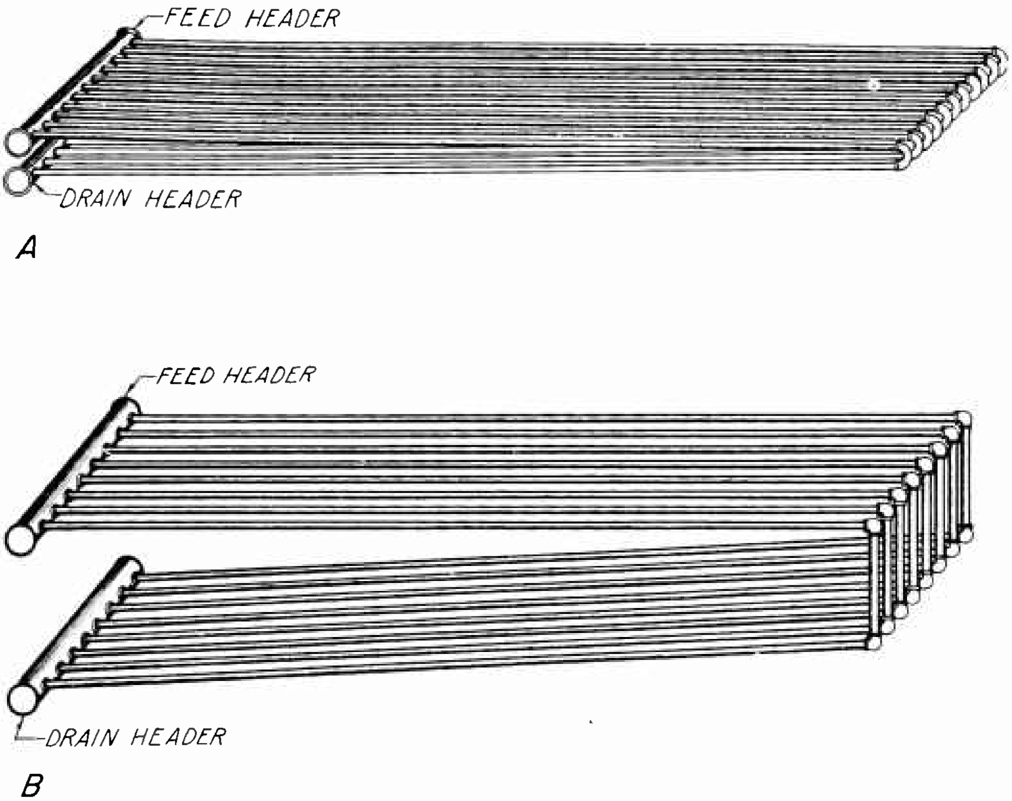


FIGURE 24.—Horizontal single-return-bend header coils: *A*, Header coil fitted with 180° return-bend elbows; *B*, coil fitted with 90° elbows and connecting nipples.

term "booster" implies, these coils raise the temperature of the air after it has passed through a trackload of lumber.

Unit heaters are generally used where concentrated radiation is desired. They are made up of rather small-diameter fin pipe running vertically or horizontally. They are generally used in blower-type kilns and in some internal-fan kilns.

Metal pipes of various diameters, usually larger than coil pipes, are used to carry the products of combustion from burners or furnaces into or through the drying chamber.

Strip heaters are used in electrically heated kilns. They are of various sizes and are so located that heat is distributed uniformly throughout the kiln.

Steam Traps and Control Valves

Steam traps and control valves are used to conserve steam and regulate its flow into heating coils.

Steam Traps.—As steam loses heat, it condenses and forms water. If this condensate is allowed to remain in the coils, they become waterlogged and cause nonuniform temperatures. Therefore, the condensate must be removed as fast as it collects. Automatic valves called steam traps are installed in the drain lines to remove condensate without loss of steam. Another function of steam traps is to release trapped air mixed with the steam. Steam traps should be installed below the coils. A bypass line around the trap allows removal for repair or replacement without shutting off the coil. All coils should be individually trapped to prevent the condensate from short circuiting from one coil to another. The return line to the boiler must be large enough to handle peak loads of condensate.

Steam traps generally used on dry kilns are of three types: thermostatic, gravity, and impulse.

A typical thermostatic trap is shown in figure 25. A bellows that expands or contracts with changes in temperature is attached to a valve stem and valve. As the bellows expands or contracts, it closes or opens this valve. When the heating system is first turned on, the coils and trap are cold and contain air and water. At this point, the bellows are contracted and the valve is open. As steam enters the heating system, it displaces the water and air and forces them through the open valve. When all the air and water have been discharged, the trap is filled with live steam. By then the trap temperature has increased enough to cause the bellows to expand, closing the valve and preventing loss of

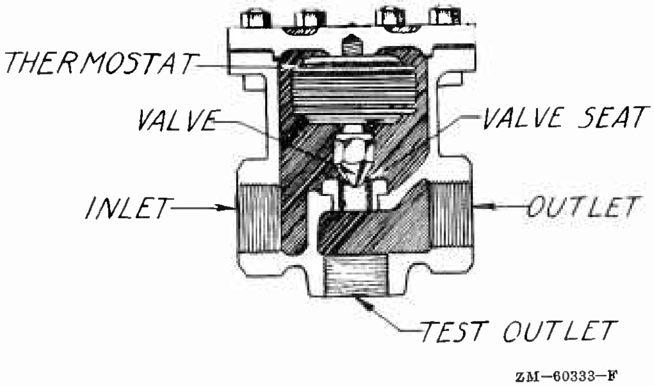


Figure 25.—Thermostatically controlled steam trap.

steam through the trap outlet. After the valve is closed, condensate again begins to accumulate and cool the bellows. This contracts the bellows enough to open the discharge valve, and the cycle is repeated.

The gravity-type traps often used on dry-kiln heating systems are of open-bucket or inverted-bucket design. An inverted-bucket type of gravity trap is shown in figure 26. As steam condenses in the heating system, the condensate flows into the trap. When the trap is filled, the condensate discharges through the outlet pipe. As soon as the system is free of condensate, steam enters the inverted bucket. The pressure of steam causes the bucket to rise against the valve arm until the valve closes the discharge port. Air trapped in the bucket escapes through a vent at the top of the bucket and accumulates in the top of the trap. Condensate again begins to flow into the trap, displacing the steam in the bucket. This reduces the buoyancy of the bucket until it again rests on the bottom of the trap. The discharge valve then opens and allows the condensate to be discharged. Since the air in the top of the trap escapes before the condensate does, air binding is kept to a minimum.

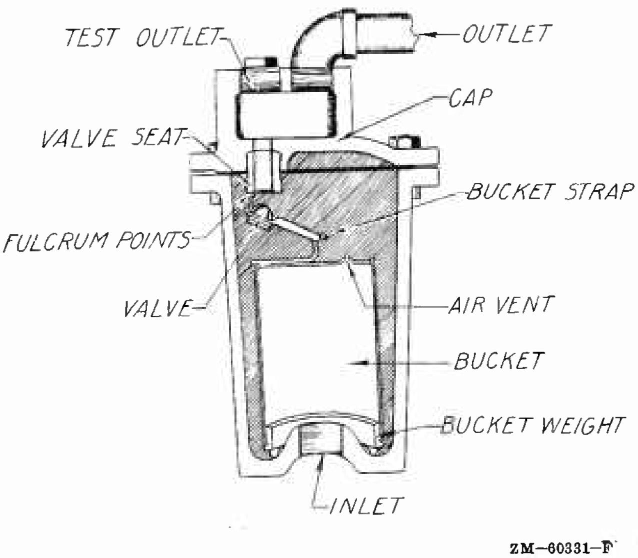


Figure 26.—Inverted-bucket steam trap.

An open-bucket (open-top float) trap is shown in figure 27. When condensate enters the trap, it, together with any scale or dirt it contains, is diverted downward by the splash plate into the bottom of the trap. As condensate accumulates in the lower part of the trap, the bucket is floated upward until the valve contacts the valve seat. The condensate eventually overflows into the bucket. The bucket loses buoyancy and begins to sink, allowing more condensate to flow into it. As the bucket sinks, the projection on the guide post is lowered until it contacts the collar at the bottom of the valve stem, pulling the valve clear of the valve seat. Condensate is discharged from the discharge tube through the valve opening and trap discharge outlet.

When the weight of condensate in the bucket is reduced sufficiently, the bucket rises, seating the valve firmly against the valve seat, and the flow of condensate from the trap is stopped. Since the valve is closed while the discharge tube is still full of condensate, the valve is water sealed while closed, and cannot blow live steam. Condensate again flows into the trap, and the cycle is repeated. A thermostatic air vent, when open, permits air to escape from the trap without loss of steam.

A trap of the impulse type is shown in figure 28. The flow of condensate through this trap is controlled by differences in pressure between the inlet chamber and the control chamber. When the steam is off and the trap is filled with air, the pressure is the same in the inlet as in the control chamber, and the control valve rests firmly against the valve seat. When condensate enters the trap, the pressure in the inlet chamber becomes greater than that in the control chamber. The pressure on the under side of the control disk lifts the control valve free of the valve seat, and air and condensate pass through the valve opening into the discharge line.

The control cylinder has a reverse taper that adjusts the flow of condensate around the control disk and into the control chamber, until the pressures above and below the disk are balanced. Then the temperature of the condensate increases because of the hot steam behind it. The hot condensate entering the lower pressure control chamber flashes into steam, which increases in volume and retards the flow of condensate through the control-valve orifice. When the downward pressure on the upper surface of the valve and valve disk exceeds the upward pressure on the rim of the valve disk, the valve is forced downward, shutting off the flow of condensate through the main orifice. The temperature in the control chamber then drops, and the cycle is repeated.

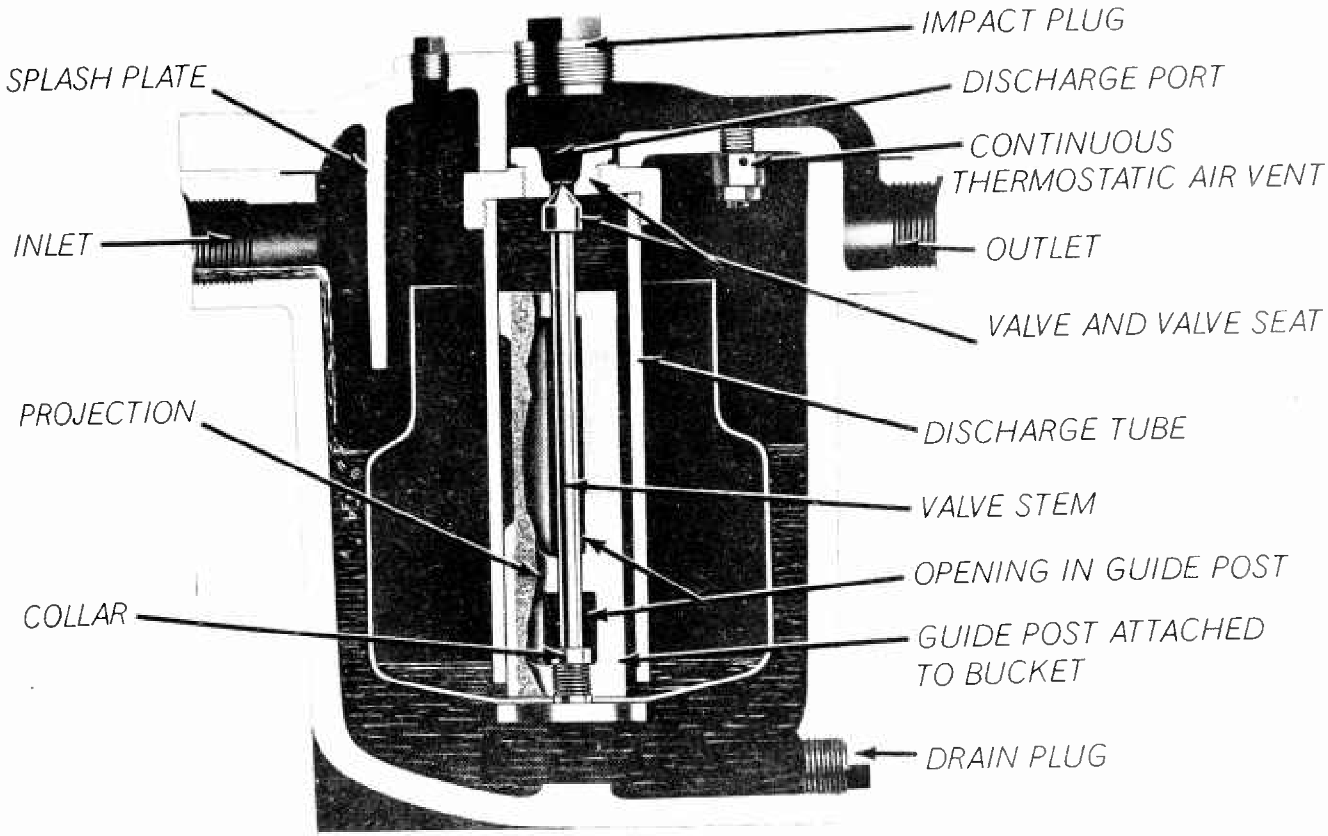


FIGURE 27.—Open-bucket steam trap.

Control Valves.—Both manually and automatically operated valves are used to control the flow of steam into the coils. Pressure regulators and reducing valves are also used to control the pressure of the steam.

Hand valves of the globe type are usually installed on the feed and drain lines of the heating coils. The hand valves on the feed lines are installed between the automatically operated valves and the heating coils in automatically controlled kilns. In manually controlled kilns, they are installed between the main feed line and the heating coils. Hand valves in the drain lines are installed between the coils and the traps. Additional hand valves are also installed in the bypass line around the traps and sometimes in the return lines to the boiler room. These hand valves should be either wide open or tightly closed.

Pressure-reducing valves or regulators should be installed in the main feed line between the boiler and the kiln. Several reducing valves may be needed in a large battery of kilns to compensate for pressure drops in the main feed line. Valves of this type prevent the pressure from going above a set maximum. A pressure gage should be installed on the low-pressure side of the reducing valve. An automatic pressure regulator of a type used on dry kilns is shown in figure 29.

Automatic valves, operated by compressed air or electricity, are recommended for control of drying conditions in a kiln. They are part of the automatic control system and, in steam-heated kilns, are installed between the main steam-supply line and the heating coils and between the main line and the steam-spray lines. A steam piping arrangement for a dry kiln is shown in figure 30.

Spraying Systems

Steam or water sprays are commonly used as a means of humidification in the dry kiln to control the wet-bulb temperatures during the drying, equalizing, and conditioning stages of the seasoning operation.

Steam Sprays.—Steam-spray lines are usually installed in steam-heated kilns and sometimes in furnace-type kilns. As a rule, the spray lines are made of plain pipe along which spray holes or jets are spaced. The spray lines may extend

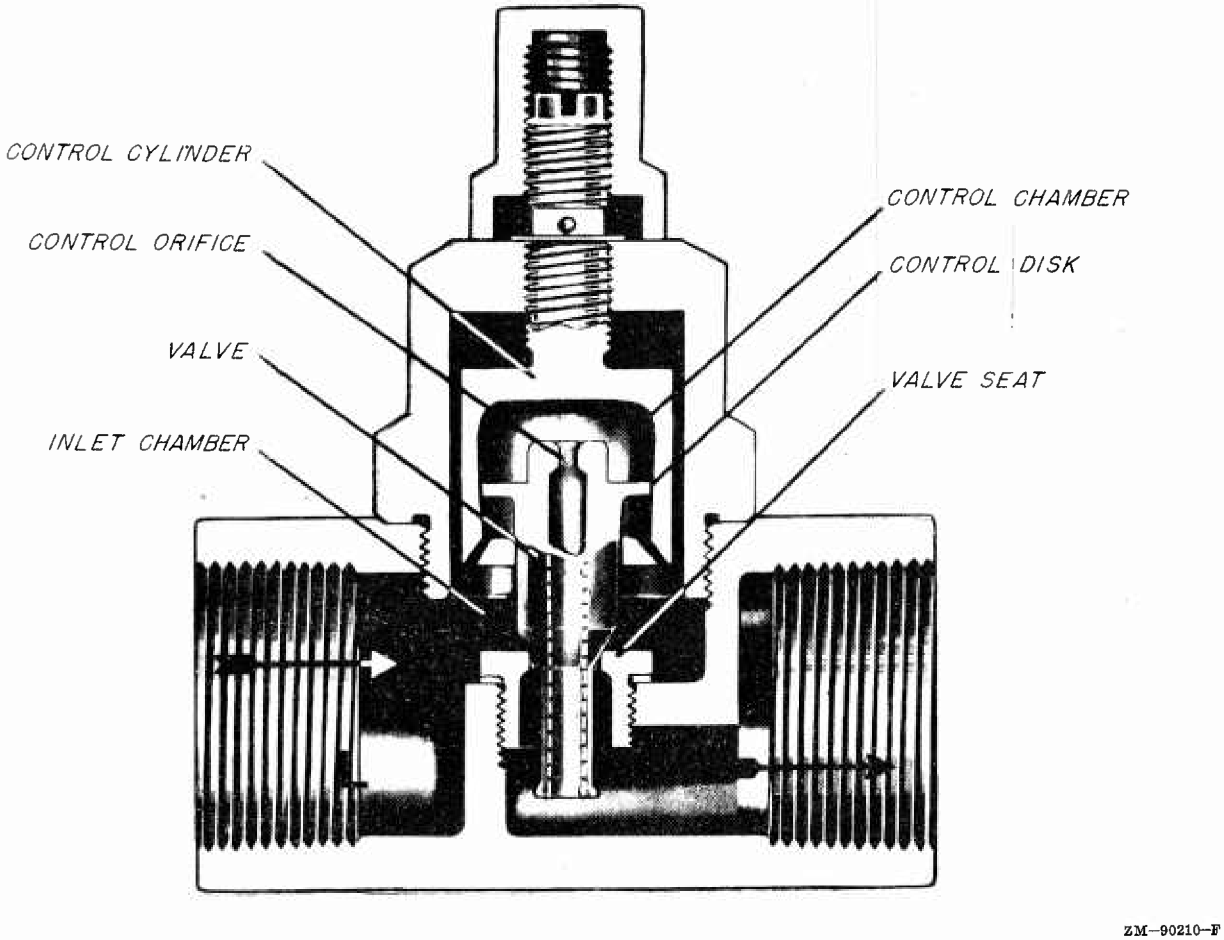


FIGURE 28.—Impulse steam trap.

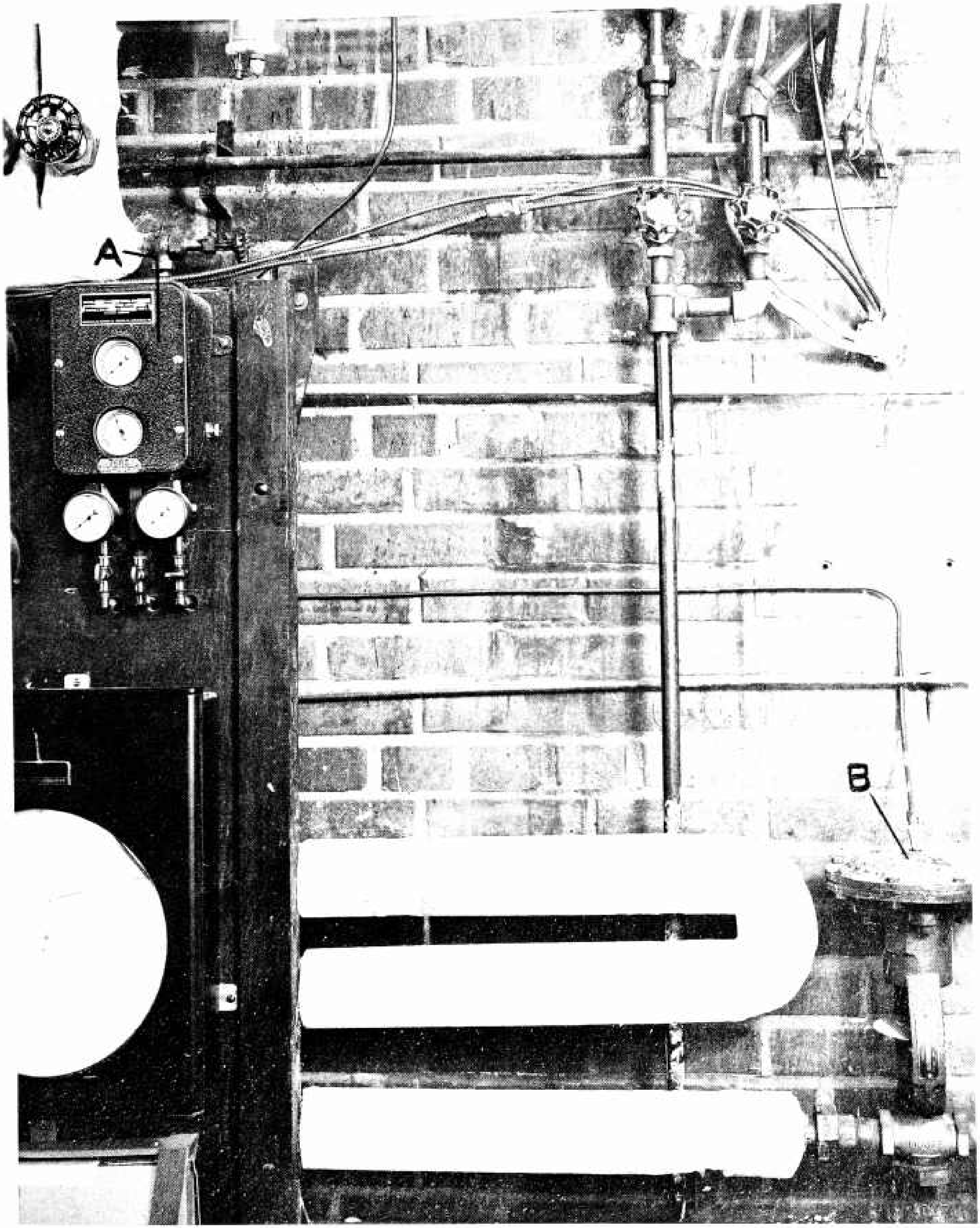
the length of the kiln, they may run across the kiln, or they may be located in the housing of external blowers. They are usually located near the fans or blower, so that the spray is mixed with the circulating air before it reaches the lumber. In natural-circulation kilns, the spray lines are usually located below track level. Steam should never spray directly on lumber, heating coils, rails, or fans. Wet steam at low pressures is more satisfactory than dry steam for control purposes.

Water Sprays.—In plants that do not have a source of steam for wet-bulb temperature control, water sprays are sometimes used for humidification. The water should be injected into the kiln in the form of a fine mist. Usually the mist is vaporized by spraying it directly onto the heat exchangers. In some kilns, water sprays are used in conjunction with steam sprays.

Venting Systems

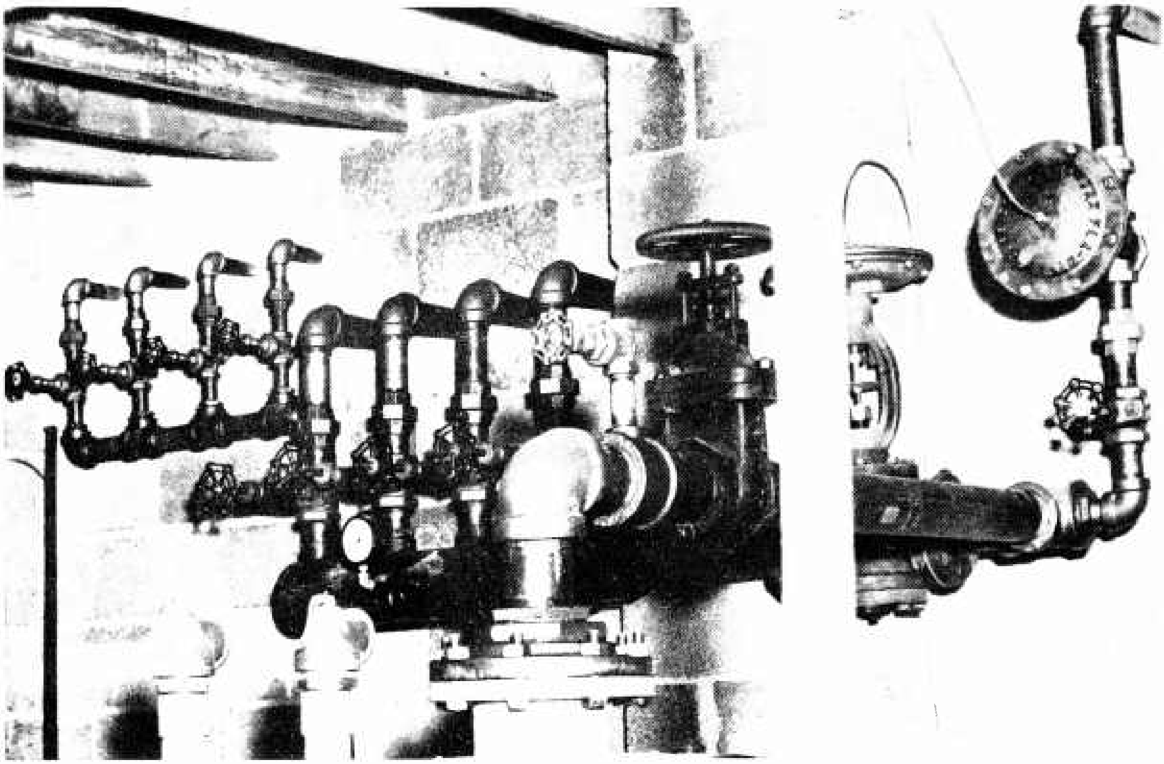
Some means of removing excess moisture from a kiln is necessary to obtain the desired wet-bulb depression during drying. This is accomplished by means of vents and fresh-air intakes. The size and number of openings required depends upon the material being dried (*4*). More venting will be required for fast-drying woods of high moisture content than for slow-drying woods of low moisture content. It is better to provide too much venting area than not enough, since the amount of venting can be reduced by adjusting the vent dampers or caps. Although venting can be controlled manually, automatic control is preferred.

Venting Natural-Circulation Kilns.—In natural-circulation kilns, the hot, moist air is vented through roof or wall vents (fig. 8, p. 24). Sliding dampers control the amount of venting through wall vents, and vent caps control roof venting. Fresh-air ducts, located as shown in figure 8, are also required. The amount of fresh air entering the kiln can be controlled by opening or closing the fresh-air doors. In old natural-circulation kilns of the progressive type, the vents are usually located at the green or loading end of the kiln (fig. 19, p. 33), but on newer kilns of this type they are spaced along the



ZM-106108-F

FIGURE 29.—*A*, Air-operated steam-pressure regulator; *B*, pressure-control valve on steam line.



ZM–106143–F

FIGURE 30.—Manual and, at right, automatic air-operated valves on steam piping for dry kiln. Copper air tubes are attached to the diaphragm heads of automatic valves.

length of the drying chamber, as in compartment kilns.

Venting Forced-Circulation Kilns.—In forced-circulation kilns, hot, moist air is exhausted through vents located on the high-pressure side of the fans or blower, while fresh air enters the kiln through openings on the low-pressure side. For the best and most economical operation at any one time, both the intake and exhaust vents should be either open or closed. In some internal-fan kilns the vents are located on the roofs, one line of vents being on each side of the kiln (fig. 14, p. 29). Long-shaft, internal-fan kilns with the fans above the loads usually have the vents installed directly over the fan shaft (fig. 17, p. 31). If additional venting is needed, manually operated auxiliary vents can be installed (fig. 31).

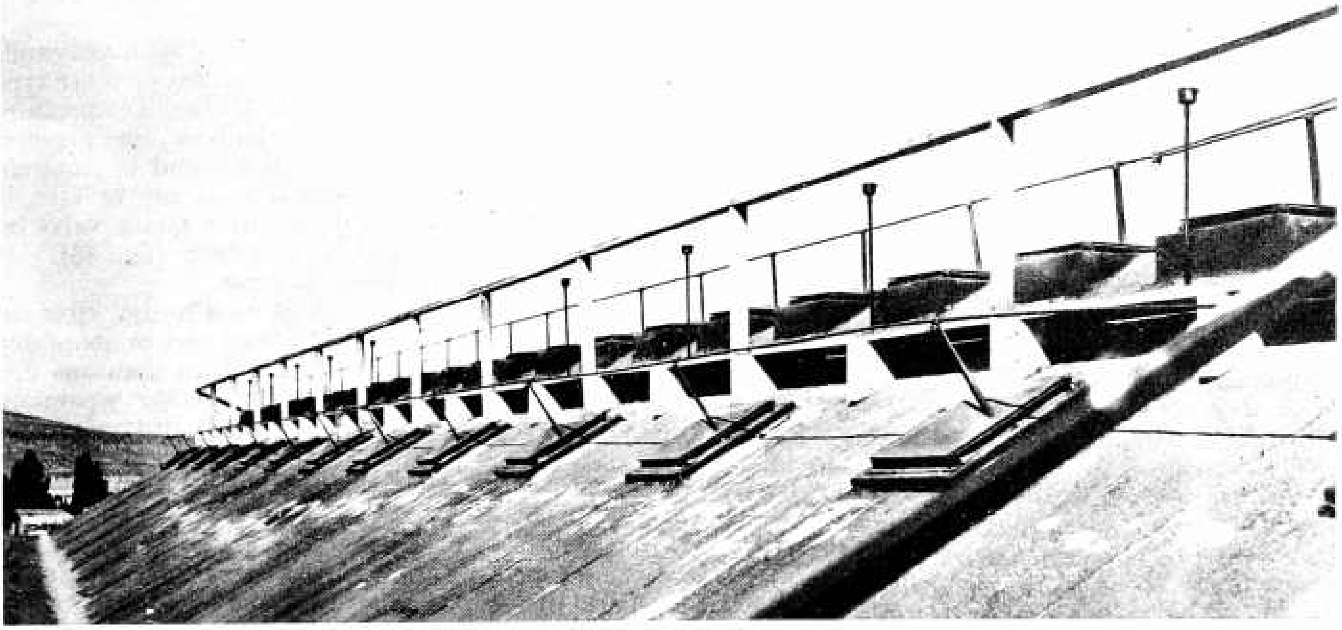
In external-blower kilns, the vents can be located in the blower housing, in the floor of the supply duct (fig. 10, p. 26), or on the roof (fig. 9, p. 25). Fresh air usually enters blower kilns through fresh-air doors located in the blower housing on the low-pressure side of the blower (figs. 9 and 10).

Air-Circulation Systems

Air can be circulated in dry kilns by natural or mechanical means. The air velocities through the loads in natural-circulation kilns are low, usually less than 30 feet per minute. In forced-circulation kilns, the air velocities may vary from 70 to 400 feet per minute, depending upon the type, size, speed, number, and location of the blowers or fans. Generally speaking, the higher the air velocity through the load, the faster will be the drying (*3*). In most forced-circulation, internal-fan kilns, and in some external-blower kilns, the direction of air circulation can be reversed manually or automatically. Some kilns are equipped with variable-speed fan motors to vary the velocity of the air passing through the loads of lumber.

Natural-Circulation Kilns.—In natural-circulation kilns, air movement depends on the fact that warm air rises and cool air falls. To take advantage of natural air movement, the heating system in a natural-circulation kiln must be properly designed and located.

The heating coils in natural-circulation kilns should be located about 1½ feet below track level, and about the same distance above the pit floor. Usually one or more coils are placed on each side of the kiln, directly below the space between the kiln wall and the lumber. This space should be at least 2 feet wide. Other coils are located below the loads of lumber (fig. 8). A space of at least 2 feet should be provided between the top of the load and the ceiling of the kiln. Load baffles should not be installed, because they inter-



ZM–105942–F

FIGURE 31.—Roof vents on overhead long-shaft, internal-fan, compartment kiln. Vent linkage is connected to diaphragm of air-operated valve. Row of auxiliary vents on side of roof is manually operated and opened only during stages of kiln run, when the main roof vents are inadequate.

fere with air movement. Obstructions at track level, such as solid floors or walks, will interfere with air circulation. Walkways, if needed, should be of the grating type.

Forced-Circulation Kilns.—In forced-circulation kilns, air is circulated by fans or blowers. The air may be moved in any direction, depending upon the kiln type and method of loading.

Some types of external-blower compartment kilns are shown in figures 9, 10, and 11. For uniform delivery of air to the loads, the supply ducts may be tapered or equipped with adjustable air scoops, or relief air slots (fig. 10). Ordinarily no baffles are required other than the closures at the top of the A flues. The space between the side walls and the loads should be large enough to permit unrestricted flow of air to the return-air ducts without causing back pressures. To make it easier to inspect the lumber as it dries, and to expedite removal of samples for examination and weighing, it is recommended that this space be not less than 18 inches wide.

The size and number of fans required in internal-fan compartment kilns will depend upon the size of the kiln and the air velocities desired. The plenum chambers should be wide enough so that the static pressure built up in them is sufficient to insure uniform air flow across the loads from bottom to top. For best drying results, the higher the loads, the wider should be the plenum chamber.

When fans are located on the side of the kiln, the distance between the fans and the loads should be great enough to assure that the air is uniformly distributed over the sides of the loads. Fan and load baffles should be so arranged that all the air flows through the loads of lumber and does not bypass them. Usually, baffles are placed at the top and bottom of the loads (figs. 14 and 17). The air in the cross-piled, internal-fan kiln shown in figure 13 moves against the stickers. Therefore a space of at least 2 inches should be left between the edges of all boards, so that the air can move through the loads.

Usually the air in a forced-circulation, progressive kiln is circulated by the same method used in a compartment kiln. One type of progressive kiln (fig. 20, p. 34) has a large blower or fan located at one end to force the air lengthwise through the drying chamber. In this kiln, side and top baffles should be installed at each truckload of lumber to cut down short circuiting of the air.

Equipment To Control Drying Conditions

Though drying conditions in a kiln are best controlled by automatic equipment (*1*), manual control is occasionally used.

Automatic Control Equipment

Most dry kilns are equipped with instruments (thermostats) that automatically control and record dry- and wet-bulb temperatures. Some thermostats consist of control bulbs connected to bellows or pressure springs by capillary tubes. Changes in temperature at the control bulbs result in pressure changes in the closed systems that directly or indirectly actuate motor valves either by air pressure or electrically. One motor valve controls steam flow into the heating coils, another controls the flow of steam or water used for humidification, and a third controls the opening and closing of the vents. In one type of thermostat, the motor valves are indirectly actuated by an electronic circuit.

The thermostat may control either the dry- or the wet-bulb temperature. To control the wet-bulb temperature, the bulb is provided with a suitable wick and water supply. The control bulbs should be so located in the kiln that they are exposed to ample air circulation.

The direct-acting thermostat is called a self-contained type, while the indirect-acting thermostat is known as an auxiliary-operated type because it actuates a power relay to a motor valve rather than directly controls a valve.

Self-Contained Thermostats.—Self-contained thermostats combine in a single unit a valve and a filled system consisting of the bulb, the capillary connecting tube, and the motor valve. The bulb of the tube system is placed in the kiln. Temperature variations at the bulb change the pressure inside the bulb, causing corresponding pressure changes on a bellows diaphragm in the motor valve. Movement of the diaphragm produces movement of the valve. The valve is usually balanced so that it moves easily. Constant counter-pressure is provided by an adjustable spring or sliding weight that tends to keep the valve open. The instrument is set for desired temperatures by changing the tension of the spring or the position of the weight. The correct setting is a matter of judgment.

The principal advantages of the self-contained thermostat are that no auxiliary source of power is required for its operation, and its initial cost is comparatively small. An important disadvantage is its relatively slow response to changes in temperature. In addition, fluctuations in the temperature of the operating room where the motor valve is located may upset the balance of the instrument and result in incorrect tempeature control.

Auxiliary-Operated Thermostats.—Auxiliary-operated thermostats are made in a number of different types and styles. Electricity or compressed air is commonly used to power them. Most auxiliary-operated thermostats in dry kiln service are air operated, and record as well as control kiln temperatures; they are therefore called recorder-controllers.

In these instruments the control bulb and capillary tube are connected to a helical or other type of pressure spring (fig. 32). Temperature changes at the control bulb cause pressure changes in the spring that expand or contract it. This movement operates an air or electric relay that regulates power to a motor valve on the heat, spray, or vent system (fig. 33). It also operates the recording pen.

Most recorder-controllers used in dry kilns are equipped with a wet bulb and one or more dry bulbs. In instruments with more than one dry bulb, the bulbs may function either separately or together in a single system. Instruments in which the dry bulbs function separately are used to control the temperature in kilns equipped with split heating systems; these are usually called multizone controllers. When two dry bulbs are connected to a common capillary tube that transmits pressure changes to a single pressure spring, the instrument is known as a dual-bulb controller. Instruments of this type are used in reversible-circulation kilns, with the dual dry bulbs located directly opposite each other on each side wall. Since the bulb on the entering-air side is at the higher temperature, it will act as the controlling bulb. It sometimes takes several minutes after the air circulation reverses for the controlling bulb to become effective, because of the time it takes for the pressure throughout the system to become equalized. This lag in control whenever the direction of air circulation is reversed causes a slight break in an otherwise smooth temperature record. Figure 34 shows an installation layout for a two-zone, dual-bulb control system.

The electronic type of auxiliary-operated thermostat controls and records temperatures by means of thermocouples and an electronic potentiometer. The electromotive force generated by the effect of temperature on the thermocouples located in the kiln is automatically balanced by the instrument. The balancing mechanism is continuously receptive to changes in electromotive force. Changes in the balancing mechanism change the position of the recorder pen and temperature indicator. Coupled to the recording unit is the control unit which operates either electric or air-actuated control valves.

The thermocouples are placed in different parts of the kiln so temperatures can be easily read at any location by means of a switching mechanism. Control can be obtained in any desired zone merely by switching to the thermocouple located in that zone. A separate instrument with a thermocouple, wick, and water supply is needed

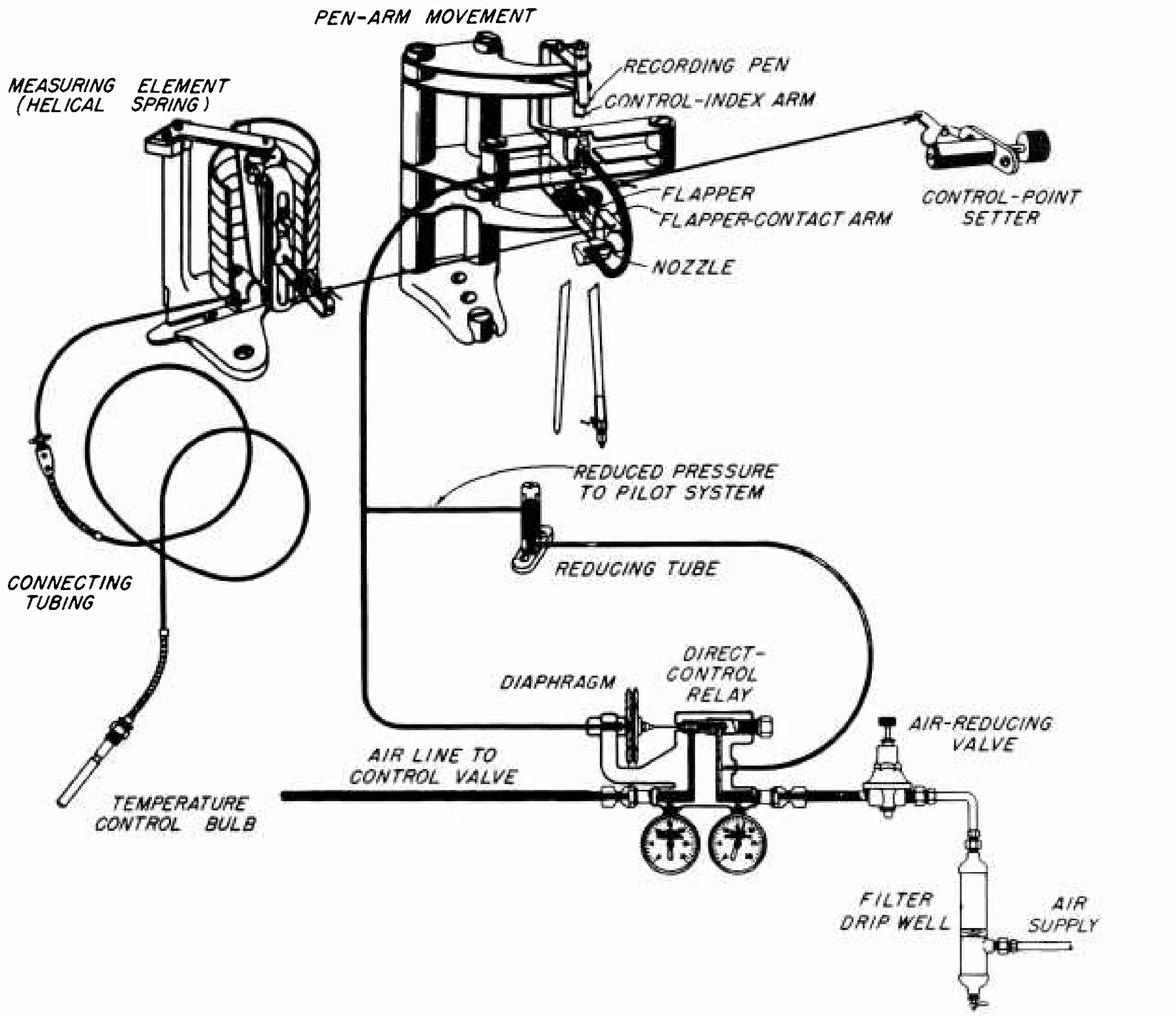


Figure 32.—Schematic drawing of an auxiliary-operated thermostat.

to control and record the wet-bulb temperature in the kiln.

Manual Control Equipment

Although automatic control of kiln-drying conditions is desirable, manual control is possible. For successful manual control of drying conditions, the dry- and wet-bulb temperatures must be known. If these temperatures differ from those desired, the valves that regulate the flow of steam and spray into the kiln must be adjusted until the desired thermometer readings are obtained.

Temperature-Measuring Devices.—The temperature-measuring devices used in dry kilns are of two classes, indicating and recording. Glass-stemmed indicating thermometers are frequently used. The most satisfactory glass-stemmed thermometers have the graduations etched on the stem. Figure 35 shows such a thermometer encased in a metal sleeve that protects it—but also causes it to be somewhat sluggish. Thermometers with separate scales stamped on an attached metal strip are not very satisfactory, since any shifting of the strip with relation to the thermometer tube will cause incorrect readings. An indicating thermometer of the pressure-spring type is shown in figure 36. The temperature at the bulb, which is placed in the dry kiln, is indicated by the needle on the gage.

Glass-stemmed thermometers of the maximum type are also used to obtain dry-bulb temperatures. Maximum thermometers show the highest temperature to which they have been exposed and after each reading must be shaken down like clinical thermometers. Care should be taken, in using maximum thermometers, to allow enough time for the mercury to reach a peak temperature.

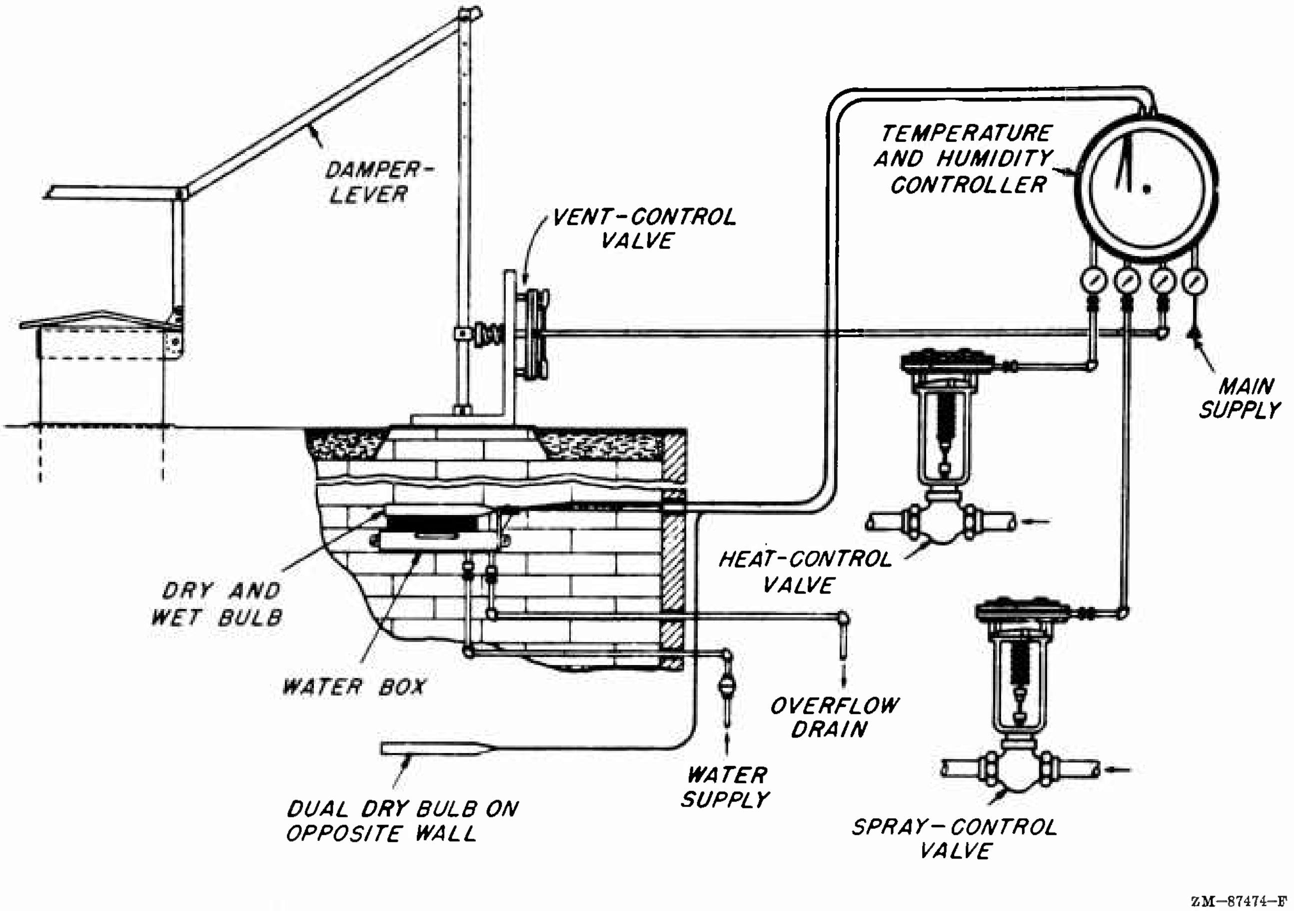


FIGURE 33.—An installation layout for automatic control equipment used on dry kilns.

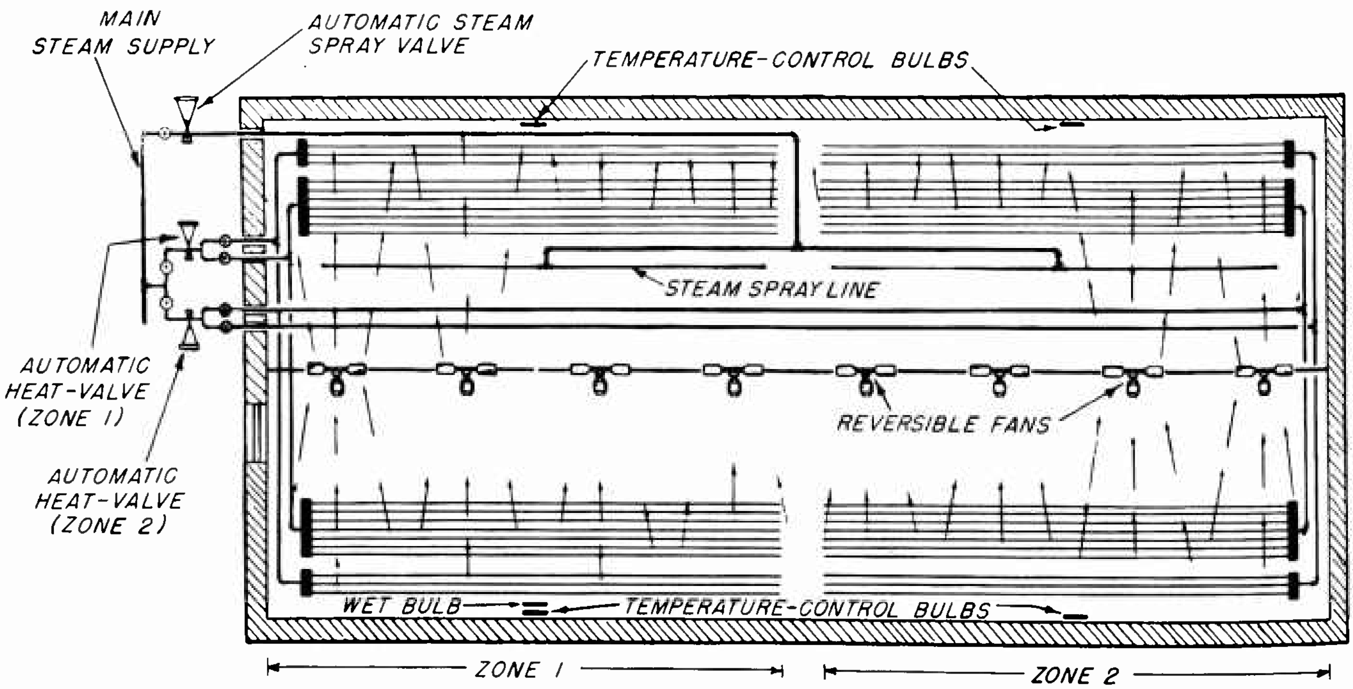
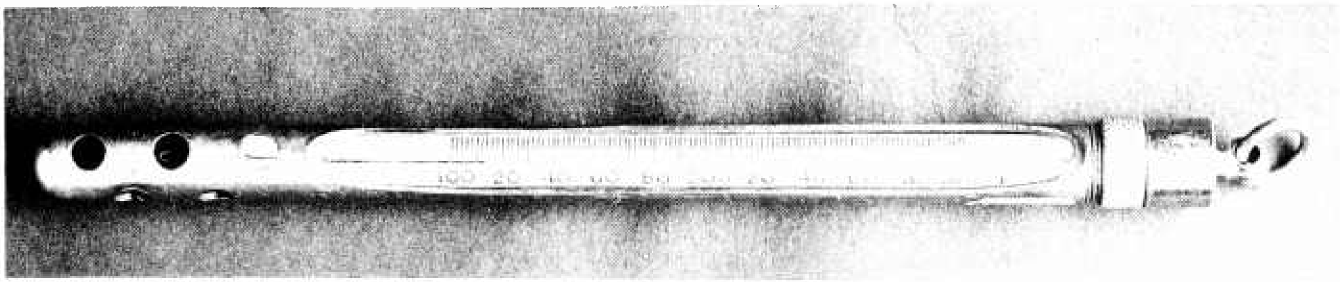
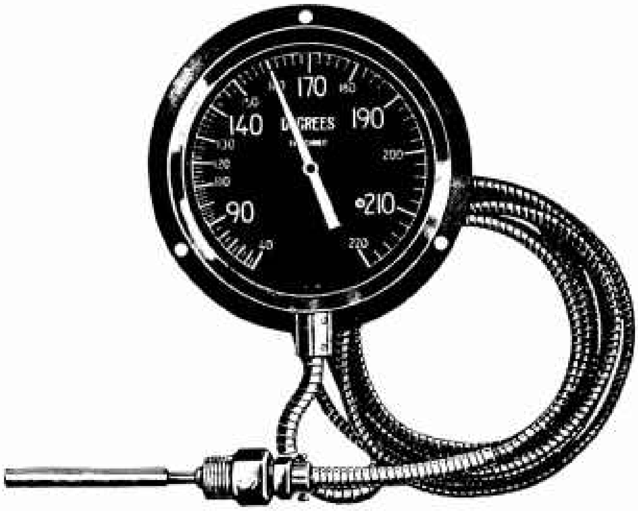


FIGURE 34.—Installation layout for control bulbs in kiln with two-zone heating system.



ZM–90208–F

FIGURE 35.—Etched-glass thermometer in metal protecting case.



ZM–87473–F

FIGURE 36.—A pressure-spring type of indicating thermometer.

Recording thermometers used in dry kilns are almost always of the pressure-spring type, in which the bulb is connected to the instrument by a capillary tube. Figure 37 shows the internal mechanisms of a recording thermometer. Pressure changes produced in the bulb are transmitted through the capillary tube to the pressure spring. The pressure changes cause the free outer end of the spring to move back and forth. The movement is transmitted through the connecting link to the pen arm, which records the temperature on the chart. The clock movement rotates the chart.

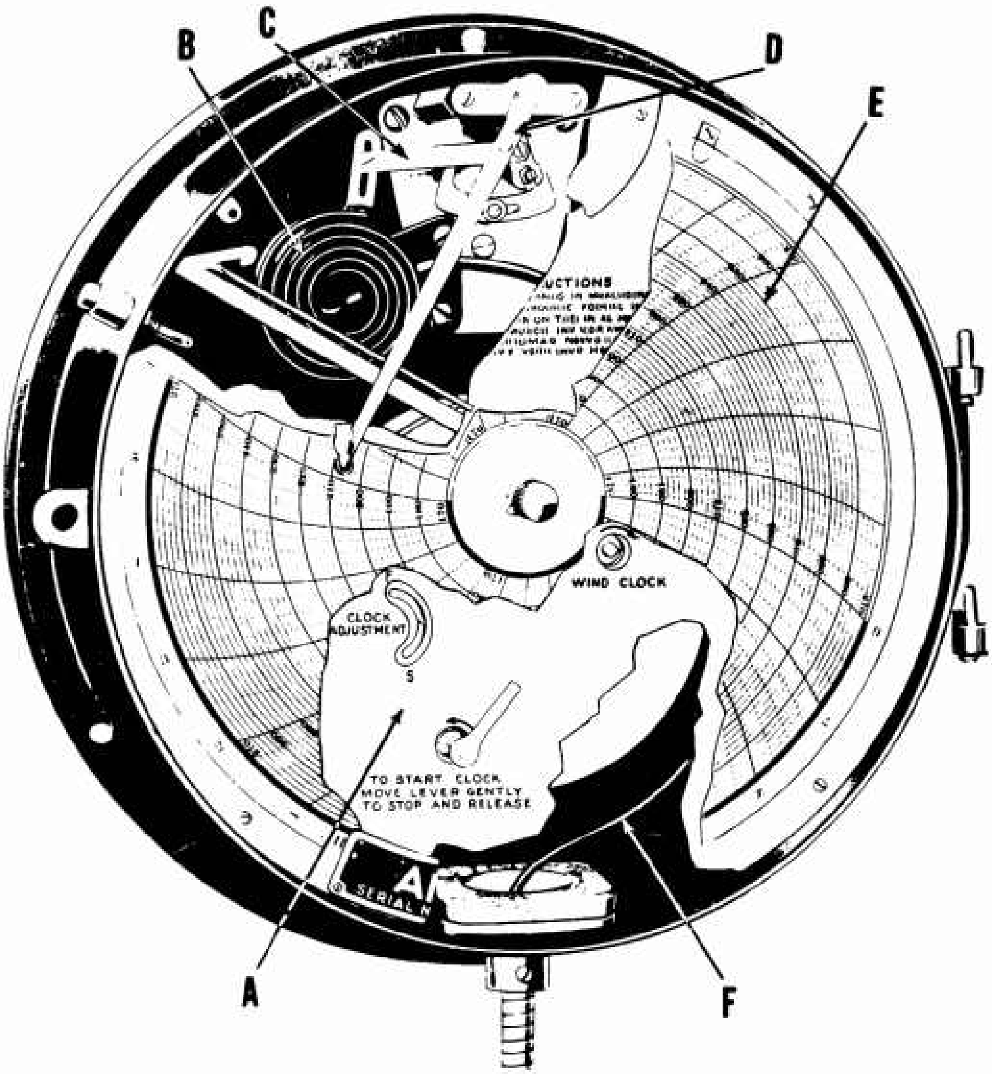
Literature Cited

(1) KIMBALL, K. E.
1956. DEVICES THAT MEASURE AND CONTROL TEMPERATURES IN DRY KILNS. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1654, 12 pp., illus. [Processed.]

(2) TEESDALE, L. V.
1956. DRY-KILN BUILDING MATERIALS AND CONSTRUCTION. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1646, 10 pp., illus. [Processed.]

(3) TORGESON, O. W.
1953. CIRCULATION OF AIR IN A LUMBER DRY KILN. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1678, 6 pp. [Processed.]

(4) ———
1954. FUNCTION AND CALCULATION OF VENTILATION IN DRYING COMPARTMENTS. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1265, 3 pp., illus. [Processed.]



ZM–8912–F

FIGURE 37.—Pressure-spring recording thermometer: *A*, Clock; *B*, pressure spring; *C*, connecting link; *D*, pen arm; *E*, chart; and *F*, capillary tube.

CHAPTER 3. AUXILIARY KILN EQUIPMENT

Certain auxiliary equipment is needed to operate a dry kiln in the most economical manner and to obtain good drying results. Drying schedules based upon moisture content cannot be successfully applied unless the moisture content of the stock is known. Therefore, equipment should be available for determining the moisture content of the stock. Equipment should also be available for determining the temperature and velocity of air in the kiln in order to maintain uniform conditions for fast drying.

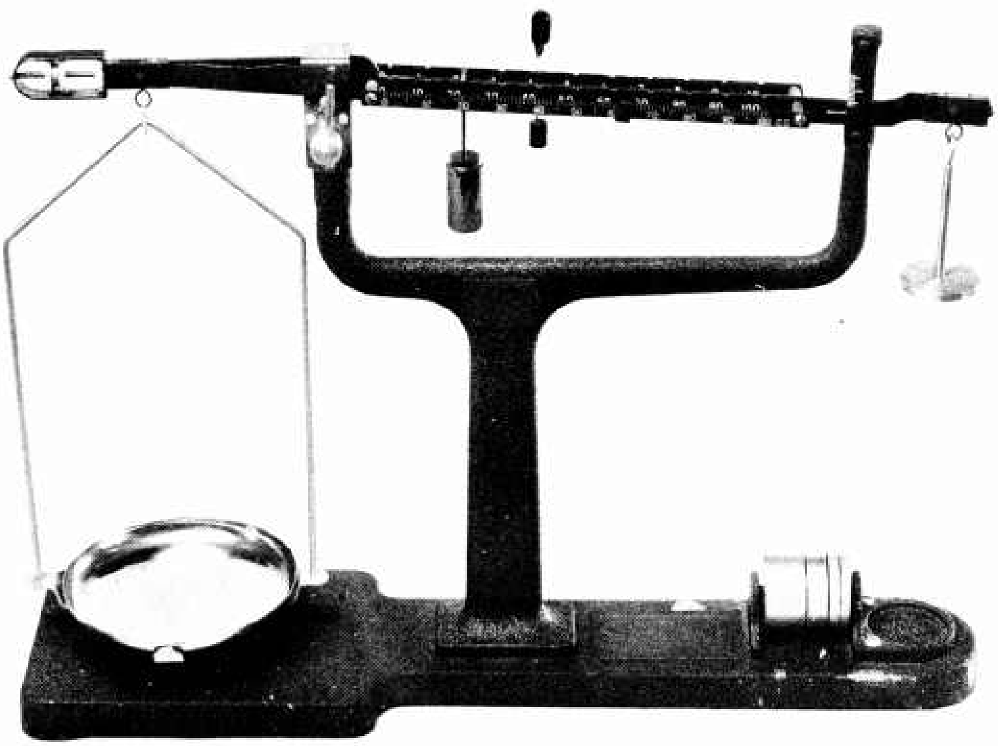
Equipment for Determining Moisture Content

Such items as balances, scales, drying ovens, saws, and electric moisture meters are used in determining the moisture content of wood. Distillation equipment is used for accurate determination of moisture content of woods that hold relatively large amounts of oil.

Balances and Scales

Many types of balances and scales can be used for determining the moisture content of wood. Most types, if properly used, give quick and sufficiently accurate results.

Triple-Beam Balance.—One of the most commonly used types of balances for weighing small moisture sections is the triple-beam balance shown in figure 38. This balance has a central beam and poise with a 100-gram capacity, a rear beam of 10-gram capacity, and a front beam of 1-gram capacity. Auxiliary weights hung on the end of the central beam increase the weighing capacity. The maximum capacity of the balance shown is 1,111 grams. Its weighing accu-



ZM–64322–F

FIGURE 38.—Triple-beam balance with auxiliary weights.

racy, when properly balanced, is within ±0.01 gram.

Pan-Type Balance.—A pan-type balance, commonly called a torsion balance, is also used to weigh small moisture sections (fig. 39). This balance also has a weighing accuracy, when properly adjusted, of ±0.01 gram. Auxiliary weights are used for weighing beyond the capacity of the beams. This balance, because of the added manipulation of the loose weights, is slower to use than one of the triple-beam type.

Self-Calculating Balance.—To calculate moisture content, it is necessary to know the original and the ovendry weight of the wood sections. The loss in weight is divided by the ovendry weight. Self-calculating balances, similar to the one shown in the upper part of figure 40, have been developed to speed up these calculations or to eliminate them entirely. As shown in the lower part of figure 40, the moisture readings can be estimated to the nearest 0.5 percent when the values are less than 10 percent, and to the nearest 1.0 percent when the values are more than 10 percent. A prescribed sequence of operating steps, supplied by the manufacturer, must be followed in carrying out a moisture content determination with this balance.

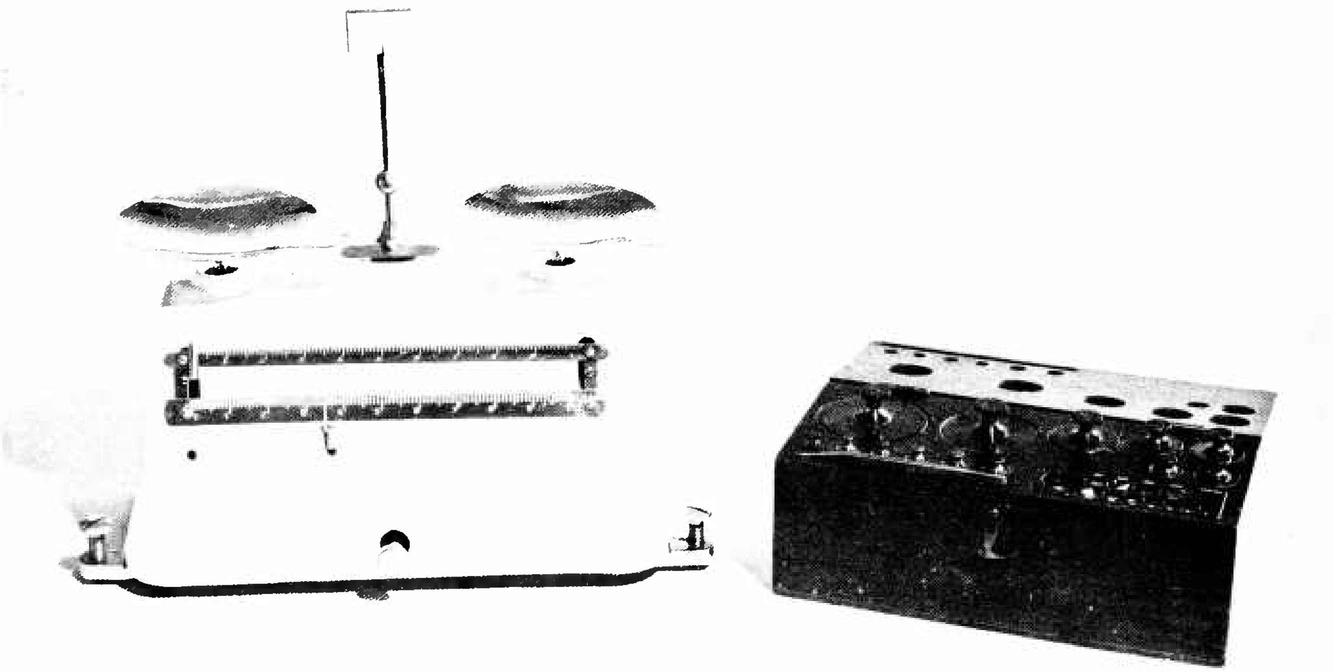
Platform and Indicating Scales.—Scales of the platform type with a capacity of about 35 to 40 pounds are commonly used to weigh kiln samples (fig. 41). For simplifying moisture content calculations, they should be graduated in decimals of a pound rather than in ounces. When a considerable number of kiln samples are weighed daily, an indicating type of scale (fig. 42) is useful, since the indicator can be read directly to the nearest graduation, 1 gram or 0.01 pound.

Self-Calculating Scale.—Another type of scale used to determine the daily or current moisture content of kiln samples is the moisture guide (fig. 43). It has a movable weight on the long arm of a graduated beam. Attached to the short arm of the beam is a semicircular plate graduated in terms of percentage of moisture content. Above this plate is a movable indicator arm with a hook.

If this moisture guide is to be used with reasonable accuracy, certain procedures must be followed:

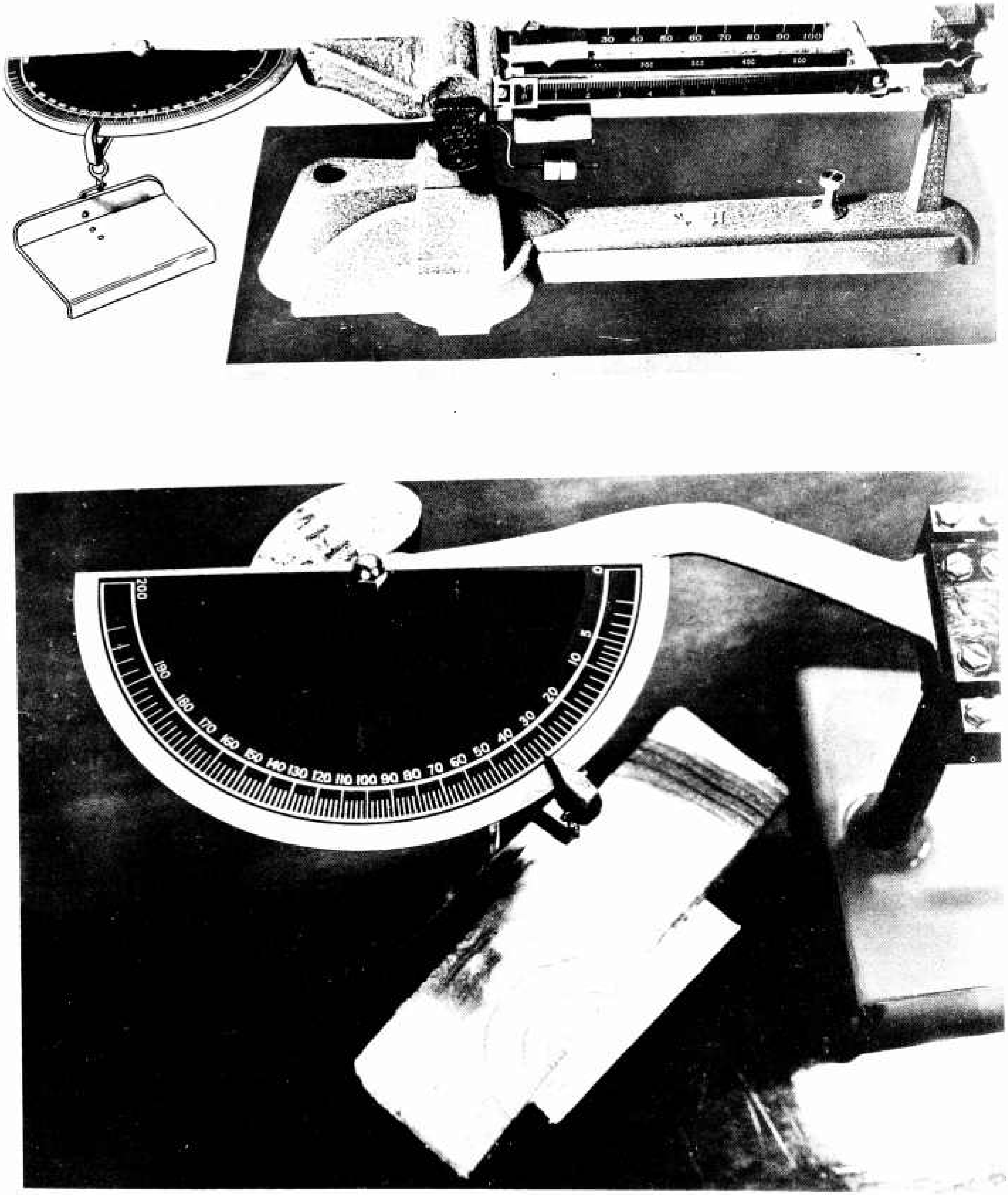
(1) Immediately after the moisture content sections have been cut and weighed, hang the kiln sample from the hook on the movable indicator arm, with the indicator set at zero. Move the sliding weight on the long beam to a point that brings the beam in balance. Record the value of the balancing point on the kiln sample, and place the sample in the kiln with the truckload of lumber it represents.

(2) Ovendry the moisture content sections to constant weight and calculate their moisture content values.



ZM–64321–F

FIGURE 39.—Pan or torsion balance with double beam and auxiliary weights.

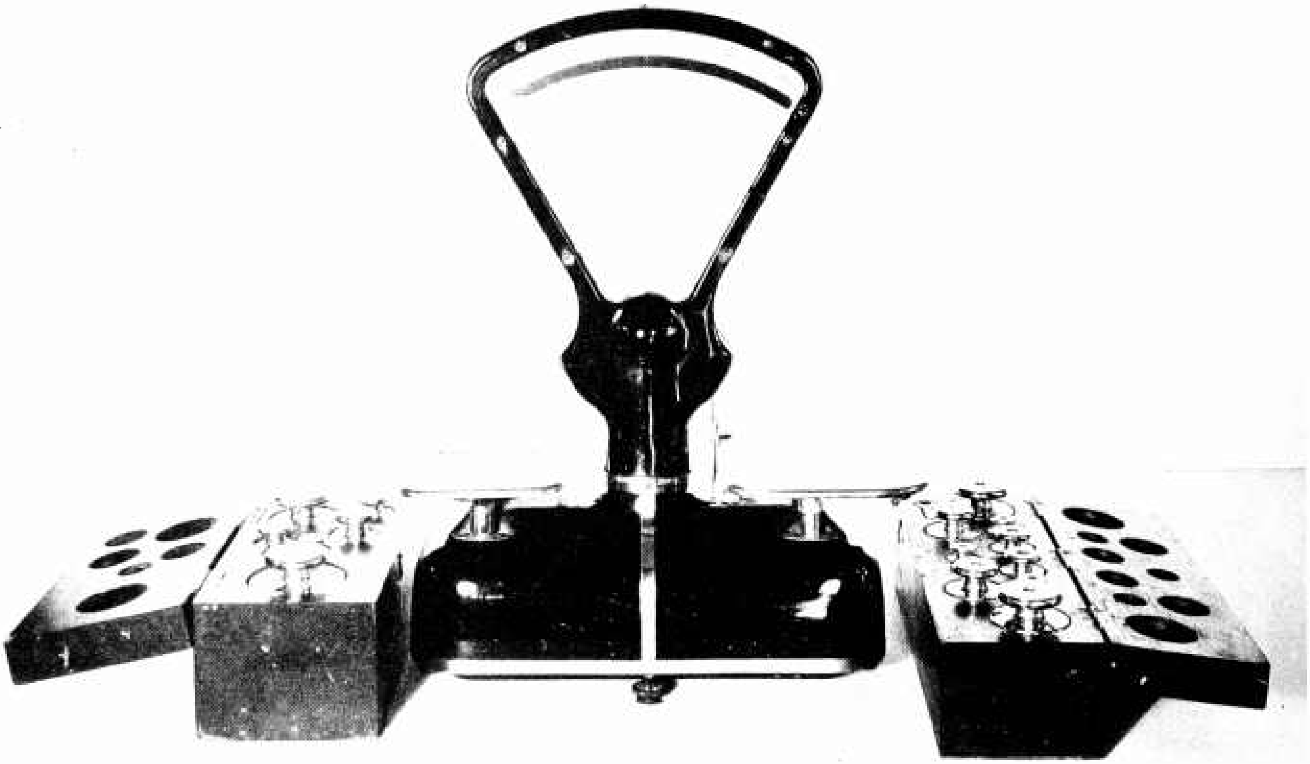


ZM—90343—F

FIGURE 40.—Self-calculating moisture-content balance. *Top*, Triple-beam balance with special scale on specimen pan used to calculate moisture content after ovendrying. *Bottom*, Specimen pan is carried on revolving indicator, which, when properly used, indicates moisture content directly on scale.

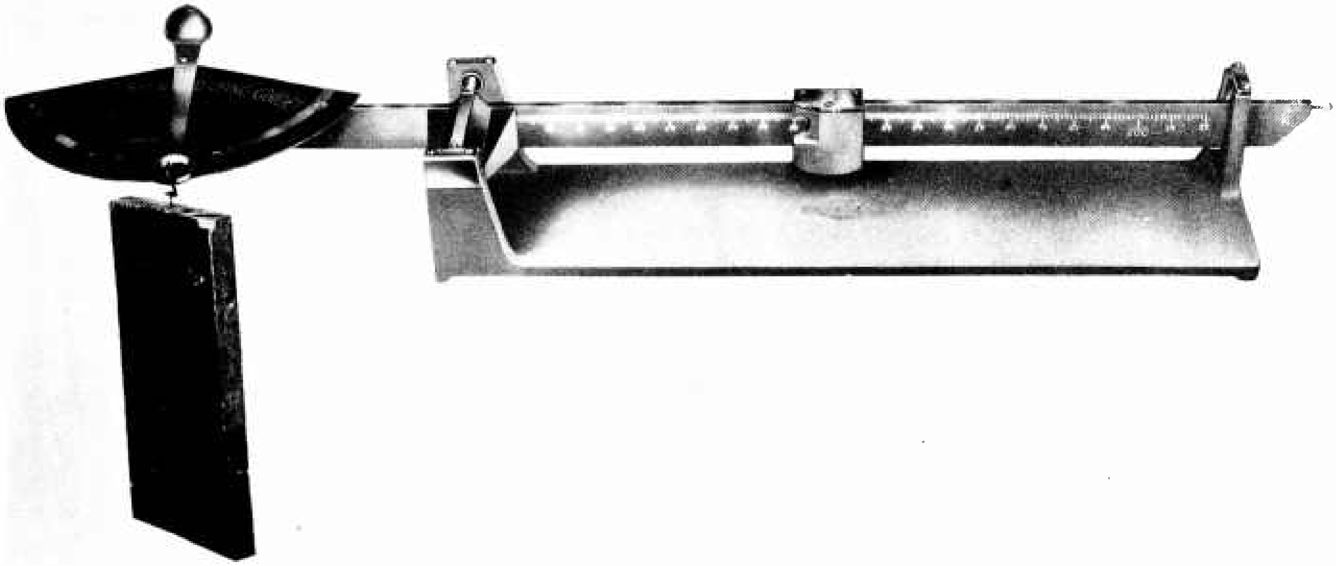
ZM—64323—F

FIGURE 41.—Platform scale with capacity of 36 pounds and accuracy of 0.01 pound.



ZM—60557—F

FIGURE 42.—Indicating scale.



ZM–89780–F

FIGURE 43.—Self-calculating scale or guide for determining moisture content of kiln samples.

(3) When the moisture content of the moisture sections has been obtained, remove the sample from the kiln, hang it on the movable indicator hook with the indicator set at zero, and move the sliding weight on the long beam to the setting determined in step 1. Then place metal weights, such as washers or lead slugs, on the end of the kiln sample until the long beam balances.

(4) With added metal weights in place, set the movable indicator arm to the moisture content value of the sections determined in step 2, and move the sliding weight on the long beam until balance is again obtained. Erase or cross out the previously recorded value on the kiln sample and record the new balance value. This new value will be the setting of the sliding weight on the long beam used for all subsequent moisture determinations.

(5) Remove the metal weights from the sample. With the sliding weight set at the new value obtained in step 4, move the indicator arm until the long beam balances. The current moisture content of the kiln sample can then be read on the semicircular plate.

(6) Subsequent moisture content values of the samples are obtained by setting the sliding weight on the long beam at the new balance value obtained in step 4, hanging the kiln sample on the movable indicator hook, and moving the indicator arm until the long beam is balanced. The current moisture content is read on the semicircular plate.

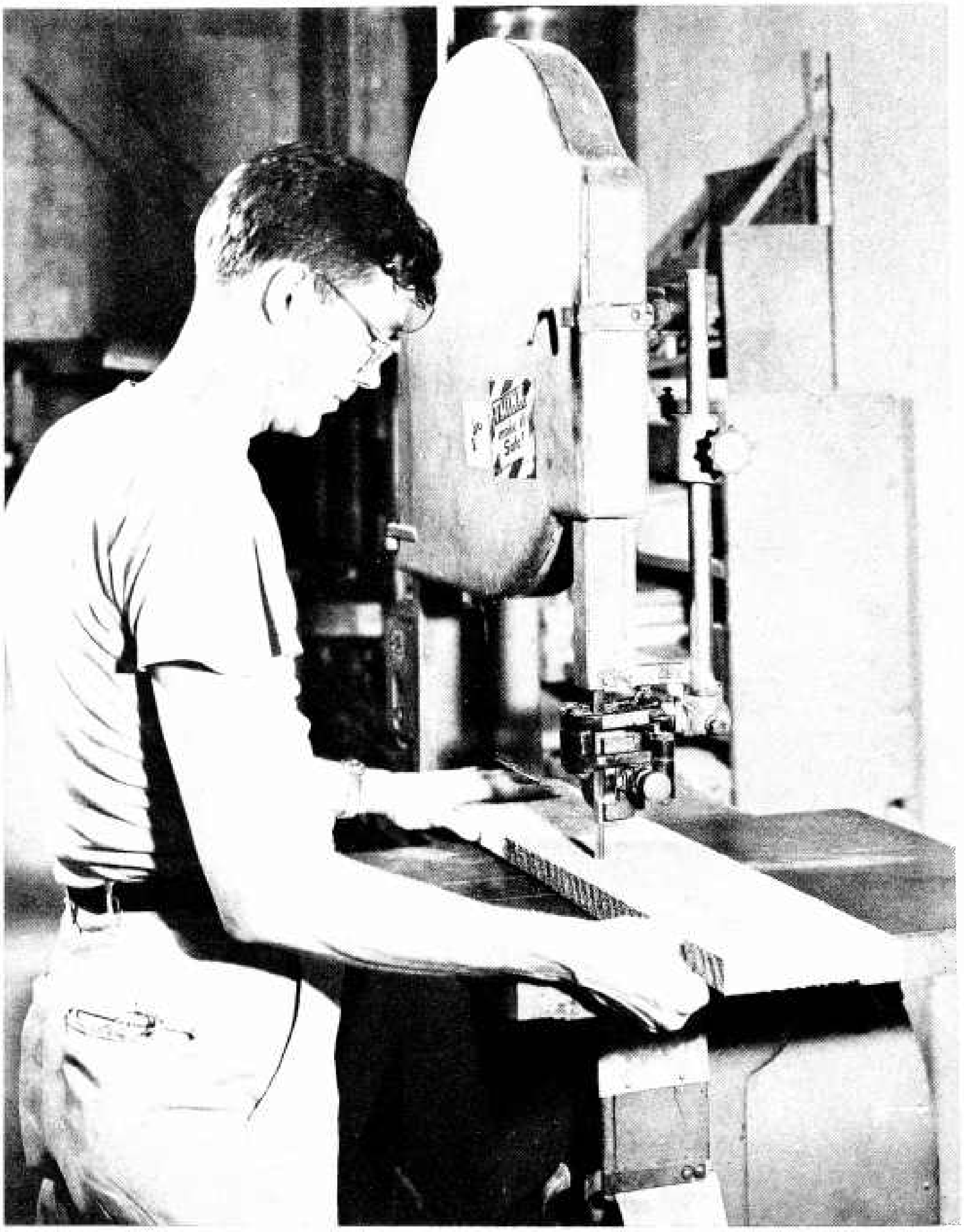
Saws

Handsaws are not recommended for the cutting of moisture sections. Table, swing, portable, and band saws are generally used. A band saw (fig. 44) is particularly suitable for slotting and slicing small sections for moisture-distribution and casehardening tests. Saws should be sharp, properly set, and provided with suitable safety devices.

Drying Ovens

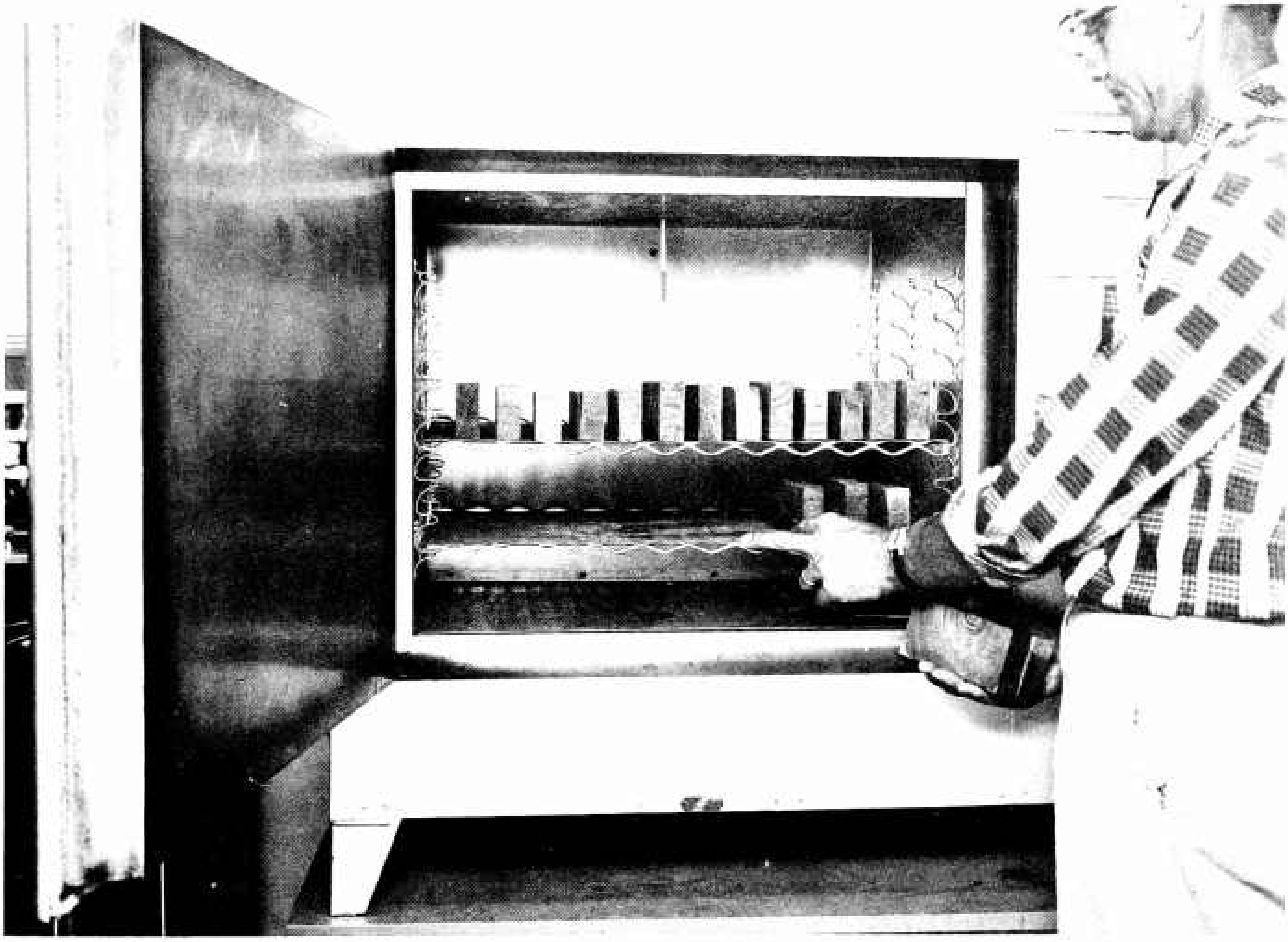
Several kinds of ovens are used for the drying of moisture sections. Drying ovens should be large enough to provide adequate open spaces between the sections of wood being dried. The temperature of the oven should be controlled with a thermostat or other means so it will not rise above the desired setting (212° to 220° F.). Excessive temperature will char the sections and may also start fires. The oven should have ventilators on the top or sides and bottom to allow the evaporating moisture to escape.

Electrically Heated Ovens.—Ovens commonly used in kiln-drying work are electrically heated (fig. 45). Clean the contact points of the thermostat from time to time to prevent them from sticking. Check the thermostat setting when the oven is empty, using a thermometer inserted in the top of the oven. Some ovens contain fans to circulate the air and speed up drying (fig.



ZM-90101-F

FIGURE 44.—Bandsaw being used to prepare kiln sample. A saw of this type is best suited for cutting casehardening test specimens.

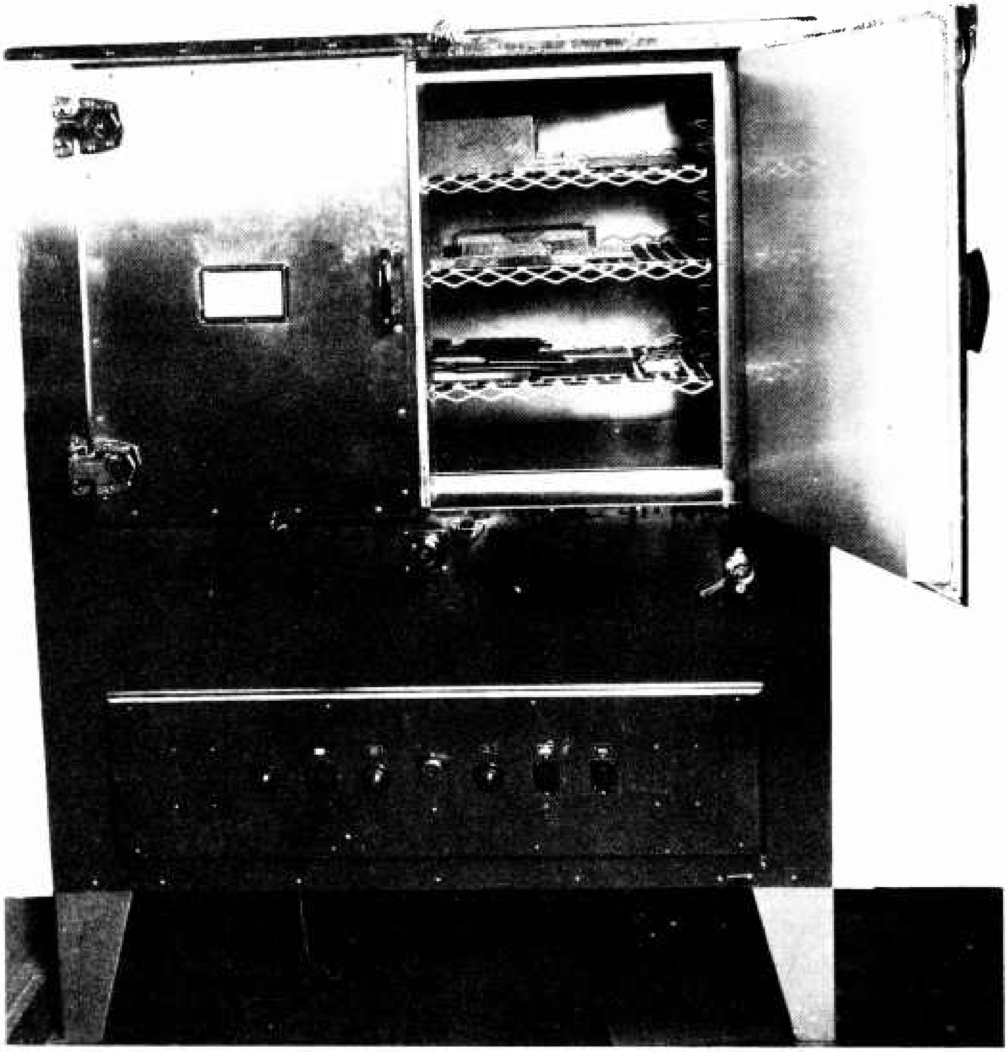


ZM–115694–F

FIGURE 45.—Natural-circulation electric oven for drying moisture sections.

46). Ovens of this type are recommended if large numbers of moisture sections are dried continually.

Steam-Heated Ovens.—Steam-heated drying ovens are satisfactory if a suitable supply of steam is continuously available. Ovens of this type are usually homemade and may be equipped for either natural- or forced-air circulation. The temperature in the oven is usually regulated or controlled by a reducing valve on the steam feed line. The reducing valve is adjusted to maintain the desired temperature in accordance with a thermometer inserted through the top of the oven. Set the temperature when the oven is empty. Shelves for the moisture sections should be made of perforated metal or large mesh, heavy wire. Provide ventilators to remove the moisture-laden air.



ZM-90189-F

FIGURE 46.—Forced-air-circulation electric drying oven for drying large quantities of moisture sections.

Electric Moisture Meters

Electric moisture meters,[1] if properly used, provide a rapid, convenient, and for most purposes a sufficiently accurate means of determining moisture content when it is less than 30 percent. They are frequently used to segregate wet from dry boards as a preliminary to kiln-drying and to determine the moisture content of air- or kiln-dried stock. Electrical moisture meters are usually provided with temperature and species correction data. There are two types of meters, power loss and resistance.

Power-Loss-Type Moisture Meters.—A moisture meter of the power-loss type is shown in figure 47. The surface-contact electrodes vary in design according to the material on which they are to be used. The instrument shown has eight spring-cushioned contact points equally

ZM-86262-F

FIGURE 47.—A radio-frequency power-loss-type moisture meter.

[1] JAMES, W. L. ELECTRICAL MOISTURE METERS FOR WOOD. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1660. [Processed.] 1958.

spaced on the circumference of a circle. The range of these meters is from 0 to about 25 percent moisture content.

Resistance-Type Moisture Meters.—The electrodes of resistance-type moisture meters consist of needles or contact pins that are driven into the wood to be tested. The accurate range of most meters of this type is between 7 and 25 percent moisture content, although some instruments have scales that read above the fiber saturation point. A meter of this type is shown in figure 48. Special electrodes have been developed to be used with resistance-type meters for measuring the moisture content of veneer and thick lumber or poles. A two-pin electrode for use on thick lumber, timbers, and poles is shown in figure 49. This electrode is provided with a depth-indicating scale. To determine the average moisture content of thick planks that have a normal drying gradient, the pins are driven to a depth that is about 20 percent or 1/5 of the thickness of the item. To get an estimate of the average moisture content of a pole, the electrodes are driven to about 15 percent of the pole diameter at the location of the test. In another type of two-pin electrode, the shanks of the pins are insulated so that moisture-content readings can be obtained on stock with a wet surface.

Distillation Equipment

Some woods contain a high percentage of volatile compounds or have been impregnated with oily preservatives. These volatiles will be driven off in the ovendrying process, resulting in an incorrect moisture-content value. Distillation equipment should be used for determining the moisture content of such woods.[2]

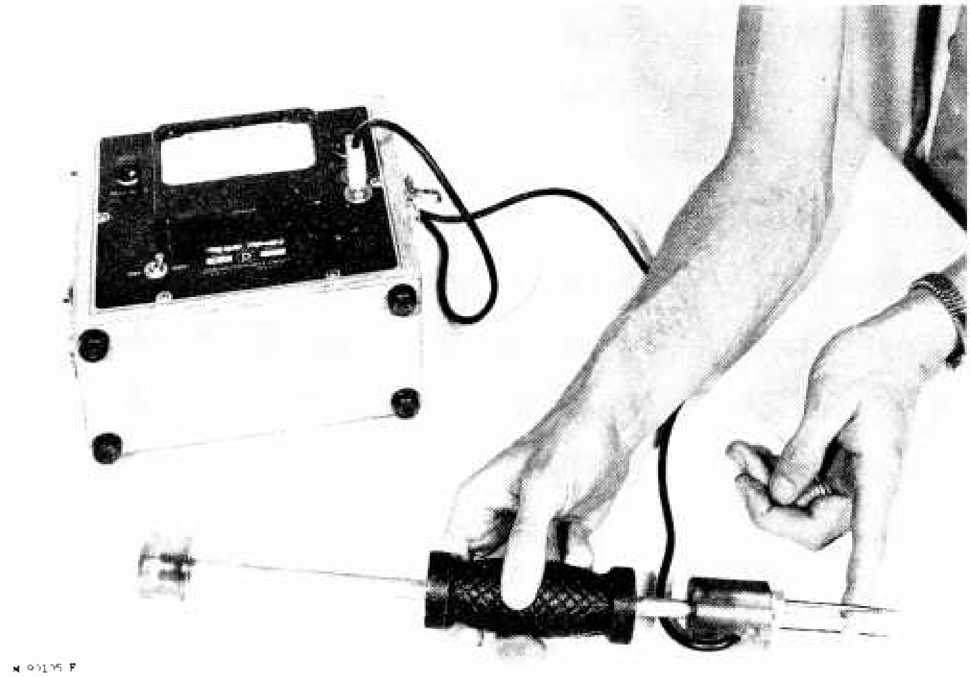
Equipment for Determining Temperatures

It frequently becomes necessary to check temperatures in a dry kiln to determine the causes for nonuniform drying and the differences in temperature between the areas around the control bulbs and other areas of the kiln. These temperature measurements are usually made on the entering-air side of the loads, although at

[2] McMillen, J. M. Methods of determining the moisture content of wood. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1649. [Processed] 1956.

ZM–86262–F

Figure 48.—A resistance-type moisture meter.



ZM–90105–F

FIGURE 49.—A special electrode connected to a resistance meter for making moisture tests on thick lumber, timbers, and poles.

times leaving-air temperatures are simultaneously obtained so that the temperature drop across the load can be determined. Etched-stem glass thermometers, hygrometers, pressure-spring thermometers, and thermoelectric thermometers are used for this purpose.

Etched-Stem Thermometers

Mercury-in-glass thermometers with the temperature scale etched on the glass stem are frequently used to check dry kiln temperature. They should be accurate to ±1° F. These thermometers should be placed in the kiln at the locations to be checked, and not moved when temperature readings are taken. Obviously, it is necessary for the kiln operator to go into the kiln to make these temperature readings. If the wet-bulb temperature is above 120°, he should wear protective clothing and a face mask to provide cooled air.

The temperature survey of the kiln can be quickly made if several thermometers are placed at the different zones in the kiln where temperature checks are desired. The possibility of breaking glass thermometers is reduced by putting them in metal sheaths (fig. 35, p. 47). The sheathed thermometer is suitable for making dry-bulb measurements, but if wet-bulb temperatures are also being measured, the sheath must be removed so that a wick can be applied directly over the mercury well or bulb of the thermometer.

Sometimes dry kiln operators make hygrometers out of etched-stem thermometers by mounting them on a metal plate, frame, or other suitable support. A water cistern is also attached, and the hygrometer is placed in the kiln where it is desired to check temperatures. Such a combination is shown in figure 50, *A*.

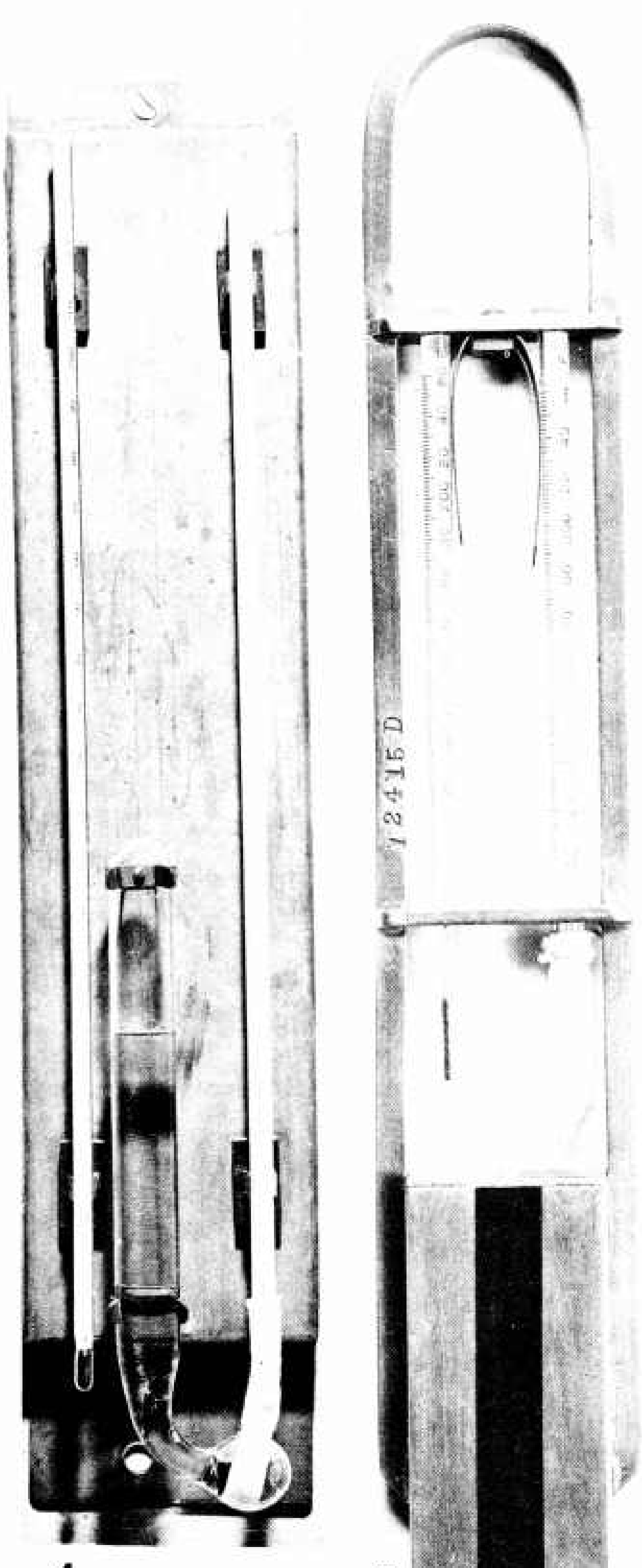
Maximum thermometers are also used for checking kiln temperatures. By mounting two maximum thermometers on a frame and supplying one with a wick and a water cistern (fig. 50, *B*), both the maximum wet- and dry-bulb readings can be obtained.

Hygrometers

Hygrometers of the type shown in figure 51 are sometimes used to check kiln temperatures. These hygrometers are cheaper than etched-stem thermometers. There is always, however, the possibility that the thermometers may move on the metal graduated bases and so give inaccurate temperature readings.

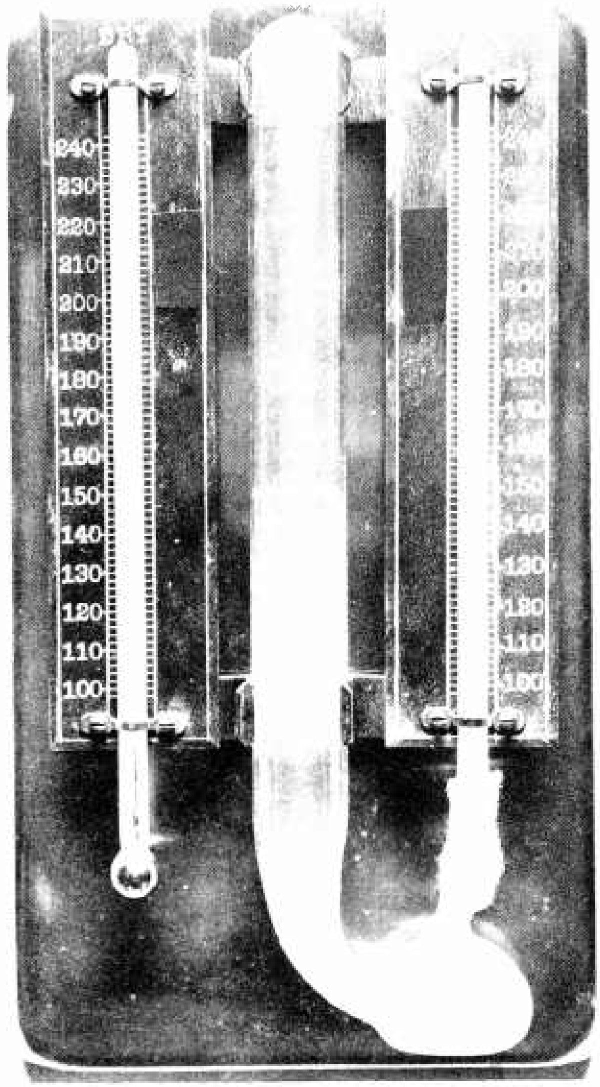
Pressure-Spring Thermometers

Pressure-spring thermometers, sometimes called dial thermometers, are used to indicate or record kiln temperatures. An indicating pressure-spring thermometer is shown in figure 36. A description of these thermometers and their operation is given on page 47. The advantage of the recording thermometer over the indicating type is that a continuous record is made of the



ZM–86250–F, ZM–90337–F

Figure 50.—*A*, Wet- and dry-bulb hygrometer made from two etched-stem glass thermometers; *B*, wet- and dry-bulb hygrometer with maximum thermometer.



ZM–90339–F

Figure 51.—Wet- and dry-bulb hygrometer with thermometer calibration on metal.

temperature conditions at the location of the bulb. Sometimes the recording pressure-spring thermometer is used to check dry kiln control instruments or to record the temperatures in parts of the dry kiln or duct systems other than where the control-instrument bulbs are located. The indicating or recording pressure-spring thermometers can be obtained with various lengths of capillary tubing. It is necessary to check them for calibration occasionally.

Thermoelectric Thermometers

The thermoelectric thermometer used for measuring kiln temperatures consists of a thermocouple, lead wires, and a potentiometer. The thermocouple is usually made from copper and copper-constantan wires that are soldered or fused together to make the junction. Both wires act

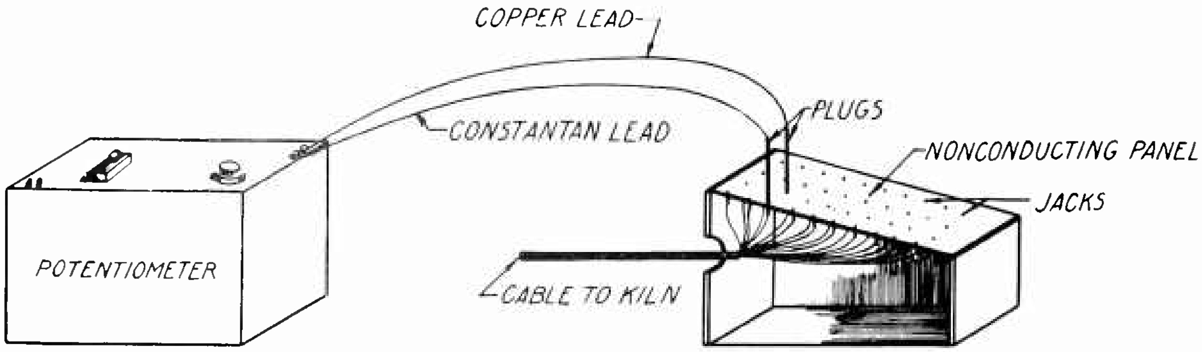


FIGURE 52.—Method of attaching thermocouple cable to jack box and potentiometer.

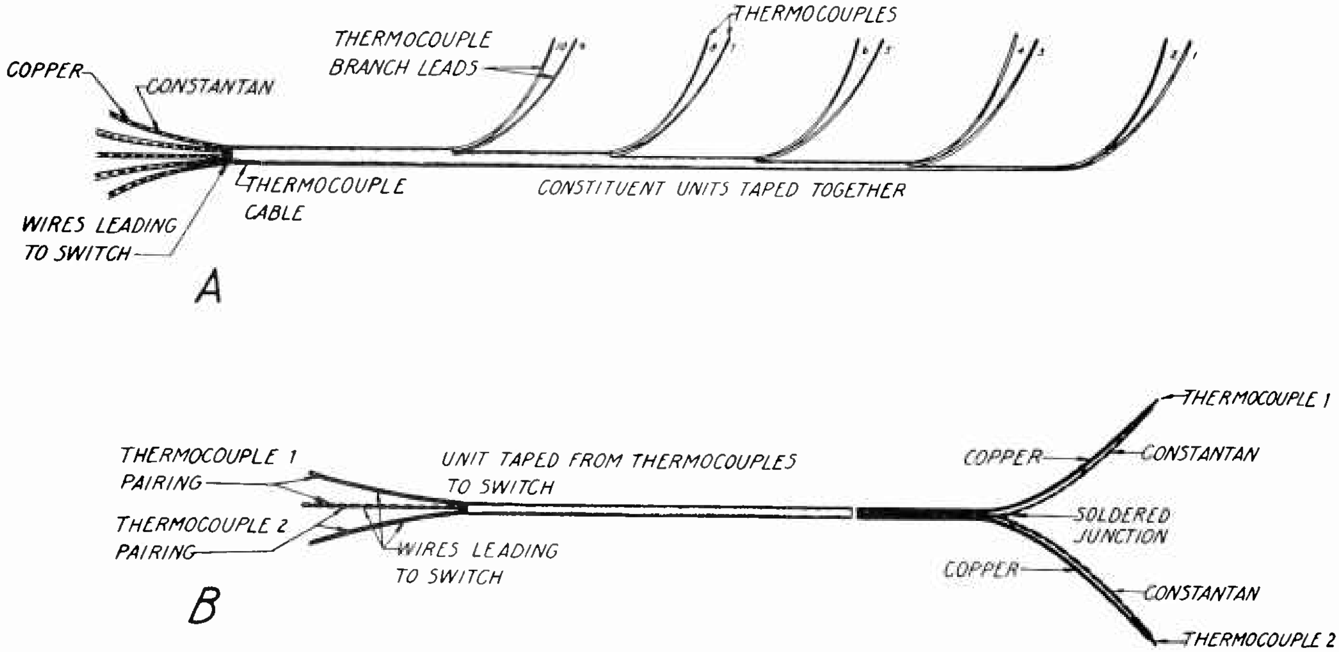


FIGURE 53.—*A*, A 50-foot thermocouple cable; *B*, section of a typical unit of main cable.

as lead wires back to the potentiometer. One of the advantages of the thermoelectric thermometer is that any number of thermocouples can be installed in the dry kiln.

If several thermocouples are used, the wires are run to a switchbox that is connected to the potentiometer (fig. 52). With a thermocouple cable containing several lead wires the thermocouples can be installed rapidly and easily. A 50-foot cable with thermocouples spaced at 10-foot intervals is shown in figure 53, *A* and *B*. The wire size best suited for dry kiln work is about 20 gage. Thermocouples should be shielded from direct radiation.

An indicating potentiometer can be either portable or stationary. A portable type is shown in figure 54. Recording-controlling potentiometers are permanently mounted on a panel board (fig. 55). The instrument can be switched to any thermocouple at any time to measure the temperature at that location.

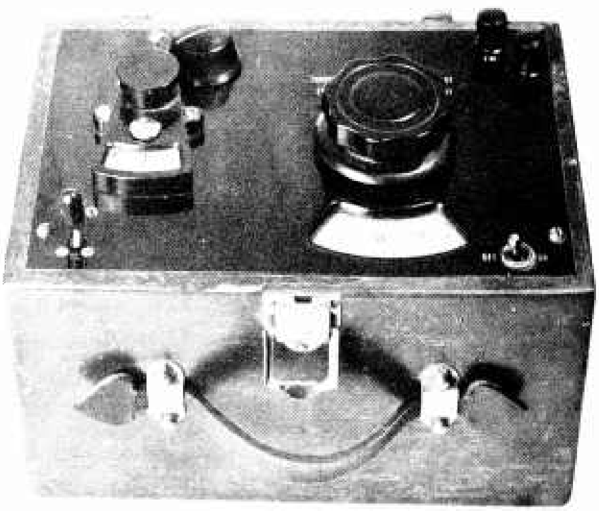
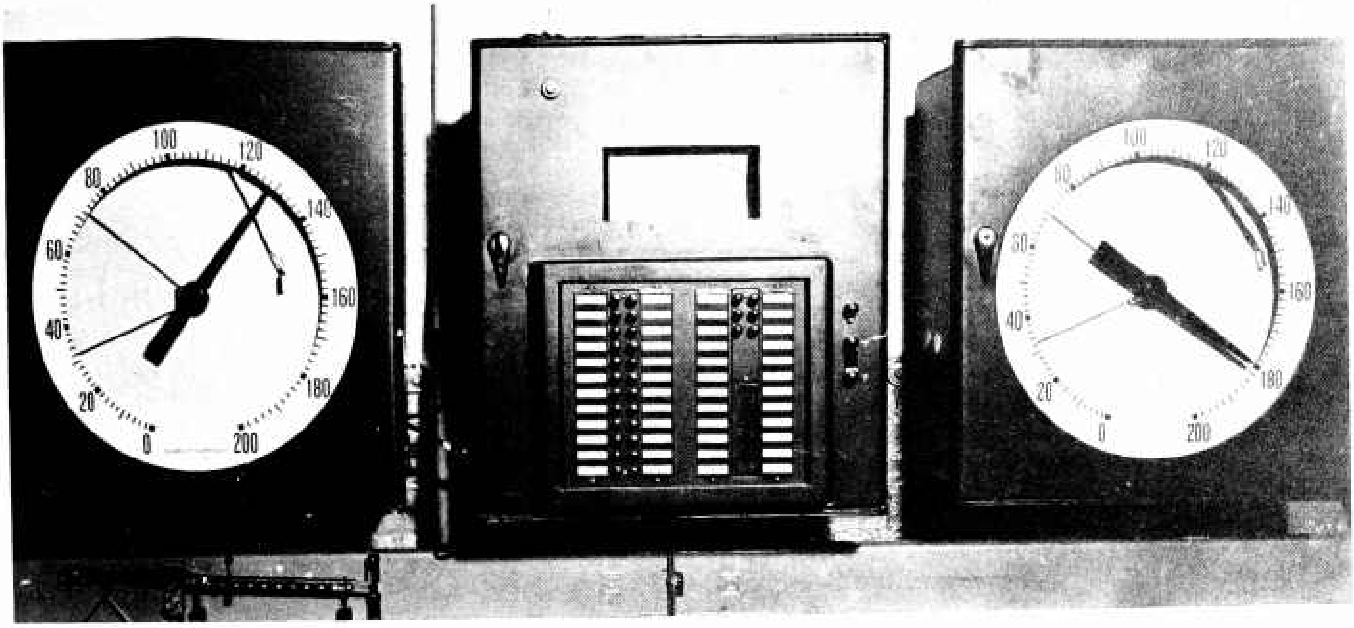


FIGURE 54.—Portable potentiometer used for measuring temperatures.



ZM-99177-F

FIGURE 55.—Indicating-recording and controlling potentiometer in dry kiln operating room.

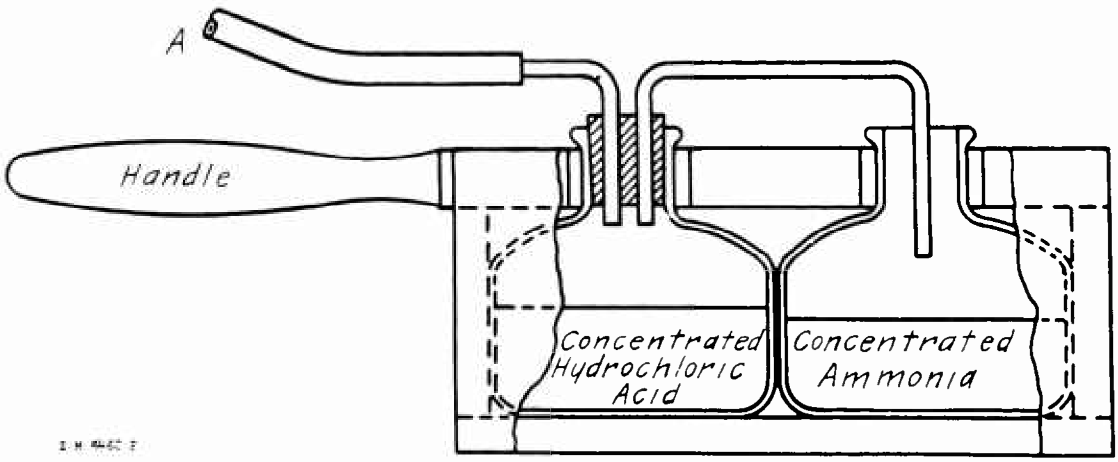
Equipment for Determining Air Movement

Since the direction and rate of air flow are important in the operation of a dry kiln, means of determining these factors are necessary. The direction of flow may be determined by smoke tests, while the rate may be measured by anemometers.

Smoke-Making Devices

A special chemical smoke generator has been devised for use in dry kilns (fig. 56). It consists of two small bottles and a few pieces of tubing. One bottle contains concentrated hydrochloric acid and the other strong ammonia water. When air is blown through the bottles, the fumes of the two chemicals mix and produce a dense smoke that drifts with the air current. The vapor of titanium tetrachloride also produces a fireless smoke when exposed to a current of air. *Caution:* A mask and rubber gloves and apron should be worn when handling these chemicals, to avoid injury to the eyes, skin, or clothing.

The smoke of burning tobacco, punk sticks, rope, or cloth is sometimes used to detect the di-



ZM-8482-F

FIGURE 56.—A smoke-making device for testing air circulation in dry kilns. Almost any kind of bottles can be used, but to avoid bulkiness comparatively narrow ones are desirable. Common ink bottles are shown in the drawing. A box with handle makes a convenient container. Two pieces of bent-glass tubing, a cork, and a rubber tube (*A*) complete the apparatus. Short lengths of glass and rubber tubing may be used instead of the bent glass. Air is blown by mouth through tube *A*, so it should be long enough to allow the operator to hold the box at arm's length. Some operators prefer to fit the end of the rubber tube with a syringe bulb, and this is almost a necessity when a mask is worn.

555315 O—61——5

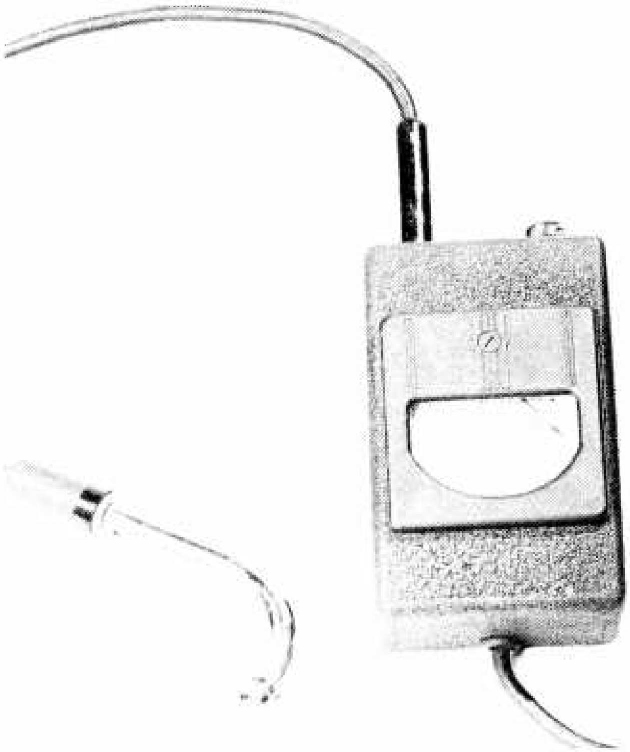
rection of air flow. The use of these materials is not recommended. They produce only a small quantity of smoke and embody a fire hazard. Also, the smoke is hot and tends to rise; therefore the true direction of the circulation may not be known until the smoke has cooled to the temperature of the surrounding air.

Anemometers

Several types of anemometers are used to determine the velocity of air in dry kilns. One type (fig. 57) consists of a disk fan mounted on pivot bearings and provided with a revolution counter. It is customary to let the fan run for several minutes and note the number of feet indicated by the counter. The air-velocity measurement in feet per minute is obtained by dividing the number of feet indicated by the number of minutes the fan has operated. If the fan is not set perpendicular to the direction of air flow, the reading may be less than it should be.

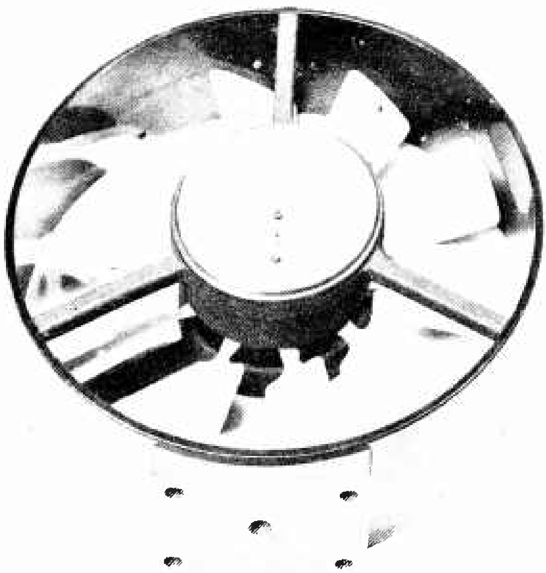
Another type of anemometer, called a hot-wire air meter (fig. 58), is also used to determine air velocities. The wire in the probe is heated with electricity. The amount of cooling of the hot wire is proportional to the velocity of the air. Velocities are indicated directly on a scale calibrated in feet per minute.

In another type, the air enters the instrument through a shutter, jet, or port, and velocity is read directly in feet per minute on a dial. An instrument of this type is shown in figure 59.



ZM–86244–F

FIGURE 58.—Hot-wire air meter.



ZM–86248–F

FIGURE 57.—Fan-type anemometer.

ZM–86243–F

FIGURE 59.—A type of air velocity meter.

CHAPTER 4. INSPECTION AND MAINTENANCE OF DRY KILNS AND EQUIPMENT

Adequate kiln maintenance is as essential as good design and construction are to efficient dry kiln operation. It can only be accomplished through regular, frequent inspections of the kiln and auxiliary equipment. If inspections reveal the necessity for repairs or replacements, they should be made as soon as possible to avoid many seasoning difficulties.

Regular, systematic inspections should cover such items as the kiln structure; doors; tracks; control equipment; heating, spraying, and venting system; trucks; lumber-handling equipment; and general housekeeping. To make sure that inspections are thorough, the operator should use a checklist on which the condition of the kiln structure and the equipment can be noted. A checklist that can be made to fit any specific kiln installation follows:

KILN INSPECTION CHECK LIST

(Where maintenance or replacement is recommended, indicate kiln number.)

I. AIR CIRCULATION SYSTEM

1. *Fans and Motors*, present condition: --
   Condition of electrical connections and switches: ------------------------------------
   What maintenance or replacement is recommended: ------------------------------------
   ----
2. *Shafts and bearings*, present condition: --
   Are motor and shaft bearings properly lubricated: ------------------------------------
   What maintenance or replacement is recommended: ------------------------------------
   ----
3. *Fan baffles*, present condition: --
   What maintenance or replacement is recommended: ------------------------------------
   ----
4. *Load baffles*, present condition: ---
   Can load baffles be improved: ---
   What maintenance or replacement is recommended: ------------------------------------
   ----
5. *Air passageways*
   Are air passageways open and unobstructed: --
   Could air movement be improved: ---
   What maintenance or replacement is recommended: ------------------------------------
   ----

II. HEATING AND HUMIDIFYING SYSTEM

1. *Feed lines and headers*, present condition: ---
   Are they properly insulated: --
   What maintenance or replacement is recommended: ------------------------------------
   ----
2. *Heating coils*, present condition: --
   Are all pipes open to full flow of steam: ---
   Condition of supports: --
   What maintenance or replacement is recommended: ------------------------------------
   ----
3. *Traps*, present condition: --
   Are traps in best possible location: --
   What maintenance or replacement is recommended: ------------------------------------
   ----
4. *Hand valves and automatic control valves*, present condition: -----------------------
   Are hand valves provided for blowing out coils: -------------------------------------
   Are hand valves provided for shutting off individual coils: -------------------------
   Are check valves working properly: --
   What maintenance or replacement is recommended: ------------------------------------
   ----
5. *Spray lines*, present condition: --
   Are spray holes or nozzles open: --
   Does condensate from spray line drip on lumber: -------------------------------------
   What maintenance or replacement is recommended: ------------------------------------
   ----
6. *Vents*, present condition: --
   Do vents open and close properly: ---
   What maintenance or replacement is recommended: ------------------------------------
   ----

III. CONTROL SYSTEM

1. *Recorder-controller*, present condition: ____________
   Is recorder-controller properly calibrated: ____________
   Are capillary tubes protected: ____________
   Are bulbs properly located and mounted for accurate readings of kiln conditions: ____________
   What maintenance or replacement is recommended: ____________

   ____
2. *Water supply*
   Is water supply line to wet bulb open: ____________
   Is wet-bulb water pan clean: ____________
   Is drain line from water pan open: ____________
   Is wet-bulb wick replaced regularly: ____________
   What maintenance or replacement is recommended: ____________

   ____
3. *Air supply*
   Is supply adequate, clean, and uninterrupted: ____________
   Is compressor in good condition: ____________
   Are water and grease traps in good condition: ____________
   What maintenance or replacement is recommended: ____________

   ____

IV. BUILDING

1. *Doors*, present condition: ____________
   What maintenance or replacement is recommended: ____________

   ____
2. *Walls*, present condition: ____________
   Is protective coating adequate: ____________
   What other maintenance is recommended: ____________

   ____
3. *Ceilings*, present condition: ____________
   Is protective coating adequate: ____________
   What other maintenance is recommended: ____________

   ____
4. *Floors and walkways*, present condition: ____________
   What maintenance or replacement is recommended: ____________

   ____
5. *Rails and supports*, present condition: ____________
   What maintenance or replacement is recommended: ____________

   ____

V. GENERAL CONDITIONS OF YARD AND KILNS

Are yard tracks and transfer in good condition: ____________
Are kiln trucks in good condition: ____________
What maintenance or replacement is recommended: ____________

____
Are kilns and surrounding area neat and clean: ____________

The Kiln Structure

Dry kilns are relatively short-lived compared to ordinary buildings, regardless of the materials used in their construction. They not only have to withstand weather but also extreme internal variations in relative humidity and temperature and frequently the corrosive action of vapors coming from the woods being dried.

Generally the doors of a dry kiln are very large. To make them serviceable, yet as light as possible for easy handling, they are usually constructed of lightweight materials with a minimum of bracing.

Walls, Roofs, and Ceilings

Dry kilns can be constructed of many materials, such as wood, concrete, concrete blocks with various types of aggregates, brick, tile, asbestos-cement boards, and sheet metal. Combinations of these materials are also used.[1] Wood is perhaps the cheapest material to use, and it has good insulating qualities. However, it does shrink and swell with changes in moisture content caused by varying drying conditions, and this eventually leads to splits in the wood members, bad cracks at the joints, and loose boards. Wood also deteriorates when exposed continuously to high temperatures. These factors increase maintenance problems and reduce the life of wood kilns much below that of kilns constructed of other materials.

Other building materials also have disadvantages. Their expansion and contraction due to temperature changes cause cracks, and their poor insulating and vapor resistance qualities lead to excessive loss of heat and vapor. Tables 7 and 8 list coefficients of heat transmission for a number of building materials.

Results of Poor Maintenance.—Cracks will eventually develop in walls, roofs, and ceilings of permanent kiln structures. If cracks are not sealed when small, they will increase in size, which leads to excessive heat and vapor losses and premature failure of the entire structure.

[1] TEESDALE, L. V. DRY KILN BUILDING MATERIALS AND CONSTRUCTION. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1646. [Processed.] 1956.

TABLE 7.—*Coefficient of heat transmission for some common dry kiln wall constructions*

WOOD FRAME WALLS

Outside covering	Sheathing material	Insulation	Inside covering	Coefficient of transmission
Bevel siding	25/32-inch shiplap	None	25/32-inch shiplap	0.245
Do	do	2-inch blanket	do	.087
Do	do	3⅝-inch blanket	do	.057
Do	¾-inch fiberboard	None	do	.191
Do	do	2-inch blanket	do	.080
Do	do	3⅝-inch blanket	do	.054
Do	25/32-inch shiplap	None	⅜-inch cement asbestos board	.320
Do	do	2-inch blanket	do	.095
Do	do	3⅝-inch blanket	do	.061

CRIB WALLS

Crib or laminated wall, 6 inches thick, no covering	.125
Crib or laminated wall, 6 inches thick, outside covered with drop siding	.114

MASONRY WALLS

Poured concrete, 8-inch	.700
Poured concrete, 12-inch	.570
Concrete block, 12 inches thick, of gravel or crushed stone aggregate	.490
Concrete block, 12 inches thick, of cinder aggregate	.380
Concrete block, 12 inches thick, of slag or burned-clay aggregate	.340
Brick wall, 13 inches thick	.360

Table 8.—Coefficient of heat transmission for a number of structural combinations of dry kiln roofs

Structural combination	Coefficient of transmission
Roof sheathing, 25/32 inch and composition roofing	0.602
Roof sheathing, 1⅝ inches and composition roofing	.380
Roof sheathing, 25/32 inch, vapor barrier, 1⅝-inch sheathing, and composition roofing	.278
Roof sheathing, 25/32 inch, vapor barrier, 2 layers of ¾-inch fiberboard	.173
Ceiling, 25/32 inch, 2-inch blanket insulation, ventilated attic under roof	.108
Ceiling, 25/32 inch, 3⅝-inch blanket insulation, ventilated attic under roof	.065
Laminated or crib roof, 6 inches thick, and composition roof	.125
Laminated or crib roof, 8 inches thick, and composition roof	.096
Concrete slab, 4 inches thick with gravel aggregate composition roof	1.010
Concrete slab, 4 inches thick with gravel aggregate, 2 layers of ¾-inch fiberboard or 1½-inch cork composition roofing	.195
Concrete slab, 3 inches thick, expanded slag aggregate, and composition roofing	.530
Concrete slab, 6 inches thick, expanded slag aggregate, and composition roofing	.326
Corrugated asbestos-cement board, vapor barrier, 5 inches vermiculite concrete (1 to 6 mixture), composition roofing	.159

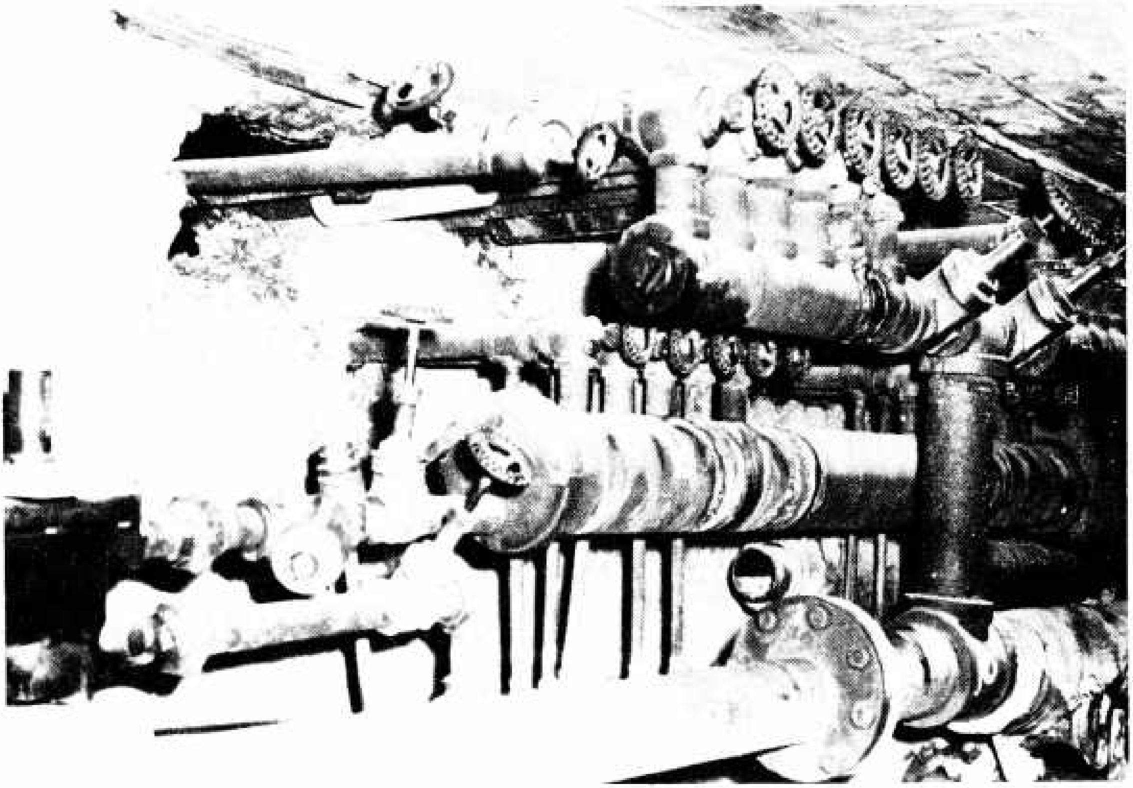
Large cracks may also cause cold zones in the kiln that slow up drying and permit mold and stain to develop in the lumber located in those zones. Excessively large holes are sometimes made in the kiln structure for steam lines (fig. 60), from which there is an excessive loss of heat and vapor. Lack of a suitable kiln paint on the interior walls, ceiling, and metal items will lead to corrosion of the metal, the rapid deterioration of some kinds of mortar, and loss of heat and vapor.

Corrective Measures.—If corrective measures are taken promptly to maintain the kiln walls, roofs, and ceilings, the repair and operating costs will be reduced and the life of the kiln prolonged. Some good maintenance practices for kiln structures are as follows:

(1) Regardless of the type of material of which the kiln is constructed, coat the inside surfaces with a vapor- and corrosion-resistant material before the kiln is used and whenever required thereafter. Usually recoating is necessary each year or two. Suitable coatings can be obtained from dry kiln manufacturers.[2] Never put vapor-resistant coatings on the exterior surfaces of dry kilns, though a water-repellent coating can be applied if desired.

(2) As soon as possible, seal cracks that develop in the structure as a result of repeated

[2] U.S. FOREST PRODUCTS LABORATORY. LIST OF DRY KILN MANUFACTURERS AND CONSULTANTS IN THE UNITED STATES. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1031. [Processed.] 1955.



M-109802-F

FIGURE 60.—Excessively large hole cut through kiln wall for steam-feed lines.

expansion and contraction of the building material. If the cracks are small, a coating of kiln paint may be sufficient, but fill larger cracks with mastic, mortar, or cement. Coat the mortar or cement fillers with a kiln paint after they have set.

(3) Cracks that develop because of settling of the structure can be temporarily repaired in the same manner as expansion and contraction cracks. To reduce future maintenance costs, however, determine the cause of the settling and correct it as soon as possible.

(4) Openings in the kiln structure for steam lines, tubing, fan shafts, and the like should be as small as possible. Insert sleeves in the openings, and plug the space not occupied by pipe with mastic, asbestos, or similar material.

(5) Promptly caulk with a nonhardening filler any open joints and splits that occur in wood dry kilns. Refasten all loosened boards as soon as possible.

(6) Use noncorrosive metal fastenings if possible.

(7) Immediately repair or replace supporting members of the structure that fail.

Doors

Doors are usually the weakest and probably the most troublesome part of a kiln structure. They are often damaged when they are opened or closed carelessly or when an improperly blocked truckload of lumber rolls into them. It is difficult to make a large door that is strong, lightweight, easy to handle, well insulated, and resistant to corrosion. The special composition doors now available have most of the desired properties. Lightweight wood doors that are properly designed have also proved fairly satisfactory, although their life is usually shorter than that of metal doors.

Results of Poor Maintenance.—Doors, door stops, hangers, rollers, and roller tracks that are poorly maintained cause excessive losses of heat and vapor and are difficult to open and close. Lower temperatures occur near damaged or poorly fitted doors, and drying is slower in that zone.[3] Neglect of doors and door equipment may also create a hazard to workmen.

Corrective Measures.

(1) Immediately repair or replace damaged door hangers, rollers, and roller tracks.

(2) Lubricate parts in accordance with the manufacturer's recommendations.

(3) Coat with a kiln paint inside faces of doors that are likely to corrode, and recoat whenever necessary. Repair or replace badly corroded doors.

[3] RASMUSSEN, E. F. NEED FOR UNIFORMITY OF TEMPERATURE IN A FORCED-AIR-CIRCULATION, VENTILATED, COMPARTMENT DRY KILN. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1669. [Processed.] 1956.

(4) Make poorly fitting doors tighter by attaching a strip of heavy felting, canvas, or special rubber gasket to the door frame. Some kinds of stripping material deteriorate rapidly, and frequent replacement may be necessary.

(5) Block wheels of standing loaded kiln trucks so that the trucks cannot roll into the kiln door.

(6) Repair or replace damaged doors as soon as possible. If repairs or replacements must be delayed, install heavy canvas, thin plywood, or other suitable material temporarily over the door opening.

Floors

The floor in a dry kiln is ordinarily constructed of lumber or concrete, though occasionally it may be dirt, gravel, crushed stone, or sand. All types of floors require maintenance.

Results of Poor Maintenance.—Poorly maintained floors increase the likelihood of accidents and may result in nonuniform drying conditions and damage to heating, humidifying, and air-circulation systems located below track level. Neglected floors may also result in loose rails or weakened supports, causing loaded kiln trucks to leave the track or tiers of packaged lumber to collapse. Both may cause additional damage to the kiln and be a work hazard to the men. If the floors of pits constructed below ground level in areas where the ground water table is high are not kept in good condition, water may seep in. If this occurs, the drying time will be extended because of excessively high relative humidities. Mold and stain may also develop on green lumber in the initial stages of drying.

Corrective Measures.

(1) As soon as possible, seal bad cracks or holes that develop in a floor built over underload fan systems. This will prevent the forced air from short circuiting the lumber being dried.

(2) Cover with gratings the openings in the floor of a forced-circulation kiln that has fans or ducts located below the loads of lumber. Gratings prevent debris from falling into and damaging the heating or air-circulating equipment. They also provide a safe, substantial walkway for workers.

(3) The floors of kilns in areas where water seepage is likely should be constructed of waterproof material. Promptly seal all cracks developing in these floors.

(4) Cover dirt, gravel, or sand floors, particularly in forced-air-circulation kilns, with lumber, blacktop, or concrete to prevent abrasive material from being blown into the loads of lumber, fans, and fan motors. A lumber, blacktop, or concrete covering is also easier to keep clean.

(5) As needed, paint all of the metal parts in a floor with a corrosive-resistant paint.

(6) Replace badly corroded metal floors or gratings, not only to insure better air circulation through the loads of lumber but as a safety measure.

Rails and Rail Supports

Generally, rails and rail supports in kilns with fans or blowers located above or on the sides or ends of the drying compartment do not give much trouble, since the rails are usually well supported and anchored. Weak rails or rail supports in natural-circulation kilns and in forced-circulation kilns, where the fans or the air-supply ducts are located below track level, may collapse or spread under heavy loads.

Results of Poor Maintenance.—Rails or rail supports weakened by corrosion, or improperly supported rails, eventually collapse under the weight of the loads of lumber. This can seriously damage kiln equipment, workmen may be injured, and drying time will be lost. If rail fastenings fail, the rails may spread, causing similar damage.

Corrective Measures.

(1) Place additional supports under sagging rails or adjacent to track supports that show signs of failure.

(2) Immediately replace or tighten broken or loose rail fastenings.

(3) Promptly realine spread rails and securely fasten them to the rail supports.

(4) Leave a break in the rails under the doors, to minimize rail corrosion caused by condensate dripping from the doors.

(5) As needed, apply corrosive-resistant paints to the rails, metal rail supports, and rail fastenings.

(6) Replace rails or rail supports so badly corroded as to be unsafe.

Recording-Controlling Instruments

Accurate control of both the dry- and wet-bulb temperature is essential for efficient kiln operation. The most common and the best method of control is by the use of automatic recording-controlling instruments. While these instruments are usually efficient, they do at times give trouble. Some of the trouble is associated with improper location of the bulbs. Once the bulbs are properly located, troubles may arise from improper calibration, faulty flow of water to the wet-bulb pan, and dirty wet-bulb wicks. The efficiency of air-operated instruments may be seriously impaired by oil, water, and dirt in the compressed air.

Improperly Located Control Bulbs

Dry bulbs that are improperly located may result in very high temperatures that increase seasoning losses, or in very low temperatures that prolong the drying time and result in mold and stain.[4]

In figure 61, the dry and wet bulbs are mounted so close to the kiln wall that the circulating air does not contact them properly, and erratic control of drying conditions can be expected. For example, if the dry bulb is on a wall adjoining a kiln that is operating at much higher temperatures, the temperature at the bulb may be higher than the set point on the control instrument because of radiation of heat from the wall. When that occurs, the actual kiln temperature will be lower than the set point.

Improperly located control bulbs are also shown in figures 62 and 63. The bulbs shown in figure 62 are in a bypass duct near floor level, between tracks in a double-track kiln. The dry bulb is too close to the wet bulb, too close to one side of the duct, and mounted parallel to the direction of air flow. Water from the wet-bulb wick dampened the dry bulb and caused erratic dry-bulb temperature control. The location of the bulbs shown in figure 63 exposes them to damage, and the planks at track level shield them to some extent from the circulating air. Here also the dry bulb was dampened because the water supply to the porous sleeve covering the wet bulb was excessive and the bulbs were too close together.

[4] See footnote 3, p. 66.

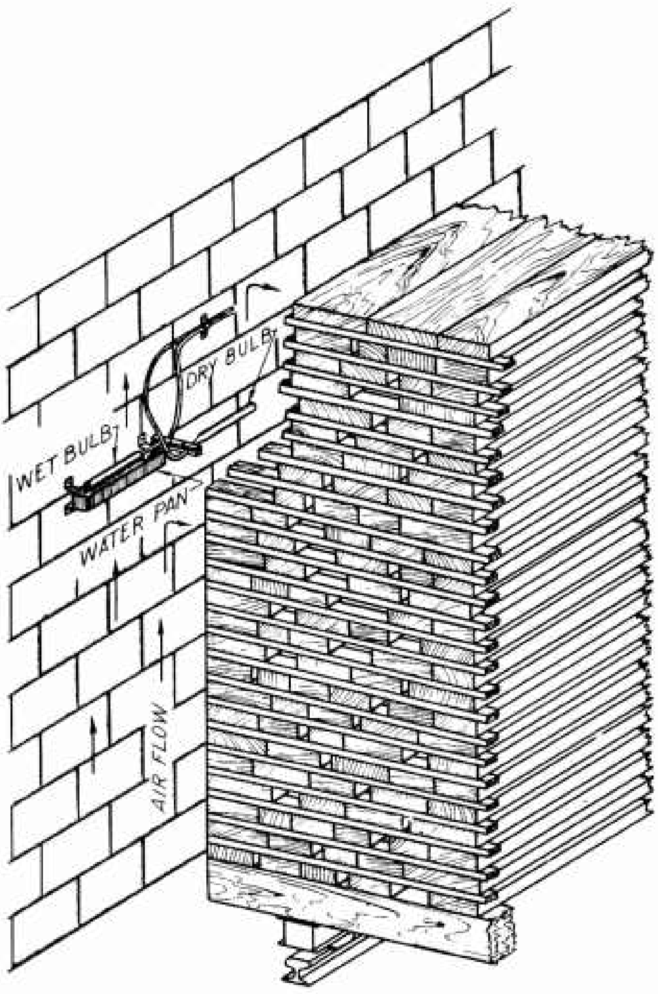


FIGURE 61.—Control bulbs mounted too close to kiln wall.

Never locate the dry bulb directly below the wet bulb. If the wet-bulb water pan were to overflow, water would fall on the dry bulb.

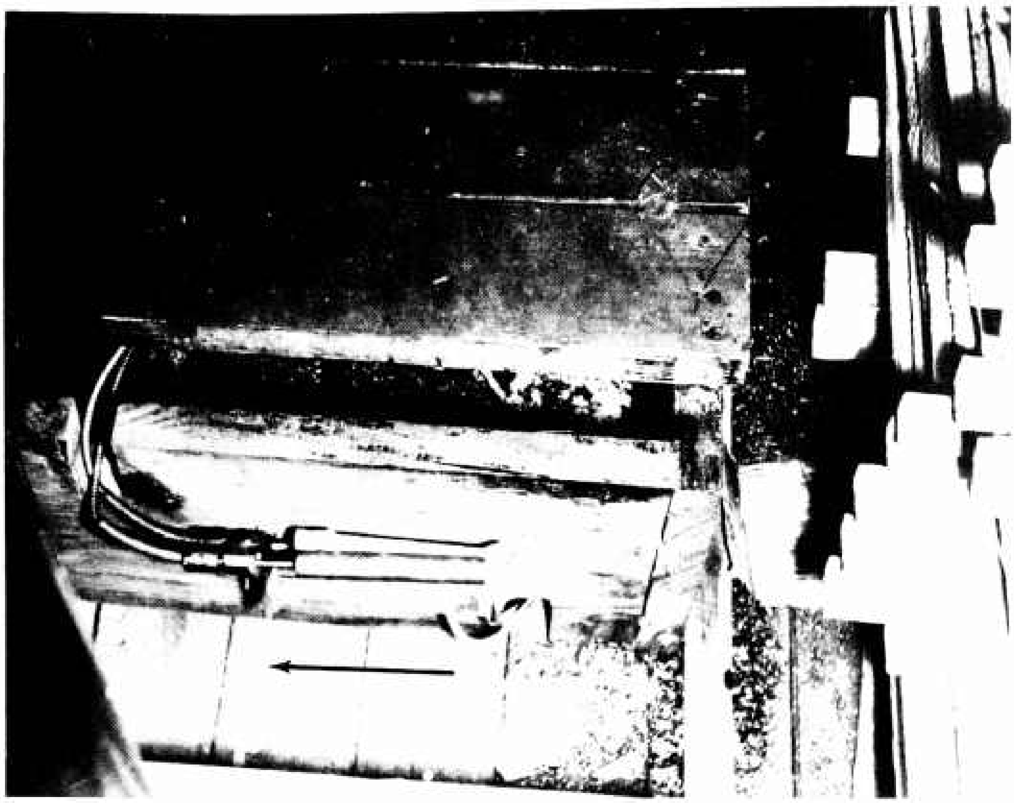
A dry bulb may be improperly placed in relation to temperature differences within the kiln. Only a small zone is measured and controlled by each bulb. If considerable longitudinal or vertical temperature differences persist after all practical measures to insure uniformity have been taken, move the dry bulb to the hottest zone on the entering air side of the load. If this cannot be done, use auxiliary thermometers to find the difference in temperature between the hottest zone and the control bulb location. Then, underset the instrument's dry-bulb control indicator by this amount.

Proper Location of Dry Bulbs

Place control bulbs in the entering-air stream at right angles to the direction of air flow and as far from the wall as practical (fig. 64). When bulbs are in this position, the kiln must be loaded carefully to avoid damaging them. The hazard can be minimized by mounting the control bulbs on a hinged extension arm so they can be swung toward the wall when loading the kiln. Be careful not to bend the capillary tube too sharply, because a sharp bend could rupture or collapse it.

The bulbs can be mounted horizontally, and parallel or perpendicular to the kiln wall. In figure 64 they are placed parallel to the kiln wall, and in figure 65 they are placed perpendicular. When mounted parallel to the wall, the bulbs can be placed end to end as shown in figure 61. Place them high enough above the floor so that they will not be accidentally bumped by someone walking through the kiln, and away from heat-radiating surfaces and spray lines.

When a reversible-circulation kiln is equipped with a single dry bulb, place the bulb in a bypass duct so that it will control the entering-air temperatures regardless of the direction of air flow. The duct can be located above or below the loads in most internal-fan kilns, and where it will not interfere with loading and unloading. The bypass principle is shown in figures 66, 67, and 68. Make the duct large enough to allow free flow of air and easy access to the bulbs, and flare it at each end to increase the velocity of the air flowing through it. Use exterior type plywood or other



M–109803–F

FIGURE 62.—Control bulbs improperly mounted in a bypass duct at track level. Arrow indicates direction of airflow. Dry bulb is mounted too close to wet bulb, too close to side of duct, and parallel to flow of air.

material that does not radiate heat. If a long bypass duct is installed, provide a trapdoor beside or below the control bulbs so they can be examined and removed for calibration from time to time.

When dual dry bulbs are used to control kiln temperature, place them on the side walls, directly opposite each other (fig. 69).

In some types of kilns, such as external-blower kilns, it is impractical to locate the control bulb in the entering-air stream. In such instances, place it where it controls leaving-air temperature. To compensate for the temperature drop across the load, underset the dry-bulb temperature control indicator the amount of the temperature drop.

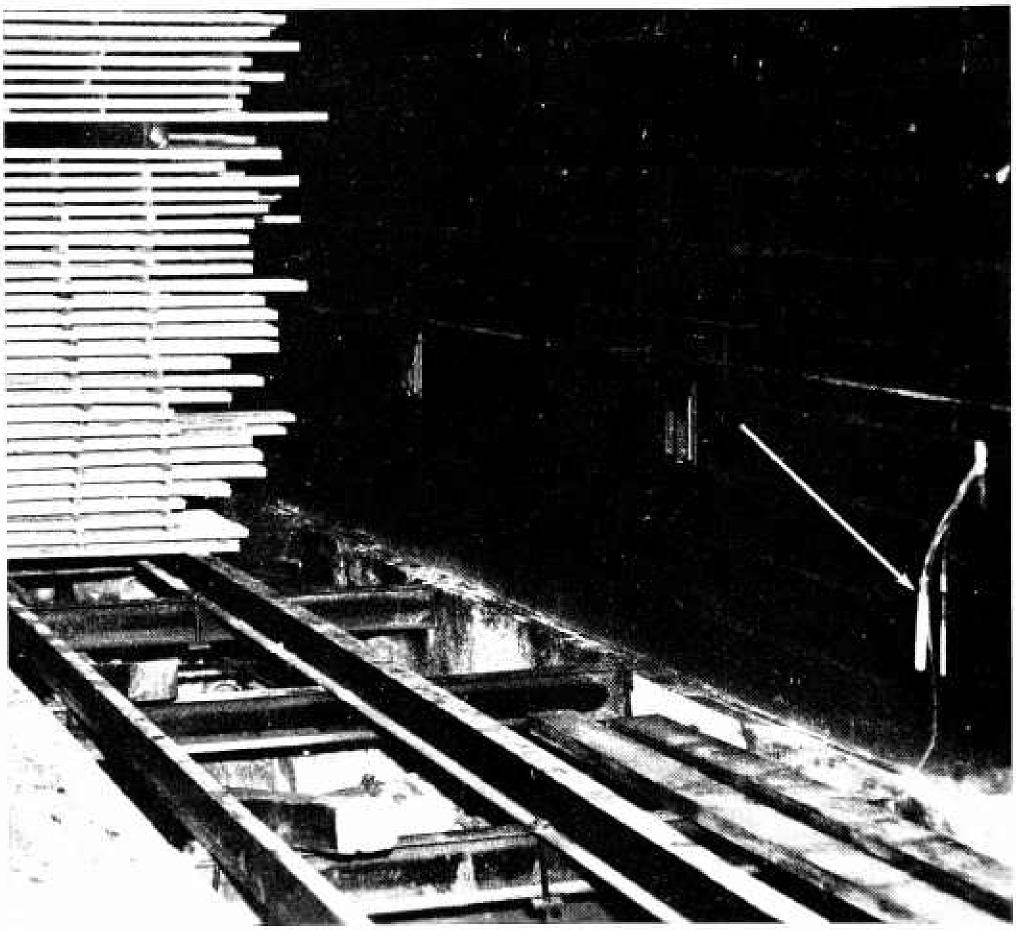
Location and Care of Wet Bulb

Improper location and care of the wet bulb results in poor control of the wet-bulb temperature. The wet bulb must be located so that air circulates around it at all times. When the kiln is operating, there must be a constant supply of clean water to the water pan to keep the wick wet. A dry or partially dry wick will cause an actual wet-bulb temperature in the kiln lower than that recorded or indicated on the instrument. Therefore, occasional cleaning of the water pan and supply line is recommended. The flow of water to the water pan is usually controlled by a needle valve, which needs to be regulated from time to time. If the flow of water is too rapid, its temperature when reaching the bulb may be too low.

In some kilns equipped with overhead coil systems, condensate from the drain end of the coils is used to supply water to the wet-bulb wick. The condensate is piped from the drain line through a coiled copper tube for cooling, and then to the water pan. A needle valve regulates the flow.

Equip the water pan with an overflow line that has its discharge end outside the kiln, and regulate the water supply so that a very slow drip, not a steady flow, appears as discharge. The overflow line must be kept open to prevent water spilling over the top of the pan into the kiln. If the kiln is shut down for a day or more, shut off the water supply, and if during this time the temperature in the kiln is likely to drop below freezing, drain the water lines and water pan. After a kiln is shut down, the wick needs to be replaced.

A dirty or badly encrusted wick affects wet-bulb control. The wet-bulb wick should be made of highly absorbent cloth. Replace it frequently with a new or laundered one.



M–109804–F

FIGURE 63.—Control bulbs improperly mounted on side wall of kiln. Bulbs are too close together and exposed to damage. Planks at track level shield them from circulating air.

The wet bulb is usually plated to minimize corrosion. When the plating has worn off so that corrosion fouls the wick, have the bulb replated by the instrument manufacturer.

The wet-bulb temperature in a dry kiln is usually lower than the dry-bulb temperature; at no time can it be higher. If the reading is higher, the instrument is out of calibration.

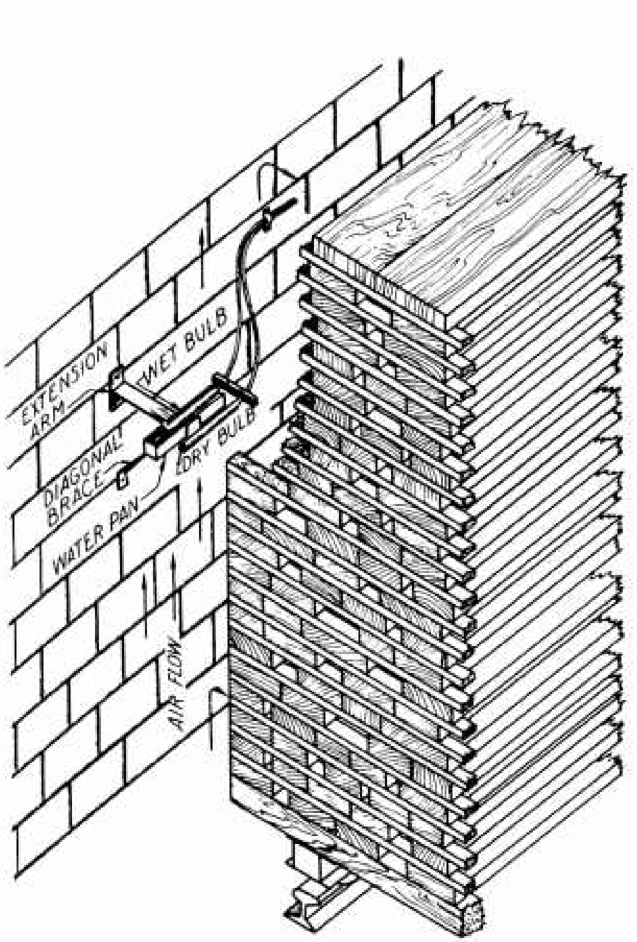
Sensitivity and Loose Linkage in Recorder-Controllers

Some recording-controlling instruments lack the degree of sensitivity necessary for the desired control of drying conditions. Sometimes this is due to faulty manufacture, but more often to loose, worn linkage.

Lack of sensitivity can be detected by comparing the temperature cycles shown on the instrument chart with those obtained at the control bulb by another thermometer of known satisfactory sensitivity. If the range of temperature recorded on the instrument is one-third or more of that shown by the check thermometer, the instrument can be considered sufficiently sensitive. If it is less than one-third, repair or replace the instrument linkage.

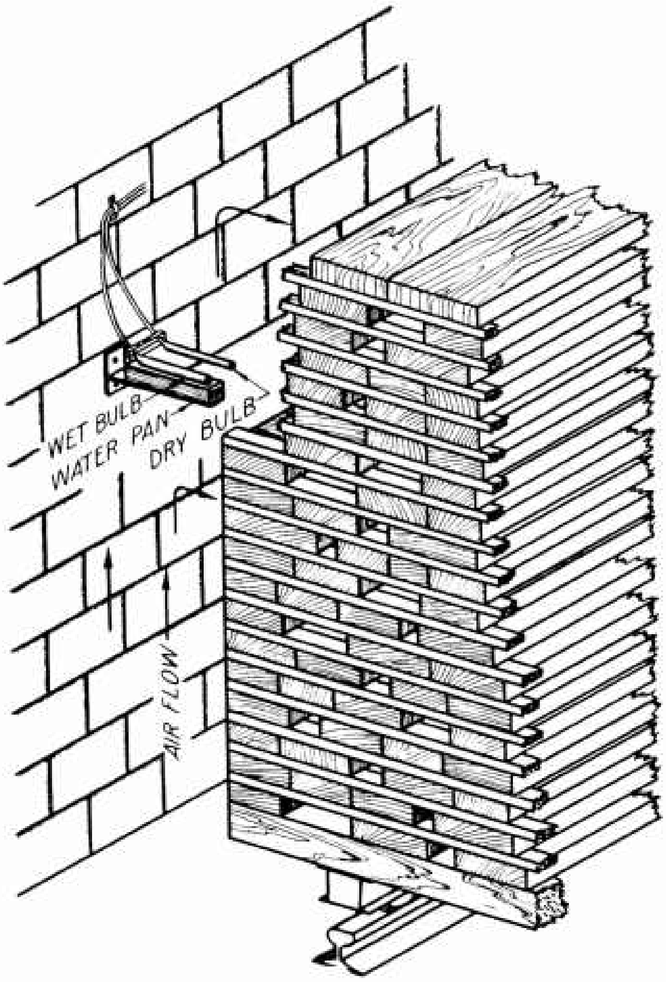
Care of Recording-Controlling Instruments

The period of reliable performance of control instruments can be greatly increased by proper care. The parts of a recorder-controller are precision built and can be easily damaged. However, they are well protected against injury and dust, and will give trouble-free service for many years if the case is not left open long at a time. Replace broken cover glass immediately. Never use compressed air, brushes, or cloth to clean off dust that may settle within the instrument case. Instrument cleaning and repairs require special tools, skills, and equipment. Such work should be done at the manufacturer's plant or by an authorized serviceman.



ZM–59899–F

FIGURE 64.—Control bulbs placed on kiln wall so that the bulbs project well into and at right angles to the entering-air stream.



ZM–59969–F

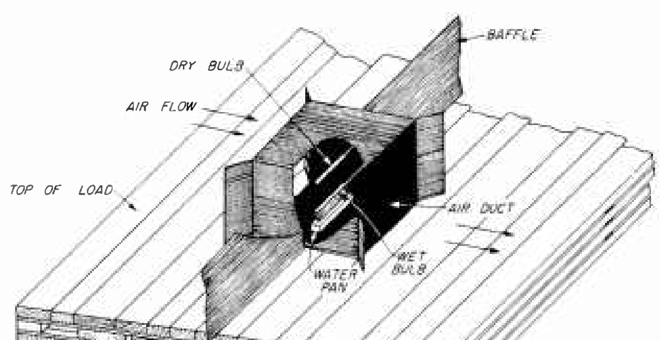
FIGURE 65.—Control bulbs mounted horizontally, and perpendicular to the kiln wall.

The only part of the control instrument that requires lubrication is the clock, and this should not be done too frequently. Never lubricate the pivot points on the linkage arms.

The air flowing into an air-operated instrument must be free of oil and moisture. For this reason, the air is passed through a filter dripwell or trap before entering the instrument. The trapped oil or moisture is blown from the dripwell or trap at least once daily by opening a blowoff valve. Usually the elements in filters must be replaced once a year.

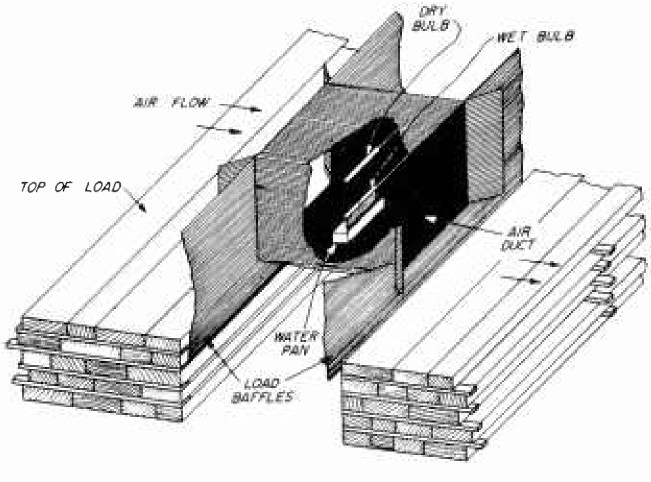
Calibration of Recording-Controlling Instruments

When instruments are out of calibration, the actual drying conditions within the kiln differ from those recorded on the chart, and serious kiln-drying defects or increased drying time may result. Because a new instrument may be jarred during shipment, calibrate it at the time of in-



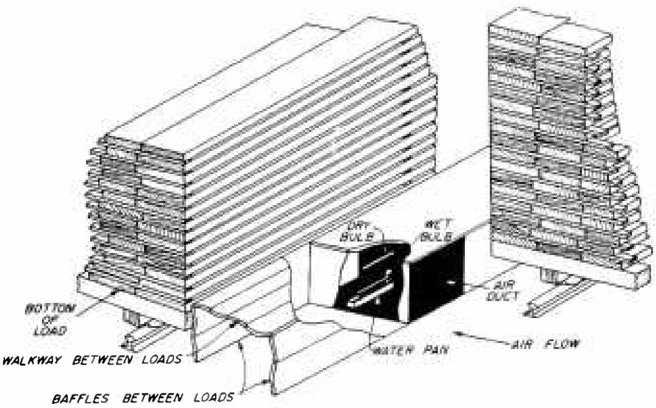
M–109441–F

FIGURE 66.—Single dry bulb so located that it will control kiln temperature on entering air. Bulb is located above the load in a single-track kiln.



M–109439–F

FIGURE 67.—Single dry bulb so located that it will control kiln temperature on entering air. Bulb is located above the loads in a double-track kiln.



M–109440–F

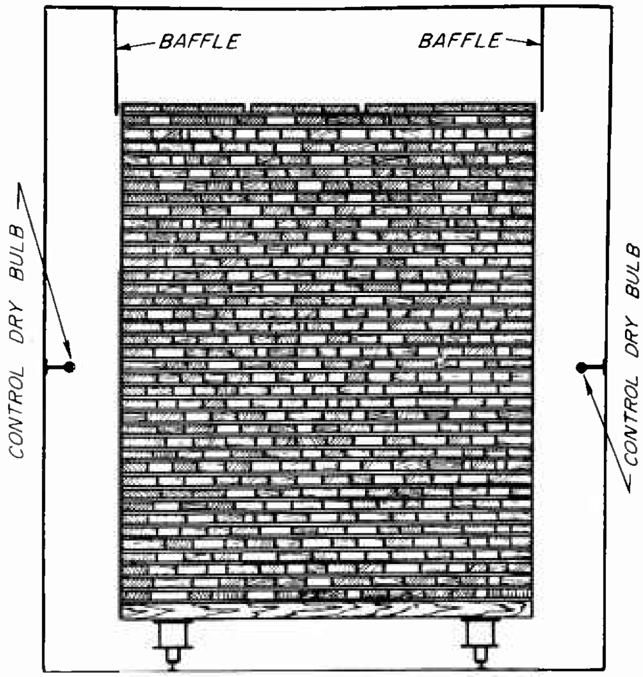
FIGURE 68.—Single dry bulb so located that it will control kiln temperature on entering air. Bulb is located below the loads in a double-track kiln.

stallation. Thereafter, check it for accuracy frequently by using glass-stemmed thermometers or other temperature-measuring devices.

Recalibration of an instrument found to be in error is not difficult, but it must be carefully done. The equipment required includes a water container and an accurate temperature-measuring device (a glass-stemmed thermometer is commonly used). Since the difference in height between the bulbs and the instrument case affects the recorded temperatures, calibrate the instrument with the bulbs at about the same height above or below the instrument case where they will be in service. Two men are needed—one stationed at the water container and one at the instrument.

The procedure is as follows:

(1) Fill a container at least 14 inches deep with water heated to about 200° F., and place it near the bulbs.



M–109805–F

FIGURE 69.—Dual-bulb control system showing control bulbs located on opposite walls.

(2) Remove the bulbs from their fastenings and completely submerge them in the hot water. If the dry and wet bulbs are located together in the kiln, calibrate them together. Avoid sharp bends in the tubing. The bulbs should not touch the sides or bottoms of the container. Usually in a dual-bulb system (fig. 69), only one dry bulb need be calibrated. If there has been a difference in the recorded temperature upon reversal of air circulation during kiln operation, check each bulb separately. The man stationed at the container gently and constantly agitates the water during calibration.

(3) After about 10 minutes, the man stationed at the container takes a temperature reading of the hot water with the thermometer. He then calls this reading to the man at the instrument, who records it, together with the corresponding temperature indicated by the instrument pen.

(4) Make a check at every 20° or 30° F. drop in the temperature of the water as it gradually cools. If cool water is added to the hot water to reduce calibration time, let 5 or 10 minutes elapse before temperatures are taken, so that the temperature change is reflected at the instrument. Make the periodic check readings until the water temperature drops to about 100°.

(5) If the indicated temperatures on the instrument chart are consistently lower or higher than the water temperatures by a constant amount, adjust the recording-pen arms upward or downward by that amount. This is done by adjusting a small screw located on the pen arm

or on the pen-arm pivot. If the differences between the indicated temperatures and the water temperatures are not constant, have a trained serviceman make the adjustment. A correction chart can be made so that the instrument can be used until the adjustment is made.

(6) The next step is the adjustment of the control setting indicator. This must be done with the air or electricity on. Lower the setting indicator to a temperature below that indicated by the pen on the chart and then move it slowly upward until the motor valve it controls begins to open. Record the temperature shown by the setting indicator. Then move the setting indicator slowly downward until the motor valve begins to close, and record the indicated temperature. If the average of the two recorded temperatures is different than the temperature indicated by the pen, move the control indicator—by means of adjustment screws on the indicator—upward or downward by the amount of difference.

Some kiln operators prefer not to adjust the instrument pens or control indicators. Instead, they list the calibration data on a small card, which they place inside the face of the instrument. These data are used as a guide for setting the instrument in subsequent control of drying conditions.

When dry kilns are provided with double-end heating systems (fig. 34) with the coils at opposite ends controlled by separate dry bulbs, each bulb must be calibrated. Many kiln operators prefer to have a gap of about 5° F. between the two recorded dry-bulb temperatures, so that temperature fluctuations at each end of the kiln are readily seen on the chart. After calibration, therefore, the pen arm of one dry bulb is intentionally adjusted upward or downward the desired amount. The amount of underset or overset should be noted on a card attached to the instrument, so that anyone reading the chart will know that the temperature recorded by that pen does not show the actual kiln temperature.

Dry kiln technicians should be familiar with the manufacturer's instructions for the care and maintenance of recorder-controllers. If the instrument should fail, however, call in an authorized serviceman to locate and correct the trouble.

Heating Systems

A correctly designed and properly maintained heating system produces uniform drying conditions in a kiln. Unfortunately, the maintenance of heating systems is often neglected and the consequent nonuniform drying conditions cause kiln degrade, extended drying time, nonuniform moisture in the lumber, and increased drying cost. On the other hand, frequent inspection and prompt corrective action can minimize, if not eliminate, many ill effects.

Steam Heating System Problems and Corrective Measures

Improperly Insulated Feed Lines.—Insulate all main feed lines from the boiler to the kiln to reduce steam consumption. Radiation from some feed lines within the kiln, running from the control valves to the coil headers or to the spray line (fig. 34), may produce excessively high temperatures in certain zones. If this occurs, the lines should be insulated. The insulation on many steam feed lines is either improperly installed or damaged. Replace deteriorated or damaged insulation as soon as possible.

Leaking Pipes.—Leaking pipes within the kiln, caused by corrosion or mechanical damage, increase steam consumption and may upset the wet-bulb temperature. Repair or replace them. When necessary clean all pipes and fittings and coat them with a corrosion-resistant material that will not affect heat transfer.

Sagging or Distorted Pipes.—Feed-line and coil supports frequently fail, causing the pipes to become distorted and to sag. Condensate and scale accumulate in the sagged pipes and eventually plug them. Straighten or replace sagging and distorted pipes. Protect pipe supports against corrosion, and reinforce or replace them when examination shows they are failing.

Debris.—Carelessness and poor housekeeping frequently cause debris to accumulate on under-load heating systems. This not only reduces the efficiency of the heating system but is a fire hazard. Such debris consists of stickers, lumber, bark, knots, sawdust, and the like. Move trucks carefully in loading and unloading operations so that boards, stickers, and bolsters are not dislodged. Seal cracks around doors and screen air intakes and vents to minimize infiltration of sawdust and other foreign matter. In spite of all precautions, however, debris will accumulate; remove it at frequent intervals.

Defective Reducing Valves and Pressure Regulators.—Fluctuations in steam pressure caused by faulty reducing valves and regulators result in nonuniform drying conditions. If adjustment does not correct the condition, repair or replace the defective parts.

Faulty Pressure Gages.—The pressure gages used in conjunction with the reducing valves and regulators occasionally go out of calibration; therefore, recalibrate them at intervals against a gage known to be accurate, or replace them.

Faulty Motor Valves.—Motor valves may leak or fail to open or close properly. If an air-operated motor valve fails to open, the trouble is usually associated with a leak in the air supply line, a damaged diaphragm, or a packing nut that is too tight. If the valve fails to close, the trouble may be due to improper adjustment of the compression spring. Failure of electrically operated valves may be associated with power failure, damaged wiring, or the motor. A valve that leaks because of worn parts or the presence of scale on the seat can usually be detected by a slow, continuous rise in temperature above the set point. A valve that fails to open can be detected by a slow drop in temperature below the set point when the instrument is calling for heat.

Repair or replace faulty valves. Keep a spare motor valve on hand for replacement purposes, and also spare motor valve parts, including diaphragms. If leaks occur around the valve-stem packing nut, tighten the nut or replace the packing.

Hand-Operated Valves.—Hand valves are used extensively on steam heating systems. These valves, which are usually of the globe type, should be operated wide open or completely closed. If leaks occur around the valve-stem packing nut, follow the procedure outlined under faulty motor valves. Keep replacement valves and spare parts on hand.

Faulty Steam Traps.—Consult kiln manufacturers, engineers, and steam-trap manufacturers on trap installations to minimize failures in the trapping system. The following summary will assist the operator in locating and correcting trap troubles.

The failure of a steam trap to discharge may be due to (1) excessive operating pressures, (2) no water coming to the trap, (3) a plugged bucket vent, (4) a trap filled with dirt, (5) worn or defective parts, or (6) excessive back pressures in the return line. Excessive operating pressures may be caused by the failure of the reducing valve or pressure regulator, by inaccurate readings on the pressure gage, by back pressures in the return line from the trap to the boiler caused by a discharge line that is too small or is plugged, or by the raising of steam pressures without changing the valve orifice in the trap. When condensate fails to reach the trap, the failure may be due to a plugged line, to a closed valve in the line between the coils and the trap, or to open or leaking bypass valves that allow the condensate to flow around the trap. Dirt in the condensate may plug the bucket vent. Trouble from dirt can be minimized by installing a strainer ahead of the trap and cleaning it at frequent intervals. A strainer will also prevent the trap body from becoming filled with dirt. Install blowoff valves on all traps, and blow out the traps for a short period each day the kiln is in operation.

When the discharge of water from a trap is continuous, the trap is too small or it has an orifice too small for the steam pressure used. These difficulties can be prevented by installing a trap that has an orifice of proper size and is large enough to handle the peak condensate load, which will usually occur during the warmup period.

If the trap blows live steam, the discharge valve may not be seating or the trap may have lost its prime. A badly worn valve seat or dirt lodged between the valve and valve seat will cause improper seating of the valve. A trap that loses its prime is usually subjected to sudden or frequent drops in steam pressure. If this occurs frequently, install a good check valve ahead of the trap and below the coil being drained. Maintaining fairly constant steam pressures will also minimize this trouble.

Worn or defective trap parts may cause complete failure. Some parts can be easily replaced on the job with very little, if any, loss in operating time. Replacement is even simpler if a bypass line has been installed around the trap. When a defective trap cannot be repaired on the job, replace with a new or reconditioned one. Repair the defective trap at the first opportunity. Annual cleaning and overhaul of all traps is recommended.

Trap failure can be detected by observing discharge from the trap, obtaining temperatures on the supply and discharge sides, or by listening to its action. The discharge action of most traps can be observed from test outlets. These should be opened frequently. If steam discharges continuously from a correctly sized trap, it is not functioning properly; determine the cause and correct it. Do not confuse flash steam with live steam. Flash steam is due to pressure changes and appears for only short periods of time when the trap is discharging, but live steam generally appears in a continuous flow.

Temperatures obtained on the supply and discharge lines of the trap are useful in checking trap performance. A spot test pyrometer can be used to obtain these temperatures. If the supply-line temperature is about 10° to 15° F. above the discharge-line temperature, the trap is working satisfactorily. If there is no difference in temperature between the inlet and the outlet pipes connected to the trap, it is blowing live steam or has insufficient capacity. A large difference in temperature is an indication that the trap is water-logged.

On some types, trap action can be checked by listening to the operation. Place the bit end of a screwdriver firmly against the top of the trap and then put one ear firmly against the end of the handle. If the valve action is plainly heard, the trap is working properly; if movement of condensate inside the trap is heard, the discharge is blowing through.

Indirect-Heated Furnace Kilns

In indirect-heated kilns with gas, oil, coal, or wood furnaces, the products of combustion flow through a system of heat exchangers located within the kiln. If excessively hot exchangers are too close to the lumber being dried, seasoning defects may develop, and the lumber may catch fire. Checks of the temperature throughout the kiln will help find hot spots in the heat exchanger. To eliminate hot zones, modify, relocate, or insulate the heat exchanger.

Keep heat exchangers free of debris to minimize the possibility of fire. Fly ash deposited in heat exchangers may cause nonuniform temperatures; therefore, disconnect the exchangers and clean them occasionally. Compressed air is frequently used for this purpose. Since heat exchangers deteriorate rapidly because of the high temperatures, inspect them frequently and replace them if they are defective. Badly deteriorated heat exchangers are likely to cause fires.

Direct-Heated Furnace Kilns

Because the products of combustion in direct-heated furnace kilns are discharged directly into the drying chamber, both the kiln and the lumber are exposed to the danger of fire from sparks and flames. Therefore, carefully control the rate of burning of the fuel, and install spark arrestors when necessary. Ducts carrying the products of combustion are subject to deterioration. Inspect them frequently and repair or replace them when they are unsafe. *Caution:* The products of combustion are likely to contain toxic gases; never enter the kiln during operation or brief shutdown periods unless you are wearing a self-contained breathing apparatus or the kiln has been aired out by opening the large doors.

Furnace-type dry kilns (fig. 21) that are heated by gas or oil burners located within the kiln are particularly susceptible to fires and often contain toxic gases. Keep the burners free of deposits that may catch fire and blow into the lumber. Repair leaking gas or oil feed lines immediately. Do not allow debris to gather around burners or on plates heated by the burners. Keep the thermostats that automatically control the operation of the burners in good repair.

Electrically Heated Kilns

All wires leading to the heating units should be well insulated to avoid short circuits that could be the cause of fires or injuries to workers. The electrical system should be installed and checked by qualified electricians. Inspect the electric circuits frequently. If damaged circuits or heating units are found, have a qualified serviceman immediately repair or replace them. Do not permit debris to accumulate.

Humidifying Systems

Steam Spray

Steam sprays are used to supply moisture to the kiln atmosphere when required to maintain the desired relative humidity. Exhaust steam, if available, is preferable to live steam for this purpose. Hand or motor valves controlling the flow of steam spray into a kiln are subject to the same failures as those in steam heating systems. Follow the inspection and maintenance procedures discussed on pages 73–74. A flow of steam or condensate from the steam spray line when the valves are closed indicates leakage. A falling wet-bulb temperature when the control instrument is calling for steam spray indicates that the steam spray motor valve has failed to open. Repair or replace defective valves immediately.

The steam spray lines usually pitch downward from the feed end. Usually a small drain line discharging outside the kiln is provided to drain off the condensate that collects at the low end. Keep this drain line open. Inspect the steam spray line itself periodically to see that the discharge holes or nozzles are open and that the pipe has not been bent or turned so that the spray discharges onto the lumber or the instrument control bulbs.

Water Spray

Occasionally water-spray lines are installed in kilns to supply moisture when required for humidification. Inspect the valves frequently that control the flow of water into the spray line and, if they are defective, repair or replace them immediately. Open plugged spray holes or nozzles, and repair or replace damaged lines.

Venting Systems

Most kilns are provided with ventilators for exhausting hot, moist air from the kiln and taking in fresh air. Excessive venting increases heating and humidification requirements, and it should be avoided by proper adjustment and maintenance of the venting system.

Vent Operation and Care

Although vents can be manually or automatically operated, automatic ones are recommended. To prevent excessive venting, frequently inspect the system and keep it in good repair. Following are a number of items to observe in the inspection and maintenance of vents:

(1) Keep the linkage system connecting two or more vent caps or dampers lubricated, and inspect it periodically for damage. Straighten, repair, or replace bent or broken rods, chains, and levers.

(2) Inspect the vent caps or dampers when they are in a closed position. If some are partially open, adjust the linkage so that the caps or dampers fit tightly. This adjustment can be made quickly and easily on most kilns.

(3) Install gaskets around vent openings if there is excessive leakage when the vent caps are closed.

(4) Avoid overventing. Adjust the linkage so that the caps or dampers are open just wide enough to obtain the desired venting.

(5) Examine air lines or electric circuits connecting the vent mechanism to the control instrument for air leaks and short circuits.

(6) The compressed air used to operate the vent mechanism should be dry. Water in the air supply line may freeze the motor valve during winter weather. If dry compressed air cannot be obtained, protect the air supply line against freezing.

(7) Use screen inserts in the ventilators to minimize the fire hazard associated with venting. These will keep sawdust, other debris, and sparks from entering the kiln. Remove and clean the screens periodically.

(8) Keep the fresh air doors, dampers, and ducts in natural-circulation kilns in good repair and free from obstructions.

Air-Circulation Systems

The uniform circulation of air in a kiln is dependent on well-maintained air-circulating equipment.

Natural-Circulation Systems

Because air movement is comparatively slow in natural-circulation kilns, the air passageways from the heating coils into and around the loads of lumber must be unobstructed. Walkway gratings also should be free of planks, debris, and other obstructions.

Internal-Fan Systems

Any failure or damage to the component parts of the air-circulation system in internal-fan kilns extends drying time and may also result in nonuniform drying. Therefore, the maintenance and care of the component parts of the air-circulation system is essential.

Inspection and Maintenance.—The items to be checked in the periodical inspection of the air-circulation system and some of the maintenance procedures include the following:

(1) Fan Motors.—Lubricate fan motors in accordance with the manufacturer's instructions. Replace leaky bearing seals.

Keep windings and armatures free of dust. Dry compressed air may be used for blowing out dust.

Keep motor mounts and anchor bolts tight.

Protect from the weather fan motors located outside the kiln.

Properly ventilate a control room to avoid overheating fan motors located there. Fan motors located in the kiln must be designed for high temperatures and high relative humidities.

Protect fan motors against overloading. Relays should be set to kick out under small overload.

Repair or replace damaged or badly worn motors.

Have a qualified electrician inspect all elements of the electrical circuits periodically and keep them in good condition.

(2) Fan Shafts.—Lubricate shaft bearings according to the manufacturer's instructions and replace leaking oil seals.

Keep bearing supports tight and alined with the shaft. Misalinement may overload the fan motor and damage the fan shaft and bearings.

Keep friction bearings tight.

Replace damaged or badly worn bearings.

Replace or repair badly worn keys or keyways.

Keep shaft couplings tight.

Replace damaged fan shafts.

(3) Pulleys and Belts.—Keep pulleys tight on the shafts.

Replace badly worn or damaged pulleys to prevent excessive belt wear or belt slippage.

Tighten belts according to manufacturer's recommendations. Do not overtighten.

Replace badly stretched or damaged belts.

(4) Fans.—Repair minor damage to fans; replace badly damaged fans.

Keep fans tight on fan shafts.

See that the clearance between the tips of fan blades and the fan rings conforms to the manufacturer's recommendations.

(5) Fan Baffles and Fan Floor.—Repair or replace damaged fan baffles or fan floors.

Keep anchor bolts in fan baffles tight to minimize vibration and possible damage to fans.

(6) Load Baffles.—Repair or replace damaged load baffles.

Lubricate baffle hinges.

Maintain pulleys and cables on hinged baffle systems in good condition.

(7) Oil Lines, Connections, and Bearings.—Leaking oil lines, connections, or bearings increase safety and fire hazards, and the oil may stain the lumber. Make a systematic inspection for oil leaks and tighten loose connections. Repair or replace damaged lines.

Caution: Exercise extreme care when fans must be inspected while they are running. Serious injuries have resulted from carelessness during the inspection of moving fans.

External-Blower Systems

The inspection and maintenance of internal-fan kilns is also applicable to external-blower kilns. Other maintenance items include:

(1) Repair or replace leaky blower housing panels.

(2) Repair or replace damaged supply- and return-air ducts to insure maximum air circulation through the loads of lumber and to avoid short circuiting.

(3) Inspect air scoops in the supply-air duct slots for damage and maladjustment so that air delivery remains uniform throughout the length of the duct. Adjust, repair, or replace them when necessary.

(4) Remove any debris covering the supply-air slots or ports.

(5) Repair or replace badly worn or damaged reversing dampers.

(6) Keep fresh-air doors in the blower housing in good repair.

(7) Repair damaged vent dampers.

Kiln Trucks

Frequent inspection and proper maintenance of kiln trucks can minimize down-time and accidents. Proper lubrication will help extend truck life. Recommended maintenance procedures are:

(1) Repair or replace damaged truck frames, axles, and bearings promptly.

(2) Keep bolts or rivets in truck frames tight.

(3) Repair or replace damaged metal or wood cross supports.

(4) Provide enough kiln trucks so that no truck is loaded over its capacity.

Prevention of Corrosion

Since much of the metal in a dry kiln will corrode, frequent inspection of metal parts is essential. Remove rust and coat the affected surface with a suitable protective paint. Such paints can be obtained from dry kiln manufacturers.

555315 O—61——6

Housekeeping and Maintenance Around Dry Kilns

Good housekeeping around dry kilns is essential. To minimize the possibility of injuries, damage to equipment, derailment of kiln trucks, and fires, keep the dry kiln, the operating room, and the surrounding area clean and free of safety and fire hazards. The following are good housekeeping practices:

(1) Immediately pick up stickers falling from loads of lumber and place them in conveniently located sticker racks.

(2) Pick up lumber falling from loads and repile it on the loads or return it to the storage area.

(3) Collect and remove sawdust and other debris that sifts or drops into the kiln.

(4) Keep walkways in a kiln free of debris.

(5) Push back into the load of lumber any boards that project into walkways, to prevent injuries to workmen. Projecting boards also cause nonuniform air velocities through the loads of lumber in some types of kilns.

(6) Stop oil or grease leaks around bearings, fans, blowers, and motors, and wipe up spilled oil or grease as soon as possible. Use drip pans to catch oil or grease dripping from bearings. Place oily or greasy rags in closed containers.

(7) Keep control rooms and operating pits clean and well ventilated at all times.

(8) Keep transfers, tracks, and tramways on the loading and unloading ends of dry kilns in good alinement and repair.

(9) Inspect stairways and ladders frequently and replace weak members at once.

Locating Troubles in Kiln Maintenance and Operation

To assist the dry kiln operator in rapidly finding the causes of poor drying, the more common sources of trouble are summarized.

If the dry-bulb temperature does not reach the set point in a reasonable length of time, the causes may be—

(1) Steam pressure is too low.

(2) Insufficient radiation.

(3) Heating coil is damaged, waterlogged, air-bound, or plugged.

(4) Hand valves on feed or drain lines are closed or only partially open.

(5) Automatic motor valve fails to open.

(6) Steam trap is defective.

(7) Valves are open on bypass line around steam trap.

(8) Excessive back pressures in return line to boiler.

(9) Excessive venting.

(10) Excessive leakage from kiln structure and around doors.

If dry-bulb temperature continues to climb above the set point, the causes may be—

(1) Leaking hand valves on feed lines.

(2) Leaking automatic motor valve.

(3) Motor valve remains open.

(4) Heat transfer through a common wall from an adjacent kiln.

If the wet-bulb temperature fails to reach the set point in a reasonable length of time, the causes may be—

(1) Insufficient steam entering the spray line because—

(a) Automatic motor valve fails to open.

(b) Hand valve on feed line is closed or only partially open.

(c) Holes or nozzles in spray line are plugged.

(2) Excessive leakage of heat and vapor from kiln structure or around doors.

(3) Excessive venting.

If the wet-bulb temperature continues to rise above the set point, the causes may be—

(1) Leaking motor valve.

(2) Motor valve remains open.

(3) Water seeping into kiln.

(4) Leaking steam or water lines in kiln.

(5) Valve in bypass line around motor valve is open.

(6) Insufficient venting.

If the lumber is not uniformly dried or has excessive degrade associated with hot or cold zones within the kiln—

(1) Hot zones may be caused by:

(a) Excessive radiation due to uninsulated feed lines or headers.

(b) Higher than average air velocities across radiating surfaces due to faulty stacking and inadequate baffling.

(c) Leakage of heat through a damaged wall common to two kilns.

(2) Cold zones may be caused by:

(a) Infiltration of colder air through cracks in the kiln wall or around doors.

(b) Damaged fans or fan motors.

(c) Short circuiting of the air because of faulty stacking or inadequate baffling.

(d) Condensate from the drain end of plain-header coils is not draining properly.

(e) Down drafts through the ventilators.

Incorrect recording of dry- and wet-bulb temperatures may be caused by—

(1) Control instrument out of calibration or damaged.

(2) Improper air circulation over control bulbs.

(3) Control bulbs exposed to direct radiation from heating coils and feed lines or heat from steam spray.

(4) Water on the dry bulb.

(5) Wet bulb wick dirty, dry, or made of improper cloth.

(6) Water flowing at either too fast or too slow a rate to the wet bulb water pan.

(7) No wick on the wet-bulb.

(8) Wick placed on the dry bulb instead of on the wet bulb.

(9) Wrong recorder chart.

CHAPTER 5. STACKING LUMBER AND OTHER ITEMS FOR KILN-DRYING

Much of the degrade and waste that occurs during kiln-drying results from poor stacking. Well-stacked lumber dries faster, more uniformly,[1] and with less warp, and fewer stickers break and deform. Stacking procedures vary among plants because of differences in plant layout, material to be dried, and types of kilns and stacking equipment. Several principles of good stacking, however, apply at all plants.

Sorting

Sorting the stock simplifies stacking and also aids in getting material of like drying characteristics into a kiln charge. Sorting, therefore, should be as complete as is practical. It is planned to accomplish various purposes.

Sorting for Species

Some species of wood have markedly different drying characteristics than others. For example, the time required to kiln-dry green 4/4 red oak to a final moisture content of 7 percent is two to three times that required to kiln-dry green 4/4 hard maple; moreover, a much milder drying schedule must be used for the oak. If these two species were in the same kiln charge, the hard maple would have to be dried under the oak schedule, and the cost of drying the maple would become excessive. On the other hand, the drying characteristics of hard maple and yellow birch do not differ greatly, and these species, if of the same thickness and moisture content, can be dried together economically. Whenever possible, therefore, a kiln charge should be composed of a single species or of species that are closely similar in drying characteristics.

Sorting for Moisture Content

It is not desirable to mix air-dried, partially air-dried, and green stock in the same kiln charge. The wetter stock requires milder initial drying conditions and a longer drying time than the drier stock. For example, 4/4 red oak air-dried to a moisture content of 25 percent can be kiln-dried to a moisture content of 7 percent in about one-quarter of the time that is required to kiln-dry green 4/4 red oak to the same final moisture content. The dried stock should be kiln-dried separately.

Because of the many variables involved, specific recommendations cannot be made as to the maximum allowable difference in initial moisture content between the driest and wettest stock in a kiln charge. This difference must be determined by each kiln operator on the basis of production needs and the quality of drying desired. In general, the difference in moisture content between the driest and wettest stock composing a kiln charge should be smaller (1) for air-dried or partially air-dried stock than for green stock, (2) for shorter drying times than for longer times, and (3) for a narrow range in the desired final moisture content.

Electrical moisture meters are frequently used for sorting.

Sorting for Heartwood and Sapwood

In some species, sapwood and heartwood differ considerably in green moisture content (table 1, p. 9). In addition, sapwood generally dries more rapidly and with fewer defects than does heartwood. Because of these differences, it is advantageous to separate sapwood from heartwood where large quantities of lumber are handled.

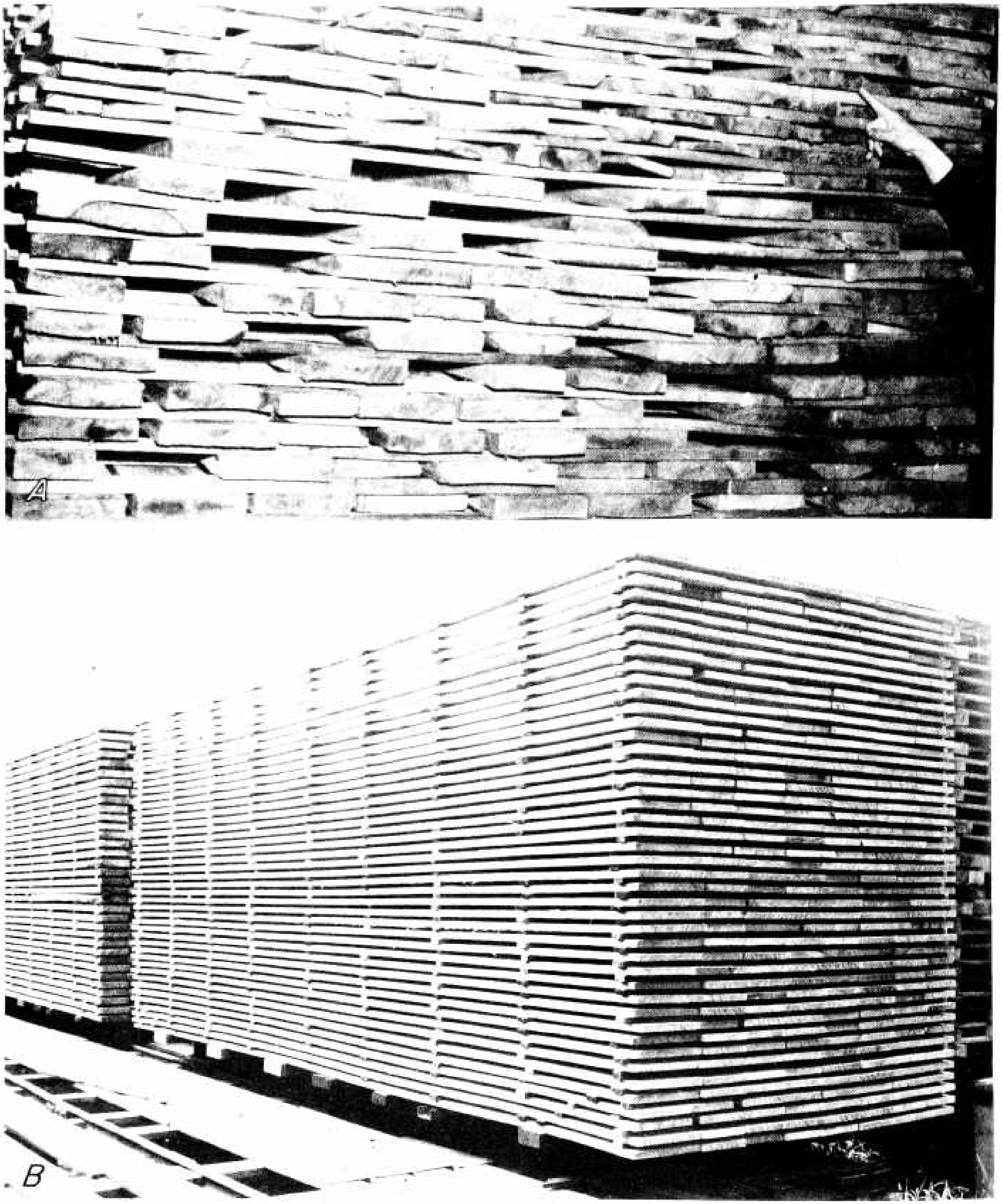
Sorting for Grain

A plainsawed board (fig. 2, p. 7) generally dries faster than a quartersawed board, but it is more susceptible to such drying defects as surface and end checks and honeycomb. Therefore, plants producing large amounts of quartersawed lumber can segregate it and dry it under more severe kiln conditions, thereby shortening the drying time.

Sorting for Grade

The upper grades of lumber, both hardwood and softwood, are generally used in products that require higher strength, closer control of final moisture content, and better appearance than the lower grades. Therefore, the higher grade material is usually sorted out and kiln-

[1] Rasmussen, E. F. Need for uniformity of temperature in a forced-air-circulation, ventilated, compartment dry kiln. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1669, 5 pp. [Processed.] 1956.



M-115549, M-87929-F

FIGURE 70.—*A*, Stacking lumber of different thicknesses on the same kiln truck results in cupping of the lumber and deformation and breakage of stickers. *B*, Lumber of uniform thickness remains flat during drying, and stickers stay straight.

dried according to schedules different from those used for the lower grades.

Sorting for Thickness

Sorting for thickness is essential. Stock of uniform thickness simplifies stacking and drying. It also reduces warping in the lumber and breakage and deformation of the stickers.

The thicker the material, the longer the drying time and the milder the drying conditions required. Cupping of the lumber and deformation and breaking of the stickers resulting from stacking material of various thicknesses are shown in figure 70, *A*. The cupping and twisting in the thinner boards is caused by a lack of contact between the boards and the stickers, and it results in a nonuniform flow of air across the load. Damaged stickers often have to be discarded.

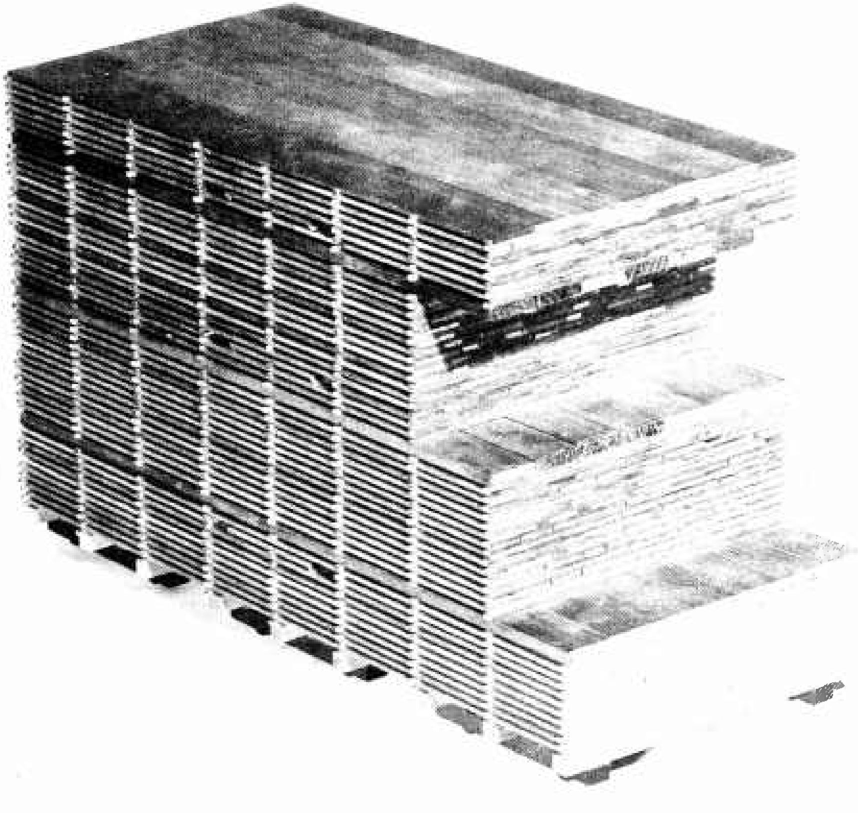
A truckload of dried boards of uniform thickness is shown in figure 70, *B*. Air movement between the courses of lumber was uniform. The dried lumber is flat and the stickers are straight.

Miscut Lumber.—Lumber that is miscut is likely to vary considerably in thickness across the width and along the length of the piece. Miscut lumber is not only difficult to stack, it is impossible to hold the thinner part of the boards flat. The thicker parts dry more slowly and may develop more defects. Some plants find it economical to skip-dress such stock to a uniform thickness before stacking.

Sorting for Length

For good stacking, one of the best and easiest methods is to pile lumber of a single length on kiln trucks (fig. 70, *B*) or in packages. If the stickers are well supported and in good alinement, such stacking results in flatter and straighter kiln-dried stock. Overhanging ends of the longer boards in a truckload of mixed-length stock are likely to warp during drying.

Stacking lumber of uniform length on a kiln truck or in packages is a common practice among producers of softwoods, and some of the larger manufacturers follow the same practice with hardwoods. Most of the hardwood producers, however, either box-pile the lumber or stack various segregated lengths on a kiln truck, using the "step-back" or "step-out" method. Figure 71 illustrates a combination of step-back and step-out stacking. Step-back stacking generally results in less deformation of the lumber.



M-75793-F

FIGURE 71.—Scale model showing "step-back" stacking in lower part of load and "step-out" stacking in upper part. Courses of thick dunnage, located as shown, will minimize warp. Sample pockets and kiln samples are shown.

Courses of thick dunnage put a solid "floor" under each of the upper sections of the load and thereby help prevent warping (fig. 71).

Stickering the Lumber

Proper selection and use of stickers greatly reduces warp in lumber and assures fast and uniform drying, and it reduces sticker breakage and deformation. Among important considerations of stickering are the size of the stickers and their placement in the pile, the species and grades of wood used, and sticker supports, guides, and racks.

Sticker Material

Many stickers are required in a kiln-drying operation, and replacement is costly. Practical measures for obtaining long sticker life therefore pay off. Many plants find it worthwhile to make stickers from clear, straight-grained stock rather than from low-grade stock. The initial cost of such stickers may be higher, but their longer service life generally offsets this. Straight-grained stickers made from the harder woods stay straighter and last longer than irregular-grained stickers made from softer woods.

Species such as hickory, hard maple, beech, oak, Douglas-fir, and larch make good stickers. Usually, however, the species being dried at the plant are used for stickers.

Moisture Content of Stickers

The lumber from which stickers are made should be kiln-dried. There is less chance of sticker stain, which is a discoloration of the material where it contacts the sticker during drying. In addition, stickers made from kiln-dried lumber will distort and change thickness less during use.

Sticker Size

The sizes of stickers vary considerably, from 1/4 inch to 2 inches in thickness and from 3/4 inch to 4 inches or more in width. The usual range is from 3/4 inch to 1 1/4 inches in thickness and from 1 to 2 inches in width. Sticker length is governed by the width of the load or package, thickness and width by the kind and size of lumber being dried.

Sticker Width.—Wide stickers slow up the drying of lumber at areas of contact, and may leave it at a higher final moisture content in these areas. Stickers used for hardwoods are usually 1 1/4 inches in width and should not exceed 1 1/2 inches. Stickers for softwoods average about 2 inches in width, but widths up to 4 inches may be used for the softer species, such as sugar, ponderosa, and white pine.

Sticker Thickness.—Stickers used for lumber and dimension are generally 3/4 to 1 inch thick. Some plants, however, use stickers as thin as 1/2 inch. The thinner stickers make it possible to load more lumber on a kiln truck and, in forced-circulation kilns, make air velocity faster and more uniform across the loads. They break and deform more readily, however, and sagging boards are more likely to obstruct air movement. Regardless of the thickness used, all stickers in a kiln charge should be surfaced to uniform thickness.

Load Supports

Unless the load of lumber is properly supported, sagging and distortion in the lower courses will result (fig. 72, *A*). Lumber piled as in figure 72, *B*, will not sag because the load supports are directly under the tiers of stickers.

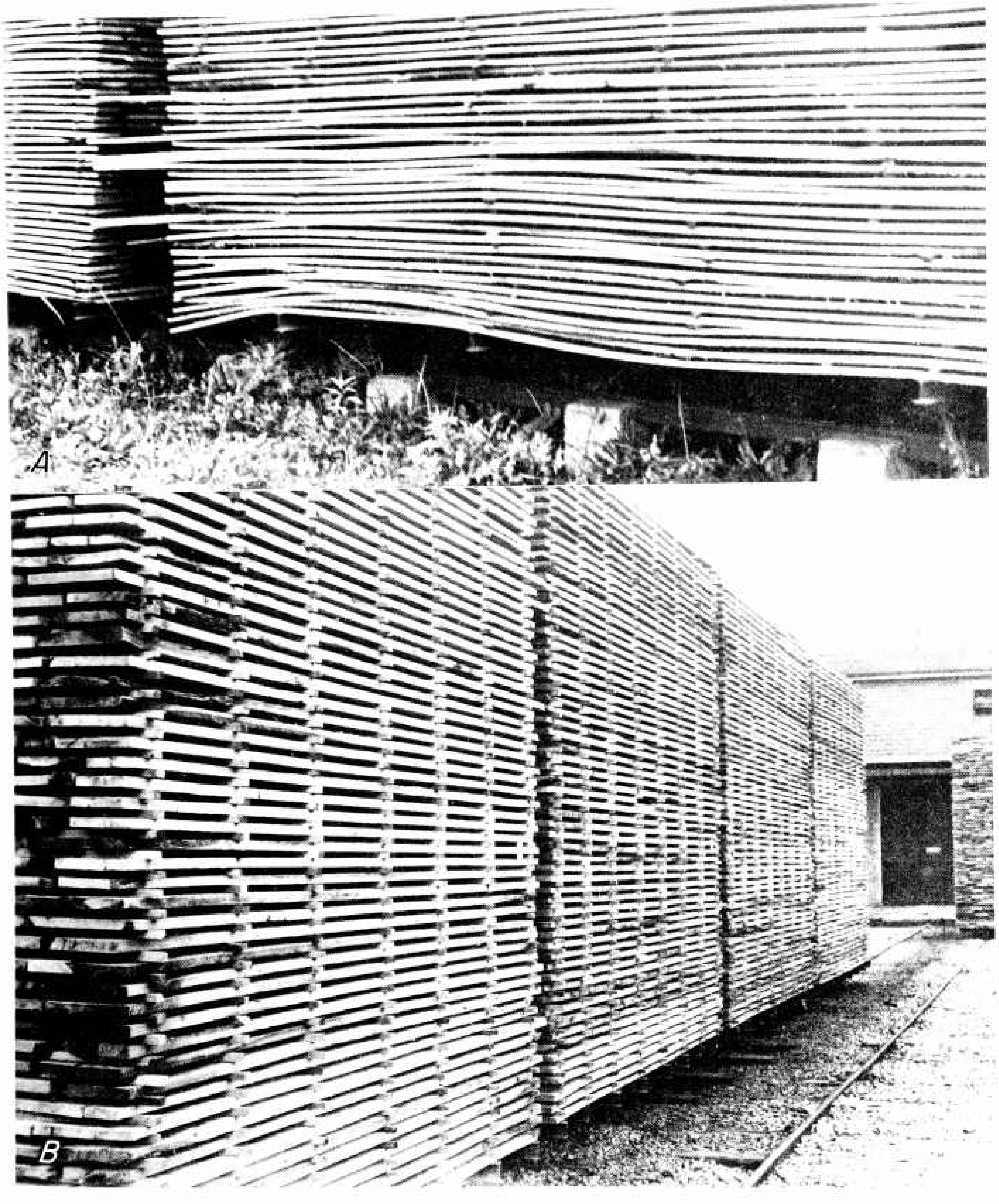
The thinner the material being dried, the greater the number of load supports required. Sometimes a bottom course of thick dunnage is used instead of additional supports. Generally, the maximum spacing of load supports for 1-inch hardwood lumber is about 2 feet and for 1-inch softwood lumber about 4 feet. In thicker lumber the distance between load supports usually can be increased, but it is better to use too many load supports than too few.

Sticker Location, Spacing, and Alinement

Good location, spacing, and alinement of stickers reduces warping and minimizes end checking and splitting in some species of lumber.

Location of Stickers.—If possible, place the end stickers flush with the ends of the boards (fig. 71). Warping of the ends of the boards will be reduced and also end drying will be retarded to some extent, thus helping to minimize end checking and splitting. Other tiers of stickers should be close enough to control warping.

Spacing of Stickers.—Sticker spacing is governed by the stock's tendency to warp, its thickness, and its resistance to crushing. A spacing of 3 to 4 feet is satisfactory for softwoods. A 2-foot spacing is satisfactory for most 4/4 hardwood stock, but some species, such as sweetgum and the elms, require closer spacing, as little as 15 inches, to prevent warping. Sticker all hardwood stock less than 1 inch thick with this closer spacing. Softer hardwoods, such as aspen and basswood, may require closer than 2-foot spacing to prevent crushing of the stock. Also, to avoid crushing of stickers between the bottom courses of heavy loads, the sticker spacing may need to be reduced.



M–115545, M–115696–F

FIGURE 72.—*A*, An insufficient number of load supports, improperly placed, caused this truckload of hardwood lumber to sag badly. *B*, Good load supports on truckload of hardwood lumber.

Sticker Bridging.—When cross supports cannot be located under each tier of stickers, the weight carried by the unsupported tier can be distributed to some extent to adjacent cross supports by bridging. Bridging is an A arrangement of extra stickers starting at the supported tiers of stickers at the bottom of the load, extending progressively inward and upward until they intersect the tier of unsupported stickers. The inward offset of the bridging stickers at each successive course of lumber should be no greater than the width of the stickers.

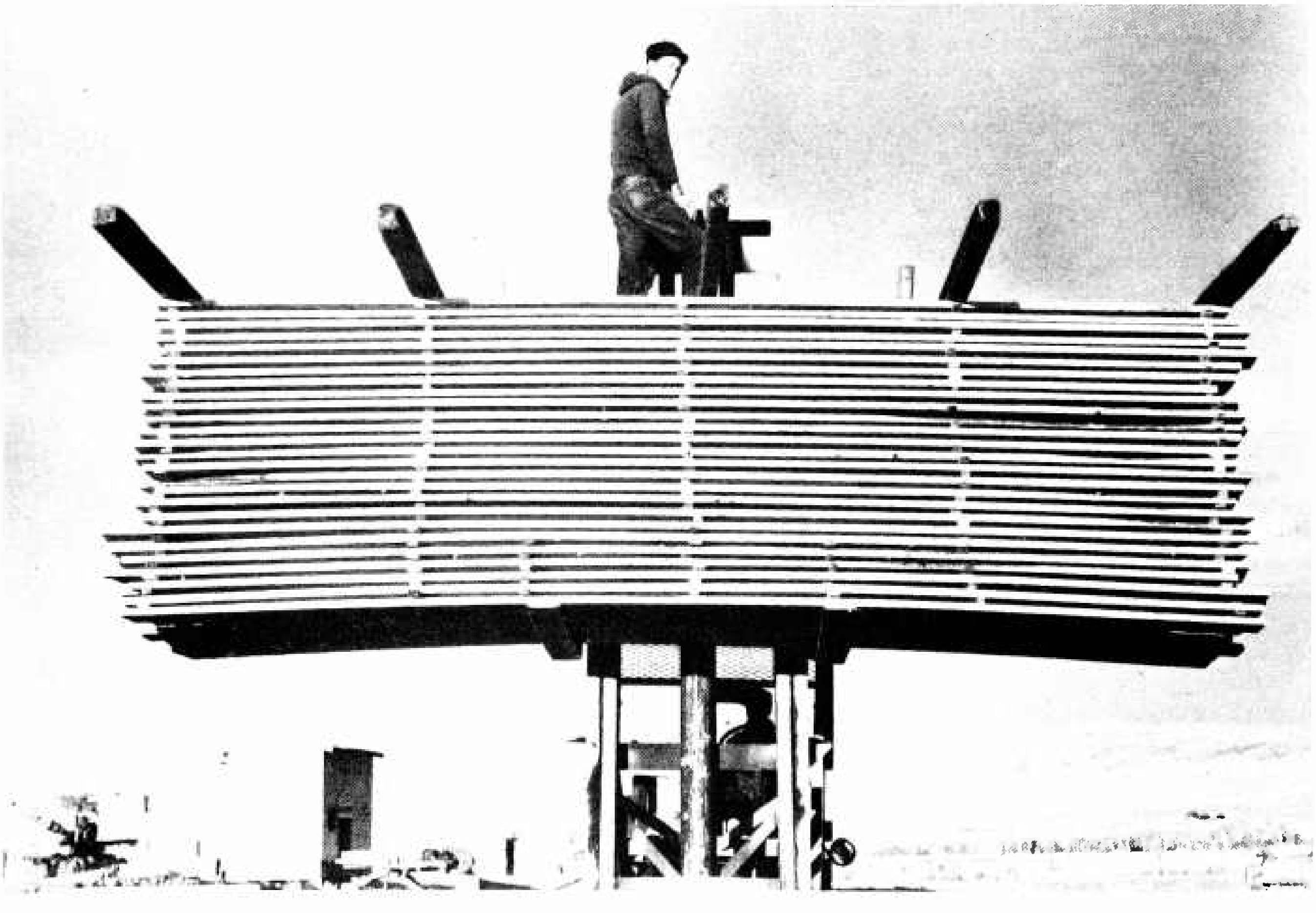
Alinement of Stickers.—For fullest control of warp in lumber during drying, the tiers of stickers should be alined vertically. (Figs. 71 and 72, *B*). Misalined stickers (fig. 72, *A*), particularly in stacks of green lumber, invariably cause nonuniform distribution of weight and result in sharp kinks in the lumber where the stickers contact it. The thinner the lumber, the greater the possibility of kinking. Much waste results from incorrectly alined stickers, particularly in lumber 1 inch or less in thickness.

Auxiliary Tiers of Stickers in Packages of Lumber.—Packages of lumber are commonly transported around dry kilns with forklift trucks and straddle carriers. When lifted by this kind of equipment, lumber in the lower courses of a package has a tendency to sag and stickers at the ends may be lost. This trouble can be largely avoided by locating short tiers of stickers above the forks (fig. 73) or the carrier bunks. The number of stickers needed in these extra tiers depends upon the thickness of the lumber and the weight of the package. Usually stickers are interlaid between the bottom 6 to 10 courses of lumber.

Sticker Guides

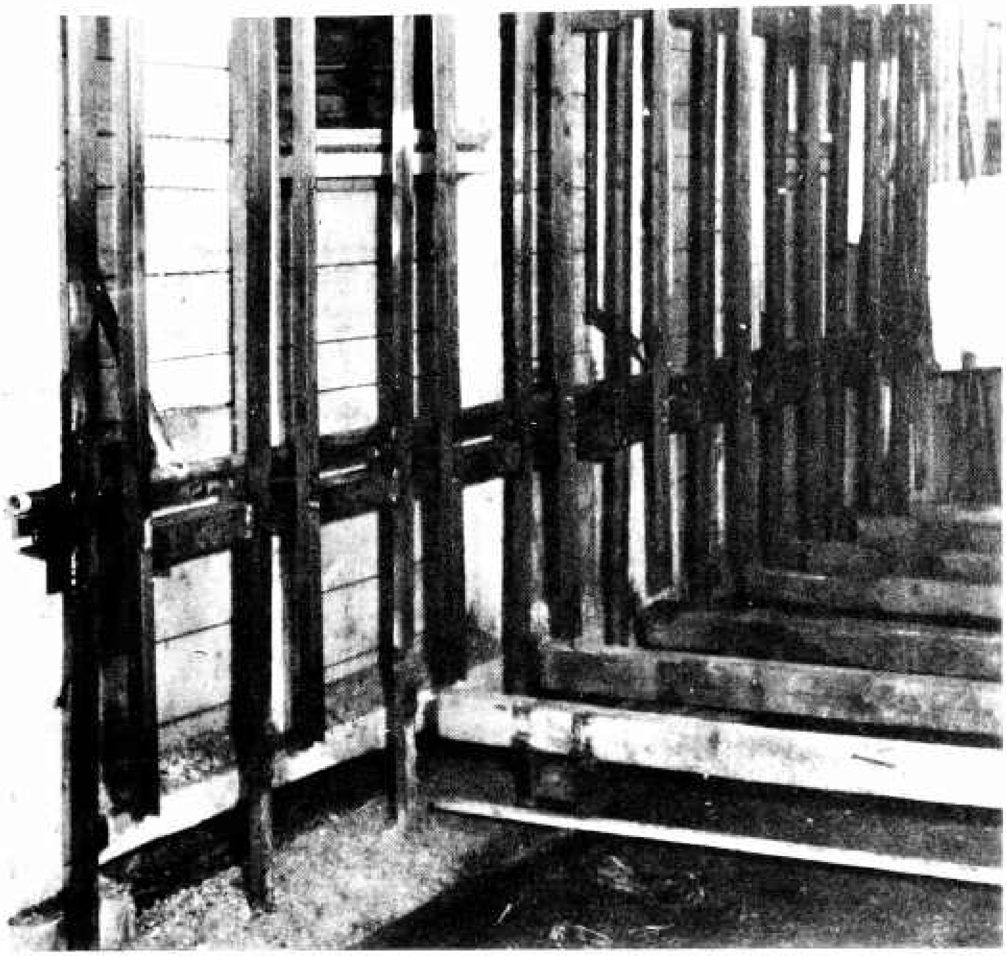
The use of sticker guides insures good spacing and alinement.

Sticker guides vary considerably in design and initial cost. Two types of guides are shown in figures 74 and 75. These guides are pivoted on both sides so that they can be pulled free of



M–115553–F

FIGURE 73.—Package of lumber raised by forklift truck. Short tiers of stickers above point of contact with forks reduce sag in the lower courses of lumber and help prevent dislodging of end stickers.



M–115546–F

FIGURE 74.—Combination metal and wood sticker guide for stacking lumber on kiln trucks.

the stacked loads of lumber. A simple locking device holds the guides in place while the lumber is stacked. Vertical channel irons or wood strips equal in length to the height of the load are positioned along each guide at points corresponding to the desired sticker spacings. The stickers, cut about 2 inches longer than the desired width of the load, are held in place by the guide channels or strips. Sticker racks located adjacent to, or attached to, the guide hold a supply of stickers.

A sticker guide of another design is shown in figure 76. This guide consists of a rectangular frame made of 2- by 12-inch lumber attached by means of sleeves to vertical pipes. Cleats nailed on the inside of the frame hold the stickers in place. The frame is lifted when required by means of a small electrically operated hoist attached to the ceiling of the stacking shed. When a load is completed, the frame is lifted clear of the top courses of lumber. The load is moved out of the stacking shed and empty kiln trucks put in its place. The frame is lowered over the empty truck, and the stacking of a new load is started. A supply of stickers can be kept on each side of the stacking area. Boards too long for the frame are trimmed off with a portable powersaw.

Portable sticker guides for stacking packages of lumber are shown in figure 77. Guides like these are used on one side of the package only.

Care of Stickers

Large plants invest considerable money in sticker-handling equipment, such as conveyors of various types, to reduce handling costs. This equipment, if properly designed, may also reduce sticker breakage. Smaller plants can construct racks or other devices, at fairly low cost, that will reduce sticker losses and possibly handling costs. A metal-roofed sticker rack mounted on kiln trucks is shown in figure 78. This arrange-

M–91974–F

FIGURE 75.—All wood sticker guide device for stacking lumber on kiln trucks.

ment protects the stickers to some extent from the rain and sun and facilitates stacking and unstacking.

There are many other types of low-cost sticker racks that will reduce sticker losses and handling costs. For example, a simple rack can be constructed on a pallet and carried around the plant by forklift truck or straddle carrier.

Stickers should be stored under cover to keep them reasonably dry and free of stain and decay.

Mechanical Stacking and Unstacking Equipment

Many plants use semiautomatic and automatic equipment for the stacking and unstacking of lumber. Properly designed equipment will serve well if correctly operated. Several types of lumber stackers and unstackers are available.

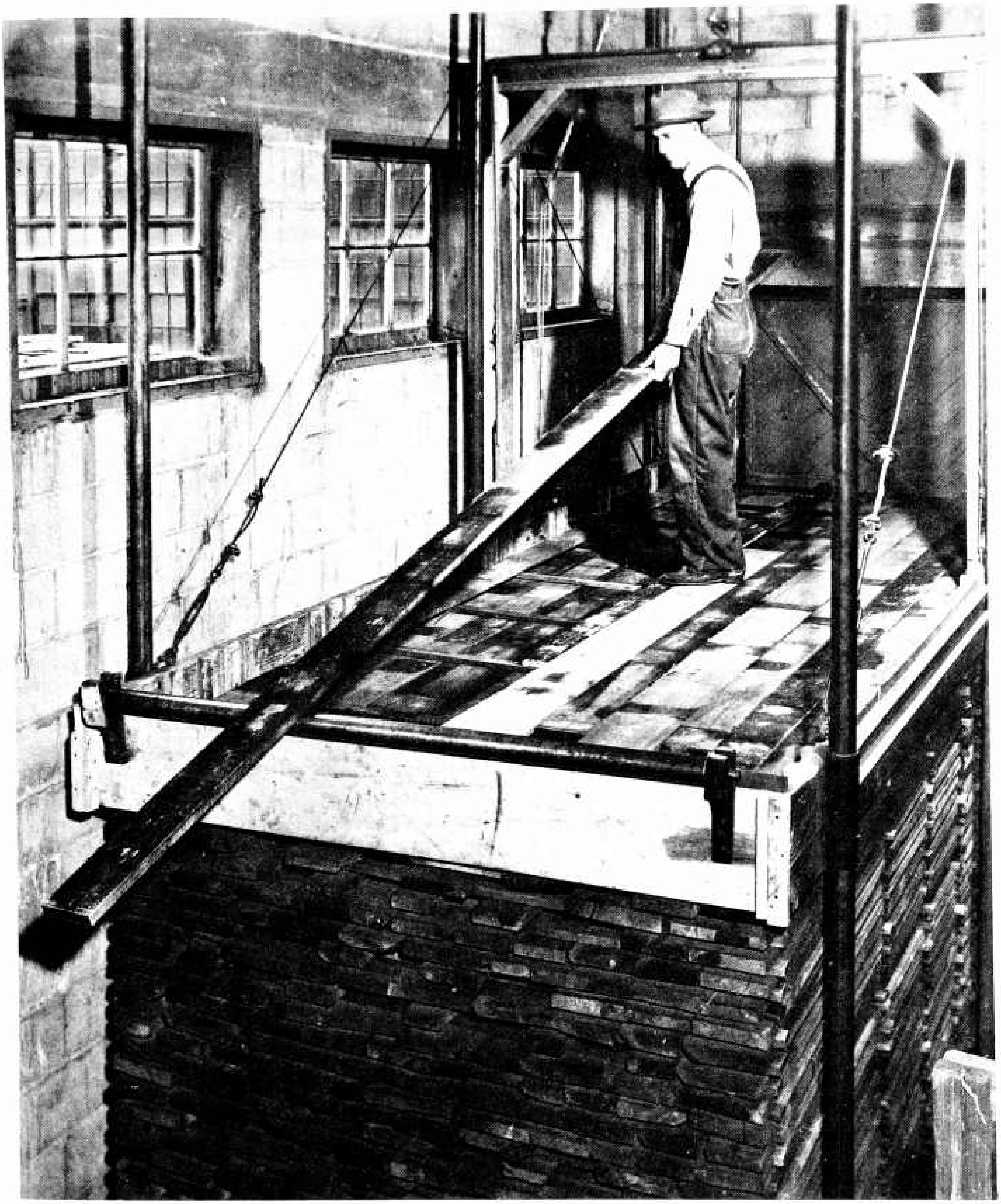
Mechanical Stackers

With one type of semiautomatic stacker for lumber of uniform length, a solid package of lumber is placed on a tilting breakdown hoist, from which the lumber slides onto a horizontal table equipped with chain conveyors where the courses are assembled. The kiln trucks are placed on a hydraulic lift controlled by the stackerman, and elevated to the desired height; the conveyor is started, and a course of lumber is moved onto the truck. The hydraulic lift is lowered a distance equal to the thickness of the boards, stickers are placed in stationary guides located on each side of the lift, and another course of lumber is moved into position.

Sticker magazines are used in conjunction with automatic stackers. A set of these magazines is located over the load of lumber. One end of a sticker is automatically dropped from each magazine onto the load. The other end of the sticker is forced from the magazine by the weight of the next course of lumber as it is moved onto the load.

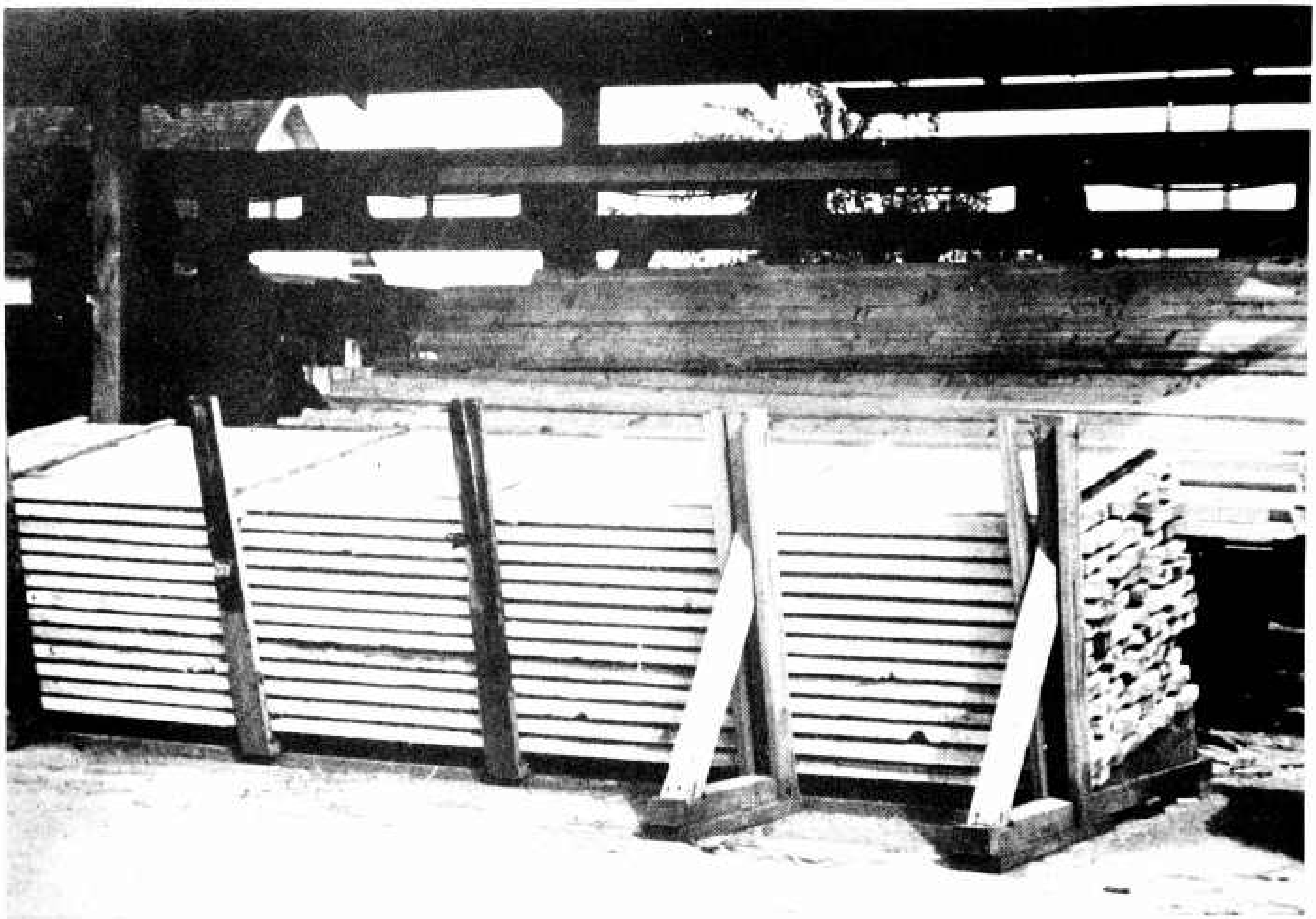
Lumber Unstackers

With one type of lumber unstacker in common use, the load of dried lumber is placed on a tilting hydraulic lift. The lift is raised and tilted, and the topmost course of lumber moves by gravity to the dry chain. The stickers slide down a ramp to a sticker bin or conveyor. The lift is then raised to the next course of lumber and the cycle repeated.



M–87927–F

FIGURE 76.—Box frame sticker guide of 2- by 12-inch lumber can be raised or lowered by means of a small, electrically operated hoist attached to metal beam shown directly above head of workman. Frame insures good side and end alinement of the load.



M-115541-F

FIGURE 77.—Portable sticker guide for stacking packages of lumber.

Box Piling Random-Length Lumber

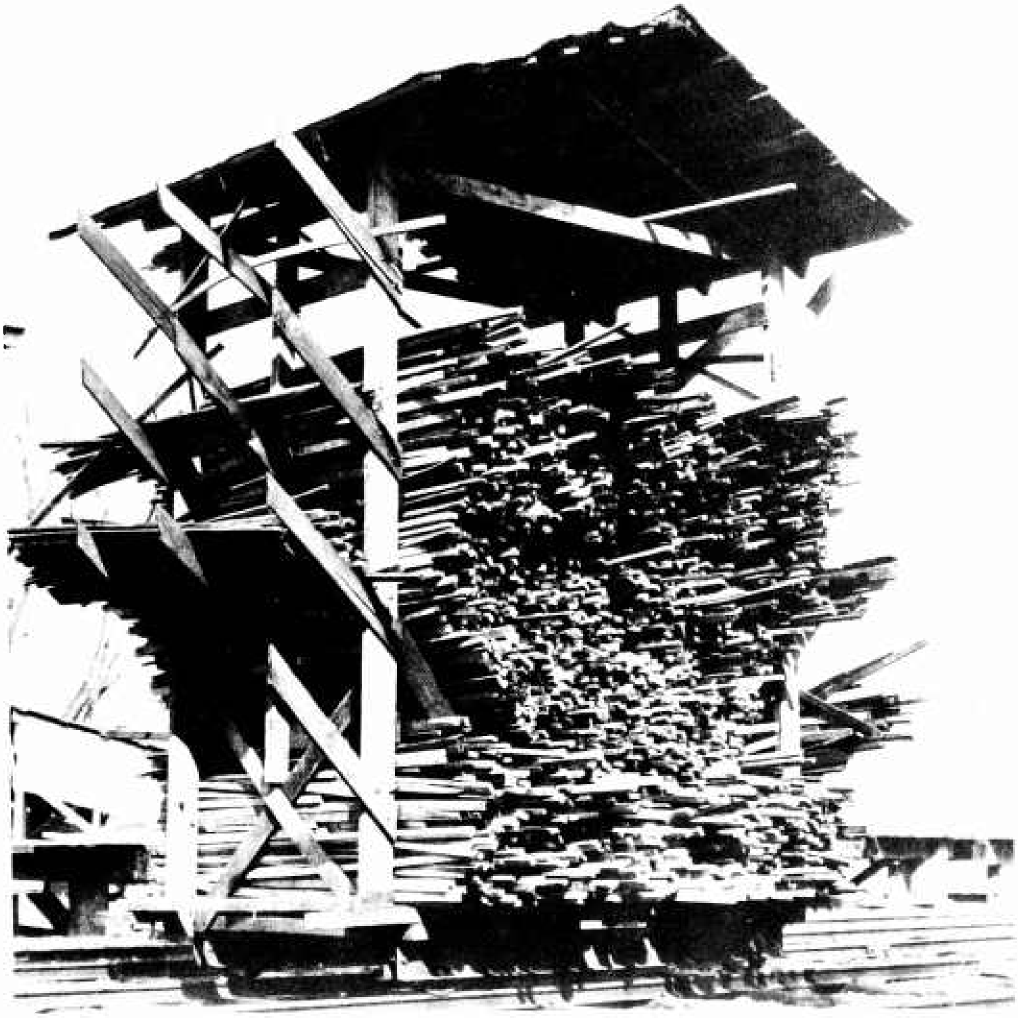
At many plants, particularly those drying hardwoods, segregation for length is not practical. The box-piling method of stacking is recommended for these plants. Random-length lumber that is box piled will dry straighter, flatter, and more uniformly, and sticker losses will be minimized.

Three methods of box piling are in general use. For purposes of description they are termed methods I, II, and III.

Method I

In box piling by method I, the length of the outside boards in each course is equal to the full length of the pile. Thus, in figure 79, boards Nos. 1 and 7 in all courses are as long as the pile. Other full-length boards, when available, are usually placed near the center of the courses, such as boards 4 in courses A and B of figure 79. The shorter boards in the same course are alternately placed with one end even with one end of the load or the other. The shorter boards in all courses in the same tier of boards are all placed with one end even with the same end of the load. For example, in figure 79 all the even-numbered short boards, with the exception of board 6, course D, are placed even with the front end and all odd-numbered boards even with the rear end of the load. Occasionally two narrow, short boards, such as boards 5 and 6 of course D, are placed over a wider board, such as board 5 of course C. Also, two or more short boards can sometimes be laid end to end in the same tier of lumber. For example, 6- and 8-foot boards could be laid end to end in a load of lumber 14 to 16 feet long.

The column effect obtained insures that all boards are well supported and held down, and warp, particularly cup and bow, is thereby lessened, along with sticker deformation and break-



M–91975–F

FIGURE 78.—Rack for transporting stickers on a kiln truck.

age. The unsupported ends of the short boards within the load may warp to some extent.

If enough full-length boards are not available for placement on the sides of the load in occasional courses, shorter boards, laid end to end if short enough, can be used. When this is done, place filler blocks in any gaps between the stickers above and below the course of lumber, particularly when the gaps occur at the ends of the load (fig. 80). These blocks will keep the ends and sides of the loads from sagging and will also reduce sticker breakage. The blocks should be of the same thickness as the lumber being dried.

Method II

Method II box piling, as illustrated in figure 81, is used for random-width lumber. This method of piling prevents the building of definitely vertical tiers, except the outer ones. The short boards in the interior of each course are alternately placed at opposite ends of the load as by method I; this results in some stickers and board ends being unsupported. In such cases, the restraint exerted by the stickers is not sufficient to prevent warping of the lumber. Also, stickers may deform and break.

Method III

In method III box piling of lumber of random length and width, the length of the outside boards in each course is equal to the length of the load or package. All of the shorter boards are laid with one end even with the same end of the load. Whenever possible, however, two or more short boards together equaling the length of the load

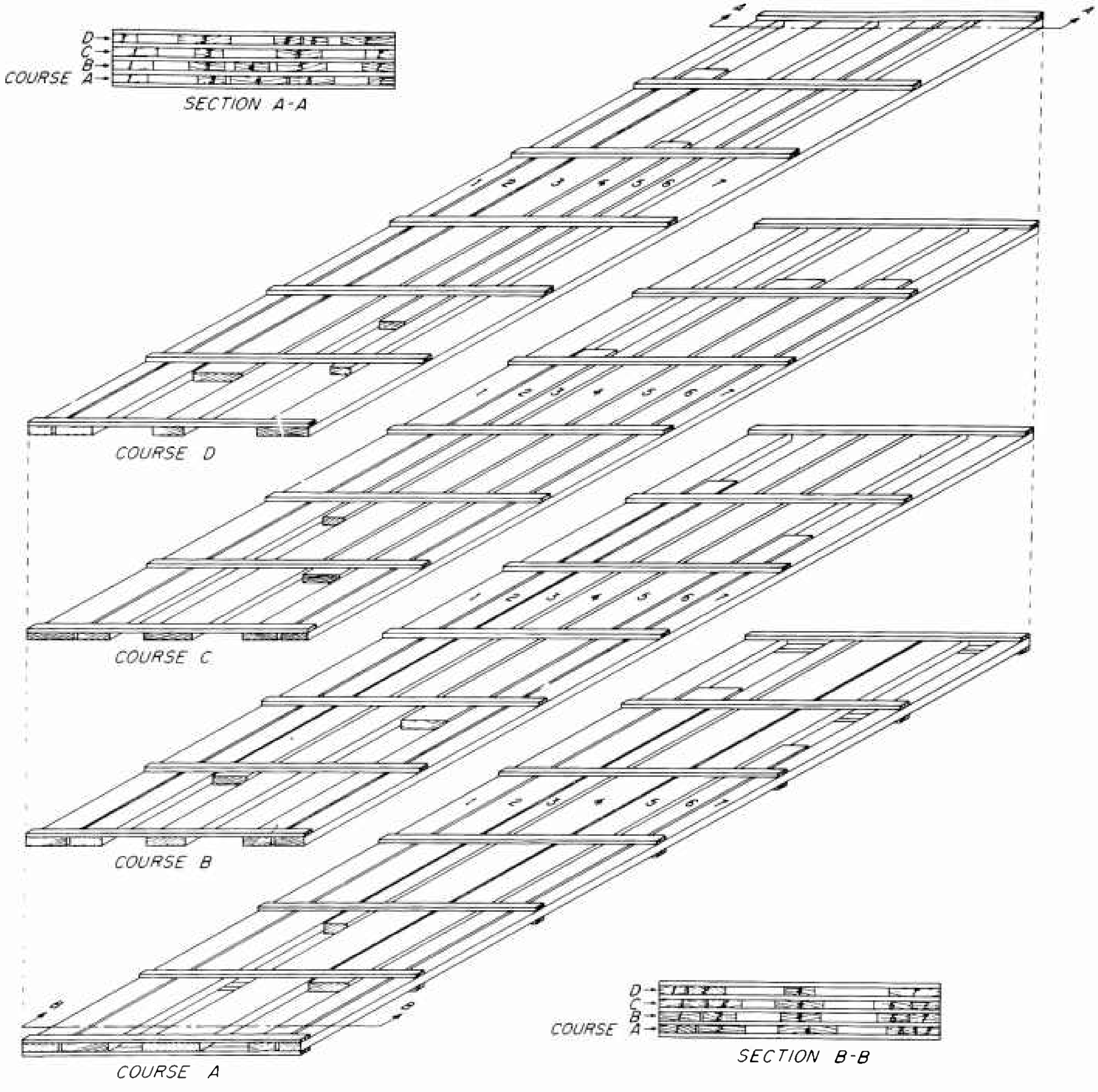
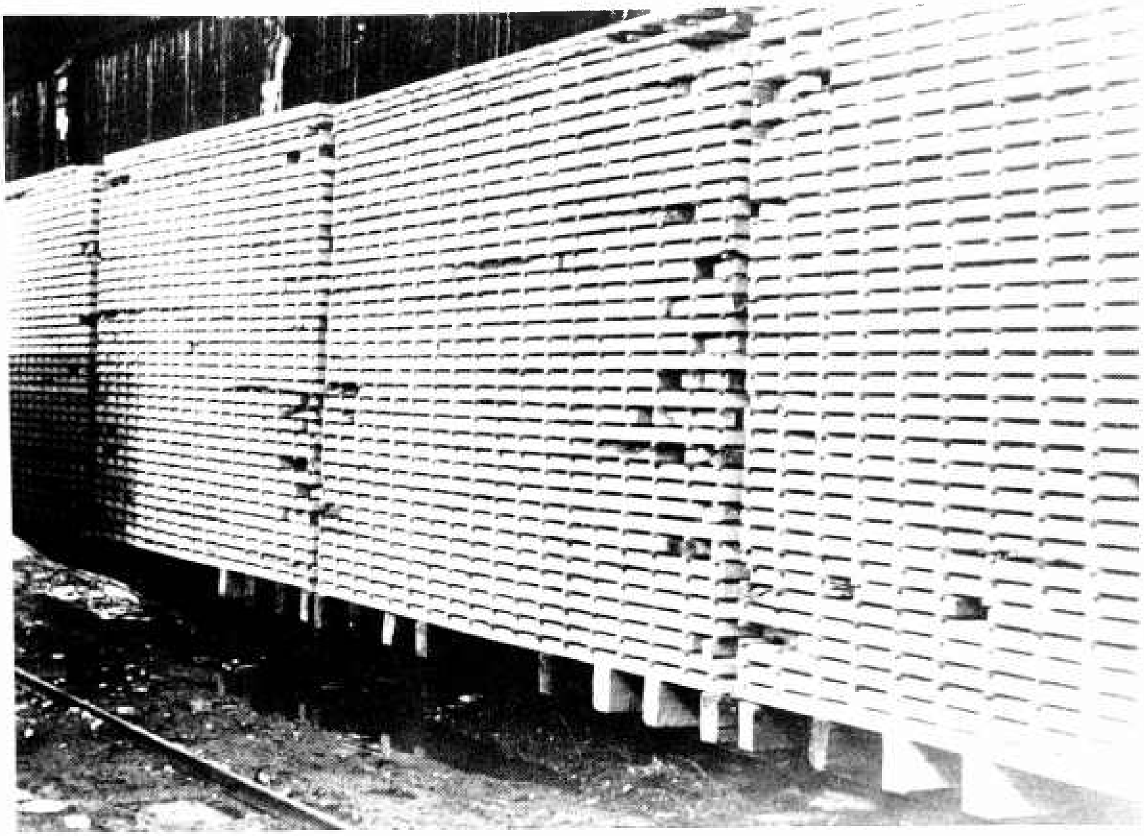


FIGURE 79.—Method I box piling for random-length lumber.



M–115543–F

FIGURE 80.—Box-piled loads with short boards on the outside and blocks between unsupported stickers.

M–115555–F

FIGURE 81.—Method II box piling, used for lumber of random length and width.

are laid end to end. This method of stacking results in large empty spaces at one end of the load. Because of these spaces, lumber warping and sticker damage may be heavy. Lumber at that end of the load may dry too fast and increase surface and end checking.

Stacking Lumber for Various Types of Dry Kilns

Stacking procedures must conform to the type of kiln used, especially its air-circulation system. The direction of airflow—whether up, down, across, or lengthwise through the load—must be considered.[2] Uniform drying depends on uniform air movement through the loads, for which correct stacking is essential.

Stacking for Natural-Circulation Kilns

The principal direction of airflow through the loads of material being dried in a natural-circulation kiln is vertical, mostly downward. Air velocity is low, usually 15 to 25 feet per minute. The vertical movement of air through the loads is obtained by building flues in the piles (fig. 8, p. 24). Usually, these flues are 3 to 5 inches wide and are spaced about 18 to 24 inches apart. The sides of the flues need not be perfectly alined vertically, since boards projecting into the flues will not deflect the slowly moving air to a great extent. The flues, however, must be open from the bottom to the top of the load.

Stacking Lumber.—One frequently used method of stacking lumber for natural-circulation kilns (fig. 82) has a large central flue; in addition, all boards in each course are spaced 1 inch or more apart. The flue is generally 8 to 12 inches wide and need not be tapered; the top is left open.

Stacking Special Items.—Special items such as furniture squares, gunstock blanks, barrel staves, and other short-length stock must be piled with special care to permit adequate circulation of air around the pieces for uniform drying. The shape and size of the item often dictates how it must be piled. Following are a few suggestions and cautions.

1. In any load, be sure to include vertical flue.
2. Space the pieces in any course so that air can circulate between them.
3. Keep area of contact between pieces in adjacent courses as small as possible, thereby improving the chance of uniform drying.
4. Don't pile as much stock as possible on the kiln truck at the sacrifice of adequate air circulation; this merely prolongs kiln-drying time and invites nonuniform drying.

Two ideas for piling special items are shown in figures 83 and 84. Figure 83 shows a kiln truckload of barrel staves piled on edge. Unless too loosely piled, the pieces will stay reasonably upright, allowing air to circulate among them. Figure 84 shows a method of stacking short-length material, such as barrelhead stock, that works reasonably well provided the pieces do not overlap more than 2 inches.

Stacking for Forced-Circulation Kilns

The air-circulation systems in forced-circulation kilns may move the air vertically, transversely, or longitudinally through the material being dried. Therefore, the method of stacking the material depends on the direction of airflow. Because of the higher air velocities produced in these kilns, boards projecting from the sides of the loads can act as scoops and should be avoided.

External-Blower Kilns.—In some external-blower kilns, the air is blown upward through the loads (figs. 9 and 10, pp. 25, 26) and A flues are therefore required (fig. 85). This flue is usually 12 to 14 inches wide at the bottom and should taper to about 1 to 2 inches at the top. If boards project into the flue, air will not circulate evenly and drying will be nonuniform throughout the load. To avoid this, two A-shaped forms, one at each end of the load, are used as guides. The edges of boards adjacent to the flue are laid snugly against these forms, thereby giving uniform taper to the flue from bottom to top. To prevent air from short circuiting over the top of the load, the top of the flue is covered with a course of plywood or dunnage.

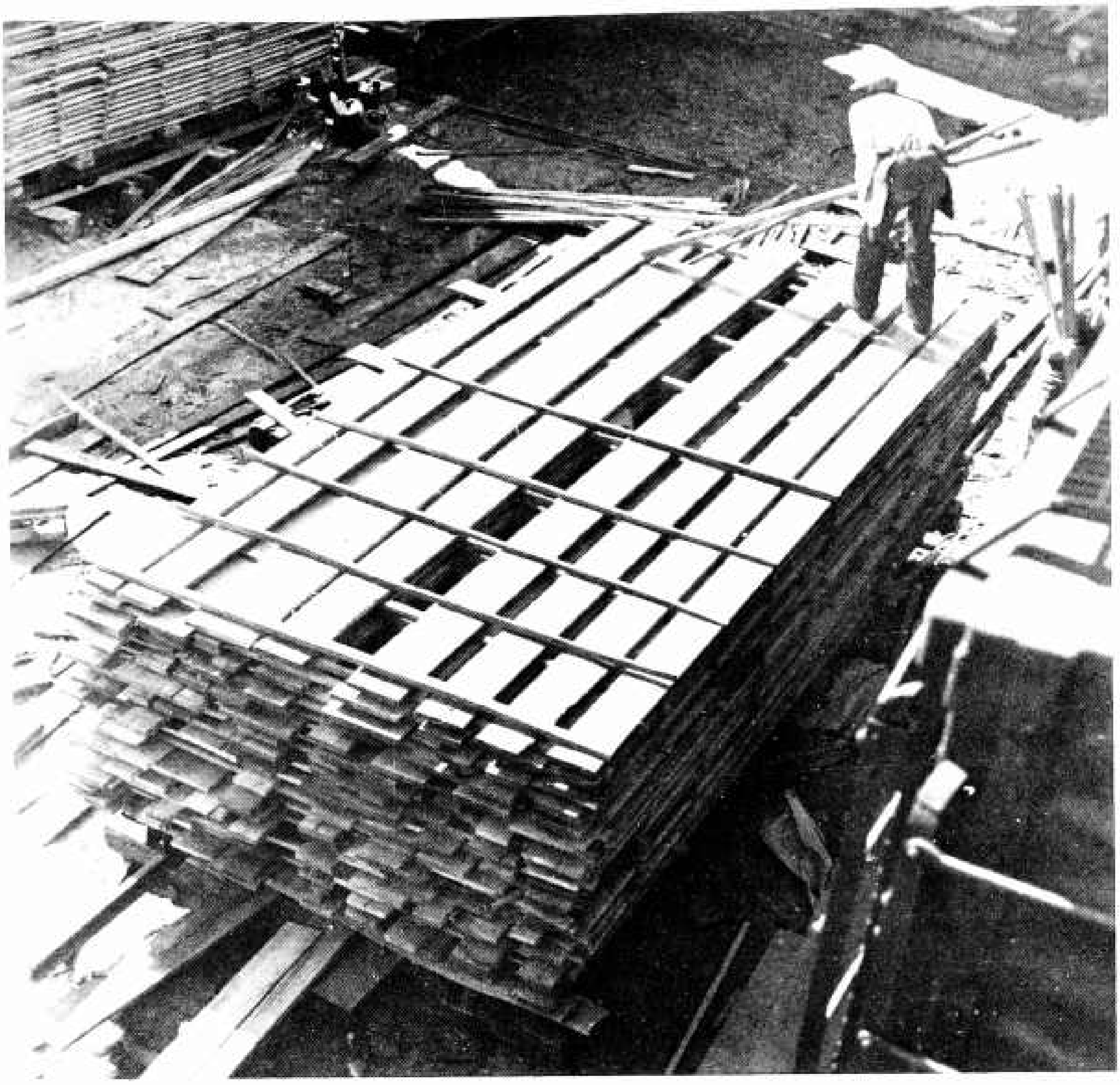
Internal-Fan Kilns.—The fans in some kilns are located below the loads and blow the air upward through the vertically stacked lumber (fig. 86). Tension springs on the chain ties attached to the bottom and top of the vertical beams take up slack as the lumber shrinks, thereby preventing load distortion and holding stickers in place.

In cross-piled, internal-fan kilns, the air moves from end to end of the loads, perpendicular to the stickers. A space of at least 1½ inches must therefore be left between the edges of all boards in each course (fig. 13, p. 29). If these spaces are not provided, the air cannot move through the loads.

The movement of air through end-piled kilns with fans located above or below the loads is across the loads and parallel with the stickers (figs. 14 and 17). In these kilns, the edges of

---

[2] TORGESON, O. W. EFFECT OF PILING METHODS ON AIR CIRCULATION IN A LUMBER DRY KILN. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1653, 5 pp. [Processed.] 1950.



M–115554–F

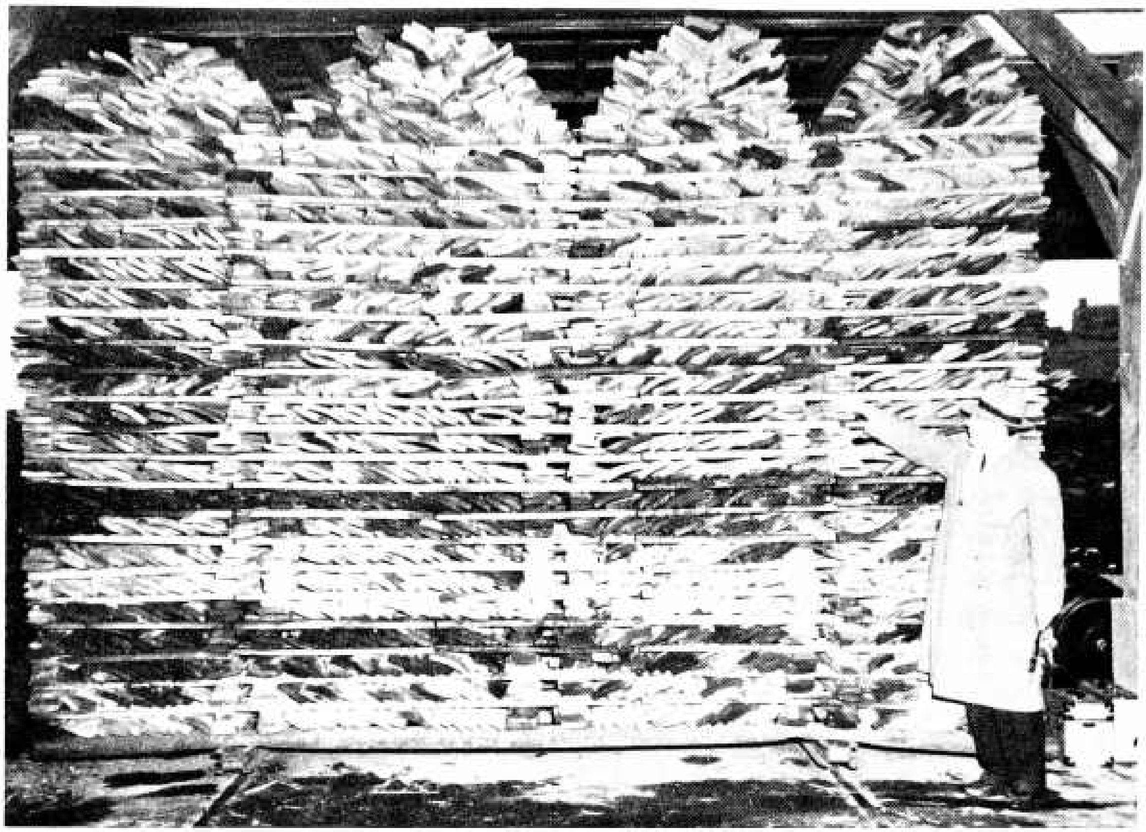
FIGURE 82.—Lumber being stacked for drying in a natural-circulation kiln. The large central flue allows free vertical circulation of air.

any boards projecting beyond the side of the load into the plenum chamber (the space between the side of the load and the kiln wall) will act as air scoops and uniform air circulation across the loads will not be obtained. Also, overhanging ends of boards at the ends of the loads should be avoided. The openings left between such loads when they are placed end to end in the kilns permit large amounts of air to short circuit through them. In loads stacked for transverse circulation, boards can be placed edge to edge in each course. A load of softwood lumber stacked for kilns of this type is shown in figure 70, *B*, p. 80.

Stacking of special items for drying in internal-fan kilns is illustrated in figures 87, 88, 89, and 90.

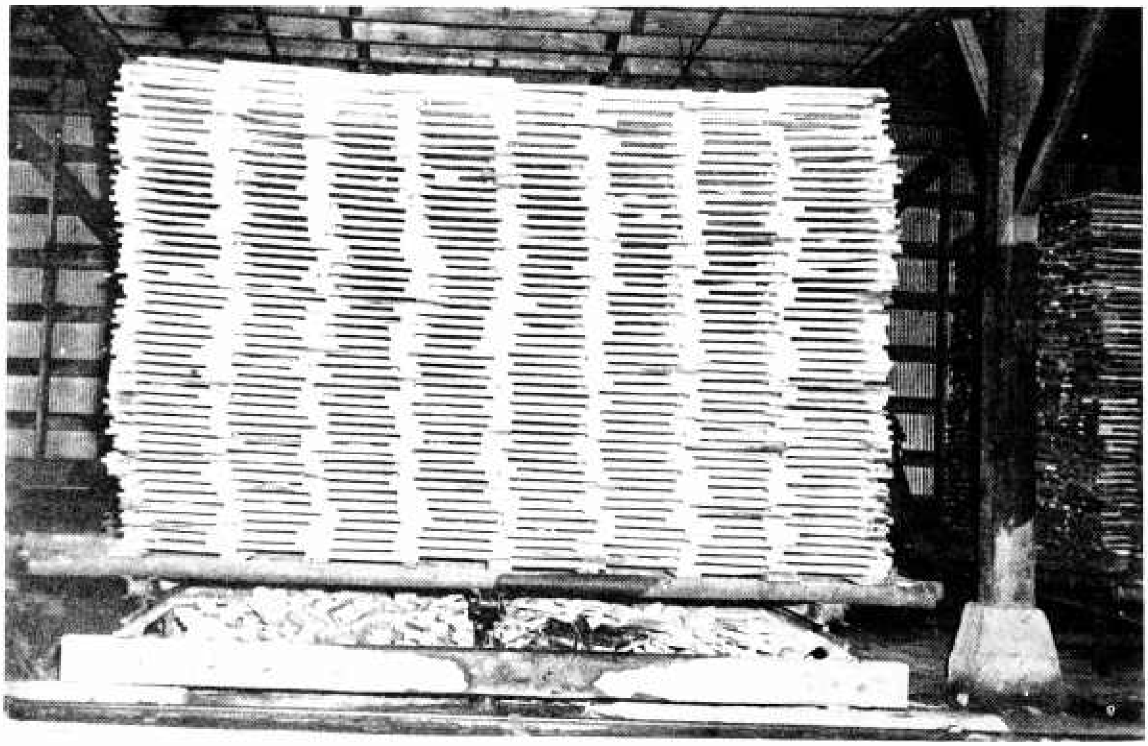
Multiple-Course Stacking of Lumber

It is poor practice to stack loads of lumber with two layers of boards laid face to face in a course. The boards in contact with each other will dry more slowly and will be more susceptible to stain and warping then if in single courses. When stacking miscut lumber, place the thicker boards on the outer edges of the load; this will avoid the need for doubling up boards on the



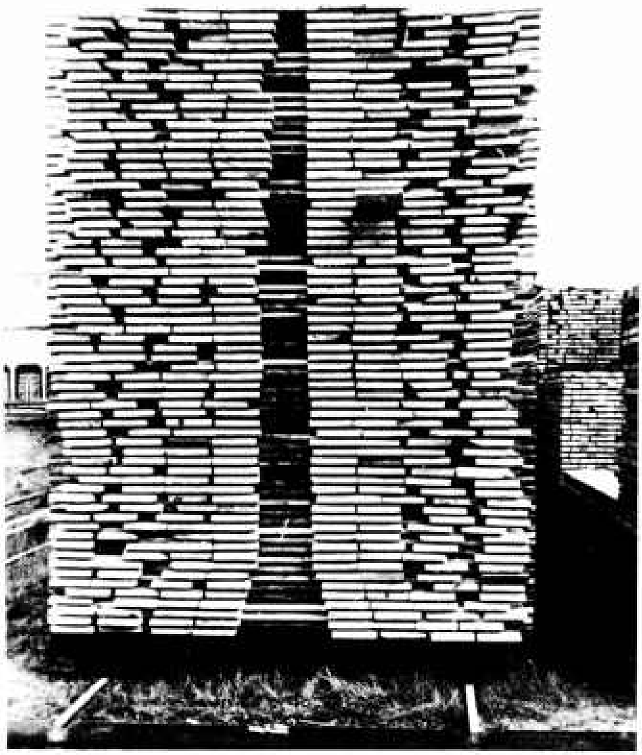
M–98547–F

FIGURE 83.—Kiln truckload of staves stacked for a natural-circulation kiln. The small size of the vertical flues (note hand) and the topping of the load reduce circulation and extend drying time.



M–115550–F

FIGURE 84.—Barrelheading stacked for a natural-circulation kiln. This load was built with adequately sized flues, but the rather large overlap could slow the drying of the ends.

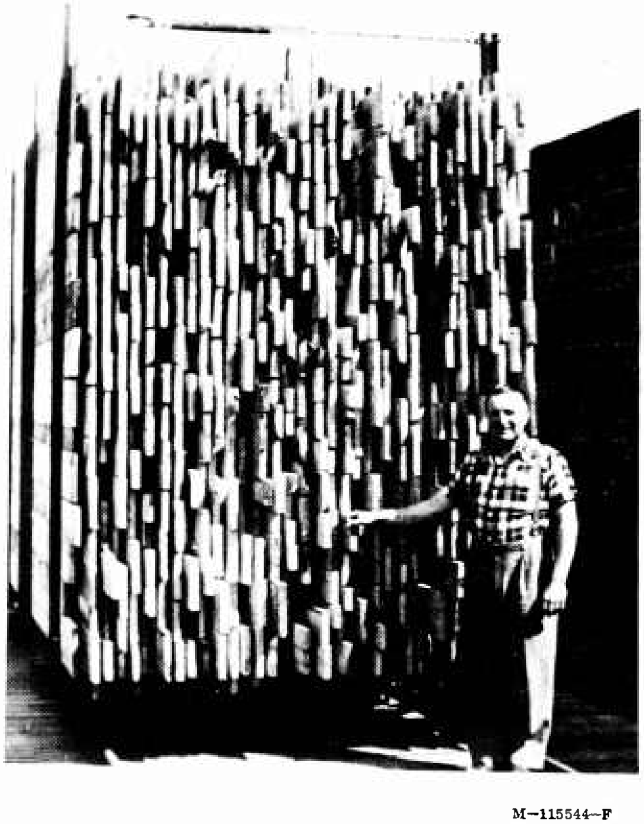


M–115548–F

FIGURE 85.—Lumber stacked with an A flue for an external-blower type kiln.

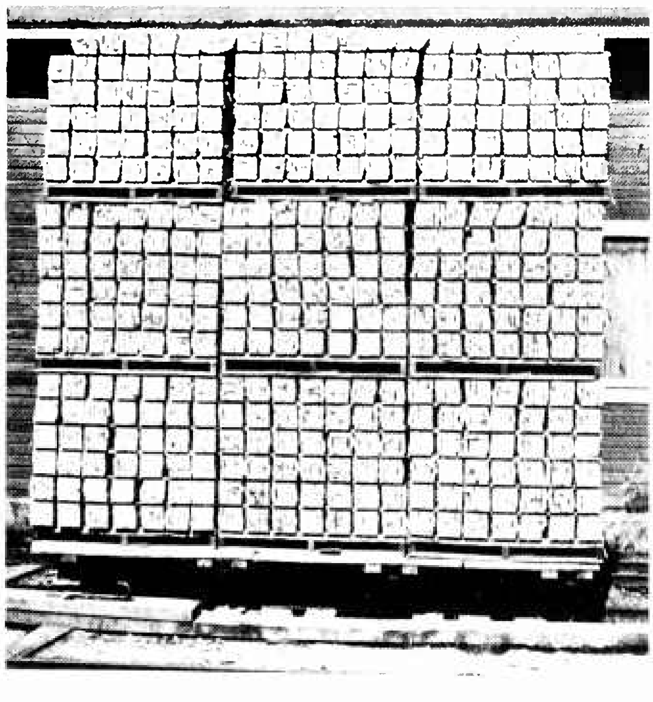
M–115551–F

FIGURE 87.—Good stacking of hardwood squares on kiln trucks for drying in an end-piled dry kiln with forced transverse circulation.



M–115544–F

FIGURE 86.—Vertically stacked lumber for internal-fan kilns with vertical air circulation.



M–115556–F

FIGURE 88.—Bundles of softwood squares stacked on pallets and placed on kiln trucks for drying in an end-piled kiln with forced transverse circulation.

M–115547–F

FIGURE 89.—Barrel staves stacked for drying in an end-piled kiln with forced transverse circulation.

outer edges to prevent crowning of the load. If additional cross support is required at the bottom of the load to prevent sagging of the lumber, a course of dry 2- or 3-inch material is preferable to a multiple course of the unseasoned lumber being stacked.

Kiln Sample Pockets

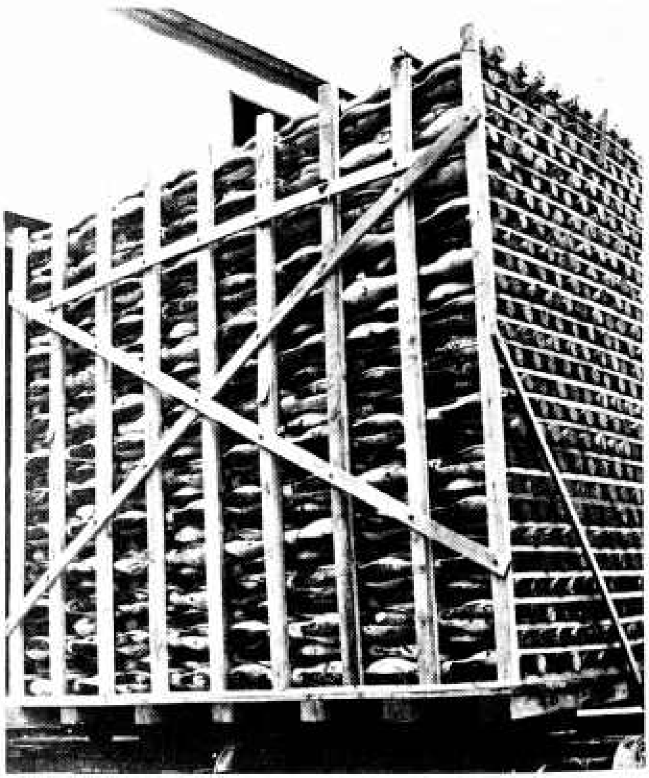
Kiln samples are placed in pockets built into the loads or packages of lumber at the time of stacking (fig. 91). The stackermen should be told where to provide sample pockets in the load (page 103). Since the kiln samples are usually longer than the space between tiers of stickers, the sticker or stickers immediately above the sample should be shortened the width of the sample. Otherwise these stickers will bear on the sample and make it difficult or impossible to remove for periodic weighing and examination, especially if the sample cups.

Cover Boards on Loads Stacked for Kiln-Drying

Loads or packages of material stacked for kiln-drying are often air-dried first or held on the tracks at the loading end of the kiln for several days before going in the kiln. Such stock should be protected from the elements. Portable roofs made from such materials as roofing paper, plywood, or corrugated metal are often used for this purpose (fig. 92). An open shed at the loading end of a kiln is an effective means of protecting stock from rain and sun before it goes into the kiln.

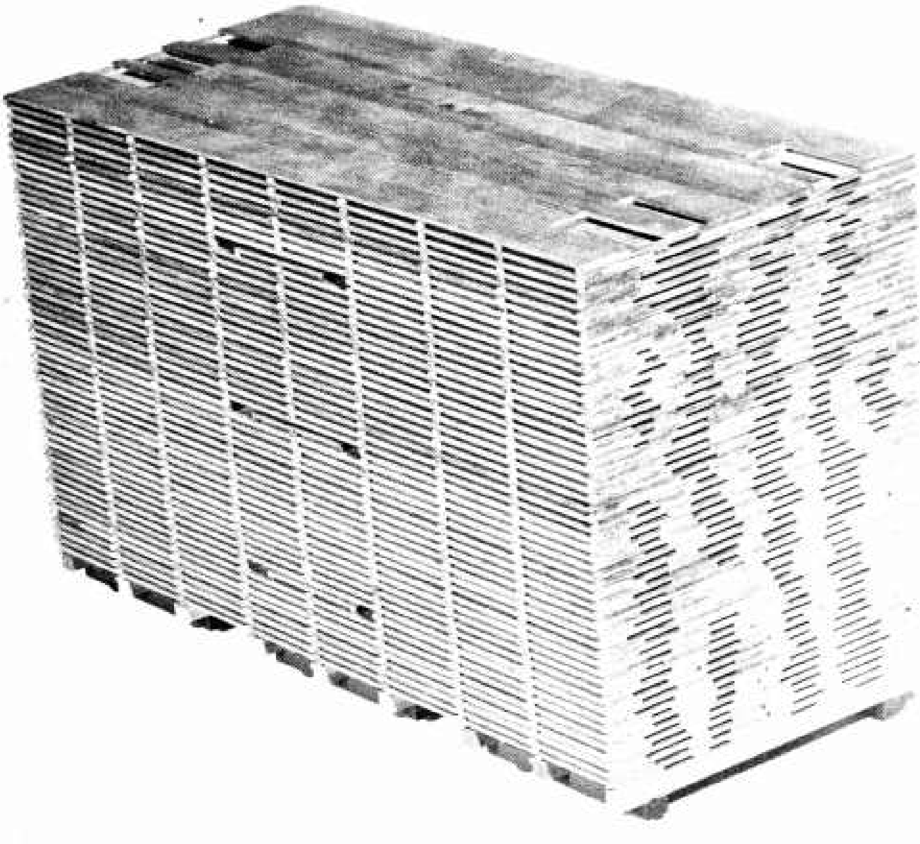
Weights and Restraining Devices

Weights placed on top of a load or restraining devices that exert pressure are frequently used to reduce warping of the top courses. Short lengths of rail are sometimes used for this purpose. The weights should be placed directly over the tiers of stickers. Restraining devices sometimes used consist of wire rope and tension springs attached to each end of light I-beams that extend across the load directly over the stickers and about 6 inches beyond each edge. The tension spring is pulled into heavy tension and hooked into a sticker opening about 5 to 6 feet below the top of the load. Occasionally, as the lumber shrinks during drying, the hooks are pulled from the load and reinserted at a lower point, thus taking up slack in the rope. Turnbuckles or load binders are occasionally used instead of springs.



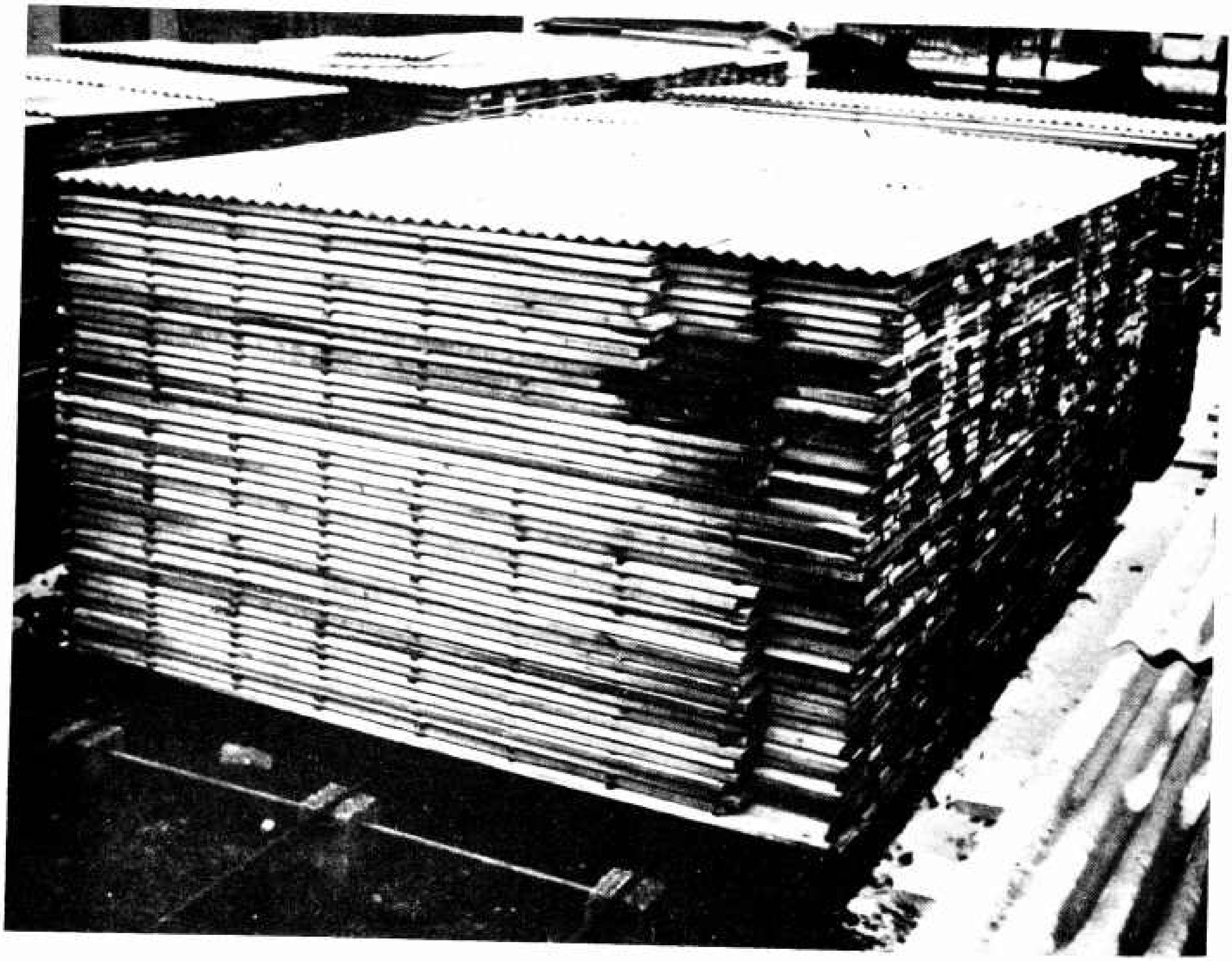
M–115542–F

FIGURE 90.—Bowling-pin blanks stacked for kiln-drying in an end-piled kiln with forced transverse circulation. Rack holds blanks in place. Air circulation is parallel to the stickers.



M–75804–F

FIGURE 91.—Box pile of random-length lumber showing sample pockets and kiln samples.



M–115539–F

FIGURE 92.—Corrugated asbestos-cement board roofs cover kiln truckloads of lumber stored out of doors prior to kiln-drying.

CHAPTER 6. KILN SAMPLES

The temperature and relative humidity schedules used in a dry kiln affect the drying stresses that develop in the wood (ch. 8). Such stresses follow a well-defined pattern closely associated with the changing moisture content of the wood. Therefore, moisture content, which can be determined easily at any stage of drying is a logical basis for applying a drying schedule.

Since it is impractical to make moisture determinations on all the lumber in a kiln charge, samples are cut from boards representative of the material being dried. These samples, called kiln samples, are so placed in the charge that they can be removed easily for weighing, examination, and testing periodically during drying. Thus, the moisture content of the charge can be estimated and the progress of drying charted.

The handling of kiln samples requires much of an operator's time, and sometimes additional manpower is needed. Also, some material is lost when kiln samples are taken. These disadvantages, however, are more than offset by several advantages. The selection, preparation, placing, and weighing of kiln samples, if properly done, provide information that enables a kiln operator to (1) reduce kiln degrade, (2) obtain better control of the desired final moisture content, (3) reduce drying time and improve quality, (4) develop time schedules, and (5) locate sources of trouble that affect kiln performance. All of these advantages add up to lower drying costs and more uniformly dried, stress-free material.

This chapter covers selection and preparation of kiln samples; the number of samples required in a kiln charge; determination of moisture content and ovendry weight of kiln samples; how to use samples during drying; how to make intermediate moisture determinations; final test procedures; and the recording and plotting of drying data.

Variability of Material

In order that full use be made of known drying techniques and equipment and that good drying be assured in the shortest time, each kiln charge should consist of material having about the same drying characteristics. In order to do this and to select representative kiln samples, the operator must consider certain variables in wood that affect drying: (1) Species; (2) thickness; (3) moisture content; (4) heartwood and sapwood; (5) grain (plainsawed or quartersawed); and (6) final moisture content.

Species

Woods of the many species that grow in this country have a wide range of physical properties (*5*).[1] Several physical properties influence the ease of drying; among them are specific gravity, shrinkage, moisture diffusion, and strength perpendicular to the grain. Such woods as basswood, yellow-poplar, and the pines are relatively easy to dry with few or no serious drying defects. Others, such as the oaks, black walnut, and redwood, are more likely to check, honeycomb, and collapse during kiln-drying. For this reason, dry only one species in a kiln at a time or, at most, a few that have similar drying characteristics.

Thickness

When lumber dries, the moisture evaporates from all surfaces, but principally from the broad faces. Thickness, therefore, is the most critical dimension. The thicker the stock, the longer the drying time and the more difficult the drying job. Lumber of different thicknesses cannot be dried in the same kiln charge without either prolonging the drying time or risking drying degrade.

Badly miscut lumber needs to be watched for. Even nominal 1-inch-thick lumber may, if badly sawn, vary in thickness from 3/4 to 1 1/2 inches in the same board. The thinner parts will dry more rapidly than the thicker ones. Dress such lumber to a more uniform thickness or segregate it from well-cut material.

Moisture Content

The extent to which lumber has been dried before it is put in the kiln must also be considered, because moisture content governs the drying conditions that can be used. If all the free water has already been removed, more severe drying conditions can be used in the initial stages of kiln-drying with little or no danger of producing the usual drying defects (ch. 9). Further, a uniform initial moisture content makes drying to a uniform final moisture content much

[1] Italic numbers in parentheses refer to Literature Cited, p. 111.

faster. If the boards vary considerably in initial moisture content, a longer equalizing time may be required at the end of the run.

Heartwood and Sapwood

Sapwood usually dries considerably faster than heartwood. Resins, tannins, oils, and other extractives retard the movement of moisture in the heartwood. Tyloses and other obstructions may be present in the pores of the heartwood of some species, notably white oak and the locusts. Sometimes it is practical to segregate the heartwood and sapwood boards. The green moisture content of sapwood is usually higher than that of heartwood, particularly in the softwoods. For these reasons, heartwood lumber may not reach the desired final moisture content as soon as sapwood, or vice versa. One or the other may therefore be overdried unless an equalizing treatment is used.

Grain

Quartersawed boards generally dry more slowly than plainsawed, but they are less susceptible to surface checking. Therefore, a more severe drying schedule can be used on quartersawed boards to reduce drying time. For this reason, in the drying of such items as vertical-grained flooring strips it is advantageous to segregate flat- from vertical-grained material.

Final Moisture Content

As a rule, two or more classes of material should not be put in the same kiln charge if they are to have different final moisture content values. If the stock to be dried to the highest final moisture content reaches that value at about the same time that the rest of the charge becomes adequately dried, no harm will result. If, however, this stock reaches the desired moisture content first, it must be removed from the kiln to prevent overdrying. Its removal leaves empty spaces in the kiln that can disrupt air circulation through the remainder of the charge, with resultant nonuniform drying and prolonged drying time.

Drying Mixed Charges

Ideally, segregation of lumber is based on all of the factors that affect drying rate and drying quality. Since this is frequently not possible or practical, a kiln operator must be guided in his selection of kiln samples primarily by the drying rate of the most critical, slowest drying material. That is, he must select the largest number of samples from the slowest drying material. Some samples of the fastest drying material are also needed, however, since these will determine the time when the equalizing treatment should be started (ch. 8).

Number of Kiln Samples

The number of kiln samples needed for any kiln charge depends upon the condition and drying characteristics of the wood being dried, the performance of the dry kiln, and the final use intended for the material.

Drying a Charge by a Prescribed Kiln Schedule

By far the most important purpose of kiln samples is to enable a kiln operator to dry a charge of lumber in accordance with a predetermined schedule. Such schedules generally call for changes in drying conditions that are based on the moisture content of the stock during various stages of drying.

Because of the many variables that affect drying results, the specific number of kiln samples required for each kiln charge must be determined through experience. A rule of thumb is to use at least four samples in charges of 20,000 board feet or less. For charges of 100,000 board feet or more, 10 to 12 kiln samples per charge are usually satisfactory. Use more samples, however, when (1) drying a charge of material composed of different species, thicknesses, moisture content levels, grain, or mixed heartwood and sapwood; (2) drying a kind of wood not previously handled; (3) drying costly special items, such as gunstock, bowling-pin, and shoe-last blanks; (4) obtaining drying data for use in modifying a drying schedule or in developing a time schedule; and (5) when the performance of the dry kiln is unknown or erratic.

Developing a Time-Temperature Schedule

At plants where certain items are regularly dried in sufficient quantity, the operator can utilize kiln samples to develop time-temperature schedules for subsequent charges of the same item dried to the same moisture content in the same kiln. This may involve extra sampling work to measure the full range of variables, but after sufficient information and experience have been obtained, kiln sampling can be dispensed with for future charges of the item. Obtain drying data on at least eight charges of the item before deciding on a time schedule.

Time schedules are generally used in the drying of softwoods. It is possible, however, to develop satisfactory time schedules for some of the more easily dried hardwoods. Some samples should, of course, be used occasionally to check the performance of the kiln and the final moisture content of the stock. Some operators using time schedules for drying softwoods employ kiln samples to determine when to equalize, condition, and shut off the kiln.

Checking Kiln Performance

Studies of kiln performance show that dry-bulb temperature and rate of air circulation throughout a kiln may vary considerably and affect the time and quality of drying (*3*). Variations in temperature and circulation can be determined with testing equipment (pages 57–62) (*1*). If such equipment is not available to the operator, kiln samples can be used to check kiln performance. Cut all samples for this purpose from the same board or from boards having much the same drying characteristics. Place them near the top and bottom and on both sides of each load, at intervals of 10 to 16 feet along the length of the kiln.

Kiln samples that dry slowly indicate zones of low temperature or low air circulation, and those that dry rapidly indicate zones of high temperature or high rates of air circulation. If the drying rates of the samples vary greatly, find and correct the causes (*4*). Differences in drying rates between the samples on the entering- and leaving-air sides of the loads will assist the operator in determining how often to reverse the airflow. The greater the difference in drying rate between the entering- and leaving-air samples, the more frequently should the direction of air circulation be reversed.

Selection of Kiln Samples

Boards from which kiln samples are to be cut should be selected while the lumber is being stacked for drying. This can be done by a trained stackerman. The operator cuts kiln samples from those boards most representative of the heavier, wetter, and thicker stock of the charge and containing a comparatively high percentage of heartwood. Usually one kiln sample is cut from each sample board to assure a representative group of kiln samples (fig. 93). In random-width material, kiln samples are cut from boards about 7 to 9 inches wide.

Some kiln samples are also cut from boards that represent the drier and faster drying stock. Such boards will generally be flatsawed, narrow, or scant in thickness, will contain a high percentage of sapwood, or be drier than the rest at the time the lumber is stacked for kiln-drying. These kiln samples are used during the final stages of drying (ch. 8).

For studies of kiln performance, two or more matched samples are cut from the same board (fig. 93).

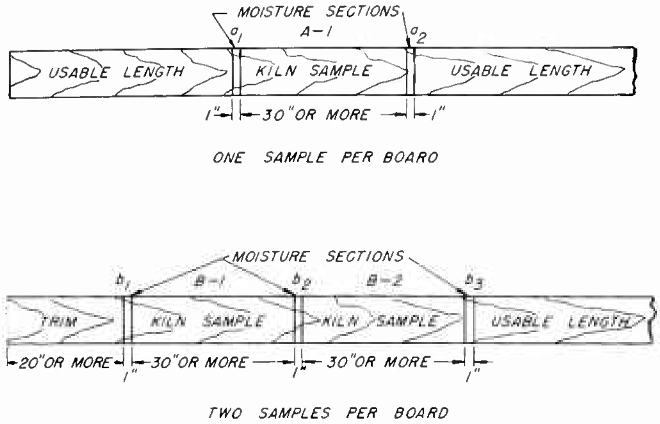


FIGURE 93.—Method of cutting and numbering kiln samples and moisture content sections.

Preparation of Kiln Samples

Knots, bark, pitch, and even a small amount of decay should preferably not be included in the parts of boards cut for kiln samples, except when drying lumber of common grades. The moisture sections that are cut from each end of a kiln sample (fig. 93) must be of clear, sound wood. Completely remove any bark present on the moisture sections and kiln sample before they are weighed. The bark interferes with moisture content determinations and the rate of drying of the kiln samples.

Cutting the Moisture Sections and Kiln Samples

Mark the moisture sections and kiln samples for identification, as shown in figure 93, before they are cut. Usable lengths of lumber can be salvaged from each end of the board when the moisture sections and kiln samples are cut. If no usable lengths would be left, cut the moisture sections and kiln samples about 20 inches or more back from the ends of the boards to eliminate the effects of end drying.

With certain exceptions, moisture sections are cut not less than 1 inch along the grain and across the full width of the board. It may be necessary to cut moisture sections less than 1 inch along the grain, particularly for obtaining quick moisture determinations and when using a self-calculating moisture content scale. To minimize errors, take extra precautions in cutting, handling, and weighing these thinner sections. In dimension stock 1 inch square or less in cross section, moisture sections are cut 2 inches or more in length along the grain. Cut the moisture sections on a sharp, cool-running saw and weigh them immediately. If it is necessary to cut a number of sections at a time before weighing them, wrap each one separately in aluminum foil to prevent drying.

Keeping saw, scales, and oven close together in a well-lighted, draft-free area is helpful in obtaining accurate moisture content determinations. If the sample boards must be cut some distance from the scale, cut long pieces from the boards and take them to the weighing area, where the moisture sections and kiln samples can be cut from them with a bandsaw. In such cases, trim and discard a section at least 1 inch long from one end of each piece.

Determining Moisture Content and Ovendry Weight of Samples

The moisture content of a kiln sample is determined from the moisture sections cut from each end of the kiln sample. The average moisture content of these two sections and the weight of the kiln sample at the time of cutting are used to calculate the ovendry weight of the kiln sample. This calculated ovendry weight and the subsequent weights of the kiln sample obtained at intervals during the drying—called current weights—are used to compute the moisture content at those times.

Weighing Moisture Sections.—After the moisture sections are cut, rapidly remove all bark, loose splinters, and sawdust adhering to them, and weigh them immediately. Weigh each section to ½ of 1 percent of its weight; it is necessary to use a scale capable of weighing within this degree of precision. Obtain the weights in grams, instead of grains or ounces, so that calculations will be simplified by using the decimal system. A triple-beam balance (fig. 38, p. 49) is a convenient type to use for weighing moisture sections. Other types of balances are illustrated in figures 39 and 40.

To remain accurate, the knife-edge bearing surfaces of a triple-beam balance must be kept free of dirt, oil, grease, and corrosion. Protect the scale with a dustproof cover when it is not in use, and check its accuracy and sensitivity at least once a year against standard weights. The scale should be balanced on zero before each series of weighings.

To save weighing and calculating time, the two moisture sections cut from each kiln sample can be weighed together. This, however, does not give the difference in moisture content usually present between the two moisture sections. After weighing them, mark the weight on each section and, when weighings are completed, enter the weight on tabulation paper or a data form drawn for the purpose.

Weighing Kiln Samples.—After the kiln samples are cut, remove all bark, loose splinters, and sawdust adhering to them and apply a good end coating. Many effective end coatings are available (*2*). They should be used as recommended by the manufacturer. Immediately after end coating, weigh the kiln samples on a scale or balance that is sensitive to 0.01 pound or approximately 5 grams, and that has a capacity of about 35 pounds (fig. 41, p. 52). The weights should be in either the metric system or in pounds and hundredths of a pound, but not in pounds and ounces. Mark the weight on the kiln sample and also record it on a data form.

Usually, the weight of the end coating can be disregarded. In drying some special items, however, it may have to be considered. When that is necessary, weigh the kiln sample before and after it is end coated, the difference being the weight of the coating. Record that weight and subtract it from all subsequent weights of sample obtained during drying.

Ovendrying Moisture Sections.—After weighing them, dry the moisture sections until moisture-free in an oven maintained at 214° to 221° F. (101° to 105° C.). This usually takes 24 to 48 hours. To test whether they are thoroughly dry, weigh a few sections, replace them in the oven for about 3 or 4 hours, and reweigh them. If they have lost no weight, the entire group of sections can be assumed to be moisture-free. Electric ovens suitable for ovendrying are illustrated in figures 45 and 46, pages 55 and 56.

Open-pile the moisture sections in the oven to permit air to circulate around each (fig. 45). Avoid excessively high temperatures or prolonged drying, because they cause destructive distillation and oxidation of the wood. Never place newly cut moisture sections in the oven with sections already partly dry: the drier sections would temporarily absorb moisture from the newly cut sections, and this would prolong the drying time. Newly cut moisture sections, once weighed, need not be put in the drying oven immediately. Kiln operators short on drying-oven capacity frequently place them on radiators until oven space is available. This reduces ovendrying time.

Weighing Ovendry Moisture Sections.—It is essential that moisture sections be rapidly weighed immediately after they are removed from the oven. Weighing is done as described for freshly cut moisture sections.

Calculating Moisture Content of Sections.—Moisture content of the moisture sections is calculated by dividing the weight of the water removed by the ovendry weight of the section and multiplying the quotient by 100. Since the weight of the water equals the original weight of the section minus its ovendry weight, the formula for this calculation is:

Moisture content in percent=

$$\frac{\text{original weight} - \text{ovendry weight}}{\text{ovendry weight}} \times 100 \qquad (1)$$

Example: Calculate the average moisture content of two moisture sections (fig. 93, top) when:

Green weight of moisture section a_1 $=98.55$ grams

Ovendry weight of moisture section a_1 $=59.20$ grams

Green weight of moisture section a_2 $=86.92$ grams

Ovendry weight of moisture section a_2 $=55.02$ grams

Wanted: The average moisture content of moisture sections a_1 and a_2.

Two methods of calculating average moisture content in percent can be used.

Method 1

Moisture content of section a_1=

$$\frac{98.55-59.20}{59.20}\times 100=66.5 \text{ percent}$$

Moisture content of section a_2=

$$\frac{86.92-55.02}{55.02}\times 100=58.0 \text{ percent}$$

The average moisture content of moisture sections a_1 and a_2 is:

$$\frac{66.5+58.0}{2}=62.2 \text{ percent}$$

Method 2

If the sections are weighed together, the combined green weight of sections a_1 and a_2 is 185.47 grams and their combined ovendry weight is 114.22 grams. Then:

Average moisture content=

$$\frac{185.47-114.22}{114.22}\times 100=62.4 \text{ percent}$$

While the average moisture content of moisture sections a_1 and a_2 calculated by method 2 results in a slightly higher value than that obtained by method 1, the calculated ovendry weight of the kiln sample using either method will be the same when corrected to the nearest 0.01 pound.

It is sometimes convenient, when making slide-rule or machine calculations, to use a short-cut method of calculating moisture content by the formula:

$$\text{Moisture content}=\left(\frac{\text{original weight}}{\text{ovendry weight}}-1\right)\times 100$$

Substituting the weights for moisture section a_1 in this formula:

Moisture content in percent of section a_1=

$$\left(\frac{98.55}{59.20}-1\right)\times 100=(1.6647-1)\times 100=66.5$$

Calculating Ovendry Weight of Kiln Sample.—The moisture content of a kiln sample at the time of cutting and weighing is assumed to be the same as the average of the moisture content values of the two moisture sections cut from each end of the sample. Knowing this value and the weight of the sample at the time the sections were cut, the ovendry weight of the kiln sample can be calculated by using the following formula:

Ovendry weight of sample=

$$\frac{\text{Original weight of kiln sample}}{100+\text{moisture content of sample in percent}}\times 100 \quad (2)$$

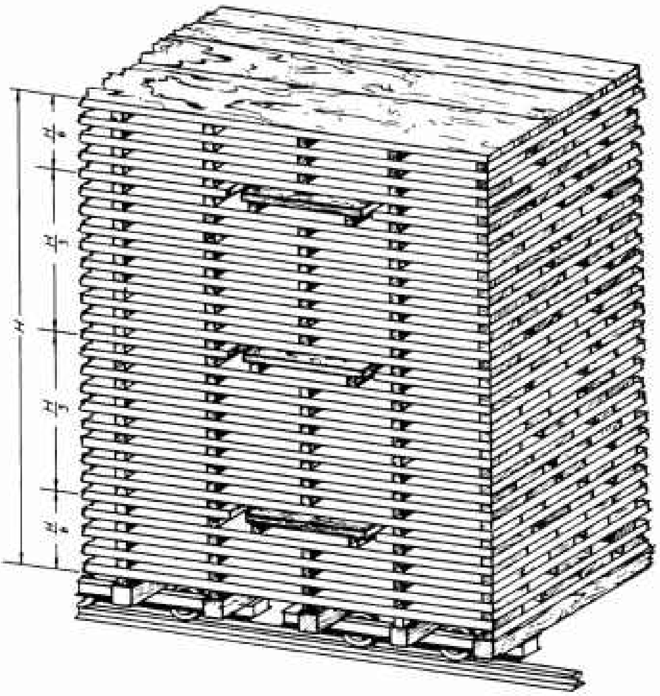
Example: Calculate the ovendry weight of kiln sample A–1 (fig. 93, top), the original weight of which is 4.46 pounds, using the average moisture content calculated for moisture sections a_1 and a_2, 62.2 percent:

Ovendry weight of sample=

$$\frac{4.46}{100+62.2}\times 100=0.02749\times 100=2.75 \text{ pounds}$$

Placing Samples in Kiln Charges

After kiln samples are cut, end coated, and weighed, they are placed in sample pockets built into the loads or packages of lumber during the stacking operation (fig. 94). Since the kiln sam-



ZM–59968–F

FIGURE 94.—Placement of three kiln samples in sample pockets built in the side of an end-piled load of lumber. The pockets should be deep enough so that the kiln samples do not project beyond the edge of the load.

ples are representative of the stock being dried, they must at all times be exposed to the same drying conditions or they will give a false indication of the moisture content of the charge. For example, considerable moisture may be lost from kiln truckloads or packages of lumber that are not loaded into the kiln for several days or weeks after the samples are cut and weighed. The kiln samples representing this stock must be in the loads or packages during this period. Since kiln samples may dry faster than the lumber in the central parts of a load, it may be desirable to shield the sample pocket to slow up air circulation at that point.

Locate the sample pockets at places in the loads where the samples can be easily removed and replaced. In end-piled forced-circulation kilns the locating of sample pockets is relatively easy, because there is usually a walkway alongside the loads. In a double-track kiln, the pockets are placed in the sides of the loads nearest the walls. In natural-circulation kilns and most kilns of the external-blower type, however, the entering-air side of the loads is usually not accessible, and the kiln samples have to be placed on the leaving-air side.

In cross-piled dry kilns of both natural- and forced-circulation types, there is seldom sufficient room between the ends of the loads and the walls to allow the operator to walk into the kiln. Only the load nearest the door is accessible. Samples can be placed in the ends of this load, or in the side facing the door. These locations are not the most deseirable, but there is usually no other choice. In such kilns, the operator can get a good idea of how the dryness of the samples compares with that of the stock in other parts of the charge by making a thorough check of the final moisture content and quality of the kiln-dried stock. With this information he may, when drying future charges, be better able to judge from the moisture content of the samples when to change drying conditions or pull the charge.

If a mixed kiln charge is being dried, place the samples representing each type of material in the truckloads or packages containing that material. For example, if 4/4 and 6/4 pine lumber are being dried in the same charge, put the 4/4 samples with the 4/4 lumber and the 6/4 samples with the 6/4 lumber.

Some operators of unlighted kilns use small colored-glass reflectors or reflective tape on the edge of the sample or the edges of boards above or below the sample pocket. These reflectors are easily found with a flashlight. To guard against replacing samples in the wrong pocket after weighing them, put the number or letter of each sample on the edge of the board immediately above or below its pocket.

Using Kiln Samples During Drying

As drying progresses, the drying conditions in the kiln are changed on the basis of the moisture content of the samples at various times during the run. How frequently the samples must be weighed will depend on the rate of moisture loss; the more rapid the loss, the more frequently they must be weighed. Immediately after they are weighed, they must be returned to their pockets.

Calculating Current Moisture Content of Sample

To calculate the current moisture content of a sample, two weights are required; the current weight and the calculated ovendry weight. The formula used is as follows:

$$\text{Current moisture content} = \frac{\text{Current weight} - \text{calculated ovendry weight}}{\text{Calculated ovendry weight}} \times 100 \quad (3)$$

Thus, if the calculated ovendry weight of the sample is 2.75 pounds and its current weight 4.14 pounds, then:

$$\text{Current moisture content} = \frac{4.14 - 2.75}{2.75} \times 100 = 0.5054 \times 100 = 50.5 \text{ percent}$$

After another day of drying, this sample may weigh 3.85 pounds. The current moisture content of the sample will then be:

$$\frac{3.85 - 2.75}{2.75} \times 100 = 0.400 \times 100 = 40.0 \text{ percent}$$

If a slide rule or machine is used in calculating the current moisture content, the following short-cut formula can be used:

$$\text{Current moisture content} = \left(\frac{\text{Current weight}}{\text{Calculated ovendry weight}} - 1\right) \times 100$$

Substituting the above values in this formula:

$$\left(\frac{3.85}{2.75} - 1\right) \times 100 = (1.400 - 1) \times 100 = 0.400 \times 100 = 40.0 \text{ percent}$$

Use of Samples to Follow Kiln Schedules

Kiln schedules provide for changes in kiln conditions as drying progresses. If the Forest Products Laboratory schedules are used, it is recommended that drying conditions be changed when the average moisture content of the wettest 50 percent of the kiln samples equals a given moisture content in the schedule. Sometimes an operator may change drying conditions according to the wettest one-third of the samples or the average moisture content of a smaller group of samples that may be distinctly wetter or more difficult to dry than the others. These are called the controlling samples. The moisture content of the driest sample determines when equalizing of the kiln charge should be started.

Intermediate Moisture Content Tests

If the moisture content of the moisture sections does not truly represent that of the kiln sample, the calculated ovendry weight of the kiln sample will be wrong. This may mislead the operator into changing kiln conditions at the wrong time, with such serious consequences as prolonged drying time, excessive amounts of drying defects, or nonuniformly dried stock. For example, if water pockets are present in the moisture sections but not in the sample, the calculated ovendry weight of the sample will be too low and its current moisture content too high. Conversely, if water pockets are present in the sample and not in the moisture sections, the calculated ovendry weight of the sample will be too high and its current moisture content too low. These potential ill effects may be avoided by making intermediate moisture content determinations.

When To Make Intermediate Tests

When the calculated moisture content of one or a few kiln samples is much higher than that of the other samples, or if their rate of drying appears to be much slower than the average rate, make a check moisture content test on those samples to obtain a better estimate of their calculated ovendry weight. The best time for making these intermediate determinations is when the average moisture content of most of the samples is at about 20 percent. The intermediate determinations can be made on all of the samples in the charge if the operator wants a precise estimate of the final moisture content.

How To Make Intermediate Tests

Trim a section about 5 inches long off one end of the kiln sample. Then cut a 1-inch-wide moisture section from the newly exposed end of the sample, weigh it immediately, and ovendry it. Coat the freshly cut end of the shortened sample and weigh it immediately. The new weight of the sample is the new "original" weight used in formula (2). After weighing the sample, place it in its pocket in the kiln charge. As soon as the moisture section has reached constant weight in the oven, weigh it and calculate its moisture content with formula (1). Substitute the new moisture content value, together with the new original weight of the sample, in formula (2) to obtain a new calculated ovendry weight. Use the new calculated ovendry weight in formula (3) to obtain the current moisture content of the sample in all subsequent weighings.

A moisture content test may be necessary near the end of the run to check the moisture content of the samples before starting equalizing and conditioning treatments.

Final Moisture Content and Stress Tests

After the lumber has been dried to the desired final moisture content, the drying stresses relieved by a conditioning treatment, and the charge pulled from the kiln, the final moisture content and stress tests can be made on the samples. Tests of boards selected at random from the charge can also be made.

Cut three 1-inch sections, several inches in from an end, from the samples and selected boards. Use one of these sections to determine the average moisture content by formula (1). Use the second section to determine the distribution of moisture in the section by cutting it into a core and shell (fig. 95). Weigh the core and shell separately; ovendry and reweigh them; and calculate their moisture content by formula (1). Use the third section for a stress test to deter-

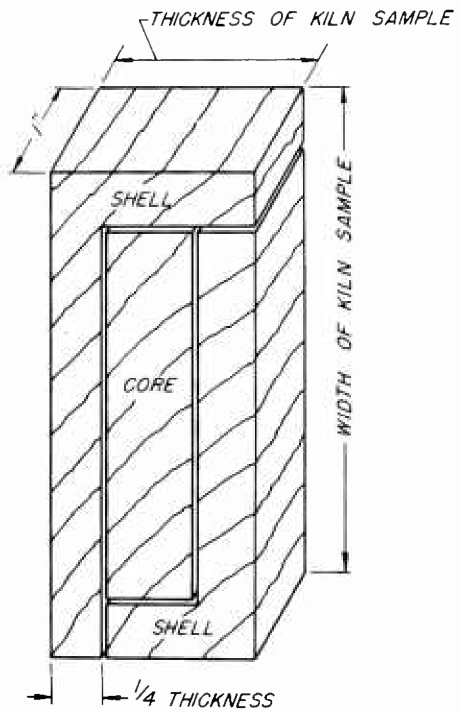


FIGURE 95.—Method of cutting section for determination of distribution of moisture in shell and core.

mine the effectiveness of the conditioning treatment in relieving casehardening (fig. 96).

Recording Drying Data

Properly recorded and evaluated kiln sample data assist the operator to (1) modify the drying schedule on subsequent charges to obtain faster drying without sacrificing quality; (2) develop time schedules for certain classes of material; (3) determine the effect of seasonal weather conditions on drying time; and (4) check the performance of the dry kiln and determine the causes for nonuniform drying and seasoning degrade.

The kinds of data to be recorded will vary with the drying job. On a test run in a new kiln, on a new class of material, or on a new or modified schedule more drying data are required than are ordinarily necessary. Likewise, the more precise the drying job, the more data needed.

The data can include such items as species, grade, origin of material, date of cutting, kind of grain (flat or quartered), percentage of sapwood, rings per inch, moisture content, thickness, date drying was started, the drying schedule used, drying time, drying defects, method and length of storage before and after drying, and shipping date.

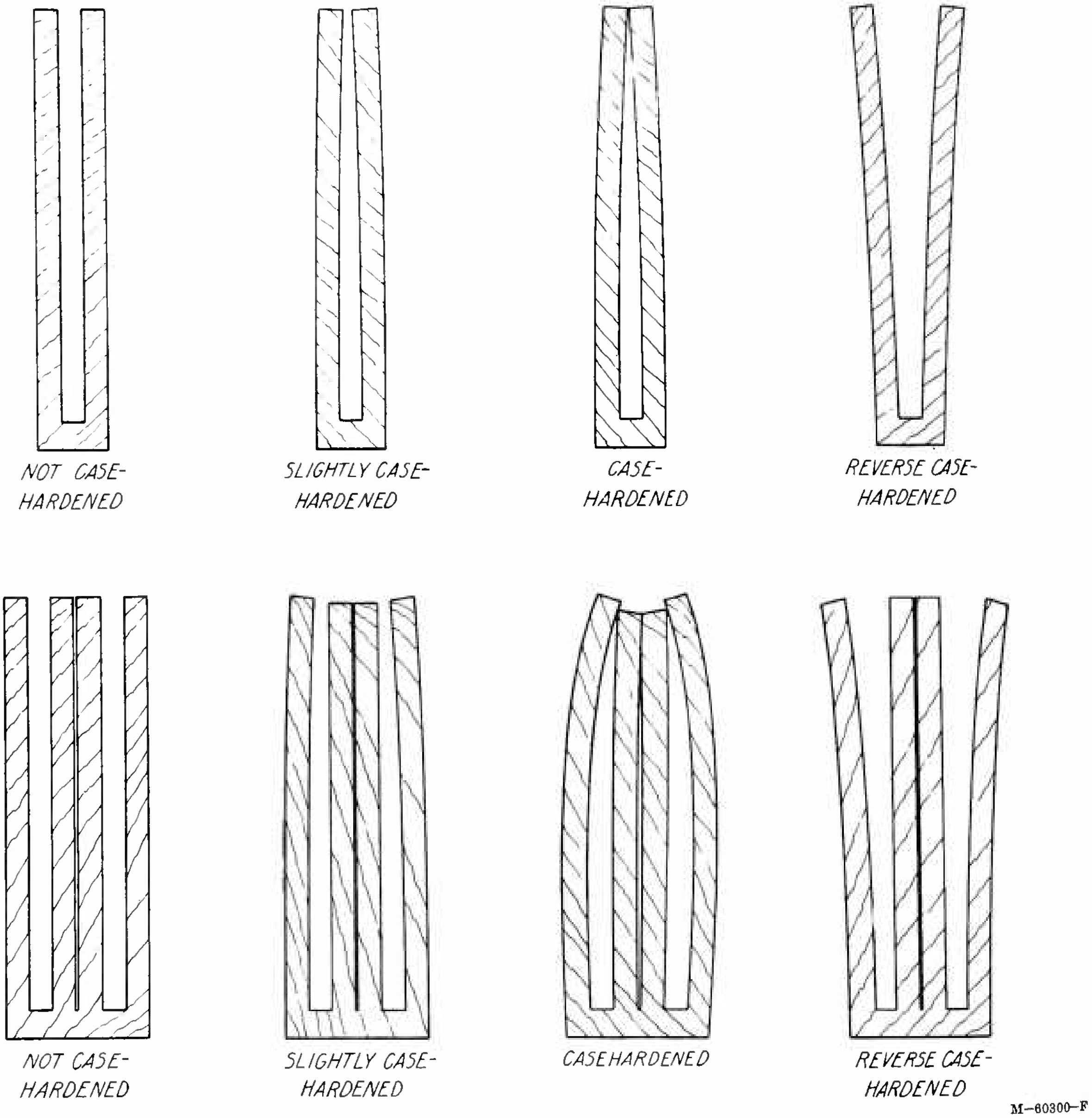


FIGURE 96.—Method of cutting specimens for casehardening tests. Material that is less than 1½ inches thick is cut into three prongs, and the middle prong is removed; material that is 1½ inches thick or thicker is cut into six prongs, and the second and fifth prongs are removed.

Kiln sample data should be recorded on suitable forms, such as those supplied by dry kiln manufacturers. Many kiln operators develop their own data forms, or modify available forms to fit their specific needs. Forms for recording drying data on 3 of 10 samples in an experimental charge of 4/4 soft maple are shown in figures 97, 98, and 99.

Preliminary kiln sample data should include moisture section and kiln sample numbers and other data shown in figure 97. Origin of material, grain, rings per inch, defects, and other data can be added if required.

Drying data obtained for each sample during the kiln run are entered on a kiln sample record form (fig. 98). Other data, including kiln number, board footage in the charge, species and thickness, and date drying was started, can be entered as required. Some of the data recorded on the kiln sample preliminary data form (fig. 97) can also be entered on the sample record form. Also recorded are the data covering the intermediate moisture determinations and the data for the moisture regained during the conditioning treatment. If a record of the weight of the end coating used on the kiln samples is required, it also would be entered on this form.

Moisture and Stress Data.—The data for the final moisture and stress determinations can be recorded on a form like the one shown in figure 99. The degree of casehardening present in the stock is noted in this form. Supplemental moisture data, such as those obtained with moisture meters, should also be recorded.

KILN SAMPLE

PRELIMINARY DATA FORM

Sheet No. 1

Species SOFT MAPLE Origin WISCONSIN

Grade MIXED Nominal thickness 4/4

Grain MIXED Date 10/30/51

Remarks: PARTIALLY AIR DRIED

Sample No.	Moisture content sections: Section No.	Green or initial weight	Ovendry weight	Moisture content	Kiln sample: Green or initial weight	Calculated ovendry weight	Rings per inch	Defects
		Gm.	Gm.	Percent	Lb.	Lb.		
1	1a and 1b	225.20	165.04	36.4	7.96	5.84	14	NONE
2	2a and 2b	195.34	147.41	32.5	6.95	5.24	18	SLIGHT CHECKING
3	3a and 3b	199.04	135.86	46.5	10.43	7.12	15	NONE

M–115535–F

FIGURE 97.—Data form filled in with preliminary data on 3 of 10 kiln samples representing a charge of 4/4 soft maple. The 2 moisture sections cut from each sample were weighed together.

KILN SAMPLE RECORD

Company FOREST PRODUCTS LABORATORY Species SOFT MAPLE Kiln No. 4

Charge Footage 1500 B.F. Material Size 4/4 Date Started 10/31/51 4PM

Sample No.		Moisture sections Wt.	Moisture sections O.D. Wt.	Green wt. of sample	Calc. O.D. wt.	End coat corr. wt.	End coat correction weight subtracted from daily weights								Remarks
						Date:	10/31	11/1	11/2	11/3	11/4	11/5	11/6		
						Hour:	4P	1P	9A	9A	9A	4P	2P		
						Total hours:	0	21	41	65	89	120	142	MADE INTERMEDIATE MOISTURE TESTS AT 2PM—11/6	
		Gm.	Gm.												
1	Wt.	225.20	165.04	7.96	5.84	—	7.96	7.55	7.44	7.30	7.08	6.72	6.41		
	M.C.	36.4					36.4	29.3	27.4	25.0	21.2	15.1	9.8		
2	Wt.	195.34	147.41	6.95	5.24	—	6.95	6.90	6.83	6.72	6.51	6.13	5.80		
	M.C.	32.5					32.5	31.7	30.3	28.2	24.2	17.0	10.7		
3	Wt.	199.04	135.86	10.43	7.12	—	10.43	9.74	9.40	9.05	8.71	8.22	7.82		
	M.C.	46.5					46.5	36.8	32.0	27.1	22.3	15.4	9.8		
	Wt.														
	M.C.	AFTER INTERMEDIATE				DATE	11/6	11/7	11/8		11/9				
	Wt.	MOISTURE TESTS				HOUR	2P	2P	2P		3P				
	M.C.					TOTAL HOURS	142	166	190	STARTED CONDITIONING 11/8—2P	215	KILN SHUT OFF 11/9—3P			
1	Wt.	84.67	77.29	4.78	4.37	—	4.78	4.69	4.64		4.79				
	M.C.	9.5					9.5	7.3	6.2		9.6				
2	Wt.	79.54	72.30	4.30	3.91	—	4.30	4.21	4.17		4.30				
	M.C.	10.0					10.0	7.7	6.6		10.0				
3	Wt.	101.90	92.78	5.78	5.26	—	5.78	5.68	5.63		5.80				
	M.C.	9.8					9.8	8.0	7.0		10.3				
	Wt.														
	M.C.														

M—115536—F

FIGURE 98.—Form used for recording kiln sample data in a dry kiln run of 4/4 air-dried soft maple. Data for 3 of 10 kiln samples are shown.

MOISTURE AND STRESS RECORD

Kiln No. 4 Run started 10/31/51

Date 11/9/51 After conditioning ____________

Sample No.	Shell Wt.	Shell O.D. wt.	Shell M.C.	Core Wt.	Core O.D. wt.	Core M.C.	Average Wt.	Average O.D. wt.	Average M.C.	Casehardening
	Gm.	Gm.	%	Gm.	Gm.	%	Gm.	Gm.	%	
1	35.80	32.81	9.1	36.55	33.60	8.8	75.19	68.74	9.4	NONE
2	38.59	35.77	7.9	29.57	27.35	8.1	75.37	69.85	7.9	SLIGHT
3	43.70	40.70	7.4	44.81	41.59	7.7	104.16	96.70	7.7	NONE

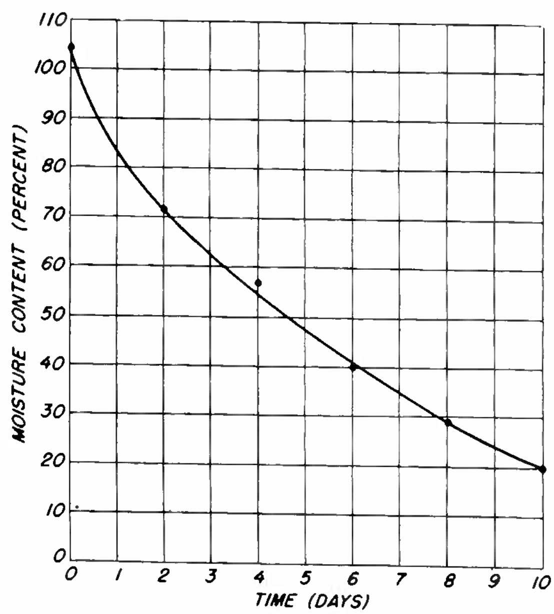
M–115534–F

FIGURE 99.—Form for recording final moisture content and stress data for three kiln samples.

Plotting of Data

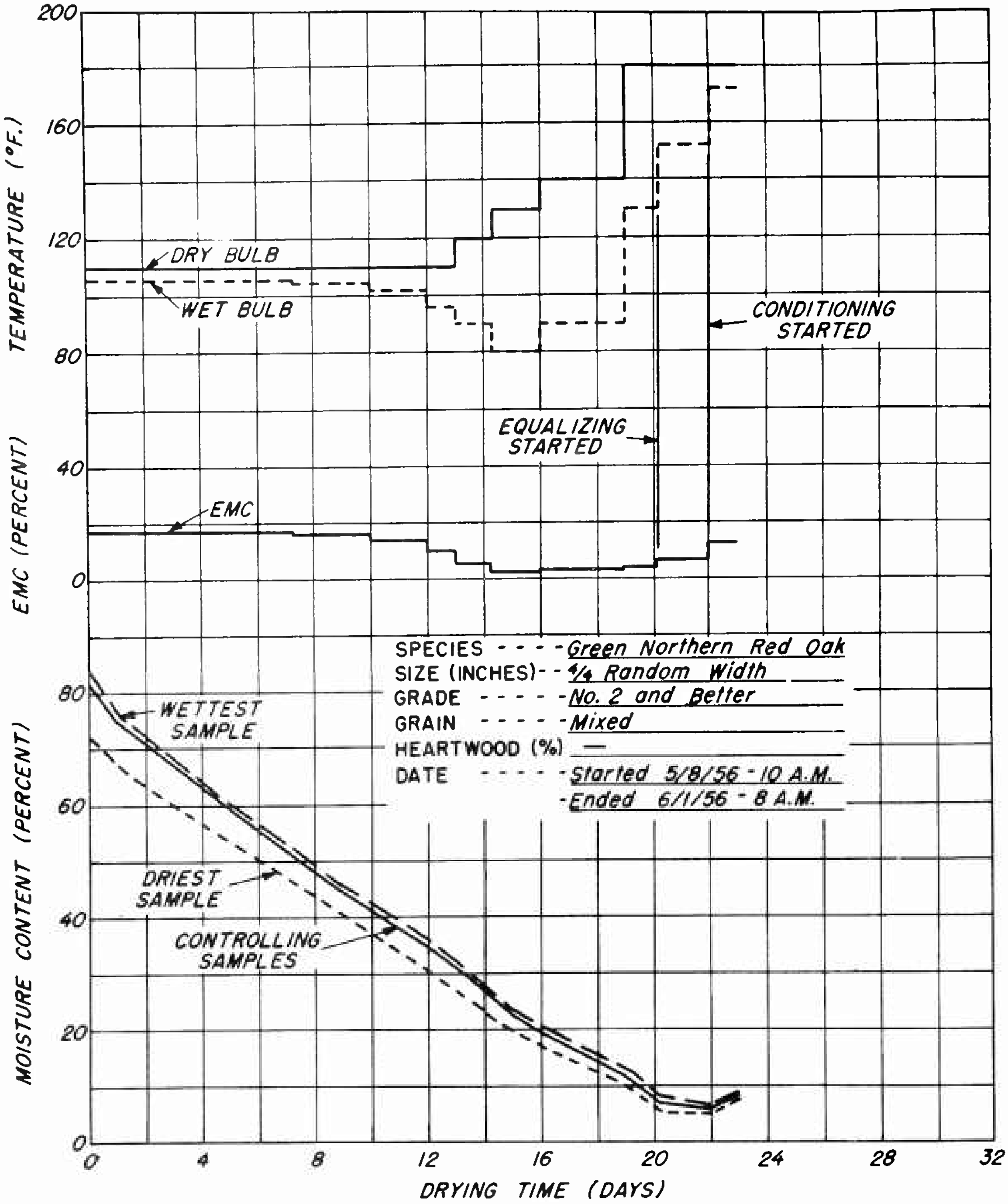
Plots of drying data show at a glance the time required to reach a certain moisture content. A plot of the average moisture content of the controlling samples in a kiln charge of 2-inch black tupelo is shown in figure 100. The curve shows the moisture loss to be fast and steady. Curves plotted from data obtained from each sample are useful for checking kiln performance and the reliability of the moisture content values of the samples. For example, if the moisture loss data on samples in the same zones in a kiln consistently indicate, on several charges, a slower or faster drying rate than the other samples in the charge, it is evidence of a cold or a hot zone in that location. The source of trouble can usually be found and corrected. On the other hand, if it is known, or an investigation shows, that the cause is not associated with a cold or hot zone in the kiln, it can be suspected that the calculated ovendry weight of this sample is inaccurate and an intermediate moisture content determination is needed.

Drying data obtained for an experimental kiln charge of green 4/4 northern red oak are plotted in figure 101. The drying conditions during the run are plotted, along with the moisture loss of the controlling samples and the driest and wettest samples. The effect of changes in drying conditions on the rate of moisture loss from the samples is apparent. Also shown is the effect of the equalizing and conditioning treatments in reducing the difference in average moisture con-



M–109007–F

FIGURE 100.—Moisture content-time curve for 2-inch black tupelo, showing a fast, steady loss of moisture.



M–115577–F

FIGURE 101.—Chart showing kiln-drying schedule and moisture content at various times during drying of 4/4 northern red oak.

tent between the driest and wettest samples in the kiln charge.

Literature Cited

(1) KIMBALL, K. E.
1955. TESTING COMMERCIAL KILNS FOR UNIFORMITY OF DRYING CONDITIONS. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1643, 9 pp., illus. [Processed.]

(2) MCMILLEN, J. M.
1956. COATINGS FOR THE PREVENTION OF END CHECKS IN LOGS AND LUMBER. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1435, 13 pp., illus. [Processed.]

(3) RASMUSSEN, E. F.
1956. NEED FOR UNIFORMITY OF TEMPERATURE IN A FORCED-AIR-CIRCULATION, VENTILATED, COMPARTMENT DRY KILN. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1669, 6 pp. [Processed.]

(4) ———
1955. ANALYSIS OF PROBLEMS RELATING TO UNIFORMITY OF KILN CONTROL. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1645, 9 pp., illus. [Processed.]

(5) U.S. Forest Service Forest Products Laboratory.
1955. WOOD HANDBOOK. U.S. Dept. Agr. Handbook 72, 528 pp., illus.

CHAPTER 7. LOADING THE DRY KILN

Basically, all kilns are designed to be loaded in a specific way. As terms used throughout this manual indicate, "end-piled" kilns are loaded with the lumber running lengthwise in the kiln, and "cross-piled" kilns are loaded crosswise. These two basic loading patterns are directly associated with the direction of airflow in the kiln or the plant's method of handling the lumber.

Overloading and underloading affect the quality of drying achieved in a given kiln. A capacity load assumes not only that the lumber is properly piled in the kiln but that the loads or packages of lumber are of lengths that provide suitable overall dimensions. That is, the spaces between truckloads and between the charge and the walls and ceiling are those called for by the kiln designer. If these spacings are materially altered through underloading or overloading, air circulation is changed, with consequent effects on drying time and quality.

This does not mean that a particular dry kiln can be loaded only with certain lengths of lumber. It does mean, however, that a kiln operator must consider the effects on air circulation imposed by overloading and underloading, and plan his loading patterns to best advantage, deviating as little as possible from the overall charge dimensions best suited for his kiln. When circumstances are such that the loading pattern must be seriously changed, he should exercise special care to keep air circulation as uniform as possible by adding auxiliary load baffles.

Loading Natural-Circulation Compartment Kilns

The air velocities through loads of lumber in a natural-circulation kiln are very low, usually not more than 25 feet per minute; hence short circuiting through voids is small and has little if any effect on drying time or uniformity. To get maximum benefits from the low air velocities, however, certain loading procedures must be followed.

For uniform air circulation in well-designed, natural-circulation, end-piled kilns (fig. 8, p. 24), spaces between the sides of the load and the walls should be at least 18 inches, and preferably 2 feet wide, while the clearance between the top of the load and the ceiling should be about 2 feet. Smaller openings, caused by overloading, limit the volume of air flowing through, reduce its velocity, and prolong drying time. Spaces left between the ends of the kiln and the load have no appreciable effect on air circulation.

In natural-circulation kilns of the cross-piled type, the spaces between the kiln walls and ceiling and the loads should be the same as for end-piled kilns of this type. In addition, a space of at least 8 inches, and preferably 1 foot, should be provided between the loads and also between the ends of the kiln and the loads.

Load baffles should not be used in a natural-circulation kiln. Neither should solid obstructions, such as plank walkways, be placed at track level; walkways should be of the open-grating type. Flues built into the loads to permit air movement through the loads must be open at the top.

Loading Forced-Circulation Compartment Kilns

The higher the air velocity in a dry kiln, the greater is the possibility of short circuiting. In designing forced-circulation kilns, therefore, engineers give careful consideration to the sizes of air ducts, plenum chambers, load flues, and other passages through which air must flow at given rates. When these carefully calculated controls are upset in any way—and overloading and underloading are two of the most common ways—drying time and quality are both altered unless adequate compensatory steps are taken. Naturally, the particular design of a kiln determines to what extent this is so. Loading characteristics of several basic types of forced-circulation kilns are reviewed here.

Loading External-Blower Kilns

In some types of external-blower kilns, air moves upward from ducts at or below floor level (figs. 9, 10, pp. 25, 26). Air velocity is quite high at floor level, but drops off as the air moves upward and laterally through the truckloads of lumber. Both air velocity and air volume are carefully calculated to provide suitable drying rates throughout the kiln when the chamber is loaded to its rated capacity. Proper loading is therefore necessary for efficient operation, and truckloads of stock must be properly located in the kiln.

The external-blower kiln shown in figure 11 was especially designed for package loading, and movement of air is downward through and between the tiers of packages.

End-Piled Kilns.—In the loading of external-blower kilns of the end-piled type, whether of single- or double-track design, the A flues in the loads of lumber must be centered over the slots or portholes in the air ducts. Avoid spaces between the ends of the loads and between the loads and the ends of the kiln that will short circuit the air excessively.

If the kiln cannot be fully charged, use one of two loading methods that help insure uniform airflow through the loads. By method 1, the truckloads of lumber are built low enough so that the full number of trucks is positioned along the track. Thus, short circuiting of air through open areas of the kiln will be avoided. By method 2, full-size loads of lumber are placed in the kiln, thereby "shorting" one or both tracks of loads. Cover boards are laid over the entering- and return-air slots or ports in parts of the ducts that have no truckloads of lumber above them, thus preventing air from short circuiting through these empty areas of the kiln. Method 1 is usually preferred. In double-track kilns, most effective use of method 2 requires that the same number of kiln trucks be put on each track. If a track is not fully occupied, push the loads to one end of the kiln, preferably to the end without doors.

Cross-Piled Kilns.—The Λ flues in the loads of lumber in cross-piled, external-blower kilns must be centered over the supply air ducts so that air can rise directly into the Λ flues. Improper placement upsets air circulation, disrupts drying schedules, and leads to nonuniform drying.

Package-Loaded Kilns.—External-blower kilns designed for package loading (fig. 11, p. 27) have certain definite loading requirements. Since air circulation is downward from overhead ducts, packages must be built and stacked one on another with this direction of airflow in mind. Leave a space of about 12 to 18 inches between the tiers of packages, and locate each alternate space directly below the air supply nozzles. Partially block off the bolster or spacer openings between packages of lumber in each tier, to hold to a minimum the short circuiting of air through them. Short circuiting of air around the ends of the packages of lumber can be largely prevented with vertical baffles that extend from the bottom to the top of the tiers at each end of the entering-air space.

Loading Internal-Fan Kilns

The air velocities obtained in most internal-fan kilns make proper loading of topmost importance because of the greater tendency of the air to short circuit. The loading procedures to be used for each of the several types vary to some extent.

Cross-Piled Kilns.—In cross-piled, track-type, internal-fan kilns, the air movement is either parallel to the stickers or at right angles to them (fig. 13, p. 29).

Maximum efficiency is obtained in cross-piled kilns with air movement parallel to stickers by leaving a space of about 3 inches between the loads and installing load baffles at each end of the kiln.

In kilns with air movement at right angles to the stickers, spaces are provided between the edges of all boards in each course. The space between the sides of the loads of the kiln charge should be as small as possible. Install top load baffles as illustrated in figure 13, between the tops of the truckloads of lumber and the ceiling. If the kiln charge is short one or more truckloads, baffle off the empty part of the kiln.

End-Piled Kilns.—In end-piled, single-track, internal-fan kilns, in which the air moves parallel to the stickers, the distance between the loads of lumber and top load baffles should not exceed 4 inches. Butt the ends of the truckloads of lumber snugly together. If this is not possible because excessively long boards overhang from the ends of the loads or because of step-back or step-out loads, block the voids so caused. If the kiln charge lacks one or more truckloads of lumber, push the entire charge to one end of the kiln and close the empty area by solid baffles extending from the track level to the kiln ceiling, the fan floor, or the top load baffle. If the kiln has doors on one end only, push a charge that is short one or more truckloads toward the closed end rather than the door end of the kiln.

More care is required in loading end-piled, internal-fan kilns having two or more tracks (fig. 14, p. 29, and fig. 17, p. 31) than single-track kilns with the same type of loading. Short circuiting through voids in a charge of lumber in a single-track kiln can be controlled with solid baffles. In a multiple-track kiln, however, a solid baffle blocking a space in one trackload of lumber may reduce airflow through some of the lumber on the other tracks.

A method of baffling voids in a double-track, end-piled, internal-fan kiln is illustrated in figure 102. Track 1 has three truckloads of lumber, one of which is a short load, and track 2 is fully loaded. The void spaces on both tracks between kiln end *D* and the loads are small, about 1 foot wide. A temporary solid baffle extending from the kiln floor to the fan floor can be installed in this opening if desired, but since the opening is quite small the value of a baffle here is questionable. The larger voids between the short and long loads on track 1 and between kiln end *C* and the ends of the loads are blocked off by temporary baffles to prevent excessive short circuiting of the air. The baffles shown on track 1, however, should not be solid. A solid baffle here would block off track 2 from air circulating through the loads from side *A* to side *B*, and the lumber on this track would be shorted of air and dry more slowly than the rest of the charge. Slotted or perforated plywood baffles have been used in a situation like this. Snow fence has

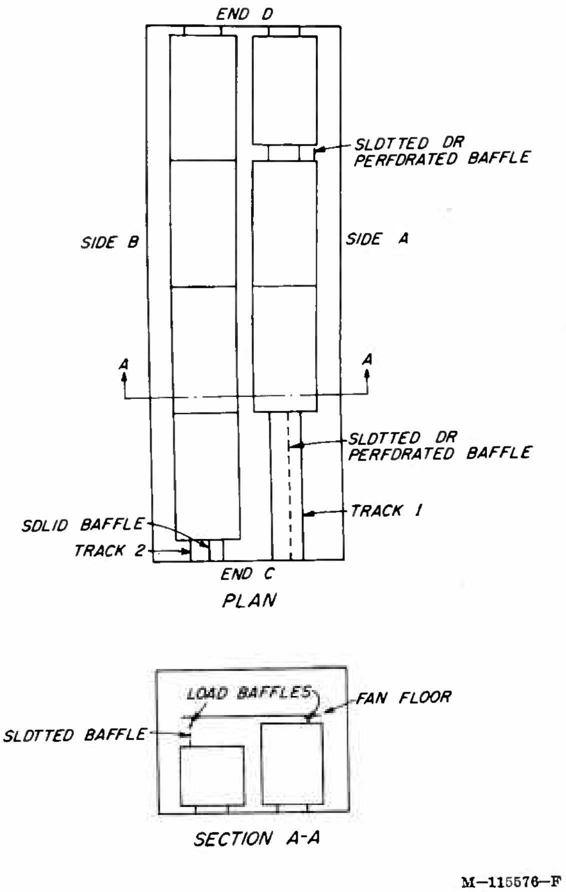


FIGURE 102.—A method of baffling voids in a charge of lumber in a double-track, end-piled, internal-fan kiln.

also been used successfully. Perforated baffles do not provide the same resistance to airflow as a load of lumber, but they reduce short circuiting considerably. The space on end *C*, track 2, is is blocked off with a temporary solid baffle.

The low load illustrated on track 2 (section *A–A*) would produce a large void permitting excessive short circuiting of air if it were not baffled. The slotted or perforated baffle shown between the load baffle and the top of the low load permits air to move across the loads on both tracks in both directions of air flow with very little short circuiting.

If a charge in a double-track kiln is short two truckloads of lumber, load each track one truckload short. Butt the truckloads on each track together. Load both tracks as closely as possible to the same end of the kiln, so that most of the space occurs at the opposite end. Then, with both tracks evenly loaded, two solid, temporary baffles can be used to block off the space on each track.

Placing Packaged Lumber on Kiln Trucks.—At many plants operating track-type kilns, lumber is stacked in packages to reduce handling costs, and the packages are placed on kiln trucks as shown in figure 103. The sides of adjacent packages should be spaced 3 or 4 inches apart. If this is not done, the sticker openings between courses of lumber will not line up as drying progresses and the circulating air may be blocked off, because wood does not shrink uniformly in thickness during drying. A strip of lumber nailed to the ends of the spacers between packages of lumber is also shown in figure 103. Blocking of the openings produced by the spacers (usually 4 inches high) is recommended in forced-circulation kilns, since large volumes of air can short circuit through these spaces.

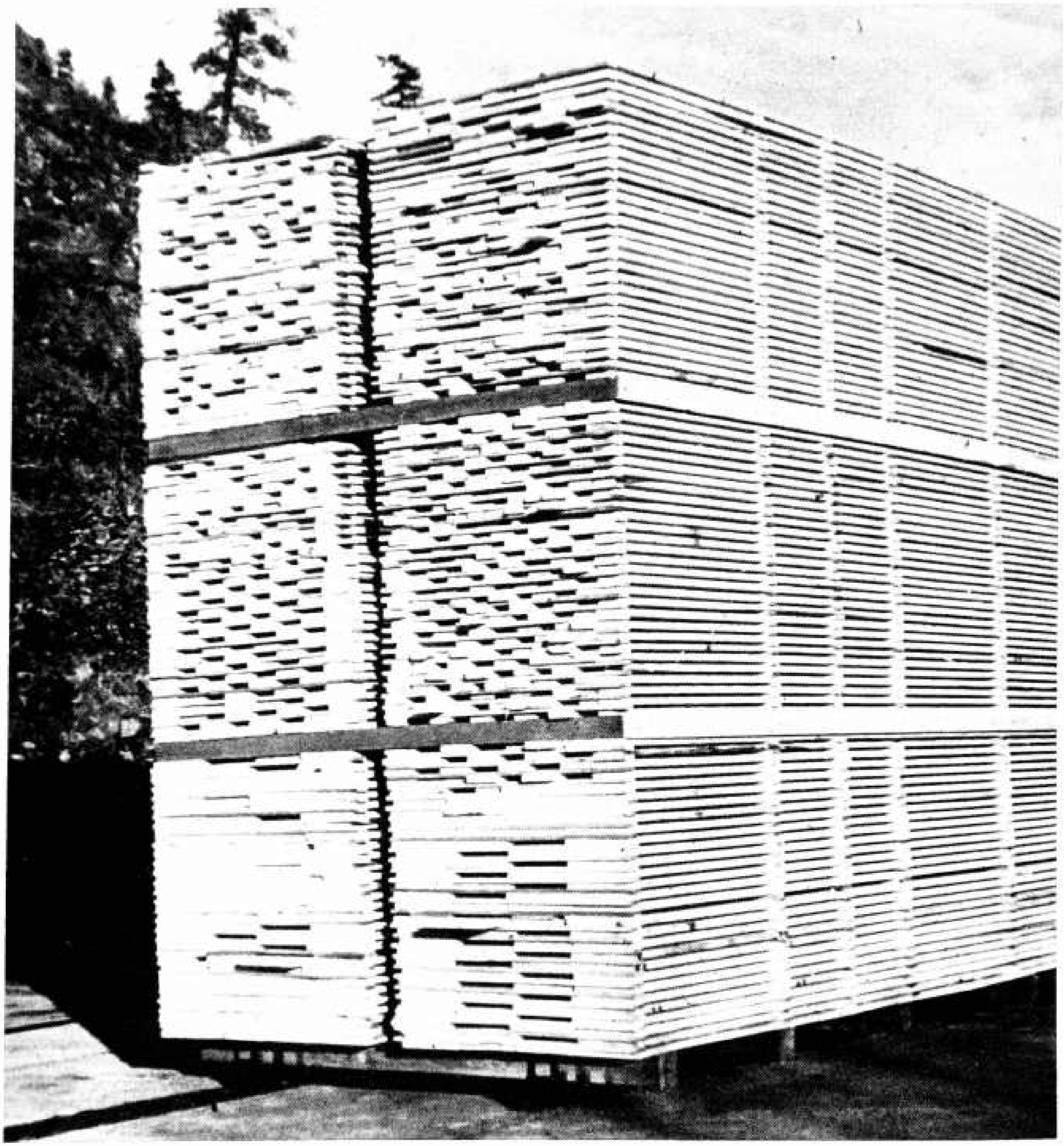
Package Loading of Internal-Fan Kilns.—Careful placement and baffling of the packages of lumber in internal-fan kilns (fig. 15, p. 30 and fig. 18, p. 32) are essential in order to prevent excessive short circuiting. Short circuiting is more critical in this type of kiln than in the track type because of the generally longer distance air must travel from the entering-air to the leaving-air side of the charge. The greater the capacity of these kilns, usually the more difficult it becomes to prevent short circuiting.

Often an extra tier of packages is added to a package-loaded kiln to increase its output. This makes the space between the outside tier of packages and the kiln wall or door (the plenum chambers) narrower than the manufacturer recommends and causes nonuniform air circulation through the charge.

The spaces between adjacent tiers of packages are sometimes made smaller or larger than recommended. If they are too small, circulation through the sticker openings may be stopped. If they are too large, a considerable volume of air will short circuit through these openings over or around the ends of the tiers of packages.

The installation of additional top and side load baffles reduces short circuiting over or around the ends of the tiers of packages and increases kiln efficiency. Temporary solid or slotted baffles may be required when large voids occur in a kiln charge that is short one or more packages or in which the tiers of packages are incomplete. Never use a solid baffle, however, to block off a void space if it will affect airflow through lumber on either side of the void space.

Because of the generally long distance air travels across a charge of lumber in package-loaded kilns, spacer openings between packages should be covered as shown in figure 103 to prevent short circuiting through them.



M–100902–F

FIGURE 103.—Packages of lumber properly spaced side to side on kiln trucks for drying in an internal-fan kiln.

Loading Progressive Kilns

Good practices for loading progressive dry kilns (fig. 19, p. 33 and fig. 20, p. 34) are the same as those for compartment kilns. If the kiln is of the natural-circulation, cross- or end-piled type, the suggestions made herein for compartment kilns of this type are recommended.

The correct loading and baffling of the external-blower, progressive kiln shown in figure 20 is the same as that of the package-loaded, internal-fan compartment kiln. The loading procedures for internal-fan, cross-piled or end-piled progressive kilns should conform to those of the corresponding compartment-type, internal-fan kilns given herein.

CHAPTER 8. KILN SCHEDULES AND DRYING TIME

A kiln schedule is a carefully worked out set of dry-bulb and wet-bulb temperatures which the operator can use to dry a specific wood product at a satisfactory rate without causing objectionable drying defects. Schedules may be classified as general and special. General schedules cover the entire range of drying conditions normally used in dry kilns. One of the general schedules will dry any wood product with reasonable economy. Special schedules are those developed to attain certain drying objectives; for example, to reduce drying time, dry chemically treated wood properly, or maintain maximum strength for special uses. Because of the many variabilities in the character of the wood, type and condition of the kiln, quality of drying required, and cost considerations, no schedule, either general or special, can be considered ideal. The schedules in this chapter are presented as guides for the kiln operator in developing schedules best suited to his operations.

In addition to drying schedules, information is given on sterilizing, equalizing, and conditioning treatments, and drying time.

Rapid drying is achieved in kilns by the use of high temperatures and low relative humidities. Misuse of these may lead to drying defects. These defects are caused by stresses that develop in the wood as it dries. Drying stresses are related to the average moisture content of the stock. That is why drying schedules are often based upon the moisture content of the stock. Since moisture content decreases as drying progresses, it is also possible to base kiln schedules on drying time.

Hardwoods generally take a long time to dry, and many of their uses are critical as to drying defects and moisture content. Hence, their schedules are usually based on moisture content. The development of drying stresses in hardwoods usually makes it possible to lower relative humidity and raise temperature independently to obtain the fastest drying rate (*14*).[1] Such moisture content schedules can be changed to time schedules when very similar stock of the same species is dried repeatedly in the same kiln. When the type of stock or operating procedures are changed, the operator should return to the moisture content schedules.

Satisfactory time schedules have been worked out by industry for repeatedly drying softwood items of a very uniform character in the same type of kiln. An operator inexperienced in drying softwoods, however, may get better results by using moisture content schedules. Also, an experienced operator may be able to save time by using moisture content schedules, when drying time is unduly long.

The schedules given in this chapter are designed for use in modern forced-air kilns with air velocities of between 200 and 400 feet per minute through the load. Modifications are given for kilns operated with lower air velocities. Other modifications may be necessary in kilns with higher air velocities.

The selection of a kiln schedule should be based on an understanding between the operator and management as to what standards of drying are desired, such as drying defects allowable, final average moisture content, degree of moisture uniformity, and final stress condition.

The general schedules are conservative enough to produce stock with a minimum of drying defects in a reasonably short time. The operator should not make the schedules more conservative unless he is drying abnormal stock or kiln performance is below standard. With properly maintained kilns, it is possible to modify the general schedules to shorten the time.

Hardwood Schedules

General Hardwood Schedules

Extensive pilot testing and widespread commercial use have demonstrated that the general schedules for hardwoods developed by the Forest Products Laboratory and presented here are satisfactory for the drying of 2-inch and thinner hardwood lumber and numerous other products. They form a base from which an operator can develop the most economical schedule for a specific type of kiln. Related information on application and modification of schedules is also presented together with suggestions for drying thick hardwoods.

Moisture Content Basis.—The successful control of drying defects in hardwoods depends upon the proper regulation of temperature and relative humidity in the drying procedure.

At the start of drying, a fairly low temperature is required to prevent collapse and honeycombing. Relative humidity must be kept high to keep surface and end checking at a reasonable minimum.

[1] Italic numbers in parentheses refer to Literature Cited, p. 145.

Even at these mild conditions, the lumber will lose moisture rapidly. To maintain a fast drying rate, relative humidity must be lowered and temperature raised as soon as the moisture content and stress condition of the wood will permit. Relative humidity can be dropped gradually after the wood has lost about one-third of its moisture content when green. The temperature can be raised gradually from the time the average moisture content reaches 30 percent. When the moisture content at midthickness reaches 30 percent, the temperature can be raised drastically. Therefore, the principles of efficient drying require that hardwood schedules be based on moisture content of stock. Plenty of kiln samples should be used. The recommended operating procedure is to take the average moisture content of the wetter half of the kiln samples—called the controlling samples—as the factor that determines when to change drying conditions (see ch. 6).

Material Considerations.—The general schedules are for hardwoods that are to be dried from the green condition. They can be modified to apply to previously air-dried material. The schedules are also set up to handle the more difficult-to-dry types of wood within a species—for example, flat-grain heartwood. Because of the difference in the moisture content of sapwood and heartwood in many species, most of the kiln samples should be taken from the wettest heartwood and their moisture content used in applying the drying schedules. Modifications are suggested later in this chapter for stock that is all sapwood.

Operation Considerations.—The general schedules are designed for full-time operation in modern forced-circulation compartment kilns that have the control bulbs properly located on the entering-air side of the loads. (See ch. 4, p. 68, for proper location of control bulbs, especially the procedures to use if the control bulb is not located in the hottest zone.) The schedules must be modified if the bulbs are located on the leaving-air side; otherwise, the wood on the entering-air side will be subject to excessively severe drying conditions (ch. 4).

Also, wet-bulb depressions in the schedules must be modified if air velocity through the load is less than 200 feet per minute. In external-blower kilns, initial wet-bulb depressions can be 1° or 2° F. greater than those recommended in the schedule. In natural-circulation kilns, they can be increased as much as 4°. As drying progresses, the wet-bulb depressions should be gradually brought into accord with the schedules. If air velocity through the load is more than 400 feet per minute, it may be necessary to use slightly smaller initial wet-bulb depressions than those shown in the schedule.

Recommended and Suggested Schedules.—Schedules for dry-bulb temperatures and wet-bulb depressions are given in tables 9 and 10. Together, the dry-bulb temperature and the wet-bulb depression determine the relative humidity and the wood equilibrium moisture content (table 2, p. 11).

Table 9 gives 14 temperature schedules ranging from a very mild schedule, T1, to a severe schedule, T14. Initial temperatures, in all cases, are maintained until the average moisture content of the controlling samples reaches 30 percent.

Table 10 gives the wet-bulb depression schedules for six moisture content classes. These classes are related to the green moisture content of the wood (table 11). Another moisture content class, "H," is discussed on page 125. There are eight numbered wet-bulb depression schedules, No. 1 being the mildest and No. 8 the most severe. The wet-bulb temperature to be set on the recorder-controller is obtained by subtracting the wet-bulb depression from the dry-bulb temperature.

Table 12 is an index of recommended schedules for 4/4 to 8/4 hardwood lumber and other items. While the same schedule is given for 4/4, 5/4, and 6/4 stock, these thicknesses obviously will have different drying times and should be dried separately. For drying 6/4 stock of such refractory species as oak, the use of the schedule indicated for 8/4 stock may be desirable.

Kiln-drying hardwoods thicker than 8/4 from the green condition is usually impractical because of long kiln time. The best practice for this material is to end coat and air-dry it under a roof before kiln-drying it. Table 13 is an index of suggested schedules for 10/4 and thicker hardwood lumber. They should be considered as tentative until tested commercially.

Assembly of a Drying Schedule.—Using a form like that shown in table 14, work up a drying schedule as follows:

(1) From table 12, find the schedule code numbers for the material to be dried. The example worked out in table 14 is for 4/4 sugar maple that calls for code numbers T8–C3. Place the code numbers in the space provided at the top of the form.

(2) Since the first change in drying conditions involves the wet-bulb depression, write down the wet-bulb depression step nos. 1, 2, 3, 4, 5, and 6, in column 2.

(3) In column 3 of the form write the moisture content values corresponding to these steps from the appropriate moisture content class of table 10. In this example the class is "C" and the values are: above 40, 40, 35, 30, 25, and 20, respectively.

(4) In columns 5 of the form write down the wet-bulb depression values corresponding to the

TABLE 9.—*General temperature schedules for hardwoods*

Temperature step No.	Moisture content at start of step	Dry-bulb temperatures for temperature schedule No. —													
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14
	Percent	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
1	Above 30	100	100	110	110	120	120	130	130	140	140	150	160	170	180
2	30	105	110	120	120	130	130	140	140	150	150	160	170	180	190
3	25	105	120	130	130	140	140	150	150	160	160	160	170	180	190
4	20	115	130	140	140	150	150	160	160	160	170	170	180	190	200
5	15	120	150	160	180	160	180	160	180	160	180	180	180	190	200

TABLE 10.—*General wet-bulb depression schedules for hardwoods*

Wet-bulb depression step No.	Moisture content at start of step for moisture content class—						Wet-bulb depressions for wet-bulb depression schedule No. —							
	A	B	C	D	E	F	1	2	3	4	5	6	7	8
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
1	Above 30	Above 35	Above 40	Above 50	Above 60	Above 70	3	4	5	7	10	15	20	25
2	30	35	40	50	60	70	4	5	7	10	14	20	30	35
3	25	30	35	40	50	60	6	8	11	15	20	30	40	50
4	20	25	30	35	40	50	10	14	19	25	35	50	50	50
5	15	20	25	30	35	40	25	30	35	40	50	50	50	50
6	10	15	20	25	30	35	50	50	50	50	50	50	50	50

TABLE 11.—*Moisture content classes for various green moisture content values*

Green moisture content	Moisture content class	Green moisture content	Moisture content class
Percent		*Percent*	
Up to 40	A	80 to 100	D
40 to 60	B	100 to 120	E
60 to 80	C	Above 120	F

TABLE 12.—*Code number index of schedules* [1] *recommended for kiln-drying hardwood 4/4 to 8/4 lumber and other products*

Species	Lumber: 4/4, 5/4, and 6/4 stock — Temperature	Lumber: 4/4, 5/4, and 6/4 stock — Wet-bulb depression	Lumber: 8/4 stock — Temperature	Lumber: 8/4 stock — Wet-bulb depression	Other products: Name	Other products: Temperature	Other products: Wet-bulb depression
Alder, red	T10	D4	T8	D3			
For darker color	T11	D3	----	----			
For lighter color	T5	D5	----	----			
Apple	T6	C3	T3	C2			
Ash, black	T8	D4	T5	D3			
Ash, green, Oregon, white	T8	B4	T5	B3			
Aspen	T12	E7	T10	E6			
Basswood	T12	E7	T10	E6			
Beech	T8	C2	T5	C1	1-inch squares	T8	C3
					2-inch squares	T5	C2
Birch, paper	T10	C4	T8	C3	1-inch squares	T10	C6
					2-inch squares	T8	C4
Birch, yellow	T8	C4	T5	C3	1-inch squares	T8	C5
					2-inch squares	T5	C4
Buckeye, yellow	T10	F4	T8	F3			
Butternut	T10	E4	T8	E3			
Cherry, black	T8	B4	T5	B3			
Chestnut	T10	E4	T8	E3			
Cottonwood, normal	T10	F5	T8	F4			
Cottonwood, wet streak	T8	D5	T6	C4			
Dogwood	T6	C3	T3	C2	Shuttles	T3	B2
Elm, American and slippery	T6	D4	T5	D3			
Elm, rock	T6	B3	T3	B2			
Hackberry	T8	C4	T6	C3			
Hickory	T8	D3	T6	D1	White handles—Small	T1	D2
					—Large	T1	C2
					Pink handles —Small	T8	D1
					—Large	T8	C1
Holly	T6	D4	T4	C3			
Hophornbeam (ironwood)	T6	B3	T3	B1			
Lauan, dense	T8	C2	T7	B2			
Lauan, light and medium	T11	D4	T10	D3			
Laurel, California (Oregon Myrtle)	T6	A4	T5	A3			
Locust, black	T6	A3	T3	A1			
Madrone	T4	B2	T3	B1			
Magnolia	T10	D4	T8	D3			
Mahogany	T6	C4	T4	C3			
Maple, bigleaf, red, silver	T8	D4	T6	C3			
Maple, sugar (hard)	T8	C3	T5	C2	Bowling pins (end coated)	T3	A3
					1-inch squares	T8	C4
					2-inch squares	T5	C3
Oak, California black	T4	E2	T3	E1			
Oak, red	T4	D2	T3	D1			
Oak, white	T4	C2	T3	C1			

TABLE 12.—*Code number index of schedules*[1] *recommended for kiln-drying hardwood 4/4 to 8/4 lumber and other products*—Continued

Species	Lumber: 4/4, 5/4, and 6/4 stock: Temperature	Lumber: 4/4, 5/4, and 6/4 stock: Wet-bulb depression	Lumber: 8/4 stock: Temperature	Lumber: 8/4 stock: Wet-bulb depression	Other products: Name	Other products: Temperature	Other products: Wet-bulb depression
Oak, southern lowland	T2	C1	---	---			
Osage-orange	T6	A2	T3	A1			
Pecan	T8	D3	T6	D1			
Persimmon	T6	C3	T3	C2	Golf club heads	T3	C2
					Shuttles	T3	B2
Sweetgum (sap gum)	T12	F5	T11	D4	1-inch squares	T12	F6
					2-inch squares	T11	D5
Sweetgum (red gum)	T8	C4	T5	C3			
Sycamore	T6	D2	T3	D1			
Tanoak	T4	C1	T3	B1			
Tupelo, black	T12	E5	T11	D3			
Tupelo, swamp	T10	E3	T8	D2			
Tupelo, water	T6	H2	---	---			
Walnut, black	T6	D4	T3	D3	Gunstock blanks	T3	D4
Willow, black	T10	F4	T8	F3			
Yellow-poplar	T11	D4	T10	D3			

[1] Schedules are given in tables 9 and 10.

TABLE 13.—*Code number index of kiln schedules suggested for drying thick hardwoods*[1]

Species	Schedules for—[2] 10/4 stock: Temperature	10/4 stock: Wet-bulb depression	12/4 stock: Temperature	12/4 stock: Wet-bulb depression	16/4 stock: Temperature	16/4 stock: Wet-bulb depression
Alder, red	T6	C3	T6	C3	---	---
Ash, white	T5	B3	T3	B2	T3	A1
Aspen	T8	E5	T8	D5	T7	C4
Birch, yellow	T5	B3	T3	B2	T3	A1
Cherry	T5	B2	T3	B2	T3	A1
Cottonwood	T6	E3	T5	D2	---	---
Cottonwood, wet streak	T4	D3	T3	C2	---	---
Elm, American	T5	D2	T3	C2	---	---
Elm, rock	T3	B2	T3	B1	T3	A1
Hackberry	T6	C3	T5	C2	T3	B1
Lauan (medium and light)	T9	C3	T7	C2	T5	C1
Mahogany	T4	B3	T3	B2	T3	B1
Maple, bigleaf, red, silver	T5	C2	T3	B2	---	---
Maple, sugar (hard)	T3	B2	T3	A1[3]	T3	A1[3]
Oak, red	T3	C1	T3	C1	---	---
Oak, white	T3	B1	T3	B1	---	---
Sweetgum (sap gum)	T11	D3	T9	C3	---	---
Sweetgum (red gum)	T5	C2	T5	B2	---	---
Sycamore	T3	D1	T3	C1	T3	B1
Tupelo, black	T11	D3	T9	C2	T7	C2
Walnut, black	T3	D3	T3	C2	---	---
Yellow-poplar	T9	C3	T7	C2	T5	C2

[1] A good end coating should be applied to all stock in most cases.
[2] For squares, use a wet-bulb depression number one unit higher than the one suggested for lumber. Thus, for 3- by 3-inch birch, use T3-B3.
[3] After passing 30 percent moisture content, gradually shift to wet-bulb depression schedule B2.

steps from the appropriate wet-bulb depression schedule number from table 10. The number is 3 in this example, and the wet-bulb depression values are 5, 7, 11, 19, 35, and 50, respectively.

TABLE 14.—*Method of assembly of kiln-drying schedule for green 4/4 sugar maple*

Schedule Code No. T8–C3

Temperature step No.	Wet-bulb depression step No.	Moisture content at start of step	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature
		Percent	°*F.*	°*F.*	°*F.*
1	1	Above 40	130	5	125
1	2	40	130	7	123
1	3	35	130	11	119
2	4	30	140	19	121
3	5	25	150	35	115
4	6	20	160	50	110
5	6	15	180	50	130

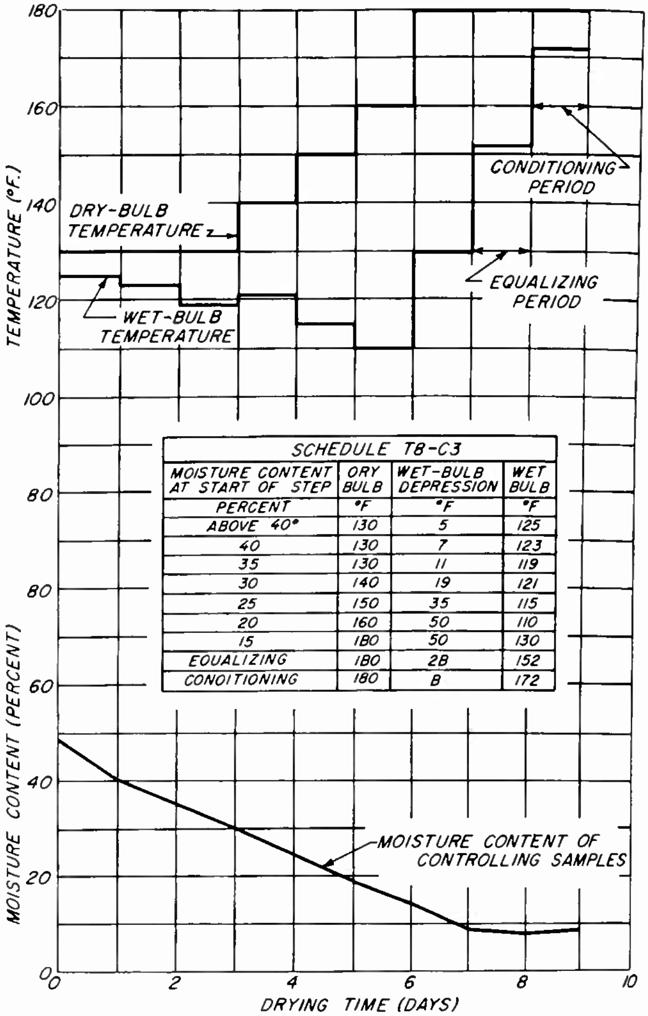
(5) Write down the temperature step numbers in column 1 of the form. Since dry-bulb temperature changes are not made until the average moisture content of the controlling samples reaches 30 percent, repeat temperature step number 1 as often as necessary. In this example it is repeated 3 times. The moisture content at the start of temperature step 5 is 15 percent (table 9). Therefore, in filling out the schedule form it is necessary to repeat wet-bulb depression step 6 as shown in table 14.

(6) In column 4 of the form write down the dry-bulb temperature that corresponds to the temperature step number in table 9. If step 1 is repeated, the initial dry-bulb temperature must be repeated as shown in table 14.

(7) Subtract the wet-bulb depression from the dry-bulb temperature in each step to obtain the corresponding wet-bulb temperature. These values are entered in column 6 of the form.

Columns for relative humidity and equilibrium moisture content can be added at the right of the table, if desired. The values can be obtained from table 2. The T8–C3 schedule for 4/4 sugar maple and a drying curve obtained in a pilot test kiln run are illustrated in figure 104.

In the final stages of drying, wet-bulb temperature does not need to be under exact control. When the wet-bulb depression schedule calls for a 50° wet-bulb depression while the dry-bulb temperature is still fairly low, discontinue control of



M–91938–F

FIGURE 104.—Kiln schedule and drying curve for 4/4 sugar maple.

the wet-bulb temperature by closing the steam spray hand valve and opening the vents. Do not raise the dry-bulb temperature, unless you are deliberately modifying the schedule.

Uniformity of moisture content and relief of drying stresses are achieved by equalizing and conditioning treatments near the end of drying as described on pages 142 to 144.

Examples of Assembled Schedules.—Some general schedules for 4/4 and 8/4 hardwoods, assembled from tables 9 and 10, are illustrated in table 15. A study of these will be helpful when assembling schedules for other types of material.

The schedules listed in tables 9 and 10 may be conservative for some types of dry kilns and for some drying requirements. As an operator gains experience, he should, when possible, modify them to reduce drying time. Schedule modifications are discussed later in this chapter.

TABLE 15.—*Examples of general kiln schedules for drying lumber of certain hardwood species*

Moisture content at start of step	4/4, 5/4, 6/4 stock			8/4 stock		
	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature
OAK, SOUTHERN LOWLAND						
	Schedule T2–C1			No schedule established		
Percent	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
Above 40	100	3	97	---	---	---
40	100	4	96	---	---	---
35	100	6	94	---	---	---
30	110	10	100	---	---	---
25	120	25	95	---	---	---
20	130	50	[1]	---	---	---
15	150	50	[1]	---	---	---
OAK, WHITE						
	Schedule T4–C2			Schedule T3–C1		
Above 40	110	4	106	110	3	107
40	110	5	105	110	4	106
35	110	8	102	110	6	104
30	120	14	106	120	10	110
25	130	30	100	130	25	105
20	140	50	[1]	140	50	[1]
15	180	50	[1]	160	50	[1]
MAHOGANY						
	Schedule T6–C4			Schedule T4–C3		
Above 40	120	7	113	110	5	105
40	120	10	110	110	7	103
35	120	15	105	110	11	99
30	130	25	105	120	19	101
25	140	40	100	130	35	95
20	150	50	[1]	140	50	[1]
15	180	50	[1]	180	50	[1]
ASH, WHITE; CHERRY						
	Schedule T8–B4			Schedule T5–B3		
Above 35	130	7	123	120	5	115
35	130	10	120	120	7	113
30	140	15	125	130	11	119
25	150	25	125	140	19	121
20	160	40	120	150	35	115
15	180	50	[1]	160	50	[1]
MAGNOLIA						
	Schedule T10–D4			Schedule T8–D3		
Above 50	140	7	133	130	5	125
50	140	10	130	130	7	123
40	140	15	125	130	11	119
35	140	25	115	130	19	111
30	150	40	110	140	35	105
25	160	50	[1]	150	50	[1]
20	170	50	[1]	160	50	[1]
15	180	50	[1]	180	50	[1]

[1] Close control of wet-bulb temperature not necessary.

TABLE 15.—*Examples of general kiln schedules for drying lumber of certain hardwood species*—Continued

TUPELO, BLACK

Moisture content at start of step	Schedule T12–E5: 4/4, 5/4, 6/4 stock — Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature	Schedule T11–D3: 8/4 stock — Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature
Percent	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
Above 60	160	10	150	150	5	145
60	160	14	146	150	5	145
50	160	20	140	150	7	143
40	160	35	125	150	11	139
35	160	50	(1)	150	19	131
30	170	50	(1)	160	35	125
25	170	50	(1)	160	50	(1)
20	180	50	(1)	170	50	(1)
15	180	50	(1)	180	50	(1)

ASPEN, BASSWOOD

Moisture content at start of step	Schedule T12–E7: Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature	Schedule T10–E6: Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature
Above 60	160	20	140	140	15	125
60	160	30	130	140	20	120
50	160	40	120	140	30	110
40	160	50	(1)	140	50	(1)
35	160	50	(1)	140	50	(1)
30	170	50	(1)	150	50	(1)
25	170	50	(1)	160	50	(1)
20	180	50	(1)	170	50	(1)
15	180	50	(1)	180	50	(1)

[1] Close control of wet-bulb temperature not necessary.

Use of Schedules for Air-Dried Stock.—The general schedules for green hardwoods are also recommended for the kiln-drying of previously air-dried stock or stock that has gone through a predrier. Prepare most of the representative kiln samples from the wettest and slowest drying material, but have at least one sample from the driest and fastest drying stock (see chapter 6). Determine the average moisture content of the wettest half of the samples before the kiln is started. Both the temperature step and the wet-bulb depression step of the recommended schedule corresponding to that moisture content should be entered directly if the stock has not undergone surface wetting or been exposed for a considerable period to high relative humidity just before it was placed in the kiln. For stock that has regained surface moisture, follow the recommended temperature schedule, but use a wet-bulb depression of 8° to 10° F. for 12 to 24 hours before changing to the wet-bulb depression of the schedule. This change can be abrupt for 6/4 and thinner stock but should be gradual for 8/4 and thicker stock.

The kiln-drying conditions for 4/4 air-dried black cherry that has regained surface moisture before entering the kiln are shown in figure 105.

Air-dried stock should not be steamed at the start of kiln-drying. Steaming may cause surface checks to open during subsequent drying and thereafter remain open. It also may increase warping.

Modifications of General Hardwood Schedules

Once a kiln operator has dried a certain species and item by one of the general kiln schedules without incurring defects or excessive degrade, he should consider modification of the schedule to reduce drying time. Perhaps the material can stand a more severe schedule without developing serious defects, or the dried product does not need to be defect free. The operator should try to develop the fastest drying schedules consistent with acceptable amounts and types of defects. Schedule modification should be done in a systematic manner, for which good records will be helpful. It must be recognized, however, that modification satisfactory for material from one source and dried in one kiln may not be

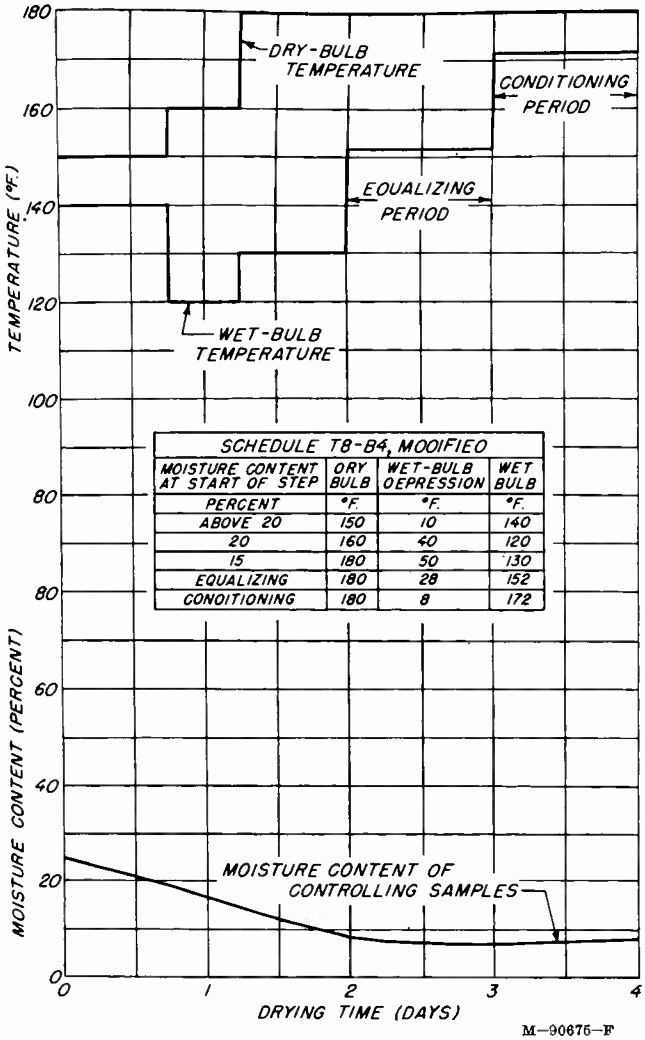


FIGURE 105.—Kiln schedule and drying curve for air-dried 4/4 black cherry that had regained surface moisture before entering the kiln.

satisfactory for material from another source and dried at another plant.

Kiln schedule modifications required by factors of kiln operation or performance are dealt with in chapter 10.

The first move in systematic schedule modification is to shift from one wet-bulb depression schedule to another; the second is to shift temperature schedules; and the third is to modify certain steps within the schedule.

Shifting Wet-bulb Depression Schedules.—The moisture content classes (table 11, p. 120) are set up so that a species of wood can be classified in accordance with the green moisture content of its heartwood. The moisture content limits of the classes were chosen on a conservative basis. Thus the first modification that a kiln operator should try is to shift to a higher moisture class letter, particularly if the green moisture content is near the upper end of the values in the class. For example, 4/4 northern red oak at 95 percent moisture content has been successfully dried in pilot tests on the E2 instead of the D2 schedule, with a saving of 4 or 5 days in drying time. This modification is especially useful when the wood to be dried is mostly sapwood.

The next modification that should be tried is to shift to the next higher wet-bulb depression schedule number. This modification may cause minor surface and end checks that are generally of little concern for many uses. A drastic change in wet-bulb depression may cause severe surface and end checks.

H Wet-Bulb Depression Schedules.—A special moisture content class, designated as H, has been devised to permit more intensive use of the principles that the first change in wet-bulb depression can be made at the time one-third of the green moisture is gone and that additional increases in wet-bulb depressions can be made soon after. This is particularly useful in drying woods with a green moisture content in excess of 140 percent, but may also be applied with some advantage to stock with a green moisture content of 100 percent or more. The H schedules are given in table 16. The wet-bulb depressions for each wet-bulb depression schedule number are the same as those in table 10, p. 119.

To set up a specific H schedule, find the moisture content for the first change in wet-bulb depression by taking two-thirds of the average green moisture content of the controlling samples. If, for example, their average green moisture content is 168 percent, the first change point is 112 percent. For convenience, this is rounded to 110. Subsequent changes in wet-bulb depression are made after each 10 percent loss in moisture. An H schedule developed for 6/4 water tupelo heartwood is shown in figure 106. In view of the long drying time in this particular case, the stock probably should have been air-dried before being kiln-dried. The principle is, of course, applicable to other woods that dry more readily.

Shifting Temperature Schedules.—Temperature is critical in preventing collapse and honeycombing, two defects that may not show up until later in the drying process. Until the kiln operator has gained experience in drying a material, he should adhere to the recommended temperature schedule number. The general temperature schedules will safely dry the most defect-susceptible material commonly encountered in commercial drying. If the material being dried is almost all sapwood or is relatively free of natural characteristics that contribute to seasoning defects, increasing the temperature (T) number by 1 or 2 so as to get a 10° F. greater initial temperature generally is permissible. For example, 9/4 all-sapwood sugar maple free of path-

TABLE 16.—*H-type wet-bulb depression schedules for hardwoods*

Wet-bulb depression step No.	Moisture content at start of step	Wet-bulb depressions for wet-bulb depression schedule No. —							
		1	2	3	4	5	6	7	8
	Percent	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
1	Green (G.)	3	4	5	7	10	15	20	25
2	2/3 G.	4	5	7	10	14	20	30	35
3	2/3 G.–10	6	8	11	15	20	30	40	50
4	2/3 G.–20	10	14	19	25	35	50	50	50
5	2/3 G.–30	25	30	35	40	50	50	50	50
6	2/3 G.–40	50	50	50	50	50	50	50	50

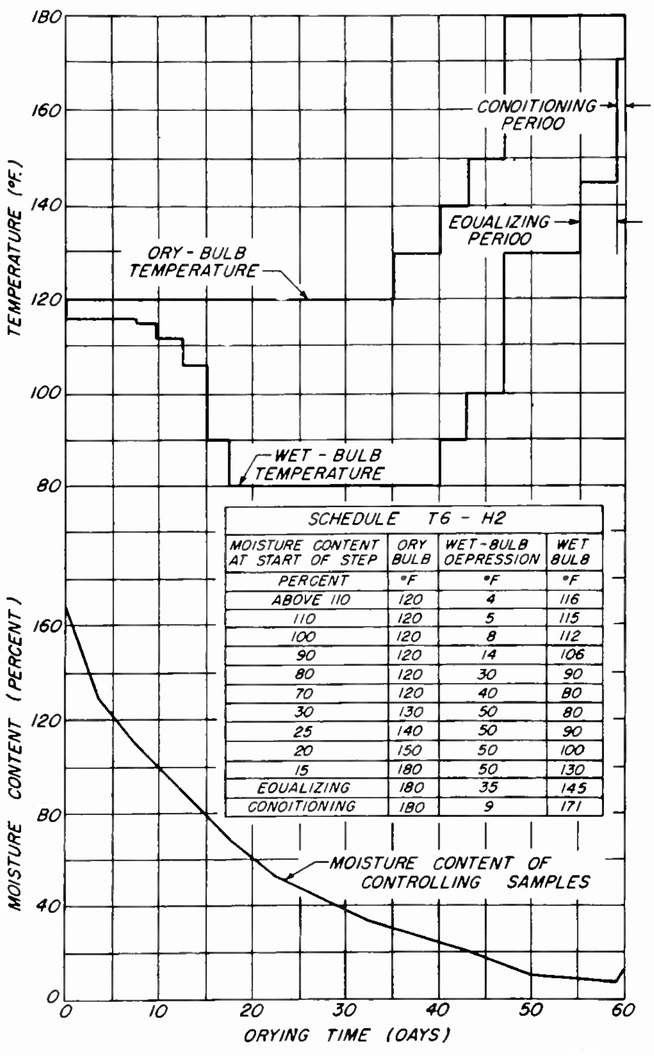


FIGURE 106.—Kiln conditions and drying curve for 1½-inch water tupelo heartwood, based on kiln schedule T6–H2.

ological heartwood and mineral streak has been dried on a T7 temperature schedule instead of the recommended T5 schedule. The milder T5 schedule would be used for drying a charge of sugar maple that had a considerable amount of heartwood or mineral streak.

Changes Within the Schedules.—The only significant change that can be made within a wet-bulb depression schedule would be a more rapid reduction of wet-bulb temperature during the intermediate stages of drying. Limited studies on drying stress reversal show that this is possible for some woods and may be possible for more. Some examples are given below under the heading of "Special Hardwood Schedules," but until research establishes which woods can be subjected to this modification, proceed with caution. The logical approach is to increase the wet-bulb depressions in steps 3 and 4 of table 10, p. 119. Dry several charges on the modified schedule before making further modification. If an objectionable amount of checking occurs, ease back the wet-bulb depression to the previously satisfactory schedule.

Three types of temperature changes within the T schedules (table 9, p. 119) can be considered. One is using a temperature in the initial stage of drying that is intermediate between steps 1 and 2 of the recommended schedule. For some slow-drying woods, such as 4/4 red oak, the use of an initial temperature of 115° F. instead of 110° until the stock reaches 30 percent moisture content may be satisfactory. Another type of change is to increase the dry-bulb temperature during the intermediate stages of drying. This is to be avoided unless it has been shown to be satisfactory by special research. A third type of change is to increase the temperature during the last stages of drying. After the average moisture content of the controlling samples has reached 15 percent, temperatures up to 200° can be used without damaging the wood, except for very slight strength reductions.

When modifications are being made in the temperature schedules, use the recommended wet-bulb depressions or those found satisfactory through modification.

Special Hardwood Schedules

While the general hardwood schedules, with minor modifications such as any kiln operator should make, will do a good job of drying most species, the special schedules developed by research are advantageous in some cases. A few examples follow.

Maximum Strength Schedules.—Exposure of wood to temperatures above 150° F. can cause some permanent reductions in strength. At kiln temperatures of 200° or less, the exposure would have to be prolonged to cause excessive strength reductions. Thus, the general kiln schedules and proper operating procedures produce kiln-dried wood with so little strength reduction that the loss is insignificant for most uses of the wood. However, when the wood is to be used for products requiring high strength per unit of weight, such as aircraft, ladders, and sporting goods, somewhat lower temperatures throughout the drying process should be used. The special temperature schedules set up to dry aircraft lumber are given in Military Spec. MIL–W–6109 (*18*).

Alternate Schedules for Some Species.—Special schedules have been developed at the Forest Products Laboratory for hickory, black tupelo (black gum), swamp tupelo, and water tupelo. Some examples of special schedules are given in table 17. As schedules become more severe, the range of quality of material on which they can be used becomes more restricted. The literature on the subject should be consulted (*1*, *9*, *10*, *15*, *16*, *17*) before trying these schedules, especially those for water tupelo. Some of the heartwood of this species may be difficult to distinguish from sapwood (*9*).

TABLE 17.—*Special kiln schedules for certain hardwood species*

HICKORY, ALL SPECIES

Moisture content at start of step	Temperature schedule for—					
	4/4 stock		6/4 stock		8/4 stock	
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb
Percent	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
Above 50	130	125	120	115	120	117
50	130	123	120	113	120	116
40	130	114	125	114	120	113
35	130	114	130	97	125	114
30	150	112	140	104	130	97
25	150	100	140	104	140	90
20	180	130	180	130	150	100
15	180	130	180	130	180	130

TABLE 17.—*Special kiln schedules for certain hardwood species*—Continued

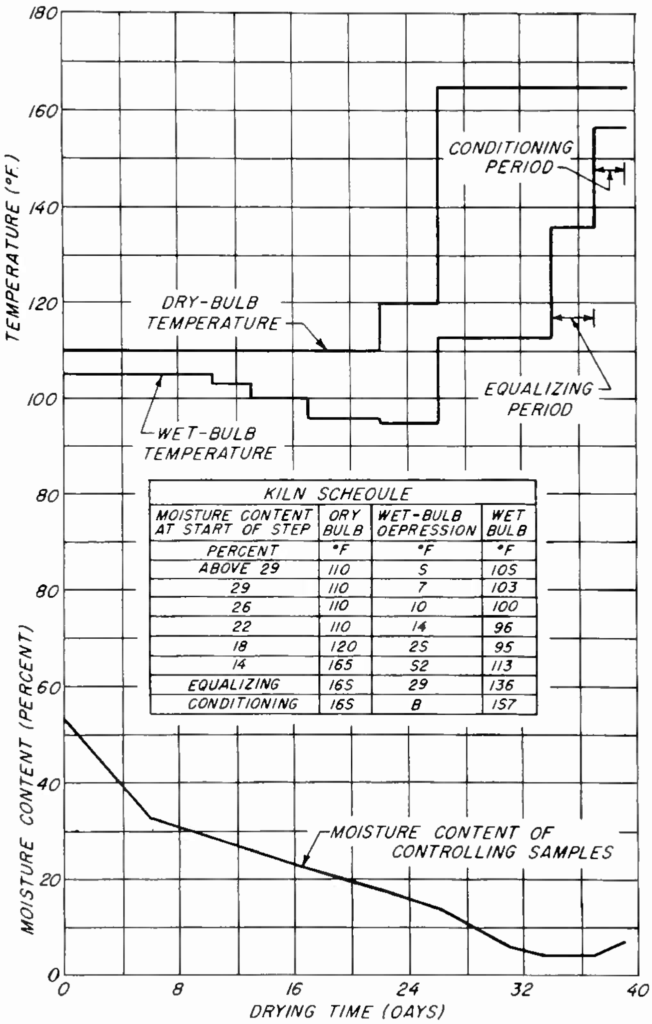
Moisture content at start of step	Temperature schedule for—					
	4/4 stock		6/4 stock		8/4 stock	
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb
	TUPELO, BLACK, HEART- OR SAPWOOD					
Percent	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
Above 70	160	147	------	------	160	154
70	180	162	------	------	160	154
50	180	162	------	------	180	172
40	180	152	------	------	180	172
30	180	152	------	------	180	159
20	200	150	------	------	200	150
	TUPELO, SWAMP; HEARTWOOD [1]					
Above 60	------	------	140	135	------	------
60	------	------	140	133	------	------
50	------	------	140	129	------	------
40	------	------	140	121	------	------
35	------	------	140	105	------	------
30	------	------	150	100	------	------
25	------	------	160	110	------	------
20	------	------	170	120	------	------
15	------	------	180	130	------	------
	TUPELO, SWAMP, SAPWOOD					
Above 60	160	150	160	150	------	------
60	160	146	160	150	------	------
50	160	146	160	140	------	------
40	160	146	160	125	------	------
35	160	110	160	125	------	------
30	170	120	170	120	------	------
25	170	120	170	120	------	------
20	180	130	180	130	------	------
15	180	130	180	130	------	------
	TUPELO, WATER; HEARTWOOD					
Above 70	130	123	120	[2] 116	------	------
70	130	120	120	80	------	------
60	130	115	120	80	------	------
50	130	105	120	80	------	------
40	130	90	120	80	------	------
35	130	80	120	80	------	------
30	140	90	130	80	------	------
25	150	100	140	90	------	------
20	160	110	150	100	------	------
15	180	130	180	130	------	------
	TUPELO, WATER, SAPWOOD					
Above 70	160	150	140	133	------	------
70	160	150	140	130	------	------
60	160	146	140	125	------	------
50	160	146	140	115	------	------
40	160	146	140	100	------	------
35	160	110	140	90	------	------
30	170	120	150	100	------	------
25	170	120	160	110	------	------
20	180	130	170	120	------	------
15	180	130	180	130	------	------

[1] Use 6/4 schedule for 4/4 stock. A more severe schedule is possible but it has not been specifically tested.

[2] See figure 106 for changes between 110 and 70 percent moisture content on the H2 schedule.

Schedules for Thin Stock.—While thinner lumber dries faster than 4/4 lumber on the 4/4 schedule, there are unusual possibilities for greatly accelerating the drying of thin stock by special schedules. Such proved to be the case in an experiment at the Forest Products Laboratory with ½-inch northern red oak (*7*). While the commercial drying time for 4/4 to 5/4 red oak to be resawn to ⅜ or ½ inch is from 18 to 30 days, the ½-inch test material was dried in only 36 hours. The schedule is shown in table 18.

Schedules for Specific Products.—Special schedules have been developed for such hardwood products as bowling-pin, shoe-last, shuttle, and gunstock blanks, and tight cooperage and handle stock. Although general schedules are listed for some of these in table 12, p. 120, it would be advisable to examine the literature before attempting to dry them (*1, 8, 10, 13*). A special schedule for bowling-pin blanks is shown in figure 107. This schedule also may be suitable for No. 11 shoe-last blanks, though they have been successfully dried on the general T3–A3 schedule.



M–87200–F

FIGURE 107.—Kiln schedule and drying curve for maple bowling-pin blanks, regulation size, end coated but not side coated.

TABLE 18.—*Kiln schedule for ½-inch northern red oak*

Moisture content at start of step	Temperature		Time in experimental kiln
	Dry-bulb	Wet-bulb	
Percent	*°F.*	*°F.*	*Hrs.*
Above 70	170	165	0–7
70	170	123	7–24
20	200	150	24–[1] 36

[1] Includes an equalizing treatment of 4 hours.

Schedules for Chemically Treated Wood.—One purpose of treating wood with chemicals is to assist in drying the wood without seasoning defects. This is called chemical seasoning. Other purposes are to help preserve the wood or to retard fire. Chemically treated materials generally require modified drying procedures.

A hygroscopic chemical is used in chemical seasoning to retain moisture in the surface layers, so that they do not check. The relative humidity in the kiln at the start of kiln-drying must be low enough to prevent surface condensation, leaching of the chemical, and possible corrosion of metal within the kiln. If the relative humidity is too low, however, excessive checking may result. One chemical seasoning agent is composed largely of salt (sodium chloride) having, at kiln-drying temperatures, an equilibrium relative humidity of about 75 percent. This requires an initial wet-bulb depression of at least 9° F., and preferably slightly more, if the salt-treated stock is green. Hold this rather small initial depression until a larger one is called for by the recommended schedule. If the stock has been air-dried to 25 percent moisture content or less, initial wet-bulb depressions of 14° or more should be satisfactory. The recommended dry-bulb temperature schedules can be used, but limit the maximum temperature to 150°.

The same general considerations apply in the drying of preservative-treated or fire-retardant-treated wood. The chemicals used for preservative treatment are not very hygroscopic, so little or no adjustment in the recommended wet-bulb depression schedules need be made. Generally, preservative-treated wood dries more rapidly than untreated wood with the same average moisture content.

Fire-retarding chemicals generally are more hygroscopic than preservative chemicals and are used in much higher amounts. Follow the adjustments of the wet-bulb depression schedule, as suggested for chemically seasoned material.

Chemicals accelerate the strength-reducing effect of prolonged exposure of moist wood to high temperatures, some faster and more seriously than others. Some chemicals decompose at normal kiln-drying temperatures, dissipating the gaseous products, so that the chemical treatment becomes ineffective. Before attempting to kiln-dry treated wood, obtain drying-temperature recommendations from the treating company or manufacturer of the chemical.

Schedules for Foreign Woods

Drying studies made at the Forest Products Laboratory on foreign woods, though limited, indicate that the general principles involved in drying native woods are applicable, but that some of the foreign woods may be considerably more difficult to dry without seasoning defects. Information on schedules for foreign woods may be available from several sources, including dry kiln manufacturers, State laboratories, and forestry schools, as well as the Forest Products Laboratory. Because of confusion in the common names of foreign woods, the botanical name of the wood and its origin, and also a sample of the wood if available, should always be sent along with requests for information.

Softwood Schedules

Softwood Moisture Content Schedules

The softwood moisture content schedules presented in this manual are derived from Forest Products Laboratory research results and a study of current industry practice. These schedules can be used with the aid of kiln sample procedures (ch. 6) to dry softwoods with a minimum of seasoning defects. Because softwoods are generally easy to dry, however, it may be more practical to use the commercial time schedules described in a later section.

Moisture Content Basis.—As in the drying of hardwoods, there is a relationship between the moisture content of the stock and the drying conditions it can withstand. Although the stress patterns developing in softwoods as drying progresses differ from those in hardwoods, the surface zones do become stressed in tension during the first stages of drying and ultimately become stressed in compression. Stress reversal generally does not occur, however, until the stock reaches a moisture content somewhere between 20 and 15 percent. Therefore, wet-bulb depressions should not be drastically increased until the stock reaches this moisture content. Gradual changes in wet-bulb depression can be made early in drying, however, in accordance with the moisture content of the stock. The temperature and moisture content relationships that cause collapse and honeycombing in hardwoods affect softwoods similarly.

Material Considerations.—The difference between sapwood and heartwood moisture content is considerable in many softwoods (table 1, p. 9). Generally, the heartwood is more susceptible to drying defects, so most of the schedules are based on the moisture content of the heartwood. In some situations, however, the heartwood dries to a safe moisture content value before the sapwood is dry enough to stand drastic increases in wet-bulb depression. In these cases, the schedules are based on the moisture content of the sapwood or of a mixture of sapwood and heartwood. In working out a time schedule for a species in which both sapwood and heartwood are present in quantity, select kiln samples from both types of wood.

So-called "sinker" stock can be a problem when drying softwoods. Sinker stock is wood containing so much water and so little air in the cell cavities that the logs sink in water. This wood dries slowly and is subject to collapse if too high a temperature is used during the initial stages of drying. It is desirable to sort green softwoods into different moisture content classes, if practical, and to dry each class separately. When it is necessary to dry them together, each should be represented by kiln samples.

The softwood moisture content schedules are set up for drying green wood, but they can be applied to partially air-dried material.

Operation Considerations.—The schedules are designed for full-time operation in modern forced-circulation compartment kilns. The scheduled drying conditions are for the entering air. If it is necessary to locate the dry bulb in the leaving air (see ch. 4, p. 69), adjust the control instrument setting to compensate for the temperature drop across the load. Modify the schedules if the air velocity through the load is less than 200 feet per minute, as described for drying hardwoods, p. 124.

Moisture Content Schedules.—The softwood moisture content schedules are given in tables 19 and 20. These schedules are the same as the general kiln schedules for hardwoods, except for a few important differences. Wet-bulb depressions of 40° F. or more are avoided until the controlling moisture content reaches 15 percent. Changes in wet-bulb depression between 15° and 35° are made gradually, 5° at a time. For the drying of lower grade stock, final wet-bulb depressions generally do not exceed 30°, and in some cases they do not exceed 20°. The main features of moisture content kiln schedules of this type were discussed under hardwood schedules earlier in this chapter. Under the moisture content method of operation, the initial temperature is maintained until the controlling kiln samples have an average moisture content of 30 percent.

TABLE 19.—*Moisture content temperature schedules for softwoods*

Temperature step No.	Moisture content at start of step	Dry-bulb temperatures for temperature schedule No. —													
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14
	Percent	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
1	Above 30	100	100	110	110	120	120	130	130	140	140	150	160	170	180
2	30	105	110	120	120	130	130	140	140	150	150	160	170	180	190
3	25	105	120	130	130	140	140	150	150	160	160	160	170	180	190
4	20	115	130	140	140	150	150	160	160	160	170	170	180	190	200
5	15	120	150	160	180	160	180	160	180	160	180	180	180	190	200

TABLE 20.—*Moisture content wet-bulb depression schedules for softwoods*

Wet-bulb depression step No.	Moisture content at start of step for moisture content class—						Wet-bulb depressions for wet-bulb depression schedule No. —							
	A	B	C	D	E	F	1	2	3	4	5	6	7	8
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
1	Above 30	Above 35	Above 40	Above 50	Above 60	Above 70	3	4	5	7	10	15	20	25
2	30	35	40	50	60	70	4	5	7	10	14	20	25	30
3	25	30	35	40	50	60	6	8	11	15	20	25	30	35
4	20	25	30	35	40	50	10	14	15	20	25	30	35	35
5	(1)	20	25	30	35	40	15	20	20	25	30	35	35	35
6		(1)	20	25	30	35	20	25	25	30	35	35	35	35
7			(1)	20	25	30	25	30	30	35	35	35	35	35
8				(1)	20	25	30	35	35	35	35	35	35	35
9					(1)	20	35	35	35	35	35	35	35	35
10	15	15	15	15	15	15	50	50	50	50	50	50	50	50

[1] Go directly to step 10.

Table 21 is an index of recommended schedules for 4/4, 6/4, and 8/4 softwood lumber, of both upper and lower grades. The schedules for lower grade stock generally call for lower final temperatures and smaller final wet-bulb depressions to reduce loosening of knots and hold planer splitting to a minimum.

Table 22 is an index of suggested schedules for 10/4 and thicker softwoods. The drying time may be too long for ordinary commercial operations, but the schedules are suitable for special cases where thick stock of the upper grades is to be dried.

Instructions for assembling a softwood mois-

TABLE 21.—*Code number index of moisture-content schedules*[1] *recommended for kiln-drying 4/4, 6/4, and 8/4 softwood lumber*

Species	Lower grades[2]			Upper grades[2]		
	4/4 stock	6/4 stock	8/4 stock	4/4 stock	6/4 stock	8/4 stock
Baldcypress				T12–E3		T11–D2
Cedar:						
Alaska-				T12–A3		T11–A2
Atlantic white-				T12–A4		T11–A3
Eastern redcedar				T5–A4		T5–A3
Incense-				T11–B5		T10–B4
Northern white-				T12–B4		T11–B3
Port-Orford-				T11–B4		T10–B3
Western redcedar:						
Light	T9–A6			T10–B5		T10–B3
Heavy				T5–F4		T5–F3
Douglas-fir:						
Coast region	T7–A4		T7–A4[3]	T11–A4		T10–A3
Inland region	T9–A4[4]		T9–A4[4]			
Fir:						
Balsam				T12–E5		T10–E4
California red				T12–E5		T10–E4
Grand				T12–E5		T10–E4
Noble				T12–A5	T11–A4	T10–A3
Pacific silver				T12–B5		T10–B3
Subalpine				T12–B5		T12–B4
White	T9–D6		T9–D5	T12–E5	T11–E5	T10–E4
Hemlock:						
Eastern				T12–C4		T11–C3
Western	T11–E5[3]		T11–E5	T12–C5	T11–C5	T11–C4
Larch	T7–C5[4]		T7–C5[3]	T9–B4	T7–C4	T7–C3
Pine:						
Eastern white:						
Regular	T9–C5		T9–C4	T11–C5		T10–C4
Antibrown-stain				T7–E6	T7–E6	T7–E5
Jack	T9–C4		T9–C3			
Lodgepole	T5–C5			T10–C4		T9–C3
Ponderosa:						
Heartwood	T9–A6	T7–A6	T5–A5			
Sapwood	T11–C7			T9–C6	T7–C6	T7–C5
Antibrown-stain				T7–E6		T7–E5
Red				T12–B4		T11–B3
Southern yellow	T12–C5			T13–C6	T12–C5	T12–C5
Sugar:						
Light	T9–E7	T7–E6		T5–E6	T5–E6	T5–E5
Heavy				T5–F6	T5–F6	T5–F5
Western white:						
Regular	T9–C6		T7–C6[4]	T9–C5	T7–C5	T7–C4
Water core	T9–E6					
Redwood:						
Light				T5–D6		T5–D4
Heavy				T4–F5	T3–F5	T3–F4
Spruce:						
Eastern (black, red, white)				T11–B4		T10–B3
Englemann	T7–B6	T5–B5	T5–B5[3]	T9–E5		T7–E4
Sitka	T7–A5			T12–B5	T12–B4	T11–B3
Tamarack				T11–B3		T10–B3

[1] Schedules are given in tables 19 and 20.
[2] Lower grades include commons, dimension, and box; upper grades include clears, selects, shop and factory, and tight-knotted panelling.
[3] Maximum wet-bulb depression 25° F.
[4] Maximum wet-bulb depression 20° F.

TABLE 22.—*Code number index of moisture-content kiln schedules*[1] *suggested for drying thick softwood lumber*[2]

Species	Thickness of lumber—		
	10/4	12/4	16/4
Baldcypress	T8–A4	T8–A4	
Cedar:			
Atlantic white-	T7–A3	T7–A3	
Incense-	T5–F3	T5–F3	
Northern white-	T7–A3	T7–A3	
Western redcedar (light)	T7–A2	T7–A2	
Douglas-fir, coast region	T5–A1	T5–A1	T5–A1
Fir:			
Balsam	T8–A4	T8–A4	
California red	T8–A3	T8–A3	
Grand	T8–A4	T8–A3	
Noble	T5–A2	T5–A2	
White	T8–A4	T8–A4	
Hemlock:			
Eastern	T8–A3	T8–A2	
Western	T8–A4	T8–A3	
Larch, western	T7–A3	T7–A2	
Pine:			
Eastern white	T10–C4	T8–C3	T5–C2
Ponderosa	T7–A4	T7–A4	
Red	T7–A3	T7–A3	
Southern yellow	T10–C4	T10–C4	
Western white	T7–C4	T5–C3	
Redwood (light)	T5–C4	T5–C3	
Spruce:			
Eastern (black, red, white)	T5–A2	T5–A2	
Engelmann	T7–A4	T7–A3	
Sitka	T5–B2	T5–B2	
Tamarack	T7–A3	T7–A3	

[1] Schedules are given in tables 19 and 20.
[2] Upper grades, including clears, selects, and factory lumber.

ture content schedule are the same as those given for hardwoods. Schedules for a few softwood species have been assembled in table 23.

Kiln-Drying Air-Dried Softwoods.—Since preliminary air-drying is uncommon for softwoods that are to be kiln-dried, recommended schedules for kiln-drying air-dried stock have not been worked out. The following steps are suggested for the assembly of such a schedule.

(1) Determine the moisture content of representative samples of slow- and fast-drying material (ch. 6) and use the average moisture content of the wettest half of the samples as the controlling moisture content.

(2) Use the temperature step of the recommended schedule corresponding to that moisture content (table 19).

(3) If the controlling moisture content is above 40 percent, dry the material as green stock.

(4) If the controlling moisture content is 40 percent or less, change the wet-bulb depression as follows:

(a) Use a depression of 10° to 15° F. for the initial 8 to 16 hours.

(b) After this period, if the controlling moisture content is between 15 and 25 percent, change the wet-bulb depression to 20° F.

(c) Use a depression of 30° F. or more after the stock reaches 15 percent moisture content.

An example of a schedule for 4/4 eastern spruce previously air-dried to 24 percent moisture content is given in table 24.

Modifying Softwood Moisture Content Schedules.—The principles described above for hardwood schedule modification generally can be applied to softwoods.

Commercial Softwood Time Schedules

In general, the softwood mills of the West and South use time schedules to dry both upper- and lower-grade items. The drying conditions are changed at convenient time intervals, such as every 12 or 24 hours. These schedules have been developed from experimental work and mill experience. They are being continuously modified at individual mills to allow for differences in material, kiln type, and kiln performance.

Table 23.—*Examples of moisture-content schedules for drying upper-grade lumber of certain softwood species*

EASTERN WHITE PINE, ANTIBROWN-STAIN

Moisture content at start of step	Schedule T7–E6: 4/4 stock			Schedule T7–E6: 6/4 stock			Schedule T7–E5: 8/4 stock		
	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature
Percent	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
Above 60	130	15	115	130	15	115	130	10	120
60	130	20	110	130	20	110	130	14	116
50	130	25	105	130	25	105	130	20	110
40	130	30	100	130	30	100	130	25	105
35	130	35	95	130	35	95	130	30	100
30	140	35	105	140	35	105	140	30	110
25	150	35	115	150	35	115	150	35	115
20	160	35	125	160	35	125	160	35	125
15	160	50	[1]	160	50	[1]	160	50	[1]

SOUTHERN YELLOW PINE

Moisture content at start of step	Schedule T13–C6: Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature	Schedule T12–C5: Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature	Schedule T12–C5: Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature
Above 40	170	15	155	160	10	150	160	10	150
40	170	20	150	160	14	146	160	14	146
35	170	25	145	160	20	140	160	20	140
30	180	30	150	170	25	145	170	25	145
25	180	35	145	170	30	140	170	30	140
20	190	35	155	180	35	145	180	35	145
15	190	50	[1]	180	50	[1]	180	50	[1]

WHITE FIR

Moisture content at start of step	Schedule T12–E5: Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature	Schedule T11–E5: Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature	Schedule T10–E4: Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature
Above 60	160	10	150	150	10	140	140	7	133
60	160	14	146	150	14	136	140	10	130
50	160	20	140	150	20	130	140	15	125
40	160	25	135	150	25	125	140	20	120
35	160	30	130	150	30	120	140	25	115
30	170	35	135	160	35	125	150	30	120
25	170	35	135	160	35	125	160	35	125
20	180	35	145	170	35	135	170	35	135
15	180	50	[1]	180	50	[1]	180	50	[1]

[1] Close control of wet-bulb temperature not necessary. Steam spray shut off.

Table 24.—*General kiln schedule T11–B4 applied to 4/4 upper-grade eastern spruce previously air-dried to 24 percent moisture content*

Time	Moisture content at start of step	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature
Hr.	*Percent*	°*F.*	°*F.*	°*F.*
0–8	24	160	15	145
[1]	20	170	20	150
	15	180	50	[2]

[1] Change to moisture-content method of operation.
[2] Close control of wet-bulb temperature not necessary.

The information given here was obtained by studying the time schedules and drying procedures of a large number of the average and better-quality producing softwood mills. There was a wide diversity in schedules used successfully for the same item. Average time schedules were developed from them.

These time schedules, like the moisture content schedules, are intended only as guides from which an operator can make up the best schedules for his specific drying requirements and type of kiln. Time schedules are very dependent upon rates of air circulation and kiln performance, since these affect drying rate greatly. The schedules in this section are based on the performance of single-track or of booster-coil-equipped double-track, internal-fan kilns with air velocities of between 200 and 400 feet per minute through the loads. Most such kilns have wide plenum chambers and other design features that insure uniform air distribution. The schedules should be modified for other types of kilns.

Time Basis.—Changes are made in kiln conditions at a stated time interval, usually every 12 or 24 hours. The 12-hour interval is generally used for stock that dries in 2 to 5 days. It is convenient at larger mills having kiln operators on duty at all times. At smaller mills where an operator is on duty for only 8 hours each day, drying conditions can be modified for changes at 8-, 16-, and 24-hour intervals.

Material and Operation Considerations.—The material and operation considerations discussed under "Softwood Moisture Content Schedules," p. 129, apply to time schedules. Small variations in material and operations at individual mills or in individual kilns at the same mill may require adjustment of the time schedules. Major differences in initial moisture content or in drying rate of different types of stock require changing to entirely different schedules.

Kiln Samples.—Although kiln samples are not necessary for operating kilns on a time basis, many operators find them helpful. They can be used to tell when to start equalizing or conditioning treatments or when to shut the kiln off. This is especially helpful when loads of lumber with different average moisture content values are to be dried in the same kiln.

Time Schedules.—Softwood time schedules are shown in tables 25 and 26. The temperature and wet-bulb depression schedules are set up separately. Contrary to the method of changing drying conditions for hardwoods, temperature and wet-bulb depression are changed simultaneously in drying most softwood items. The two sets of time intervals, A and B shown in tables 25 and 26, are arranged in 12- and 24-hour periods, respectively. Longer time intervals are indicated by other letters as explained in footnotes.

An index of commercial time schedules for 4/4, 6/4, and 8/4 softwood lumber is given in

TABLE 25.—*Average commercial time-temperature schedules for softwoods*

Time intervals [1]		Dry-bulb temperatures for temperature schedule No. —											
A	B	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Hr.	*Hr.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
0–12	0–24	115	120	125	130	135	140	145	150	155	160	165	170
12–24	24–48	120	125	130	135	140	145	150	155	160	165	170	175
24–36	48–72	125	130	135	140	145	150	155	160	165	170	175	180
36–48	72–96	130	135	140	145	150	155	160	165	170	180	180	190
48–60	96–120	140	140	150	150	160	160	170	170	180	180	190	190
60–72	120–144	150	150	160	160	170	170	180	180	180	190	190	200
72–Final	144–Final	160	160	160	160	170	180	180	180	190	190	200	200

[1] Additional time intervals used in a few schedules are: C=48 hours on each step; D=72 hours on each step; and E=96 hours on each step.

TABLE 26.—*Average commercial time wet-bulb depression schedules for softwoods*

Time intervals [1]		Wet-bulb depressions for wet-bulb depression schedule No. —							
A	B	K1	K2	K3	K4	K5	K6	K7	K8
Hr.	*Hr.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
0–12	0–24	3	4	5	7	10	15	17	20
12–24	24–48	4	5	7	10	15	20	23	25
24–36	48–72	6	7	10	15	20	25	30	30
36–48	72–96	9	10	15	20	25	30	30	35
48–60	96–120	12	15	20	25	30	30	35	43
60–72	120–144	18	20	25	30	35	35	43	50
72–Final	144–Final	25	30	30	35	50	50	50	50

[1] Additional time intervals used in a few schedules are: C=48 hours on each step; D=72 hours on each step; and E=96 hours on each step.

table 27. The table also gives the maximum wet-bulb depression for the lower grades and the average total kiln time for both lower and upper grades. Total kiln time for the upper grade lumber generally includes a short conditioning period. Because the schedules were developed from a wide diversity of actual schedules, the times given are for guidance purposes only. The actual time required for individual kiln charges may vary considerably from those given. Any changeover from an operating schedule to one of these should be done gradually. If at the end of a kiln run, the average moisture content and degree of moisture uniformity do not meet consumer requirements, modify the drying or equalizing time, or both, on subsequent charges accordingly.

Assembly of a Time Schedule.—The procedure for assembling a time schedule for softwoods is similar to that given for hardwoods earlier in this chapter. A form similar to table 14, p. 122, is used, except that the third column is headed "Time" instead of "Moisture content at start of step." All times are shown in hours. If the time interval letter (A or B) is the same for both temperature and wet-bulb depression schedules, the procedure is simple. When this is not the case, use the A values in setting up the time column, and repeat either the temperature or the wet-bulb depression step numbers and values, as the case may require.

Examples of Assembled Time Schedules.—Table 28 shows some examples of assembled time schedules for several softwoods. A few of the schedules do not fit into the general time-schedule scheme.

Modification of Schedule for Variations in Initial Moisture Content.—There is no standard procedure for modifying time schedules to allow for variations in the initial moisture content of stock. The most common practice is to use the same drying conditions and the same hourly intervals for the initial and intermediate drying steps, and then to lengthen or shorten the final step to obtain the desired final average moisture content. At some mills, however, when the stock is placed in the kiln quite wet in the wintertime, the initial step is prolonged or is preceded by a milder step. In view of the late reversal of softwood drying stresses, this practice favors reduction in kiln degrade.

The nonuniformity in final moisture content that can occur in two charges of softwood placed in a kiln at different initial moisture content and dried by the same time schedule is illustrated in table 29. This shows the necessity for checking final moisture content of lumber and modifying time schedules to compensate for differences in initial moisture content. An equalizing treatment can also be used to reduce differences in final moisture content.

Lumber from trees that have been dead for some time, such as insect-killed trees, is likely to be lower in moisture content and therefore require less drying time than lumber from live trees. It may check early in drying, however, unless the initial drying conditions are mild.

Softwood Schedules for Special Purposes

A number of softwood items require special drying schedules, and a few are discussed here. Also discussed are suggestions for reducing brown stain, setting pitch, retaining desirable oils, and drying chemically treated wood.

Brown Stain Control.—Brown stain is a discoloration of wood that can occur during kiln-drying as a result of a change in the color of substances normally present in green softwoods. It can be a considerable problem in the drying of sugar pine, eastern and western white pine, and ponderosa pine. This stain also occurs in some other softwoods, such as western hemlock and Sitka spruce.

Brown stain can be severe when high dry- and wet-bulb temperatures are used at the start of drying. If it is a problem, the initial dry-bulb temperature should not exceed 130° F. Use as large a wet-bulb depression as the stock will tolerate without excessive surface and end checking. The wet-bulb temperature should not exceed 120° F. throughout the drying. During the equalizing and conditioning treatments, however, higher wet-bulb temperatures are required. Use enough venting to obtain the desired wet-bulb depression. See chapter 9, p. 152, for other suggestions for reducing the development of brown stain.

Setting Pitch, Retaining Cedar Oil.—Kiln schedules can be modified either to retain oil in wood, as in the drying of eastern redcedar used for cedar chests, or to set pitch that might exude later from pine and cause paint and finishing problems (*2*). High temperature in the presence of moisture and steam causes volatile material to vaporize. Therefore, when drying eastern redcedar, avoid high temperatures and do not condition the stock unless it is to be resawed or is surfaced unequally.

On the other hand, to set pitch it is desirable to drive off the volatile turpentine and other solvents normally present. This can be done most easily at the start of drying by using a high temperature but, if brown stain is a prob-

TABLE 27.—*Code number index of average commercial*

Species	Lower grades [2]					
	4/4 stock			6/4 stock		
	Code number	Maximum wet-bulb depression	Total time	Code number	Maximum wet-bulb depression	Total time
		° F.	*Hr.*		*° F.*	*Hr.*
Cedar:						
Incense-	AS5–AK7	40	90	---	---	---
Port-Orford-	---	---	---	---	---	---
Western redcedar: [3]						
Light	---	---	---	---	---	---
Medium	---	---	---	---	---	---
Douglas-fir:						
Coast type	BS5–BK4	---	52	---	---	---
Inland type	AS5–AK4	20	63	---	---	---
Douglas-fir—Western larch	AS6–AK5	22	61	---	---	---
Fir:						
Noble	---	---	---	---	---	---
White	AS7–AK6	28	60	BS10–BK8	---	96
Hemlock, western	AS8–AK5	25	77	---	---	---
Larch, western	BS5–BK6	30	72	---	---	---
Pine:						
Eastern white	BS6–BK5	---	139	---	---	---
Lodgepole	---	---	---	---	---	---
Ponderosa:						
Calif., Oregon	AS7–AK7	30	48	AS5–BK7	33	100
Inland, Southwest	AS5–AK7	30	60	BS4–BK6	28	101
Southern yellow	BS11–BK5	---	67	---	---	---
Sugar:						
Light	AS6–AK7 [7]	---	55	BS5–BK7 [7]	---	154
Heavy	---	---	---	---	---	---
Western white:						
Regular	AS7–AK6	---	58	---	---	---
Water core	AS6–BK6	---	102	---	---	---
Redwood, light	---	---	---	---	---	---
Spruce:						
Engelmann	AS5–BK7	---	37	---	---	---
Sitka	AS4–BK5	---	48	---	---	---

[1] Schedules indicated are given in tables 25 and 26. Refer to footnote 1 of these tables for C, D, and E time intervals.
[2] Lower grades include commons, dimension, and box; upper-grades include clears, selects, shop and factory.
[3] Average moisture content values: light, below 80 percent; medium, about 90 percent.
[4] 5/4 stock.
[5] Maximum dry-bulb temperature 145° F.

time schedules for 4/4, 6/4, and 8/4 softwood [1] lumber

Lower grades [2]			Upper grades [2]					
8/4 stock			4/4 stock		6/4 stock		8/4 stock	
Code number	Maximum wet-bulb depression	Total time	Code number	Total time	Code number	Total time	Code number	Total time
	° F.	Hr.		Hr.		Hr.		Hr.
			AS5–AK7	90				
			BS8–AK5	129			CS6–BK6 [1]	345
			AS6–AK6	50				
			BS4–BK7	203	BS2–BK6 [4]	296		
BS7–AK4	25	75	AS7–AK4	104	BS7–BK4	150	BS7–BK3	200
AS7–BK6	20	55						
AS5–BK5	20	94	AS6–BK6	103	AS6–CK5	204		
					AS7–AK4	145		
BS–10–BK8		96	AS7–AK7	72	BS9–BK7	144	AS6–AK5	72
BS11–BK6	40	109	AS9–AK5	123	BS8–BK5	195	BS11–BK5	204
BS3–BK6	25	120	BS6–BK5	112	BS2–BK4	220		
BS7–BK4		224	BS6–BK5	139			BS7–BK4	224
			AS4–AK5 [5]	63				
			AS5–AK6 [6]	86	AS4–BK6 [6]	137	BS4–BK5 [6]	192
BS2–BK5	30	174	AS5–AK6 [6]	74	BS3–BK6 [6]	137	BS2–BK5 [6]	200
AS11–BK6		100	AS11–BK6	96	AS10–AK4		AS10–AK4	
BS1–BK6 [7]		228	AS3–BK8	144	BS2–BK7 [7]	264	BS1–BK8 [7]	360
			BS3–BK8 [7]	264	BS1–BK8 [7]	316		
BS4–DK6 [1]	22	204	AS5–BK7	76	AS4–CK8 [1, 4]	124	CS6–CK6 [1]	276
			BS1–CK8 [1]	208	CS1–EK6 [1]	370	ES1–EK5 [1]	516
AS6–AK6	25	54	AS5–AK6 [8]	57				
			BS8–BK5	144	BS7–BK4 [1]	200	BS6–BK4	244

[6] Dry-bulb temperature generally does not exceed 160° F.; wet-bulb depression does not exceed 35°.
[7] In industry these items are generally dried with a dry-bulb temperature 5° or 10° F. lower in step 1 or steps 1 and 2, and 5° or 10° higher in steps 4 to 7 than called for in the average schedule.
[8] Maximum wet-bulb depression 25° F.

TABLE 28.—*Examples of commercial time schedules for drying lumber of certain softwood species*

Time	4/4 stock			6/4 stock			8/4 stock		
	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature
DOUGLAS-FIR, COAST TYPE, LOWER GRADES									
	Schedule BS5–BK4			No schedule established			Schedule BS7–AK4 [1]		
Hr.	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
0– 12	135	7	128	----	----	----	145	7	138
12– 24	135	7	128	----	----	----	145	10	135
24– 36	140	10	130	----	----	----	150	15	135
36– 48	140	10	130	----	----	----	150	20	130
48– 60	145	15	130	----	----	----	155	25	130
60– 72	145	15	130	----	----	----	155	25	130
72– 75	----	----	----	----	----	----	160	25	135
WHITE FIR, UPPER GRADES									
	Schedule AS7–AK7			Schedule BS9–BK7			Schedule AS6–AK5		
0– 12	145	17	128	155	17	138	140	10	130
12– 24	150	23	127	155	17	138	145	15	130
24– 36	155	30	125	160	23	137	150	20	130
36– 48	160	30	130	160	23	137	155	25	130
48– 60	170	35	135	165	30	135	160	30	130
60– 72	180	43	137	165	30	135	170	35	135
72– 96	----	----	----	170	30	140	----	----	----
96–120	----	----	----	180	35	145	----	----	----
120–144	----	----	----	180	43	137	----	----	----
SOUTHERN YELLOW PINE, UPPER GRADES									
	Schedule AS11–BK6			Schedule AS10–AK4			Schedule AS10–AK4		
0– 12	165	15	150	160	7	153	160	7	153
12– 24	170	15	155	165	10	155	165	10	155
24– 36	175	20	155	170	15	155	170	15	155
36– 48	180	20	160	180	20	160	180	20	160
48– 60	190	25	165	180	25	155	180	25	155
60– 72	190	25	165	190	30	160	190	30	160
72– 96	200	30	170	190	35	155	190	35	155
96–120	----	----	----	190	35	155	190	35	155
120–144	----	----	----	----	----	----	190	35	155
WESTERN REDCEDAR, HEAVY-TYPE,[2] UPPER GRADES									
	Special schedule			Special schedule for 5/4 [3]			No schedule established		
0– 24	100	6	94	110	10	100	----	----	----
24– 48	110	13	97	114	12	102	----	----	----
48– 72	120	20	100	117	15	102	----	----	----
72– 96	130	34	96	121	17	104	----	----	----
96–120	140	44	96	125	20	105	----	----	----
120–144	150	50	100	125	20	105	----	----	----
144–168	160	50	110	130	24	106	----	----	----
168–192	170	50	120	130	24	106	----	----	----
192–240	170	50	120	134	27	107	----	----	----
240–288	170	50	120	138	30	108	----	----	----
288–336	170	50	120	143	33	110	----	----	----
336–384	170	50	120	147	36	111	----	----	----
384–440	----	----	----	157	45	112	----	----	----

See footnotes at end of table.

TABLE 28.—*Examples of commercial time schedules for drying lumber of certain softwood species*—Continued

REDWOOD, LOWER GRADE

Time	Special schedule			No schedule established			No schedule established		
	4/4 stock			6/4 stock			8/4 stock		
	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature
Hr.	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
0–120	110	10	100	----------	----------	----------	----------	----------	----------

REDWOOD, UPPER GRADES, HEAVY-TYPE

Time	Special schedule			No schedule established			No schedule established		
0–144	110	15	95	----------	----------	----------	----------	----------	----------
144–192	115	20	95	----------	----------	----------	----------	----------	----------
192–240	120	20	100	----------	----------	----------	----------	----------	----------
240–288	125	25	100	----------	----------	----------	----------	----------	----------
288–336	130	25	105	----------	----------	----------	----------	----------	----------
336–384	135	25	110	----------	----------	----------	----------	----------	----------
384–432	140	25	115	----------	----------	----------	----------	----------	----------
432–480	145	30	115	----------	----------	----------	----------	----------	----------
480–504	155	30	125	----------	----------	----------	----------	----------	----------
504–588	170	40	130	----------	----------	----------	----------	----------	----------

[1] Maximum wet-bulb depression 25° F.
[2] Stock about 120 percent average moisture content.
[3] 5/4 "sinker" stock, at about 160 percent average moisture content, has been dried in about 600 hours using steps of about 5 days each with conditions similar to those of steps Nos. 1, 3, 5, 7, and 8 of this schedule.

TABLE 29.—*Variation in final moisture content of lumber from two kiln charges of a softwood with different average initial moisture content when dried by the same time schedule* [1]

Moisture content	Pieces in each final moisture content class		Moisture content	Pieces in each final moisture content class	
	Run 1	Run 2		Run 1	Run 2
Percent	*Number*	*Number*	*Percent*	*Number*	*Number*
7	161	3	13	2	30
8	76	13	14	----------	29
9	40	59	15	----------	7
10	21	75	16	----------	21
11	4	63	17	----------	----------
12	4	46	18	----------	11

[1] Source: Central California Dry Kiln Club.

lem, the best compromise is to use an antibrown stain schedule at the start of drying and finish up with 160° or higher. The temperature of 160° is probably satisfactory for setting pitch in 4/4 stock, but the final temperature for thicker stock should be 170° or higher.

Chemically Treated Wood.—The procedures given for drying chemically treated hardwoods, p. 128, also apply to treated softwood lumber.

Unique problems arise in the treatment and drying of plywood. During treatment with waterborne chemicals, the cross-banded construction of plywood prevents normal swelling of the face plies, and compression set occurs. The amount of set can be kept low by having the treating temperature as low as possible. At the start of drying, use a comparatively high temperature with a relative humidity that is as high as possible without causing leaching. Some checking must be expected when the surface plies are of rotary-cut veneer, because knife checks are often present in this veneer.

Maximum-Strength Schedules.—For drying ladder stock, oar stock, aircraft lumber, and other stock where it is necessary to preserve maximum strength, use comparatively low temperature schedules. Special schedules for drying aircraft lumber are given in Militay Specification MIL–W–6109 (*18*).

Width of Stock.—The softwood moisture content and time schedules given in tables 21, 22, 27, and 28 are set up for random-width stock, which generally is 6 inches or more wide. They are also satisfactory for wide flat-grain stock, but drying time is somewhat longer than that for average-width stock. Some examples of schedules for narrow stock are given in table 30. In most cases, narrow stock can stand more severe schedules and dry faster than average-width stock. At mills with large volume, sorting to width results in a considerable reduction in kiln time. If both narrow and wide material are included in the same kiln charge, use an equalizing treatment.

Bevel Siding, Venetian Blinds, Resawed Paneling.—Softwood lumber that is to be resawed into bevel siding, venetian-blind slats, or paneling should be properly equalized and conditioned to obtain a uniform moisture content over the cross section and relieve drying stresses. Before equalizing, use the final wet-bulb depression given in the schedules to get the stock down to a low average moisture content as soon as possible.

TABLE 30.—*Representative drying schedules for narrow softwood stock*

Time	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature
4/4 UPPER GRADE DOUGLAS-FIR, COAST TYPE			
Hr.	*° F.*	*° F.*	*° F.*
0– 12	184	31	153
12– 24	188	34	154
24– 36	193	39	154
36– 48	194	42	152
48– 54	195	39	156
8/4 UPPER GRADE DOUGLAS-FIR, COAST TYPE			
0– 24	150	6	144
24– 48	154	12	142
48– 72	162	20	142
72– 96	171	29	142
96–120	182	37	145
120–168	188	42	146
4/4 UPPER GRADE WESTERN HEMLOCK			
0– 12	176	23	153
12– 24	178	25	153
24– 36	183	27	156
36– 48	185	27	158
48– 60	185	30	155
60– 72	187	32	155
72– 91	190	33	157

Bundled Short-Length Stock.—Most of the drying of bundled short-length items takes place from the end-grain surfaces. Because some of these items do not end or surface check readily, kiln schedules for them can be rather severe. Other items, however, require low dry-bulb temperatures to avoid collapse.

Since western redcedar shingles produced from wet stock logged in low areas may collapse, they are dried with an initial dry-bulb temperature of about 95° F. This temperature is gradually increased over a 10- to 14-day period to 150° or higher. Shingles produced from stock at a relatively low moisture content can be started at 150° or higher and finished at 180°. In both cases there is no control of wet-bulb temperature and the vents are kept open.

Incense-cedar pencil material is usually dried from a green to a partially dry condition in the form of 3-inch planks or squares and then cut into slats and graded. These slats are coated with a small amount of wax, bundled, and treated with a water-soluble dye. Because the treatment generally is a full-cell treatment in which all the cell cavities become filled with liquid, the slats may collapse under severe kiln-drying conditions. Use low-temperature, high-humidity conditions at the start of drying, and gradually make them more severe as drying progresses. Drying times are long, 23 to 30 days.

Ponderosa pine squares, 4/4, 5/4, and 6/4 in cross section and 24 to 36 inches long, are dried in bundles about 5 inches square. Use constant kiln temperatures of 140° F. on the dry bulb and 110° on the wet bulb. Drying time is 13 or 14 days. Similar drying conditions can be used on other short, rough items of pine or other easily dried softwoods.

Timbers, Poles, Crossties.—It is not customary to kiln-dry large timbers, poles, crossties, and other large items because of the long drying times required. They are either air-dried or used green. Before they are given preservative treatment, they are conditioned by steam, or a Boulton treatment, or air-dried. Materials of this size do not need to be completely free from seasoning defects.

The kiln-drying of small to medium-sized Douglas-fir timbers is aided by a chemical preseasoning treatment. Chemical treatment consists of a dry-spread application of urea, 40 to 60 pounds per thousand board feet, followed by solid piling until the urea is absorbed. This treatment results in some surface browning of the wood.

The schedules for all sizes of urea-treated material in this class start with a dry-bulb temperature of 140° F. and a 7° or 8° wet-bulb depression. Gradually increase the temperature to 160° or 170° and the wet-bulb depressions to 15° or 30°. The larger the timber, the milder the drying conditions in the intermediate and final stages. Approximate drying time is 6 days for 2½- by 12-inch stock, 8 days for 4- by 6-inch, 16 days for 6- by 8-inch, and 32 days for 8- by 10-inch. Final average moisture content is about 19 percent. A minor amount of checking may occur.

Tank Stock.—Tank stock can be kiln-dried by the schedules used for upper grade lumber of the same thickness. Since the stock is used in contact with water or aqueous solutions, it should not be dried lower than 15 to 20 percent moisture content. Therefore, put it on an equilibrium moisture content condition of about 12 percent when the driest material reaches about 16 percent, and hold that condition until the wettest material reaches about 20 percent.

Veneer, Battery Shims.—Although softwood veneer is usually dried in mechanical veneer dryers, forced-circulation kilns are sometimes used. Douglas-fir sheathing-grade veneer of 3/16-inch thickness is dried in a kiln stacked 4 sheets per course. Initial drying conditions are 160° F. dry-bulb and 145° wet-bulb temperatures. The final dry-bulb temperature is 190° and the wet-bulb 140°. Drying time to 7 percent moisture content is 72 to 96 hours. Ponderosa and sugar pine veneer can be kiln-dried on special racks in 4 to 6 hours.

Douglas-fir and Port-Orford-cedar battery shims are stacked 8 to 10 per course for kiln-drying. Each shim is 6¼ inches wide and 0.06 to 0.09 inch thick. A constant dry-bulb temperature of 140° F. is used, and the wet-bulb temperature is gradually dropped from 134° to 128°. Drying time for Douglas-fir is 4 days. For Port-Orford-cedar, it is 3 days for the sapwood and 5 days for the heartwood.

Knotty Pine Stock.—The moisture content or time schedules for lower grade lumber are generally satisfactory for preventing excessive checking or loosening of knots during the first stages of drying. Drying time, however, must be prolonged to reach a final moisture content of 7 or 8 percent. Somewhat lower relative humidities may be needed to obtain this moisture content without an undue lengthening of the drying time. Use a final temperature of 160° F. or higher to "set" the pitch. Conditioning to relieve drying stresses is desirable. Some tight-knotted paneling stock is dried in accordance with schedules for upper grade lumber.

Roof Decking.—Western redcedar, Engelmann spruce, white fir, and other softwood species have been successfully used as 4- by 5-inch, double tongue-and-groove roof decking. The industry practice is to dry the outer ½ inch to 15 percent moisture content or less in from 7 to 10 days under a schedule that allows a small amount of surface checking. Table 31 shows typical kiln schedules for this kind of material.

TABLE 31.—*Time schedules for kiln drying 4- by 5-inch roof decking*

Time	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature
WHITE FIR			
Hr.	*° F.*	*° F.*	*° F.*
0– 24	150	10	140
24– 48	155	15	140
48– 72	160	15	145
72– 96	165	15	150
96–192	170	15	155
ENGELMANN SPRUCE			
0–144	165	20	145
144–168	177	7	170
WESTERN REDCEDAR			
0– 48	130	10	120
48– 72	135	15	120
72– 96	140	15	125
96–120	145	20	125
120–144	150	25	125
144–168	155	30	125
168–192	160	30	130
192–216	165	30	135
216–240	170	30	140

Sterilizing, Equalizing, and Conditioning Treatments

Sterilizing Treatments

A kiln sterilizing treatment can be used to stop the growth of excessive mold on the surface of wood under certain conditions (ch. 9). The dry kiln can also be used to sterilize wood that has been infected with stain or decay fungi, or attacked by wood-destroying insects.

Mold.—Mold can develop on green lumber in a kiln operating at temperatures up to 120° F. Although the mold generally does not penetrate the wood enough to cause serious stain during kiln-drying, it can fill up the air spaces in a load of lumber and seriously interfere with air circulation. Not only does this slow up the drying of the load as a whole, but the wood under the mold may be subject to honeycombing when the temperature is increased later in the drying process.

To sterilize for mold, steam the kiln charge at or near 100 percent relative humidity at a dry-bulb temperature of 130° F. or higher for 1 hour after all parts of the kiln have come up to that temperature. After such steaming, reset the control instrument to the scheduled conditions. Infrequently, two sterilizing treatments may be required about a day apart to stop the development of mold. If the growth is not heavy enough to stop air circulation, do not use the sterilizing treatment.

Fungus Stain and Decay.—The temperatures normally used at the start of kiln-drying are usually high enough to stop the growth of stain or decay organisms that may have infected green wood during storage or air-drying. A temperature of 110° F. stops the growth of these organisms, but does not kill them. Tests show that a temperature of 150° will kill major wood-destroying fungi in green wood in 75 minutes. Kiln schedules that have a dry-bulb temperature of 150° or higher for at least 24 hours should kill all stain and decay fungi. As long as the wood is kept below 20 percent moisture content, new stain and decay will not start.

Insects.—Both softwoods and hardwoods are attacked by a number of wood-boring insects, whether the wood is green or dry (*4*). Imported wood or air-dried wood that has been stored for a long time should be examined for evidence of insects. If they are found, a sterilizing treatment should be given immediately.

Lyctus beetles and their eggs and larvae are killed by subjecting the wood to the conditions given in table 32. These conditions include allowances for heating the lumber to the center, for "cold spots" in the kiln and additional time for a factor of safety. To sterilize, use an equilibrium moisture content that is within 2 percent above or below the moisture content of the wood. If the wood has less than 8 percent moisture content, a temperature above 140° F., a relative humidity somewhat below 60 percent, and the times given in table 32 for 130° should be satisfactory. Exact data on temperatures and times required to kill other insects are not available. Presumably, the higher temperatures with the corresponding treatment time given in table 32 would be adequate.

Normal kiln-drying or sterilization will not prevent future infestation by insects. Give the wood a chemical treatment if there is danger of infestation during storage or use (*4*, *6*).

Equalizing and Conditioning Treatments

Frequently the moisture content varies considerably among boards in a kiln charge during the final stage of drying. Such variation may cause serious trouble during storage, fabrication, or use. Also, satisfactory relief of drying stresses (casehardening) of all boards in a charge cannot be obtained if the moisture content varies too much. Therefore, use an equalizing treatment to overcome excessive variation in moisture content near the end of drying.

TABLE 32.—*Schedule for killing Lyctus powder-post beetles and their eggs*

Kiln setting: Dry-bulb temperature	Kiln setting: Wet-bulb depression	Relative humidity	Equilibrium moisture content	Thickness of lumber	Total time after kiln reaches set conditions
° *F.*	° *F.*	*Pct.*	*Pct.*	*In.*	*Hr.*
140	7	82	13.8	1	3
				2	5
				3	7
130	16	60	9.4	1	10
				2	12
				3	14
125	15	61	9.7	1	46
				2	48
				3	50

Source: Leaflet 13, British Forest Products Research Laboratory (*3*).

If the boards are to be resawed, ripped into thin strips, or machined nonuniformly, use a conditioning treatment. Such a treatment accomplishes two things: it relieves drying stresses, and it produces a more uniform moisture content throughout the thickness of the boards. Drying stresses and nonuniformity of moisture can result in serious deformation during fabrication and use (ch. 9).

The procedures for equalizing and conditioning discussed here require the use of an adequate number of properly selected kiln samples (ch. 6). These procedures will give satisfactory results on lumber that is to be dried to final average moisture content values of from 5 to 11 percent. Table 33 contains basic information on the moisture content of the kiln samples and the kiln equilibrium moisture content (EMC) conditions for these treatments. Wet-bulb depression values required to obtain desired EMC conditions are given in table 2, p. 11. Use of table 2 is explained in chapter 10, p. 164.

Equalizing Treatment.—The procedure for equalizing a kiln charge of lumber, using table 33, is as follows:

(1) Start equalizing when the driest kiln sample in the charge has reached an average moisture content 2 percent below the desired final average moisture content. If, for example, the desired final average moisture content is 8 percent, equalizing would be started when the driest kiln sample reaches 6 percent.

TABLE 33.—*Kiln sample moisture content and equilibrium moisture content values for equalizing and conditioning a charge of lumber*

Desired final average moisture content	Equalizing			Conditioning equilibrium moisture content values	
	Moisture content of driest sample at start	Equilibrium moisture content during this step	Moisture content of wettest sample at end	For softwoods	For hardwoods
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
5	3	3	5	8	9
6	4	4	6	9	10
7	5	5	7	10	11
8	6	6	8	11	12
9	7	7	9	12	13
10	8	8	10	13	14
11	9	9	11	14	15

(2) As soon as the driest sample reaches the moisture value stated in step 1, establish an equalizing EMC in the kiln equal to that value. In the example given in (1), the equalizing EMC would be 6 percent. During equalizing, use as high a dry-bulb temperature as the drying schedule permits.

(3) Continue equalizing until the wettest sample reaches the desired final average moisture content. In the example given in step 1, the wettest sample would be dried to 8 percent.

If the equalizing treatment is to be followed by a conditioning treatment, it may at times be necessary to lower the temperature to obtain the desired conditioning equilibrium moisture content condition. When this is necessary, begin lowering the temperature 12 to 24 hours prior to the start of conditioning. Also lower the wet-bulb temperature to maintain the desired equalizing equilibrium moisture content (ch. 10).

Conditioning Treatment.—The conditioning treatment, whether or not preceded by an equalizing treatment, should not be started until the average moisture content of the wettest sample reaches the desired final average moisture content.

The procedure for conditioning a kiln charge of lumber is as follows:

(1) The conditioning temperature is the same as the final step of the drying schedule or the highest temperature at which the conditioning equilibrium moisture content (EMC) can be controlled. For softwoods set the wet-bulb temperature so the conditioning EMC will be 3 percent above the desired final average moisture content. For hardwoods the conditioning EMC is 4 percent above the desired final average moisture content. The wet-bulb depression that will give the desired conditioning EMC is obtained from table 2, p. 11. If, at the desired conditioning temperature, a wet-bulb depression value is not shown for the desired EMC, choose the wet-bulb depression value for the nearest higher EMC given for that temperature.

EXAMPLE.—Assume that this case involves a hardwood, a final desired moisture content of 8 percent, and a conditioning temperature of 170° F. The conditioning EMC from table 33 is 12 percent. At 170°, an 8° wet-bulb depression will give an EMC of 12.4 percent (table 2). If the material was a softwood, the conditioning EMC would be 11 percent and the wet-bulb depression 10°.

(2) Continue conditioning until satisfactory stress relief is attained.

The time required for conditioning varies considerably, depending upon species and thickness of the lumber, the type of kiln used, and kiln performance. Hardwoods generally require 16 to 24 hours for 4/4 stock and up to 48 hours for 8/4. The 4/4 thickness of some softwood species can be conditioned in as short a time as 4 hours.

The least time necessary to get stress relief in a certain thickness of a particular species is obtained by prong tests, as described in chapter 6, figure 96, p. 106, and chapter 10, p. 164. It is advisable to hold conditioning time to a minimum so as to decrease steam consumption and avoid excessive moisture pickup in low-density woods.

If average moisture content determinations are made immediately after the conditioning treatment, the moisture content obtained will be about 1 to 1½ percent above the desired value because of the surface moisture regain. After cooling, the average moisture content of the lumber should be close to that desired.

The general equilibrium moisture content rule stated in step 1 of the conditioning procedure does not apply to moisture content values above 11 percent. Conditioning is hard to accomplish at the higher values, but if the kiln will maintain a very high EMC at temperatures of 140° F. or above, the required conditioning EMC values for obtaining up to about 14 percent average moisture content can be calculated (*11*).

Kiln-Drying Time

An operator needs some prior idea of the time required for lumber to dry. Table 34 gives the

TABLE 34.—*Approximate kiln-drying periods for 1-inch lumber* [1]

SOFTWOODS

Species	Time required to kiln-dry 1-inch stock from—	
	20 to 6 percent moisture content	Green to 6 percent [2] moisture content
	Days	*Days*
Baldcypress	4– 8	10–20
Cedar:		
Alaska-		4– 6
Atlantic white-		8–10
Eastern redcedar	2– 3	6– 8
Incense-		3– 6
Northern white-		8–10
Port-Orford-		4– 8
Western redcedar		10–15
Douglas-fir:		
Coast type		2– 4
Intermediate type		4– 7
Rocky Mountain type		4– 7
Fir:		
Balsam		3– 5
California red		3– 5
Grand		3– 5
Noble		3– 5
Pacific silver		3– 5
Subalpine		3– 5
White		3– 5
Hemlock:		
Eastern		3– 5
Western		3– 5
Larch, western		3– 5
Pine:		
Eastern white	2– 3	4– 6
Lodgepole		3– 5
Ponderosa		3– 6
Red		6– 8
Southern yellow:		
Loblolly		3– 5
Longleaf		3– 5
Shortleaf		3– 5
Sugar:		
Light		3– 4
Heavy		5–10
Western white		3– 5
Redwood:		
Light	3– 5	10–14
Heavy	5– 7	20–24
Spruce:		
Eastern, black, red, white		4– 6
Engelmann		3– 5
Sitka		4– 7
Tamarack		3– 5

TABLE 34.—*Approximate kiln-drying periods for 1-inch lumber* [1]—Continued

HARDWOODS

Species	Time required to kiln-dry 1-inch stock from—	
	20 to 6 percent moisture content	Green to 6 percent [2] moisture content
	Days	*Days*
Alder, red	3– 5	6–10
Apple	4– 7	10–15
Ash:		
Black	5– 7	10–14
White	4– 7	11–15
Aspen	3– 5	6–10
Basswood, American	3– 5	6–10
Beech, American	5– 8	12–15
Birch:		
Paper		3– 5
Yellow	5– 8	11–15
Buckeye, yellow	5– 8	12–16
Butternut	5– 8	10–15
Cherry, black	5– 7	10–14
Chestnut, American	4– 8	8–12
Chinkapin, golden	7–12	22–28
Cottonwood	4– 8	8–12
Dogwood, flowering	5– 8	12–16
Elm:		
American	4– 6	10–15
Rock	5– 8	13–17
Hackberry	4– 6	7–11
Hickory	4–12	7–15
Holly, American	5– 8	12–16
Hophornbeam, eastern	5– 8	12–16
Laurel, California	5– 7	10–15
Locust, black	5– 8	12–16
Madrone, Pacific	8–11	15–20
Magnolia	4– 6	10–15
Mahogany	4– 7	12–15
Maple:		
Red, silver (soft)	4– 6	7–13
Sugar (hard)	5– 8	11–15
Oak:		
California black	6–10	25–35
Live		30–40
Red	5–10	16–28
White	6–12	20–30
Osage-orange	5– 8	12–16
Persimmon, common	5– 8	12–16
Sweetgum:		
Heartwood	8–12	15–25
Sapwood	5– 7	10–15
Sycamore, American	4– 7	6–12
Tanoak	7–12	24–30
Tupelo:		
Black	4– 6	6–10
Water	5– 7	6–12
Walnut, black	5– 8	10–16
Willow, black	5– 8	12–16
Yellow-poplar	3– 6	6–10

[1] Because of the many factors affecting drying rate and the lack of specific data covering each case, wide variation from these values must be expected. They only present a general idea of average drying periods and should not be used as time schedules. Some of the drying times shown were obtained from commercial kiln operators.

[2] Some softwoods are usually dried to about 10 percent moisture content, but the drying times shown will still apply.

approximate time required to kiln-dry 1-inch lumber from 20 to 6 percent moisture content and from green to 6 percent moisture content. The time required to dry a given material varies with its character, the type of kiln, and the kiln schedule used. Drying times for some softwoods are also given in table 27, p. 136. These are actual average values obtained at the mills studied.

While softwoods are generally kiln-dried from the green condition, the lower grade stock is dried only to a moisture content of about 17 percent. Shop-grade and clear-grade softwoods are usually kiln-dried to 9 or 10 percent. Hardwoods may be kiln-dried from either the green or the air-dried condition. They are generally dried to lower moisture content values, such as 6 to 8 percent (*12*).

The drying periods given in table 34 apply only to 1-inch lumber. For thicker stock, the increase in drying time is theoretically nearly proportional to the square of the thickness, but commercial experience indicates it is somewhat less than this. A set of factors for estimating commercial drying times of various thicknesses of hardwoods has been published (*5*).

Literature Cited

(1) Baker, G., and McMillen, J. M.
1955. Seasoning beech lumber. U.S. Forest Serv. Northeast. Forest Exp. Sta. Beech Util. Ser. 11, 22 pp., illus.

(2) Browne, F. L., and Rietz, R. C.
1953. Exudation of pitch and oils in wood. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1735, 11 pp., illus. [Processed.]

(3) [Gt. Brit.] Department of Scientific and Industrial Research.
1952. The kiln sterilization of lyctus-infested timber. Forest Prod. Res. Lab. Leaflet 13, 4 pp. Rev.

(4) Hatfield, I.
1949. Wood-boring beetles that damage furniture and interior woodwork. Forest Prod. Res. Soc. Proc. 3: 235–249.

(5) Higgins, N. C.
[n.d.] A rule-of-thumb method for estimating drying time. Mich. State Univ. Coop. Ext. Serv. Forest Prod. Rpt. 8023, 5 pp. [Processed.]

(6) Johnston, H. R., Smith, R. H., and St. George, R. A.
1955. Prevention and control of lyctus-powder-post beetles. South. Lumberman 190 (2375): 72–3.

(7) Kimball, K. E.
1955. Drying schedule for thin red oak lumber. South. Lumberman 191 (2393): 252–54.

(8) McMillen, J. M.
1951. How can black walnut gunstock blanks be kiln dried without honeycombing? U.S. Forest Serv. Forest Prod. Lab. Rpt. 1769–13, 2 pp., illus. [Processed.]

(9) ———
1953. Kiln drying water and swamp tupelo. Jour. Forest Prod. Res. Soc. 3(5): 189–196.

(10) ———
1956. Seasoning hickory lumber and handle blanks. U.S. Forest Serv. Southeast. Forest Expt. Sta. Hickory Task Force Rpt. 4, 36 pp., illus.

(11) ———
1958. Stresses in wood during drying. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1652, 33 pp., illus. [Processed.]

(12) Peck, E. C.
1955. Moisture content of wood in use. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1655, 5 pp., illus. [Processed.]

(13) Rasmussen, E. F., and McMillen, J. M.
1956. Seasoning of white oak for tight cooperage. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1784, 15 pp., illus. [Processed.]

(14) Rietz, R. C.
1950. Accelerating the kiln drying of hardwoods. South. Lumberman 181 (2262): 43–44, 54.

(15) Smith, H. H.
1947. Seasoning of aspen. U.S. Forest Serv. Lake States Forest Expt. Sta. Aspen Rpt. 5, 19 pp., illus. [Processed.]

(16) ———
1954. Seasoning California hardwoods: tanoak, madrone, golden chinkapin, and California laurel. U.S. Forest Serv. Calif. Forest and Range Expt. Sta., Tech. Paper 5, 15 pp., illus. [Processed.]

(17) Torgeson, O. W.
1946. Accelerated-type of kiln drying schedule for 1- and 2-inch blackgum. South. Lumberman 173 (2177): 206–208.

(18) U.S. Department of Defense.
1950. Wood, method of kiln drying. Mil. Specif. MIL-W-6109. 11 April 1950.

CHAPTER 9. DRYING DEFECTS

Many features of wood affect its utility when it is processed into lumber and special wood products. These include knots, ring shake, bark and mineral streaks, pitch pockets, compression and tension wood, and spiral or interlocked grain that form in a tree and directly influence the grade and value of each individual board. Ordinary processes of lumber manufacturing may remove some of these natural features by trimming and thus improve the quality and value of the remaining piece.

Defects that reduce the grade and value of lumber often develop during logging, sawmilling, drying, finishing, and mechanical handling. A principal objective is to accomplish drying with as little development of defects as possible consistent with economy. The degree of care to exercise in controlling the development of defects depends on the final use of the material. Before adopting a drying procedure to curtail development of a specific drying defect, the kiln operator should determine whether the procedure will induce other defects that may lower the value of the material. He should always modify the drying procedures to hold down losses from all defects.

Effect of Temperature on Strength of Wood

High temperatures reduce the strength of wood, particularly if it has a high moisture content; the higher the temperature and moisture content and the longer the drying time, the greater the reduction in strength.

For most uses of wood, some reduction in strength is not important. Temperatures up to 160° F. reduce the strength of wood very little during the normal drying cycle. Where high strength and toughness are desired, however, temperatures in excess of 160° should not be used. Wood for aircraft, ladders, tennis rackets, bats, gunstocks, bowling-pin blanks, cooperage stock, and similar products is in this category.

The effect of temperature on the strength of wood was considered in preparing the drying schedules given in chapter 8. When using them, therefore, the kiln operator need have no concern about the effect of heat on the strength properties of wood he is drying.

Defects Occurring During Drying

Drying defects fall into three classes, based on their causes: (1) shrinkage, (2) fungi, and (3) chemicals in the wood. Defects associated with shrinkage are usually increased when excessively high dry-bulb temperatures or large wet-bulb depressions are used during critical stages of drying. Fungal defects generally occur when low temperatures and high relative humidities are used in drying wet wood. Chemical stains that occur in wood during drying are due mainly to the effect of heat on extractives in the wood.

Defects Associated With Shrinkage

Many defects are associated with the shrinking of wood as it dries. Knowing where, when, and why they occur will enable an operator to take action to keep them at a minimum. Kiln-drying is frequently blamed for defects that have occurred during air-drying, but most defects can occur during either process. In kiln-drying they can be kept down by modifying drying conditions, and in the air-drying by altering piling procedures.[1]

Surface Checks.—Surface checks are failures that usually occur in the wood rays on the flat-sawed faces of lumber or other wood items (fig. 108). They can also occur in resin ducts and in mineral streaks. They rarely appear on the edges of flat-sawed material 6/4 inches or less in thickness, but do appear on the edges of thicker flat-sawed and quarter-sawed material. These failures usually take place early in the drying process, but in some softwoods the danger persists beyond the initial stages of drying. They develop because the surfaces of the lumber get too dry as a result of excessively low relative humidity. Thick, wide, flat-sawed lumber is more prone to surface check than thin, narrow stock.

Many surface checks, particularly those in the hardwoods, close during the drying process. In products requiring highly finished wood surfaces, such as some types of interior trim, cabinets, and furniture, closed surface checks are undesirable. They may open to some extent during use because

[1] PECK, E. C. AIR DRYING OF LUMBER. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1657, 21 pp., illus. 1956. [Processed.]

M–22523–F

FIGURE 108.—Surface checking in Douglas-fir dimension lumber.

of fluctuations in atmospheric conditions. Superficial surface checks that will be removed during machining need cause no concern. In such products as bowling pins, tennis rackets, tool handles, and certain structural members, surface checks either closed or open will increase splitting tendencies during use. Products whose value would be unaffected by closed surface checks include flooring and some types of furniture.

Material that has surface checked during air-drying should not be wetted or exposed to very high relative humidities before or during kiln-drying. Such treatments frequently lengthen, widen, and deepen checks. Neither should materials be wetted that have open checks after kiln-drying, because subsequent exposure to plant conditions will dry out the wetted surface and enlarge the checks.

End Checks.—End checks (fig. 109), like surface checks, generally occur in the wood rays, but on end-grain surfaces. They also occur in the initial stage of drying, and can be minimized by using a higher relative humidity. End-checked stock should not be wetted or subjected to very high relative humidities prior to, during, or after drying.

The tendency to end check becomes greater in all species of wood as the thickness and width of the stock increases. For this reason, the end-grain surfaces of thick and wide stock and of larger special items, such as squares, gunstocks, and bowling-pin blanks, should be end coated.[2] To be most effective, end coatings should be applied to freshly cut, unchecked ends of the green wood.

End Splits.—End splits usually result from the extension of end checks. Therefore, if excessive extension of end checks can be avoided, end splitting is less likely to occur. The placing of tiers of stickers at the extreme ends of the boards being dried helps reduce end splitting.

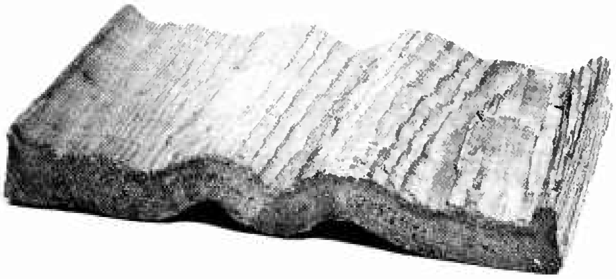
Collapse.—Collapse is a severe distortion or flattening of wood cells. A slight amount of this defect may be difficult, if not impossible, to detect. When severe, it often shows up as grooves or corrugations on the wood surfaces (fig. 110).

Collapse may be caused by (1) compressive drying stresses on the interior parts of the wood that exceed the compressive strength of the wood, or (2) liquid tension in cell cavities that are completely filled with water. Both of these con-

[2] MCMILLEN, J. M. COATINGS FOR THE PREVENTION OF END CHECKS IN LOGS AND LUMBER. U.S. Forest Serv. Prod. Lab. Rpt. 1435, 13 pp., illus. 1956. [Processed.]

M–3510–F

FIGURE 109.—End checks in oak plank.



M–111997–F

FIGURE 110.—Severe collapse in western redcedar.

ditions occur early in the drying process. Collapse is not usually visible on the wood surface, however, until later in the process. This defect is generally associated with excessively high dry-bulb temperatures in the early stages of drying, and these temperatures should be lowered on subsequent kiln charges if collapse occurs.

Collapse is a serious defect and should be avoided if possible. The use of special drying schedules planned to diminish its occurrence in susceptible woods is recommended. Some woods susceptible to this defect are generally air-dried before being kiln-dried.

Honeycomb.—Honeycomb (fig. 111) is an internal void caused by tensile failure across the grain, and it usually occurs in the wood rays. It is produced by the use of excessively high temperatures for too long a time while free water is still present in the cell cavities. While the wood may not actually fail until midway or later in the drying process, the reduction in its strength may begin at any stage of the process if temperatures are excessively high. Therefore, honeycombing can be held to a minimum by avoiding excessively high dry-bulb temperatures until all the free water has been evaporated from the entire piece.

Deep surface and end checks that have closed tightly on the surfaces of the stock, but remain open below the surface, are often called honeycomb. These failures are also sometimes called bottleneck checks.

Honeycomb can result in heavy footage losses. Unfortunately, in many cases, it cannot be detected at the surface of the lumber and is not found until the wood is being machined. Severely honeycombed stock, however, frequently has a corrugated appearance on the surface. Honeycomb is frequently associated with collapsed wood in zones of high moisture concentration.

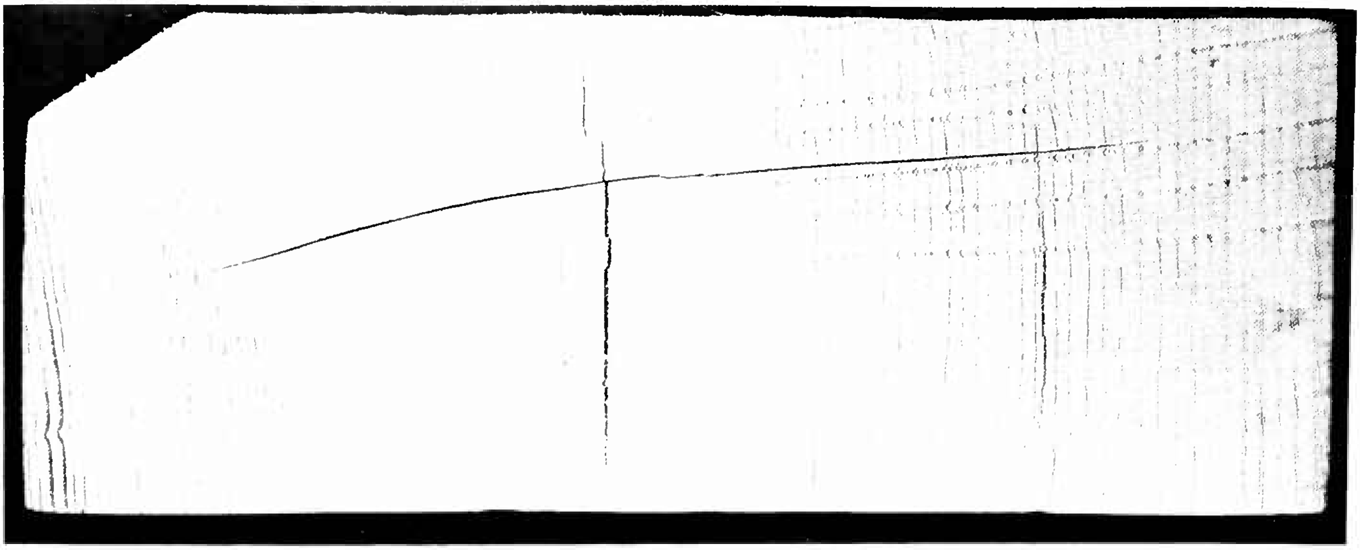
Ring Failure.—Ring failure (fig. 112) occurs parallel to the annual ring either within the ring or between rings. In appearance it is similar to shake, which takes place in standing trees or in trees when they are felled. Frequently the failure involves several annual rings, starting in one and breaking across to others along the wood rays. It can occur as a failure in the end grain in the initial stages of drying, and extend in depth and length as drying continues. The failure can also occur internally, because of casehardening and a weakening of the bond between annual rings when high temperatures are used. Ring failure can be kept to a minimum by end coating stock and by using higher initial relative humidities and low dry-bulb temperature schedules.

Boxed-Heart Splits.—A boxed-heart split is shown in figure 113. These splits start in the initial stages of drying and become increasingly worse as the wood becomes drier. The difference between tangential and radial shrinkage of the wood surrounding the pith causes such severe stresses in the faces of the piece that the wood is split. It is virtually impossible to prevent this defect.

Warp.—As wood dries it may become distorted in shape and form because of the differences in radial, tangential, and longitudinal shrinkage (ch. 1, p. 15). Warping is also aggravated by irregular or distorted grain and the presence of abnormal types of wood. The various types of warp are illustrated in figure 114.

M–11293–F

FIGURE 111.—Honeycombing in oak.



M–52591–F

FIGURE 112.—Two ring failures (vertical breaks) and a check (horizontal break) in a 3- by 8-inch Sitka spruce.

Cup (fig. 114) is a distortion of a board in which there is a deviation flatwise from a straight line across the width of the board. It begins to appear fairly early in the drying process and becomes progressively worse as drying continues. Cup is caused by greater shrinkage parallel to than across the annual rings. In general, the greater the difference between tangential and radial shrinkage, the greater the degree of cup. A flat-sawed board cut near the bark tends to cup less than a similar board cut near the pith. Flat-sawed boards cup toward the face that was closest to the bark. Cup may result in excessive losses during machining. It can be reduced to some extent by modifying the drying schedule and avoiding overdrying, and to some extent by air-drying the stock before kiln-drying it. The best method of controlling cup, however, is by good piling or stacking practices (ch. 5, p. 82). The thinner the lumber, the greater is its tendency to cup.

M–115582–F

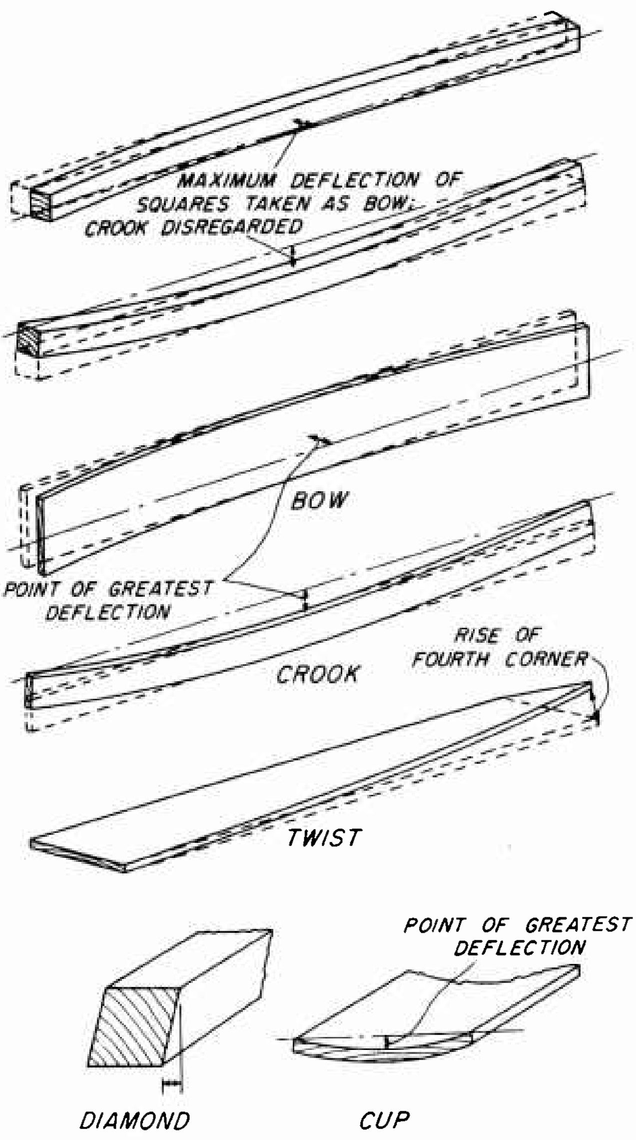
FIGURE 113.—Boxed-heart split in red oak.

Bow (fig. 114) is a deviation flatwise from a straight line drawn from end to end of a board. This defect is associated with longitudinal shrinkage in wood adjacent to the pith of the tree, compression or tension wood that occurs in leaning trees, and cross grain in wood. It can be controlled by the same procedures used to diminish cupping.

Crook (fig. 114) is a deviation edgewise from a straight line drawn from end to end of a board. The causes of crook are the same as those for bow. It is more difficult to prevent than cup or bow.

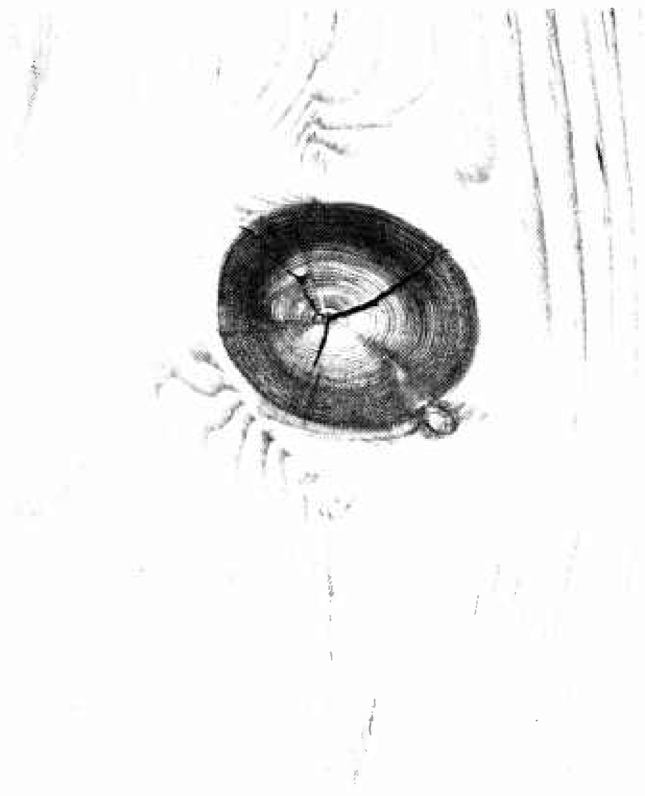
Twist is the turning or winding of the edges of a board so that the four corners of any face are no longer in the same plane (fig. 114). It occurs in wood containing spiral, wavy, diagonal, distorted, or interlocked grain. Lumber containing these grain characteristics can sometimes be dried reasonably flat by using proper piling procedures.

Diamonding is a form of warp found in squares (fig. 114); the cross section assumes a diamond shape in drying. This defect is the result of



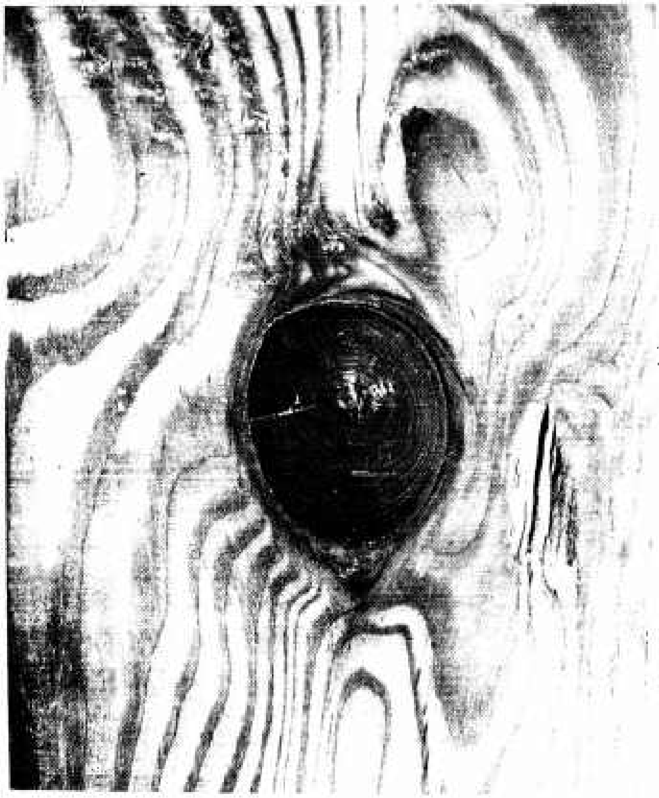
M–89552–F

FIGURE 114.—Various types of warp.



M–15953–F

FIGURE 115.—Checked knot in sugar pine.



M–16268–F

FIGURE 116.—Loose knot in southern yellow pine.

differences between radial and tangential shrinkage in squares in which the annual rings run diagonally from corner to corner. It can be controlled to some extent by air-drying the squares before kiln-drying them.

Checked Knots.—Checked knots are often considered defects. The checks appear on the end grain of knots in the wood rays (fig. 115). They are the result of differences in shrinkage parallel to and across the annual rings within the knots. They occur in the initial stages of drying and are aggravated by using too low a relative humidity. Knot checking can be controlled by using higher relative humidities and by drying to a higher moisture content, but is almost impossible to prevent.

Loose Knots.—Encased knots (dead or black knots) invariably loosen during drying (fig. 116).

This is due to the fact that they are not grown to the surrounding wood, but are held in place only by bark and pitch. They shrink considerably in both directions of the face of the lumber, i.e., across the width and along the length, whereas the board shrinks considerably in width but very little in length. Consequently, the dried knot is smaller than the knothole, and frequently falls out of the lumber during handling and machining. Nothing can be done to prevent the loosening of dead knots during drying. Fewer dead knots will fall out during machining, however, if the lumber is not dried to a low moisture content before it is machined.

Casehardening.—Casehardening is the inevitable result of the drying stresses associated with shrinkage—the stresses persisting when the wood is uniformly dry. Whether or not it is considered to be a defect depends on the final use of the dried material. Casehardened lumber is difficult to machine. Casehardening can be relieved in a compartment dry kiln by a conditioning treatment (ch. 8, p. 143, and ch. 10, p. 164).

Defects Associated With Fungal Attack

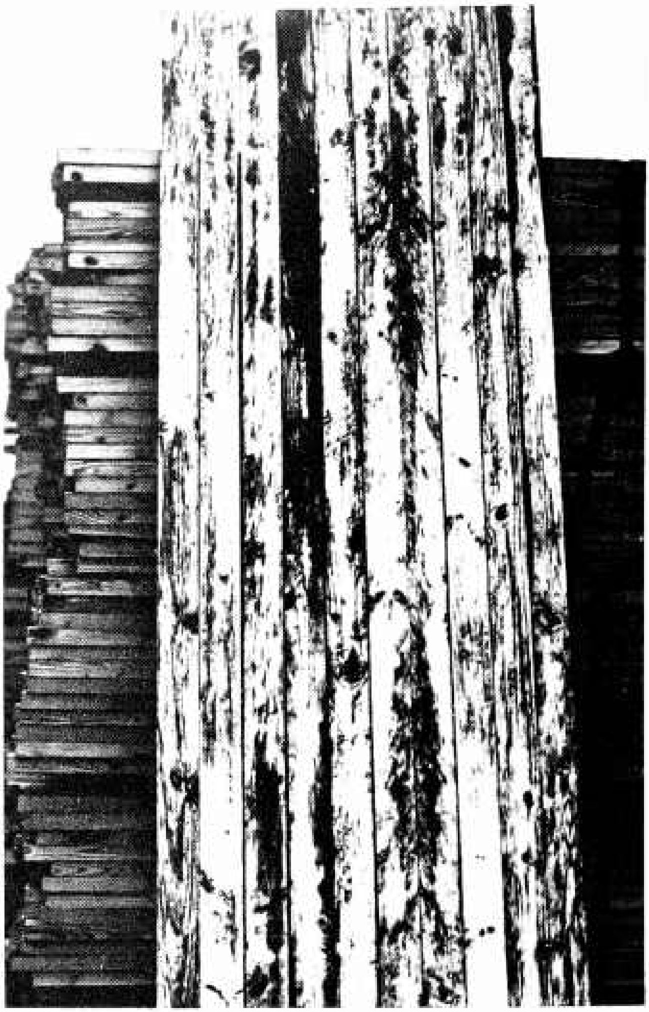
Three defects are associated with fungal attack—sap stain, decay, and mold. All, as discussed earlier, can occur under favorable temperature and moisture conditions during kiln-drying.

Sap stain, commonly called blue stain, is considered a defect for many uses of lumber, and the sapwood of many species of wood are susceptible to it (fig. 117). This defect takes place in the early stages of drying. It is caused by fungi that depend for growth upon proper food, moisture, air, and temperature. If any of these factors are unfavorable, the stain will not occur. The fungi grow most rapidly between temperatures of 75° and 85° F. in wood that has a moisture content of 20 percent or more.

Sap stain can be materially reduced and quite frequently eliminated by the rapid drying of green lumber, fast air-drying, or kiln-drying at temperatures of 150° F. or higher. The kiln conditions necessary to control sap stain are described in chapter 8, p. 142. If green lumber must be held in solid piles under conditions conducive to attack by sap stain fungi before it is dried, it should be treated with a toxic chemical solution.

Defects Associated With Chemicals in the Wood

Extractives in wood undergo chemical changes during drying that may cause discolorations—or chemical stains, as they are generally called. If pitch fails to harden or set during drying, trouble may result, particularly with products to which sealers, varnishes, and paints are applied.



M–92499–F

FIGURE 117.—Sap stain in southern yellow pine. Sap stain color ranges from bluish gray to black.

Brown Stain.—Brown stain (fig. 118) is a chemical stain that occurs in many softwoods, though principally in sugar, ponderosa, and white pine. Its color varies from light to very dark brown. While it affects appearance, it does not impair strength. It is believed to be caused by chemical reactions that take place in the water-soluble extractives as they are concentrated and deposited during drying. The stain may develop within the piece as well as on its surfaces. Planing may remove some of the stain, but it may expose zones of darker stain.

The stain can be reduced considerably by (1) cutting the logs into lumber as soon as possible after the tree is felled; (2) drying the lumber without delay; and (3) using an initial dry-bulb temperature that does not exceed 130° F., with a relative humidity as low as the stock will tolerate without excessive surface and end checking, and a wet-bulb temperature that does not exceed 120° throughout the drying.

M-374-F

FIGURE 118.—Chemical brown stain in white pine.

Sticker Marking.—Sticker marking (fig. 119) occurs in many woods during air- and kiln-drying. These discolorations, which vary in color, may occur on and beneath the surface of the board under the sticker or appear as narrow, dark streaks on the surface at the edges of the sticker. Sometimes they can be removed by surfacing or sanding. Sticker marking is believed to be associated with concentrations of, and chemical changes in, the extractive substances during drying. No means of preventing the discoloration is known. Certain seasoning procedures will, however, lessen sticker staining. These include the use of dry, narrow stickers or of grooved stickers to reduce the contact area, and starting the drying of the green lumber as soon as possible.

Other Color Changes.—Other color changes that take place during the drying of some species of wood appear to be associated with chemical action. One example is "pinking" in hickory —a pink coloration that has no effect on the strength of the wood, but is considered to be a defect for some uses. Pinking can be prevented to a large extent by using a special drying schedule (ch. 8, p. 127). This schedule, though effective in controlling the discoloration, extends the drying time considerably.

Soft Pitch.—All of the pines, Douglas-fir, the spruces, and western larch have resin canals or pockets. As these woods dry, some of the volatile substances in the pitch evaporate, causing it to harden somewhat. If the pitch is not hardened sufficiently, it will ooze or bleed to the surface of the wood during use (fig. 120). Pitch can be thoroughly set by using a temperature of 160° F. or higher.

Effects of Drying Defects on Machining

Lumber can be damaged during machining if it contains certain drying defects. Such damage includes planer splitting, broken knots, knotholes, chipped and torn grain, raised grain, and warp. Precautions taken during drying can help diminish or avoid such damage.

Planer Splitting

A long split often develops when cupped lumber is flattened as it passes through the planer. End splits of course aggravate planer splitting. This type of split, also called a roller split or check, lowers the grade and value of the lumber and causes waste. Not only does the amount of cupping increase as the wood dries, but the wood becomes stiffer and is more likely to split when flattened.

Splitting on the planer can be reduced by taking steps to minimize cupping and end splitting through good stacking practices. Planing at moisture content levels of 12 percent and higher will also reduce splitting. For example, softwood construction lumber is frequently dried to a moisture content of 12 to 18 percent. On the

M-20977-F

FIGURE 119.—Sticker marking in hard maple.

M-34091-F

FIGURE 120.—Pitch exudation in a painted board.

other hand, in the upper grades of both hardwood and softwood lumber, drying must be carried to moisture levels of 10 percent or less to meet end-use requirements. If, in so doing, the lumber becomes cupped, splitting cannot be easily avoided during planing. Splitting on the planer can also be lessened somewhat by relieving casehardening stresses and raising the moisture content of the surfaces of the lumber.

Broken Knots and Knotholes

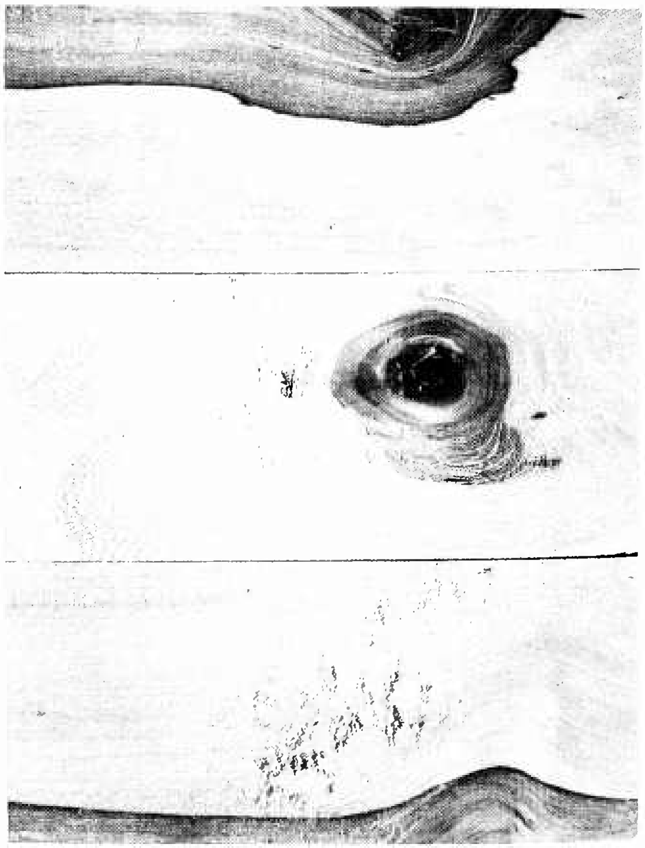
In most grades of lumber it is desirable that the knots in the surfaced board be smooth, intact, and unbroken. Knots check and loosen as drying proceeds, and they become more brittle as the moisture content decreases. The knots are severely hammered as well as cut while in the planer. This hammering breaks checked knots and knocks out loose ones. Knotholes and broken knots lower the grade of the board.

In much of the softwood lumber industry, knotty grades of construction lumber are dried to final moisture content levels ranging from 12 to 18 percent to permit better machining of the knots. At such a moisture content, the sound knots are not severely checked and the encased knots are fairly tight. Therefore, common grades of softwood lumber are separated from finish grades and dried by different schedules, the finish grades being dried to a moisture content of about 8 to 10 percent.

Encased knots in some species of wood are held in place largely by a deposit of pitch between the knots and the board proper. This deposit is of appreciable thickness, and if it is removed, the knots fall out of the board. Old-growth Douglas-fir, for example, characteristically has many encased or black knots. If temperatures of 160° to 180° F. are used to kiln-dry such lumber, the resin becomes so soft that it runs out from around the encased knots, which drop out. At a drying temperature of 125° or lower, relatively little resin will soften and run out.

Chipped and Torn Grain

During the machining of dry lumber, wood may be chipped and torn from scattered areas on the machined surface (fig. 121). The occurrence of chipped and torn grain is influenced largely by the operating condition of the machine; the sharpness and setting of the knife; the rate of feed into the machine; and the slope of the grain in the wood, including grain variations. To some extent, however, the susceptibility of lumber to chipping and tearing is affected



M-34965-F

FIGURE 121.—Chipped grain in elm.

by the moisture content of the wood layer being removed. Lumber of extremely low surface moisture content—5 percent and less—chips and tears more during machining than if the surface moisture content is 8 percent or higher. Consequently kiln operators can, to some extent, help prevent this trouble by avoiding overdrying and by increasing the surface moisture content with a conditioning treatment.

Raised Grain

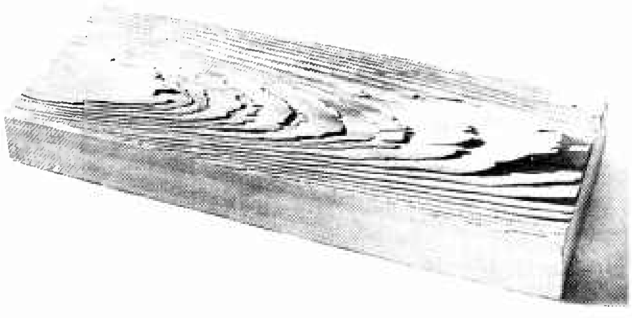
Raised grain (fig. 122) occurs primarily when lumber is not uniformly dried to a low enough moisture content at the time of machining. Generally, raised grain does not develop in wood that is machined while at a moisture content of 12 percent and less. When wood is machined at a higher moisture content, the action of the knives forces the summerwood bands into the springwood bands on the flat-grained surface. Subsequently, the compressed springwood recovers and lifts the bands of summerwood above the surface. The uneven surface produced usually reduces the grade and usefulness of the finished product.

Casehardening

Whether casehardening is considered a defect or not depends upon the manner in which the lumber is sawed or machined during fabrication. The more common fabrication difficulties that occur in the use of casehardened lumber are end checking, planer splitting, and warping.

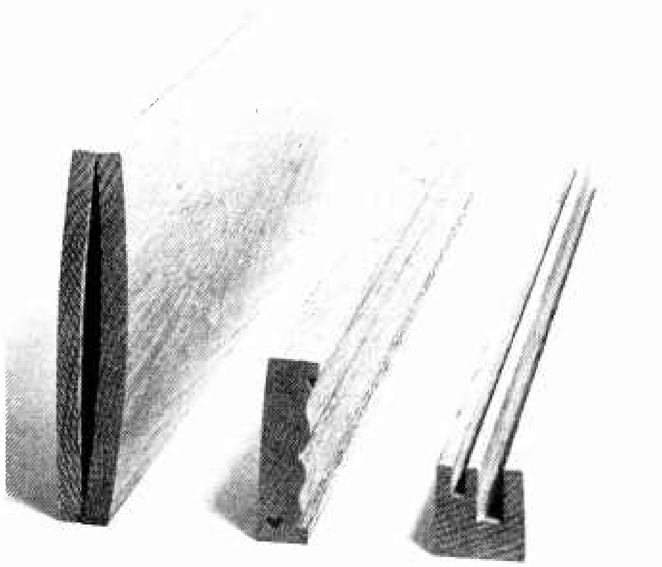
End Checking.—End checks will frequently develop in the core of a freshly crosscut casehardened board that is exposed to low atmospheric relative humidity, even though the average moisture content of the board is fairly low. The tensile stresses present in the core, coupled with additional stresses brought about by end drying, exceed the strength of the wood, which therefore checks. These checks may develop into splits.

Planer Splits.—Splits can occur in relatively flat casehardened boards that are being surfaced. The splits are caused by the internal drying stresses in the boards, coupled with the forces applied by the machine knives. As mentioned before, planer splits due to casehardening will be appreciably reduced by a conditioning treatment.



M—97880—F

FIGURE 122.—Raised grain in Douglas-fir.



M—111992—F

FIGURE 123.—Distortion caused by casehardening. Left to right—resawed stock; heavy machining on one face; and grooved.

Warping.—If during any sawing or machining operation on a casehardened board the transverse or longitudinal stresses are unbalanced, distortion will result. Resawing may cause cupping or bowing. The concave faces will be toward the saw (fig. 123). Ripsawing may result in crook, the concave edges usually being those along the saw cut. In planing, the depth of cut is not likely to be the same on both faces; so if the board is casehardened, it will cup, and the concave face will be the one most heavily cut (fig. 123). When casehardened stock is edgegrooved, the lips of the groove may pinch inwards (fig. 123). A tongue or spline inserted into such a groove may break the lips. When machining casehardened stock to patterns, as in the manufacture of molding and trim, or in routing and carving operations where unequal cuts are taken from the faces and edges, cupping usually results. Any warping of casehardened stock that is due to sawing or machining is a source of trouble in fabrication and gluing.

The relief of casehardening by a conditioning treatment is strongly recommended for lumber that is to be used in furniture, architectural woodwork, sash and door stock, and other products, which may require sawing and machining operations that may unbalance the casehardening stresses.

Drying Defects of Major Concern in Commercial Woods

All woods are subject to drying defects. In attempting to hold drying defects to a minimum, the final use of the stock should be considered, since some defects can be tolerated for certain uses. It is the kiln operator's responsibility to develop and use drying procedures that fit the specific requirements. Use of procedures to obtain defect-free kiln-dried stock when the final use permits some defects would, of course, be poor practice. The operator must also keep in mind that procedures to reduce or prevent one defect may aggravate or cause others. Therefore, he must follow a course of action that will result in the smallest amount of degrade.

A list of commercial woods and the major defects occurring in drying them follows. Certain defects are excluded for various reasons. For example, boxed-heart split is not listed because this defect is very likely to occur in boxed-heart material of all species. Casehardening is excluded; it is not always considered a defect. All types of warp are excluded; warp is controlled by stacking procedures rather than by drying schedules. Other defects associated with shrinkage are omitted because their severity is related more to thickness of material than to species.

SOFTWOODS

Species	*Major drying defects*
Baldcypress	End checks. Water pockets.
Cedar:	
Alaska-	Failure to set resin.
Eastern red-	Checking in and around knots. Excessive loss of aromatic oils.
Incense-	Collapse. Surface checking in flat-sawed 12/4 or thicker stock.
Port-Orford-	Failure to set resin.
Western redcedar	Collapse and honeycomb, particularly in sinker stock.
Douglas-fir: coastal, intermediate, and mountain types.	Loose and checked knots. End-check penetration resulting in internal failures in thick stock. Ring failure in quarter-sawed lumber.
Fir:	
California red	End and surface checks. Water pockets.
White	End and surface checks. Water pockets.
Hemlock:	
Eastern	End and surface checks. Opening of ring shakes.
Western	Water pockets. Chemical stain.
Larch, western	End and surface checks.

SOFTWOODS—Continued

Species	*Major drying defects*
Pine:	
Eastern white	Brown stain. Water pocket. End and surface checks in 8/4 and thicker stock.
Lodgepole	Checked knots. Checks and end splits in 8/4 and thicker stock.
Ponderosa	Brown stain. Checked knots. End and surface checks in 8/4 and thicker stock.
Southern yellow	End and surface checks in 8/4 and thicker stock.
Sugar: light and sinker	Brown stain. End and surface checks in 8/4 and thicker stock.
Western white	Brown stain. End and surface checks in 8/4 and thicker stock.
Redwood:	
Light and medium	End and surface checks in 8/4 and thicker stock.
Sinker	Collapse and honeycomb.

HARDWOODS

Alder, red	Sticker marking.
Ash:	
Black	Surface checks, particularly in 6/4 and thicker stock.
White	End and surface checks. Honeycomb, particularly in 6/4 and thicker stock.
Aspen	Collapse in "wet wood." Water pocket.
Basswood, American	Brownish chemical stain.
Beech, American	End and surface checks.
Birch:	
Paper	End checks. Brownish chemical stain.
Yellow:	
normal	End and surface checks.
mineral streaked	Collapse and honeycomb.
Cherry, black	Honeycomb in 8/4 or thicker stock; surface checks.
Chinkapin, golden	End and surface checks. Collapse.
Cottonwood, eastern	Water pocket.
Dogwood, flowering	End checks. Chemical stain. Sticker stain.
Elm, American	End and surface checks in 8/4 and thicker stock.
Hackberry	End checks.
Hickory	End checks. Chemical stain (pinking).
Laurel, California	End checks.
Locust, black	End and surface checks.
Madrone, Pacific	End and surface checks.
Mahogany	End and surface checks in thick stock.
Maple, sugar:	
normal	End checks in 8/4 and thicker stock. Honeycomb, usually associated with end-check penetration, in thicker stock. Chemical stain.
mineral streaked	Checking, collapse, and honeycomb.

HARDWOODS—Continued

Species	*Major drying defects*
Oak:	
California black	End and surface checks. Honeycomb.
Red	End and surface checks. Honeycomb, particularly in 8/4 and thicker stock.
White	End and surface checks. Honeycomb, particularly in 8/4 and thicker stock.
Persimmon, common	End and surface checks. Chemical stain.
Sweetgum (heartwood)	Honeycomb, collapse, and water pocket.
Sycamore (heartwood)	Surface checks and honeycomb.
Tanoak	End and surface checks. Honeycomb.
Tupelo, water	End checks. Honeycomb and collapse, particularly in 8/4 and thicker heartwood stock.
Walnut, black	End checks. Honeycomb, usually associated with end-check penetration in 6/4 and thicker stock.
Willow, black	End checks; honeycomb.
Yellow-poplar	End checks in 10/4 and thicker stock.

555315 O—61——11

CHAPTER 10. OPERATING A DRY KILN

A dry kiln, no matter how well equipped with controls, is only as efficient as the operator who runs it. In the final analysis, it is the operator's judgment that determines whether a charge of lumber will go through the kiln in minimum time and emerge uniformly dried to the desired moisture content and free of undesired stresses and defects. It is the operator who selects, prepares, and uses kiln samples, who decides what drying schedules to use, who manipulates the controls as drying progresses, who applies and modifies drying schedules to suit the stock in the kiln, who applies equalizing and conditioning treatments, and who makes the final necessary determinations of drying quality. Some of the basic techniques are discussed elsewhere in this manual.

In this chapter, certain aspects of kiln operation are presented to guide the operator in exercising good judgment as to when and how to reach the necessary decisions he needs to make while a charge is being dried. Such judgment, of course, must be predicated upon adequate knowledge of wood and how it dries as well as on the characteristics and capabilities of the kiln being operated.

Compartment Kiln Operation

A compartment kiln is loaded fully at one time, and the entire charge remains in the kiln until all the lumber has been dried to the desired moisture content. For best results, the dry-bulb temperature of the entering air must be uniform throughout the kiln.

The two types of drying schedules used in compartment kilns, those based on the moisture content of the stock and those based on time, are discussed in chapter 8. Kiln samples are not required when a time schedule is followed, though many operators use them to check the performance of their kilns and the final moisture content of the stock. A drying schedule based on moisture content—which requires kiln samples—is generally used when drying hardwoods.

Kiln Samples

The selection, preparation, and use of kiln samples are important in kiln operation, and their neglect can result in erroneous moisture content values that may cause increased kiln degrade or drying time and improperly dried stock. Instructions in chapter 6 on kiln samples should be followed as closely as possible.

Selecting a Drying Schedule

The drying schedule is selected by the operator after careful consideration of the stock to be dried, as described in chapter 6, p. 99. This consideration includes species, thickness, moisture content, heartwood or sapwood, quarter-sawed or flat-sawed, and density. Selection of a drying schedule is obviously simplified when the charge consists of one species of one thickness and a fairly uniform moisture content, and is either all heartwood or all sapwood and entirely quarter-sawed or flat-sawed.

Schedules for Homogeneous Charges.—For charges that consist entirely of one class of stock, a schedule recommended for that class in chapter 8 should be used to start with. After experience is gained with that particular class, the schedule can be modified, as discussed in chapter 8.

Schedules for Mixed Charges.—In selecting a drying schedule for a mixed charge of lumber, consider the drying characteristics of all the stock. Mixed charges are usually dried according to moisture content schedules. The following examples and suggestions should be helpful in selecting a drying schedule for mixed charges. In all of these examples, the schedules recommended in chapter 8 are used.

Example 1.—If a charge of lumber is composed of the same species and moisture content but of varying thicknesses, use the schedule recommended for the thickest stock. For example, if the kiln charge is composed of 6/4 and 8/4 sugar maple, follow the drying schedule T5–C2 rather than T8–C3. If the charge is composed of 4/4, 5/4, and 6/4 sugar maple, schedule T8–C3 could be used, and the changes in drying conditions would be based on the kiln samples having the highest moisture content.

Example 2.—If two or more species of the same thickness and moisture content are dried together, use the schedule recommended for the species that is the most difficult to dry. Make every effort to mix species that require much the same drying schedule and about the same drying time. Examples are 4/4 white ash and 4/4 black cherry. Both call for the same drying schedule, T8–B4. Several species have approximately the same drying characteristics. These include 4/4 yellow birch, schedule T8–C4; 4/4 black cherry, T8–B4; and 4/4 sugar maple, T8–C3. They have the same temperature schedule—T8—but their wet-bulb depression schedules are different. Since the mildest drying condition is recommended, use the C3 wet-bulb depression schedule. The penalty in drying time or drying degrade connected with the mixing of species with widely different drying characteristics, such as green 4/4 red oak and 4/4 sugar maple, would be severe. The oak requires a much milder drying schedule, T4–D2, than the sugar maple, T8–C3. Also, the drying time required for the oak is almost twice that required for the maple. Avoid such mixtures.

Example 3.—Another example of a mixed charge is two species or more of the same thickness but of varying moisture content, such as a mixture of green 4/4 black cherry and air-dried 4/4 sugar maple having an average moisture content of 25 percent. Green black cherry calls for schedule T8–B4 and green sugar maple for schedule T8–C3. The air-dry sugar maple with a moisture content of 25 percent calls for initial drying conditions of 150° F. dry-bulb temperature (step 3 of T8 schedule) and a wet-bulb depression of 35° (step 5 of C3 schedule), whereas the T8–B4 schedule for the green black cherry calls for an initial dry-bulb temperature of 130° and a wet-bulb depression of 7°. To avoid damage to the green cherry, use the milder T8–B4 schedule.

These examples of mixed kiln charges are only a few of the many that may occur in commercial drying. However, they serve to illustrate two points, (1) that the drying of mixed charges usually results in either excessive drying time, nonuniform final moisture content, or excessive drying degrade on some of the stock, and (2) that the selection of the drying schedule depends on the drying characteristics of the item in the charge that is most difficult to dry.

An operator must exercise good judgment in weighing the quality against the quantity of kiln-dried stock produced and also consider the total value of the various classes of stock composing the kiln charge. In some cases it may be economical to choose the faster schedule and take some kiln degrade.

Starting the Kiln

Steam-Heated Kilns.—Drying defects and drying time can be reduced if the proper starting procedures are used. These vary somewhat between kilns equipped with automatic control instruments and those manually operated.

Automatically Controlled Kilns.—Generally the starting procedure for automatically controlled kilns is as follows:

(1) Set the dry- and wet-bulb control indicators or pointers of the control instrument at the initial temperatures called for by the drying schedule.

(2) Keep the hand valve on the steam-spray feed line closed during the warmup period to avoid excessive steam consumption and condensation of vapor on the lumber. If there is no hand valve on the steam-spray feed line, set the wet-bulb temperature indicator to the lowest temperature on the instrument chart to prevent opening of the automatic spray valve. An alternate procedure for adjusting the wet-bulb indicator is described in item 12.

(3) If the kiln is of the forced-circulation type, open the small inspection doors or leave the main door partly open. Start the fans or blower. Close the doors after the fans have operated for several minutes.

(4) Open the hand valve on the main steam supply line.

(5) Open the hand valves on the feed lines to all the heating coils.

(6) Open the hand valves between all the heating coils and steam traps and in the return lines from the steam traps to the boiler.

(7) If the control instrument is air operated, open the blowoff valve on the air filter located on the air supply line to the control instrument until the air is free of water and oil.

(8) Open the main air supply valves to the control instrument and to the air-operated valves on the heat and spray lines. If the control system is electrically operated, turn on the power switches.

(9) Blow all the steam traps to the atmosphere for a short time to remove scale and dirt from them.

(10) Just before the dry-bulb temperature reaches that desired, open the hand valve on the steam-spray feed line, or reset the wet-bulb indicator on the control instrument to the recommended wet-bulb temperature.

(11) If the kiln is equipped with auxiliary vents, keep them closed during the warmup period until the wet-bulb temperature reaches the set point.

(12) Some operators, when warming up a kiln charge of green wood susceptible to checking, prefer to bring the wet-bulb temperature up in easy stages rather than follow the procedure given in steps 2 and 10. For example, if the initial drying conditions call for a wet-bulb depression of 4° F., they try to maintain this depression during the warmup period. This is done

by opening the hand valve on the steam-spray line for short periods of time, or by gradually raising the wet-bulb indicator if it was initially set at the lowest point on the chart. Under this procedure the recorded temperatures on the control instrument must be checked at frequent intervals during the warmup period.

Manually Operated Kilns.—A manually operated kiln is started as outlined in steps 2, 3, 4, 5, 6, 9, 10, and 11 above. Manual operation requires the use of auxiliary temperature-indicating devices.

Furnace-Type Kilns.—Both direct- and indirect-heated kilns of the furnace type vary widely in the design of the heating and the air-circulation systems. Kilns of this type with automatic control of temperatures are generally started as follows:

(1) Set the dry- and wet-bulb control indicators or pointers of the control instrument at the initial temperatures called for by the drying schedule.

(2) If the kiln is of the forced-air-circulation type, open the small inspection doors or leave the main door partly open. Start the fans or blowers. Close the doors after the fans have operated for several minutes.

(3) Start the furnace according to the instructions given by the furnace manufacturer.

(4) If the kiln is equipped with auxiliary vents, keep them closed during the warmup period.

(5) If the kiln is equipped with steam or water sprays, keep them shut off until the dry-bulb temperature has almost reached the initial setting. In warming up a charge of wood susceptible to checking, the operator may prefer to raise the wet-bulb temperature in easy stages by following the procedure outlined above for a steam-heated kiln.

Spray During Warmup

Many dry-kiln operators use both heat and steam spray to "warm up" a charge of lumber. This procedure will reduce to some extent the time required for warmup, but the potential ill effects connected with it may more than offset the gain in time.

When both the heating and steam-spray systems are on during warmup, a large quantity of steam is used. The steam consumption may exceed the boiler output and thereby affect the drying conditions in other dry kilns already operating on schedule.

With the steam spray on, condensing of the excess moisture in the air on the cold lumber, cold kiln walls and ceilings, and cold metal surfaces within the kiln has several effects. It allows very little if any drying of the lumber during the warmup period; instead, the lumber will sometimes pick up considerable moisture. It may cause water stain on the lumber and more rapid deterioration of the kiln structure. Checks may widen and deepen in surface-checked lumber.

Time Needed to Warm Up Charge

The time required to attain the desired drying conditions for a charge may vary from 1 to 24 hours or more. Warmup time is lengthened if (1) the temperature of the lumber and the kiln structure is low; (2) the temperature of the outside air is low; (3) the initial moisture content of the lumber is high; (4) heat losses through the kiln walls, vents, roof, and around the kiln doors are excessive; (5) if some of the heating coils are inactive; and (6) if the boiler output is too low or the heating system is not functioning properly.

Long warmup periods will, of course, be more costly with short drying cycles than with long ones. For example, a warmup period of 12 hours will increase the overall drying costs more on a 3-day drying cycle than on a 20-day drying cycle.

Operating Kiln After Warmup

Reduction of Radiation.—About 1 hour after the kiln reaches the desired drying conditions, start to reduce radiating surface, steam pressure, or both. This is done by closing the hand valves in the feed and drain lines to some of the heating coils or by adjusting the steam pressure regulator. The usual procedure in reducing radiation is to cut off the larger heating coils first and gradually work down to the smallest coil that will maintain the desired dry-bulb temperature. This procedure should be followed unless past experience has shown how much radiation is required to maintain the desired temperature. Note on the recorder chart when and what coils are turned off and the steam pressure used. These notations will be helpful in the drying of subsequent kiln charges of similar material.

Control of Dry-Bulb Temperature.—Variations in dry-bulb temperature on the entering-air side of the loads are the greatest source of poor control of drying conditions. These variations are sometimes associated with faulty kiln design, but they are usually attributable to poor maintenance (chs. 2 and 4). The most common cause of temperature variations is heat radiation in excess of that needed. Excessive radiation results in large temperature cycles and waterlogging or air binding of the active heating coils, and these in turn cause excessive temperature variations along the length of the coils. To reduce these effects, operate the kiln on the smallest amount of radiation and the lowest steam pressure necessary to maintain the desired dry-bulb temperature at any stage of drying.

If the subdivision of the coils is not fine enough and the steam pressure cannot be regulated, the kiln may have to be operated at a dry-bulb temperature slightly below the desired one in order to obtain a nearly constant flow of steam. In that event, the wet-bulb temperature will also have to be adjusted slightly downward so as to obtain the desired wet-bulb depression.

In a manually operated kiln, temperatures can be controlled by reducing or increasing the radiating surface and by regulating steam pressures through the use of reducing valves. Though globe valves are sometimes used for regulating steam pressure in the coils, they are not recommended. A gate valve should never be operated partly opened (throttled), because this results in "wiredrawing." Wiredrawing eventually erodes the entire gate, making the valve unfit for use.

Control of Wet-Bulb Temperature.—Generally, poor control of wet-bulb temperature is associated with inadequate kiln maintenance (ch. 4). Quite frequently, however, the use of a high-pressure steam spray causes wide variations in both the dry- and wet-bulb temperatures. The use of wet low-pressure steam should overcome this difficulty. If the reduction in pressure does not have the desired effect, desuperheaters may have to be installed on the steam-spray lines. Some kiln operators inject water into the steam-spray line. The flow of water should not be excessive and may be controlled by a needle valve. To make this possible, the water pressure must be greater than the steam pressure. Ordinarily water is used to saturate the steam spray only during the equalizing and conditioning treatments.

Proper venting is also required to obtain good control of wet-bulb temperatures. In kilns equipped with automatic vents, such control is attained by good maintenance and operation of the vent system (ch. 4). In kilns with manual vent control, the operator should regularly observe the wet-bulb temperatures and open or close the vents when required. Excessive venting will add to steam consumption and favor the development of drying defects. On the other hand, operating the kiln for extended periods with insufficient venting and at wet-bulb temperatures above those called for by the schedule will prolong drying time.

Some drying schedules call for low wet-bulb temperatures at certain stages of drying. An example of this is the schedule for green 4/4 red oak (T4-D2). When this stock reaches a moisture content of 25 percent, the recommended wet-bulb temperature is 80° F. Occasionally, in some areas and at certain times of the year, the wet-bulb temperature of the outside air may be above 80°. When this occurs, the wet-bulb temperature in the kiln cannot be reduced to 80° regardless of the amount of venting, and the kiln must be operated at the lowest wet-bulb temperature attainable. Do not raise the dry-bulb temperature above that called for in the schedule.

Full-Time or Part-Time Operation.—Full-time operation is the usual practice in industry, but some plants, particularly secondary producers, operate kilns part time. Under full-time operation, drying is uninterrupted from the start to the finish of the process. In part-time operation, the kiln is usually shut down during night hours, over the weekend, and on holidays. Part-time operation is generally practiced when fuel and power costs are high and kiln capacity is greater than required.

Most woods, particularly air-dried stock can be dried under part-time operation. However, equalizing and conditioning treatments must usually be given under full-time operation in order to be successful. On green, refractory hardwoods, part-time operation during the initial stages of drying may result in excessive defects such as checking, because of a more rapid drop in the wet-bulb than in the dry-bulb temperature during the off-time period. When this occurs, operate the kiln on a full-time basis until the danger of checking is past. Keep the vents closed during the off-time period to reduce heat losses from the kiln.

The Drying Process

After the kiln has been started, the lumber is dried in accordance with the schedule selected (ch. 8). Near the end of the drying process, equalizing and conditioning treatments are applied as required, depending upon the final use of the lumber. Final tests should be made on the stock before it is pulled from the kiln.

Operation on a Moisture Content Schedule.—A moisture content schedule requires changes in drying conditions based on the average moisture content of the controlling kiln samples (ch. 6, p. 99). Operation on a moisture content schedule is best illustrated by examples.

Example 1.—A charge of green 4/4 sugar maple lumber is to be kiln-dried. Six kiln samples are used so that the average moisture content of the three wettest samples will govern the drying conditions. The drying schedule for this charge is given in table 35, and the schedule is applied as follows:

Since the lumber is green, the initial moisture content will be above 40 percent. Therefore, the initial drying conditions will be those given for this moisture content.

TABLE 35.—*Moisture content schedule for 4/4 sugar maple (T8–C3)*

Temperature step	Wet-bulb depression step	Moisture content at start of step	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature
No.	*No.*	*Percent*	°*F.*	°*F.*	°*F.*
1	1	Above 40	130	5	125
1	2	40	130	7	123
1	3	35	130	11	119
2	4	30	140	19	121
3	5	25	150	35	115
4	6	20	160	50	110
5	6	15	180	50	130

Subsequent changes in drying conditions are made when the average moisture content of the controlling samples reaches the values given in the schedule. For example, when the average moisture content of the three wettest samples is less than 30 percent but more than 25 percent, the dry-bulb temperature is 140° F. and the wet-bulb temperature is 121°. Because the drying rate of the kiln samples may vary from day to day, the same three samples may not be the wettest during all stages of drying. Therefore, the moisture content of all the samples in the charge should be calculated each time they are weighed (ch. 6, p. 104). The last drying conditions are maintained until the desired moisture content has been reached.

Occasionally the controlling kiln samples lose more moisture between weighings than the interval given in the schedule. When this occurs, a step in the schedule can be skipped. For example, if the kiln is operating at 130° F. and 119° dry- and wet-bulb temperatures, respectively, and the next weighing indicates that the average moisture content of the controlling kiln samples is 24 percent, the drying conditions should be set at a 150° dry-bulb and a 115° wet-bulb temperature, rather than at 140° and 121°. In some instances, even two steps can be skipped.

As soon as the final moisture content is reached, the kiln is shut off unless equalizing and conditioning treatments are required (ch. 8, p. 142).

Example 2.—A charge of partially air-dried 4/4 sugar maple is to be kiln-dried. Eight kiln samples are to be used. Therefore, drying conditions will be governed by the average moisture content of the four wettest samples. The drying schedule will be the same as that used in example 1, and the procedure will be as follows:

If the initial moisture content of the four wettest samples averages more than 40 percent, the initial drying conditions will be those listed for this moisture content. Subsequent drying procedures will be the same as for example 1.

If the average moisture content of the four wettest samples is 34 percent, the initial drying conditions will be 130° F. and 119°. Subsequent drying conditions will be as given in the schedule.

If, however, the stock has regained moisture just before entering the kiln, modify the drying procedure to conform to the recommendations given for air-dried hardwoods, chapter 8, p. 124.

Operation on a Time Schedule.—Under a time schedule, the drying conditions are changed at predetermined periods of time. A time schedule for 4/4 white fir (AS7–AK7) is given in table 36.

The kiln is started at 145° F. dry-bulb and 128° wet-bulb temperature and these temperatures are maintained for 12 hours.

TABLE 36.—*Time schedule for 4/4 white fir (AS7–AK7)*

Temperature step	Wet-bulb depression step	Time	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature
No.	*No.*	*Hrs.*	°*F.*	°*F.*	°*F.*
1	1	0–12	145	17	128
2	2	12–24	150	23	127
3	3	24–36	155	30	125
4	4	36–48	160	30	130
5	5	48–60	170	35	135
6	6	60–72	180	43	137

After 12 hours of drying, the kiln temperatures are changed to those of the second temperature step; further changes are made every 12 hours as shown.

After a total drying time of 72 hours, the charge is pulled from the kiln if equalizing and conditioning treatments are not required.

Kiln samples are sometimes used in conjunction with time schedules to obtain information on kiln performance. They are particularly useful in determining final moisture content. If the samples indicate a consistently high or low moisture content, the duration of the final temperature step should be changed to produce the desired final moisture content.

Final Wet-Bulb Temperature.—The control of wet-bulb temperature is not critical during the final stage of drying even though the maximum wet-bulb depression given in the moisture content schedules (table 10, p. 119) is 50° F. The hand valve on the steam-spray feed line should be closed. In kilns equipped with automatic vent control, the wet-bulb temperature indicator on the control instrument should be set to obtain a 50° wet-bulb depression. If the vents are manually operated, they should be manipulated to maintain a wet-bulb depression of at least 50°.

Intermediate Moisture Content.—Near the final stage of drying, the moisture content of the stock must be known within fairly close limits, or the stock may be dried to a different moisture value than desired. Furthermore, equalizing and conditioning treatments, if required, will not be successful if the moisture content of the kiln samples is in error. The original calculated ovendry weights of kiln samples cut from green or partially dried stock are sometimes in error. To minimize trouble of this nature, an intermediate moisture content determination of the kiln samples is made as the final stage of drying is approached. The purpose and method of making such a determination is described in detail in chapter 6, p. 105.

Intermittent Steaming.—Some kiln operators steam charges of lumber at or near saturation at intervals throughout the drying process, believing that it speeds up moisture movement and reduces drying defects. On the contrary, such steaming is likely to increase drying time. It can also result in more severe end and surface checking, possible internal failures, and increased warping.

Sterilizing Treatment

The growth of mold and fungal stains can be stopped by a sterilizing treatment as described in chapter 8, p. 141.

Equalizing, Conditioning Treatments

Good moisture quality and stress-free stock can be obtained by equalizing and conditioning treatments described in chapter 8, p. 142. To get good results from them, the following details should be observed.

Equilibrium Moisture Content Table.—In order to apply the equalizing and conditioning procedures, an operator must know how to determine the wet-bulb depression needed to give the required equilibrium moisture content (EMC) condition. Equilibrium moisture content values are given in table 2, p. 11. In the example presented here, however, the use of this table is the reverse of the explanation given in chapter 1. Assume, for example, that a dry kiln is operating at a dry-bulb temperature of 170° F. and it is desired to know what wet-bulb temperature is needed in order to obtain an EMC of 6 percent. The dry-bulb temperature of 170° is found in the lefthand column. In the line to the right of this temperature, the EMC of 6 percent is found (in italic type) in the column indicating a wet-bulb depression of 29°. Therefore, to obtain an EMC of 6 percent at a dry-bulb temperature of 170°, a wet-bulb temperature of 170° minus 29°, or 141°, would be used.

General Considerations.—

(1) The recommended procedures for equalizing and conditioning a charge of lumber will produce good results in a compartment-type kiln that is performing satisfactorily, but one factor must not be overlooked; the control instrument must be in calibration (ch. 4, p. 71). If because of poor calibration the wet-bulb depression in the kiln is different than the recommended setting on the instrument, the EMC condition in the kiln will not be correct and the treatments may not give satisfactory results.

(2) An equalizing treatment is not necessary if the driest and wettest kiln samples at the end of the drying process have moisture contents within the permitted range.

(3) Some operators prefer drying the driest samples in the kiln charge to a moisture content 1 percent lower than the value recommended in table 33, p. 143, before starting equalization. This might reduce equalizing time, and it might even eliminate the equalizing treatment.

(4) If the recommended EMC value for conditioning at a specific temperature cannot be found in table 2, use the next highest value given in the table for that temperature. For example, it is desired to condition a charge of lumber at 170° F. with an EMC condition of 11 percent. Referring to table 2, no wet-bulb depression is given for an EMC condition of 11 percent at a temperature of 170°. Use the next highest value—11.3 percent. The wet-bulb depression for the 11.3 percent EMC condition is 10°.

Conditioning Time.—High dry-bulb temperatures coupled with high EMC conditions hasten the deterioration of dry kiln buildings and metal within the kiln. Also, large quantities of steam are required during the conditioning treatment. Therefore, do not extend the treatment beyond the time required for the relief of casehardening. Conditioning time depends upon the degree of stress in the lumber, its species, thickness, and moisture content, and the kiln's performance. It may vary from 4 hours for 1-inch softwoods to 48 hours or more for the thicker hardwoods. The minimum time required is determined by making prong tests at intervals when it is believed that casehardening has been nearly relieved. Information so collected will be a guide for estimating the conditioning time for later charges of similar stock. The prong test is described in chapter 6, p. 105.

When air-dried lumber is kiln-dried, the conditioning time varies from charge to charge, because the degree of casehardening in the air-dried material varies. Casehardening tests made on air-dried stock at the time the kiln samples are prepared will give an idea of the time required for conditioning.

Conditioning Temperature.—The higher the dry-bulb temperature used during the conditioning treatment, the faster will be the relief of casehardening. Generally, the required conditioning EMC can be obtained at a dry-bulb temperature of about 180° F. in most well-kept kilns operated on low steam pressure and equipped with a desuperheater on the spray line or with auxiliary water sprays. Sometimes it is impossible, however, to obtain at very high temperatures the rather high EMC conditions that are required.

If the required EMC cannot be obtained at a dry-bulb temperature of about 180° F., the temperature will have to be reduced. In such instances, lower the setting on the control instrument 12 to 24 hours before conditioning is started. For example, assume the kiln is operating on a dry-bulb temperature of 180° and the temperature must be reduced to 170° to obtain the desired EMC. Twelve to twenty-four hours before treatment is started, set the control instrument at a dry-bulb temperature of 170°.

Casehardening Relief at High EMC.—To reduce the time required for conditioning, some kiln operators use an EMC considerably higher than that recommended for the treatment. This approach may be satisfactory if the treatment is not continued for too long a time. If the treatment is too long, reverse casehardening—a condition equally as serious as casehardening—will result. No satisfactory method of relieving reverse casehardening has been established. In many instances the use of very high equilibrium moisture contents during conditioning gives only superficial relief of the drying stresses. Therefore, to obtain good conditioning without incurring risk of reverse casehardening, the conditioning treatment should be given at the recommended EMC (table 33, p. 143).

Moisture Content, Casehardening Tests

Kiln samples are generally used for final moisture and stress tests to make sure that the lumber has been dried to the desired moisture content and is free of casehardening. Other boards from the kiln charge can also be used.

Method of Testing.—To properly interpret the casehardening test sections, certain information concerning the final moisture content and moisture gradient is essential. The method of cutting sections for such tests is given in chapter 6, p. 105. One section should be weighed immediately after cutting, placed in a drying oven, dried to constant weight, reweighed, and its moisture content calculated (ch. 6). This calculation will give the average moisture content of the kiln sample or board from which the section is cut. If this test is made immediately after the conditioning treatment, the moisture content obtained will be about 1 to 1½ percent high, because surface moisture has been regained during the conditioning treatment. If, however, the test is made after the stock has cooled for about 24 hours, the regained surface moisture will have evaporated.

A second section should be cut as shown in figure 95, p. 105, to get an outer shell having a thickness of about one-fourth the total thickness of the stock, and a core. The core and shell are weighed separately as quickly as possible after cutting, placed in a drying oven, dried to constant weight, reweighed after drying, and their moisture content calculated. These tests will give the moisture content of the shell and core. Section 3 should be cut into prongs (fig. 96, p. 106). If the stock is less than 6/4 inches in thickness, three prongs of equal thickness are cut and the center prong removed; if the stock is 6/4 inches or greater in thickness, six prongs of equal thickness are cut and the prongs next to the outside prongs are removed.

Evaluation of Casehardening.—When you judge that casehardening has been relieved, shut off the kiln and remove and test some of the kiln samples or other boards. If, at the time of sawing, the outer prongs of the test section turn away from the saw a distance about equal to the thickness of the prong or slightly more, the stock is usually free of casehardening and the charge can be pulled. If, however, the outer prongs remain straight or pinch the saw, the stock is casehardened; continue the conditioning treatment until tests show satisfactory relief.

After the preliminary evaluation is made, room-dry the test sections for about 24 hours. The following conditions may then be observed.

(1) The outer prongs have turned in considerably. This indicates that the stock is still casehardened; lengthen the conditioning time for subsequent charges of the same material.

(2) The outer prongs are straight. This indicates that the lumber is free of casehardening; use the same conditioning time for subsequent charges of the same material.

(3) The outer prongs have turned out considerably. This indicates that the stock is reverse casehardened. Shorten the conditioning time for subsequent charges of similar material.

Modifying Schedules for Compartment Kilns

Perhaps one of the greatest causes for excessive drying cost is blindly following a recommended kiln-drying schedule. No drying schedule will produce the best drying results on a specific item or species of wood in all types of kilns and under all types of conditions. To obtain the best results, some modification of the recommended schedules is usually necessary.

Before modifications can be made, the recommended schedule must be tried. By observing (1) the type and severity of drying defects, their time of occurrence, and their effect on degrade; (2) the drying time required; and (3) the final moisture content, information is obtained by which schedules can be modified. Schedule modifications are described in chapter 8, p. 124.

Drying Defects.—Defects associated with kiln-drying are described in chapter 9. Most of these defects can be detected by periodic examination of kiln samples during the drying process.

Knowledge of drying defects, such as their cause, time of occurrence, and how they can be minimized, should help a kiln operator to develop a drying schedule that will give the fastest and best drying.

Drying Time

The time required to dry a charge of lumber depends on the characteristics of the wood, the type of dry kiln, and the drying schedule used. Ordinarily an operator has no control over the type of material being dried. He may, however, be able to improve kiln performance, thereby reducing drying time to some extent. The greatest reduction in drying time can generally be accomplished through schedule modifications (ch. 8, p. 124).

Operation of a Progressive Dry Kiln

A progressive kiln can be used with fair to good results if the stock does not have to be dried to close moisture content limits and relieved of casehardening. Generally speaking, this type of kiln should be used only to dry softwoods and well air-dried hardwoods.

Because of the design of a progressive kiln, the drying schedules recommended in chapter 8 cannot be completely followed.

Application of the following points will simplify the operation of progressive kilns and assure better drying of lumber:

(1) Arrange the heating system so that the dry-bulb temperature gradually increases from the green to the dry end. This temperature difference is usually 50° to 60° F. in kilns 100 feet or more in length. In shorter kilns it is usually smaller.

(2) Provide thermostatic control of the heating system, so that lower or higher temperatures can be obtained as needed.

(3) Provide thermostatic control of the wet-bulb temperature, so that the wet-bulb depression at the green end can be changed when necessary.

(4) Do not move the stock into zones of more severe drying conditions until it has been dried to a moisture content low enough to withstand those conditions without developing excessive seasoning defects. To determine when to move the stock, weigh and examine the kiln samples in each load at intervals during drying.

(5) Do not pull a truckload of lumber from the kiln until it has been dried to the desired moisture content.

(6) Do not attempt to equalize or condition lumber within the kiln. This will upset drying conditions throughout the kiln, and the drying of most of the charge will be extended excessively. Some progressive kiln installations have auxiliary chambers in which these treatments are given. When lumber has dried to the desired moisture content in these kilns, it is transferred to the auxiliary chamber and there equalized and conditioned in accordance with the procedures outlined in chapter 8, p. 142.

Pulling a Charge From a Dry Kiln

After lumber has been kiln-dried, it is usually cooled before it is machined. Some operators cool it in the kiln, and others remove it from the kiln and place it in cooling sheds. Either method is satisfactory. However, lumber kiln-dried to a low moisture content should never be stored outdoors or exposed to conditions of high relative humidity for extended periods of time, regardless of whether it is stickered or solid piled (ch. 11, p. 172).

Operating Rules for Safety

Working in or around dry kilns is not hazardous if ordinary precautions are taken. Carelessness may lead to serious or fatal injuries, however. Care must be exercised at all times, and observance of the safety rules given here will help prevent accidents:

(1) Shut off the heat, spray, and fans before entering a kiln in which a charge of lumber is being dried. If the kiln has been operating at high temperatures, it should be cooled to some extent by opening the doors and ventilators before it is entered.

(2) If it is necessary to enter a kiln that has the heat, spray, and fans on, station someone outside the door to give assistance if it is needed. If a guard cannot be stationed at the door when a person enters the kiln, leave the door open and hang a sign on it reading "Man Inside Kiln, Do Not Close Door."

Never enter kiln when the wet-bulb temperature is 120° F. or more without wearing protective clothing that covers the head and body. This temperature limit applies to a person in good health. Anyone afflicted with heart or respiratory ailments should never enter dry kilns when the wet-bulb temperature is 110° or more. The critical dry-bulb temperature depends on the individual. If the kiln atmosphere feels too hot, do not enter the kiln.

(3) Equip all small access doors in the kiln with a latch that can be operated from both sides. Repair faulty latches immediately. Never use props to hold a door closed. The wrong person may use these at the wrong time. Set up an emergency signal that can be used if a man is accidentally locked in. A signal rapped on kiln pipes will carry a considerable distance.

(4) Exercise care in opening and closing large kiln doors. If they are too heavy for one man to handle, use two or more men to open them.

(5) Door carriers that are worn or poorly maintained may slip from the door or jump the track. Keep them in good repair.

(6) Be on guard against falling or protruding objects when in a kiln.

(7) Shut off the fans when they are to be inspected or lubricated and lock the fan switch in an "off" position. If the fan switch is not provided with a lock, place a sign on the switchbox reading "Do Not Start Fans."

(8) The fan floor of an overhead fan system may be oily. Be on guard against slipping.

(9) Install good open-type walkways over track level openings in natural-circulation or underload fan kilns. Keep these in good repair.

(10) Install guards around shafts and pulleys.

(11) If truckloads of lumber are pushed into and out of the kiln by men, make sure the men have good footing and that they will not be crushed between loads of lumber.

(12) If loaded kiln trucks are moved into and out of a dry kiln by cable, stay clear of the cables when they are under tension.

(13) Always carry a flashlight when entering a kiln, whether or not it is equipped with lights.

(14) Keep the dry kilns and the area around them free of debris to reduce the tripping hazard.

Prevention of Fire in Dry Kilns

Fires in dry kilns are usually caused by carelessness, improper maintenance, and poor housekeeping. Suggestions that will minimize the possibility of fires follow:

(1) Never smoke in a dry kiln.

(2) Use care with welding and cutting torches. When they are used for repair work in a kiln, have a fire extinguisher available for immediate use.

(3) Keep all electrical circuits in good condition.

(4) Keep all moving parts well lubricated. A hot bearing may cause a fire.

(5) Never run uninsulated steam pipes through, or allow them to contact, flammable material.

(6) Install an automatic water sprinkler system in the kilns.

(7) Keep the kiln and the surrounding area free of all debris.

A fire in a dry kiln should be put out promptly. Instruct the watchmen to check on the kilns at regular intervals to detect fires that may occur when the regular crew is off duty. Be sure they know what action to take in the event of fire.

The following will at least reduce the spread of a fire in a kiln, if not extinguish it completely:

(1) Keep the kiln doors closed.

(2) Close the ventilators.

(3) If the kiln is of the natural-circulation type, close the fresh-air supply doors.

(4) If the kiln is of the forced-circulation type, shut off the fans or blower.

(5) Saturate the air in the kiln with steam by opening the hand valve in the bypass line around the steam-spray control valve, or set up the wet-bulb indicator on the control instrument.

CHAPTER 11. STORAGE OF WOOD

Kiln-drying is only one step—although a critically important one—in the harvesting, handling, and processing of wood. The best results can be obtained in kiln-drying, therefore, when adequate attention is paid to related phases of wood processing. Although a dry kiln operator may have no responsibility for these related phases, he needs to know that important sources of difficulty can be the methods used to store logs and lumber before they reach the kiln, and those used to store kiln-dried stock and finished products.

The proper storage of wood, from log to finished product, is essential if quality is to be maintained. Any lowering of quality before the wood is dried will be reflected in the quality of the kiln-dried stock. Similarly, good storage is necessary for kiln-dried stock and finished products because their quality may be improved or lowered depending on storage conditions.

Log Storage

Logs need to be stored under conditions that will prevent occurrence of defects associated with shrinkage or attacks by fungi and insects. Defects associated with shrinkage are at a minimum during periods of precipitation and high relative humidity. Fungi and insects are inactive at low temperatures.

Logs should be sawed into lumber as soon as possible after they are taken from the woods, particularly during warm weather. If prompt sawing is not practical, two general types of log storage—ponding and cold decking—provide reasonable protection for woods-run logs. For high-quality logs, other precautions can be taken.

Pond Storage

A log submerged in water is protected completely from drying defects and from insect and fungus attack. Of course, some parts of most logs stored in ponds are above water (fig. 124). The parts above the water may develop drying defects, such as end checking, and they are exposed to attack by insects and stain and decay fungi if stored too long during warm weather.

Frequently logs stored in ponds are banded together (fig. 125). This method increases the log-holding capacity of the pond, prevents sinker logs from sinking, and submerges more logs in each bundle when some sinkers are included. Some logs, however, may be completely above water and subject to deterioration during warm weather.

Cold-Deck Storage

Logs in cold decks (fig. 126) may end check and be attacked by fungi and insects, especially during warm weather, when higher temperatures speed up drying and fungus and insect activity.

Occasionally logs in cold-deck storage are sprayed with water to keep them wet, especially during warm, dry weather, thereby lessening the development of end and heart checks and end splits. End checks and end splits in logs can also be reduced by applying a good coating to the ends of the logs (fig. 127) (*2*).[1] Losses caused by stain and decay fungi can be reduced and often prevented by the application of chemical solutions to the exposed wood (*5*).

If chemical changes occur in the sap of logs during storage, they may cause stains during subsequent drying. Some of the pines are particularly susceptible to a stain that ranges from light to dark brown in color. This stain, however, can be lessened considerably by the practice of "hot logging,"—that is, by sawing the logs into lumber without delay—and promptly drying the lumber (*6*). Treatment of the logs or lumber with the usual antistain solutions does not prevent chemical stains.

Lumber Storage

There are five types of lumber storage. These are (1) outdoors; (2) in an open shed; (3) in a closed, unheated shed; (4) in a closed, heated shed; and (5) in a conditioned shed. The desirable type of storage to use depends on the moisture content of the lumber and on weather conditions during storage.

Outdoor Storage

All kinds of lumber can be stored outdoors. The storage time, however, varies considerably for different classes of lumber. Also, certain classes of lumber must be protected from wetting. The storage area should be open and well drained, and kept free of weeds and debris that

[1] Italic numbers in parentheses refer to Literature Cited, p. 176.

M–99041–F

FIGURE 124.—Logs stored in a pond. Parts of the logs above the waterline may sustain drying defects and be attacked by insects and micro-organisms if stored too long in warm seasons.

M–108919–F

FIGURE 125.—Logs banded together in log pond. Some logs are completely submerged, others entirely out of the water.

M–74441–F

FIGURE 126.—Cold-decked logs. These logs are subject to checking and insect and fungus attack.

M–2161–F

FIGURE 127.—End checking was prevented in the right half of this sweetgum log by coating it.

restrict air movement along the surface of the ground, harbor fungi and insects, and create a fire hazard when dry. The ground, particularly along runways for lumber-handling equipment, should be surfaced with gravel, crushed rock, blacktop, or concrete. Surfacing or paving permits vehicles to operate efficiently in all sorts of weather, and tends to restrict weed growth. The method used to pile lumber on an area is governed by the species involved, its moisture content, and the degree of drying desired during the storage period.

Green Lumber.—To lessen drying defects and obtain as much drying as possible, thereby reducing kiln-drying time, the kiln operator should have knowledge of air-drying procedures (*4*). Briefly, these include (1) piling the lumber course by course on dry stickers properly spaced to minimize warping, (2) providing good pile bottoms or foundations, (3) laying out the yard with adequate spacing between piles and rows of piles, (4) constructing firm piles or packages, and (5) providing good pile roofs.

If green lumber must be stored in solid piles for more than 24 hours, particularly during warm weather, dip it in an antistain solution (*5*). Green lumber properly piled and protected on a good site will lose moisture quite rapidly with a minimum of defects and can remain outdoors indefinitely without excessive deterioration.

Partly Dried Lumber.—If the moisture content of the lumber is above 20 percent, or if further drying is desired, store it as green lumber. Lumber that is below 20 percent can be solid piled, if no additional drying is desired. The piles, however, must be fully protected against infiltration of water. Water that penetrates a lumber pile is not readily evaporated, and it is likely to cause stain and decay. Lumber surfaces that are alternately wetted and dried are likely to check.

Kiln-Dried Lumber.—Lumber kiln-dried to a moisture content of 12 percent or less can be stored outdoors in dry weather in stickered or solid piles for a short time. Extended storage will result in excessive moisture regain. Figure 128 shows the change in moisture content of southern yellow pine during yard storage in solid piles in inland Louisiana. If the lumber had been piled on stickers, its moisture content would have risen to the maximum of about 13½ percent in a much shorter time. During the warm, dry season in areas such as the arid Southwest and in parts of Idaho, Montana, Nevada, Oregon, and Washington, the outside storage period can be extended considerably without serious effects. It is advisable, however, to cover piles of high-grade lumber with a roof.

Open Shed Storage

Open sheds provide excellent protection for green and partially dried lumber. Lumber that has been kiln-dried to a low moisture content can also be stored in open sheds for varying periods of time, depending on the weather conditions.

The shed should be located on an open, well-drained area. It should be large enough to permit rapid handling of the lumber, and have a floor of gravel, crushed rock, blacktop, or concrete firm enough to support the piles of lumber and the weight of loaded lumber-handling equipment. Use enough pile supports to prevent the lumber from warping, and provide at least 6 inches of clearance between the floor and the bottom of the piles. The roof should overhang far enough beyond the piles of lumber to protect them from driving rains and snow.

Green Lumber.—Green lumber can be stored for long periods in open sheds without danger of serious deterioration, provided it is stickered. Such sheds protect the lumber from the sun, rain, and snow, thereby keeping end and surface checks and splits at a minimum. To obtain rapid air-drying in open sheds, provide adequate spaces between the sides and ends of the stickered piles of lumber.

Partly Dried Lumber.—Open sheds afford excellent protection to partly dried lumber. Pile

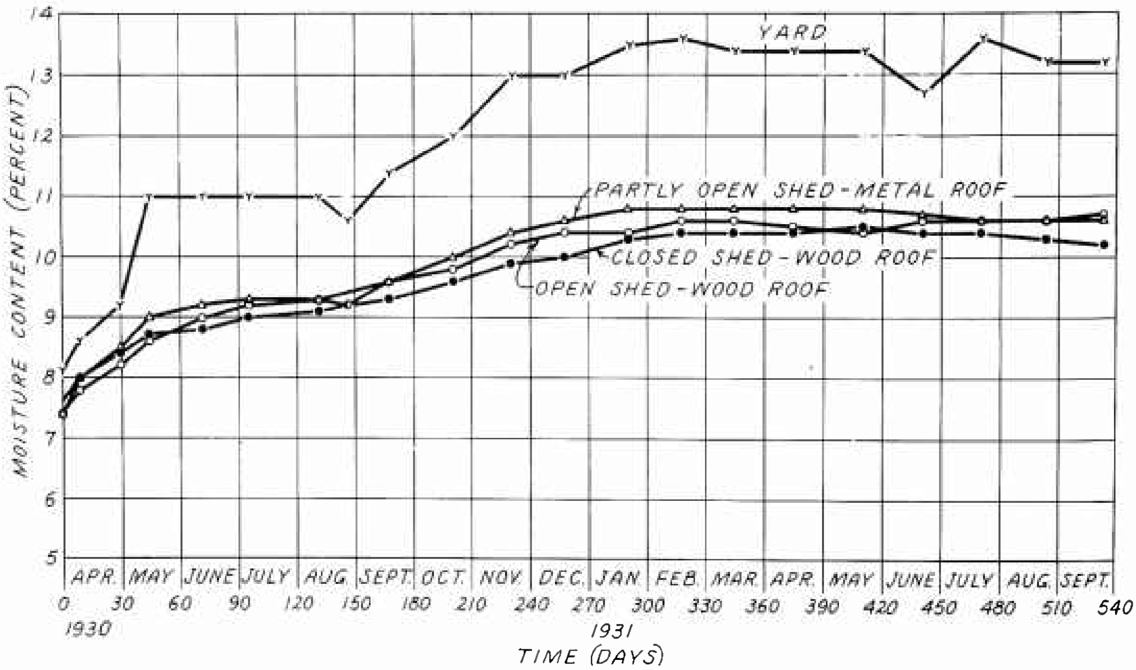


FIGURE 128.—Change in average moisture content of kiln-dried southern yellow pine 1- by 4-inch flooring and 1- by 8-inch dressed boards during storage in solid piles within sheds, and in the yard with a protective roof.

the lumber on dry stickers if it has a moisture content higher than 20 percent. If it has a moisture content below 20 percent, it can be solid piled unless further drying is desired, in which case it should be sticker piled.

Kiln-Dried Lumber.—Kiln-dried lumber is afforded good protection from sun, rain, and melting snow when stored in an open shed. An open shed will not, however, prevent the lumber from absorbing moisture during periods of high relative humidity, especially when air temperatures are high. Therefore, limit the storage time during warm, humid weather. The lumber piles can be either solid or stickered. Figure 128 illustrates the effect of long-time storage in an open shed on the average moisture content of solid-piled kiln-dried lumber. Moisture regain would have been more rapid in stickered piles.

Closed Shed Storage

Closed sheds, of course, protect lumber from the elements. The shed should be provided with reasonably tight-fitting doors. Sometimes closed sheds are provided with ventilators. The need for ventilators will depend upon the moisture content of the material being stored and the tightness of the structure. Closed sheds can be used for the storage of green or partly dried lumber, but they are used primarily for air-dried or kiln-dried stock.

Green Lumber.—Green lumber is sometimes stored in closed sheds in stickered piles. This type of storage will, however, retard drying. If rapid drying is desired, provide intake and exhaust vents and fans to circulate air through the piles of lumber. The solar heat absorbed through the roof of a closed shed will raise the temperature within it, particularly near the roof. Therefore, if green lumber that is susceptible to checking must be piled so that the tops of the piles are close to the roof, cover them with a layer of dunnage.

Partly Dried Lumber.—Partly dried lumber that is properly piled can be stored in a closed shed without developing drying defects. Pile the lumber on stickers if it has a moisture content of 20 percent or more; if its moisture content is below 20 percent, it can be solid piled if no further drying is desired. If further drying is desired, sticker the lumber and install fans to move the air through the piles. High shed temperatures should not cause checking or splitting in partly dried lumber, since these defects usually occur during the initial stages of drying.

Kiln-Dried Lumber.—Kiln-dried lumber in a closed storage shed, though fully protected, can, of course, pick up moisture during periods of high relative humidity, and in such weather the storage period must be reduced. In arid or semiarid areas, kiln-dried lumber can be stored indefinitely during hot, dry weather. The effect of long-time storage in a closed shed on average moisture content of kiln-dried lumber is shown in figure 128. With this method of storage, as much moisture is regained as in an open shed. Stickering the pile would have hastened the moisture regain.

Moisture Regain in Unheated Sheds

Lumber dried to a moisture content of 10 percent or less, and items manufactured from it, will regain moisture if stored for extended periods under conditions of high relative humidity. Excessive regain of moisture frequently results in (1) swelling of whole pieces or of certain parts, such as the ends of the pieces; (2) warping of items, as of glued-up panels for example; (3) wood or glue line failures in solid-piled items where the moisture regain is confined to the ends.

During fabrication and use, lumber and items that have absorbed excessive moisture during storage, may (1) end check and split when the high moisture content surfaces are exposed to low relative humidities in heated buildings; (2) shrink excessively; (3) warp; (4) suffer extension of end splits; (5) open at glue joints; and (6) give difficulty in matching material like dimension stock or stock run to pattern.

Closed, Heated Shed Storage

Storage in closed, heated sheds provides excellent protection for lumber and special products that will be used inside heated buildings. Stock generally stored in heated sheds includes hardwood dimension, furniture stock, interior trim, flooring, cabinet material, bowling-pin and shoe-last blanks, and similar items.

A heated shed should be reasonably tight, but insulation generally is not required. Unit heaters are commonly used. Since the temperature normally required in heated sheds is only 10° to 20° F. above the outside temperature, the amount of heat required is not great. Circulation of the air in the shed is desirable. Ventilators may or may not be needed, depending on the moisture content of the stock being stored, the temperature maintained, and the tightness of the structure.

The shed should be located on a well-drained site. Its floor should be of gravel, crushed rock, blacktop, or concrete, and sufficiently firm to support the piles of lumber and loaded lumber-handling equipment.

555315 O—61——12

Green Lumber.—Green lumber is not ordinarily stored in heated sheds, because the higher temperatures within the shed may cause end and surface checks and splits. Occasionally, however, it is sticker-piled in such sheds for drying. When this is done, the shed, if tightly constructed, must be provided with ventilators and the air circulated with fans.

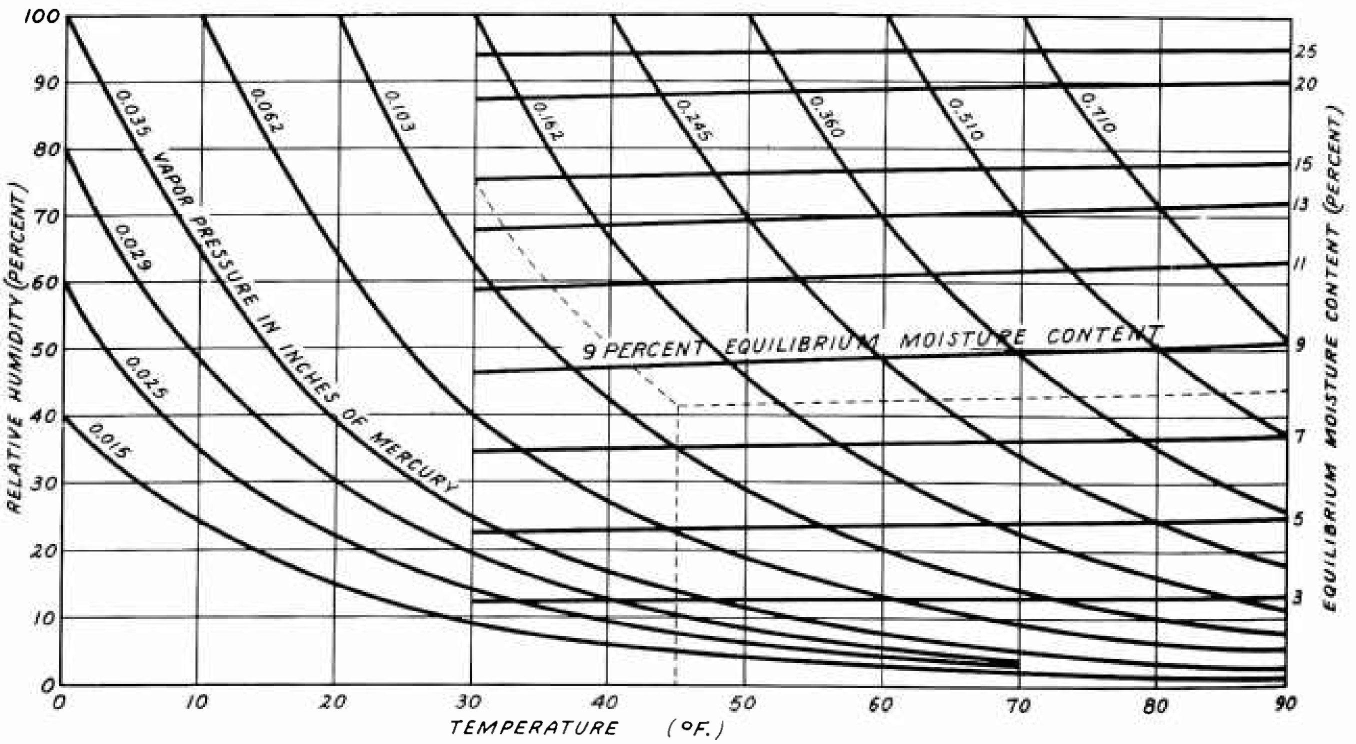
Partly Dried Lumber.—Partly dried lumber can be stored in heated sheds for further drying. Stickering is necessary. If further drying is not desired, store this lumber outdoors or in an open shed.

Kiln-Dried Lumber.—Closed, heated sheds are excellent for the storage of lumber kiln-dried to a moisture content of 12 percent or less. The desired moisture content of the lumber can be attained or maintained by regulating, manually or with a hygrostat (*3*), the dry-bulb temperature in the shed. For example, assume that the outdoor temperature is 30° F. and the relative humidity is 75 percent. This point is located on the chart in figure 129 by a dashed line that intersects the 30° temperature line at a relative humidity of about 75 percent. The corresponding wood equilibrium moisture content at these conditions is 15 percent (heavy line running slightly upward to the right side of the chart). If no moisture is added to this air and its temperature is increased to 45°, the relative humidity becomes about 41 percent (located by the curved dash line downward to the right, parallel to the adjacent vapor pressure lines until it intersects the 45° temperature line); the corresponding equilibrium moisture content of the lumber will be about 8 percent (dashed approximately horizontal line), a reduction of about 7 percent. The chart shows that if this same air—that is, air with the same vapor pressure—is heated to a temperature of 60°, the relative humidity will be reduced to about 25 percent and the equilibrium moisture content to about 5 percent.

Figure 130 shows moisture content data obtained on ponderosa pine during extended storage in a heated shed. The shed temperature was controlled by a hygrostat that maintained the equilibrium moisture content at about 8 percent. Thus the fluctuations in the outdoor relative humidity had little effect on the moisture content of the stored lumber.

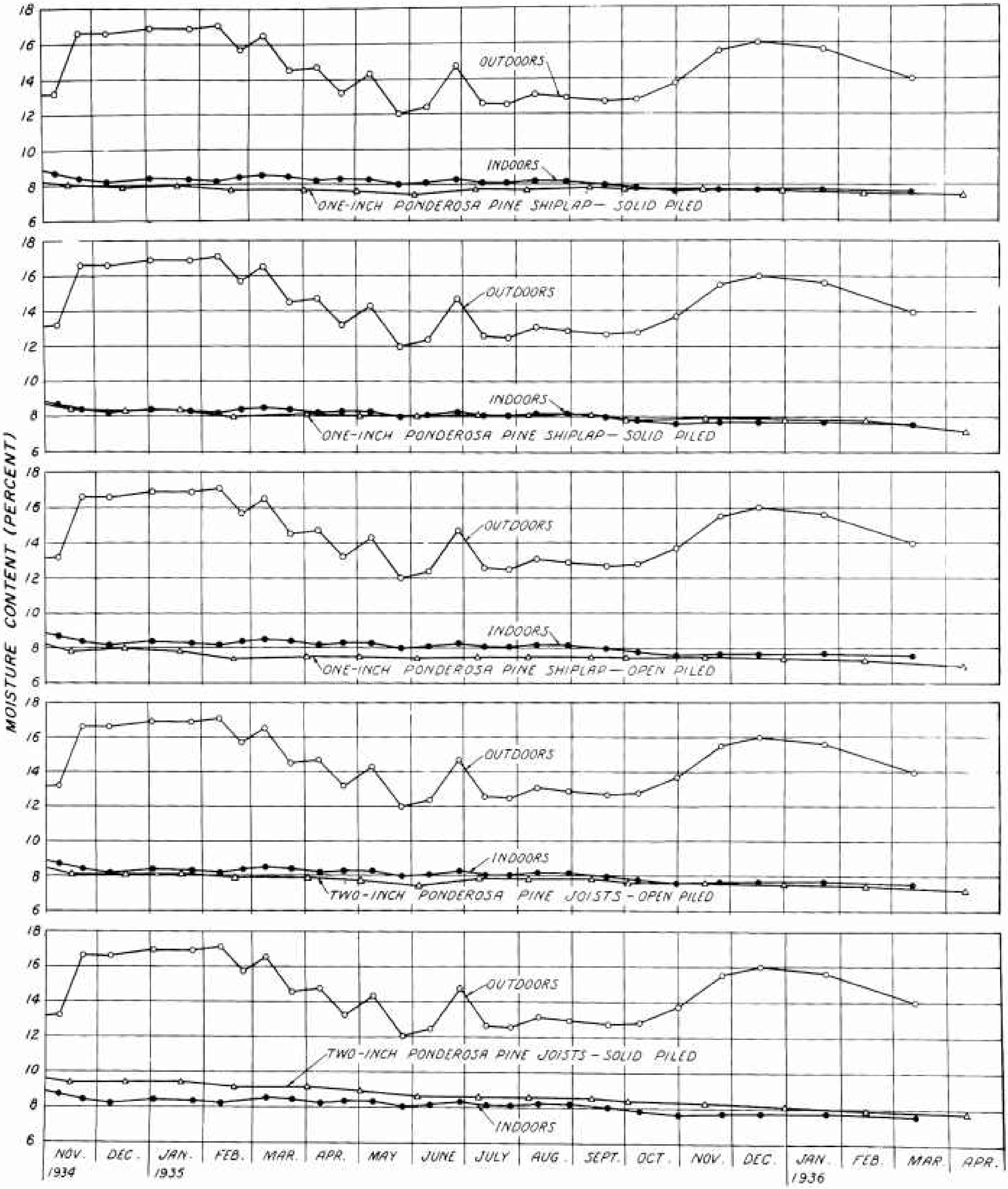
Conditioned Storage Sheds

Kiln-dried lumber can be held at any desired moisture content in a storage shed in which temperature and relative humidity are controlled (*1*). This type of storage is generally used only for special material, such as airplane propeller stock, which requires very close control of moisture content.



ZM–44797–F

FIGURE 129.—Relationship between the temperature, relative humidity, and vapor pressure of air and the equilibrium moisture content of wood.



ZM-29829-F

FIGURE 130.—Moisture content of 1-inch shiplap and 2-inch joists of ponderosa pine stored in a closed, heated shed maintained at an equilibrium moisture content of about 8 percent for 18 months. The curves marked INDOORS and OUTDOORS are the indoor and outdoor equilibrium moisture content values.

Literature Cited

(1) Dunlap, M. E.
1958. methods of controlling humidity in woodworking plants. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1612, 4 pp., illus. [Processed.]

(2) McMillen, J. M.
1956. coatings for the prevention of end checks in logs and lumber. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1435, 13 pp., illus. [Processed.]

(3) Mathewson, J. S.
1953. electrically operated wood element hygrostats for control of moisture fluctuations in lumber stored in closed sheds. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1140, 3 pp., illus. [Processed.]

(4) Peck, E. C.
1956. air drying of lumber. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1657, 21 pp., illus. [Processed.]

(5) Scheffer, T. C.
1958. control of decay and sap stain in logs and green lumber. U.S. Forest Serv. Forest Prod. Lab. Rpt. 2107, 13 pp., illus. [Processed.]

(6) U.S. Forest Service Forest Products Laboratory.
1951. chemical brown stain in pine. Forest Prod. Lab. Tech. Note 254, 3 pp. [Processed.]

GLOSSARY

This glossary includes the generally accepted definitions of a limited number of terms currently used in wood seasoning literature. It also includes closely related terms that are not fully defined in their special application to present-day seasoning in most dictionaries or glossaries.

Common abbreviations:

B.t.u.	=British thermal unit
C.O.D. Wt.	=Calculated ovendry weight
C. Wt.	=Current weight
D.B.	=Dry bulb
EMC	=Equilibrium moisture content
F.S.P.	=Fiber saturation point
G. Wt.	=Green weight
M.C.	=Moisture content
O.D. Wt.	=Ovendry weight
R.H.	=Relative humidity
Sp. gr.	=Specific gravity
W.B.	=Wet bulb
W.B.D.	=Wet bulb depression
Wt.	=Weight

Air binding.—The presence of air, generally in pockets, in steam coils and traps, which interferes with the normal flow of steam and condensate.

Air drying.—(See *Drying, air.*)

Air, entering.—Heated air just as it enters the kiln loads of lumber.

Air, leaving.—Air just after it leaves the kiln loads of lumber. It is usually at a lower temperature than the entering air.

Air, short circuiting of.—The movement of air through other than desired channels. Usually results when a kiln charge is improperly loaded and/or baffled.

Air travel, length of.—The distance between the entering- and leaving-air sides of the kiln charge.

Air velocity.—The speed at which air moves, generally measured in feet per minute.

Air volume.—The total amount of air occupying or moving through a given space, generally measured in cubic feet.

Annual growth ring.—The growth layer put on a tree each year in temperate climates, or each growing season in other climates; each ring includes springwood and summerwood.

Baffle.—A piece of canvas, metal, or wood used for deflecting, checking, or otherwise regulating the flow of air.

Bark.—Outer layer of a tree, consisting of a thin, living inner part, and a dry, dead outer part that is generally resistant to moisture movement.

Bastard sawn.—Lumber in which the annual growth rings make angles of 30° to 60° with the surface of the piece.

Bow.—The distortion in a board that deviates from flatness lengthwise but not across its faces.

Boxed heart.—The term used when the pith falls entirely within the outer faces of a piece of wood anywhere in its length. Also called boxed pith.

British thermal unit.—(B.t.u.) The amount of heat necessary to raise 1 pound of water 1° F. in temperature.

Bulb.—The temperature-sensitive part of a thermostatic control system.

- **Control.**—The bulbous part of the controlling system, located in the kiln, which contains the temperature-sensitive liquid or gas.
- **Controlling dry.**—The bulb that controls the dry-bulb temperature.
- **Controlling wet.**—A bulb, kept completely covered at all times with a clean, water-saturated wick or porous sleeve, which automatically controls the wet-bulb temperature.
- **Double-end control.**—Control bulbs, usually located in each longitudinal half of the kiln, which control kiln temperatures for their respective zone, independent of each other.
- **Dual control.**—Two bulbs of a Y-shaped control system. They are usually located on each kiln wall directly opposite each other and control the temperature of the entering air regardless of the direction of air movement.
- **Recorder.**—The temperature-sensitive part of a system that records but does not control kiln conditions.
- **Recorder-controller.**—A bulb attached by means of a capillary tube to a recording-controlling instrument.

Cambium.—The one-cell-thick layer of tissue between the bark and wood that repeatedly subdivides to form new wood and bark cells.

Capillary action.—The combination of solid-liquid adhesion and surface tension by which a liquid is elevated in a vertical tube or moved through a cellular structure.

Casehardening.—A condition of stress and set in wood in which the outer fibers are under compressive stress and the inner fibers under tensile stress, the stresses persisting when the wood is uniformly dry.

Casehardening, reverse.—A final stress and set condition (in lumber and other wood items) in which the outer fibers are under a tensile stress and the inner fibers are under a compressive stress as a result of overconditioning.

Cell.—A general term for the minute units of wood structure, including wood fibers, vessel segments, and other elements of diverse structure and function, having distinct cell walls and cell cavities.

Chamber, plenum.—A chamber on the pressure side of a fan or blower in which the air is maintained under pressure.

Charge.—(See *Kiln charge.*)

Chart, recorder.—A sheet, usually circular, on which a graphic record of kiln temperatures is transcribed.

Check.—A lengthwise separation of the wood that usually extends across the rings of annual growth and parallel to the wood rays, resulting from drying stresses.

Surface check.—A check starting on a side-grain surface and extending into the interior of a board.

End check.—A check starting on an end-grain surface and extending along the length of a board.

Internal check.—Checks originating in the interior of a piece of wood or extensions of surface and end checks.

Circulation, air.—The movement of air within a kiln by either natural or mechanical means.

Direction of.—The direction of movement of air through the kiln charge, expressed as longitudinal, transverse, or vertical.

Forced.—The movement of air within a kiln by mechanical means.

Longitudinal.—Air movement through the kiln charge to be expressed as front to rear or rear to front.

Natural.—The movement of air within a kiln by natural means.

Reversible.—Capable of change in the direction of air movement.

Transverse.—Air movement through the kiln charge from wall to wall to be expressed as right to left or left to right.

Vertical.—Air movement through the kiln charge from top to bottom or bottom to top.

Coil header (or manifold).—A pipe fitting to which a number of pipes are connected on one side.

Coil, intermittent operation of.—The alternate opening and closing of the valve controlling steam flow into the coil.

Coil, pipe.—One or more runs of pipes, the function of which is to heat the air in the kiln.

Booster.—A supplementary coil, usually located between tracks of a multiple-track kiln, used to add heat to air that has already moved across a trackload of lumber.

Ceiling.—A coil placed near the kiln ceiling to warm the ceiling and roof, thus preventing moisture condensation.

Plain header (horizontal or vertical).—A coil consisting of a supply and discharge header at opposite ends with the pipes running from one to the other.

Single-return-bend header (horizontal or vertical).—A coil with the discharge header usually located under or on the side of the supply header, the pipes running from the supply header to a 180° bend and back to the discharge header.

Multiple-return-bend header.—A coil usually with the discharge header located below the supply header, the pipes running back and forth with a 180° elbow at the bends.

Double-end.—Coils usually extending half the length of the kiln from both ends and usually operating as separate units.

Coil radiating surface.—The entire uninsulated surface area of a heating coil.

Collapse.—The severe distortion or flattening of single cells or rows of cells in wood during drying, often evidenced by a caved-in or corrugated appearance of the surface of the piece.

Compression failure.—Rupture of the wood structure resulting from excessive compression along the grain. It may develop as a result of bending in the living tree or during felling. In surfaced lumber, compression failures appear as fine wrinkles across the face of the piece.

Compression wood.—Abnormal wood formed on the lower side of branches and inclined trunks of softwood trees. It has relatively wide, eccentric growth rings with little or no demarcation between springwood and summerwood and more than normal amounts of summerwood. Compression wood shrinks more than normal wood longitudinally, causing bow, crook, and twist.

Condensate.—Water formed by the cooling of steam.

Conditioning.—(See *Stresses, relief of.*)

Conditioning treatment.—A controlled high temperature-high relative humidity condition used in a dry kiln after the final stage of drying to bring about a uniform moisture distribution in the boards and to relieve drying stresses.

Conduction, heat.—Transmission of heat through or by means of a conductor.

Controller.—An instrument that automatically controls kiln temperatures.

Convection, heat.—Transfer of heat from heating coils to lumber by means of air.

Course, lumber.—A single layer of lumber.

Crook.—A distortion of a board in which the edges deviate from a straight line from end to end of the board.

Cup.—A distortion of a board in which there is deviation from flatness across the width of the board.

Cycle, heating.—The time intervening between successive openings of a control valve.

Cycle, temperature.—The time between the maximum and minimum temperatures during a heating cycle.

Decay.—The decomposition of wood substance by fungi.

Advanced (or typical) decay.—The older stage of decay in which the destruction is readily recognized because the wood has become punky, soft and spongy, stringy, ringshaked, pitted, or crumbly. Decided discoloration or bleaching of the rotted wood is often apparent.

Incipient decay.—The early stage of decay that has not proceeded far enough to soften or otherwise perceptibly impair the hardness of the wood. It is usually accompanied by a slight discoloration or bleaching of the wood.

Defects, drying.—Any irregularity occurring in or on wood, as a result of drying, that may lower its strength, durability, or utility value.

Degrade, kiln.—A drop in lumber grade that results from kiln drying.

Density.—The weight of a body per unit volume.

Depression, wet-bulb.—The difference between the dry- and wet-bulb temperatures.

Dew point.—The temperature at which steam or water vapor begins to condense.

Diamonding.—A form of warp in which the cross section assumes a diamond shape.

Diffuse-porous wood.—A hardwood in which the pores tend to be uniform in size and distribution throughout each annual ring or to decrease in size slightly and gradually toward the outer border of the ring.

Diffusion.—Spontaneous movement of heat, moisture, or a gas throughout a body or space. Movement is from high points to low points of temperature or concentration.

Dry-bulb temperature.—The temperature of the air indicated by any type of thermometer not affected by the water vapor content or relative humidity of the air.

Drying, air.—Process of drying lumber by natural conditions in a yard or in an open unheated shed.

Drying in transit.—The partial or complete kiln-drying of lumber by a drying facility located between the shipping and fabrication points.

Drying, precision kiln.—Process of drying wood in which controlled procedures are followed in order to obtain a stress-free product that has a desired moisture content and has suffered a minimum loss in strength.

Drying rate.—The amount of moisture lost from the lumber per unit of time.

Duct, air.—A rectangular, square, or circular passageway to conduct air.

End coating.—A coating of moisture-resistant material applied to the end-grain surface to retard end drying of green wood or to reduce moisture changes in dried wood to a minimum.

Equalization.—Bringing the pieces of lumber in a kiln charge to a nearly uniform moisture content.

Equilibrium moisture content (EMC).—The moisture content at which wood neither gains nor loses moisture when surrounded by air at a given relative humidity and temperature.

Evaporation.—The changing from the liquid to the vapor form.

Extractives.—Substances in wood, not an integral part of the cellular structure, that can be removed by solution in hot or cold water, ether, benzene, or other solvents that do not react chemically with wood substance.

Fiber saturation point.—The stage in the drying or wetting of wood at which the cell walls are saturated with water and the cell cavities are free from water. It is usually taken as approximately 30 percent moisture content, based on weight when ovendry.

Fiber, wood.—A comparatively long (1/25 or less to 1/3 inch), narrow, tapering hardwood cell closed at both ends.

Flat-sawed.—Lumber sawed in a plane approximately perpendicular to a radius of the log. (See *Grain*).

Fluctuation, steam pressure.—Variation of steam pressure.

Flue, "A".—A vertical wedge-shaped space provided in the transverse center and extending the length of a kiln load of lumber, usually 15 inches wide at the bottom and tapering to a point 1 or 2 courses down from the top of the load.

Flue, vertical.—A vertical space, usually 6 inches or less in width and extending the length and height of a kiln truckload or package of lumber.

Grain.—The general direction of the fibers in wood or lumber. When used with qualifying adjectives it has special meanings concerning the direction of the fibers or the direction or size of the growth rings.

Under *fiber direction* the specific terms are:

Cross grain.—Grain deviating from a line parallel to the sides of the piece.

Diagonal grain.—A form of cross grain resulting from sawing at an angle with the bark of the log.

Interlocked grain.—A form of spiral grain in which the fiber direction gradually alternates from right-hand to left-hand spiral and back again in adjacent groups of annual rings.

Spiral grain.—A form of cross grain resulting from the fibers, during growth, taking a spiral course about the trunk of the tree instead of the normal vertical course.

Straight grain.—Grain parallel to the sides of the piece.

Under *growth ring direction* or ring pattern, the specific terms are:

Coarse grain. —Wood in which the growth rings are wide or have major differences in density and color between springwood and summerwood.

Edge grain (or vertical grain).—The grain in lumber produced by quartersawing so that the edges of the growth rings are exposed on the widest faces of the piece, and the rings form angles of 45° to 90° with the widest faces.

Fine grain.—Wood in which the growth rings are narrow and inconspicuous.

Flat grain.—The grain in lumber produced by flat sawing so that the tangential faces of the growth rings are exposed on the widest faces of the piece and the rings form angles of less than 45° with the widest faces.

Green lumber (or grass green).—Lumber cut from freshly felled trees.

Hardwoods.—Woods produced by one of the botanical groups of trees that have broad leaves in contrast to the needles or scalelike leaves of the conifers or softwoods. The term has no reference to the actual hardness of the wood.

Heartwood.—The wood extending from the pith to the sapwood, the cells of which no longer participate in the life processes of the tree. Heartwood may be infiltrated with gums, resins, and other materials that usually make it darker and more decay resistant than sapwood.

Honeycombing.—Checks, often not visible at the surface, that occur in the interior of a piece of wood, usually along the wood rays. (See *Ring failure.*)

Humidity, absolute.—The weight of water vapor per unit volume of space.

Humidity, relative.—Ratio of the amount of water vapor present in the air to that which the air would hold at saturation at the same temperature. It is usually considered on the basis of the weight of the vapor, but for accuracy it should be considered on the basis of vapor pressures.

Hygroscopicity.—The property of a substance which permits it to adsorb and retain moisture.

Hysteresis.—The tendency of wood exposed to any specified temperature and relative humidity conditions to reach equilibrium at a lower moisture content when absorbing moisture from a drier condition than when losing moisture from a wetter condition.

Kiln.—A heated chamber for drying lumber, veneer, and other wood products in which temperature and relative humidities are controlled.

Compartment.—A dry kiln in which the total charge of lumber is dried as a single unit. At any given time, the temperature and relative humidity are uniform throughout the kiln.

Progressive.—A dry kiln in which the total charge of lumber is not dried as a single unit but as several units, such as kiln truckloads, that move progressively through the kiln. The temperature is lower and the relative humidity higher at the entering end (green end) than at the discharge end (dry end).

Automatically controlled.—A dry kiln in which drying conditions are controlled by the action of thermostats.

Forced-circulation.—A dry kiln in which the air is circulated by mechanical means.

Manually controlled.—A dry kiln in which drying conditions are controlled by the manual operation of valves and ventilators.

Multiple-track.—A dry kiln equipped with two or more tracks.

Natural-circulation.—A dry kiln in which air circulation depends on the power of gravity and the varying density of air with changes in its temperature and moisture content.

Reversible circulation.—A dry kiln in which the direction of air circulation can be reversed at desired intervals.

Single-track.—A dry kiln equipped with one track.

Kiln charge.—The total amount of lumber or wood items in a dry kiln.

Kiln charge, mixed.—Same as kiln charge but composed of more than one species or thickness of lumber or wood items.

Kiln-drying.—Process of drying lumber in a dry kiln.

Kiln leakage.—The undesirable loss of heat and vapor from a kiln through badly fitted doors and ventilators or through cracks in the walls and roof.

Kiln run.—The term applied to the drying of a single charge of lumber.

Kiln sample.—A section 30 inches or more in length cut from a sample board and placed in the kiln charge so that it can be removed for examination, weighing, and testing.

Controlling.—Some of the wettest samples used to control the drying. The number depends on the total number of samples used and the composition of the kiln charge.

Driest.—The kiln sample containing the least amount of moisture.

Fastest drying.—The kiln sample that loses the largest amount of moisture in a given period of time.

Pocket.—A space provided for the kiln sample in the kiln truckloads of lumber.

Slowest drying.—The kiln sample that loses the smallest amount of moisture in a given period of time.

Weight, current.—The weight of a kiln sample at given times during the drying process.

Weight, final.—The weight of a kiln sample after the completion of the drying.

Weight, green (or initial, or original).—The weight of a kiln sample prior to kiln drying regardless of its moisture content.

Wettest.—The kiln sample containing the largest amount of moisture.

Knot.—That part of a branch which has become overgrown by the body of a tree. The shape of the knot depends on the angle at which the branch is cut.

Loading, cross-piled.—Lumber piled on kiln trucks and placed in a dry kiln with the long axis of the load perpendicular to the length of the kiln.

Loading, end-piled.—Lumber piled on kiln trucks and placed in a dry kiln with the long axis of the load parallel to the length of the kiln.

Longitudinal.—Generally, the direction along the length of the grain of wood. A longitudinal section may be a plane either tangential or radial to the growth rings.

Lumber, kiln-dry. Lumber that has been dried in a dry kiln to a specified moisture condition.

Lumber, shipping-dry.—Lumber that has been partially air- or kiln-dried to an average moisture content of approximately 30 percent.

Lumber storage room.—A room maintained within specified equilibrium moisture content limits so that lumber stored in it will not gain or lose moisture beyond fixed limits.

Meter, moisture.—An instrument used for rapid determination of the moisture content in wood by electrical means.

Mineral streak.—An olive to greenish-black or brown discoloration of undetermined cause in hardwoods, particularly hard maples; commonly associated with bird pecks and other injuries; occurs in streaks usually containing accumulations of mineral matter.

Moisture content of wood.—Weight of the water contained in the wood, expressed as a percentage of the weight of the ovendry wood.

Average.—The percentage of moisture content of a single piece or the sum of the moisture contents of a number of pieces divided by their number.

Core.—The moisture content of the inside part of a moisture section remaining after a shell ¼ the thickness of the section has been removed.

Determination of.—The testing of lumber to determine the amount of moisture present. This is usually exprcssed in terms of percent of the ovendry weight.

Final.—The moisture content of the wood at the end of kiln-drying.

Green.—The moisture content of wood in the living tree.

Initial.—The moisture content of the wood at the start of kiln-drying.

Shell.—The moisture content of the outer one-fourth of the thickness of a moisture section.

Moisture distribution.—The variation of moisture content throughout a piece of wood, usually from face to face but sometimes from end to end, or from edge to edge.

Moisture gradient.—A condition existing during drying in which the moisture content uniformly decreases from the inside toward the surface of a piece of wood. Also a term used specifically to denote the slope of the moisture content distribution curve.

Moisture gradient, reverse.—A condition following moisture regain in which the moisture content is higher at the surface than inside the wood.

Moisture range.—The difference in moisture content between the driest and wettest boards or samples.

Moisture section.—A cross section, 1 inch in length along the grain, cut from a kiln or random sample and used to determine moisture content.

Moisture section, initial weight of.—The weight of a moisture section immediately after being cut from a kiln sample or board.

Moisture section, ovendry weight of.—The weight of a moisture section after being ovendried to a constant weight.

Mold.—A fungus growth on lumber taking place mainly at or near the surface and, therefore, not typically resulting in deep discolorations. They are usually ash green to deep green in color, although black is common.

Old growth.—Timber in or from a mature, naturally established forest. When the trees have grown during most if not all of their individual lives in active competition with their companions for sunlight and moisture, the timber is usually straight and relatively free of knots.

Ovendry.—A term applied to wood dried to constant weight in an oven maintained at temperatures of from 214° to 221° F.

Pervious wood.—A wood through which moisture moves readily.

Piling, box.—The flat piling of random length boards on kiln trucks so that the ends of the completed load are in vertical alinement. The longest boards are placed on the outside of the load and the shorter boards are alternately placed with one end even with one end of the load or the other.

Piling, edge.—Piling lumber so that the broad face of the board is vertical.

Piling, flat.—Piling lumber so that the broad face of the board is horizontal.

Pit.—A relatively unthickened part of a wood cell wall where a thin membrane may permit liquids to readily pass from one cell to another. A "bordered" pit has an overhanging rim that is not present in a "simple" pit.

Pitch.—The mixture of rosin and turpentine or other volatiles produced in the resin canals of pines and other conifers. Term also applied to mixtures of nonvolatile liquids or noncrystalline solids and volatile oils in other species.

Pitch pocket.—An opening, extending parallel to the growth rings, that contains or has contained pitch.

Pitch streak.—A well-defined streaky accumulation of pitch in the wood of certain softwoods.

Pith.—The small, soft core occurring in the structural center of a tree trunk, branch, twig, or log.

Plainsawed.—Another term for flat-sawed or flat-grained lumber.

Pore.—The cross section of a specialized hardwood cell known as a vessel. (See *Vessels.*)

Quartersawed.—Lumber sawed so the wide faces are approximately at right angles to the annual growth rings. (See *Grain.*)

Radial.—Coincident with or generally parallel to a radius of the tree from the pith to the bark. A radial section is a lengthwise section in a plane that passes through the pith.

Radiation.—Heating coils or elements with a dry kiln.

Balanced.—Construction and arrangement so as to insure equal radiating surface and uniform temperatures throughout the kiln.

Direct.—The transmission of heat energy to a body or substance by direct heat rays from the heating system.

Excessive.—A greater amount of radiation than required.

Flexible.—The arrangement of the heating system into small coils equipped with hand valves that, when opened or closed, permit rapid adjustment of the radiating surface to meet the required needs.

Raised grain.—A roughened condition of the surface of dressed lumber in which the hard summerwood is raised above the softer springwood but not torn loose from it.

Rate of growth.—The rate at which a tree has laid on wood, measured radially in the tree trunk or in the radial direction in lumber. The unit of measure in use is the number of annual growth rings per inch.

Rays, wood.—Strips of cells extending radially within a tree and varying in height from a few cells in some species to 4 inches or more in oak. The rays serve primarily to store food and transport it horizontally in the tree.

Resin canal (or duct).—Intercellular passages that contain and transmit resinous materials. They extend vertically or radially in a tree.

Ring failure (or separation).—A separation of the wood during seasoning. Occurs along the grain and parallel to the annual rings, either within or between rings; called honeycomb and ring check in some localities. (See *Shake.*)

Sample board.—A board from which one or more kiln samples will be cut, or a board taken from a kiln truckload during drying for the purpose of cutting a moisture section.

Sample.—(See *Kiln sample.*)

Sap.—The moisture in unseasoned wood and all extractives it holds in solution.

Sapwood.—The layer of wood near the outside of the log, usually lighter in color than the heartwood, that is actively involved in the life processes of the tree.

Seasoning.—Removing moisture from green wood, and in some cases relief of stresses, in order to improve its serviceability.

Second growth.—Timber that has grown after the removal, whether by cutting, fire, wind, or other agency, of all or a large part of the previous stand.

Set.—A localized semipermanent deformation in wood caused by internal tensile or compressive stresses.

Compression set.—Set, occurring during compression, that tends to give the wood a smaller than normal dimension after drying, usually found in the interior of wood items during the last stage of drying but sometimes in the outer layers after overconditioning or rewetting. Also caused by external restraint during rewetting of dried wood.

Tension set.—Set. occurring during tension, that tends to give the wood a larger than normal dimension after drying, usually occurring in the outer layers during the first stages. Also caused by external restraint during drying of wet wood.

Shake.—A separation along the grain, the greater part of which occurs between the rings of annual growth. Found in stumps and ends of freshly cut logs and green lumber. (See *Ring failure.*)

Shrinkage.—The contraction of wood caused by drying the material below the fiber saturation point.

Longitudinal.—Shrinkage along the grain.

Radial.—Shrinkage across the grain, in a radial direction.

Tangential.—Shrinkage across the grain, in a tangential direction.

Softwood.—Wood produced by one of the botanical group of trees that, in most species, have needle or scalelike leaves.

Specific gravity.—The ratio of the ovendry weight of a piece of wood to the weight of an equal volume of water (39° F.). In the field of seasoning, specific gravity values are usually based on the volume the wood has when green.

Split.—A lengthwise separation of the wood, due to the tearing apart of the wood parallel to the wood rays.

Spray line.—A plain pipe of varying sizes and lengths and drilled with holes of various sizes and spacing through which steam is injected into the kiln.

Springwood (early wood).—The part of the annual growth ring that is formed during the early part of the season's growth. It is usually less dense and weaker mechanically than summerwood.

Stain.—A discoloration in wood that may be caused by such diverse agencies as microorganisms, metal, or chemicals. The term also applies to materials used to impart color to wood.

Blue stain (sap stain).—A bluish or grayish discoloration of the sapwood caused by the growth of certain dark-colored fungi on the surface and in the interior of the wood, made possible by the same conditions that favor the growth of other fungi.

Chemical stain.—A general term including all stains that are due to color changes of the chemicals normally present in the wood, such as pinking of hickory and browning of some softwoods, particularly the pines.

Chemical stain, brown.—A chemical discoloration of wood, which can occur during the air-drying or kiln-drying of several softwood species, caused by the concentration and modification of extractives.

Iron-tannate stain.—A surface stain, bluish-black in color, on oak and other tannin-bearing woods following contact of the wet wood with iron, or with water in which iron is dissolved.

Mineral stain.—An olive to greenish-black or brown discoloration in hardwoods, particularly maple, caused by bird peck or other injury and found either in mass discoloration or mineral streaks. The mineral associated with such streaks is frequently calcium oxalate, which has a tendency to dull machining knives.

Sticker stain.—A gray to blue or brown chemical stain occurring on and beneath the surface of boards where they are in contact with stickers, (also fungus sap stain when found only in the sticker area).

Water stain.—A yellowish to blackish surface discoloration caused by water that dripped onto the wood during seasoning.

Weather stain.—A very thin grayish-brown surface discoloration on lumber exposed a long time to the weather.

Steam.—The vapor into which water is converted when heated.

Exhaust.—Steam which has already passed through a steam engine or machine.

Flash.—The reevaporation of hot water produced by the excess heat, when the water is discharged to a lower pressure.

Live.—Steam obtained directly from the boiler.

Superheated.—Steam at a temperature higher than the saturation temperature corresponding to the pressure.

Steam binding.—The presence of steam in the drain line between the heating coil and trap which temporarily prevents the drainage of condensate and air from the coil.

Sticker.—A wooden strip placed between the courses of lumber in a kiln load and at right angles to the long axis of the boards, to permit air circulation.

Alinement.—The placing of stickers in a pile, package, or truckload of lumber so that they form vertical tiers.

Spacing.—The distance between stickers measured from center to center.

Stress, drying.—An internal force, exerted by either of two adjacent parts of a piece of wood upon the other during drying, caused by uneven drying and shrinking, and influenced by set.

Tensile stress.—The stress found in the outer layers of wood during the early stages of drying when they are trying to shrink but are restrained by the still-wet interior region; also the stress in the interior layers later in drying as they try to shrink and are restrained by the set outer shell.

Compressive stress.—The stress found in the interior region of wood during the early stages of drying, caused by the shrinking of the outer shell; also the stress in the outer layer later in drying caused by the shrinking of the interior.

Stress-free.—Containing no drying stresses.

Stress section.—A cross section of a sample that is cut into prongs of equal thicknesses, from face to face.

Stresses, relief of.—The result of a conditioning treatment, following the final stage of drying, which causes a redistribution of moisture and a relief of the sets.

Summerwood (late wood).—The part of the annual growth ring that is formed during the latter part of the growing season. It is usually denser and stronger mechanically than springwood.

Tangential.—Coincident with or generally parallel to a tangent at the circumference of a tree or log, or growth rings. A tangential section is a longitudinal section through a tree perpendicular to a radius.

Temperature.—Degree of hotness or coldness.

Cold zone.—The lowest entering-air dry-bulb temperature in the kiln.

Drop across the load.—The reduction in the dry-bulb temperature of the air as it flows through the load and is cooled by evaporating moisture from the load of lumber.

Dry bulb.—The temperature of the kiln air.

Hot zone.—The highest entering-air dry-bulb temperature in the kiln.

Longitudinal variation of.—The range of entering-air dry-bulb temperatures in a kiln measured along its length.

Wet bulb.—The temperatures indicated by any temperature measuring device, the sensitive element of which is covered by a smooth, clean, soft, water-saturated cloth (wet-bulb wick or porous sleeve).

Temperature gradient, longitudinal.—A term used to denote longitudinal temperature differences within a dry kiln.

Tension wood.—A type of wood found in leaning trees of some hardwood species, characterized by the presence of fibers technically known as "gelatinous" and by excessive longitudinal shrinkage. Tension wood fibers tend to "pull out" on sawed and planed surfaces, giving so-called "fuzzy grain." Tension wood causes crook and bow and may collapse. Because of slower than normal drying, tension wood zones may remain wet when the surrounding wood is dry.

Texture.—A term referring to the size of wood cells. Thus, "fine-textured" wood has small cells; "coarse-textured" large cells. Where all the cells of a softwood, or all the pores of a hardwood, are approximately the same size, as seen on the cross section, the wood can be called "uniform textured." The term is sometimes erroneously used in combination with soft or hard.

Tracheids.—The elongated cells that make up the greater part of the wood of the softwoods; frequently referred to as fibers.

Transverse.—The directions in wood at right angles to the wood fibers or across the grain, including radial and tangential directions. A transverse or cross section is a section through a tree or timber at right angles to the pith. It has an end-grain surface.

Treatment, equalization.—A controlled temperature and relative humidity condition used in a dry-kiln at the end of drying to stop the drying of the driest boards while allowing the wettest boards to continue drying, thus reducing the moisture range between boards.

Treatment, steaming.—Spraying steam directly into the kiln to attain a condition at or near saturation in the initial stages of kiln-drying to retard the growth of mold. Also used to increase the rate of heating cold lumber. Sometimes used needlessly during other stages of drying to restore surface moisture, and often used without proper control to partially relieve stresses at the end of drying.

Twist.—A form of warp caused by the turning or winding of the edges of a board so that the four corners of any face are no longer in the same plane.

Tyloses.—Extensions of parenchyma cells into the pores or vessels of some hardwoods, notably white oak and black locust, prior to or during heartwood formation. They tend to prevent or greatly retard moisture movement through the vessels.

Vapor barrier.—A material with a high resistance to vapor movement, such as asphalt-impregnated paper, that is used in combination with insulation to control condensation.

Vapor pressure.—The pressure of a confined body of vapor. The pressure of a given saturated vapor is a function of temperature only.

Ventilator (or vent). — An opening in the kiln roof or wall, or in the blower duct work, that can be opened or closed in order to maintain the desired relative humidity condition within the kiln.

Automatic control.—A ventilator that is opened or closed by a thermostat.

Linkage.—The adjustable, pivoted rods connecting the vent cover to an air valve or to a hand-operated lever which facilitates the opening and closing of the vents.

Manual control.—A ventilator that is opened or closed by hand.

Vessels.—Wood cells in hardwoods of comparatively large diameter that have open ends and are set one above the other so as to form continuous tubes. The openings of the vessels on the surface of a piece of wood are usually referred to as pores.

Virgin growth.—The original growth of mature trees.

Wane.—Presence of bark or the lack of wood from any cause on edge or corner of a piece.

Warp.—Any variation from a true or plane surface. Warp includes cup, bow, crook, twist, and diamonding, or any combination thereof.

Water, bound (adsorbed, hygroscopic).—Moisture that is bound by adsorption forces within the cell wall; that is, the water in wood below the fiber saturation point.

Water, free.—Moisture that is held in the cell cavities of the wood, not bound in the cell wall.

Water pocket.—An area of unusually high moisture content of various sizes and shapes found in lumber.

Waterlogging.—The presence of water in steam coils, which interferes with the normal flow of steam and seriously affects the heating efficiency of the coil.

Wet-bulb temperature.—(See *Temperature.*)

Wood.—The hard material between the pith and the bark in the stems and branches of trees, made up of a variety of organized hollow cells and consisting chemically of cellulose, hemicelluloses, lignin, and extractives.

Wood substance.—The extractive-free solid material of which the cell walls of ovendry wood are composed, having essentially the same specific gravity in all species.

INDEX

U.S. GOVERNMENT PRINTING OFFICE: 1961 O—555315