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“”’v’”-’ KILN DRYING OF WESTERN CANADIAN LUMBER

G. Bramhall and R. W. Wellwood

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by

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FOREWORD

The previous kiln-drying manual for western Canada, prepared by Jenkins and Guernsey in 1954, served the industry well by providing reference and instruction for many hundreds of operators. But the past 20 years have seen some great changes in kiln-dfying requirements and techniques. Direct-heated kilns, fired by natural gas, propane or butane, which had just been introduced in 1954, now dry approximately half of all kiln-dried lumber. Drying times have been reduced by the use of higher drying temperatures, and dried lumber is now clearly defined as that having not more than 19 percent moisture content. In addition, research has provided more and better information about drying techniques. Consequently, there is a need for a new manual more in keeping with practices of the 1970s and 1980s.

At the time this bulletin was being written, Canada was introducing the metric system into general use. Consequently, the bulletin contains both the old and new systems of measurements. Conversions from one system to the other in the text are approximate only and reflect values which are reasonable in each system. Accurate conversions are found in Appendix A.

The department is indebted to several people for their constructive criticism of the manuscripts of this bulletin. These include W. W. Calvert, C. F. McBride, J. F, G. Mackay and M. Salamon, all of the Western Forest Products Laboratory, as well as S. J. Magee of Pacific Industrial Coatings Ltd., J. L. Bachrich of Intercan Mill and Kiln Co. Ltd., G. H. Eaton, formerly of Moore (Canada) Ltd., Allan Mellor of Federated Cooperative Lumber Co. Ltd., Don F. Turner of Fryer-Cruickshank Kilns Ltd. and J. W. Raven of the Council of Forest Industries of British Columbia.

The authors have extracted freely much of the material contained in the earlier manual by Jenkins and Guernsey where it is still applicable to current practice. We hope this bulletin will be as valuable to kiln operators as was its predecessor.

AVANT= PROPOS

Le manuel précédant sur le s6chage industrial clans l'ouest du Canada, préparé par Jenkins et Guernsey en 1954, a bien servi l'industrie en procurant références et instructions à plusieurs centaines d'opérateurs. Cependant les derniers 20 ans ont connu de vastes changements relativement aux exigences et aux techniques de séchage industrial. Des séchoirs à chauffe directe, aliment6s au gaz naturel, propane ou butane, qui venaient tout juste de faire leur apparition en 1954, servent aujourd'hui à sécher approximativement la moitié du bois séché au séchoir. On a réduit le temps nécessaire au s6chage au moyen de temperatures plus élevées, et il est maintenant clair que le bois d'oeuvre séché présente une teneur en humidité ne dépassant pas 19p. cent. De plus, la recherche a fourni de plus nombreuses et de meilleures information touchant les techniques de s6chage. Par consequent, le besoin d'un nouveau manuel, qui tienne compte des pratiques en vogue pour les années 1970 et 1980, était manifeste.

A l'époque ou ce bulletin fut rédigé, le Canada généralisait l'usage du système m&rique. C'est pour cette raison que le bulletin contient les mesures de l'ancien et du nouveau systèmes. Les conversions d'un système à l'autre clans le texte sent done approximatives et reflètent des valeurs raisonnables pour chacun des systèmes. On trouvera les conversions exactes à l'Appendice A.

Les auteurs ont extrait volontairement une bonne partie du mat&iel contenu clans l'ancien manuel de Jenkins et Guernsey, là ou il &ait encore possible de s'en servir clans la pratique courante. Nous espérons que ce bulletin sera aussi commode aux op6rateurs de séchoirs que le fut son prédécesseur.

INTRODUCTION

Reasons for Seasoning Wood

Processes involved in the growth and development of a living tree depend on the movement of water from roots to leaves, where food is manufactured by photosynthesis, and the movement of the dissolved food (sap) back to the areas where wood growth is taking place. As a result, the presence of large quantities of water in a tree is a natural and necessary condition for its life.

The moisture content (me) of a standing tree ranges from about 35 percent in the heartwood of some softwood species to about 200 percent in the sapwood of some species. Removal of moisture from lumber during its manufacture is traditionally called **seasoning** or drying. Commercial seasoning practice infers the maintenance of good quality in lumber and the removal of stresses which develop during some stages of drying. Since wood, on exposure, will ultimately reach a mc determined by the temperature and relative humidity of the surrounding air, there are many advantages to drying before placing lumber in service. Some of these are:

1. **To provide a dimensionally stable material** which **can** be cut or **turned to exact dimensions.** Wood will swell or shrink with changes in its mc. If it can be dried to the mc it will ultimately attain in use, and is then placed in a reasonably stable environment, further changes in dimensions will be imperceptible. For this reason, manufacturers of furniture and other high-quality products made from wood should be extremely careful about maintaining a proper and stable relative humidity in their plants. Moisture contents attained by various wood commodities in use are shown in Fig. 1.

2. **To eliminate warping, splitting and checking of products in use.** When wood dries, the outer surfaces dry first, resulting in surface shrinkage and drying stresses. If these stresses exceed the strength of the wood, it may check and split. Properly controlled drying eliminates or minimizes these defects and ensures that they will not occur after lumber is placed in service.

3. **To render wood less subject to biological stain, decay or insect attack.** Biological stains and decays are caused by the growth of fungi which use wood or its contents as food. Wood at less than about 22 percent mc is immune to fungal attack. Wood which has already been infected with the spores of these organisms is sterilized at temperatures of more than about 150"F (65°C), but can be reinfected if it becomes damp. Wood dried to less than about 10 percent mc is not attacked by insects. Dry-wood termites and certain beetles, however, will attack at lower mcs.

4. **To prepare** for further treatment. Wood must be dried to suitable mcs for gluing and for impregnation treatments. For glued-laminated timbers, the mc should be about 11 percent and, for the gluing of softwood plywood, 3 to 4 percent.

Wood intended for preservative or fire-retardant treatment should be dried to the mc it will attain in service, so that inevitable drying checks can be treated with preservatives; in the case of fire-retardant treatment, drying permits the maximum uptake of fire-retardant solutions.

5. **To** reduce the weight of lumber and thereby minimize shipping and handling costs. Shipping charges for lumber transported by rail or truck are based on shipping weight. There is, therefore, a direct economic benefit in shipping dry lumber. Traditionally, this has been the prime reason for drying softwood dimension construction lumber in areas serviced by railways.

Kiln drying is used in preference to air drying for several reasons:

1. **To** maintain shipping schedules. Demands for dry lumber cannot be anticipated sufficiently far in advance to ensure that lumber can be air dried when required.

2. To reduce drying costs. Financing and land-rent costs for lumber stored for air drying for several months exceed the cost of kiln drying in most cases.

3. **To** attain low moisture contents. In most cases, air drying will reduce moisture content to 12 to 15 percent. Where drier lumber is required, kiln drying is necessary.

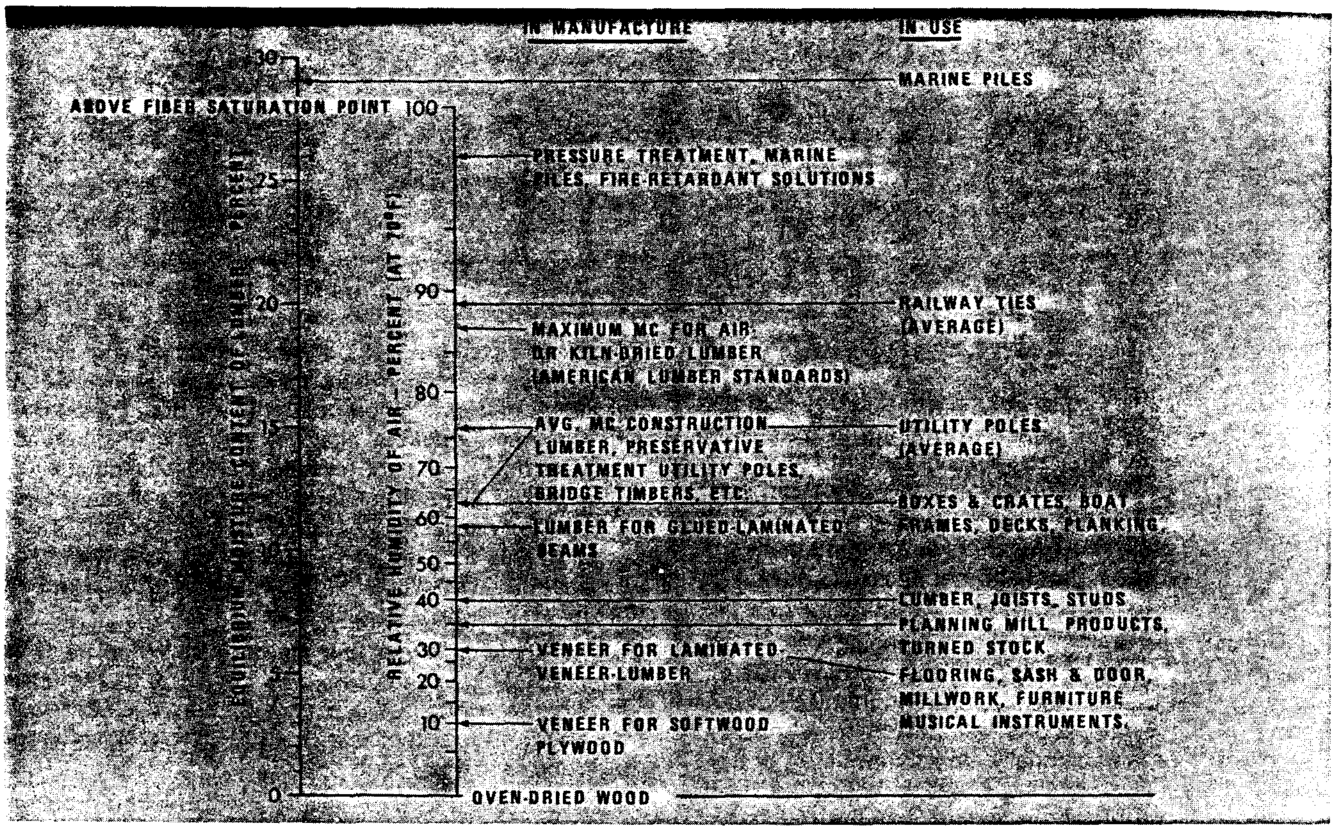


Fig. 1. Moisture contents of various lumber products

National Standards

As a result of the benefits accruing to consumers in the use of properly dried lumber, various specifying organizations have defined dried lumber in two categories. In the first, consisting of dimension lumber, dry lumber is defined as that which has been dried to a mc of 19 percent or less. Green lumber is defined as that having a mc of more than 19 percent. Five percent of the pieces in any shipment of dry lumber are permitted to exceed 19 percent mc.

Clears, selects, factory lumber and moulding stock less than 2 inches thick make up the second category and must be dried to a mutually agreed upon maximum mc, usually from 8 to 12 percent depending on user requirements.

Canadian Lumber Standards division of the Canadian Standards Association enforces conformance to lumber standards through the various lumber associations. Lumber must conform to the standard to be stamped S-dty (surfaced when dry) with the appropriate dimension.

The Role of Lumber-Drying Research

Since 1924, the two Canadian Forest Products Laboratories, in Vancouver and in Ottawa, have been engaged in studying the drying of lumber. Each laboratory is equipped with kilns of small capacity in which experimental runs can be made under a wide range of accurately controlled conditions. Each laboratory also has at least one semicommercial experimental kiln capable of duplicating commercial practice. Schedules developed by both laboratories have been extensively used in Canada. Scientists at the Vancouver laboratory also are investigating the movement of moisture in wood, how it can be moved most efficiently, what schedules are most effective, and how drying time can be minimized.

In this bulletin, the general principles of lumber drying and the application of these principles to the commercial kiln drying of the major western Canadian woods are presented. A glossary of terms is found in Appendix Bat the end of the bulletin to provide a reader with the generally accepted meanings of terms used in kiln drying.

CHAPTER 1
STRUCTURE OF WOOD IN RELATION TO DRYING

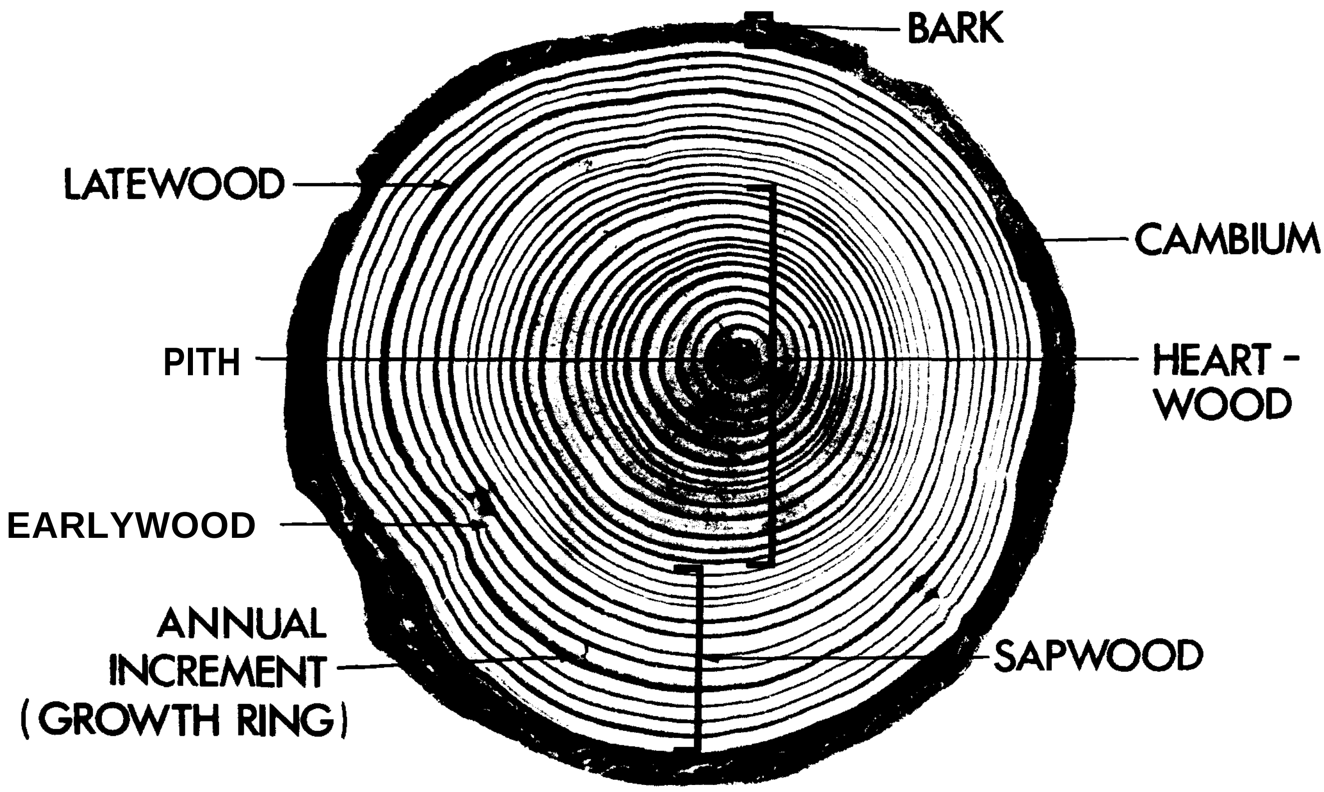


Fig. 1.1 Cross section of tree showing various wood zones

A knowledge of the behavior of wood under various conditions of temperature and humidity is essential to the successful kiln drying of lumber. To understand this behavior, it is helpful to know something of the structure of wood and its relation to moisture content (me), shrinkage, and development of defects during drying.

The structure of wood is complex, but the presence or absence of certain features and cell types, and the patterns they produce, makes it possible to divide wood into two broad categories — softwoods from coniferous trees and hardwoods from broadleaved trees. Further differentiation based on anatomical features identifies various subgroups (e.g. the pines, the oaks) and, finally, the individual species. Some of these differences in structure are responsible for differences in physical and mechanical properties and drying characteristics of different woods and their utilization for various specific purposes.

Macroscopic Features

The woody part of a tree stem or log consists of two zones, the **sapwood** and the heartwood (Fig. 1.1). The outer portion, the sapwood, is distinguished in most woods by its lighter color and also in softwoods by its **greater mc.** The main function of sepwood is to conduct water and minor amounts of dissolved mineral nutrients from the roots to the leaves.

The formation of heartwood in a tree stem is a process in which extraneous materials or **extractives** form at the sapwood-heartwood boundary. These extractives include tannins, resins, oils, dyes and like substances. The natural durability, color, and some other characteristics of certain woods are dependent upon the amount and kind of extrectives present. Their presence in heartwood reduces its permeability to the passage of liquids through the wood.

Because of its reduced permeability, the heartwood of most hardwoods dries much more slowly than the corresponding sapwood. In softwood lumber, however, this feature is compensated for by the lower mc of heartwood and both zones dry in about the same time.

Trees from temperate regions grow by adding an annual increment (growth ring) each year at the cambial layer under the **bark** (Fig. 1.1). Each annual increment is roughly in the form of a progressively larger cone. The first part of each increment, the **earlywood,** is composed of large-diameter, thin-walled cells formed during the period of most rapid growth (the spring). The later part of the ring, the Iatewood, consists of smaller-diameter, thick-walled cells formed when growth is slower. Latewood bands are most pronounced in Softwoods, such as Douglas-fir and lodgepole pine, and least so in hardwoods such as poplar.

Because the orientation of the annual rings within a board affects its properties, two types of lumber cut are recognized. In vertical-grain lumber (edge grain or quarter sawn), the wide face of a board is perpendicular to the annual rings; whereas in flat-grain lumber, the wide face is essentially parallel to the annual rings.

Specialized Wood Types

Knots

Knots are normal features of all trees. They represent that portion of tree branches embedded in the stem as a tree increases in diameter. If the branch is live, the knots are tight or intergrown (Fig. 1.2). If the branch is dead, it does not grow with the growing trunk. As a result, such knots are loose or encased. Because knot wood has greater density and different grain orientation than normal wood, it has important effects on lumber seasoning. Tight knots tend to remain fixed in sawn boards, although they may check in drying, but encased knots may loosen and fall out.

Reaction Wood

Reaction wood is a specialized type of wood

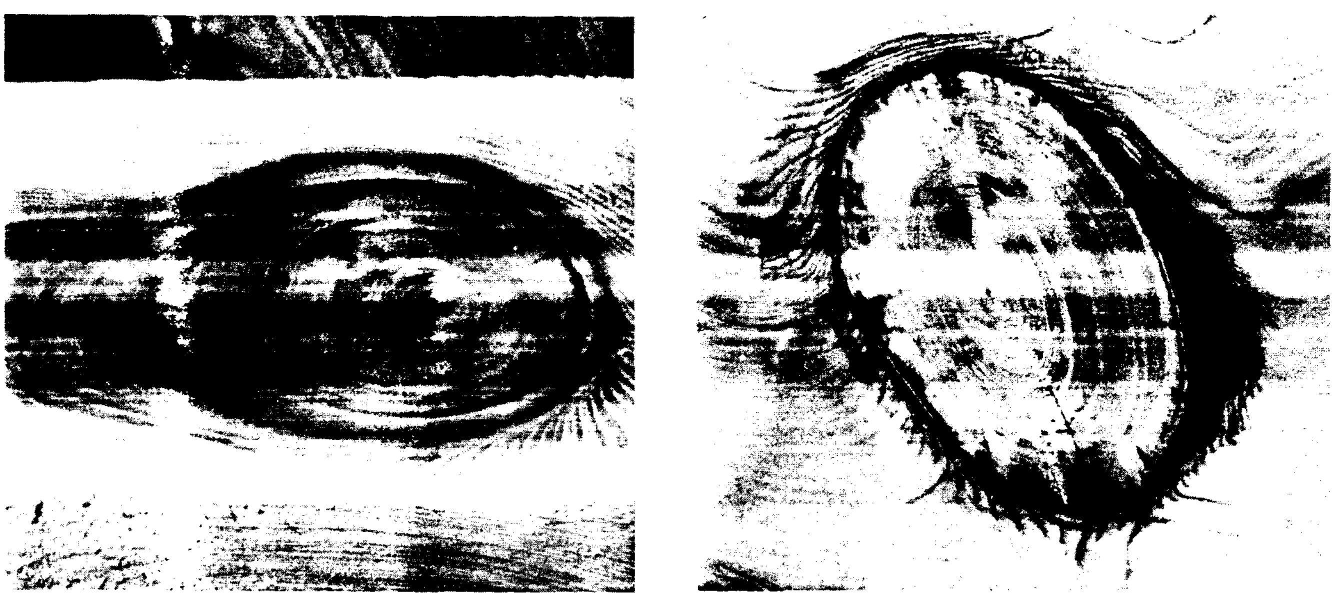


Fig. 1.2 Knot types — a. tight knot, b. loose or encased knot

developed in a tree to support a leaning trunk or a branch. In coniferous trees, it grows on the underside of the leaning part of a tree and is called compression wood. In broadleaved trees, it grows on the upper side and is called tension wood.

In compression wood, the annual growth rings are usually very wide and appear to have an unduly high percentage of latewood. The usual clear line of demarcation between earlywood and latewood is often lacking in the compression wood of Douglas-fir, for example. Compression wood appears as a half-moon pattern of dark-colored wood on the lower side of the tree or branch. Thus the pith of a log is not in its geometric center. In the green condition, compression wood is distinguishable by its dark reddish color. It is heavy and hard, and when dry has a dull, lifeless appearance which on wetting returns to the dark reddish color of undried wood. Compression wood shrinks longitudinally during drying much more than normal wood and its strength along the grain is much less. As a result, a piece of lumber with compression wood near one face will bow or warp during drying.

Tension wood performs the same function in broadieaved trees as compression wood does in the conifers; i.e., it supports branches and a leaning trunk. Because it is on the upper side and acts in tension, its structural features are quite different from those of compression wood. When cut into lumber, tension wood shrinks abnormally, resulting in warping and splitting of lumber.

Logs containing tension wood are quite often but not always eccentric in outline, with the major radius on the upper side of the lean. The end surface of a log (e.g., of trembling aspen) may show a characteristic woolliness and silvery sheen in the tension wood. On the board surface, the tension wood zones may be darker than the normal wood surrounding them. In cutting green tension wood, a saw blade becomes dull more readily than in cutting normal wood and leaves a woolly surface. Upon machining in the green condition, zones of tension wood are indicated by torn grain and fuzzy surfaces, resulting from pulled-out fibers. Dry lumber containing tension wood is not so seriously affected.

Tension wood is widespread in its occurrence and is particularly prevalent in certain woods, such as cottonwood.

Juvenile Wood

Wood from close to the pith of softwood trees (juvenile or core wood) tends to have less than average weight. Longitudinal shrinkage is greater than

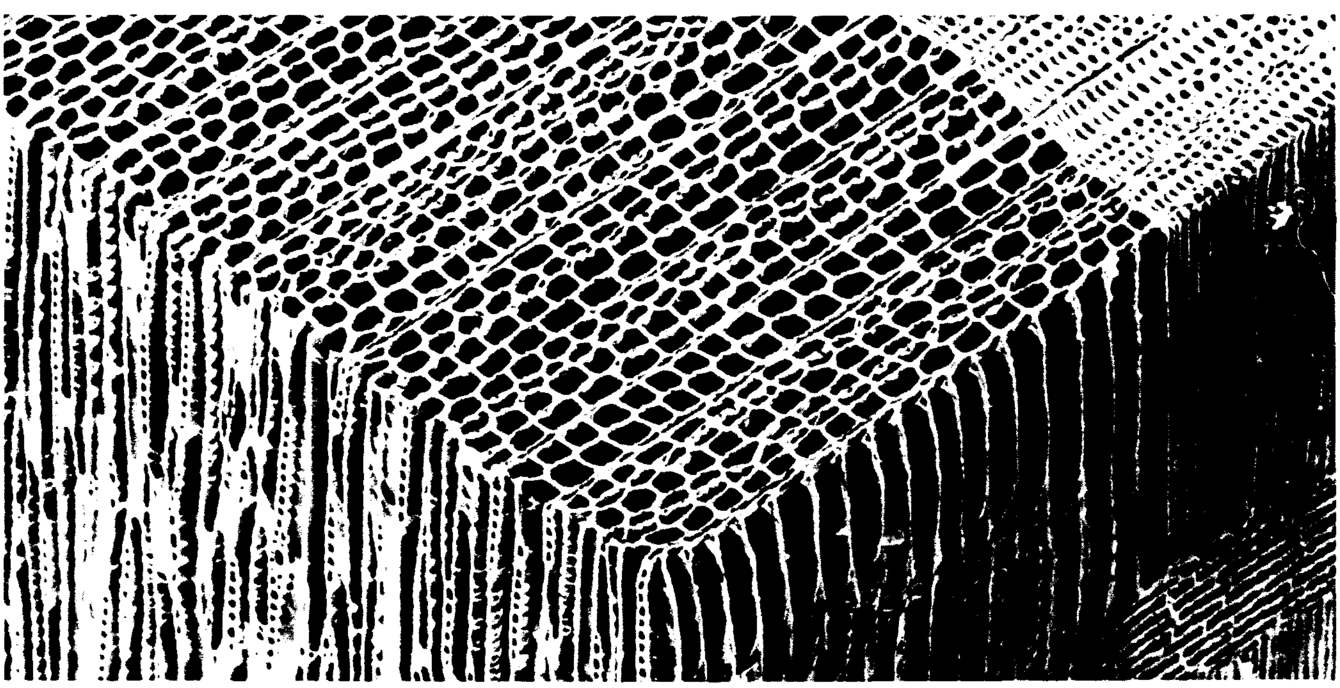


Fig. 1.3 Scanning electron micrograph of a typical softwood

normal; transverse shrinkage is less than normal. Although juvenile wood tends to have the lifeless appearance of compression wood, it lacks its high density and should not be confused with it. It occurs in all trees, but is more prevalent in pines. It is also more prevalent in fast-grown plantation trees than in forest-grown material.

Wetwood

Zones of wetwood are particularly common at the sapwood-heartvvood boundary of certain species, such as trembling aspen. There is no precise definition for wetwood. The term is usually applied to pockets of wood having one or more of the following characteristics: high mc, presence of bacteria (but not decay-producing fungi), an unpleasant odor, higher pH than adjacent wood, and lower permeability than is normal for the species. The wood has an abnormally high water content, with a translucent or water-soaked appearance. This condition develops only in living trees and does not originate through soaking logs or lumber in water.

Microscopic Features

Wood is composed of cells — thin walls of wood substance surrounding minute cavities — mainly oriented in the vertical plane of a stem. Cell-wall substance is heavier than water, with specific gravity of about 1.5. The amount of cell-wall substance per unit volume determines the specific gravity of wood: those woods with thick cell walls are heavy, while those with thin cell walls are light in weight. Since some air is normally present in the cell cavities, a piece of wood will generally float. However, if most or all cell cavities in the wood are filled with water or the wood is extremely dense, it will be heavier than an equal volume of water and will, therefore, sink.

softwoods

Over 90 percent of the volume of a piece of softwood lumber is composed of longitudinally aligned fiberlike cells, or **tracheids.** These cells are typically 0.10 to 0.25 inch long (2.5 to 6.4 mm), with a diameter about one one-hundredth of their length, and with a central cavity or lumen occupying about three-quarters of the cell volume. The tracheids, which are arranged in regular radial rows (Fig. 1.3), perform the dual function of conveying water and providing mechanical support for a tree. Free water in cell lumens moves from one tracheid to the next through **bordered pita.** A photomicrograph of a greatly magnified bordered pit in a Douglas-fir tracheid, taken by scanning electron microscope (Fig, 1.4), shows the **pit** membrane with microscopic gaps (pores) through which water can pass. The central part of this membrane generally has a dense thickening called a torus that may act as a closing valve by becoming appressed to the cell wall, thereby sealing or aspirating the pit. This mechanism contributes to a slower rate of drying in heartwood, since most pits are aspirated during the transition from sapwood to heartwood.

Also present is a system of horizontally aligned cells, or wood **rays.** In living trees, these cells carry dissolved food materials radially inward from the living cambium.

Some woods (pines, spruces, larches, Douglas-fir) have both vertical and horizontal systems of enlarged cavities, called resin canals. Resin (pitch) will often exude from these canals during seasoning, and can be detected on end and flat grain as small droplets. In some species, resin canals are formed only when a tree is injured during growth. The occurrence of occasional pitchy streaks in western hemlock, which normally has no resin canals, furnishes a familiar example. Pitch may also occur in pockets or openings extending parallel to the annual growth rings.

Fig. 1.4 Bordered pit in typical softwood

Hardwoods

The structure of wood of broadleaved trees (hardwoods) is more complex than that of softwoods because more cell types are present in hardwoods: also the regular radial alignment of the vertical elements may be obscured (Fig. 1.5). The most obvious difference is that in wood of broadleaved trees there are large vertical ducts called vessels. Vessel elements can be very large in diameter (0.01 in or 0.25 mm). Vessels of some heartwoods (e.g. white oak) may become blocked with balloon-like outgrowths of cell walls called tyloses, thereby making them ineffectual in moisture movement. Approximately one-half of the volume of a piece of hardwood is composed of **fibers.** Their function in a tree is primarily one of mechanical support.

Hardwoods are classified as ring-porous or diffuse-porous depending upon the arrangement of the vessels within an annual increment. Ring-porous hardwoods (e.g., the oaks) are characterized by layers of vessels formed during the early spring, followed by the formation later in the growing season of denser fibrous wood containing smaller scattered vessels, making the annual increments very obvious. In diffuse-porous woods, the vessels are distributed uniformly throughout an annual ring, so that the limits of each annual layer are sometimes difficult to determine without magnification (e.g., as in trembling aspen). The wood rays in hardwoods are more prominent than those in softwoods and in some (e.g., the oaks and beech) are large and readily visible by the naked eye. The diversity in structure of hardwoods results in a much greater variety in seasoning behavior than occurs with softwoods.

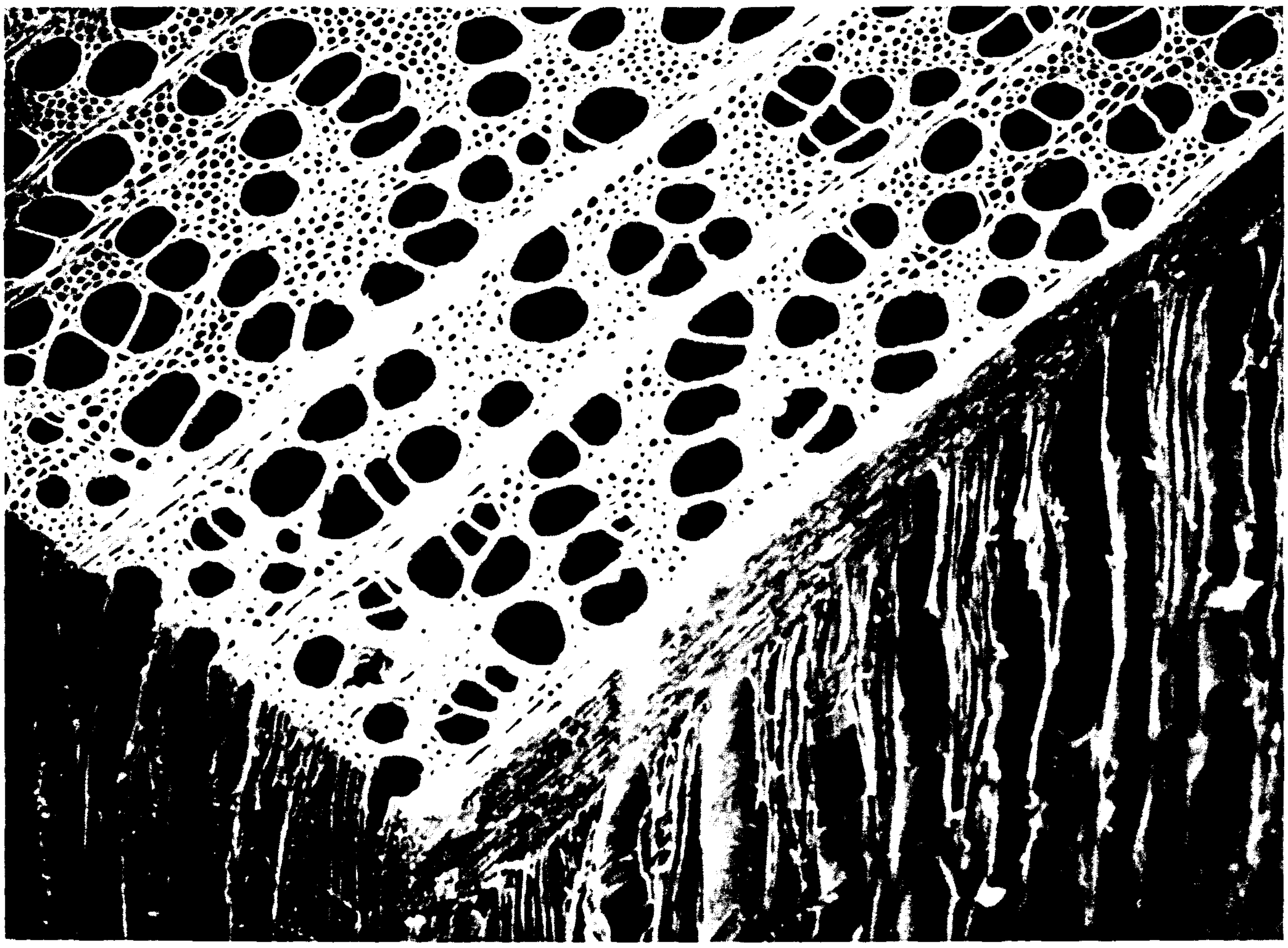
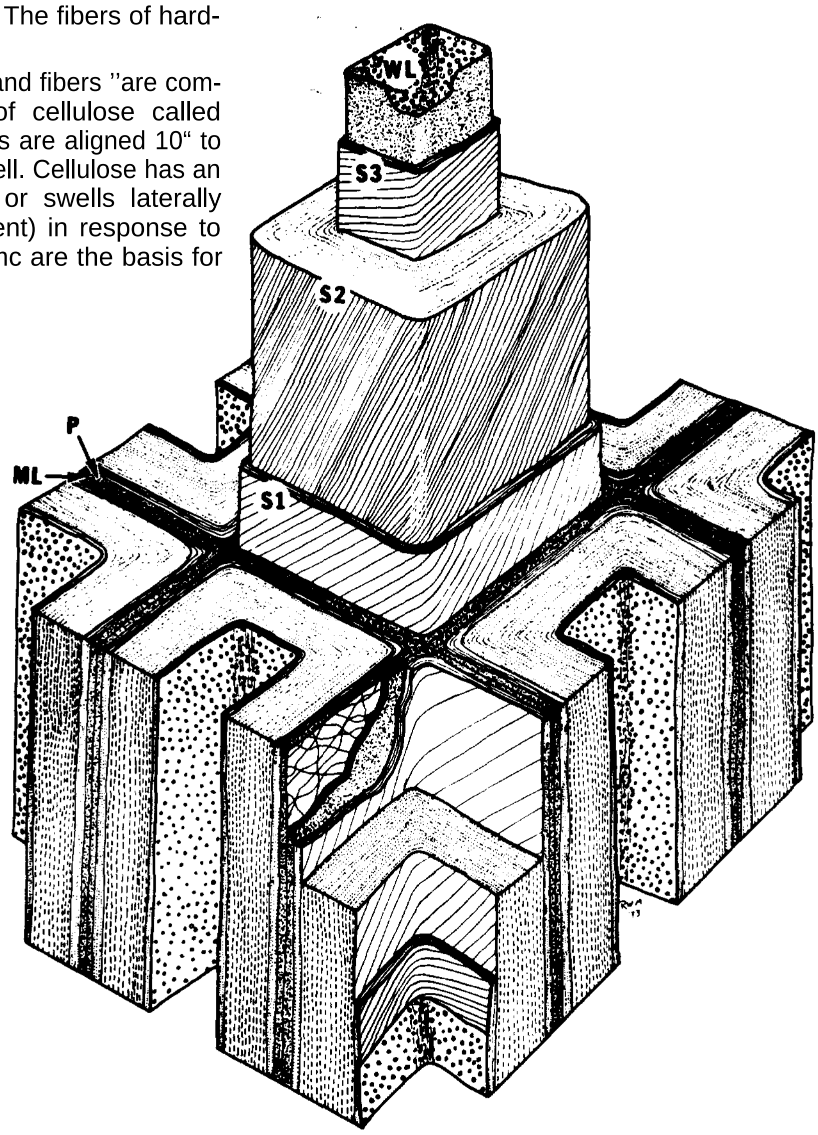


Fig. 1.5 Scanning electron micrograph of a diffuse-porous hardwood

Submicroscopic Features

The cell-wall structure of coniferous tracheids has been intensively studied (Fig. 1.6). The fibers of hardwoods are similar in structure.

The cell walls of both tracheids and fibers "are composed of thread-like structures of cellulose called fibrils. For the most part, these fibrils are aligned 10" to 15° from the longitudinal axis of a cell. Cellulose has an affinity for moisture and shrinks or swells laterally (perpendicular to the fibril alignment) in response to changes in mc. Such changes in mc are the basis for shrinkage and swelling in wood.



ML — middle lamella
WL — warty layer
P — **primary wall**
S1, **S2, S3, layers within cell wall**

Fig. 1.6 Diagrammatic view of sections of tracheid walls

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CHAPTER 2
WOOD-MOISTURE RELATIONS

Moisture in Wood

Since one of its major functions is water conduction, sapwood normally contains large quantities of water, even after a tree is felled and its bole converted to lumber. In hardwoods and certain softwood species, heartwood also retains large quantities of water. In other softwoods, heartwood is characterized by its relatively low moisture content (me). Moisture in wood occurs in three forms:

(1) **as free water** in cell cavities;
(2) as vapor in the air in the part of cell cavities not occupied by liquid; and
(3) as hydroscopic or bound water, absorbed primarily on the cellulose and hemicellulose molecules which constitute the greater part of wood substance.

For wood and wood products, the **moisture content** is defined as the weight of water contained in the wood, expressed as a percentage of the weight of ovendry wood. It can be calculated as the difference between the green and dry weights, divided by the dry weight, and multiplied by 100 percent.

$$mc = \frac{W_G - W_D}{W_D} \times 100\% = \frac{W_W}{W_D} \times 100\%$$

where: W_W = weight of water;
W_D = ovendry weight of wood;
W_G = green weight of wood.

For example, the mc of a piece of wood which weighs 40 grams green and 30 grams ovendty is calculated as follows:

$$mc = \frac{40-30}{30} \times 100\% = \frac{10}{30} \times 100 = 33.3\%$$

The fiber saturation point (fsp) is defined as the mc at which cell walls are saturated with bound water, but no free water exists in cell cavities. This mc differs in different woods, due to the presence of various amounts of nonhygroscopic substances in their constitutions, but it is usually between 23 and 34 percent. The mc corresponding to the fsp varies with temperature also, decreasing as temperature increases. It is also affected by prolonged exposure of wood to high temperatures, which results in a permanently reduced fsp.

Equilibrium moisture content (emc) is the term used to define the mc of wood which has been exposed to the same conditions of temperature and humidity for a sufficiently long period to reach equilibrium. A change in temperature or humidity will result in a corresponding change in the emc of the wood. Relationships between humidity and temperature of air and emc of wood have been determined and are shown in Tables 2.1 and 2.2. At the emc, as much moisture evaporates from the wood as condenses on it, so that the mc remains constant.

Vapor Pressure

An understanding of the term **vapor pressure** is necessary to an understanding of the drying of lumber. It is a governing factor in determining the rate of moisture movement and therefore of wood drying.

If a closed container without air is partly filled with water, the liquid will begin to evaporate and vapor will occupy the space above the liquid. As the space above the liquid becomes more and more concentrated with vapor, some will condense and return to the liquid, reducing the net rate of evaporation. Finally, a condition will be reached when the vapor is condensing at the same rate as the liquid is evaporating. The system is then in equilibrium and the space is saturated with water vapor. The pressure in the container is then the **saturated vapor pressure** of water at that temperature. A decrease in temperature will cause some of the vapor to condense, and a new equilibrium will be established with a lower saturated vapor pressure. Similarly, an increase in temperature will result in further evaporation and a higher vapor pressure. For each temperature, then, there is a specific value of saturated vapor pressure, these values being listed in published tables (Tables 2.2, 9.1 and 9.2). In fact, the steam tables used by steam engineers and boiler operators are vapor-pressure tables using pounds per square inch gauge (Psi9) as the Pressure units, i.e., with atmospheric pressure (1 4.7 psi) being subtracted from each vapor-pressure value. Because this gives a reading of zero at

212°F (1 OO"C), steam tables do not extend below the boiling point of water whereas vapor-pressure tables are published for temperatures even below the freezing point of water. It maybe seen from tables that the vapor pressure of water increases with increasing temperature, and at higher temperatures the increase is rapid. It should also be recognized that the rate of evaporation is proportional to the degree of unsaturation (the saturation deficit) of the space above the liquid.

At any time before equilibrium is attained, that is, when the space is not saturated with water vapor, the vapor pressure (or **partial** pressure) is less than the saturated vapor pressure at that temperature. When using the term "vapor pressure", then, it is necessary to show by context or by definition whether "saturated vapor pressure" or "partial pressure of water vapor" is meant.

Humidity and Relative Humidity

Humidity, or the "moisture content" of the air, may be expressed in two ways, absolute or relative. **Absolute humidity** is the actual quantity of water vapor contained in a given volume of air. It is measured by weight per unit volume or by vapor pressure. For example, saturated air at 140°F (60"C) has an absolute humidity of 57 grains per cubic foot (Table 2.3) and a vapor pressure of 19.9 kilopascais (kPa) (Tables 2.2, 9.1 and 9.2).

Relative humidity is the ratio of the amount of water in the air compared with the amount at saturation at the same dry-bulb temperature. To continue the example, saturated air at 140"F holds 57 grains of water vapor per cubic foot. However, if only 31 grains are present at this temperature, the relative humidity is 31 /57 of 100 percent or 55 percent. It can be calculated on the basis of vapor pressures also, with the same result. If the humidity is 31 grains per cubic foot, its vapor pressure is 10.9 kPa. Since the saturated vapor pressure is 19.9 kPa, this is a relative humidity of 10.9/1 9.9 of 100 percent or 55 percent.

Increasing the temperature of the air increases its capacity for holding moisture, so that it requires more grains of moisture per cubic foot to saturate it. increasing the temperature of the air without adding more moisture will, thereby, cause the relative humidity to decrease; for example, if air with a relative humidity of 100 percent at 140°F (60"C) is heated to 158°F (70°C), its vapor pressure will remain at 19.9 kPa (approximately). But since the saturated vapor pressure of water at 158°F is 31.2 kPa, the relative humidity will fall from 100 percent to 19.9/31.2 or 64 percent.

In the temperature range above the boiling point of water (21 2"F, 10O°C at sea level), the term "relative humidity" should be used with reservation. In this range, it still means the actual weight expressed as a fraction of the weight at saturation, or the partial pressure expressed as a fraction of the saturated vapor pressure, but the saturated condition cannot be attained at atmospheric pressure. The maximum relative humidity attainable will, therefore, always be less than 100 percent. For example, the relative humidity at 230"F dry bulb and 212°F wet bulb (1 10"C dry bulb and 100° wet bulb) can be calculated by the vapor-pressure method as follows: vapor pressure at 230°F as follows: vapor

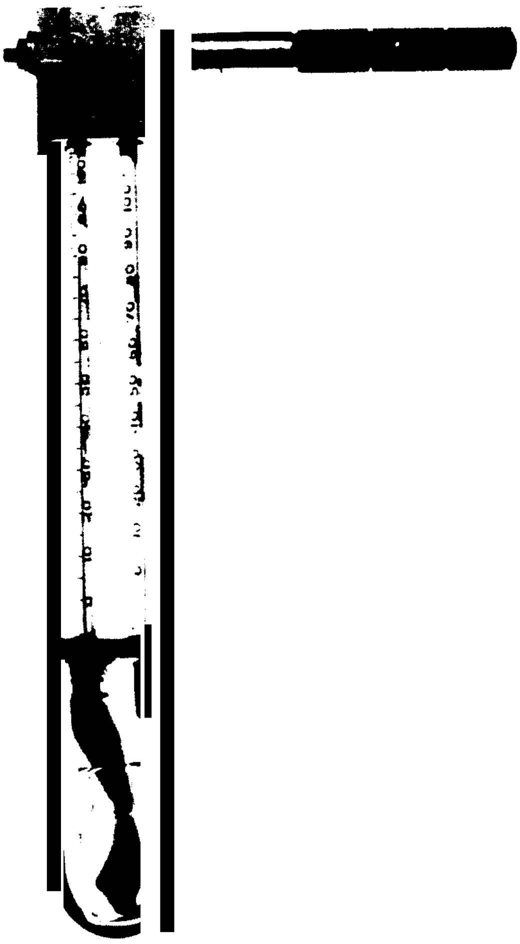

Fig. 2.1 Hygrometer for determining dry- and wet-bulb temperatures

Table 2.1 Relative humidity[1] and equilibrium moisture content[2] table for use with dry-bulb temperatures and wet-bulb depressions — °F

Difference between wet- and dry-bulb temperatures in degrees Fahrenheit

Temperature dry bulb (F.)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	22	24	26	28	30	34	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	31	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	62	58	53	48	43	39	34	30	26	21	17	13	9	5									
		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									
65	95	90	84	80	75	70	66	61	56	52	48	44	39	36	32	27	24	20	16	13	6								
		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	1.4								
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	22	19	12	6							
		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	2.9	1.5							
75	95	91	86	82	78	74	70	66	62	58	54	51	47	44	41	37	34	31	28	24	18	12	7	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	4.1	2.9	1.7	0.2					
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35	32	29	23	18	12	7	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	5.0	4.0	3.0	1.8	0.3				
90	96	92	89	85	81	78	74	71	68	65	64	58	55	52	49	47	44	41	39	36	31	26	22	17	13	5			
		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	6.1	5.3	4.6	3.8	2.8	1.3			
100	96	93	89	88	83	80	77	73	70	68	65	62	59	56	54	51	49	46	44	41	37	33	28	24	21	13	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	6.7	6.1	5.4	4.9	4.2	3.1	0.7		
110	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	52	50	48	46	42	38	34	30	26	20	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	7.2	6.6	6.0	5.4	4.8	4.0	2.5	1.1	
120	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60	58	55	53	51	49	45	41	38	34	31	25	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	7.4	6.8	6.3	5.8	5.4	4.6	3.3	2.3	1.1
130	97	94	91	89	86	83	81	78	76	73	71	69	67	64	62	60	58	56	54	52	48	45	41	38	35	29	21	15	10
		21.0	18.8	17.2	16.0	14.9	14.0	12.4	12.7	12.1	11.5	11.0	10.5	10.0	9.7	9.4	9.0	8.7	8.3	8.0	7.6	7.0	6.6	6.1	5.6	4.9	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	51	47	44	41	38	32	25	19	14
		20.7	18.6	16.9	15.8	14.8	13.8	13.2	12.5	11.0	11.4	10.9	10.4	10.0	9.6	9.4	9.0	8.7	8.4	8.0	7.6	7.1	6.6	6.2	5.8	5.1	4.1	3.4	2.6
150	98	95	92	90	87	85	82	80	78	76	74	72	70	68	66	74	72	60	58	57	53	49	46	43	41	36	28	23	18
		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	7.5	7.1	6.7	6.2	5.8	5.2	4.2	3.6	2.9
160	98	95	92	90	88	86	83	81	79	77	75	73	71	69	67	65	64	62	60	58	55	52	49	46	43	38	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	7.4	7.0	6.7	6.2	5.8	5.2	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	57	53	51	48	45	40	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	7.3	6.9	6.6	6.2	5.7	5.2	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	58	55	52	50	47	42	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	7.2	6.8	6.4	6.0	5.7	5.2	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	60	57	54	51	49	44	37	32	28
		18.5	16.9	15.2	14.2	13.5	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	7.0	6.6	6.2	5.9	5.5	5.0	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	61	58	55	53	51	46	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	6.9	6.4	6.0	5.7	5.4	4.9	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	63	60	57	54	52	47	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	6.8	6.3	5.9	5.5	5.3	4.8	4.2	3.7	3.2

[1]Relative humidity values in roman type.

From U.S. Forest Service, Forest Products Laboratory

Table 2.2 Relative humidity-equilibrium moisture content table and saturated vapor pressure for use with dry-bulb temperature and wet-bulb depression —°C

Difference between wet- and dry-bulb temperatures in degrees Celsius

Temp. dry bulb (°C)	V.P. kPa	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	22.0	24.0	26.0	28.0	30.0
0	0.6	91 / 20.5	82 / 17.0	73 / 14.3	64 / 12.2	56 / 10.5	47 / 9.0	39 / 7.6	31 / 6.3	22 / 4.9	14 / 3.5																				
5	0.9	93 / 21.6	86 / 18.4	79 / 15.9	72 / 14.0	65 / 12.3	58 / 10.9	51 / 9.7	45 / 8.5	38 / 7.5	32 / 6.5	19 / 4.4	6 / 1.9																		
10	1.2	94 / 22.4	88 / 19.5	82 / 17.2	76 / 15.3	71 / 13.7	65 / 12.4	60 / 11.2	54 / 10.2	49 / 9.3	44 / 8.4	33 / 6.8	23 / 5.2	14 / 3.5	4 / 1.3																
15	1.7	95 / 23.0	90 / 20.3	85 / 18.1	80 / 16.3	75 / 14.8	70 / 13.6	66 / 12.4	61 / 11.5	57 / 10.6	52 / 9.8	44 / 8.3	35 / 7.0	27 / 5.8	19 / 4.5	12 / 3.0	4 / 1.3														
20	2.3	96 / 23.4	91 / 20.9	87 / 18.8	83 / 17.1	78 / 15.7	74 / 14.4	70 / 13.4	66 / 12.4	62 / 11.5	59 / 10.8	51 / 9.4	44 / 8.2	37 / 7.2	30 / 6.2	24 / 5.2	17 / 4.1	11 / 2.9	5 / 1.6												
25	3.2	96 / 23.6	92 / 21.2	88 / 19.3	84 / 17.7	81 / 16.3	77 / 15.1	74 / 14.0	70 / 13.1	67 / 12.3	63 / 11.5	57 / 10.2	50 / 9.1	44 / 8.1	38 / 7.2	33 / 6.4	27 / 5.6	22 / 4.8	16 / 3.9	11 / 3.0	7 / 1.9										
30	4.2	96 / 23.7	93 / 21.5	89 / 19.6	86 / 18.0	83 / 16.7	79 / 15.5	76 / 14.5	83 / 13.6	70 / 12.8	67 / 12.1	61 / 10.8	55 / 9.7	50 / 8.8	44 / 8.0	39 / 7.2	34 / 6.5	29 / 5.8	25 / 5.2	16 / 4.5	12 / 3.8	12 / 3.0	8 / 2.2	4 / 1.3							
35	5.6	97 / 23.7	93 / 21.5	90 / 19.8	87 / 18.2	84 / 16.9	81 / 15.8	78 / 14.8	75 / 13.9	72 / 13.1	69 / 12.5	64 / 11.2	59 / 10.2	54 / 9.3	49 / 8.5	44 / 7.8	40 / 7.1	36 / 6.5	31 / 5.9	27 / 5.4	23 / 4.8	20 / 4.3	16 / 3.7	13 / 3.1	9 / 2.4	6 / 1.7					
40	7.4	97 / 23.6	94 / 21.5	91 / 19.8	88 / 18.3	85 / 17.1	82 / 16.0	80 / 15.0	77 / 14.1	74 / 13.4	72 / 12.7	67 / 11.5	62 / 10.5	57 / 9.6	53 / 8.8	48 / 8.1	44 / 7.5	40 / 7.0	36 / 6.4	33 / 5.9	29 / 5.5	26 / 5.0	22 / 4.5	19 / 4.1	16 / 3.6	13 / 3.1	8 / 2.0	2 / 0.7			
45	9.6	97 / 23.4	94 / 21.4	91 / 19.7	89 / 18.3	86 / 19.1	83 / 16.0	81 / 15.1	78 / 14.2	76 / 13.5	73 / 12.8	69 / 11.6	64 / 10.6	60 / 9.8	56 / 9.0	52 / 8.4	48 / 7.8	44 / 7.3	40 / 6.8	37 / 6.3	34 / 5.9	30 / 5.5	27 / 5.1	24 / 4.7	22 / 4.3	19 / 3.9	14 / 3.1	9 / 2.2	4 / 1.2		
50	12.3	97 / 23.1	95 / 21.2	92 / 19.6	89 / 18.2	87 / 17.0	84 / 16.0	82 / 15.0	80 / 14.2	77 / 13.5	75 / 12.8	71 / 11.7	66 / 10.7	62 / 9.9	58 / 9.2	54 / 8.5	51 / 8.0	47 / 7.5	44 / 7.0	40 / 6.5	37 / 6.1	34 / 5.8	31 / 5.4	29 / 5.0	26 / 4.7	23 / 4.4	18 / 3.7	14 / 3.0	10 / 2.3	6 / 1.5	2 / 0.6
55	15.8	97 / 22.8	95 / 20.9	92 / 19.4	90 / 18.0	88 / 16.9	85 / 15.8	83 / 15.0	81 / 14.2	78 / 13.4	76 / 12.8	72 / 11.7	68 / 10.7	64 / 9.9	60 / 9.2	57 / 8.6	53 / 8.0	50 / 7.5	47 / 7.1	43 / 6.7	40 / 6.3	38 / 5.9	35 / 5.6	32 / 5.3	30 / 5.0	27 / 4.7	22 / 4.1	18 / 3.5	14 / 2.9	19 / 2.3	7 / 1.7
60	19.9	98 / 22.4	95 / 20.6	93 / 19.1	90 / 17.8	88 / 16.7	86 / 15.7	84 / 14.8	82 / 14.0	79 / 13.3	77 / 12.7	73 / 11.6	69 / 10.7	66 / 9.9	62 / 9.2	59 / 8.6	55 / 8.1	52 / 7.6	49 / 7.0	46 / 6.7	43 / 6.4	40 / 6.0	38 / 5.7	35 / 5.4	33 / 5.1	30 / 4.8	26 / 4.3	22 / 3.8	18 / 3.3	14 / 2.8	11 / 2.3
65	25.0	98 / 22.0	95 / 20.3	93 / 18.8	91 / 17.5	89 / 16.4	87 / 15.5	84 / 14.6	82 / 13.9	80 / 13.2	78 / 12.6	74 / 11.5	71 / 10.6	67 / 9.8	64 / 9.1	60 / 8.5	57 / 8.0	54 / 7.6	51 / 7.1	48 / 6.8	45 / 6.4	43 / 6.1	40 / 5.8	38 / 5.5	35 / 5.2	33 / 4.9	29 / 4.4	25 / 4.0	21 / 3.5	17 / 3.1	14 / 2.7
70	31.2	98 / 21.6	96 / 19.9	93 / 18.5	91 / 17.2	89 / 16.2	87 / 15.2	85 / 14.4	83 / 13.6	81 / 13.0	79 / 12.4	75 / 11.3	72 / 10.4	68 / 9.7	65 / 9.0	62 / 8.5	59 / 8.0	56 / 7.5	53 / 7.1	50 / 6.7	47 / 6.4	45 / 6.1	42 / 5.8	40 / 5.5	37 / 5.2	35 / 5.0	31 / 4.5	27 / 4.1	23 / 3.7	20 / 3.3	17 / 2.9
75	38.6	98 / 21.1	96 / 19.5	94 / 18.1	92 / 16.9	90 / 15.9	88 / 15.0	86 / 14.1	84 / 13.4	82 / 12.9	80 / 12.2	76 / 11.1	73 / 10.3	70 / 9.5	66 / 8.9	63 / 8.4	60 / 7.9	57 / 7.4	54 / 7.0	52 / 6.6	49 / 6.3	47 / 6.0	44 / 5.7	42 / 5.5	39 / 5.2	37 / 5.0	33 / 4.5	29 / 4.1	26 / 3.8	23 / 3.4	19 / 3.1
80	47.4	98 / 20.6	96 / 19.1	94 / 17.7	92 / 16.6	90 / 15.5	88 / 14.7	86 / 13.9	84 / 13.2	82 / 12.5	82 / 11.9	77 / 10.9	74 / 10.1	71 / 9.4	67 / 8.8	64 / 8.2	61 / 7.7	59 / 7.3	56 / 6.9	53 / 6.6	51 / 6.2	48 / 5.9	46 / 5.7	44 / 5.4	41 / 5.2	39 / 4.9	35 / 4.5	31 / 4.1	28 / 3.8	25 / 3.5	22 / 3.1
85	57.8	98 / 20.1	96 / 18.6	94 / 17.3	92 / 16.2	90 / 15.2	88 / 14.3	87 / 13.6	85 / 12.9	83 / 12.3	81 / 11.7	78 / 10.7	75 / 9.9	72 / 9.2	68 / 8.6	66 / 8.1	63 / 7.6	60 / 7.2	57 / 6.8	55 / 6.4	52 / 6.1	50 / 5.8	47 / 5.6	45 / 5.3	43 / 5.1	41 / 4.9	37 / 4.5	33 / 4.1	30 / 3.8	27 / 3.5	24 / 3.2
90	70.1	98 / 19.6	96 / 18.1	94 / 16.9	92 / 15.8	91 / 14.8	89 / 14.0	87 / 13.3	85 / 12.6	84 / 12.0	82 / 11.4	79 / 10.5	76 / 9.7	72 / 9.0	69 / 8.4	67 / 7.9	64 / 7.4	61 / 7.0	59 / 6.7	56 / 6.3	54 / 6.0	51 / 5.7	49 / 5.5	47 / 5.2	45 / 5.0	43 / 4.8	39 / 4.4	35 / 4.1	32 / 3.7	28 / 3.4	25 / 3.2
95	84.5	98 / 19.1	96 / 17.7	94 / 16.4	93 / 15.4	91 / 14.5	89 / 13.7	99 / 12.9	86 / 12.3	84 / 11.7	83 / 11.2	79 / 10.3	76 / 9.5	73 / 8.8	70 / 8.2	68 / 7.7	65 / 7.3	62 / 6.9	60 / 6.5	57 / 6.2	55 / 5.9	53 / 5.6	50 / 5.4	48 / 5.1	46 / 4.9	44 / 4.7	40 / 4.3	37 / 4.0	33 / 3.7	30 / 3.4	27 / 3.1
100	101.3	98 / 18.5	96 / 17.2	95 / 16.0	93 / 15.0	91 / 14.1	90 / 13.3	88 / 12.6	86 / 12.0	85 / 11.4	83 / 10.9	80 / 10.0	77 / 9.2	74 / 8.6	71 / 8.0	69 / 7.5	66 / 7.1	63 / 6.7	61 / 6.3	58 / 6.0	56 / 5.7	54 / 5.5	52 / 5.2	49 / 5.0	47 / 4.8	45 / 4.6	42 / 4.3	38 / 3.9	35 / 3.6	32 / 3.3	29 / 3.1
105	120.8	98 / 18.0	97 / 16.7	95 / 15.5	93 / 14.6	92 / 13.7	90 / 12.9	88 / 12.3	87 / 11.7	84 / 11.1	84 / 10.6	81 / 9.7	78 / 9.0	75 / 8.4	72 / 7.8	69 / 7.3	67 / 6.9	64 / 6.5	62 / 6.2	60 / 5.9	57 / 5.6	55 / 5.3	53 / 5.1	51 / 4.9	49 / 4.7	47 / 4.5	43 / 4.1	39 / 3.8	36 / 3.5	33 / 3.3	30 / 3.0
110	143.2	98 / 17.4	97 / 16.2	95 / 15.1	93 / 14.1	92 / 13.3	90 / 12.6	89 / 11.9	87 / 11.3	86 / 10.8	84 / 10.3	81 / 9.5	78 / 8.7	76 / 8.1	73 / 7.6	70 / 7.1	68 / 6.7	65 / 6.3	63 / 6.0	61 / 5.7	58 / 5.4	56 / 5.2	54 / 4.9	52 / 4.7	50 / 4.5	48 / 4.3	44 / 4.0	41 / 3.7	38 / 3.4	34 / 3.2	32 / 3.0
115	169.0	98 / 16.8	97 / 15.6	95 / 14.6	94 / 13.7	92 / 12.9	90 / 12.2	89 / 11.6	87 / 11.0	86 / 10.5	85 / 10.0	82 / 9.2	79 / 8.0	76 / 7.9	74 / 7.4	71 / 6.9	69 / 6.5	66 / 6.2	64 / 5.8	62 / 5.5	59 / 5.3	57 / 5.0	55 / 4.8	53 / 4.6	51 / 4.4	49 / 4.2	46 / 3.9	42 / 3.6	39 / 3.3	36 / 3.1	33 / 2.9

Calculated from Hailwood-Horrobin single hydrate equation using parameters determined by Simpson (1973).

pressure at 230”F is equal to 143.3 kPa; vapor pressure at 212°F is 101.4 kPa. Relative humidity is, therefore, 101 .4/1 43.3 or 70.8 percent. This is true even though the atmosphere is pure water vapor.

Relative humidity is determined in seasoning by use of the wet- and dry-bulb hygrometer (Fig. 2.1). This instrument consists of a stand on which are mounted two similar thermometers. The bulb of one of these thermometers (dry bulb) is exposed in the normal manner and reads the actual temperature. The bulb of the other (wet bulb) is surrounded by a clean, cotton wick which is kept wet by a small reservoir of water into which it extends. When exposed to an air current, evaporation from the wet-bulb wick cools the wet-bulb thermometer, which as a result shows a lower temperature than the dry-bulb thermometer. The drier the air, the greater will be the difference between the readings of the two thermometers, this difference being called the wet-bulb depression. When the air is saturated, there will be no evaporation and the two thermometers will indicate the same temperature. Special tables, such as Table 2.1, are used to determine the relative humidity from the hygrometer readings.

Shrinking and Swelling

Bound water is absorbed on the sides of the cellulose and hemicellulose molecules which make up the wood cell-wall fibrils. During drying below the fsp, this water is removed and the cell-wall components are drawn closer together, resulting in **shrinkage** of the wood.

When wood is exposed to air at a higher relative humidity than is in equilibrium with it, the fibrils absorb water molecules made available to them and move apart. This is the basis for the swelling of wood. The shrinkage ratios of wood are different in the various directions. Also, the shrinkage ratios of knots and abnormal wood are different from those of normal wood. Shrinkage, swelling and these differential dimensional changes are the principal sources of problems in the seasoning, manufacture and use of lumber.

Table 2.3

A. Absolute humidity of saturated air (grains/ft^3)

Temp	“F O	1	2	3	4	5	6	7	8	9
100	20	21	21	22	22	23	24	24	25	26
110	27	27	28	29	30	30	31	32	33	34
120	35	35	36	37	38	39	40	41	42	44
130	45	46	47	48	49	51	52	53	55	56
140	57	59	60	62	63	65	86	68	69	71
150	72	74	76	78	79	61	83	85	87	89
160	91	93	95	97	100	102	104	106	109	111
170	114	116	118	121	124	126	128	131	134	137
180	140	143	146	149	152	155	159	162	165	168
190	172	175	179	182	165	190	193	197	201	205
200	209	213	217	220	225	230	234	238	243	245
210	252	257	262							

B. Absolute humidity of saturated air (grams/m^3)

Temp	“C O	1	2	3	4	5	6	7	8	9
40	51	54	56	60	63	66	69	72	76	79
50	83	87	91	96	100	105	109	114	120	125
60	131	136	142	148	155	162	168	175	183	191
70	198	207	215	224	233	242	252	262	272	283
80	294	305	317	329	341	354	367	381	395	404
90	424	440	455	471	488	505	523	541	560	579
100	598									

Table 2.4. Shrinkage values for some Canadian species

Softwood species	% Shrinkage from Green To oven-dry: Radial	Tangential	Hardwood species	% Shrinkage from Green To Oven-dry: Radial	Tangential
Cedar, eastern white	1.7	3.6	Alder, red	4.2	7.0
Cedar, western red	2.1	4.5	Ash, black	4.3	8.2
Cypress, yellow	3.7	6.0	Ash, green	3.8	5.4
Douglas-fir	4.8	7.4	Basswood	6.7	9.3
Fir, amabilis	4.2	8.9	Birch, white	5.2	7.2
Fir, balsam	2.7	7.5	Birch, western white	6.8	9.3
Hemlock, western	5.4	8.5	Elm, white	4.4	7.8
Larch, western	5.1	8.9	Ironwood	4.8	8.0
Pine, jack	4.0	5.9	Maple, broadleaf	4.1	7.6
Pine, lodgepole	4.7	6.8	Maple, Manitoba	3.9	7.4
Pine, red	3.7	6.3	Oak, bur	4.2	5.4
Pine, western white	3.7	6.8	Poplars:		
Pine, ponderosa	4.6	5.9	trembling aspen	3.6	6.6
Pine, eastern white	2.5	6.3	largetooth aspen	3.2	6.8
Spruce, black	3.8	7.5	balsam poplar	3.9	6.4
Spruce, Engelmann	4.2	8.2	eastern cottonwood	3.1	7.8
Spruce, Sitka	4.6	7.8	black cottonwood	3.6	8.8
Spruce, white	3.2	6.9			
Tamarack	2.8	6.2			

Source: Kennedy, E. I., 1965

Shrinkage Data

Table 2.4 was prepared to show the shrinkage of the principal Canadian woods from the green to ovendry condition. An ovendry condition, or zero mc, can be obtained only by drying small samples in a drying oven and is, therefore, unlikely to occur in practice.

The shrinkage figures shown in the table are average values, obtained on small samples drying with a minimum of stress. Individual boards may shrink less than these averages, this variation depending upon their specific gravity and the angle of their grain. Boards containing mostly or all sapwood have been shown by the Western Forest Products Laboratory to have a somewhat higher average shrinkage than heartwood boards of the same species. (Sapwood, being essentially extractive-free, offers less restraint to shrinkage than does heartwood.) Large sizes usually show less shrinkage owing to surface "set" developed during drying.

Effect of Moisture Content

It should be emphasized that the most important factor affecting shrinkage or swelling of wood is the change in mc below fsp. Shrinkage is found to be directly proportional to the amount of water removed from the cell walls. H is conventionally expressed as a percentage of the green dimension of a piece, since this dimension is stable at all mcs above the fsp. At zero mc, maximum shrinkage is attained. This maximum shrinkage value is listed for most woods in appropriate tables (see Table 2.4). Shrinkage allowances may be approximated using the following equation:

$$S = \frac{30 - M}{30} \times S_{max} = \left(1 - \frac{M}{30}\right) \times S_{max} \qquad (1)$$

where: S is the percentage shrinkage;
M is the mc for which S is to be calculated;
S_{max} is the maximum shrinkage for wood (from tables);
30 is the assumed fsp.

Examples of the application of Equation 1 are given in a later section of this chapter.

In the kiln drying of lumber, the surface of the wood normally dries first, and its mc may be considerably below the fsp while the core remains wet, so that the average mc of the piece is still comparatively high. Under these conditions, shrinkage will begin while the *average* mc of the lumber is well above the fsp.

Table2.5. Basic density of some Canadian species

Softwood species	Oven dry lb/ft^3 green wood	Oven dry kg/m^3 green wood	Hardwood species	Oven dry lb/ft^3 green wood	Oven dry kg/m^3 green wood
Cedar, eastern white*	18.72	300	Alder, red	23.09	370
Cedar, western red'	20.51	329	Ash, black	29.33	470
Cypress, yellow* *	26.21	420	Ash, green	30.58	490
Douglas-fir	28.08	450	Basswood	22.46	360
Fir, alpine'	20.51	329	Birch, white	31.82	510
Fir, amabilis[1]	23.51	377	Birch, western white	31.82	510
Fir, balsam	21.22	340	Elm, white	32.45	520
Hemlock, western'	26.38	423	Ironwood •	40.56	650
Larch, western'	28.06	449	Maple, broadleaf	29.33	470
Pine, jack	26.21	420	Maple, Manitoba	26.21	420
Pine, lodgepole[1]	25.50	408	Oak, bur	37.44	600
Pine, red	24.34	390	Poplars:		
Pine, western white	22.46	360	aspen, trembling	23.09	370
Pine, ponderosa[1]•• •	24.19	387	aspen, largetooth*	24.34	390
Pine, eastern white*	22.46	360	balsam poplar	23.09	370
Spruce, black	25.58	410	eastern cottonwood	21.84	350
Spruce, Engelmann[1]	22.14	355	black cottonwood	18.72	300
Spruce, Sitka	21.84	350			
Spruce, white'	22.45	360			
Tamarack	29.95	480			

• Occurs in southeastern Manitoba

•• Commonly known as yellow cedar in B.C.

* •• Commonly known as yellow pine in B.C.

Sources: 'Smith, W. J. 1970. Remainder of species: Kennedy, E. 1, 1965.

Effect of Wood Density

When a metal tube is heated, because it is made of a homogeneous material, it expands proportionally in all directions; not only does the shell become larger, but the inside diameter and the wall thickness expand in direct proportion with it. A thick-shelled tube expands by exactly the same ratio as a thin-shelled tube under the same temperature rise. In contrast, a wood cell is not a homogeneous structure, since the cellulose fibrils are aligned differently in the various layers. As a result, when the cell wall shrinks or swells due to changes of mc, the cell lumen or cavity hardly changes dimension, and all the shrinkage or swelling is experienced in the outer envelope. In consequence, when comparing the shrinking and swelling rate of thick-walled and thin-walled cells, the thick-walled cells will contract or expand more. But, since thick-walled cells result in dense (heavy) wood, the denser the wood, the greater the shrinkage that can be expected for a given mc loss. Thus, hardwoods as a group shrink more than softwoods, Douglas-fir shrinks more than western red cedar, maple shrinks more than poplar. Where there are variations in wood density in any species, the lighter pieces shrink less than the heavier ones at the same mc. There is even a variation in shrinkage between earlywood and latewood within an annual ring, owing to density differences. At the same time, there are woods of equivalent densities whose shrinkages differ due to factors other than density.

Data for basic density of common Canadian species are shown in Table 2.5.

Effect of Grain Direction

Wood is not a homogeneous material with equal shrinkage in all directions. Its anatomical structure results in shrinkage behavior which varies between the different structural axes of the wood. Since the bound water, responsible for shrinking and swelling, is attached to sites on the sides of the cellulose chains, and since most of the cellulose chains are inclined at 10° to 15° from the vertical axis, any dimensional change due to loss of moisture will be primarily across the grain, with only a very small component in the longitudinal direction. In normal wood, shrinkage of only 0.1 to 0.2 percent occurs in the longitudinal direction and, for practical purposes, can be ignored.

It is found in practice that shrinkage in the tangential plane (aligned with the annual rings) is about twice that in the radial plane (on a radius) (Table 2.4). Two explanations are proposed. First, because the ray cells have their longest dimensions in the radial direction, they swell or shrink much less in this plane than do vertically aligned cells, and have a restraining effect on radial shrinkage of the wood. Tangential shrinkage is not restrained, however, and therefore it is considerably greater than radial shrinkage. The second reason relates to the variation of swelling and shrinkage ratios with wood density. Due to the density effect, latewood shrinks more than earlywood, a fact that is often observed visually in fast-grown wood with wide annual rings. It is reasoned that, because of the stiffer, stronger character of the latewood cells, the weaker earlywood cells are forced to shrink in the tangential direction at about the same rate as the latewood cells. In the radial direction, however, the total shrinkage is the sum of the two shrinkages, a much lower value.

Since the shrinkage in width of vertical-grain lumber is much less than that of flat-grain lumber, it may be dried with less danger of checking and cupping.

Effect of Extractives

The presence of extractive materials in the ceil walls of some species, such as the eastern white and western red cedars, will result in a lower than average fsp and lower than expected shrinkage properties. This is because the extractives "bulk" the cell walls, restricting the amount they shrink when water is removed.

Shrinkage of Specialized Wood Types

Knots

Knots have a much greater density than the surrounding wood and, as a result, their shrinkage ratio is much greater. In addition, since a radial dimension of a knot is parallel to the longitudinal axis of a tree, the difference in shrinkage ratios is particularly large. The result is a high shrinkage stress at the periphery of knots. In a loose or encased knot, separation occurs and the knot may fall out. In intergrown knots, however, separation cannot readily occur and the knot will check under excessive drying stresses.

Compression wood

Because of its high fibril angle and because shrinkage is perpendicular to the alignment of the cellulose molecules, compression wood has excessive longitudinal shrinkage, in extreme cases as high as 5.5 percent. Normally, compression wood is not so extensive in a tree that lumber of pure compression wood can be cut. Rather, such lumber will contain compression wood on or near one or more surfaces. The unbalanced shrinkage that occurs in drying may result in the lumber being bent or twisted to such an extent that it has no commercial value. Particularly where only a small proportion of a piece of tumber is compression wood, these stresses may be so high that the compression wood portion will break in tension and will be seen to be broken at intervals along its length.

Tension wood

Even though the function of tension wood in hardwoods is the opposite to that of compression wood of softwoods, it also has the characteristic of high longitudinal shrinkage, although to a lesser degree than compression wood. Where excessive shrinkage of tension wood occurs, it is associated with collapse in many kinds of wood. Information on the effect of tension wood on mechanical properties is incomplete, its most serious effects being those on machining properties and on shrinkage.

Juvenile wood

Since juvenile or core wood is formed during the first several years of the life of a stem, in fast-growing trees a substantial part of the center of the stem may be juvenile wood. Such wood is characterized by a large fibril angle and excessive longitudinal shrinkage. As a result, lumber from such trees is prone to excessive bow, crook and twist during the drying process. However, this is more characteristic of fast-growing southern pines of the United States than of slower growing Canadian woods.

Curly grain

Wood with spiral, diagonal, or curly grain may also show excessive longitudinal shrinkage, owing to a transverse-shrinkage component along the length of the piece. Thus, if all the fibers ran through a board at an angle of 45°, it would tend to shrink in the same proportion lengthwise as edgewise.

Calculation of Shrinkage

As noted in Equation 1, to calculate the expected percentage shrinkage of a given kind of lumber at a given mc, subtract this mc from the fsp (assumed to be

30 percent), divide by 30, and multiply by the total shrinkage given in Table 2.4.

Example 1:

A wide, flat-grained board of western hemlock is dried from the green condition to 12 percent mc. What percent shrinkage in width should be expected? Assume fsp is 30 percent.

Tangential shrinkage of western hemlock (from Table 2.4) to O% mc is 8.5%. Therefore the percentage shrinkage to 12% mc is expected to be

$$\frac{30-12}{30} \times 8.5\% = 5,1\%$$

Example 2:

If a normal 6-in wide, flat-grain board of Douglas-fir is dried from the green condition to 15% mc, its width is reduced from 5.82 in (148 mm) to 5.61 in (142 mm). The percentage shrinkage can be calculated in the following manner:

$$\frac{5.82 - 5.61}{5.82} \times 100\%$$

$$= \frac{0.21}{5.82} \times 100\%$$

$$= 0.036 \times 100\% = 3.6\%$$

This corresponds closely with the expected tangential shrinkage of a Douglas-fir board dried from the green condition to a mc of 15%.

$$\left(\frac{30-15}{30} \times 7.4\% = 3.7\%\right) \text{ (Table 2.4}$$

Example 3:

Radial (across the face) shrinkage of vertical-grain western hemlock is expected to be **4.3%** from the green condition to a mc of 6%

$$\text{(i.e., } \frac{30-6}{30} \times 5.4\% = 4.3\%\text{).}$$

The width at 6% mc of a vertical-grain board which is **5¾-in** (146 mm) wide in the green condition can be calculated as follows:

$$\text{dimensional change} = \frac{5.75 \times 4.3}{100} = 0.25 \text{ in}$$

$$\text{or } \frac{146 \times 4.3}{100} = 6.28 \text{ mm}$$

width at **6%** mc = 5.75 — 0.25 = 5.50 in

or 146 — 6.28 = 139.72 or 140 mm

Example 4:

The approximate change in dimension which would occur if the mc of the same piece were increased to **15% may be** estimated as **follows:**

$$\frac{15-6}{30} \times \frac{5.4}{100} \times 5.50 = 0.089 \text{ in (2.3 mm)}$$

where: 15 — 6 = change in mc;
30 = fsp;
5.4 = **% shrinkage** to 0°/0 mc;
5.50 = dimension at 6% mc.

More correctly, the proper proportion of the total shrinkage should be applied to the original green dimension, so that:

$$\frac{15-6}{30} \times \frac{5.4}{100} \times 5.75 = 0.093 \text{ in (2.4 mm)}$$

The difference between the two calculations is small and, in most cases, where the original green dimension is not known, the approximate calculation is of sufficient accuracy for practical purposes.

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CHAPTER 3
FACTORS AFFECTING DRYING OF LUMBER

The various forms of water in wood — water vapor, bound water and free water — have been described. In the drying of lumber, these forms of water move to the surface by quite different mechanisms and by different flow paths. Depending on the conditions which exist in the wood, water may be converted from one form to another during this migration. For example, green lumber at ordinary temperatures contains about 30 percent of its dry weight as bound water, a negligible quantity of water vapor, and the remainder of the moisture as free water, For a wood like spruce, with an initial moisture content (me) of about 60 percent, roughly half the moisture will be bound water and half free water. For alpine fir, with 90' percent initial mc, there will be twice as much free water as bound water. In drying, the free water of the surface layers is the first to be removed. As a result, the moisture in the surface layers soon consists almost entirely of bound water, with a very small quantity of water vapor. Moisture moving from the core is converted, in turn, to bound water and then to water vapor, in which form it escapes.

Vapor Diffusion

Water vapor moves by diffusion. In this process, molecules move in a random manner in all directions. If a high concentration of molecules occurs in one area and a low concentration in another, more molecules will leave the high-concentration area than will enter it and its mc will be reduced. Similarly, if molecules are being captured, condensed or removed from another area, more molecules will diffuse in than out, and there will be a net movement in that direction. The rate of vapor diffusion is thus proportional to the difference in concentration of diffusing molecules or, more precisely, is proportional to the difference in vapor pressure. The vapor pressure within moist wood increases with increasing mc up to the fiber saturation point (fsp); thus, while drying is taking place a **vapor pressure gradient** will exist from the zone within the wood which is at or above fsp to the wood surface. There will be no significant vapor-pressure gradient within the zone that is above the fsp. This means that, within the zone above the fsp, no significant vapor movement is taking place.

Since there must be a continuous flow path available to permit vapor to diffuse from one zone to another, pure vapor diffusion is only effective in permeable wood.

Permeability results from the presence of connecting passages between wood cells. H is not related to hardness or strength, but only to the openness of these connecting passages. Liquids and gases move through permeable wood at rates which permit rapid drying. In impermeable wood, most or all passages are blocked, so that movement of liquids and gases is obstructed. Vapor diffusion must then operate in conjunction with bound-water diffusion. Examples of permeable woods are ponderosa pine and many of the hardwoods of western Canada — alder, maple and birch. The sapwood of most species is permeable, but the heartwood of most western softwoods is much less so. Heartwood of western red cedar and alpine fir is impermeable, that of lodgepole pine is semipermeable, while that of white spruce and western hemlock may be considered semi-permeable to permeable.

Bound-Water Diffusion

The movement of bound water through the cell walls is also a diffusion process. In this process, the molecules are believed to jump from one hydroscopic site to the next. As in vapor diffusion, there are fewer molecules leaving the drier sites and more leaving the wetter sites. Consequently, there is a general migration from the wet to the dry parts of the wood. Since the wood surface is usually driest because of evaporation, there is a migration from core to surface and a **moisture gradient** exists.

The force responsible for bound-water diffusion is the same as that for vapor diffusion, the vapor-pressure gradient. Bound-water diffusion is a much slower process than vapor diffusion, even though driven by the same force.

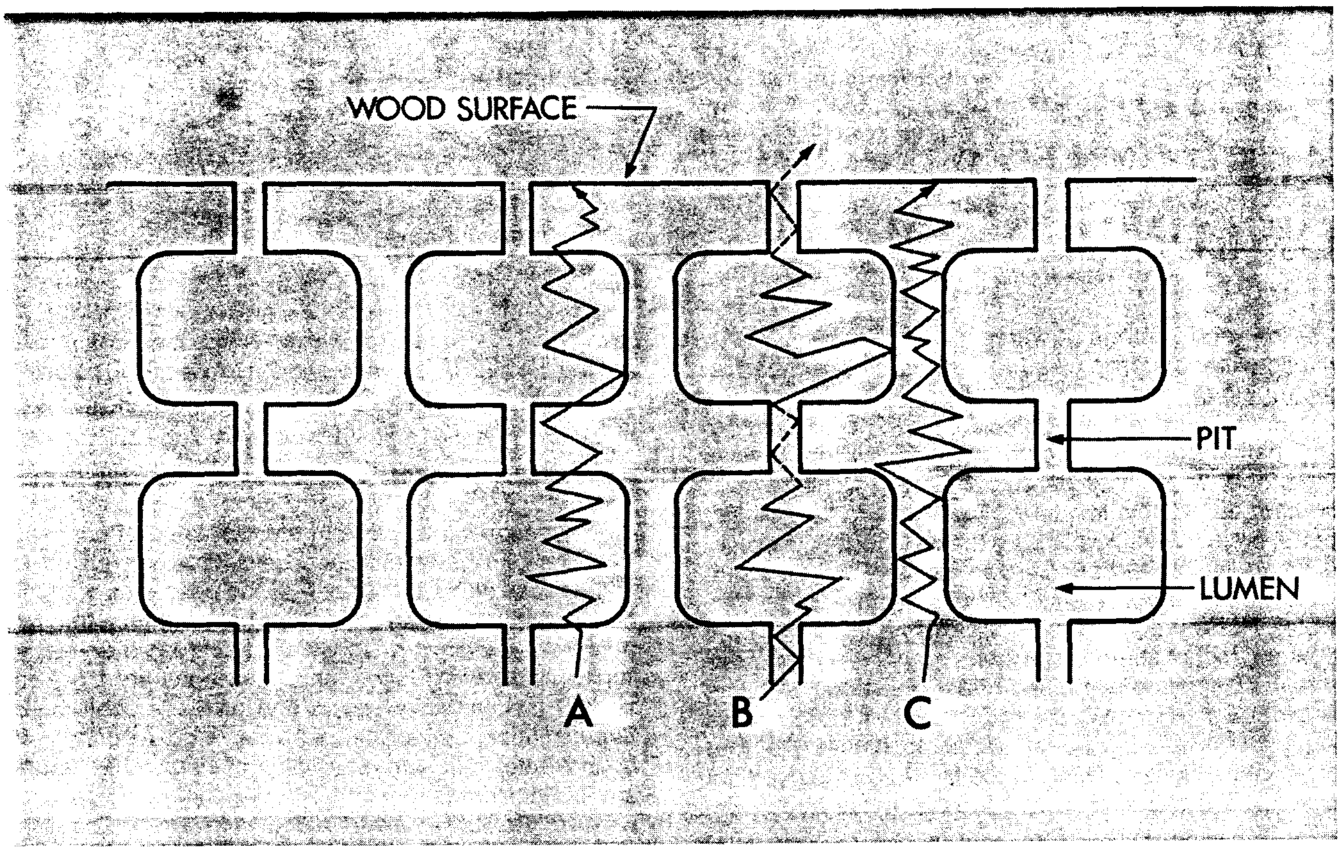

Fig. 3.1 Diffusion paths in wood: A. combined vapor and bound-water diffusion; B. vapor diffusion; C. bound-water diffusion

Combined Bound-Water and Vapor Diffusion

During drying, neither bound-water nor vapor diffusion acts alone. In moving from the core to the surface of the wood, most moisture passes in sequence through the cell walls by bound-water diffusion, evaporates into the cell lumen, passes across it by vapor diffusion, is absorbed by the next cell wall, passes through by bound-water diffusion, and soon until the wood surface is reached.

When drying takes place from the ends of lumber, the migrating moisture must pass through fewer cell walls, and the greater part of its migration is through the cell cavities by the much faster process of vapor diffusion. Consequently, drying through the ends is much faster than drying through the sides of a piece. Since dense wood contains a much higher ratio of cell wall to cell lumen than low density (light) wood, and since bound-water movement through the cell walls is slower, the rate of drying below the fsp in dense woods is much slower than in light woods. The greater resistance to drying of dense wood can result in a much greater moisture gradient being formed and much greater shrinkage stresses being developed, so that the possibility of degrade in dense hardwoods is much more than in most softwoods.

The various paths of diffusion of both bound water and water vapor are as shown in Fig. 3.1.

Moisture moves through a cell lumen as a vapor, condenses, and moves through the impeding cell wall to the next lumen as bound water. The process is then repeated as the moisture moves progressively to the outside of a board (type A).

Moisture moves through cell lumens and pit chambers as a vapor, through pit membranes as bound water, or through pit-membrane openings (pores) as a vapor (type B).

Moisture moves continuously across cell walls from cell to cell as bound water (type C).

If specific gravity of wood is 0.40 (a common value for Canadian softwoods), about 85 percent of diffusion will be the first type, 10 percent the second type, and 5 percent the last type. Thus, in softwoods, bordered pits are relatively unimportant in the movement of water below the fsp.

Free-Water Movement

Free water in wood moves in response to capillary forces created by the evaporation of water from the surface cells. These forces exert a pull on the free water in zones below the surface. The most important factor affecting capillary flow is the permeability of the wood. Capillarity requires the least energy and is the most rapid form of the various flow mechanisms. This is the major reason why moisture-laden permeable sapwood normally dries at a more rapid rate than heartwood.

Capillary flow is at least 50 times faster in the direction of the grain than *across* it, because bordered pits or other obstructions (which are bottlenecks, even in permeable woods) are encountered much less frequently.

Free-water movement can only occur where free water is present; that is, above the fsp. But it also requires the presence of enough moisture to provide a continuity of water reaching from the surface or evaporating zone to the zones below. Consequently it is faster at higher mc.

A further factor affecting capillary movement is the wood temperature. At higher wood temperatures, the viscosity of water is reduced, so that under a given capillary pull the water will flow more rapidly. A rise of wood temperature from 70"F to 21 O°F reduces viscosity by a factor of three.

Mass Flow

Another drying process is **mass flow** during high-temperature drying. When lumber at a mc greater than the fsp is heated above the boiling point of water, some of the water is converted to steam at a pressure above atmospheric. If the lumber is of a permeable wood, the steam escapes due to the pressure differential and the lumber dries. If the lumber is of an impermeable wood, drying can take place only by diffusion, although at this temperature it is a fairly rapid process. Because steam generated in wood heated above the boiling point may have enough pressure to split the wood, the use of high temperatures to dry an impermeable wood will usually result in severe degrade and should, therefore, be avoided.

Physical Elements of Drying

Heat and Temperature

The main reason for using heat in drying is to provide the energy required to evaporate the moisture present in the wood, 1000 Btu or more being required to evaporate each pound [2.25 MJ (megajoules) per kg] of water present. An additional reason, however, is to raise the temperature of the lumber, since the movement of moisture, either by capillary flow or diffusion, is more rapid at high temperatures. To produce the same rate of diffusion at 120° as at 160° (or say, 50°C and 70°C), a much lower humidity will be required and a steeper moisture gradient will result. This, in turn, increases the possibility of degrade in the lumber. increased temperature, therefore, increases the rate of moisture movement, so that a high humidity may be maintained without unduly slowing the rate of drying.

Wet wood is more plastic at high temperatures and, because of this increased plasticity, it yields more readily to any stress imposed. However, whether wet or dry, wood is weaker at higher temperatures. Wood may be more prone to checking and splitting at higher temperatures, although this has not been determined with certainty.

When the surface of lumber contains free water, the temperature of the wood is the same as that of the wet bulb and will stay at that temperature as long as there is sufficient moisture movement to keep the surface moist. When the free water at the surface is evaporated, the mc of the surface approaches the **equilibrium moisture content** (emc); concurrently, the temperature of the wood surface increases and approaches the dry-bulb temperature.

Humidity

The emc of lumber is determined largely by the relative humidity in a kiln. Therefore, to avoid excessive surface shrinkage and consequent drying defects, the relative humidity should be kept at a high value. On the other hand, high relative humidities reduce the difference in vapor pressure between the dry- and wet-bulb temperatures and, consequently, reduce the rate of drying. A practical choice of relative humidities is a compromise between a high value for a low degrade loss and a low value for rapid drying. As the kiln humidity increases due to evaporation from the lumber, provision must be made to remove the excess moisture. This is usually, but not always, done by ventilation — discharging part of the kiln atmosphere.

Circulation

To perform effective drying, a uniform movement of air is necessary to carry heat to lumber and to carry evaporated moisture away. This circulating air must pass over the surface of the boards being dried. Any air that misses a pile of lumber accomplishes no drying.

Since the air is cooled and becomes wetter as it picks up moisture, its ability to dry the lumber becomes progressively less as it passes through a load. By increasing the air velocity, the lumber near the exit side of a load receives hotter, drier air than it otherwise would. Not only will this result in faster drying of the lumber at the exit side, increasing the average rate of drying and reducing the drying time, but it will also result in higher surface transfer rates and more uniform drying of a load. These advantages must be measured against the increased cost of power to attain the greater air velocities.

At the beginning of drying, a considerable amount of water is being evaporated and, as a result, the drop in air temperature across a load is very high, and the humidity of the air increases almost to the saturation point. Under these conditions, for rapid drying the air velocity should be high. On the other hand, when the surface of the lumber has been dried below the fsp, the rate of evaporation is reduced. Under these conditions, a much reduced air velocity is acceptable. For these reasons use of variable-speed fans could be advantageous.

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CHAPTER 4

DRYING DEFECTS: THEIR CAUSE AND PREVENTION

Drying procedures may result in defects that reduce the grade and value of the lumber being dried. Such losses are referred to as drying degrade. Some defects become obvious as they occur; the effect of others may not be realized until a later stage of manufacture is undertaken, but can be related directly to the seasoning procedure used. Some defects which appear during drying are, in fact, the result of other processes. They may be due to faulty procedures in earlier stages of manufacture or to the intrinsic properties of the wood. A kiln operator must select his drying procedures so as to maximize kiln throughput and, at the same time, minimize lumber degrade losses.

Basic to an understanding of the potential seriousness and control of drying defects is an appreciation of how and why they develop. They may be grouped into four broad categories caused by:

- Unequal shrinkage of wood in different planes, of knots, and of abnormal wood;
- Capillary effects;
- Fungal attack;
- Reactions of extraneous chemical components of wood and of other chemicals.

Defects Due to Unequal Shrinkage

Shrinkage-based defects can occur when the moisture content (me) of the surface zone is below the fiber saturation point (fsp) while the mc of the interior zone is well above it.

The shrinkage of a piece of wood is normally closely related to the average mc. Where average mc of the piece is above the fsp and surface mc is below it, shrinkage of the piece occurs because the surface zone has already begun to shrink. In impermeable wood, where surface evaporation is not easily replenished by flow of moisture from the core, the surface mc will be close to the equilibrium moisture content (emc). Consequently, if impermeable wood is exposed to large wet-bulb depressions while it is green, large shrinkage stresses will be set up in the wood surface. In permeable wood, the drying stresses will be less than in impermeable woods and the possibility of checking will be considerably less.

As the average mc of the lumber decreases, and the wood shrinks, the mc can be decreased without increasing the stresses. Thus, the most efficient type of drying occurs when the dry-bulb and wet-bulb temperatures are gradually changing in order to maintain a constantly decreasing emc. Abrupt temperature and relative humidity changes cause abrupt changes in surface mc and abrupt increases in moisture gradient. Where the resulting stresses exceed the strength of the wood, checking and other shrinkage-induced defects occur.

Casehardening

In the early stages of drying, the surface layers of the board quickly dry below the fsp and attain equilibrium with the surrounding air. As a consequence, these layers tend to shrink, but shrinkage is restrained by the nonshrinking core which is still above the fsp. The surface fibers are, therefore, stressed in tension whereas the core is subjected to compressive stresses. As wood dries under these conditions, it develops a permanent surface stretch, which is called tension "set". Similarly, a compression set may occur in the core of a piece if the compressive stresses are sufficiently great.

Later in the drying process, as the core dries below the fsp, it tends to shrink, relieving some of the tensile stress in the surface layers. Further core shrinkage is resisted by the surface layers (or shell) which, as a result of tension set development, have been stretched. The stresses then reverse, the core going into tension and the shell into compression. Lumber with this pattern of stress distribution is referred to as **casehardened.**

The presence of casehardening stresses is not necessarily a disadvantage in lumber. For example, in the normal production of kiln-dried softwood dimension lumber for construction, little consideration is given to either the detection or relief of stresses. Serious problems will arise, however, if casehardened lumber is to be resawn or surfaced in a manner which removes substantially more material from one wide surface than the other. These operations unbalance the stresses and

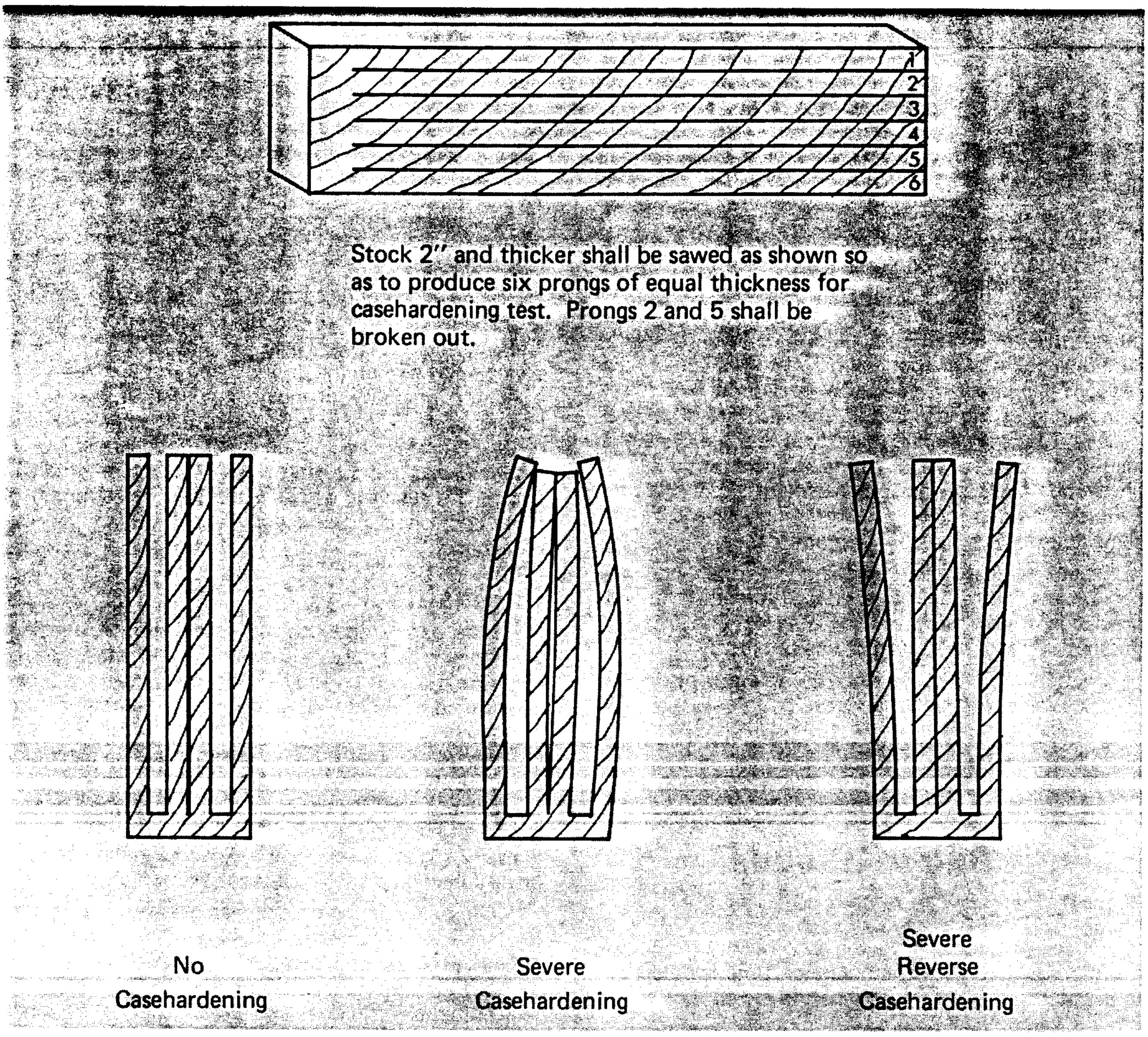

Fig. 4.1 Method of cutting and evaluating stress sections

may result in warp (usually cupping), particularly in factory lumber and in hardwoods. Therefore, where resawing, shaping or other working of lumber may be expected, as in furniture manufacture, these stresses must be removed.

Detection of casehardening stresses

The usual method of testing kiln-dried lumber for the presence of casehardening stresses is the fork test. In this test, a number of stress sections are cut from kiln-sample boards selected as being representative. These stress sections should be ¾ to 1 inch long in the grain direction and cut at least 18 inches from the end of a board. Each section is then carefully slotted on a fine saw (Fig. 4.1), the number of cuts depending upon the thickness of the lumber. For nominal 2-inch lumber or thicker, prongs two and five are then broken out. For stock less than nominal 2-inch thickness, three prongs of equal thickness are sawn and the center prong broken out.

Behavior of these prongs after sawing indicates the direction of stresses in a board. These stresses can be due either to(1) a nonuniform mc distribution, i.e. a iarge moisture differential between shell and core, or (2) an unequal springback potential as a result of differential stresses arising from set development. It is the latter type of shrinkage differential which is the cause of casehardening. Where set is present, the outer prongs will turn out, indicating tension in the outer iayers; or they will turn inward and pinch, indicating compression stress in the outer iayers. The degree to which the prongs bend inward or outward indicates the intensity of the casehardening stresses.

The prongs or stress sections cut from lumber free of appreciable casehardening stresses will remain straight when the section is first cut. When these sections are placed in a dry room, it is likely that the prongs will curve as they dry out, In making casehardening tests, therefore, the condition of the prongs should be observed immediately after sawing, when it is desired to know the condition of lumber in the kiln at the time of test. If information is required as to the behavior of this lumber when it is used in a dry room, the mc of the section should be allowed to come into equilibrium with room conditions for 24 hours before it is slotted.

Prevention of casehardening

Casehardening may be prevented by maintaining a . sufficiently high relative humidity to prevent the surface layers from drying to too low a value, especially in the early stages of drying. As lumber dries, it is possibie to progressively increase the temperature and reduce the reiative humidity to permit reasonably rapid drying with minimum casehardening stresses.

Thick lumber has more tendency to deveiop casehardening stresses than thin lumber. If the casehardened condition is undesirable, a stress relief treatment must be applied at the end of drying. The objective of this conditioning is to soften (slightly plasticize) the surface layers and to permit them to adjust.to a stress-free condition. The time when this condition is reached can oniy be determined by cutting more stress sections.

if the steaming is applied for too long a period, the removal of the casehardened set condition may be carried too far, and result in the development of reverse casehardening. In this condition, the shell develops a tension set and the core a compression set and, as a result, prongs wiil turn outward. Again, a period of time must be allowed for the mc to become uniform in the stress section prior to judging the finai stress condition.

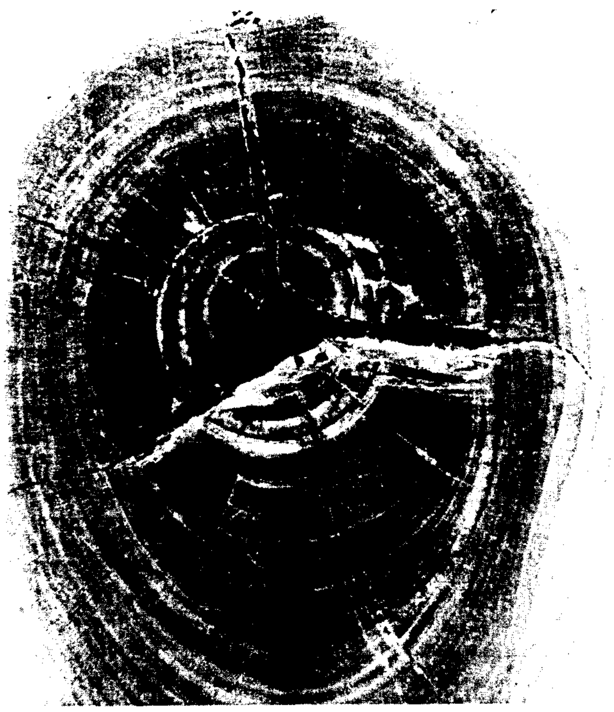

Fig. 4.2 a. Loose knot; b. tight knot which has checked due to"excess&e shrinkage

The prong movement of these various stress conditions is illustrated in Fig. 4.1.

Surface and internal checking

Studies of drying degrade made in British Columbia have shown that the most serious loss results from end and surface checking or splitting of lumber, and is greater in flat-grain than in vertical-grain lumber. Checking is due to three factors: the difference in shrinkage between surface and interior; between radial and tangential directions; and between normal and reaction wood. If surface checking occurs, it is usually in the early stages of drying in a kiln atmosphere maintained at too low an emc. Because the wood surface will approach this mc, it will also tend to shrink. If the shrinkage stresses exceed the strength of the wood across the grain, its surface will check along the wood rays. These checks may continue to penetrate as the dry zone extends to the wood interior. During stress reversal, when the wood core dries below the fsp, the surface checks may close, but the internal checks will remain. The resultant internal checking is commonly called **honeycomb".**

Under other conditions, lumber having a high mc may be incompletely dried leaving the core wet. If this lumber is later cut and the core exposed to low relative humidities, it may develop internal checking.

Although shrinkage differences between shell and core cannot be entirely eliminated, they can be partially controlled so that stresses sufficiently great to cause checking will not occur. Where shrinkage-based defects are expected, high humidities should be maintained in the early stages of drying. This will both maintain a relatively high surface mc, reducing the tendency to shrink, and maintain a high wood plasticity, permitting accommodation of the wood to the stresses. As the average mc of lumber is reduced, and its overall dimensions shrink accordingly, the emc can be progressively reduced without increasing the probability of checking.

End checking

Because of a greater rate of moisture diffusion along the grain, if the ends of boards in a kiln load are exposed to excessive air circulation by improper piling, they will dry out much more rapidly than the remainder of the load. As a result, shrinkage stresses tend to concentrate in the few inches of drier wood at the board ends. If these stresses become greater than the strength of boards, the boards will check, and the checks will extend for several inches as drying progresses. Because splitting will continue from existing checks or cracks more readily than it will originate from a smooth surface, previously checked logs or lumber are particularly subject to further checking. Checking of logs can be avoided by sprinkling of log-storage piles.

Prevention of end checking requires removal of its causes. The high rate of end drying can be slowed by using moisture-resistant coatings or sealants on the ends of lumber. This method is especially valuable for heavy stock, such as hardwoods, crossarms and small timbers. A method more applicable to softwood dimension lumber is to ensure that the stickers are placed flush with the ends of boards. This reduces the exposure to circulating air and thus reduces drying rate. Where lumber of mixed lengths is being dried, the uneven ends are particularly vulnerable. Excessive air circulation can be reduced by mixing not more than two lengths in any load, or by box piling if more than two lengths must be mixed.

Loosened and Checked Knots

Loosened or checked knots in kiln-dried lumber result from the different rates of drying and shrinkage between knots and the surrounding wood. Shrinkage stresses separate encased knots from surrounding wood so they may loosen or fall out. With intergrown knots, separation is impossible and the stresses result in checking of the knots, When lumber of resinous species, such as Douglas-fir, western larch, and the pines, is dried at low temperatures, the resin usually found surrounding an encased knot will prevent the knot from falling out; but at higher temperatures the resin dries and becomes brittle, so that it no longer fixes the knot in place. Knot loosening can, therefore, be reduced by drying at lower temperatures. Shrinkage of knots increases with lower mc (Fig. 4.2). Higher emcs during drying will minimize this cause of knot defects.

Degrade from loosened knots in softwood lumber is most apparent during machining, after seasoning, because the impact of the planer knives may jar out or break any knots loosened during seasoning. The more knives there are in the planer head, the less degrade there will be from loosened or chipped knots, other factors being equal. Because of the greater thickness of wood surrounding knots, there is much less degrade from loose knots in 2-inch than in 1 -inch lumber.

Warping

Causes

Warping may occur because of different shrinkage in drying caused by growth-ring orientation, or the presence of cross grain, spiral grain, reaction wood or juvenile wood.

• The term "honeycomb" has also been uaed incorrectly to describe internal collspse, which reaults from a different cause.

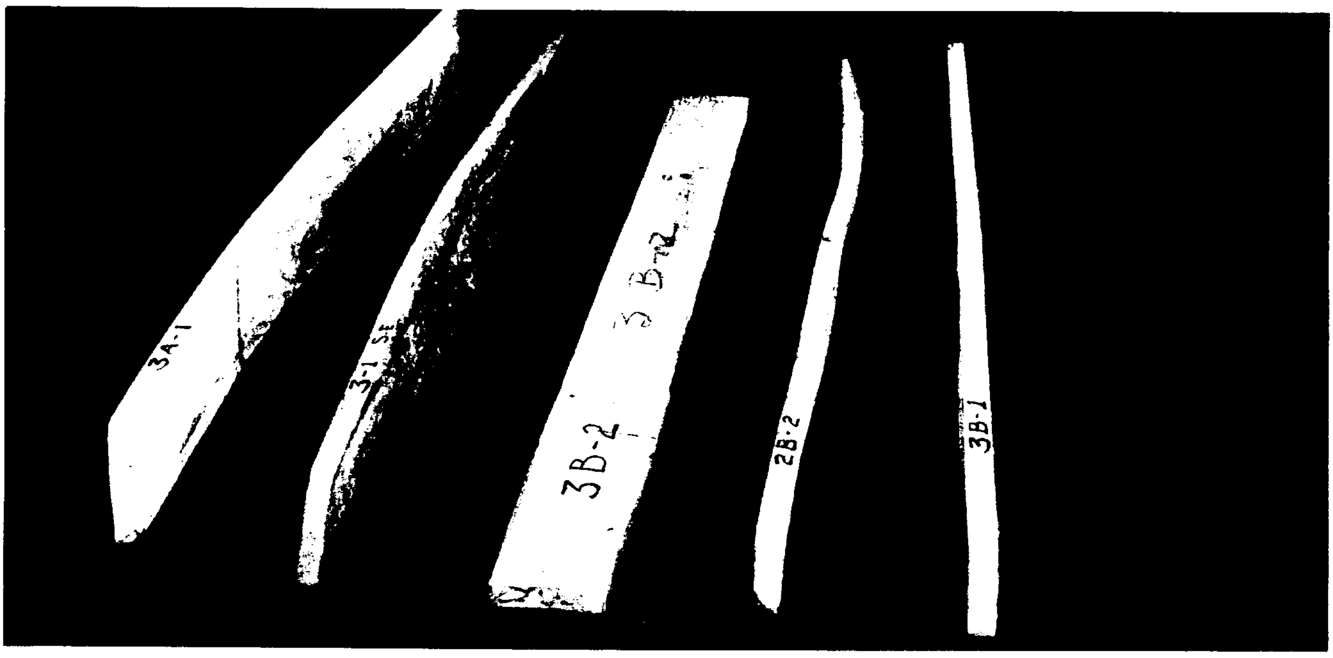

Fig. 4.3 Shrinkage defects in lumber, left to right: bow, combined bow and cup, unwarped, combined crook and kink, twist

Warping occurs as one or more of four forms of distortion: **bow,** which is a lengthwise curvature of the wide surface of a board; **crook, which** is lengthwise curvature of the narrow edge of a board; **twist,** which is the curving of the edges of a board, so that one of the four corners is no longer in the,plane of the other three; and **cup, which** is a curving across the face of a board. **Kinks may develop from localized grain distortion. Each of these is illustrated in Figure 4.3.**

Of these, cupping is most common since it results from the inherent difference between radial and tangential shrinkage. The problem is accentuated on flat-sawn lumber, except from very large trees, since the two wide faces will have different transverse shrinkage components due to growth-ring configuration. The outer face has a greater shrinkage potential than that nearer the pith, so that when the board shrinks the outer face tends to become concave or to cup.

Checks or splits often develop during the surfacing of cupped lumber, when the pressure of the planer feed rolls flattens the boards. The lower the mc of the wood, the stiffer and more cupped it will be and the more likely to split when flattened.

The other forms of warp — bow, crook, and twist — are caused by fibers not being aligned parallel to the edges of the piece. Where lumber contains compression wood or juvenile wood, the fibrils within the cell walls are canted at a steep angle to the grain, introducing an abnormal cross-grain shrinkage force. Tension wood also exhibits abnormal shrinkage forces.

Prevention

In spite of the potential for warping during drying, this form of degrade can be controlled. The first operation in which it can be controlled is in sawing: by avoiding grain deviations from the normal, and by "boxing" the heart so that the pith does not fall on one edge or face. Because variation of sawing thickness permits lumber to twist during drying, this type of warp can be avoided by cutting to uniform thickness. In extreme cases, it may be necessary to plane ("blank") the lumber to uniform thickness before drying.

A very effective way to reduce warp is to stack lumber so that it will be held flat during drying. On the other hand, improper piling can cause warp in lumber having no outstanding tendency to warp. Poor practices include not placing stickers in vertical alignment, or placing them too far apart, or building loads with overhanging board ends.

The choice of a proper kiln schedule can also reduce warp. The essential feature of such a schedule is the use of gradually decreasing humidities. High initial depressions and overdrying should both be avoided.

Cupping due to the resawing of casehardened lumber may be prevented by the use of equalizing and conditioning treatments prior to removal from the kiln.

Raised grain

The corrugated appearance of the surface of some softwood lumber, known as **raised grain,** is caused by the dense latewood projecting above the level of the soft earlywood. in dressed, flat-grain lumber, corrugation of the surface is often due to the planer knives crushing the hard latewood into the soft earlywood. Subsequently, due to mechanical springback or moisture absorption, the latewood rises above the earlywood cells, causing the corrugated effect. This effect is aggravated by dull knives and other machine conditions, such as knife bevel, speed of butterhead, pressure of feed rolls, and rate of feed. Absence of knife clearance compresses the wood, since it permits the heels of the knife to foul the cut surface.

Quarter-sawn or vertical-grain lumber, when dressed green or at high mc, will show a corrugated appearance after drying to a lower mc. Because of its greater shrinkage, latewood bands will shrink below the general level of the board surface during drying. On the other hand, if vertical-grain lumber is dressed dry then allowed to absorb moisture, the latewood bands will project above the earlywood, again resulting in a corrugated surface.

Experiments indicate that minimum corrugation occurs in lumber in which no change in mc occurs after machining, and that maximum corrugation occurs in lumber dressed at a low mc and subsequently placed in storage where it absorbs moisture. Such raising of grain is apparently a gradual process. Lumber that was smooth when graded immediately after machining will often show raising grain when reexamined after several weeks of storage. The occurrence of raised grain can be minimized by proper machine work and by avoiding, as far as is possible, any subsequent change in mc of the lumber during storage,

Fuzzy surface

The fuzzing up of the fibers of lumber during machining is caused by too high mc in the lumber. It is claimed that fuzzing can be reduced by feeding the boards through the planer so that the knives cut with the grain instead of against it. Fuzzy surface is also characteristic of hardwoods containing tension wood.

Loosened grain

The defect known as **loosened grain most frequently** occurs on softwood lumber having very dense latewood, in which the shrinkage of the latewood in one annual ring is much greater than that of the earlywood in the adjacent ring. This difference in shrinkage may cause a plane of shear to develop between the two rings. The consequent separation of the annual rings will cause slivers to occur near the surface which, when pulled, will often tear along the length of the board.

The occurrence of loosened grain is aggravated by the use of too low a relative humidity during the kiln-drying process. This does not mean that it will always cause loosened grain, but rather that certain classes of timber are prone to develop this defect under faulty drying conditions. In species prone to this defect, the pounding of the wood by improperly adjusted planer knives also can cause separation of the grain at the annual rings, particularly in wood in which there is a considerable difference between the density of earlywood and latewood. Excessive pressure on the feed rolls may also be responsible for this defect in such species.

Defects Due to Capillary Effects

Collapse

Collapse requires two conditions: a large number of wood cells must be completely filled with water, leaving no room for air, and the wood must be impermeable; that is, the pores connecting the cells must be blocked or almost blocked. Normally, as wood dries and the moisture moves out, the air within cells expands to fill the cavities. Where the wood is impermeable and is completely filled with water, there is no air to expand. Air entry by diffusion is slow and, if the water passes out of the saturated cells faster than the air can enter, the cell walls may be drawn together by the cohesive or capillary force of water pulling on the wet cell walls. It is this drawing together of the cell walls which is responsible for collapse of wood.

Where the cell walls are stronger than the forces tending to pull them in, the wood will not collapse. But, since saturated wood becomes plastic when heated, its rigidity is thereby reduced. As a result, collapse is more likely to occur at the high temperatures used in kiln drying.

The occurrence of collapse in western red cedar is largely influenced by the kind of timber from which the lumber or shingles are cut. Cedar wood from certain high-rainfall areas, particularly from poorly drained sites, is reported to be very subject to collapse (Fig. 4.4), while that from other areas rarely collapses, even when severe drying conditions are used. In collapse-prone

Fig. 4.4 Severe collapse in western red cedar

cedar, the defect occurs more often in the butt and adjacent logs than in logs higher up a tree. Collapse is also related to the quantity of extractives in the wood, the extractives apparently blocking the movement of air into the cells.

In hardwoods, collapse may occur when the initial mc is excessively high, particularly in wetwood zones and more especially in species where the development of tyloses reduces permeability. Areas of incipient decay in some hardwoods (e.g. aspen), though showing little or no outward sign of decay, may be weakened to such an extent that the cells will collapse, even at normally safe temperatures.

Collapse is sometimes difficult to distinguish from internal checking (honeycomb). The sides of internal checks are usually smooth crescents, since they are caused by shrinkage. On the other hand, the voids caused by collapse are usually quite irregular in shape, and the rows of adjacent cells are seriously distorted. Since both types of degrade are similar in appearance, but result from completely different causes, it is necessary to identify which defect is present in order to make proper correction.

Collapse in sensitive lumber is aggravated when it is kiln dried immediately after sawing, and when initial dry-bulb temperatures are above the critical point for that lumber. When stickered western red cedar lumber subject to collapse was air dried for two weeks prior to kiln drying, little degrade took place even when kiln dried at normal temperatures. However, when it was bulk piled for as long as a month after sawing, so that no air drying occurred, no lessening of the amount of collapse was observed compared with lumber dried immediately after milling. Shingles subject to collapse have been successfully dried after preheating for five days at low temperatures or piled for air drying for a few weeks.

Collapse of western red cedar lumber subject to this defect was avoided by reducing the initial temperature to 1400F (600C) until all the cells contained at least some air.

Hardwoods, regardless of mc, should be dried at fairly low initial temperatures.

Seasoning Defects Due to Fungal Activity

When green hardwoods are kiln dried at an initial temperature of about 10O"F (38"C) to minimize collapse, there is a danger of moulds developing, particularly at high humidities. Although such moulds are only on the surface, they discolor the wood, may be visually objectionable and may interfere with air circulation in the kiln. Dimension lumber may be sterilized by a toxic dip or by steaming at a temperature of 150"F (65°C) and maintaining this temperature for about two hours. Normal kiln-drying conditions will kill all forms of fungi and insects, including spores, eggs and larvae, thus sterilizing the lumber. If green lumber must be held in solid piles under conditions conducive to attack by sap stain and mould fungi prior to drying, it should be treated with a sap stain preventive applied in a water solution.

Seasoning Defects Due to Chemical Action

Kiln drying at high temperatures causes the wood of some species to appear "toasted".

Some of the brown-red to black discolorations which appear on lumber are associated with natural wood extractives and free moisture in the wood, which react with iron to form dark-colored **compounds**.

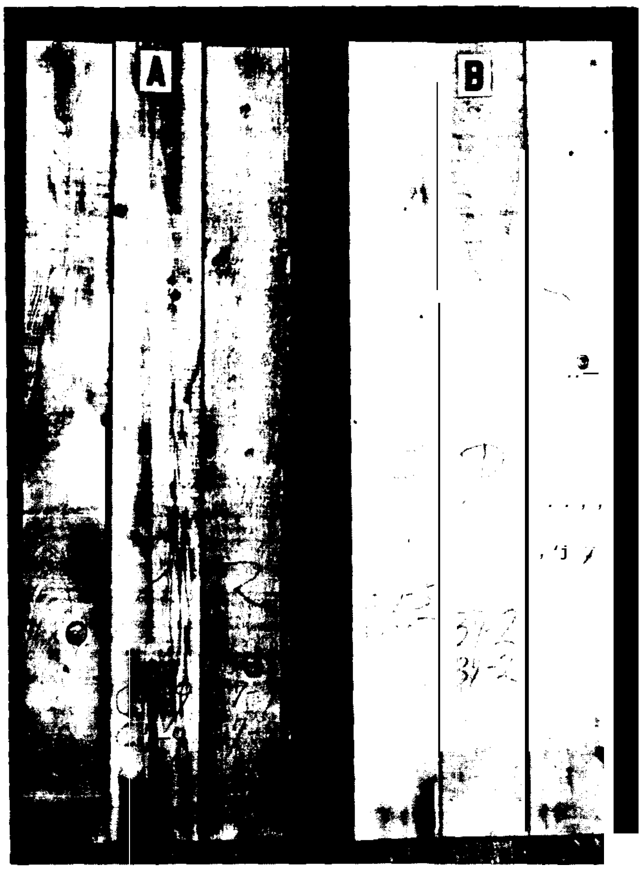

Fig. 4.5 A. Chemical stain on western white pine lumber; B. white pine lumber protected with 0.2-percent sodium fluoride solution

Whereas all commercial woods are subject to this stain, western red cedar is most susceptible, followed by yellow cedar and Douglas-fir. Such discolorations **may** occur in kiln drying, where steam pipes develop leaks and permit rust-containing water to fall on lumber.

The **brown stain** that develops in white pine lumber darkens the wood to colors ranging from dull yellow to dark brown. It is most prevalent during hot and humid months and in logs that have been stored in water for long periods. The stain usually occurs in heartwood, specially in the vicinity of knots, at the junction of heartwood and sapwood, or along lines of shake. Often it shows only at the surface of boards, but in extreme cases it may penetrate deeply into the wood causing a condition that resembles minor charring. The stain is believed to be caused by enzymatic degradation of the contents of wood cells, along with the reaction to heat in a kiln. For the latter reason, it is sometimes referred to as "kiln burn".

A similar stain may also appear during the drying of amabilis fir which has been held in prolonged storage in the green condition. Naturally produced enzymes actively convert certain wood extractives to materials that can become colored by oxidation during the kiln-drying process. The extractives are carried to the **surface** during drying and deposited there as colored materials (Fig. 4.5).

The incidence of brown stain can be lessened where the time intervals between felling of trees, skidding of logs and sawing of lumber are short and mild kiln schedules are used. The storage period of lumber between sawing and kiln drying is most critical and should be kept to a minimum, particularly if the lumber is bulk piled. Lumber kiln dried immediately after sawing is usually free of this stain.

Chemicai brown stain in white pine lumber can be practically eliminated if lumber is treated with a 0.5 percent aqueous solution of sodium fluoride immediately after sawing. Sodium azide also has been found effective, but both chemicals require careful handling procedures. More recently, dipping of green lumber in an ammoniacal zinc oxide solution for 30 seconds, placing between stickers for a few hours and then close piling for seven days prior to kiln drying has been found to produce stain-free lumber. The latter chemicals are cheap and of low toxicity to humans.

Stains ranging in color from orange to almost black, particularly on the ends of lumber, are often observed in western hemlock. They are concentrated in two main zones — the heartwood-sapwood boundary and the sapwood-cambium boundary. Chemical treatments for them are not always effective. Always confined to the lumber surface, these stains can be removed permanently by planing, provided the lumber remains dry. Since the stain is innocuous, in no way connected with decay, sapstain or mould, and can be removed by planing, its presence may be ignored.

Sticker marking

Sticker marking occurs in many woods, particularly hardwoods, during kiln-drying. These are varying color discolorations occurring on and beneath the surface of boards under stickers, or they appear as narrow, dark streaks on the surface at the edges of stickers. Sometimes they can be removed by surfacing or sanding. Sticker marking is believed to be due to concentrations of, and chemical changes in, the extractive substances brought to the surface by capillary flow of free water. No means of preventing the discoloration is known, but it can be reduced by increasing wet-bulb depression slightly in the first stages of drying. Other helpful procedures include the use of dry, narrow stickers, stickers of grooved or laminated wood or of thermosetting plastic, in order to reduce the contact area, and also starting the drying of green lumber as soon as possible.

Effect of Temperature on Strength of Wood

In kiln-drying schedules set up within conventional temperature ranges, any reduction in strength of lumber may be ignored. Results of research conducted on high-temperature drying of both hardwoods and softwoods are conflicting but, in general, there appears to be some reduction in bending strength and stiffness associated with exposure to high temperatures. Tests conducted at the Eastern Forest Products Laboratory on yellow birch and hard maple lumber showed an increase in all strength properties with high-temperature drying, but losses in elasticity and strength for pine and spruce. In spite of small changes in strength values, high-temperature drying is being accepted to an increasing degree, and is being used increasingly and successfully for certain kinds and sizes of lumber.

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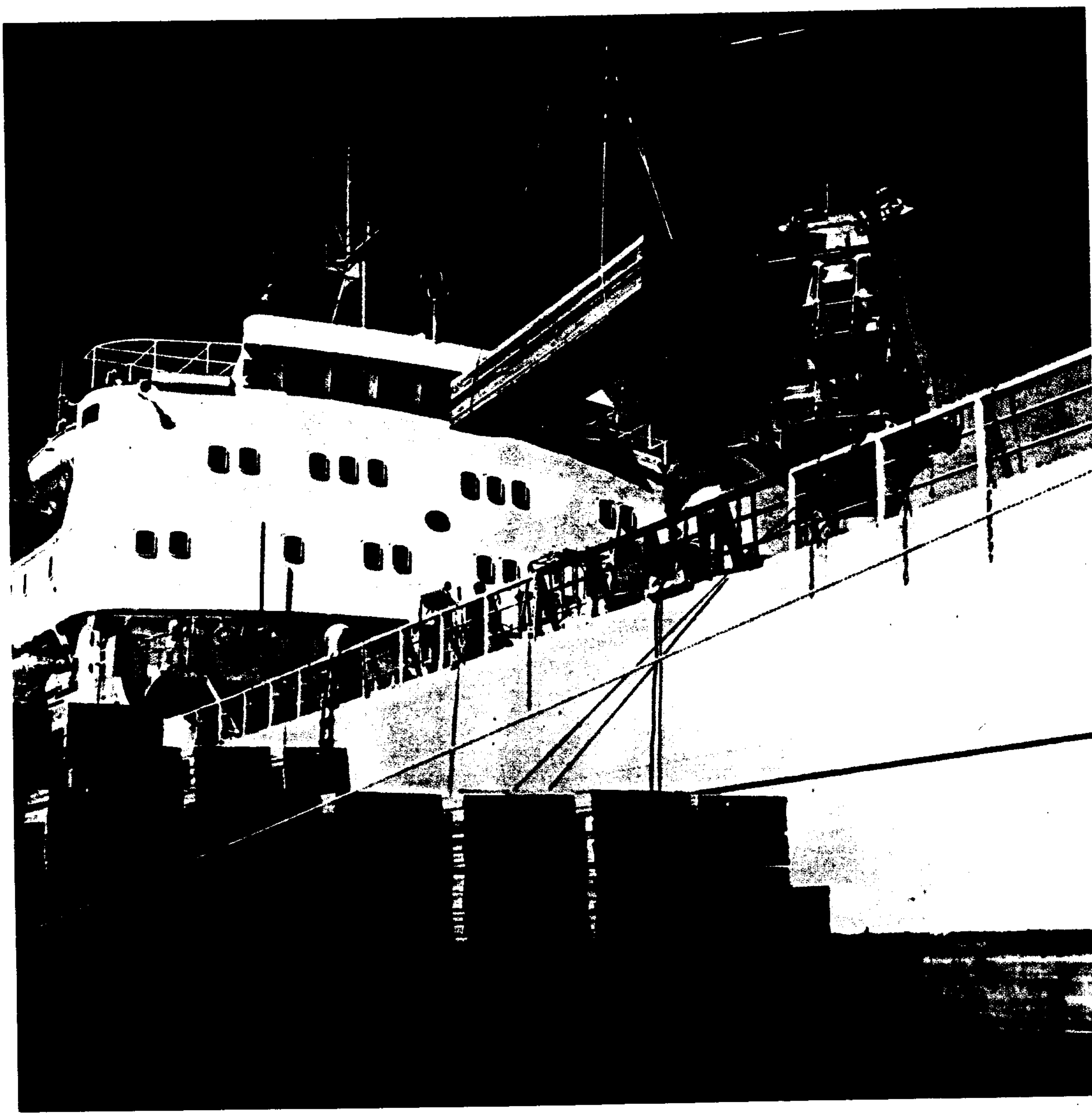

CHAPTER 5
KILN CONSTRUCTION AND EQUIPMENT

A kiln is a structure in which lumber is dried by circulation of air of controlled temperature and humidity. Consequently, a kiln must have provision for controlling the temperature and humidity of the air and for circulating it between the courses of lumber. These functions permit a variety of kiln designs, construction materials, loading arrangements, fan arrangements, heating medium and fuel source, although in many kilns provision to increase humidity is limited.

A kiln should be a sealed and insulated building in order to keep the loss of heat to a minimum and to control losses by infiltration of atmospheric air. For this reason, the foundation must provide a solid base to support both the building and the lumber in it. Winter conditions in most parts of Canada require that the kiln be built to eliminate frost damage. Because water vapor may condense on the kiln walls, provision must be made in the floor for drainage. A floor of crushed rock or of solid concrete with drainholes will serve this purpose. In most kilns, the lumber is loaded on trucks mounted on rails. Because of the heavy loads involved, the rails must be adequately supported. It is usual to mount the rails either in or on a 12-inch concrete beam running the length of the kiln.

Foundations may be shaped to provide a trough just wide and deep enough to accommodate the trucks carrying the loads of lumber. This will reduce the possibility of circulating air bypassing the lumber by traveling under the load.

Structural Materials

Various materials are used to build kilns. Wood, concrete block, clay tile, reinforced concrete, concrete-asbestos panels, and insulated aluminum panels are all commonly used, with various vapor barriers to restrict vapor movement from inside the kiln, thereby keeping the structural materials dry.

Wood

Wood has the advantage of low cost, availability and, when dry, good insulating value. Wooden kilns, drying Douglas-fir or western red cedar, can usually be assured of twenty or more years' service on the British Columbia Coast. However, where western hemlock is being dried, wooden kilns will have a service life of five years or less. An investigation by the Western Forest Products Laboratory in the 1950s, as to the causes for deterioration, showed that the higher acidity and lower resin content of the western hemlock vapors were responsible. The construction of the kilns also assisted in deterioration. Wooden kilns were roofed and painted to offer protection from the weather, but in doing so provided a vapor barrier on the external walls, trapping the acidic vapors within the structure.

Some wooden kilns are still in use, but their construction has been changed to provide an effective vapor barrier, usually aluminum, on the inside walls of the kiln. The former practice of using bare or galvanized iron or steel in contact with wood is now generally avoided, since it results in destruction of the wood under damp conditions.

Aluminum and steel

The corrosion resistance of aluminum in a kiln atmosphere, along with its excellent properties as a vapor barrier, has led to the development of the prefabricated aluminum kiln (Fig. 5.1). Reinforced panels (Fig. 5.2), having aluminum inner and outer skins with fiberglass or foamed polystyrene insulation between, are bolted to a steel frame set up over the prelaid foundation. Provision is made for thermal expansion and contraction of the walls by means of a mastic or rubber joint sealant placed between the panels (Fig. 5.3). These panels may also be used effectively to replace sloped wooden roofs, although they are unsuitable for flat roofs. Prefabricated kilns may be disassembled and moved to another site, if desired, an advantage of interest to lending institutions or equipment-leasing companies.

Although aluminum is extremely resistant to corrosion, it may still deteriorate if the interior skin of aluminum is broken or pitted, permitting vapors to pass into and condense within the panels. For this reason, all panels should be sealed absolutely to prevent penetration of the kiln atmosphere. Roof panels should be laid on a slope to permit drainage of any internal condensation.

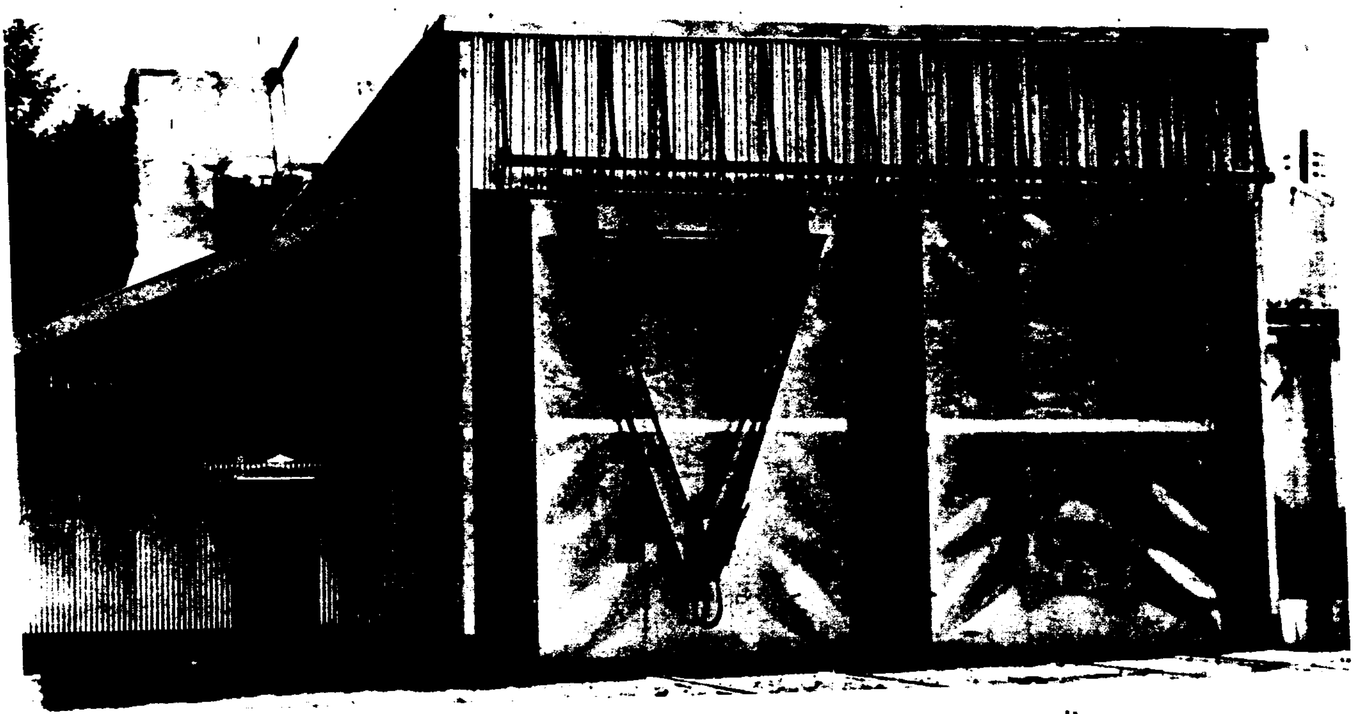

Fig. 5.1 Prefabricated, hot-air aluminum kiln of 200 Mfbm capacity

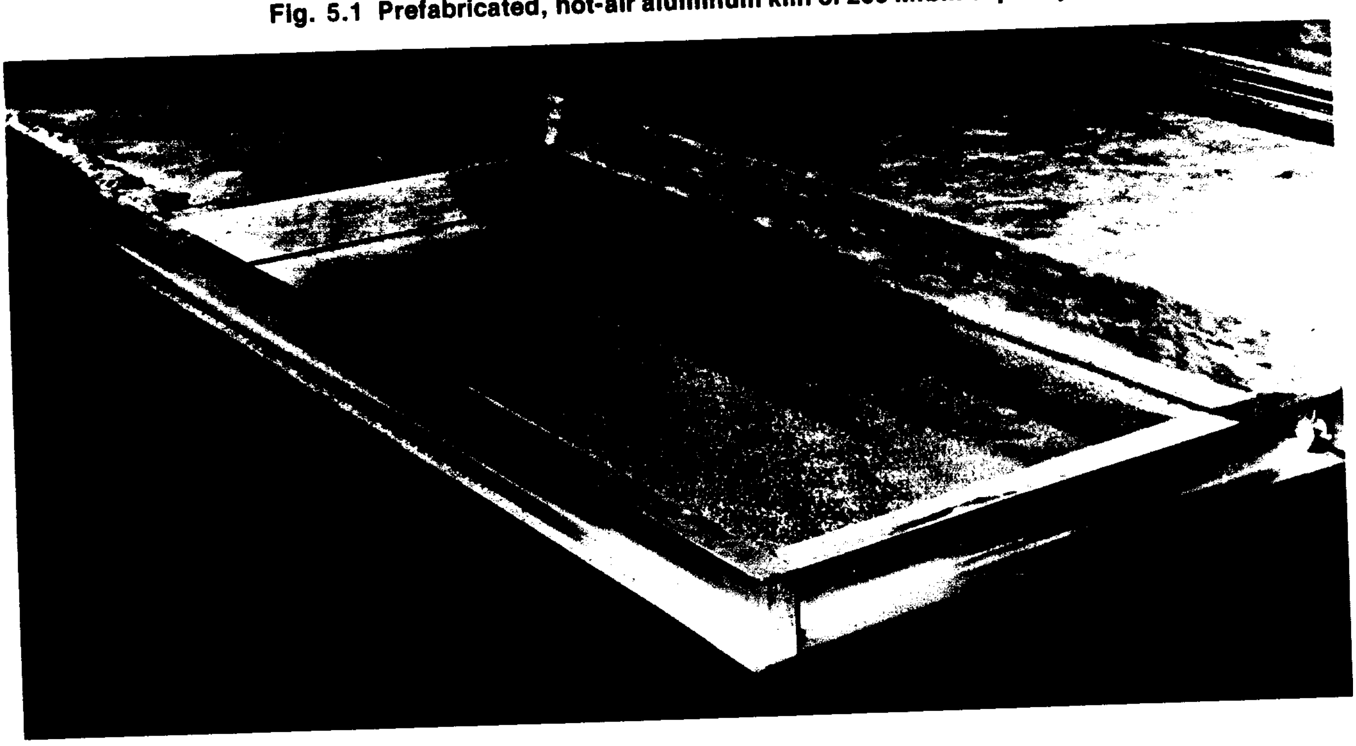

Fig. 5.2 Construction of prefabricated panei for aluminum kiln

When two dissimilar metals (like aluminum and steel) are placed in contact in a liquid, they will form a "battery" whereby small electric currents are generated while one or both of the metals dissolves or corrodes. Such metals should be separated by a good electrical insulator. Contact between recorder capillaries and other metals will also provide a situation where corrosion can occur when wet. Aluminum should not be permitted to make contact with steel at any point where loss of heat will cool one surface below the dew-point temperature, and thus permit condensation, even for a short time.

It has been found by one kiln company that increasing kiln temperatures to about 200"F results in increasingly rapid deterioration (due to condensation of the higher concentration of vapor in the kiln atmosphere), but that operating at temperatures above the boiling point of water results in reduced corrosion since liquid water is no longer present.

A particularly serious form of corrosion takes place in kilns operated at high humidities where inadequately protected steel is placed in contact with the floor or other heat sink. For example, in the case of steel rails or steel columns embedded in the floor where they are cooled by contact with the ground, moisture may condense on them causing rapid corrosion. Consequently, steel should be protected by a suitable coating. Corrosion of rails may be reduced by embedding the entire rail except the upper inch in concrete, and keeping the exposed part well lubricated or coated at all times to prevent contact with condensate.

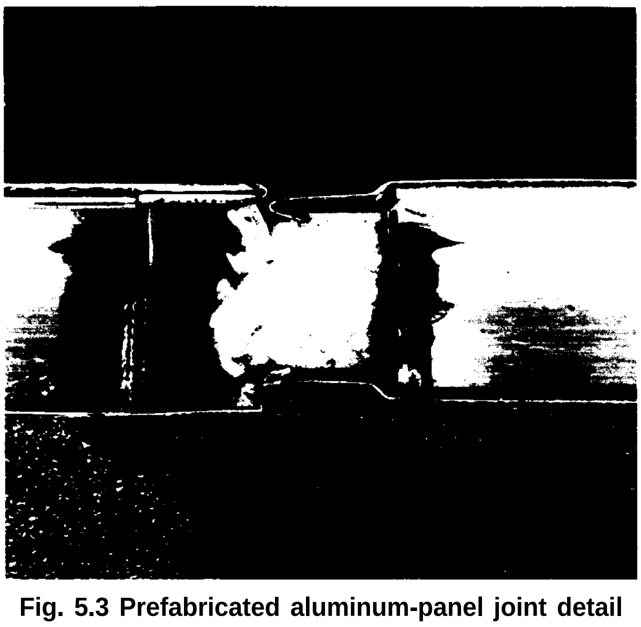

Fig. 5.3 Prefabricated aluminum-panel joint detail

Aluminum rails have been installed in a kiln in the Vancouver area drying western hemlock. These rails have now been in service for about twenty years with no sign of deterioration (Fig. 5.4). A problem may exist in fitting such rails, since steel should not be used with them as fishplates, spikes, bolts or ties. They should be flanged to the concrete floor with aluminum only.

Thermal expansion of the rails with changes of kiln temperatures is not usually serious, but must still be taken into account. Where the steel is buried in a concrete foundation, no problem exists. Where the rail is mounted on the foundation, its temperature will be somewhat above that of the foundation and some provision must be made for expansion. The usual gap of about a quarter inch per 30 feet of rail will be adequate. However, if aluminum rail is used, about half an inch per 30 feet of rail is necessary because of its greater coefficient of expansion.

Concrete block and brick

Other common construction materials for kilns are concrete block and brick (Fig. 5.5). These have the advantage of moderate cost, but only fair insulating properties. Concrete block kilns are usually insulated by pouring puffed mica (vermiculite) into the wall cavities during construction. Their construction does not usually allow for the continual thermal expansion and contraction associated with the wide ranges of temperature in operating (including unloading) the kiln. As a result, cracks often develop in the walls (Fig. 5.6). Vapor escaping through these cracks attacks the mortar and

Fig. 5.4 Aluminum rail after 20 years of service in a kiln drying western hemlock

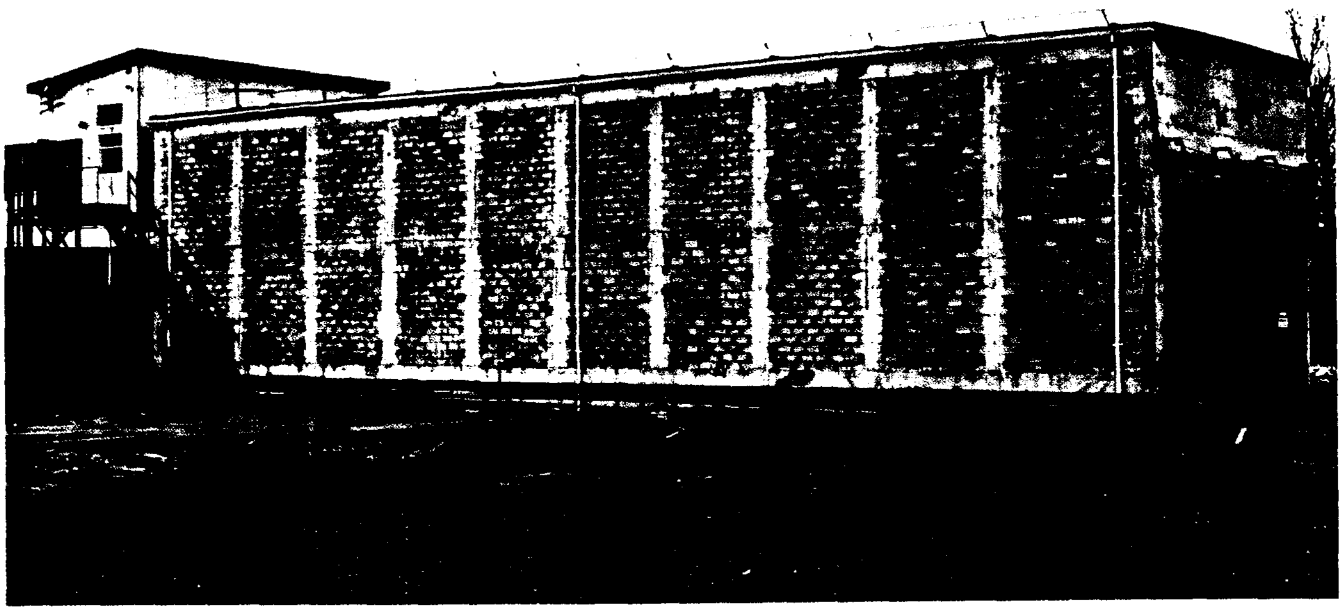

Fig. 5.5 Concrete-block kiln

concrete, resulting in the development of larger cracks, falling out of mortar and spalling of concrete. Such construction must be properly protected by a vapor barrier and deterioration must be quickly repaired.

Progressive and Compartment Kilns

Kilns can be categorized into two groups, the progressive kiln and the compartment or charge kiln.

Progressive kiln

In the progressive kiln, the loads of lumber to be dried enter the green or loading end of the kiln and are moved progressively forward daily until the dry or unloading end is reached. As each load is removed from the dry end, it is replaced by a fresh load at the green end. In order to obtain the necessary variation in drying conditions between the green and dry ends, a progressive kiln must be of the proper length — approximately 100 feet (30 m) — and must be kept fully charged. Air from the heaters normally enters the drying area at the dry end, exposing the driest load to the most severe drying conditions. As the air passes through the loads, it is progressively cooled and becomes more humid, so that by the time it reaches the green end, drying conditions are relatively mild. Some progressive kilns have cross circulation.

In a Swedish modification of this design, the heated air is introduced midway in the length of a kiln. Part of the air is directed to the loading (green) end and the rest toward the unloading (dry) end. Thus, the second zone will be conditioning the dried lumber and relieving stresses by exposure to gradually cooling air. (In a progressive kiln, the wet-bulb temperature remains constant; only the dry-bulb temperature varies)[1]. European progressive kilns are normally operated to provide milder conditions than are customary in most fast-drying North American softwood kilns. Consequently, drying times are usually about twice as long. Due to these longer drying times, however, final moisture contents are limited to a narrow range; drying degrade is minimized and specifications are more easiiy met.

The primary advantage of a progressive kiin is economic, in that where a miii has a iow daily throughput (not more than about 40M fbm) of a commodity requiring severai days' drying time, a singie kiin can be used to provide a more or iess continuous supPiY of dry ium-

[1] **The authors are indebted to Dr. Lars Malmquist, Swedish Forest Products Institute, Stockholm and AB Svenska Flaktfabriken for descriptive material on progressive lumber dryers.**

ber. As additional advantages, the progressive kiln has a fairly constant heat load; and because the exhaust air is of a constant temperature and humidity, heat exchangers or other heat recovery systems can be efficiently employed.

The principal disadvantage of a progressive kiln relates to the difficulty in changing drying conditions within the kiln: they are largely dictated by the kiln and the lumber being dried. For most woods, the gradually intensifying drying conditions are ideal and no disadvantage exists. However, for some woods requiring specific conditions these may not be attainable, Because kiln conditions are affected by the drying characteristics of the materials being dried, changes of products in the kiln are not readily made in mid-run. And, since it is not possible to dry properly with less than a full load, this type of kiln is restricted to mills producing a single type of product or, at most, a restricted number of stock items.

There are few progressive kilns left in operation in Canada. Some, however, are still used in the western red cedar shingle industry, where mill production lends itself to their use and where their lesser degree of control is acceptable. They are common in Scandinavia, including fully automated operations, and export models are made by well-known German and Swedish manufacturers of drying equipment.

Fig. 5.6 Crack in wall of concrete-block kiln

Compartment kiln

A compartment or charge kiln is completely charged with lumber in one operation, the lumber remaining stationary during drying, Temperature and humidity are controlled to a predetermined schedule, and are reasonably uniform throughout the kiln at any time. When the lumber is dry, the entire charge is removed. The chief advantage of this type of kiln is that, since all **lumber is loaded at the same time, drying conditions can be varied to suit the specific requirements of the lumber being dried. Better drying, especially in** species and sizes difficult to dry, is therefore obtained. Kiln size is flexible and individual units can be small or large. For these reasons, this is the common type of kiln used in Canada.

Loading arrangements

Compartment kilns permit of a variety of loading arrangements. Most are loaded from the end, the loads of lumber being built on trucks running on rails installed through the kilns and the loading and unloading areas. Kilns may be double-ended or single-ended (pocket kilns). The loading of double-ended kilns is more efficient. As the dried lumber is discharged from one end of the kiln into the unloading bays, the kiln can be immediately loaded at the other end with the green lumber. In pocket kilns, dried lumber must be removed from the loading area before the green lumber is loaded. Transfer cars to permit movement of loads from one track to another reduce the time involved in changing loads in such kilns.

Although end loading is more efficient for the loading and unloading of lumber, some kilns are loaded and unloaded from the sides by means of forklift trucks. Loads are placed on blocks or bolsters on the kiln floor. This arrangement is particularly flexible where a wide range of products must be dried, as by a kiln operated in conjunction with a preservative-treating plant. Because loads are not restricted to particular dimensions, such kilns can conveniently dry shingles, preservative-treated plywood, poles and posts, as well as lumber. However, a side-loading kiln has longer downtime between charges. It requires better than normal door insulation because of the large area involved. Otherwise, it would be difficult, if not impossible, to maintain the uniform conditions required to produce a uniformly dried product.

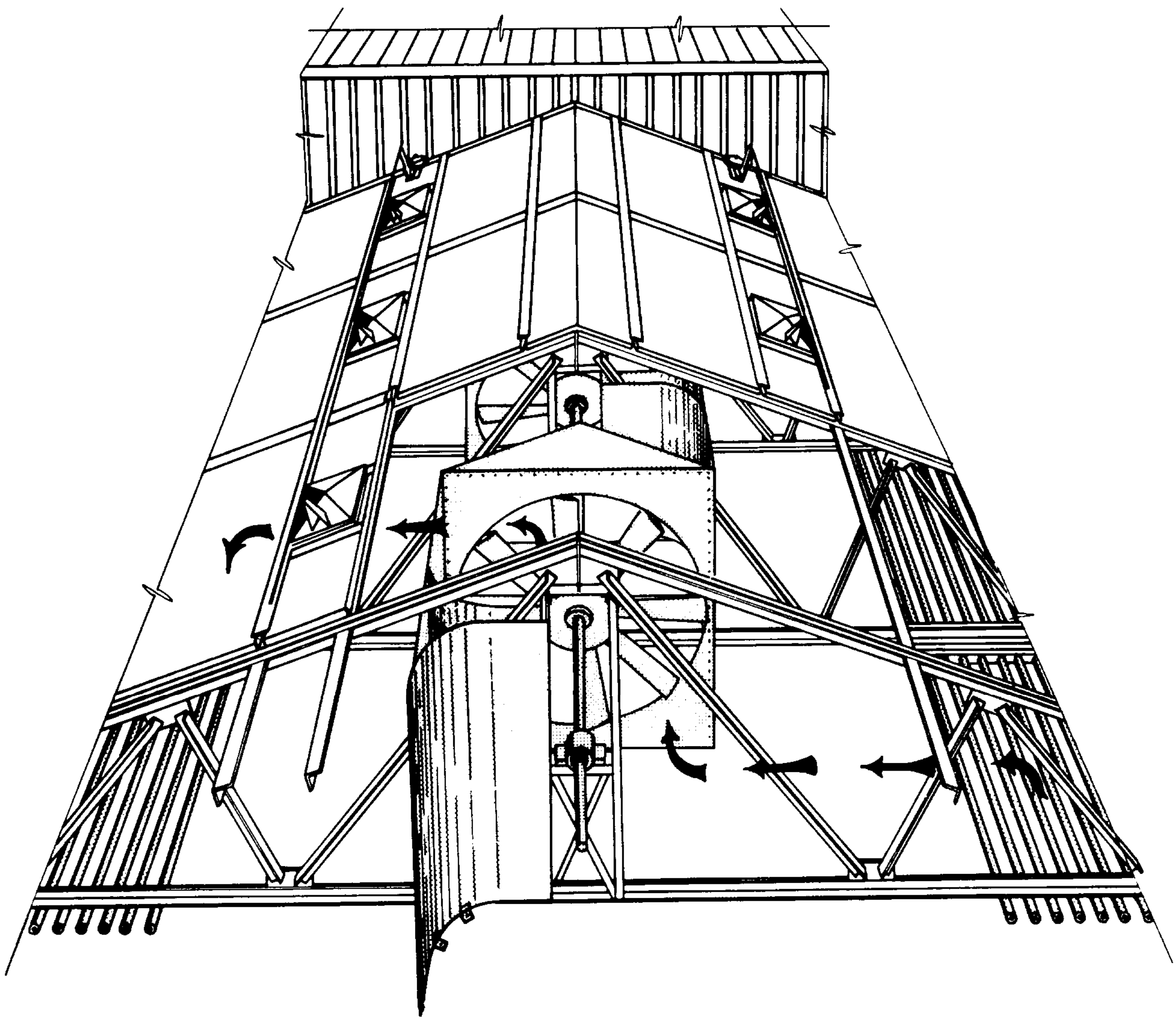

Fig. 5.7 Lineshaft **arrangement of fans**

Air circulation

In order to dry lumber, air of controlled temperature and humidity must be passed over its surface. The air performs two functions: it carries heat energy to the wood to effect evaporation and also removes the evaporated water vapor.

Effective circulation of air involves several factors: the size, location and speed of the fans to drive the air; provision for reversal of air circulation; the installation and use of baffles to direct the air through the load; and the **placing of stickers (spacers) within the load to facilitate the movement of air across each piece of lumber.**

Fans

In commercial kilns at this time, fan speeds are fixed and, therefore, cannot be varied for the material being dried nor at various times in a schedule. The choice of fan type and speed of operation should be made for the most suitable combination of drying uniformity and speed of drying for the material to be dried, recognizing the capital and operating costs resulting from the choice made.

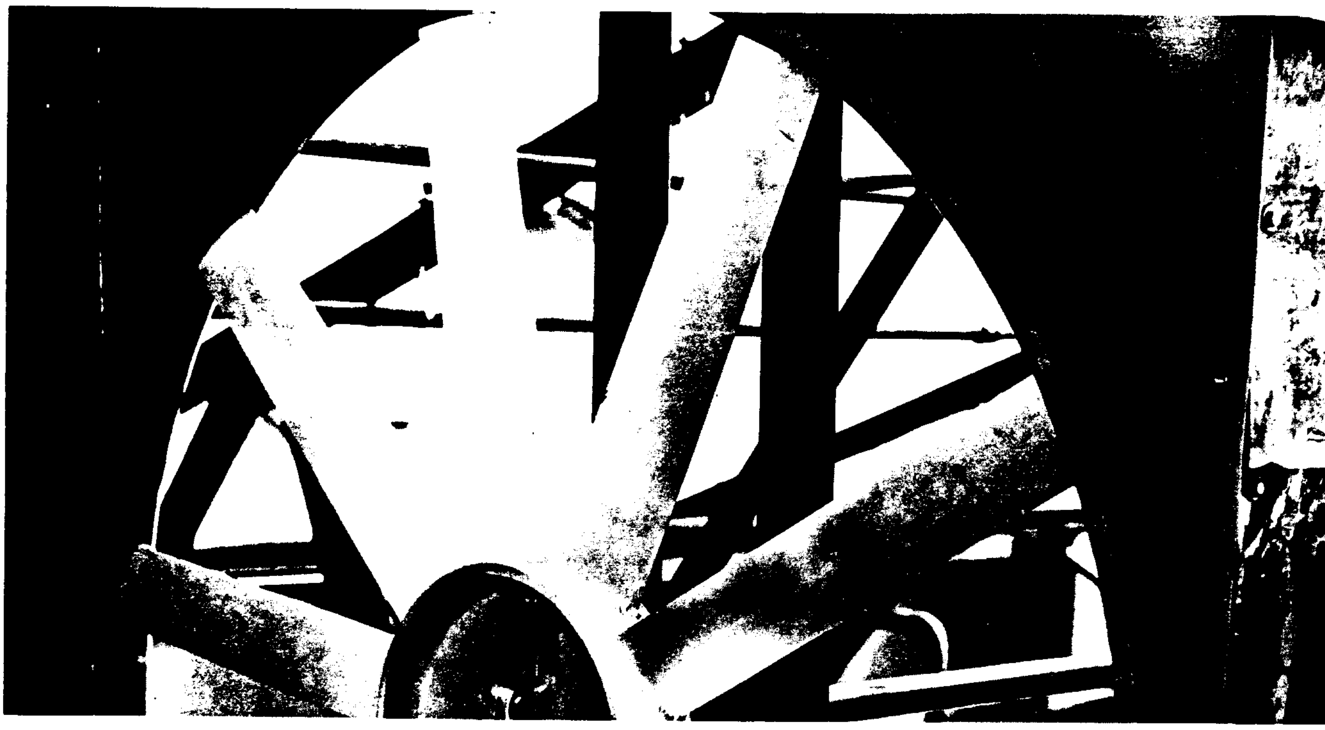

Fig. 5.8 Mounting of fans on lineshaft

The following fan laws will provide some indication of relative costs. For any specific fan, (1) the volume of air moved varies directly with the speed, (2) the static pressure varies with the square of the speed, and (3) the horsepower varies as the cube of the speed and directly as the air density. To double the air flow rate will increase power consumption eight times.

In modern kilns, the two principal arrangements of fans serve as descriptive categories of kiln construction — lineshaft and cross shaft.

Lineshaft arrangement

The lineshaft or longitudinal-shaft arrangement provides for moving large volumes of air at low air speeds (up to 400 fpm) with a minimum of power, and is particularly suited to drying lumber with a low initial moisture content or slow diffusion rate, such as Douglas-fir or western red cedar.

In this arrangement, this series of disc fans up to 72 inches in diameter is mounted on a shaft running the full length of the kiln. The fans are alternately left- and right-hand, and are housed in a zig-zag baffle system which directs the air across the kiln (Fig. 5.7). So that air circulation may be reversed efficiently, the fans are designed to operate in either direction. They may be split hub and mounted by bolts, or complete fans fixed by a keyway and taper-lock bushings (Fig. 5.8).

Various lineshaft locations have been tried. The most common placement of fans is over a false ceiling or deck. The motor, usually 50 to 75 horsepower, is generally in an operating room at the end of the kiln. In older installations, where air-circulation rate is considered too slow and is limited by the torque of the shaft, it is possible to cut the shaft at midlength, install a motor at the other end and, by increasing shaft speed, achieve higher air-circulation rates.

Cross-shaft arrangement

In the cross-shaft arrangement, fans are mounted on individual shafts aligned across the width of a kiln. The fans are usually mounted over a false ceiling and driven by individual motors of about 7.5 horsepower rating, either by a pulley system or, more commonly, by direct coupling. Motors may be mounted inside or outside the kiln. However, motors mounted inside a kiln must be of class H construction to withstand high temperatures. Even so, maintenance costs are high with such motors. Externally mounted motors must be protected from water-vapor condensation in freezing weather. Otherwise they may freeze up and be burned out.

Either multiple-blade disc fans 72 to 84 inches (1 .83 to 2.13 m) in diameter turning at relatively slow speeds,

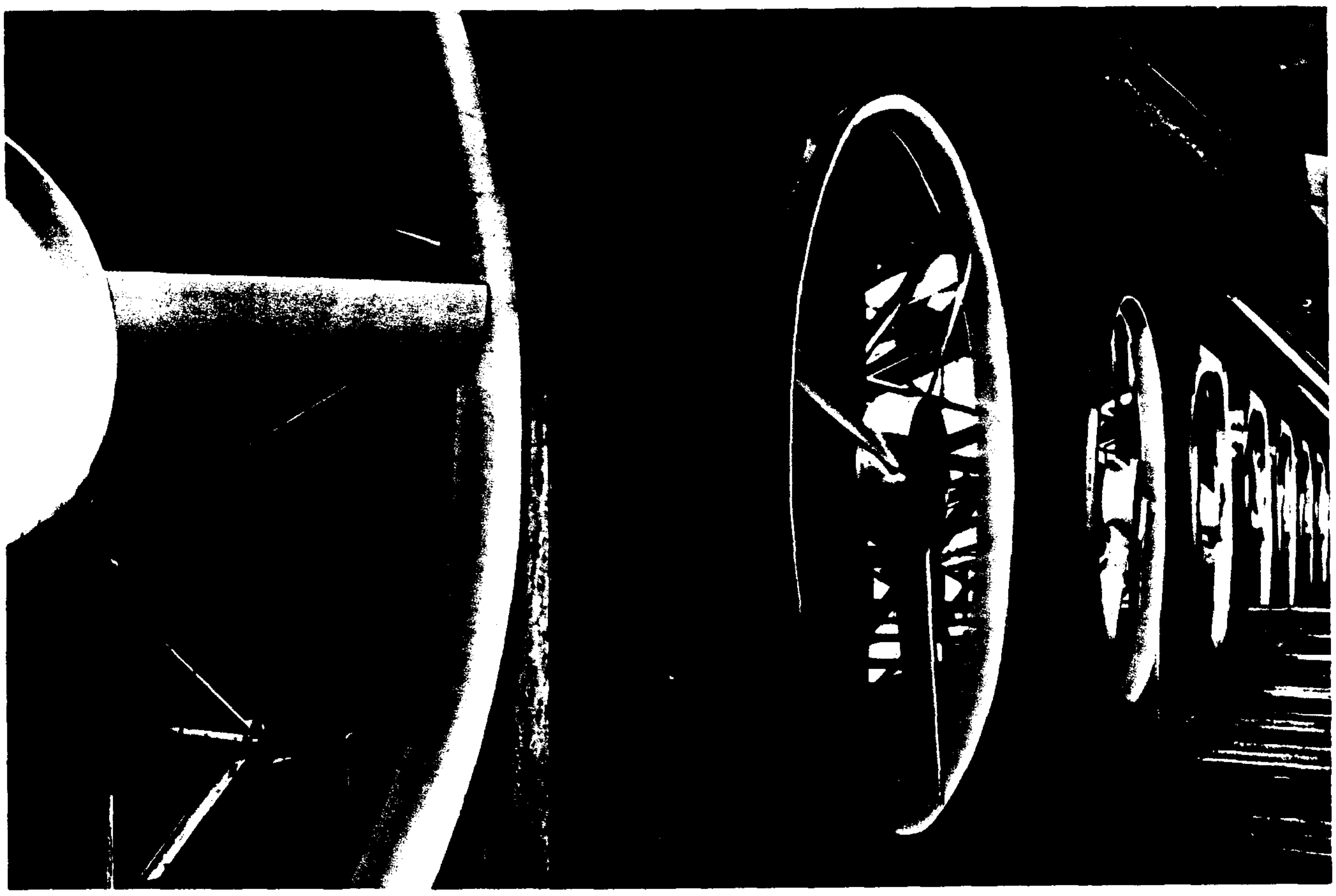

Fig 5.9 Propellorfans **in cross-circulation kiln**

or high-speed propeller-type fans up to 66 inches (1 .68 m) in diameter may be used. Propeller fans are usuaily three- or four-bladed and made of aluminum (Fig. 5.9). They can deliver large volumes of air at or above 400 feet per minute (130 m/min) through the ioad. They are particularly suitable in drying lumber having high initial mc or a rapid diffusion rate, such as spruce, pine and western hemlock.

External **blower**

A third type of arrangement, not widely used, requires only one motor and blower (or, in long kilns, a second system in parallel) to move air in the kiln. In this system, air is drawn from the discharge side of the load through large ducts to an external centrifugal blower, from which it is passed over the heater and distributed by another set of ducts to the high-pressure side of the load. The advantage of this arrangement is that the air-circulation system (which comprises the major moving parts of the kiln) is concentrated in an easily accessible place and can be readily serviced. Its disadvantages are its low air velocities due to the length of the necessary ductwork, and the fact that the direction of air circulation is difficult, if not impossible, to reverse. It is thus not suitable for materials requiring rapid drying.

Baffles

In order to achieve rapid, uniform drying, the heated air must be directed in a uniform distribution between the courses of lumber in the load. To do this effectively, all alternate flow paths must be blocked, so that air flow over, under, or around the load is prevented. The practical way to accomplish this is by baffles. Flow under the load may be prevented by constructing the floor of the kiln with a trough just wide enough to accommodate the rails and trucks, and high enough so that the lowest course of iumber just ciears the level of the floor. Alternately, baffles hinged to the floor may be leaned against the load to prevent bypassing.

Flow over the load is most effectively prevented by use of ceiling-hinged baffles arranged so that their free end rests on top of the load. As the load shrinks during drying, the baffles must be permitted to move down to keep contact with the load. Arrangements must also be made to construct all loads to the same height so that gaps will not occur over low loads.

Flow around the ends of the load can be prevented by mounting baffles in or near kiln corners, to contact the ends or corners of the loads.

Kiln Ventilation

Static venting

Excess kiin moisture is normaiiy discharged by opening roof vents. in modern kiins, this is done automatically by the recorder-controller when the kiin humidity exceeds the programmed vaiue. Automatic venting provides for better controi and economy of humidification than can be achieved by manuai or fixed venting, because automatic venting is done only when the humidity is too high.

Ventilators are pieced in the roof on the intake and exhaust sides of the fan so that, when they are opened, fresh air is drawn in on the suction side and moist air forced out on the compression side of the fan. When the direction of rotation of the fans is reversed, the fiow of air through the ventilators is aiso reversed. The size and number of ventilators required depends on the species being dried — wet woods require more ventilation than drier ones.

Vents are arranged in-line aiong the length of the kiin, hinged, and connected by means of a continuous metai rod, so that each line can be opened or ciosed as a unit by air motors operated by the recorder-controller.

Pressure venting

As an alternative to the numerous roof vents required in a standard kiln, some kiins are being designed with a pressurized venting system. Certain of these systems are patented.

in one such system, two identical metal ducts are placed inside the kiin, running fuii iength in the zone above the faise ceiiing. These ducts vent to the atmosphere through iouvered openings; one duct serves for air intake as the other exhausts. Adjustable openings aiong the length of each duct provide uniformity of air distribution throughout the kiin. A fan unit at the end of each duct acts interchangeably as intake or exhaust, depending on the direction of air circulation. When the fans are reversed, the venting system also reverses, with the louvers actuated to open immediately prior to the fans starting. it is claimed that the greater capitai cost of such a system is more than offset by lower maintenance costs.

Heating media

Since the heat of evaporation of water is approximately 1000 Btu per pound (2.3 **megajoules/kg),** great quantities of heat energy must be generated and transferred to the circuiting air and to the wood in the drying of iumber. The principal methods of conducting this heat into the kiin are (a) indirect, where a hot fiuid is conducted into the kiin in pipes, and gives off its heat to the kiln atmosphere through a suitable radiator, and (b) direct, where hot gases are discharged directiy into the kiin atmosphere. Exampies of indirect heating systems inciude steam and hot water systems. Direct heating uses the combustion products of hydrocarbon and wood fueis discharged into the kiin after dilution to safe temperatures.

Steam

The use of steam’ as a heating medium has advantages over other systems. Since heat is radiated into the kiin rather than being carried in by hot gases, there is no displacement or change of kiin atmosphere when heat is added. Consequentiy, temperature can be controlled without affecting kiin humidity. Furthermore, where steam is avaiiabie as a heating medium, it is aiso avaiiable to add water vapor, so that reiative humidity can be controlled at any desired vaiue, even at the end of the drying cycie when kilns without a steam suppiy are unabie to do so. Steam permits the use of waste wood as fuei and, in this way, resuits in considerable economy of operation where large quantities of lumber are being dried.

On the other hand, the capital costs of boilers and heating equipment are high. Boiiers operated at more than 15 psig[3] pressure are required by law to be supervised by a staff of quaiified engineers. Because of this, steam is not an economical source of heat, even using waste wood as fuel, unless more than two iarge kilns are operated at one place.

For most efficient operation, steam shouid be in adequate supply at constant pressure. it is general practice to use high-pressure steam direct from the boiier or reduced by vaives to bring the pressure to some iower vaiue. Since speciai pipes and fittings are required for steam at pressures over 150 psig (1 000 kPa gauge), there is some advantage to reducing it beiow that pressure. No heat is iost in this operation, since the steam becomes superheated at the iower pressure. However, a larger diameter steam pipe may be required and more radiating surface will be required.

[2]*See* **Appendix C.**

[3]**PSi9— pounds per square inch gauge pressure.**

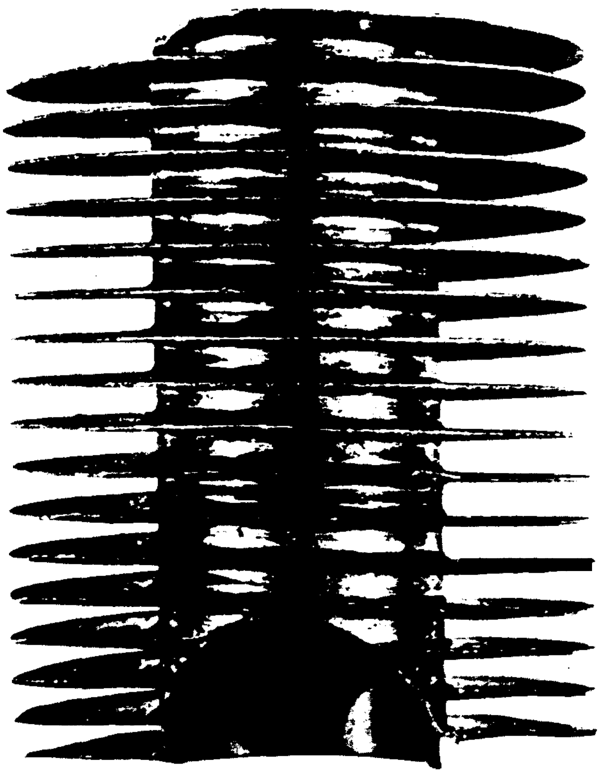

Fig. 5.10 Section of finned **pipe**

The major alternative to high-pressure steam is "waste steam" or exhaust steam from a steam engine, usually at 15 to 30 psig (100 to 200 kPa gauge). At these pressures, a very large heating surface (steam coil) is required for efficient-heat transfer. This source of steam, while having the advantage of economy, may suffer from inadequate or intermittent supply and result in inconsistent lumber mc.

Plain iron pipes were for many years the standard material for radiators. Fin piping is now almost universally used (Figs. 5.10 and 5.1 1). Depending on diameter and other factors, it is considered that fin pipes have from four to eight times the radiating capacity of conventional black iron pipes. Fin pipes may be plain iron or copper tubing, on which thin metal strips are wound or discs are affixed in order to increase the radiating surface. Fins may be of various materials, heavy gauge steel being the most rigid and serviceable, but subject to corrosion, and aluminum being an excellent heat conductor but much more subject to damage. The heat transfer rate of aluminum fins is stated to be twice as great as that of steel fins.

H is considered good practice to divide the heating coils into short, separately valved units serving ,short sections of a kiln. Short units produce more uniform temperatures along their length than do long coils. The return-bend system is the most common arrangement of steam pipes within a kiln. In this system, the pipes in each unit (kiln section), after leaving the distributing header, extend the length of the unit and return to a discharge header.

In multiple-track kilns where the circulating air passes through more than one load in series, it is customary to install booster coils between the tracks. They are used to maintain a more uniform temperature within the kiln.

Almost the entire heat given up by the steam to the kiln is latent heat of evaporation. This means that for every 1000 Btu of heat delivered, approximately one pound of water condenses in the steam lines. If it were allowed to remain in the coils, it would prevent the entry of more steam and heating would quickly stop. In order to remove condensate, steam lines and radiators are built on a slope to permit drainage to the outlet end of the line. Here, **steam traps** remove the condensate and send it back to the boiler by means of a pump, or dump it into waste lines.

Fig. 5.11 Finned-pipe radiators in place during construction

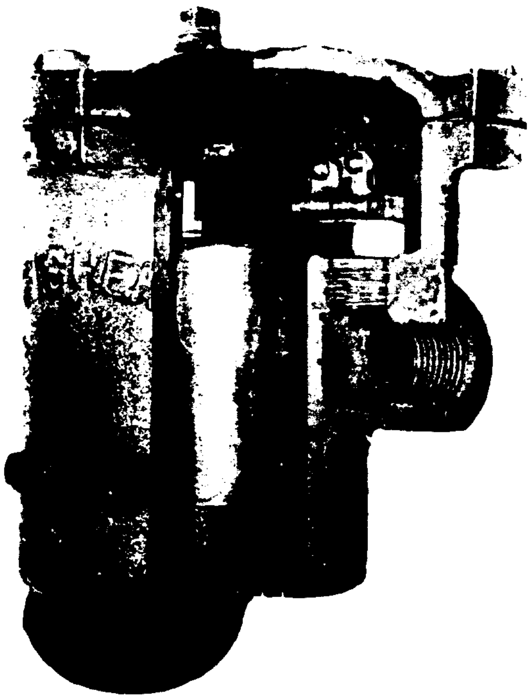

Fig. 5.12 Partial section of bucket trap

The effective working of a steam trap[4] will result in fast heat up of the heat transfer equipment, maximum kiln capacity, maximum fuel economy and minimum maintenance. Steam traps can operate properly only if they are at the low point of the system. Installation of a trap at a higher elevation will result in the accumulation of condensate in the lower part of the steam line, and will eliminate that part of the line as an efficient heat radiator.

Where a number of heating units are connected to the same trap, the capacity of that trap must be adequate to handle the maximum condensing rate. Otherwise, flooding of some units may reduce their heating surface and unbalance the heating capacity of the coils.

There are two main types of steam trap: the mechanical (or bucket type) and the thermostatic. The bucket type, illustrated in Figure 5.12, is the one in general use on the heating units of dry kilns. In the thermostatic type of trap, expansion and contraction of an oil-filled bellows inside the trap shuts and opens the outlet valve. Thermostatic traps are occasionally installed on the end of the pipe supplying the steam sprays, to remove the condensate when the sprays are operating intermittently. Both types of steam trap are designed to operate in a narrow pressure (or temperature) range. When the pressure or temperature of the system falls outside this range, neither will operate properly.

For best operation, a strainer must be placed upstream of the trap to remove dirt and oil, and a check valve downstream of the trap to prevent back pressure.

[4] Operation of steam traps is described in detail in various kiln manuals, such as McIntyre (1 975).

Hot water

An alternative to the use of steam is an enclosed system using hot water under pressure as the heat-exchange medium. The water is usually heated in a return-tube boiler to a temperature not exceeding 250"F, using waste wood as fuel. This particular temperature is the boiling point of water at 15 psig pressure, the maximum steam pressure permitted without the supervision of a steam engineer. Customarily, the system is maintained under a hydraulic pressure of 15 to 160 psig to prevent steam from forming.

The hot water is circulated by means of pumps through radiators similar to those used in a conventional steam kiln. The lower amount of heat available from hot water (where no latent heat is present) in comparison with steam requires a greater radiating surface. Maximum temperatures attainable in the kiln are about **180°F (88°C),** which is adequate for many operations, in particular those dfying hardwoods. Only a few such kilns are in use in western Canada, but they are common in the United Kingdom, Europe, and other parts of Canada. The advantages of this system are that labor costs are minimized, since full-time attendants are not required; fuel costs are minimal, since waste wood is normally used as a source of heat.

High-boiling-point liquid

Experimental and small commercial installations have been made where a high-boiling-point organic liquid (such as biphenyl, or tricresyl phosphate, or a low-viscosity oil) is used as the heat-transfer liquid. Because these liquids can be heated to more than 400"F (200"C), they can be used to heat kilns to any practical drying temperature, yet do not require a boiler engineer, since pressures are not generated.

The disadvantages are the high cost of a suitable heat-transfer liquid, the cost of boilers and heat exchangers, and the low specific heat of the heat-transfer liquid, which would probably be about half the value of water. This means that to transfer the same quantity of heat, twice as much liquid would need to pass through the heat exchanger.

Electricity

In geographic regions where large blocks of electric power are available and cheap, this form of energy is

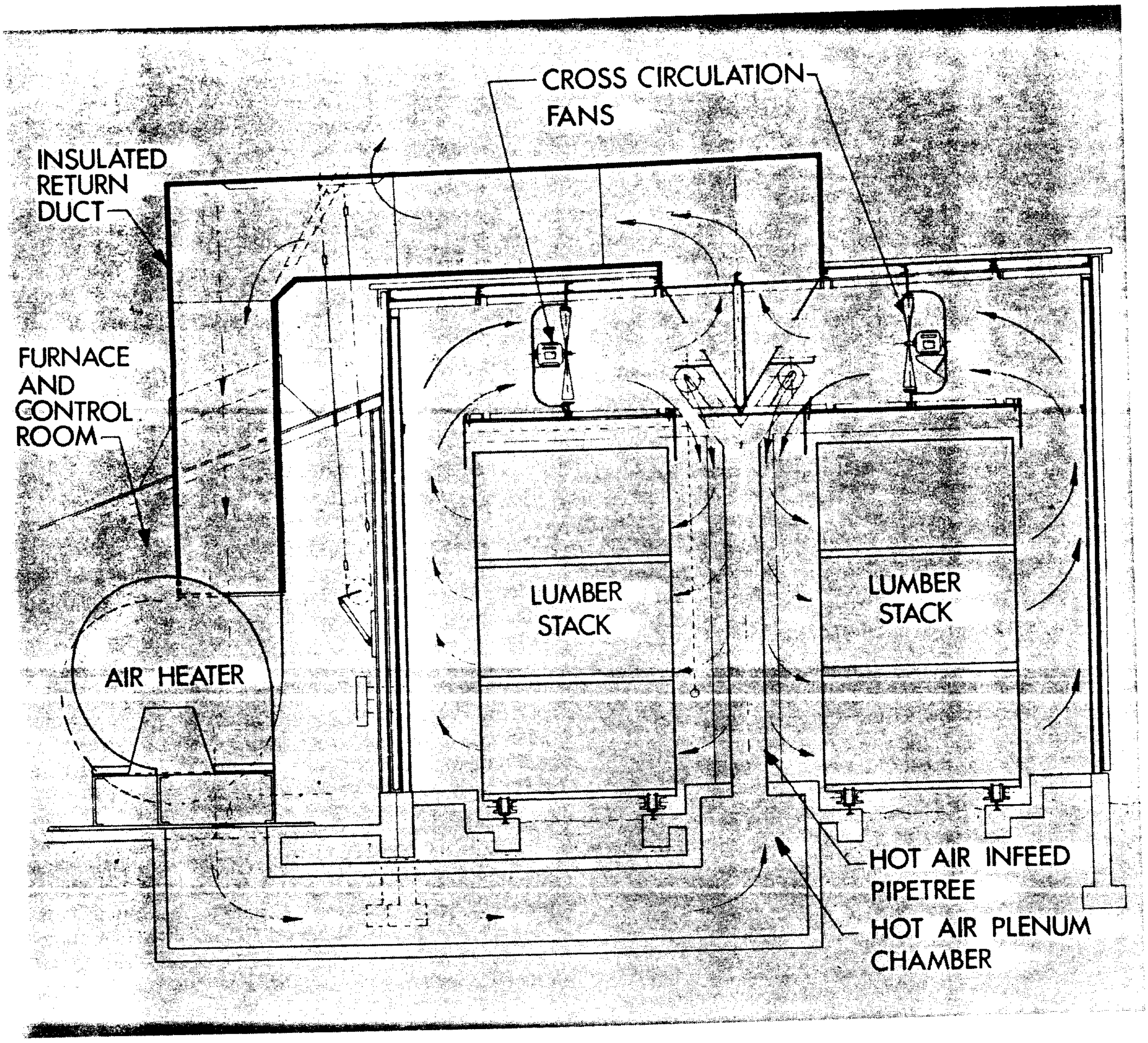

Fig. 5.13 Schematic of Bachrich method of air circulation in a hot-air kiln

sometimes used as a heat source. Strip heaters are arranged in about the same locations as the coils in a steam kiln and serve the same purpose. This form of energy is clean and easily controlled, but its cost is not usually competitive with conventional fuels and the required number of kilowatts is not often available. Electricity may be used more efficiently to operate a heat pump, discussed subsequently.

Gaseous fossil fuels

Because of the capital and labor costs of steam, and the capital costs and low operating temperatures of hot water systems, many small-and medium-sized Canadian mills have installed hot-air kilns. Almost ail these kilns use natural gas, propane or butane as fuel, although a few use oil or wood waste.

There are two basic arrangements for the burner in units burning fossil-fuel gases. In one, the burner is installed externally in the control room at one end or at the side of the kiln; in the other it is located in the kiln itself.

In the external system, gases are withdrawn from the kiln, passed around the jacket of the burner (the furnace scroll) to maintain a low jacket temperature and extend burner life, and are mixed with combustion gases in such proportion that the mixture has a temperature of 350° to 400"F (1 75° to 200°C). In one design, the hot gases enter a subfloor plenum and are led to vertical "pipe trees" which lead, in turn, to each kiln fan where the hot air is discharged (Fig. 5.1 3).

In another external arrangement, heated air is discharged into a plenum running the full length of the kiln under the false ceiling. Part of the air in the plenum is vented into the kiln through holes along the plenum, the remainder being conducted downward into a series of vertical columns, each having two full-length exhaust slots on opposite sides through which the hot air is discharged uniformly throughout the kiln.

An alternative arrangement eliminates the need for external burners and blowers, and reduces construction costs accordingly. In this arrangement, fuel gas and combustion air are separately piped to a series of urn-type burners installed over the false ceiling. Brick flues extend approximately one foot (30 cm) above the level of the burners, protecting the flames from drafts. The products of combustion are discharged directly into the kiln near the fans. To avoid condensation forming on the combustion-air intake and falling onto a load, the intake must be insulated or the combustion air heated to at least the dew point. Alternatively, the air intake may enter the kiln over the alley between loads or along the wall, so that the condensate will fall onto the floor.

Natural gas has considerable advantages where it is available: there is no need for storage facilities, and it is usually cheaper than other gases. Where natural gas is not available, condensed propane or butane may be used. At normal temperatures, all these gases mix intimately with air to give complete and smokeless combustion and are free of ash. However, since both gases are transported and stored under pressure in liquid form, evaporation of the liquid to form the gas requires considerable heat. In the case of propane, this heat is absorbed from the atmosphere and no special procedures are required. In the case of butane, with its higher boiling point, the liquid must be heated to convert it to a gas.

Fuel oil

Where fuel costs are favorable, oil is sometimes used to heat direct-fired kilns. Oil fuels differ from gaseous and compressed gaseous fuels in one important respect: they usually have sulfur-bearing components, which burn to form sulfur dioxide. Sulfur dioxide can dissolve in condensed moisture in a kiln to form sulfurous acid, which will corrode most kiln metals and shorten kiln life considerably. It is, therefore, important in purchasing fuel oils to specify oils with less than 0.1 percent of sulfur in order to avoid corrosion.

Wood waste

Recently (and in some earlier, less successful units) wood waste has been used as a fuel for direct-heated kilns. The advantage of low fuel cost is largely offset because complete, smokeless, particulate-free combustion requires an elaborate combustion unit. Several types of combustor have recently been designed on an experimental basis to fulfill this need, but only the vortex type is in commercial production as this bulletin is prepared. All the wood combustors so far produced are extremely efficient, therefore they do not consume a large proportion of the wood waste produced by a mill.

Gasification

Wood residues may be converted by an anaerobic-distillation process into producer gas, a combustible mixture of gases containing a high proportion of hydrogen and carbon monoxide. This gas is similar to the "manufactured gas" produced from coal, which was distributed in large centers before the distribution of natural gas became so widespread. The advantage of this process to a sawmill is that the gas can be burned to provide a convenient source of heat to dry lumber, heat the mill in winter, and perform other functions. At this time, the first modern commercial unit in western Canada is being installed.

Heat recovery in kilns

The cost of fuel and the large quantities used have prompted several attempts to recover heat from kiln exhaust to heat the incoming air or to maintain the temperature within the kiln.

In Scandinavia, many kilns are equipped with heat exchangers to use the exhaust gases to heat the incoming air. These kilns normally operate up to 160"F with wet-bulb temperatures of about 140"F. Air makes up about 85 percent of the discharged exhaust. Since this air must be replaced in venting, considerable energy may be saved if the incoming air is preheated by the exhaust. Under conditions used in western North American, i.e. a wet-bulb temperature of about 180°F, air constitutes only about 50 percent of the atmosphere and even less at higher wet-bulb temperatures. Consequently, because less air must be heated per pound of water evaporated, the potential savings are less and a heat-recovery system is seldom installed.

Another system developed in Europe involves the installation of a heat pump (similar to an electric refrigerator) in a kiln. Such a kiln is not equipped with vents; rather, the moisture of the kiln atmosphere is condensed on the cold coils of the heat pump and drained off, so that this type of kiln is frequently referred to as a "dehumidifier". The heat of evaporation which is given off by the condensed water is transferred by the heat pump to the hot coils, where it is used to reheat the kiln atmosphere. Substantial heat savings are realized, although the savings are partly offset by the cost of electrical energy to drive the heat pump.

Humidification

In a gas-fired kiln with complete combustion and no excess air, the wet-bulb temperature will approach 130°F at the end of drying. Where final conditioning is necessary to relieve casehardening, steam must be injected.

Even where it is available, high-pressure steam should not be used directly to humidify the kiln. Steam at 100 psig has a temperature of 338"F; at this temperature, while adding to the kiln's absolute humidity, steam will increase the kiln temperature so much that it will actually cause a reduction in **relative humidity.** Humidification should be done with steam at as low a temperature as possible; that is, at 15 psig pressure. Where high-pressure steam must be used, it should be mixed with a water spray controlled by a thermostat to desuperheat the steam.

An alternative arrangement, which has not been used commercially to the knowledge of the authors, is to place in series (a) the steam-control valve actuated by the wet-bulb controller, (b) a steam-reducing valve to about 5 psig, (c) distributor headers to a series of troughs containing water maintained at constant level by a constant-level control valve. When the wet bulb calls for humidity, steam is admitted into the water troughs, bringing the water to the boiling point and generating large quantities of low-pressure desuperheated steam,

installations of hot- or cold-water sprays are quite common in the industry. However, in many kilns so equipped the equipment is never used because of its ineffectiveness in changing kiln humidity. This is because evaporation of hot water at 212°F requires 970 Btu of heat per pound (2.3 megajoules per kg). The heat of evaporation must be taken from the air in the kiln. It can be shown that about 1200 cubic feet (34 m^3) of air must be intimately contacted and cooled 40°F (22°C) in order to evaporate one pound (0.45 kg) of water. This intimate contact and cooling is not possible in practice. Most of the water sprayed into the kiln does not evaporate, but falls to the floor and drains away. As a result, there will be little increase in kiln humidity by the use of hot-water sprays. Where cold water is sprayed, even more heat is necessary, and the kiln atmosphere will be cooled, even though little water is evaporated.

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CHAPTER 6

SCHEDULE RECORDING AND CONTROL

Recorder-Controllers

An essential feature of a modern dry kiln is the temperature recorder-controller, which measures and records conditions prevailing within the kiln and controls them so that they coincide with those preset by the operator. These are sensitive instruments, which can supply accurate information as to kiln conditions only as long as they are properly calibrated and in good operating condition; therefore, a regular maintenance program is essential. An understanding of the principles of operation of kiln instruments will enable an operator to use them most effectively.

The recording hygrometer or psychrometer records on one chart both dry-bulb and wet-bulb temperatures. Recording thermometers may be actuated by mercury, gas, or vapor. In all these, the pressure developed by expansion or evaporation of the fluid contained in the sensor in the kiln moves an expandable device in the recorder-controller housing; this, in turn, operates a recording pen and a device that controls the operation of heaters, steam valves and vents to maintain the desired conditions within the kiln.

Vapor-actuated thermometers are the most widely used in Canada. They can be recognized by the fact that temperature graduations on the chart increase in size at higher temperatures.

Automatic Control of Kiln Drying

Three distinct systems of recorder-controller have been developed to automate the kiln-drying process. The first provides automatic control of time-based schedules, the second and third of moisture-content-based schedules.

Time-based control

Practically all commercial kilns in North American are equipped for control of time-based schedules. Their use requires the preparation of two cams, one to control the dry-bulb temperature, the other to control the wet-bulb temperature. The operation and maintenance of this type of recorder are described in detail by McIntyre (see bibliography).

Moisture-content-based control

Since the changes in a stepwise drying schedule are best made when the lumber reaches various mcs, moisture-based schedules provide better potential for control of the drying process. Two control systems have been devised, based on variations of this principle.

Gann System

A European system for drying lumber, called the Gann system, controls the ratio of the actual wood mc and the equilibrium me of the kiln air. The system requires continuous measurement of kiln temperature and emc, as well as estimation of average wood mc. Lumber mc is determined by sets of resistance electrodes inserted into predrilled holes in each of three boards preselected from the kiln charge. Kiln temperature is determined by a remote sensing dry-bulb thermometer. Equilibrium moisture content of the kiln atmosphere is determined by resistance measurements across electrodes clamped to a small wood specimen in the kiln. In the case of softwoods, this specimen is usually made of the same wood as that being dried. For hardwoods, one species (abura, a west African wood) has been found representative of all.

Experiments in the United Kingdom have shown that, whereas the degrade obtained is within commercially acceptable limits, it has not been reduced over that obtained with manually controlled drying, nor has kiln-residence time been reduced. The system is relatively expensive, adding substantially to the intial investment of a kiln.

Weight-Based System

A system developed in the United States is now in operation, whereby the kiln charge itself is considered as the “sample board”. Its average initial me must be predetermined by ovendtying samples cut from several typical boards.

The whofe kiln charge, or some representative part of it in a large kiln, is mounted on one or more load cells which deliver a voltage proportional to the load. This output is made to rotate the drum of the programmer (double-track analog). The automatic programming system, using cams that call for specific dry-bulb and wet-bulb settings at each weight or mc, has three components that:

(1) continually measure the wood mc in the kiln by weight;

(2) determine the desired dry- and wet-bulb settings for the measured mc, and

(3) proportionally open or close valves or vents to obtain desired temperatures. Faster drying and better temperatures control are claimed for the system.

Moisture content determination by weight "is as reliable at high mc as at low mc — a definite advantage over the system of continuous mc monitoring of selected boards by resistance moisture meter, as described above. However (as in the kiln-sample-board system), some boards must be cut initially in order to determine the relationship between load weight and mc. Selection of the sample boards is critical to the reliability of the system. A second disadvantage is that only an average mc of the load is obtainable during the kiln run.

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CHAPTER 7
KILN MAINTENANCE

Building

Proper drying of lumber requires that the kiln building and its equipment be maintained in good working order. This means that all aspects of the kiln should be inspected at regular intervals and, where deterioration, wear, or faulty function are indicated, the affected equipment should be repaired.

Vapor barriers

The most serious factor affecting the kiln building is the action of moisture on the construction material. Heat diffuses from areas of"high temperatures to areas of low temperature. Vapor diffuses from high- to low-pressure areas. Within a kiln both the temperature and vapor pressure are high, but outside of a kiln both are relatively low. Consequently, unless prevented there is diffusion of both heat and moisture from a kiln, through the walls and roof, to the outside.

A maximum or saturation concentration of water vapor exists at any temperature. Since a temperature gradient occurs through the walls of a kiln, vapor passing through the wall may be cooled below its saturation temperature, and condense within the kiln wall. Depending on the construction of the wall, various damaging effects may occur. Wood may be decayed, metals corroded, concrete deteriorated and spalled off in freezing weather, and the effectiveness of insulation material very much reduced. Consequently, in **order to protect the kiln construction material, the inner walls must be covered with a continuous moisture or vapor barrier. Where the construction material itself is not a satisfactory heat insulator, the structure must be insulated to prevent the loss of heat.**

Various proprietary kiln coatings are used **as vapor barriers and insulators.** To be effective, the following general requirements must be met by the kiln coating system:

1. Where the construction material is not a vapor barrier, the coating must be one.
2. Where the construction material is not an insulator, the coating must be one.
3. The coating must adhere to and have substantially the same thermal coefficient of expansion as the construction material, so that it will not be cracked or broken with repeated large changes of temperature.
4. The coating must maintain its effectiveness at **any** proposed combination of operating temperatures and humidities.

The least expensive materials are the mastics consisting of asphalt, creosote and asbestos fiber, or asphalt and aluminum flakes. The use of a light initial coat followed by a heavier coat within six months is generally recommended. The light initial coat improves adhesion, while the heavier coat provides body and flexibility to accommodate temperature changes. The second coat, applied after the building has settled, bridges and fills settlement cracks in the mortar joints, thus adding to the service life of the kiln. These coatings have the disadvantage of losing their flexibility with time (more rapidty at higher temperatures) and subsequently pitting or developing microchecks, permitting vapors to pass into the kiln wall. Consequently, they must be reapplied at approximately yearly intervals: more frequently for kilns operated at high temperatures and less frequently for low-temperature operations. A normal application of a kiln coating, with some patching of cracks, will usually cost about one percent of the value of the kiln and will ensure a year's additional service.

Synthetic resin coatings are now becoming more common, in spite of their higher initial cost. They have the advantage of being a more effective vapor barrier and they are less subject to change of characteristics with time and temperature. Because they are applied in much thinner coats, however, they have less ability to accommodate to change of dimensions and must be applied to materials with similar coefficients of expansion. For this reason, epoxy resins are limited to use on steel.

Foamed-in-place (expanded) polyurethane resin applied by a spray to the inner walls and ceiling of kilns, followed by a seal coat of either polyurethane or asphalt, acts as both an excellent insulator and vapor barrier. External application of plastic foams (e.g. on kiln roofs) can be effective in reducing heat losses and, when suitably covered, provide a waterproof shield. In the past, there have been cases of separation of this foam from internal kiln surfaces at temperatures of more than 200"F (90"C), but the new formulations are said to be stable up to about 250"F (120"C). Where high humidities are used for long periods of time, kiln coatings of all types may be damaged and may become separated from the wall construction. Because of the current trend to higher drying temperatures, kiln operators should know the limits of their kiln coating and operate within them.

While vapor barriers prevent most of the vapor within the kiln atmosphere from penetrating the walls, at least a small quantity of vapor will penetrate them. The walls should, therefore, be finished on the outside so as to permit the easy escape of such vapors to atmosphere. Such walls are said to "breathe".

Doors

Because of large heat losses around doors, these are relatively cool kiln areas and are usually wet with condensation. Doors are also subject to physical damage as a result of being opened and closed, and being exposed to passing loads and forklift trucks. The result is that doors are subject to both mechanical damage and corrosion. Damaged doors provide no protection to the insulation they contain and thus provide an easy path for heat losses.

Holes in doors should be repaired as soon as discovered. Rust spots on steel should be cleaned and painted with black asphalt paint. Wheels on door carriers should be oiled regularly,

Vents

Vents should be checked at monthly intervals to ensure that all actuating rods are properly connected, and that the vent hinges are in proper repair and are well lubricated. The check should ensure that the vents will open completely and close tightly.

Fans

The proper operation of lineshaft fans requires that they be alternately left- and right-handed along the shaft. It is essential, therefore, when removing a defective fan that it be replaced by one of the same "hand". Use of the wrong fan will simply short-circuit the air being blown by adjacent fans, with the result that lumber in that part of a kiln will receive little or no air and will not be dried.

Blown fuses in cross-shaft fans will short-circuit air in the same way. If a fan fuse blows, or its breaker trips, it will not start electrically. However, the pressure generated by neighboring fans will result in the fan being driven backward. Because it is turning, a casual look will indicate that it is operating when, in fact, it is not. When fans are being checked, 'it is necessary to check also **that they are turning in the proper direction.**

When a fan fuse is being checked or replaced, it should be done when all fans are stopped. Because operating fans turn an unpowered fan backwards, suddenly applying power to such a fan will cause a very high current demand and will blow the fuse again or, in extreme cases, burn out the motor.

Every three months, the mounting bolts of all cross-shaft fan motors should be checked. If a motor has been replaced, its mounting bolts should be retightened after a week's operation. At the same time that the motor mounts are checked, the fans should be greased. To do this, remove the bottom plug at each end and pump grease into the top plug until it comes out clean at the bottom. Then run the motor for 10-15 minutes before replacing the bottom plug. This will permit the grease to heat and expand without danger to the grease seals.

Baffles

Properly working baffles are required to direct the air uniformly through the loads, yet forgetfulness or carelessness can result in baffles being damaged so that they cannot function. All baffles should be checked for proper operation as they are set for each charge. Upper baffles should be properly equipped with chains and pulleys. When released, they should swing freely to rest on a load. Floor baffles should move freely to lie flat when not in place, and to rest evenly against a load during drying. Corner baffles should contact loads and be held there during air reversals.

Burner Safety Controls

The burner has a complex set of safety controls which shut it down if it performs in an improper or dangerous manner. A satisfactory pilot flame and flame sensor circuit must be established within 15 seconds of start-up. Otherwise, a burner will shutdown and the protecto relay must be reset. A low-pressure gas switch monitors the gas pressure downsteam from the regulator to ensure adequate gas pressure. A high-pressure gas switch monitors the gas pressure before gas enters a burner to prevent overfiring. The high- and low-pressure gas switches are set by a qualified gas fitter at start-up and should not be readjusted by anyone but a qualified service representative.

Direct-fired burners require an unobstructed air source.

The combustion-air pressure switch monitors and ensures adequate pressure of combustion air. Any reduction in pressure will shut down a burner. This ensures that the combustion-air blower must be running before a burner will fire. The combustion-air blower impeller and air inlet must be kept free of accumulated dust, dirt, grease, frost or ice. Such accumulation will reduce air to a burner, resulting in a very yellow, dirty flame indicating incomplete combustion. Not only is this a dangerous situation, it also results in dirty lumber. Because of possible frosting of the plenums when outside temperatures are below freezing, makeup-air heaters (preheater for combustion air) should operate when outside temperatures are 34°F (1 ‘C) or less. To ensure proper operation of kiln controls, makeup-air heaters should be arranged so as to heat the air entering the control room.

The recirculating-air blower supplies an adequate flow of air to remove heated air from the burner and distribute it throughout the kiln. The motor controller is interlocked into the burner circuit and must be running before the burner will start. Operation of the blower is also detected by a pressure switch on the burner plenum. Any blockage of return air from the kiln, belt slippage or breakage between the blower motor and blower shaft — anything that reduces the air flow through the plenum — will be detected by this switch, which will shut down the burner or cause it not to fire-UP. This switch is set by a kiln serviceman and should not be readjusted.

The burner-plenum-temperature high-limit switch prevents overheating of the burner plenum and excessive hot air entering a kiln. This switch is adjusted when the kiln is installed and should not be readjusted without consent of the manufacturer’s or other competent serviceman.

The kiln high-limit switch, placed in the return-air duct, prevents overheating in the kiln proper. This switch locks out on excessive temperatures. The trouble must be found and the switch reset before the burner will start. The flame safeguard protecto relay will program the firing sequence and monitor the flame. The protecto relay must not be tampered with by anyone but a qualified gas fitter or qualified electrician. The cover must be kept on, since dust can make it useless and dangerous.

When not absolutely sure of the problem, contact a qualified serviceman. DO NOT operate the dry kiln with any of the relay switches or other safety devices jammed out, jumpered out, or set to abnormal limits. DO NOT operate a dry kiln with defective equipment.

If jumpers are used for trouble shooting or service checks, make them about 12 feet long, so as not to forget to remove them. Have all the instruments checked out at least once a year by a qualified serviceman for safe, trouble-free operation.

Steam Traps

Steam traps should be checked at monthly intervals. If they fail to operate, the steam coils may become waterlogged and fail to emit heat. Check valves should also be checked for dirt preventing their proper operating. If the condensate is being returned to the boiler, the filter usually installed to remove dirt and oil must be checked and cleaned regularly.

Instrumentation

The calibration of a recorder-controller should be checked at six-month intervals. The instrument should be recalibrated if more than about 3°F (2°C) out of adjustment. A recorder-controller and other instruments operate on compressed air, so the compressor and air filter should be blown down every day to remove moisture which otherwise could enter the instruments and prevent their proper operation. The air supply itself should beat 20 psi(135 kPa).

Service

It should not be expected that every kiln operator be a competent serviceman. He should, therefore, arrange for annual servicing by a qualified kiln serviceman. Such a serviceman will recommend reapplying kiln coatings when necessary, will check and grease motors, check limit switches and burner operation, and check and, if necessary, calibrate instruments.

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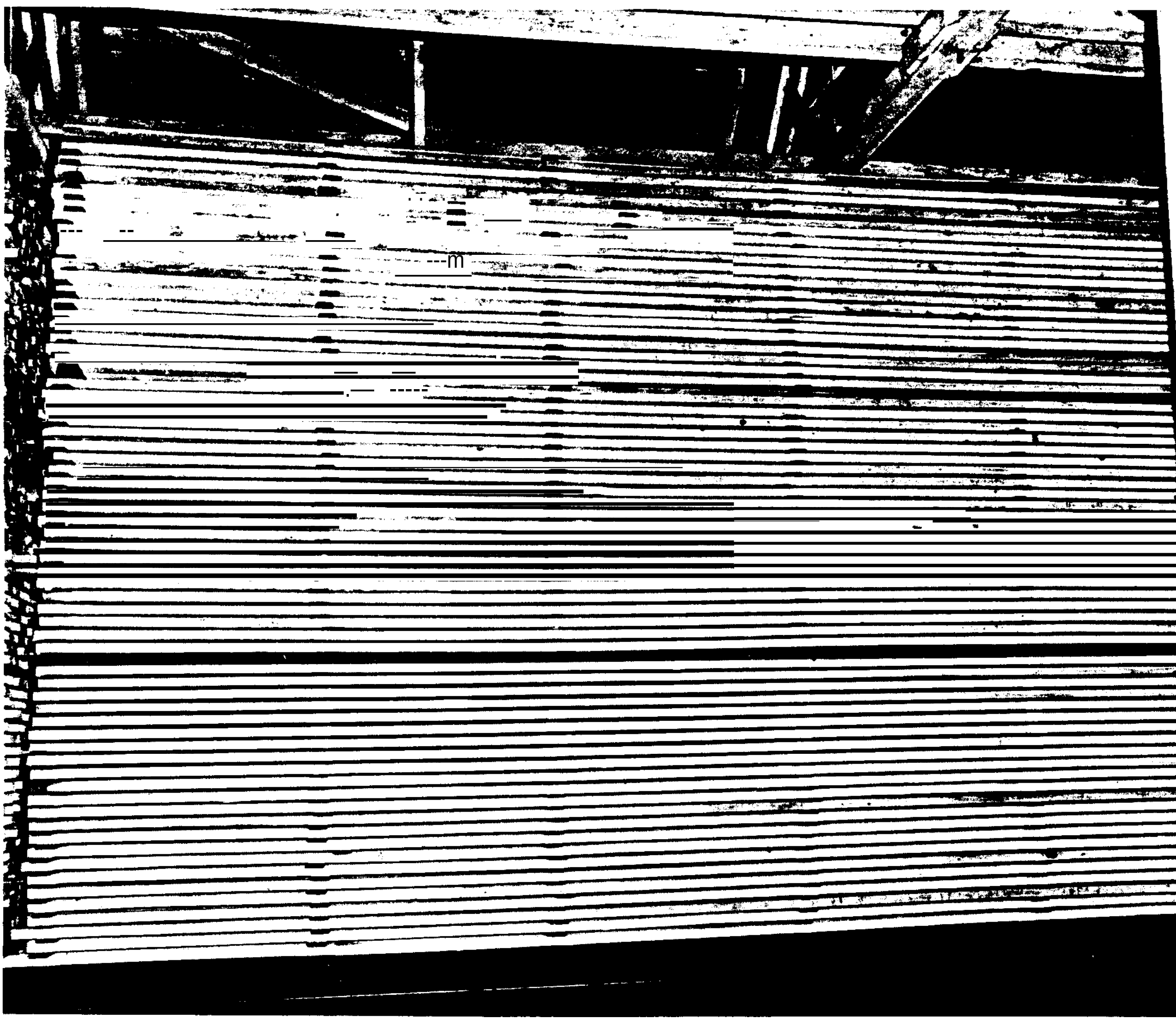

Fig. 8.1 Load of lumber properly piled and stickered in preparation for drying. Note vertical alignment of stickers.

CHAPTER 8
PILING LUMBER FOR DRYING

The objectives of proper piling are: to minimize degrade, in so far as this is affected by drying conditions; to attain the desired final moisture content as uniformly as possible; and to maximize lumber throughput.

Segregation

The drying time of any piece of lumber is determined, not onty by the schedule used, but also by lumber characteristics, such as species, which determines density and permeability, mc and thickness. Consequently, production can be increased and a more uniform product obtained by drying lumber of uniform characteristics. A charge of lumber should, therefore, consist of wood from a single species, or mixed species of similar drying characteristics, a single dimension, and a low range of initial mcs.

The mixing of several lengths in the same load results in overhanging ends, leaving large gaps between loads. Because air passing through these gaps bypasses the greater part of a load, overall circulation is reduced and drying time increased. While the greater part of the load is exposed to reduced circulation, the overhanging ends are exposed to an abnormally high volume of air and dry considerably faster than the bulk of the charge. This results in both nonuniform drying and end-checking of lumber. Furthermore, because of lack of support and restraint, the ends are subject to warping and breakage. In many mills, due to insufficient space at the green chain, it is necessary to pile more than one length in the same load. Even so, many in the industry believe that not more than two lengths should be piled together. If nonsegregated lumber must be dried, box-piling is recommended. In this method, the longest pieces are placed at the side of a pile in order to restrict the amount of air bypassing a load. Shorter pieces are placed on the inside, placed alternately flush with either end. There should be no overhanging boards.

Types of pile

In end-loading softwood kilns, loads are 8 to 9 feet (2.4 to 2.7 m) wide and maybe piled as a single unit of this width or as packages of about half the width.

A full-width unit pile must be transported on rails and requires a direct throughput from lumber stacker to kiln to unstacker. Where more than one kiln is operated, provision must be made for a transfer car to act as a switching device, to place loaded cars on the appropriate kiln track.

In mills using half-width packages, loads are transported to and from the kilns by lumber carriers or forklift trucks. While this requires somewhat more labor in preparing and unloading kiln charges, it provides considerably more versatility in the operation. Loads can be transported to air-drying yards for partial seasoning before kiln drying. Where desired, lumber of a particular type can be bypassed after being stacked for drying. In side-loading systems, because of the limitations of the lumber carrier, packages 4 to 4.5 feet (1.2 to 1.2 m) wide are used entirely. Most hardwood kilns also use the smaller packages.

Stickers

Stickers permit air to pass between the courses of drying lumber. Their characteristics and placement has an important bearing on the quality of lumber produced. Stickers should be numerous enough to avoid being compressed or compressing lumber in the lower courses of a load, but they should also be narrow enough to avoid wet spots or staining where they contact the lumber. In drying softwoods, these requirements can be met by placing 3-inch (8 cm)-wide stickers at approximately 4 foot (1.2 m) intervals and, in drying hardwoods, by placing 1.5-inch (4 cm)-wide stickers at 2-foot (0.6 m) intervals

Sticker thickness has an effect on drying efficiency. As sticker thickness is reduced to about 3/8 inch, the air **velocity** over the lumber is increased but the **quantity** of air per minute is reduced. Consequently, there is a greater temperature drop across a load with thinner stickers, so that the center and the exit side of a load dry more slowly. The additional kiln capacity obtained by the use of thinner stickers is usually offset by the increased drying time required. Some increased cost for fan power may be expected.

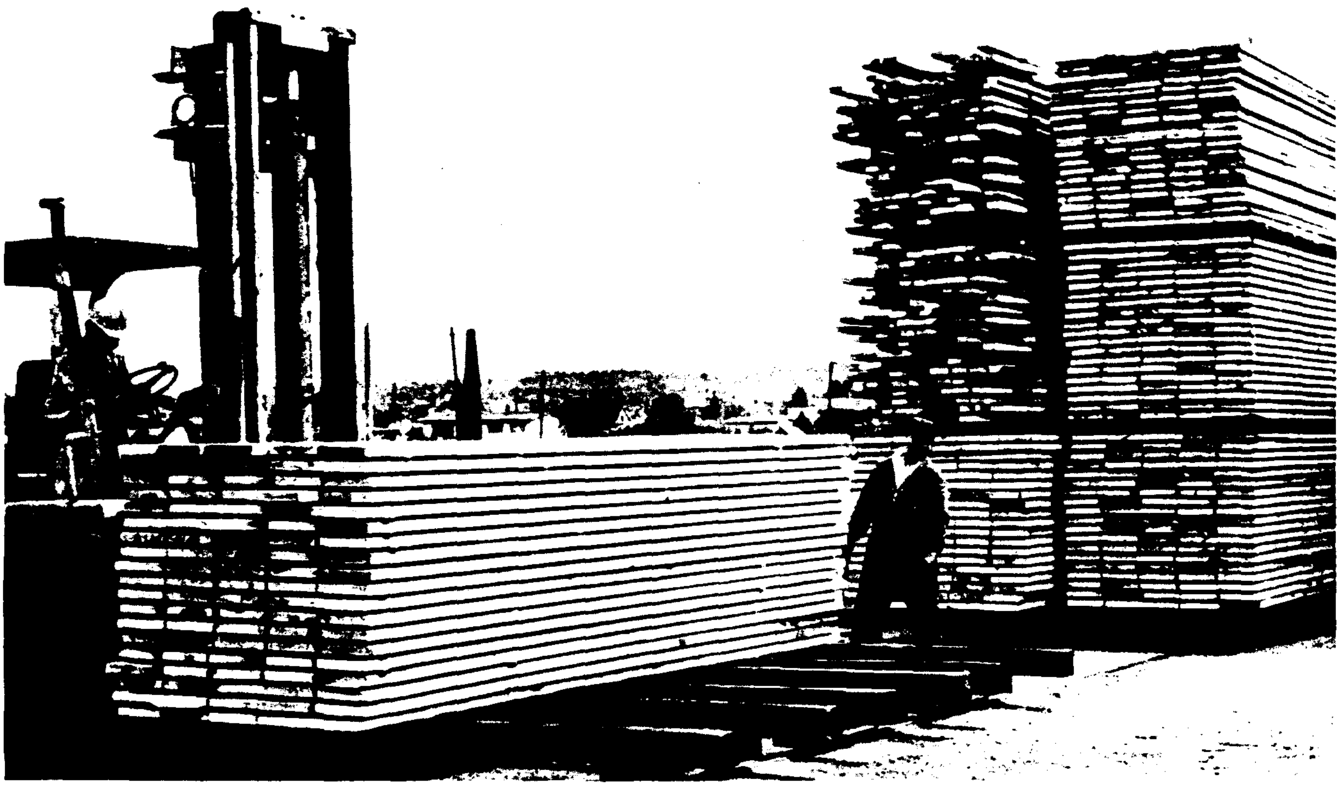

Fig. 8.2 Preparation of kiln charge using forklift packages. Note chimnev between adjacent loads.

The stiffness and strength of stickers has an effect on drying uniformity. At the bottom of a pile, stickers of low compressive strength may be crushed as a result of their **plasticity** at kiln temperatures. Furthermore, where a sticker **must bridge a gap, as when a piece of lumber is missing or thin, it may be sheared or bent, reducing or eliminating the space between** courses and cutting off the air suppiy at that point. Strong, stiff stickers of adequate thickness are therefore required to maintain uniform air flow through a load, so that uniform drying can be more readily attained.

Recently, stickers made of a thermosetting plastic were developed for drying lumber. In spite of their high initial cost, there has been a good user reaction. They are stiff enough to bridge gaps normally found in kiln loads and they withstand breakage much better than wooden stickers. They are normally about 1.5 in. (4 cm) wide, resufting in some crushing of lumber in the lower courses. However, indentations are reported to be removed in planing, so that the finished lumber shows no evidence of crushing.

Stacking the lumber

For efficient loading of a kiln, and to prevent bypassing of circulating air over short loads, all loads must be built to the same height. All courses should be of the same width and properly aligned (Fig. 8.1). When a course protrudes one inch (25 mm) beyond the adjacent courses on the air entry side of a load, the next five or six courses will have a restricted circulation.

Forklift packages are built on blocks with the same spacing as the bunks, and are then carried to the kiln truck by a forklift truck (Fig. 8.2). As with unit loads, all forklift packages must be the same height,

When these loads are picked up by a forklift truck, it is not possible to place the forks under the stickers; those points are occupied by blocks. Consequently, the bottom boards may bend, permitting stickers to fall out from the ends of a load. This can be prevented by placing stickers in the lower five or six courses above the points supported by the forks. An alternative method is

Fig. 8.3 Top loading of lumber load to prevent warp during drying

to make reusable straps which can be placed around the package ends and tightened before the package is picked up.

The load on a kiln truck will normally be two packages wide by two to four high. Packages are separated from those above and below by 4-by-4-inch (10 by 10 cm) bunks or bolsters. Packages placed side by side across the car should be separated by a 4-inch (10 cm) chimney to assist in air movement through the load.

In side-loading kilns, it is important that blocks under loads be vertically aligned with the stickers.

Mechanical Aids for Piling Lumber

Numerous mechanical aids are in use for economical piling. Automatic stackers not only reduce handling costs, but also result in better sticker alignment, thus reducing degrade from crooked lumber. Where the boards are of uniform width and length, the edges of the stack will be smooth and straight, thus ensuring better circulation and greater uniformity in drying. Where the lumber is of mixed widths, boards should be spaced to make both sides even.

Restraining mechanisms

Although most lumber has a tendency to warp when drying, the bulk of lumber in a load will be restrained by the weight of the load above it. The top courses being unrestrained, however, may warp significantly and be degraded as a result. In order to prevent this, various types of wei9hts are frequently placed on top of a load. Such weights should bear directly on the rows of stickers. In Australia, load levels of 110 to 220 lb/ft^2 (5 to 10 kPa) have been found adequate (Fig. 8.3). These are left in place throughout drying, as well as during a 24-hour cooling period.

A more complicated procedure consists of placing light I-beams across the top of a load directly over the stickers and about 6 inches(15 cm) beyond each edge. A restraining device consisting of wire rope and tension springs is attached to each end of the I-beam. The spring is pulled into heavy tension and hooked onto special metal **stickers about 5 or 6 feet (1.5 to 2 m) below the top of the load. Turnbuckles or load binders should not be used, because they do not maintain the tension as the lumber dries and shrinks.**

The restraining systems are particularity effective in the drying of warp-prone lumber from fast-grown pines. They may prove useful in Canada as smaller trees are being sawn.

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CHAPTER 9
OPERATION OF THE KILN

Kiln-Drying Factors

Temperature and Wet-bulb Depression

The rate of drying at any dry-bulb temperature increases as the wet-bulb depression is increased. This depression also determines the surface moisture content (me). Since the difference between surface mc and core mc influences the amount of shrinkage-based degrade, large depressions, particularly in the early stages of drying, can lead to excessive degrade. As drying proceeds, the wet-bulb depression can be progressively increased without resulting in degrade.

The ratè of drying for any depression increases with increasing dry-bulb temperature. Consequently, by choosing a "safe" depression for any stage in drying, the drying rate can be increased by increasing both dry- and wet-bulb temperatures by the same amount.

These rules have been used extensively in the lumber industry to produce high drying rates with an acceptable amount of degrade.

Drying at higher temperatures usually results in a wider range of final mc, although an acceptable range of mc can be obtained by a suitable choice of wet-bulb depression. In direct-fired kilns with no supplementary steam for humidification, wet-bulb temperatures cannot exceed about 170"F (75°C). Consequently, higher operating temperatures in a direct-fired kiln will usually result in large wet-bulb depressions, increasing the range of mc, and the possibilities of overdried as well as non-conforming lumber.

Species Characteristics

Commercial woods from western Canada, as well as from many other regions, may be divided into several categories, based on their tendency to develop certain types of drying defect. These are listed below:

Characteristic	Examples
(1) collapse prone	wet, impermeable woods: aspen, cottonwood, some true firs, some western red cedar;
(2) wet pockets	aspen, western hemlock, true firs, western red cedar;
(3) shrinkage defects	most woods, but especially impermeable ones: Douglas. fir, alpine fir, western red cedar.

The characteristics of the wood will dictate the type of schedule that must be used to minimize defects. Examples will be found in Chapter 14. Where these or other schedules result in the development of drying defects they should be modified in order to improve quality.

Collapse-prone wood

The conditions which bring on collapse exist at the beginning of the **drying schedule. These** area very high mc and an impermeable wood. Drying temperatures for such lumber must be as low as practical, until air has replaced some of the water in each wood cell. After this, higher temperatures may be used without fear of collapse. In practice, where collapse is encountered even after normal preventive Precautions have been taken, it is recommended that the lumber be air dried for several weeks before kiln drying.

Lumber containing wet pockets

Wet pockets are believed to be zones of high mc enclosed in an impermeable pocket within the wood. Most woods **in which they occur** are subject to collapse, but even in the absence of collapse, the movement of the abnormally **large** quantities of moisture through the outer shell is a time-consuming process. Wet pockets are usually detected by a long-probe resistance moisture meter after discharge from a kiln. it is reported that even after two or three redry ings, some of these wet pockets may still remain. While these pockets contain higher than normal mc and offer a higher than normal resistance to drying, they can be dried by high temperatures and moderate wet-bulb depressions. The purpose of the moderate depressions is to avoid overdrying the remainder of the charge while the wet pockets are being dried.

Woods subject to shrinkage defects

Shrinkage itself is not a defect, but defects arise when adjacent parts of a Piece of lumber undergo different rates of shrinkage. Consequently, where shrink-

age defects are a problem, the solution lies in maintaining a more uniform mc throughout the lumber, or by taking advantage of the plasticity of wood at high humidities and temperatures to permit the various wood components to adjust to the drying stresses. In the case of permeable woods, because capillary flow tends to keep the mc reasonably uniform within a piece, no problems are usually encountered. But in impermeable and semipermeable woods where high moisture gradients are encountered, it is necessary to maintain a relatively high emc, with a reduced rate of drying, to avoid these defects. The best compromise of fast drying rate and minimum shrinkage defects is obtained by drying at high temperatures with moderate wet-bulb depressions.

Stress Relief

The plasticity of wood at high temperatures and humidities can be used to relieve internal stresses in the wood without the development of defects. There are two principal applications of this process. The first is the relief or reduction of bow, twist and crook resulting from unbalanced shrinkage stresses. The second is in the removal of casehardening stresses. For example, shop lumber may require ripping to some other dimension after drying. This may unbalance the drying stresses in the lumber and result in crook or some other form of warp, The internal stresses can be relieved by a final steaming or conditioning treatment. A rule of thumb suggests steaming softwoods at 20"F (1 O°C) above the final dry-bulb temperature for 30 minutes for each inch of lumber thickness. Where humidifying steam is not available, the mill should not accept orders for lumber to be resawn, if the finished product must be warp free.

Precautions in high-temperature operation

Higher temperatures result in faster drying and also in some saving of fuel. Although these benefits may be desirable, it is not always possible or even advisable to substantially increase the operating temperature of an existing kiln unless it has been designed for such operation. Maximum temperatures attainable may be limited by the recorder-controller, the rating of the boiler or heaters, and the radiating surface of steam coils in the case of steam-heated kilns.

The faster drying rates achieved by higher temperatures require faster air circulation to supply heat and remove moisture. If suitable air speed is not available, a wider range of mc between the outside and center of a load results, and full advantage of the schedule is not realized. Degrade may also be increased. Higher temperatures also increase the possibility of kiln deterioration due to greater expansion and contraction of the structural components. Whereas the joints in prefabricated metal kilns can usually accommodate themselves to these dimensional changes, concrete and concrete block buildings cannot and, therefore, should not be used for the higher temperature ranges. Insulation and vapor barriers may also be limited to a critical temperature. Rails placed on the foundation may expand more than allowed for and may lift or twist. Electric motors driving cross-shaft fans may have temperature limitations. These factors shoud be considered before a decision is made to increase the operating temperature.

Kiln Schedule Categories

Temperature Categories

Because of the important relation between kiln temperature and drying rate, drying schedules have been categorized into several broad groups depending on the maximum temperatures used.

Low-temperature schedules are those where the temperature does not exceed 140"F (60°C). Drying times may be measured in weeks. Such schedules are used primarily for temperature-sensitive lumber, particularly for hardwoods. The range of final mc is narrow. Kilns designed for low-temperature schedules are simple and may be constructed of wood or concrete blocks. Air-circulation rate is usually very slow. Baffling may not exist.

Conventional schedules are in the range 140 to 180"F (60 to 80°C). Drying times run to several days. Kilns designed for these temperatures should be well insulated, of concrete block or prefabricated aluminum panels, and have air-circulation rates of 200 to 250 feet per minute (64 to 80 m/min), usually with lineshaft fans. Lumber quality is easy to maintain and, particularly where final equalizing and conditioning is used, final mc is in a narrow range. Traditionally, most softwood lumber used to be dried by these schedules; recently there has been a distinct shift to higher temperatures for construction lumber. Clears and other high-grade lumber are still dried by conventional schedules, however.

Elevated-temperature schedules range from 180 to 212°F (80 to 10O°C). Drying times are 2 to 4 days, depending on species, thickness and initial mc. Prefabricated aluminum kilns are preferred in this range, but concrete block kilns may be used. Air-circulation rates are 250 to 400 feet per minute (80 to 130 m/min). Closer control is necessary than for conventional schedules to avoid overdrying and degrade. Most softwood construction lumber is dried by elevated schedules.

High-temperature schedules are those where the dry-bulb temperature exceeds 212°F (1 OO"C), but the wet-bulb temperature never reaches 212°F (1 OO"C), In some cases, 2-inch lumber can be dried in about 24 hours. Such schedules are restricted to permeable and semipermeable lumber, usually softwoods, which are resistant to drying degrade. There is increasing risk of overdrying and degrading the lumber with increasing temperatures; therefore, control must be much better than average. Air-circulation rates must exceed 400 feet per minute (130 m/min).

Superheated-steam schedules require an atmosphere of water vapor (steam) at atmospheric pressure and a temperature exceeding 212°F (1 OO"C). The emc decreases as the temperature increases, so that the possibilities for degrade increase with increasing temperature. As in high-temperature schedules, air circulation should exceed 400 feet per minute (130 m/min).

Constantly **rising temperature (CRT)**[1] schedules provide rapid drying with good control of degrade. They start at low temperatures of 100/90°F2 (40/35°C). In a typical schedule, the dry-bulb temperature rises at about 4°F (2°C) and the wet bulb at 3°F (1 .5°C) per hour until the former reaches about 230°F (110"C), after which the wet-bulb temperature decreases at about 1°F (0.6°C) per hour until the lumber is dry. In this type of schedule, drying rate is fairly constant throughout. Because it is a fast schedule, it requires accurate monitoring of mc to determine when drying is complete. H is more efficient than step schedules because it avoids sudden changes of emc, which could result in degrade, and because it gradually increases the driving force (or dtying force) as the drying zone recedes toward the core of lumber.

Low-high **schedules** are those in which dry-bulb temperatures remain below the boiling point until the average mc of the lumber is below the fsp. The schedule is then set as a high-temperature one. This type is useful where temperature-sensitive woods are to be dried in a minimum time.

Control basis of schedules

Published schedules are of two types, moisture-content based and time based. Moisture-content-based schedules are usual for hardwoods. An example of such a schedule is shown below.

‘ a patented procesa
[2] dry-bulb/wet-bulb temperatures

mc of wettest sample board	db temp/ wb temp ‘F	db temp/ wb temp ‘C’
Over 30%	1 40/130	60/55
30% to 25%	1 50/135	65/57
25% to 20%	160/1 40	70/60
Less than 20%	1 70/140	75/60

Use of this schedule requires determining the initial mc of the charge and repeated mc determinations to determine when schedule changes should be made. A record or graph should be kept, relating mc to time (and, of course, dry- and wet-bulb temperatures) during the run. After the experience of two or three runs of the same material dried in this way, it is possible to convert it to a time-based schedule. In this case, only the initial mc or the time at which the load reaches 30 percent mc need be known. The previous schedule, partly converted to a time-based one, might therefore be:

Charge mc	db temp/ wb temp ‘F	db temp/ wb temp “F
Over30Y0	1 40/130	60/55

On reaching 30 percent

Time	db temp/ wb temp “F	db temp/ wb temp ‘C
48 hours	1 50/135	65/57
48 hours	160/1 40	70/60
72 hours	1 70/140	75/60

Published softwood schedules are usually time-based, thus relieving the operator of the necessity to make mc determinations. Unfortunately, time-based schedules usually contain no reference to initial mc, nor take into account the inherent differences between kilns, kiln-stack dimensions and air velocity. Many such schedules in the literature require excessively long drying times, and must be modified to meet production requirements. Traditionally, this has been a trial-and-error process.

Calculation of drying rates

The Western Forest Products Laboratory has developed a method of modifying conventional and elevated-temperature schedules for western spruce, lodgepole pine and alpine fir. Five tables (Tables 9.1 to 9.5) are provided to determine the amount of drying, measured in “drying units”, required between various initial and final mcs and the drying units produced per hour by various dry- and wet-bulb settings.

For example, to determine the number of drying units to dry 2-inch alpine fir from 75 percent to 13.2 percent mc, subtract the value for 75 percent (112 units) from that corresponding to 13.2 percent (3356) for a difference of 3244 units (Table 9.5).

Table 9.1

Vapor pressure of water at temperatures from 100° to 239°F (kPa)

Temp. “F	0	1	2	3	4	5	6	7	8	9
100	7	7	7	7	7	8	8	8	8	9
110	9	9	9	10	10	10	10	11	11	11
120	12	12	12	13	13	13	14	14	15	15
130	15	16	16	17	17	18	18	18	19	19
140	20	20	21	22	22	23	23	24	24	25
150	26	26	27	28	28	29	30	30	31	32
160	33	34	34	35	36	37	38	39	40	40
170	41	42	43	44	45	46	47	49	50	51
180	52	53	54	55	57	58	59	60	62	63
190	64	66	67	69	70	72	73	75	76	78
200	80	81	83	85	86	88	90	92	94	96
210	97	99	101	103	105	108	110	112	114	116
220	119	121	123	126	128	130	133	136	138	141
230	143	146	149	152	154	157	160	163	166	169

Table 9.2

Vapor pressure of water at temperatures from 30° to 119°C (kPa)

Temp. “C	0	1	2	3	4	5	6	7	8	9
30	4	4	5	5	5	6	6	6	7	7
40	7	8	8	9	9	10	10	11	11	12
50	12	13	14	14	15	16	17	17	18	19
60	20	21	22	23	24	25	26	27	29	30
70	31	33	34	35	37	39	40	42	44	45
80	47	49	51	53	56	58	60	62	65	67
90	70	73	75	78	81	84	88	91	94	98
100	101	105	109	113	117	121	125	129	134	138
110	143	148	153	158	164	169	174	180	186	192

Footnote: For 83°C, read row 80, column 3, for “53”.

Table 9.3
Drying units required for 2-inch western spruce (kPa-hr)

mc %	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
10	1860	1844	1827	1811	·1 795	1780	1763	1748	732	171.7
11	1702	1687	1671	1657	1642	1627	1613	1599	585	1571
12	1557	1543	1529	1516	1502	1489	1476	1463	450	1437
13	1424	1411	1399	1387	I 374	1362	1350	1338	326	1314
14	1303	1291	1280	1269	1257	1246	1235	1224	213	1203
15	1192	1181	1171	1160	I 150	1140	1130	1120	1110	1100
16	1090	1081	1071	1062	11052	1043	1034	1024	1015	1006
17	998	989	980	972	963	954	946	937	929	921
18	913	904	897	889	881	873	865	857	850	842
19	835	827	820	813	806	799	791	784	777	771
	0	1	2	3	4	5	6	7	8	9
20	764	699	639	585	535	489	448	410	375	343
30	314	287	262	240	220	201	184	168	154	141
40	129	118	108	99	90	82	75	69	63	58
50	53	48	44	40	37	34	31	28	26	24
60	22	20	18	17	15	14	13	12	11	10
70	9	8	7	7	6	6	5	5	4	4

A schedule with suitable combinations of drv- and wet-bulb temperatures must be prepared, so that over the duration of the schedule the total of the drying units produced adds up to the total number of drying units required for the charge. One suitable schedule would be:

Time (hr)	Temperature ‘F Dry-bulb (F”)	Wet-bulb (F”)	Drying Units perhour(kPa)	Total
(1)	(2)	(3)	(4)	(5)
10	180	160	52 –33 = 19	190
10	190	160	64— 33 = 31	310
58.4	200	160	.80 —33 = 47	2745
Total 78.4				3245

Total drying units (5) are obtained by multiplying columns (1) and (4); e.g. 10 X 19 = 190 units. The above example provides a schedule of 78.4 hours drying time, which should result in lumber of the desired mc. For reasons of simplicity, a step schedule was used in this illustration.

No two kilns are identical: since rate of air” flow through the load has a major effect on drying rate, any differences in fan speed, sticker thickness, width of alleys between loads and wall, effectiveness of baffling, and other similar factors, will result in different drying times for the same kiln schedule. Therefore, if the same schedule is used for different kilns to dry the same type of material, one will dry more quickly than the other. Consequently, the values read from Tables 9.3 to 9.5 (drying units required) will need to be modified to suit each individual kiln. This may be done by calculating the drying units expended by a schedule already used to dry the same type of lumber between known initial and final mc, and comparing the results with the drying units listed in the table. A “kiln factor” can then be calculated

Table 9.4
Drying units required for 2-inch lodgepoie pine (kPa-hr)

mc '%0	**0**	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
10	3506	3453	3402	3352	3303	3255	3209	3163	3119	3075
11	3033	2991	2950	2911	2872	2834	2797	2760	2724	2689
12	2655	2622	2589	2557	2525	2494	2464	2434	2405	2376
13	2348	2321	2294	2267	2241	2216	2190	2166	2142	2118
14	2094	2072	2049	2027	2005	1984	1963	1942	1922	1902
15	1882	1863	1844	1825	1806	1788	1771	1753	1736	1719
16	1702	1685	1669	1653	1637	1622	1607	1592	1577	1562
17	1548	1533	1519	1506	1492	1479	1466	1452	1440	1427
18	1414	1402	1390	1378	1366	1354	1343	1331	1320	1309
19	1298	1287	1277	1266	1256	1246	1236	1226	1216	1206
	0	1	2	3	4	5	6	7	8	9
20	1196	1106	1026	955	890	833	780	732	689	649
30	612	579	548	**519**	492	467	444	423	403	384
40	366	349	334	**319**	305	292	279	267	256	245
50	235	226	216	**208**	199	191	184	176	169	163
60	156	150	144	**138**	133	128	122	118	113	108
70	104	100	96	**92**	88	84	81	77	74	71

by dividing the drying units required for a known schedule by the drying units listed in the tabies.

For example, suppose that an established schedule for drying 2-inch spruce iumber from 52 percent to an average of 12.8 percent has 1625 drying units. According to Table 9.3, the listed value for this moisture content range is as follows:

Drying units at 12.8% mc	1450
at 52% mc	44
Drying units needed to dry lumber	1406

But the species-thickness-kiln combination being used, as stated above, actually dries it with 1625 units. The "kiln factor" for this combination is therefore 1625/1 406 = 1.16. All estimates of drying units required, taken from the table, should now be multiplied by 1.16 to obtain the value for that particular kiln drying 2-inch material of that wood.

The procedure outlined above is suggested for calculating schedules only for conventional and elevated-temperature drying of the woods listed. In the case of high-temperature drying, mass flow is the main process of moisture movement, and the tables will not give useful results. At this date, the method has not been used to any extent in industry, nor does it provide guidelines for avoiding degrade. It should, therefore, be used as a guide only, to indicate the relative effectiveness of various kiin settings.

Table 9.5
Drying units required for 2-inch alpine fir (kPa-hr)

mc %	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
10	4002	3980	3958	3937	3915	3893	3872	3851	3830	3809
11	3788	3767	3746	3726	3705	3685	3665	3645	3625	3605
12	3585	3565	3546	3526	3507	3488	3469	3450	3431	3412
13	3393	3375	3356	3338	3319	3301	3283	3265	3247	3229
14	3212	3194	3177	3159	3142	3125	3108	3090	3073	3057
15	3040	3023	3007	2990	2974	2957	2941	2925	2909	2893
16	2877	2861	2846	2830	2815	2799	2784	2769	2753	2738
17	2723	2708	2693	2679	2664	2649	2635	2620	2606	2592
18	2577	2563	2549	2535	2521	2508	2494	2480	2466	2453
19	2439	2426	2413	2400	2386	2373	2361	2347	2334	2322
	0	1	2	3	4	5	6	7	8	9
20	2309	2185	2068	1958	1853	1754	1660	1571	1487	1407
30	1332	1261	1193	1129	1069	1012	958	906	858	812
40	769	727	688	652	617	584	553	523	495	468
50	443	420	397	376	356	337	319	302	286	270
60	256	242	229	217	205	194	184	174	165	156
70	148	140	132	125	119	112	106	100	95	90

Operating the kiln

Starting the kiln

Once the schedule has been decided on, the kiln is started as follows:

1. Load kiln with lumber;
2. Close top baffles against loads;
3. Close bottom baffles, if required;
4. Check water flow to water box of wet-bulb thermometer; water should drip from overflow;
5. Close main kiln doors (always keep kiln doors on door carriers or door hooks in place; do not set kiln doors on blocks on the ground);
6. Check ink supply in recorder pens;
7. Replace chart on the recorder-controller. For automatic control, reset or replace appropriate cams for the type of lumber being dried. Replace cam followers on the cams. For manual control, set dry and wet bulbs at initial values.
8. Blow off condensation from air filter and compressor;
9. Check that air supply to the recorder-controller is at approximately 20 psi.

Manual kiln control

In modern kilns equipped with a recorder-controller, the two most important parameters in kiln schedules, dry-bulb and wet-bulb temperatures, may be controlled either manually or automatically. The so-called manual operation is, in fact, semiautomatic, in that the conditions, once set by hand, are maintained automatically by the controller. When new settings are required, they must be reset by hand. This type of operation results in step schedules, where constant conditions are maintained for several hours until new conditions are required.

Settings may be changed at various mcs of the charge, as is common in drying hardwoods and high-quality softwoods; or at various times, as is common in drying construction lumber. Where mc is the basis for schedule changes, it is necessary to monitor the mc more or less continuously during drying. There are several methods for doing this.

Sample board method

The sample board method is widely used in the drying of hardwoods, and is equally useful in the drying of high-quality softwood commodities, such as clears and shop lumber. It is seldom used in drying construction lumber. This method requires entering the kiln during operation; therefore, it is not useable in gas-fired kilns because of the poisonous atmosphere, nor in high-temperature kilns because of the discomfort involved. Because it requires the preparation of special slots in various loads to place the sample boards, it is difficult or impossible to use in kilns serviced by an automatic stacker.

In this method, specially prepared "sample boards" are used for determining the drying rate. These boards — 3 to 4 feet long — are placed in various parts of the kiln and are prepared in the following manner:

(1) A minimum of six boards, representative of the size, mc, angle of grain, and other characteristics of the green lumber to be dried, is selected. If the operator is inexperienced with the class of lumber to be dried, a larger number of boards should be used. The wise selection and preparation of sample boards is most important in the operation of the method. Boards at both extremes of the mc range should be included.

(2) A section 2 feet in length is cut from one end of each board and discarded. This eliminates any possibility of error which might result from previous end drying of the green boards. A sample board, free from resin and rot streaks and 3 to 4 feet in length, is then cut from each board.

(3) The green mc of each sample board is determined by means of two moisture sections %-inch ***(2*** cm)

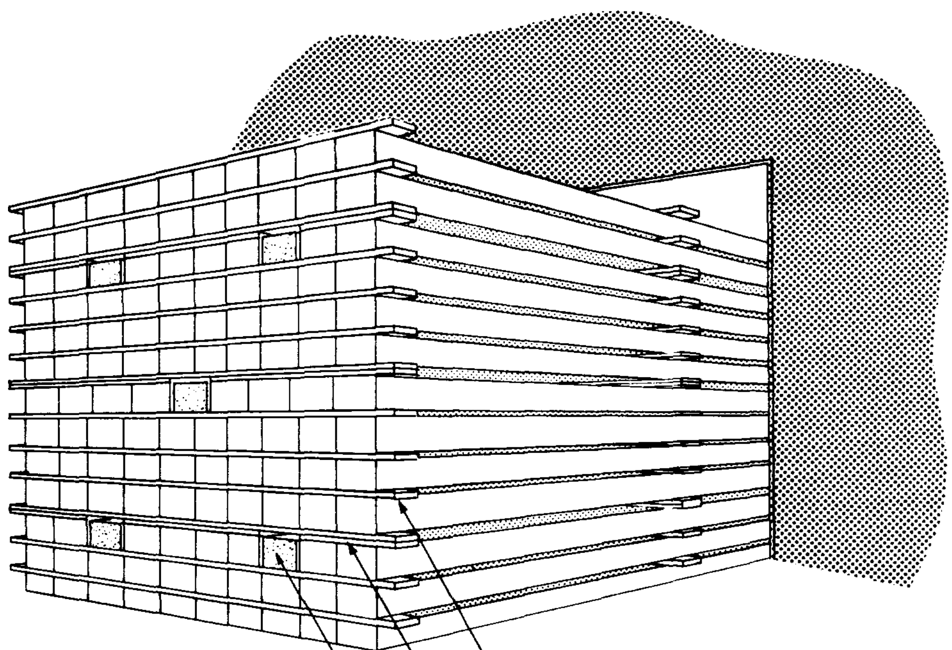

Fig. 9.1 Method of inserting test boards. Shims are used to give sufficient clearance to permit the easy removal of the test boards for weighing during a run.

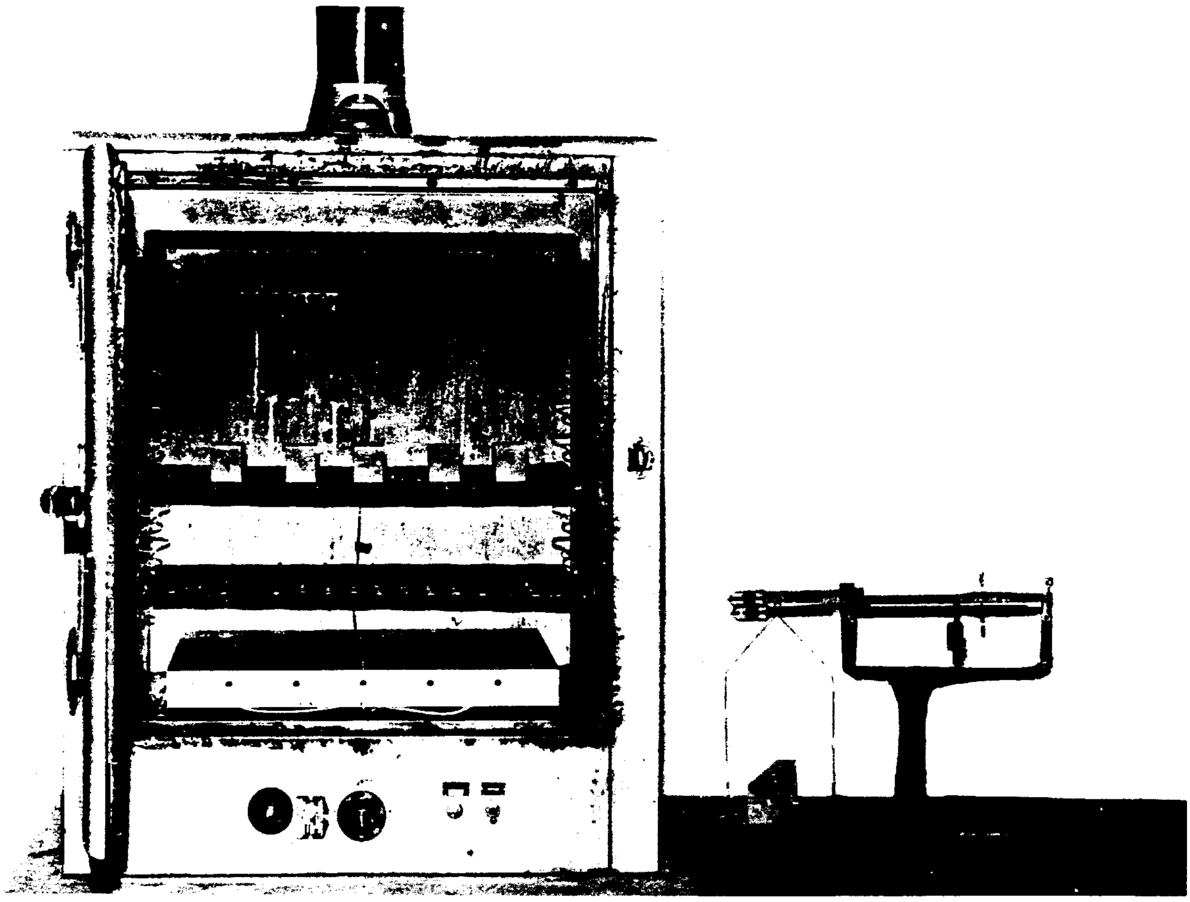

Fig. 9.2 Small oven and triple-beam balance for the determination of moisture content

long, one cut from each end of each sample board, and prepared according to the procedure of paragraph 5.

(4) After the mc sections have been removed, the sample boards are end coated with a special paint to prevent loss of moisture through end drying and are carefully weighed immediately, The weight (W) is recorded. The sample boards are then placed in specially prepared spaces in the load (Fig. 9.2), in the end car and in the sides of other cars, to give representative drying results. In progressive kilns, sample boards are placed only in the sides. Sticker thickness for the sample board is made thinner than for the other boards in the course for easy removal of the sample board.

(5) Prepare the moisture-content sections as described below:

(a) Trim off all loose slivers:

(b) Immediately weigh both sections as accurately as possible on a balance calibrated in grams. This is called the "original weight" or "green weight". Record this value.

(c) Dry the two sections together in an oven heated to 217°F or 103"C until all the moisture is removed. This requires drying to constant weight. The sections should be weighed after about 16 hours, then at 2-hour intervals until two consecutive readings are the same. This final reading is called the "ovendry weight" (Fig. 9.2).

(d) Moisture content is calculated as follows: The amount of moisture in the green sections is the difference between green weight and ovendry weight. The original percentage mc is the amount of moisture divided by the oven-dry weight, and multiplied by 100% (to convert it to percent).

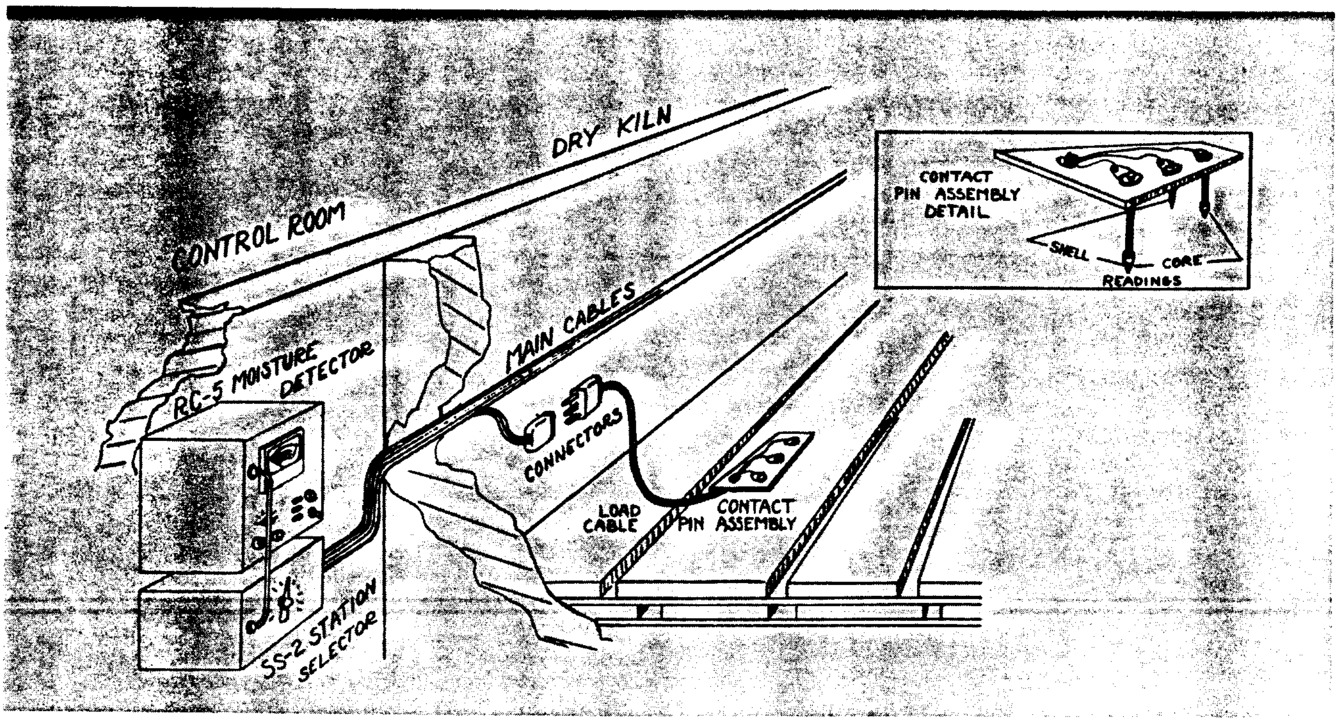

Fig. 9.3 Diagrammatic sketch of resistance method of in-kiln moisture measurement (Kil-Mo-**Trol).**

Calculation:
Both sections weighed together, green weight 63.64 g
Both sections weighed together, ovendry weight 39.32 g

$$M = \frac{\text{green weight} - \text{ovendry weight}}{\text{ovendry weight}} \times 100\%$$

$$= \frac{63.64 - 39.32}{39.32} \times 100\% = 61.8\%$$

It is assumed, therefore, that this is the average green mc of the sample board.

(6) The dry weight (D) of each sample board is calculated from its green weight (W) and the moisture content of the test sections (M). An example is shown where W = 10.6 lb (4.82 kg) for a specific sample board.

The ovendry weight of this sample board is equal to

$$D = \frac{100}{100 + M} \times w = \frac{100}{100 + 61.8} \times 10.6$$
$$= 6.55 \text{ lb } (2.98 \text{ kg})$$

(7) Periodically throughout the schedule, the sample boards are taken out of the kiln, quickly weighed and returned to their original positions in the kiln. If the weight (N) of the same board at that time is 8.06 lb (3.66 kg), its mc is equal to

$$\frac{N - D}{D} \times 100\% = \frac{8.06 - 6.55}{6.55} \times 100\% = 23.0\%$$

If the board later weighs 7.5 lb (3.40 kg), its corresponding mc is 14.5 percent. Finally, when the average mc of all the sample boards is 8.2 percent the charge is ready for removal.

This method is quite reliable where lumber of uniform initial mc is being dried. However, in the case of very wet lumber or of lumber subject to wet spots, such as western hemlock, alpine and balsam firs, western red cedar, aspen and cottonwood, an uneven distribution of moisture can render the calculated ovendry weight of the sample boards unreliable and thereby give misleading results. It is, therefore, often well to check the calculated results with a moisture meter when nearing the final stages of drying. The necessary correction factors for wood temperatures and species must be used to estimate the true mc accurately. When a charge is removed from a kiln, a large number of mc determinations throughout the charge should be made with a moisture meter to check on final average mc and the range of mcs.

Continuous moisture meter detection (resistance principle)

Systems have been devised wherein contact pin electrodes of a resistance-type meter are attached to representative boards during piling, and after connections are made, mc readings can be monitored from outside a kiln, continuously or intermittently. The system requires the prior installation of a resistance moisture meter and selector switch in the kiln control room, with cable outlets in the kiln (Fig. 9.3).

As the lumber is being stacked on the kiln trucks, a contact-pin assembly is driven into those boards whose mc is to be measured during drying. A load cable is attached to each of these pin assemblies. After the truck has been placed in the kiln, the load-cable connectors are plugged into wall outlets. The shell and core mc of up to nine different boards in various parts of the kiln can be read on the moisture meter or a strip-chart recorder. At appropriate indicated mcs, schedule settings can be changed or the charge unloaded from the kiln.

Continuous moisture meter detection (capacitance principle)

Recently, the capacitance between ground and a metal plate placed in a load at eye level has been used to determine when drying is completed. As is well known, the dielectric constant of wood varies with mc, thus the capacitance of a plate condenser with wood between the plates also changes with mc. Electronic circuitry which measures this capacitance provides a measure of wood mc. When the capacitance reaches some predetermined value, as indicated by a meter and found by previous experience to be associated with the desired mc, the lumber may be considered dry. Some models are capable of shutting down the kiln when the designated reading is reached.

Automatic kiln control

The pneumatic recorder-controller provides automatic control of the drying process according to a predetermined time-based schedule. For this type of operation, separate cams are cut for dry-bulb and wet-bulb control, according to instructions of the manufacturer (see also McIntyre*). Cam control permits the use of continuously changing temperatures, and also makes it possible to change the kiln temperatures at otherwise inconvenient hours.

Determining final moisture content

Regardless of the method used to determine that drying is complete, it must be recognized that it is only an estimate. Time-based schedules, of course, give no assurance that the desired mc has been reached. But even schedules terminated at a predetermined charge weight, sample board mc, or moisture meter indication depend on less than completely reliable indicators. It therefore is necessary to determine final mc by some other means before the decision is made to pull the charge.

In order to make this determination, one or two kiln cars should be pulled from the kiln and "metered" by an electric moisture meter, preferably of the resistance type. Electric moisture meters are discussed in Chapter 10.

H is customary to "meter" the most accessible lumber — the pieces along the sides of the pile on the kiln trucks. However, the fact that this lumber is exposed to circulating air directly from the heaters or burners makes it drier than lumber within the body of the load. Consequently, readings taken at the side of a load should be considered 1 to 2 percent drier than the load average when such measurements are taken. More accurate estimates can be made by using a special T-bar probe to permit metering of lumber within a load, provided that stickers are at least %-inch (2 cm) thick to permit inserting the probe between the courses of lumber.

Meter readings taken of hot lumber must be properly corrected for temperature as described in Chapter 10. When the load is metered within about two hours of removal from the kiln, the dry-bulb temperature may be used for temperature correction of the moisture meter. When the time is longer than two hours, or there is doubt about wood temperature, the temperature should be measured. The Delmhorst TM series electronic thermometer with a TS-2 probe has been found reliable for this work. A 0.1 35-inch (3.5 mm) hole (no. 29 drill) or a nail of the same size must be used to make a hole in a typical piece of lumber to a depth of about 3/4-inch (2 cm). The probe is placed in the hole, and the maximum temperature, which is attained in about 45 seconds, is read. This temperature is sufficiently accurate to make the proper correction to the moisture meter.

"See bibliography at end of chapter.

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CHAPTER 10
QUALITY CONTROL

A dry kiln operator is responsible for one of the most important steps in the manufacture of lumber. He must ensure that the lumber is dried to meet the appropriate standards, with minimum degrade, in as short a time as possible. He must be informed, intelligent and observant. Management must be informed and cooperative. Equipment must be maintained in proper working condition. When these conditions are met, the problems in operating an efficient lumber-drying system can be met and solved.

Calibration of Instruments

Good quality lumber, dried to specifications, is most efficiently produced when conditions required by the drying schedule are attained in practice. This requires that the recorder-controller instrument be calibrated and its operation checked at six-month intervals. Procedures are described by McIntyre*.

Green Lumber Quality

The quality of seasoned lumber cannot be any better than that of the green lumber that was dried. In fact, defects in some pieces of green lumber may cause defects to develop in neighboring pieces as well. Thick pieces take longer to dry, and result in an unnecessarily high proportion of “wets”. Alternately, if the charge is kept in the kiln until the thick lumber is dried, most pieces will be overdried. This increases costs for two reasons: excessive kiln time is required and, because drying degrade increases at lower moisture contents, excessive degrade may result. A third problem arises when thick and thin pieces are piled together for drying. Because stickers do not restrain thin pieces placed between thick ones, the thin pieces may warp resulting in further degrade. It is therefore necessary that uniformly dimensioned lumber be produced for drying.

Methods of Determining Moisture Content

The person responsible for quality control will need to determine the moisture content (me) of the lumber produced. As outlined previously, three methods are commonly used: ovendrying, resistance moisture meter, and power-loss moisture meter. Other electrical methods are also used to a lesser extent. Procedures are outlined in detail by the American Society for Testing and Materials (ASTM) Standard D201 6-74. Reinspection procedures are described in the grading rules of various agencies and by the National Lumber Grades Authority grading rules.

● see bibliography at end of chapter

Ovendrying

The ovendrying method has been described in Chapter 9 in its application to determining the green mc of lumber. It is equally useful and reliable in determining final mc.

Electrical methods

The use of moisture meters for the continuous monitoring of a drying charge was also described in Chapter 9. Similar instruments are commonly used for the instantaneous estimation of the mc of lumber after drying is completed. Most moisture meters measure the electrical resistance or capacitance of wood between two or more electrodes. Unfortunately, with all electrical methods now in use, the readings contain errors, since they are also influenced by wood temperature, species, density, extractives and moisture gradient. Temperature corrections can amount to 10 percent mc. While corrections should be made for as many of these factors as possible, only temperature and species corrections are practical. In recent publications of the Eastern and Western Forest Products Laboratories, species and temperature corrections for many Canadian woods are incorporated into combined correction tables for power-loss and for resistance-type moisture meters. Even after making appropriate corrections, individual resistance-type readings may still be in error by as much as 2 to 3 percent mc, although averages of several readings will be more reliable. Power-loss readings are less reliable.

Resistance moisture meter

The most commonly used resistance meter in North America is the Delmhorst (RMM) meter (Fig. 10.1). In this instrument, needles in a probe are driven into the wood and direct-current electrical resistance between needles is measured. A close relationship exists between mc and resistance between about 7 percent and 25 percent mc at room temperature. Within this range,

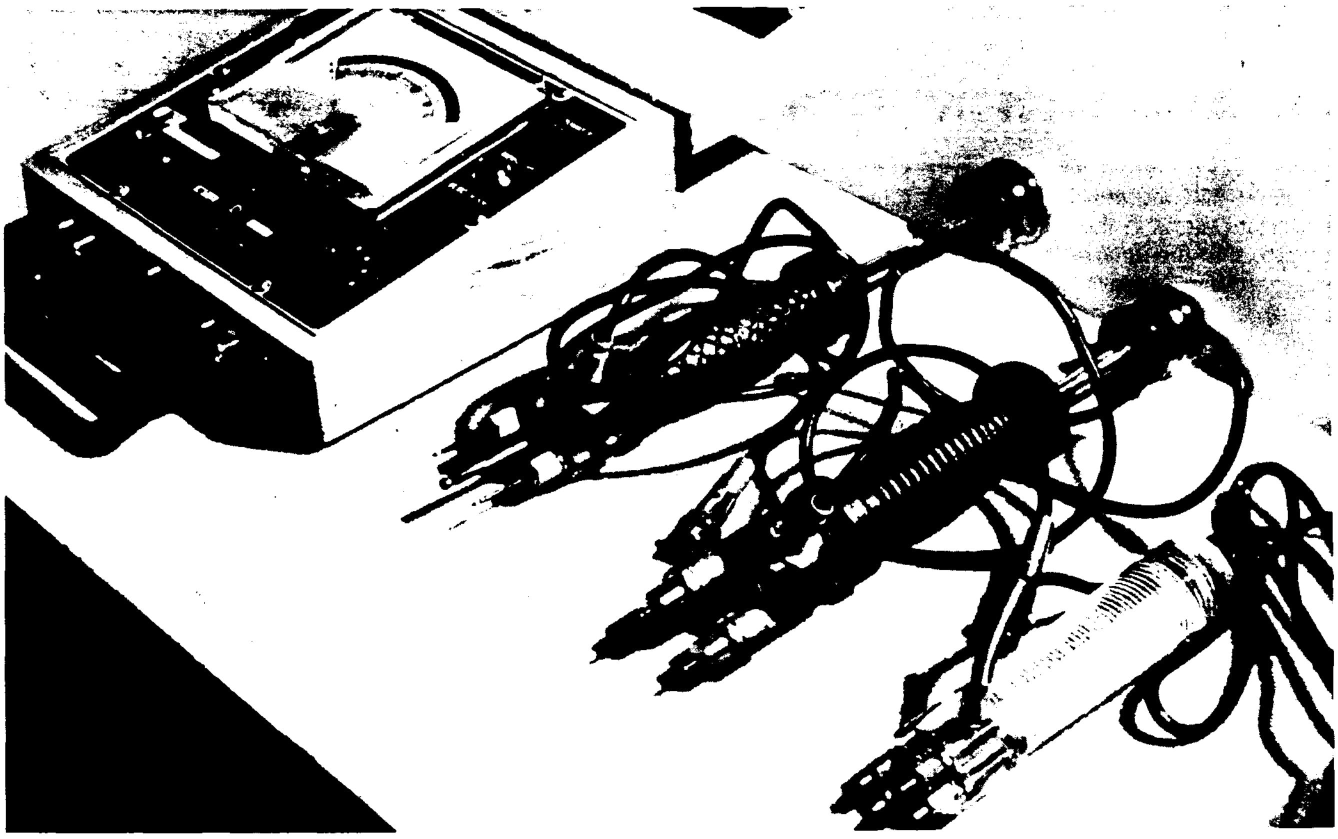

Fig. 10.1 Delmhorst resistance-type moisture meter with three different probes: (1. to r.) long insulated-needle and four-pronged, uninsulated needles Model 26E; modified 26E; Model 4E.

the resistance meter offers the most reliable electrical method of estimating wood mc. Readings of more than 25 percent are unreliable.

In order to cope with various lumber thicknesses, several probes and needle types are available. For veneer or lumber ½ inch or less in thickness, a probe with eight pins of %-inch penetration is used. For 1 -inch lumber, a probe with four insulated pins of %-inch penetration is used; for thicker lumber either four uninsulated pins or two insulated pins on a special probe are used.

Limited data indicate that when two-pin electrodes are used, the readings are lower than those obtained with standard four-pin electrodes. The difference appears to be no more than 0.5 percent mc for wood at moisture levels less than 15 percent, increasing to nearly one percent for moisture levels more than 15 percent.

In using the Delmhorst meter, certain procedures are recommended. The instrument should be zeroed before and during a set of readings to compensate for drift and should be checked at six-month intervals against "standard resistors" available from the manufacture. The needles should be inserted to between % and % of the thickness of the lumber for the best estimate of average mc. Needles must be aligned parallel to the grain of wood, otherwise readings may be in error by as much as 1 percent mc; readings should be taken quickly after inserting needles, before the indicator drifts.

Testing lumber in the rain, or when the surface of a board is damp, will cause erroneously high readings, a problem which can be overcome by using insulated needles.

Meters will indicate the mc only at the point of testing, so that it is possible to either hit or miss "wet spots" and obtain incorrect average mc of a board. Visible irregularities in wood, such as knots, pitch pockets, sap stain and irregular grain formation, will affect the accuracy of measurements and should be avoided.

Resistance meters may be used to establish moisture gradients within a board by driving the needles to various depths and noting the readings obtained at each.

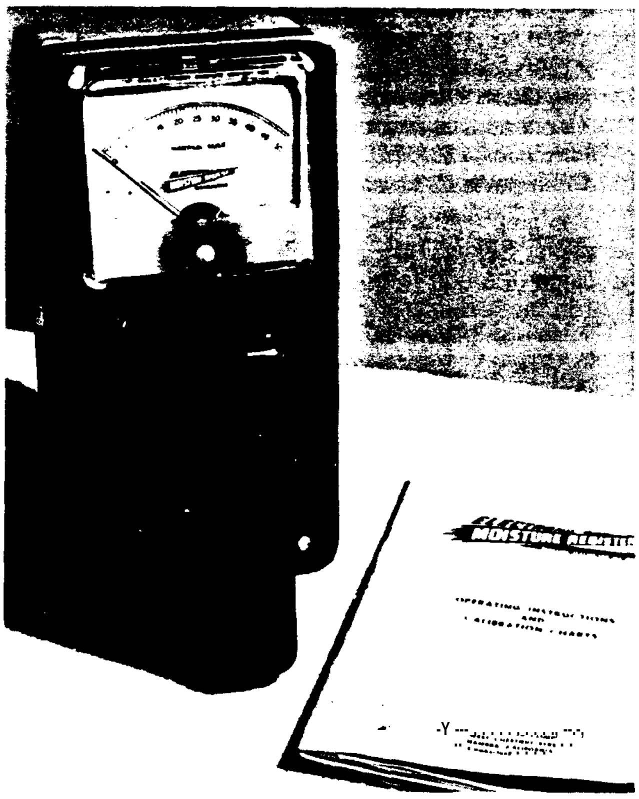

Fig. 10.2 Moisture Register Model L power-loss type of moisture meter, MC range O to 25%. Operates on ni-cad battery rechargeable from a Ii O-volt ac outlet.

Moisture Register

The Moisture Register and similar types are high-frequency meters (Fig. 10.2) which measure the power loss when radio-frequency (RF) current passes through the wood being measured. It is linearly related to me over the range from 1 percent to 12 percent and is useful up to about 25 percent mc.

Spring-loaded electrodes ensure contact with the surface of the lumber being tested. Readings of the instrument must be converted to mc by using tables supplied by the manufacturer. The meter is noticeably affected by the density of the wood and, in general, gives less satisfactory readings than the resistance-type meter. It may be used, however, on wood with as low as 1 percent mc.

Surface moisture greatly influences the readings obtained. Consequently, lumber with a significant moisture gradient or a wet surface will produce erroneous results. On lumber more than 1 inch (25 mm) thick, readings should be taken on both sides and averaged. Lack of correction tables for some woods, or the need for an operator to construct his own, restrict the usefulness of this meter. But where correction tables are available, it is more popular than the resistance-type meter, particularly for lumber-association inspectors. Preference stems from the fact that (a) it is faster and easier to use than the resistance-type meter and (b), since no electrodes are inserted, it does not mar the wood surface.

The meters are calibrated at a temperature of 80°F (27°C), so that readings should be corrected for temperatures substantially different from this value. At high temperatures, these adjustments may amount to more than 10 percent mc. The scale corrections for temperature and for species are summarized in tables provided by the instrument maker and in other references listed in the bibliography of this chapter.

Moisture Content Quality Control

The elements of a good quality control program are:

(1) to know what quality of product is required; for example, 95 percent of dimension lumber must be dried below 19 percent mc; other categories of lumber have different standards;

(2) to know what mc of lumber is being produced, which can be determined only by an adequate inspection program;

(3) to know how to modify the process so that the product meets the specifications.

Random sampling

The inspection of lumber to determine the proportion not meeting the mc standards requires considerable care. Pieces must be selected for measurement without bias. This means that any pieces known to be unusually dry along the sides and tops of a load must not be measured out of proportion to their occurrence in the charge. In practice, pieces should be selected as they move along the dry chain and only every fifth or tenth piece should be metered. It is also necessaty to make the measurements as required in the lumber-grading specifications, i.e. two feet from the ends of boards, so that excessive end drying does not give a deceptive reading. It is also strongly recommended that the resistance-type moisture meter be used.

The number of readings required presents a problem, According to statistical theory, if 100 readings are taken and 5 are found to be over 19 percent mc (i.e. "overs") because of chance, the actual proportion of the load nonconforming may range from 3 to 7 percent. By taking 200 readings, the range is narrowed to from 2.6 to 6.4 percent, and the degree of confidence is increased accordingly. ASTM Standard D201 6-74 requires that 10 percent of a charge be inspected when using a resistance meter and 20 percent when using a power-loss meter. In both cases, for small batches a sample of 20 pieces is to be the minimum tested.

As each reading is taken, it should be tallied on a special sheet. Subsequently, the readings should be corrected for species and temperature, and the average mc of the charge determined. Two quantities, average mc and percent "overs", provide the quality control inspector with the information he needs to assess the quality of lumber being produced.

The average mc and percent of nonconforming lumber will vary to some degree from day to day. If the charge has 5 percent nonconforming (the limits of acceptability), a sample of 200 readings could contain between 7 and 13 overs. If the sample contains less than 5 percent (10 readings) "overs", the operator will be satisfied. But if it contains between 11 and 13 pieces, should he recommend longer drying? The question is not easy to answer, since a single day's sample may not give a representative record of the kiln's typical production. What is required is a continuing record, so that sampling errors from day to day will cancel out and general trends and averages will be displayed. For this reason, each day's results should be plotted on a graph, and only when they are consistently or seriously nonconforming should the drying schedule be modified.

The graphs (Fig. 10.3) have charge no. on the horizontal axis. The first graph is used to plot number nonconforming; the second, average mc. A separate set of graphs should be used for each type (species, width, thickness) of lumber. The question of when to modify a schedule is then relatively easy to determine.

The following rule is recommended. The schedule should be modified to give longer drying when samples of 200 readings from:

4 consecutive charges each have 12 or more pieces of more than 19% mc;

3 consecutive charges each have 14 or more pieces of more than 19% mc;

2 consecutive charges each have 16 or more pieces of more than 19% mc;

1 charge has 18 or more pieces of more than 19% mc;

As stated, excessive drying can result in additional production costs and dtying degrade. Therefore, to assure that drying is not excessive, the schedule should be modified to give less drying when:

4 consecutive charges each have 8 or less pieces of more than 19% mc;

3 consecutive charges each have 6 or less pièces of more than 19% mc;

2 consecutive charges each have 4 or less pieces of more than 19°A mc;

1 charge has 2 or less pieces of more than 19% mc.

The graph depicting average mc will not show such variation. Since this value is the average of 200 readings, it tends to give an accurate estimate of the charge mc, except when a capacitance or power-loss meter is used to measure lumber having a large moisture gradient.

Where the graphs show that the lumber must be dried to a lower average mc, the desired mc may be found by the use of Fig. 10.4. To use this graph, find the point representing the percent "overs" (vertical scale) and the average mc (horizontal scale). Follow parallel to the curves on the graph until the 5 percent "overs" line is reached. The average mc corresponding to this value is that required. If spruce, Iodgepole pine or alpine fir are being dried, the tables of Chapter 9 will assist in modifying the schedule.

Continuous moisture meters

An alternative to random sampling to determine the average mc and proportion of "overs" is to measure the mc of all pieces kiln dried and to reject those that do not conform to specifications.

Moisture meters have been developed through which lumber may pass in a process line (e.g. a planer infeed) and have the mc monitored. They are installed as either in-line or cross-feed systems. The meters can be supplied with special accessories, such as spray markers, classifier-gate control signals, automatic counters, alarms that signal when too many wet pieces have passed, and the like.

A continuous meter should meet the same specifications as portable meters and, in addition, have the following properties: a speed of response fast enough to match the output of current mill machines, e.g. up to 1000 linea! feet per minute (305 m/min); provide means for classifying the pieces of lumber according to specified mc ranges; be simple to install and operate and require a minimum of maintenance; and be reasonably priced. These specifications can be met, but moisture meters have not yet been designed that are independent of temperature, moisture distribution, specimen size, wood density and species. For production installations, it seems necessary to assume an average value for each of the variables; the accuracy of the meters suffers accordingly.

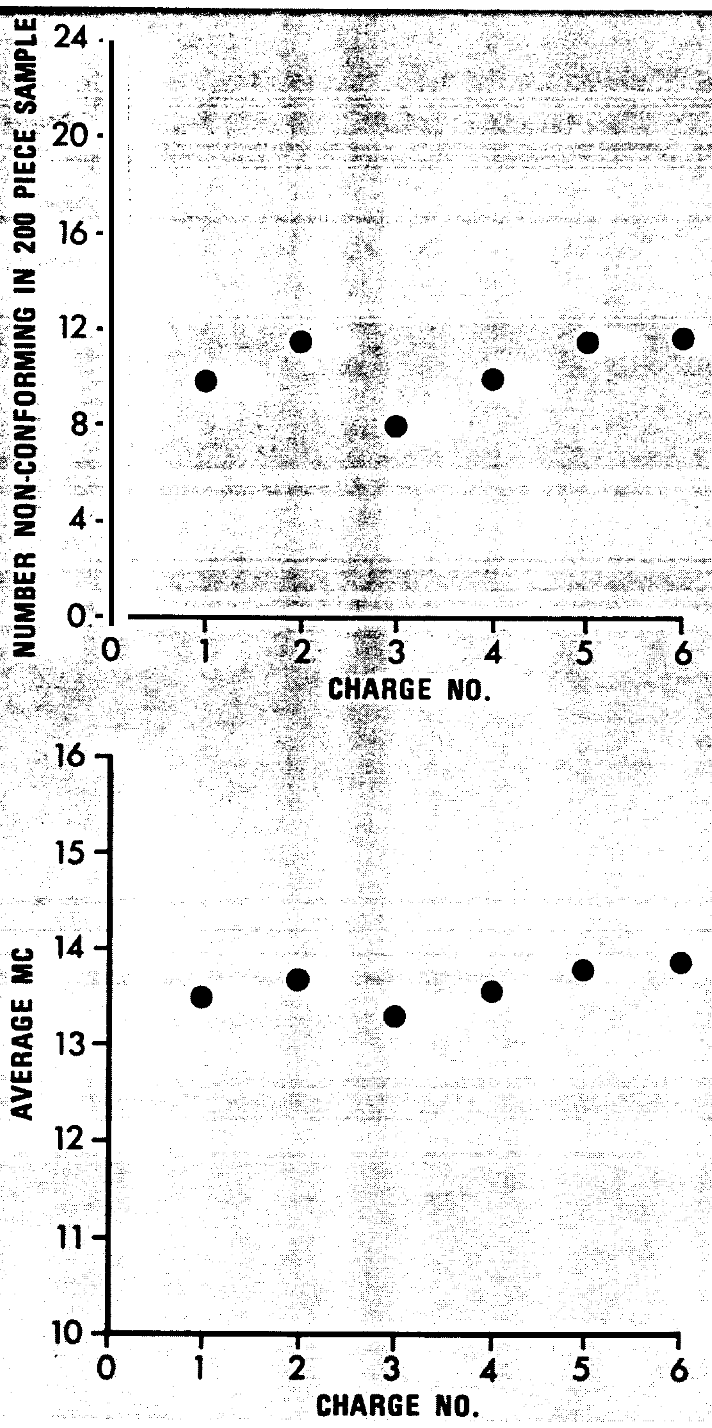

Fig. 10.3 Plots of percentage non-conforming and average moisture content.

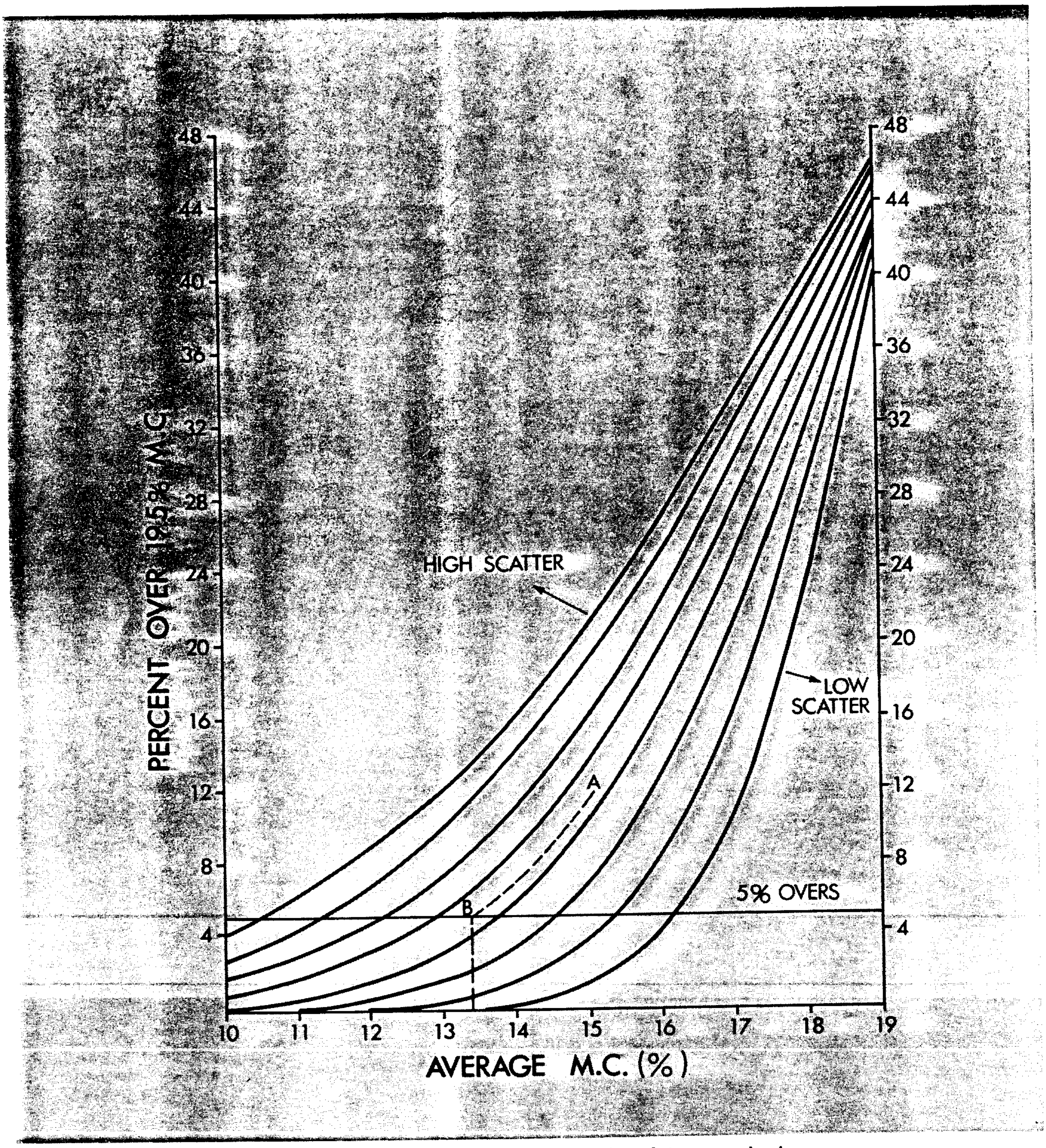

Fig. 10.4 Graph to estimate final moisture content required to pass standards. See text for use.

All of the continuous moisture meters that are used on process lines for wood, as with the portable instruments, measure a physical property which is related to mc, rather than measure mc directly. The relationship between the physical property and mc must be established before the meter is calibrated. The main problem with the continuous moisture meters is that of maintaining calibration, i.e. preventing "drifting". This condition is dependent upon proper electronic design and conditions of installation.

It is evident that the purchaser and user of a continuous moisture meter should be well aware of the factors that can produce inaccuracies in mc readings: variations in temperature, wood density, size and moisture distribution, and the measurement of species mixtures. It is also evident that the purchaser must not expect the supplier to provide effective calibration curves to cover all conditions of operation. The purchaser must be prepared to at least validate the standard calibrations, or else develop his own calibration curves using data taken under his specific operating conditions.

Lumber Grade Control

Guidelines for maintaining good lumber quality are not easy to formulate. It is first necessary to determine if lumber quality is being significantly reduced by drying degrade. The best way to do this is to grade test packages before and after drying. Green grading should assign a grade and note any defects that might later be considered drying degrade: splits, loose knots, warp. After drying and planing, the material is again graded. However, a grade change is assigned only if the defects responsible were due to drying. Skips should not be considered drying degrade. Upgrading of a piece over its green grade is not permitted. Trim to remove drying degrade should be treated as a loss of volume. By applying market value before and after drying, the dollar loss (expressed as dollars per M fbm or as percentage) can be calculated. This will indicate whether a need exists for a less severe schedule.

Drying Data for Kiln Maintenance

One duty of a kiln operator is to ensure that the kiln is maintained in good working condition: that the building is free of corrosion and damage, and that fans, baffles and other ancillary equipment provide a high level of efficiency. Detailed information on this aspect of kiln operation is found in Chapter i'.

Routine checks

Because the kiln should dry lumber efficiently' and uniformly, a good check on kiln operation can be made by determining the uniformity of drying. At regular intervals (once a month is recommended), the mc of all kiln packages should be measured, averaged, and plotted. The answers to these questions should be sought: (1) Is there a difference of mc from package to package? (2) If there is a difference, where are the high mc areas? (3) is there a pattern in this mc distribution? (4) If there are any noticeable patterns, the study should be repeated on three successive charges to determine whether the patterns resulted from nonuniform lumber being dried (mixes of partly air-dried and green). If the pattern is consistent, and cannot be attributed to the mc of the undried lumber, then the cause must be in the kiln itself. Large differences in mc across the load indicate (1) too low a fan speed, or (2) too short a drying time. increases of wet-bulb depression will not cure the problem. Alternately, there may be missing or broken stickers preventing circulation through one or more courses.

Consistently wet zones in a kiln indicate one or more of several maintenance problems: (1) baffles are not properly placed and air is bypassing the load; (2) a fan is not operating, leaving that part of the kiln without adequate circulation: (3) steam coils are flooded, due to a defective steam trap, and are not providing heat.

Measurement of Air Velocity

One of the most likely causes of nonuniform drying in a kiln is variability of air velocity throughout a charge. To determine whether this is the cause, it is necessary to measure the air velocity at many points, both at various heights above the floor and at the various loads along a kiln.

Air velocity is generally measured in feet (or meters) per minute on the leaving-air (exhaust) side of the load. Suitable measuring instruments are called anemometers or velometers.

Hot-wire anemometer. This instrument consists of a meter scale and probe with a fine wire at the tip, the wire being heated with an electric current. When placed in a stream of air the amount of cooling of the hot wire, which is proportional to the velocity of the air stream, is registered on the scale. The scale is calibrated directly in feet (meters) per minute. Although hot-wire anemometers are expensive, they have high precision.

Pressure-type velometer. With this instrument, a nozzle or jet is placed in the air stream and the velocity read directly on the appropriate scale of the instrument. The principle involved is the measurement of small differences in static pressure by means of a pitot tube. This type of velometer is usually calibrated with air at a certain temperature, humidity and barometric pressure. When used under different conditions, corrections are applied.

Several makes of pressure-type velometers are available. Their cost is modest and they provide good reliability. A velometer of this type is highly recommended as ancillary equipment for a kiln operator.

Kiln records

The keeping of kiln records is an important phase of kiln operation and quality control. This imposes no burden on a kiln operator inasmuch as he needs them in his work. Records serve the following purposes:

(1) They are a **safeguard** in that they may help a kiln operator and his company in refuting claims that a certain charge of lumber was improperly or insufficiently dried.

(2) They are a **drying tool** in providing the means by which an operator obtains experience, permitting him to understand the drying characteristics of different woods. They provide the means to improve schedules, when an analysis reveals clues that corrective measures should be taken (e.g. when undue degrade occurs or excessive time is required to dry the lumber).

(3) They bring out peculiarities of a particular kiln and indicate whether or not it is functioning properly.

(4) They provide management with a complete picture of the drying phase of the operation.

It is therefore good practice to collect and file complete records of each run.

Kiln records should be **honest, concise, comprehensive** and not too time-consuming to keep. If records meet these conditions, they will be of real value to an operator. The following records should be kept filed together (Fig. 10.5).

Recorder-controller chart

One of the most important records is the chart from a properly checked and calibrated recorder-controller, which has the following functions:

(1) It serves during the drying period as a ready reference as to what is going on in the kiln in terms of dry-bulb and wet-bulb temperatures at any given time; from these may be determined the relative humidity and emc by use of a psychometric chart or tables.

(2) It may indicate malfunction in some part of the kiln or kiln equipment.

(3) When drying is completed, the recorder-controller chart acts as a permanent record of conditions under which a particular charge was dried.

Individual kiln-charge record

The individual kiln-charge record shows such particulars as kiln number, charge number, stock dried, quantity, dates in and out of kiln, final mc and total drying time. It may also provide space for explicit operating instructions for shift men as to schedule and other matters; and space for initialing as instructions are carried out.

Other spaces should be provided for final average mc, percentage 'Covers" and percentage degrade, if this latter is determined. These figures maybe referred **to in** case of mc claims, in pinpointing trouble when properly dried lumber has been later subjected to adverse conditions, such as exposure to rain, or too long a period in dry shed during weather of high relative humidity. In addition, the tally sheet for determining mc should be filed.

Monthly kiln output

During the month, as each charge is completed, all data are entered under headings that appear on the sheet: size, grade, species, average drying time, quantity (per charge and monthly total).

Maintenance record and lost-time record

Separate sheets are maintained for individual kilns, providing a complete record of maintenance performed by dates, and time lost by date and cause. They are vital to good drying practice.

KILN CHARGE REPORT

KILN NO.: .—
CHARGE NO.: ____________
SPECIES: ____________
F.B.M.: ____________

DATE IN: ____________
DATE OUT: ____________
DRYING TIME: ____________
AVERAGE K.D., M.C.: ____________
% OF PIECES OVER MAX.: ____________

TIME:	SCHEDULE AND FAN CHANGE INSTRUCTIONS

MOISTURE METER

Tally Sheet

Reading	Species A		Species B		Species C	
	MC	Tally	MC	Tally	MC	Tally
7						
8						

DATE: ____________ MONTHLY KILN OUTPUT

SIZE	GRADE	SPECIES	AV. DRYING TIME	QUANTITY

LOST TIME RECORO KILN NO.: ______

DATE	HOURS LOST	CAUSE

MAINTENANCE RECORD KILN NO.:

EEARINGS LUBRICATED	INSTRUMENT CHECKED	INSTRUMENT CALIBRATED	TRAPS CHECKED	REPAIRS TO BUILDING

Fig. 10.5 Typical kiln records

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CHAPTER 11
AIR DRYING

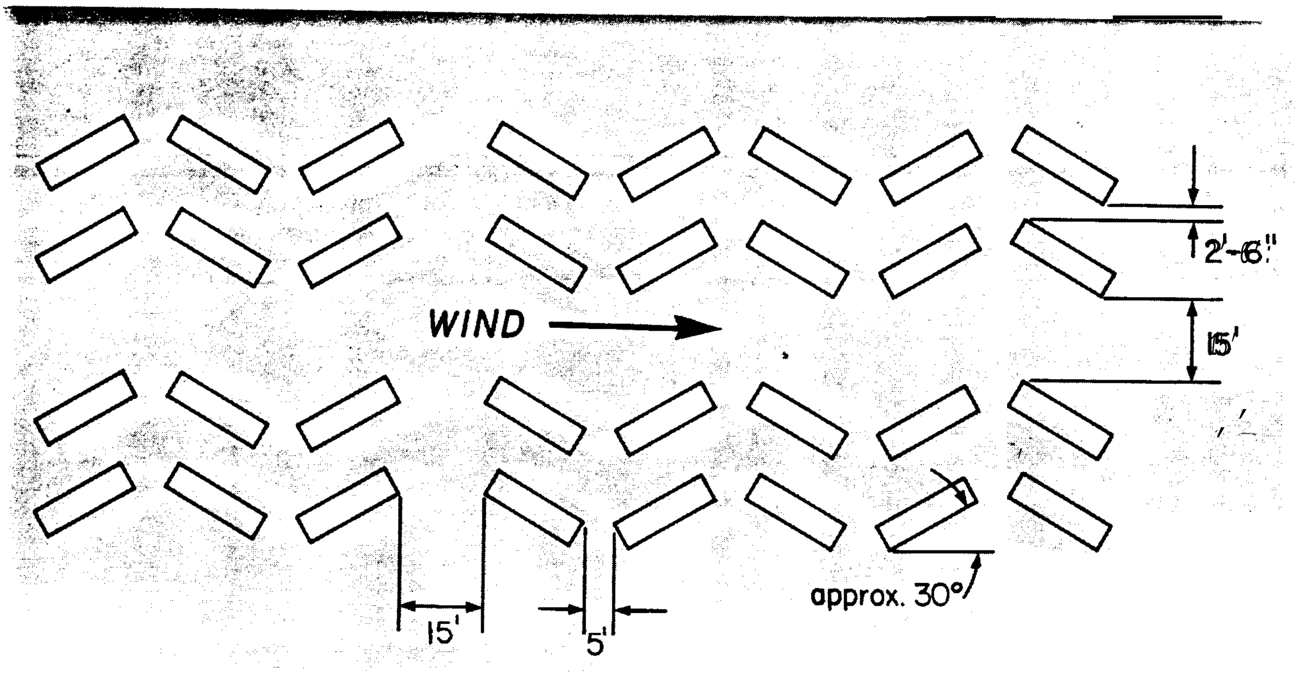

Fig. 11.1 Herringbone pattern of air-drying yard layout

The advantages of air drying over kiln drying are the requirement of no large capital investment for kiln and auxiliary equipment and no expenditure for fuel. Its disadvantages are that it permits little control of the drying rate or final moisture content (me). It is slow and seasonal and, therefore where it is the sole method of drying, large amounts of capital are tied up in drying yards and in stocks of lumber being dried. Air drying makes it difficult to schedule production to sales. In spite of being largely supplanted by kiln drying in Canada, it is still used and for this reason is discussed in this bulletin.

Intentionally or otherwise, most mills realize some advantage in kiln-drying time and fuel savings as a result of previous air drying, as is evident in comparing drying times and costs for summer and winter kiln operations. (The longer drying times and higher fuel costs in winter are also due to the need to thaw the lumber and to heat it through a greater temperature range.) Since rate of moisture loss in kiln drying is greatest during the first few hours and days, and because of the high heat demand during this period, the intelligent use of partial air drying can result in substantial savings, and may even be used to increase kiln-drying capacity during periods of high market demand.

Air seasoning has other applications: some collapse-prone woods, and such dense woods as oak, may be partially air dried prior to kiln drying with considerably less degrade than when kiln dried green from the saw. In fact, due to the extremely long times required, and the risk of degrade, the costs of kiln drying such woods from the green condition are frequently prohibitive. After partial air drying, drying can be completed to the desired final mc in a kiln in reasonable times and with substantially reduced risk of degrade.

Air-seasoning, like kiln drying, is dependent on temperature, relative humidity, and circulation of the surrounding air. Consequently, the climatic conditions of the region constitute the greatest influence, not only on the rate of drying, but also on the final mc.

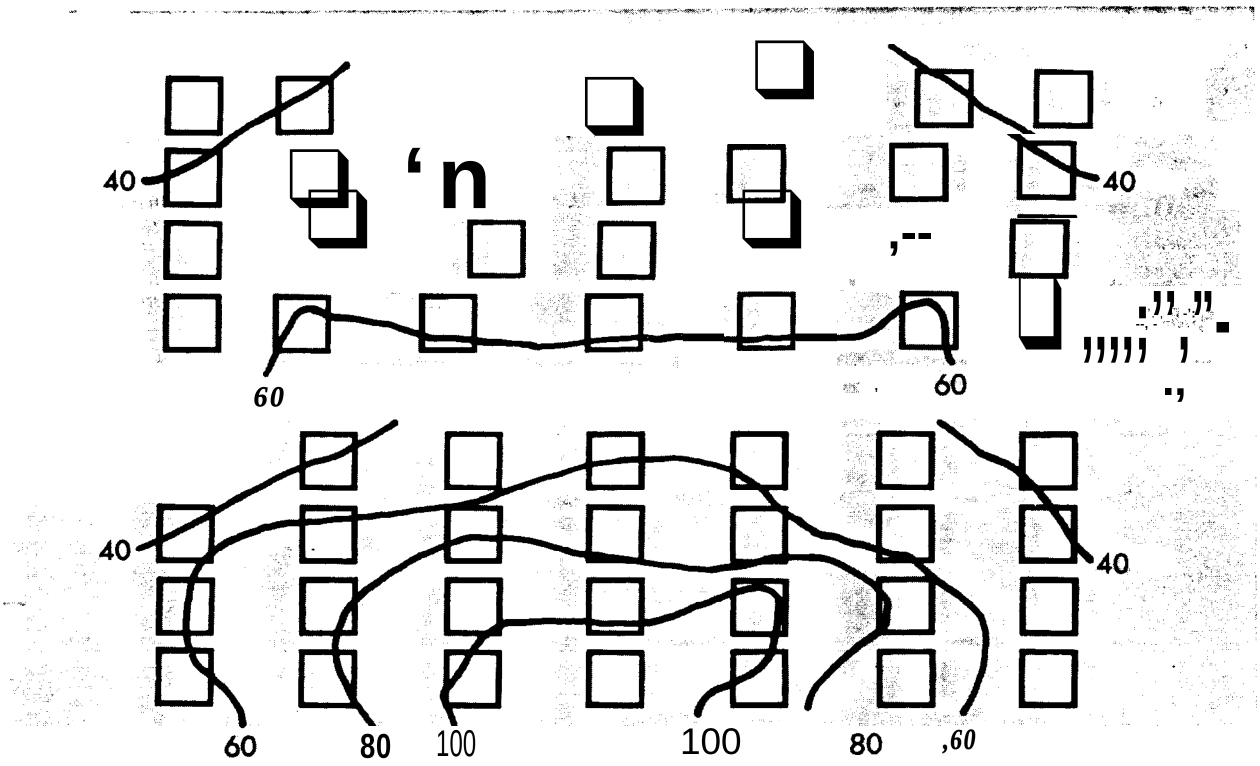

Fig. 11.2 Comparison of moisture contents (contour lines) in non-uniform and uniform pile spacing

Air Circulation

Uniformity of drying, within a yard and within individual piles, depends on an adequate and uniform circulation of air. Air movement within a yard is mainly dependent on prevailing wind currents, which may change in both direction and velocity throughout the year. These currents, however, can be affected within a drying yard by the location and layout of lumber piles.

Conventionally, lumber piles in air-drying yards are laid out in rows with the piles end to end, separated by about 5 feet. Usually, two rows are spaced 3 to 4 feet apart and these double rows are separated by 20 to 25 feet to permit access by lumber carriers. For most effective drying, the rows should be aligned in the direction of the prevailing wind currents.

Other arrangements of the piles have been tested. Variations of a herringbone pattern (Fig. 11.1) aligned with the prevailing wind direction result in much faster drying. If rows near the edge of a drying yard are spaced relatively closely, and those near the center of the yard are spread apart, more uniform drying throughout a yard is provided (Fig. 11 .2).

Selection of the air-seasoning yard location, and planning of its layout, should be done as carefully as conditions will allow. Too often the yard is relegated to land quite unsuited to that purpose. The layout should permit the smooth flow of lumber from green chain to seasoning yard, to kilns or planing mill. The yard itself should be on firm, well-drained ground; low or swampy ground should be avoided. Weeds and other vegetation should be eliminated to ensure the free movement of air at the base of piles. Preferably, the yard should be paved. Not only will this assist in drying uniformity, but also it will eliminate the blowing of sand onto the lumber which may later dull or chip planer knives. It also will provide a smooth surface for carriers or forklifts and prevent shuffling of loads and loss of stickers. A yard must be kept in good condition by removing broken lumber and other debris that is not only a safety hazard, but also increases the danger of stain and decay of lumber.

Fig. 11.3 Simple forced-air drying arrangement

Forced-air Drying

The long times involved in air drying maybe reduced by the use of fans. This method of drying requires only small initial investment and provides, not only faster air drying, but also a slightly longer practical drying season. Commercial installations of this type are uncommon in western Canada.

As a further refinement, an auxiliary heat source may be introduced to raise air temperatures above normal (ambient), particularly in winter. When control of relative humidity is provided, the process becomes equivalent to low-temperature kiln drying.

In its simplest form (Fig. 11 .3), forced-air drying requires a structure to house the fans and to guide the air into the stickered piles of lumber. The structure requires a base platform for the piled lumber, a roof, closed ends, and a wire-mesh back. A more permanent and substantial building may be used. Fans are mounted on steel stands or preferably on plywood baffles to prevent short-circuiting of air. The closest lumber pile to the fans should be located about 4 feet (1.3 m) from the fans, in order to provide a minimum plenum chamber required to give relatively uniform distribution of air. Air velocities are 350 to 600 feet per minute (100 to 180 m/min); the higher air speed being used for 1 -inch (25 mm) lumber and the lower speed for 2-inch (50 mm) and thicker lumber. Higher air velocities have been found to produce excessive checking.

To minimize power consumption, each unit should be provided with a humidity limit-switch controller to stop the fan motor when relative humidities rise above 85 to 90 percent or drop below 35 to 40 percent. No useful drying will occur at more than the upper limit, whereas surface checking may occur at less than the lower limit.

Drying times for 1 -inch (25 mm) eastern spruce, balsam fir and white pine from green to 10 percent average mc are reduced 40 percent by forced-air drying, while for 2-inch (50 mm) lumber of the same species the reduction is about 23 percent compared with air drying. Thicker lumber is less affected. The final mc variability is slightly increased by forced-air drying in 1-inch (25 mm) material only.

Air-seasoning of Timbers, Poles and Ties

Timbers, poles and railroad ties to be treated with preservatives should be dried to the lowest mc they will attain in service, so that checking in service will not extend beyond the treated zone.

Drying rates and moisture gradients for western red cedar poles, Douglas-fir timbers, and railroad ties of western hemlock and Douglas-fir, air seasoned in the southern coast region of British Columbia, have been determined by the Western Forest Products Laboratory. In the seasoning of Douglas-fir timbers and ties, the outer inch (25 mm) dries rapidly, reaching a point below fiber saturation point (fsp) in 1 month if piled in the spring. Under the same conditions, western hemlock will require approximately 2 months for the same drying. The mc at the center of the above shows a much slower reaction, especially in large timbers, where the fsp is not reached in less than about 1 year.

The initial or green mc of western red cedar poles tends to be extremely high, being in excess of 100 percent. The rate of drying during summer months is rapid, the surface mc quickly reaching equilibrium with atmospheric conditions, whereas the center mc decreases at a much slower rate. Western red cedar poles 30 inches (76 cm) in circumference at groundline should reach a uniform mc of 18 percent in the second year of drying.

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CHAPTER 12

TRANSIT AND STORAGE

Fig. 12.1 Fruiting bodies of fungi

I

Lumber is normally used under conditions which do not promote the onset of stains and decays. However, during shipment there may be lengthy periods of transit when lumber is exposed to abnormal conditions that favor these and other hazards.

Moisture Migration

Lumber at 15 percent mc contains 3 to 4 pounds of water per cubic foot. Where the wood is exposed to normal daily temperature changes, moisture will move toward the surface and evaporate. If the moisture is permitted to escape, no damage will result. If the lumber is wrapped in plastic or other vapor barrier, the evaporated moisture will be trapped within the wrapper and may condense and wet the lumber surface, raising its moisture content (me) well above the value where stain and decay fungi can attack the wood.

Staining and Wood-destroying Fungi

Fungi are specialized plants, some of which use wood as a source of nourishment. Moulds, a subgroup of fungi, normally digest food materials stored in the wood cells. As a result they do not reduce the strength of the wood, although many moulds can permanently discolor the wood, reducing its value for some uses. Wood-destroying fungi, another subgroup, attack wood's structural components, the cellulose and Iignin, and seriously reduce the strength of lumber.

These organisms reproduce by means of minute spores, produced by fruiting structures of various types (Fig. 12.1) and released as a fine dust into the air. Such spores are in the air at all times, and may generate a new plant when they land on suitable exposed surfaces, such as freshly cut lumber. Some fungi are able to penetrate the wood of standing trees, particularly in overmature forests, and thus may be present in the logs at the time of cutting. Specific conditions must be met if the spores are to regenerate or the fungi are to grow. The wood mc must be about 22 percent or more; the wood itself must be a suitable source of food, i.e., free of poisons or other deterrents; the temperature must be in a viable range; and there must be oxygen present.

The heartwood of certain species, such as Douglas-fir, larch, and especially the cedars, contains natural preservatives which are poisonous to most fungi. Even so, most heartwood can be attacked by several fungal species when other conditions are favorable. In other woods, such as spruce, true firs and hemlocks, the heartwood has little or no natural preservatives and is therefore readily attacked under favora conditions. The sapwoods of all native species have tle resistance to fungal attack.

Fungi in and fungal spores on wood maybe killed. various processes. One method is to maintain the ter perature at 150"F for 2 hours, or at higher temperi tures for correspondingly shorter times. Consequent\ kiln-dried lumber will remain free from attack as long a. the surface is not exposed to infection and is not permitted to rise to more than about 22 percent mc. On the other hand, air drying and low-temperature drying do not sterilize lumber, so that existing fungi may continue to develop from the inside to the outside if the mc is not sufficiently low.

Insects

In the natural state, or during the transport of logs from woods to mill, timber may become infested with various insects, such as ambrosia beetles. Certain countries, particularly Australia have rigid regulations to control the import of potential carriers of insects, and require fumigation of a shipment suspected of containing them. Kiln drying sterilizes lumber containing insects.

Chemical Stain

A common, though little recognized, form of chemical damage to lumber carried on flatcars results from the erosion of iron from the car wheels by the brakes and from wheel flanges on sharp curves. The fine iron powder so produced may be carried by air currents to fall on the lumber. If the lumber is wet or is subsequently wetted, a chemical reaction takes place between the iron, wood and water, with the result that the lumber will be severely discolored to an unpleasant dark blue or black. No further damage occurs and the coloration can be removed by surfacing. Western red cedar and Douglas-fir are particularly susceptible to this type of discoloration because of certain extractives which they contain.

Protective Devices and Procedures

A lumber producer should ensure that his lumber reaches the market in good condition, free from damage due to fungal, insect and chemical agencies. Since moisture is a factor involved in most forms of damage, the obvious protection is sterilization by kiln drying and the assurance that the lumber will remain dry.

The problems associated with shipping usually involve protecting lumber from wetting in transit and from iron stains. Where lumber is shipped by covered truck or boxcar, the possibility of wetting or contamination is negligible. Consequently, no additional protection is required.

There are advantages to shipping by open flatcar. Loading and unloading each require about 1 ½ hours rather than 4 hours for a boxcar.

Also, longer lengths can be handled more easily. However, lumber may be exposed to rain and other contamination. There are three common ways in which lumber has been prepared for shipment by flatcar.

Plastic wrap

Plastic has the advantages of relatively low cost and light weight. While it is effective in protecting the lumber from contamination, it does prevent the escape of evaporated moisture as described. The increased surface mc which may result from the trapped moisture can provide ideal conditions for the growth of fungi. The use of this type of wrap should therefore be discouraged.

Breather-type wrap

The water-resistant paper wrap traditionally used for the protection of lumber in transit is the breather type. It will give excellent protection provided that it is not torn in handling. It protects the lumber from rain, snow, iron and fungal spores and permits water vapor to escape. Its disadvantages include the possibility of tearing, its relatively high cost, the labor required for wrapping, and the difficulty of disposal at destination, particularly where outside burning is prohibited.

Water-repellent treatments

Various water repellents have been introduced to protect lumber in shipment. Good formulations are able to protect against rain, fungi and chemical discoloration. The use of water repellents avoids the problems associated with torn wrappings and wrapping disposal, and promises to reduce the cost of protecting lumber in transit. In 1973, for example, the cost of paper wrapping approached $3 per M fbm ($1 .27 per m^3), about ten times the estimated cost of water-repellent treatments.

The method of applying water repellents found most satisfactory is by spraying. In this method, lumber is passed through an enclosed space in which nozzles spray the liquid. Total moisture pickup by this method is about 1 percent mc. Excess liquid drains off, is collected, and is recycled through the nozzles. Because of the high speed of the lumber passing through the spray box, and the fact that the nozzles frequently become plugged, this method requires careful supervision to produce an unbroken protective film on all parts of the lumber.

Water Transport

Shipping by water has similar hazards to those of flatcars, although the causes are different. Lumber is carried both above and below deck. Water vapor entering the hold may condense on the cold hull of a ship and run into the bilge, carrying with it rust and iron compounds from the steel plates. In the same way, moisture evaporated from green or partially dried lumber can similarly condense. If the bilge is not pumped out, this water may contact the lumber, resulting in the unsightly iron stains already described.

In addition, where transit takes several weeks or months, staining fungi may grow and be well developed when the lumber reaches its destination. Green lumber unprotected with a sapstain preventive is particularly vulnerable to this attack. However, kiln-dried lumber shipped in the same hold with green lumber is also susceptible.

The use of a water repellent containing a fungicide offers protection in these cases.

Storage

When lumber arrives at its destination, it may be stored for long periods awaiting purchase, during which time it may absorb considerable moisture. As a result, it may be exposed to possible deterioration by mould and decay. It will normally be adequately protected from these hazards if stored under cover. It has been shown that a properly applied water repellent will keep the mc of kiln-dried lumber essentially constant for more than a year, at levels which ensured immunity from decay and mould.

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CHAPTER 13

ECONOMICS OF KILN DRYING

Where a choice exists between shipping lumber in the green condition or kiln drying it, a careful analysis must be made of the factors favoring one system over the other. The prime consideration must be economic; i.e., to what extent the economic benefits of each operation exceed its costs. Because costs of goods and labor change almost daily, a cost analysis made at any given time will be quickly outdated. Therefore, a general procedure has been prepared for determining the most important cost items (Table 13.1). These cost items are discussed in the text. The procedure should provide a reasonable method of estimating drying costs of any operation.

Economic benefits

Premium

A premium is usually paid on kiln-dried lumber. This amount may be from six to ten dollars per M fbm (about $3.75 **to** $6.25 **per** m^3), as compared with unseasoned material. When air-dried or partially air-dried lumber is available, the premium decreases, so that no premium may be paid if they are available in sufficient quantities. This is usually a matter to be arranged between buyer and seller.

Weight reduction

The traditional reason for kiln drying lumber in western Canada has been to reduce transportation costs. Because the cost of water transport is based on volume shipped, no advantage is gained by coast mills kiln drying lumber for shipment to off-shore markets by water. This is reflected in the fact that only about 13 percent of British Columbia coast production is dried before shipment. On the other hand, the cost of shipping by rail or truck is based on weight. Consequently, those mills that ship by rail or truck receive immediate benefits in shipping kiln dried rather than green lumber.

This is best illustrated by an example using data from Table 13.2. Dressed white spruce 2 X 4s weigh 2070 lb per M fbm when green and 1500 lb when dried to 15 percent mc. Thus, there is a weight reduction of 570 lb per M fbm. Based on freight rates of $2.35 per 100 lb from British Columbia to Toronto, the cost of shipping is reduced by $13.40 per M fbm as a result of drying. Values for other woods can be determined similarly from Table 13.2

Table 13.1

Summation of Cost Analysis of Kiln Drying

Economic benefits ($/M)	
Premium over green price	________
Reduction of transportation costs	________
Other benefits	________
Total economic benefits	________
costs	
Capital costs reduced to annual costs ($/yr)	
Cost of: kiln - yrs service	________
forktift - yrs service	________
stacker - yrs service	________
unstacker - yrs service	________
other items - yrs service	________
Total annual cost of investment ($/yr)	
Other annual costs ($/yr)	
Interest on capital Investment	
Maintenance, not including labor	________
Taxes	________
Rent	
Total annual costs, including annual cost of investment ($/yr)	________
Monthly costs ($\mo)	
Total annual costs -12	________
Fuel	
Electricity	
Handling, labor, maintenance labor	________
Total monthly costs ($/me)	________
Cost per Mfbm ($/M)	
Total monthly costs - monthly throughput in Mfbm	
Degrade losses($/M)	________
Totel drying costs ($/M)	
less "Total economic benefits'	
Net total coat of drying ($/M)	________

Table 13.2

Weights at various moisture contents of M fbm of dressed 2 x 4-inch lumber(l.5 x 3.5 in) of several western Canadian woods

Species	Ovendry weight lb per cu ft of green wood	Green mc%	Approximate wt (lb) of M fbm 2 X 4 at 1O% mc	15Y0 mc	20?40 mc	Green Wt
Western red cedar	20.51 •	62*	1280	1340	1400	1930
Yellow cedar	26.21	52	1650	1730	1800	2310
Douglas-fir	28.08	45	1800	1880	1960	2360
Alpine fir	20.51	65	1290	1350	1410	1960
Amabilis fir	23.51	69	1510	1580	1650	2300
Balsam fir	21.22	118	1350	1410	1470	2680
Western hemlock	26.38	85	1700	1770	1850	2830
Western larch	28.06	49	1810	1900	1980	2420
Jack pine	26.21	51	1660	1730	1810	2300
Lodgepole pine	25.50	50	1630	1700	1770	2220
Ponderosa pine	24.19	76	1540	1610	1680	2470
Sitka spruce	21.84	43	400	460	1520	1810
White spruce	22.45	59	430	500	1560	2070
Trembling aspen	23.09	123	480	540	1610	2980
Balsam poplar	23.09	112	480	540	1610	2840

● **Data from Dobie and Wright, 1976**

Weights per M fbm of other dressed sizes can be estimated by multiplying the appropriate weight per M fbm of nominal 2 X 4 by the following factors:

Dressed size	Factor
1 X 2 or2 X 2	. 8 5 7
1 X 3 or2 X 3	.952
1 X 4 or2 X 4	1.000
1 X 6 or2 X 6	1.048
1 X 8 or2 X 8	1.036
1 X 10 or2 X 10	1.057
1 X 12 or2 X 12	1.071

costs

Capital equipment

Capital equipment items include the kiln with all ancillary equipment, such as kiln trucks, stacker, unstscker, and transport machines such as forklift trucks, or some fraction of their cost based on the proportion of their time used in constructing and breaking down kiln charges. The cost of these items must be apportioned over their service lives and, ultimately, over the amount of lumber dried. This calculation is different from that of depreciation for income tax purposes, where some advantage is gained by using short write-off periods. When calculating actual cost of drying, it is necessary first to estimate the actual life of the kiln and other equipment. Cement-block and prefabricated-panel kilns should last 15 years or more and it would be quite safe to apportion costs over that period. A straight-line method of depreciation may be used. For example, an installation costing $300,000 might be depreciated over a 15-year period at $20,000 per year.

Other annual costs

Another major annual cost is the interest on the unpaid balance of the capital investment cost. Alternately, the total interest may be averaged and apportioned equally for each year of service life. The formula for calculating average annual interest is

$$I = \frac{R}{100} \times \frac{C(Y+1)}{2Y}$$

where: I = interest in dollars per year;
R = interest rate, percentage;
C = capital cost of installation in dollars;
Y = depreciation period in years.

Maintenance includes the cost of material for keeping the kiln and equipment in proper operating conditions. Besides such obvious items as materials for replacement and repairs, it also includes the cost of lumber for stickers and blocks or bolsters. Due to normal breakage, it had been estimated that wooden stickers have a life of 13.6 kiln charges. At 45 stickers per M fbm, this suggests a loss of 3.3 stickers per M fbm. Assuming a costof$120 per M fbm, the cost of replacing stickers is $0.43 per M fbm.

Recently, phenol-formaldehyde and laminated-wood stickers have been introduced. They have a long service life: each sticker lasts about 100 cycles. Their high initial cost, **however, has resulted** in the production of a less-expensive laminated wood sticker. Drying costs, therefore should be reduced by the use of either of these sticker types.

Monthly costs

Monthly costs include the direct costs of "drying lumber: fuel, electricity and labor, including the labor cost component of maintenance.

Cost Reductions

Fuel

When wood is dried under ideal conditions, about 1100 Btu of heat are required to evaporate each pound of water removed [2.5 megajoules (MJ) per kg]. When lumber is dried in a commercial kiln, however, conditions are less than ideal. Besides heat required to evaporate water, heat must be supplied to raise the temperature of lumber and kiln building, heat the intake air, and make up for heat losses through the walls. The additional heat required varies with kiln schedule, construction of the kiln itself, and with external weather conditions. Various quantities of heat from 1600 to 3800 Btu per pound (3.7 to 8,7 MJ per kg) have been reported, but there is some agreement that with a well-built, modern kiln a value of 2000 Btu per pound of water evaporated (4.6 MJ per kg) is a reasonable estimate of the total heat required.

Because much of the heat used in kiln drying is lost through the kiln walls at a fairly constant rate per pound, heat losses can be reduced by the use of faster, higher-temperature schedules. Kiln schedules also can be manipulated in another way for economy. With a higher wet-bulb temperature, a greater amount of water vapor is removed by each pound of venting air; consequently less heat is lost in heating venting air. The higher wet-bulb temperature might normally result in slower drying, but if the dry-bulb temperature is increased so that the same wet-bulb depression results, the rate of drying is increased also.

Degrade

It is generally agreed that shrinkage-based drying degrade is more serious when lumber is dried to lower mcs. One authority reports that approximately 1 percent of the lumber value of coastal species is lost with each 1 percent of mc reduction below 19 percent mc. This authority consequently dries until 70 or 80 percent of the lumber meets standards. The lumber is then passed through an in-line moisture detector with automatically controlled rejection of nonconforming pieces, which are redried. It is claimed that the increased total value of the lumber more **than pays for the extra** pro-**cessing. Unpublished studies at the Western Forest Products Laboratory found much lower degrade values for interior species. While no explanation for the difference is apparent, it may be attributable to the wood** species tested, the method of assessing degrade or to the schedules **used. Generally speaking, faster schedules result in more degrade than slower ones, An acceptable schedule will, therefore, result in the fastest drying with little degrade.**

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CHAPTER 14
KILN-DRYING SCHEDULES

ERRATA

Schedule 27 5/4 x 5-in shop

Schedule 29 5/4x 5in clears

Schedule 35 514-in shop

Schedule 39 **4/4** to **6/4-in factory lumber**

Schedule 40 7/4 to 9/4-in **and** . . . .
4/4 to 6/4-in **factory lumber**

Schedule 41 7/4 to **9/4-in factory lumber**

The Forest Products Laboratories of Canada have, for many years, been engaged in research on lumber drying and have deveioped schedules for the more common commercial woods. These and a number of schedules originating from industrial practice in western Canada follow. The latter schedules have been checked by the mathematical procedures described in Chapter 9 and appear to be reasonable for the woods concerned. In using a schedule for the first time, the following points should be noted:

(1) Information is not available as to the initial moisture content (me), final mc, nor the range of final mc of the lumber dried by many of these schedules.

(2) In some cases the schedules may not reflect the conditions at the load, due to faulty calibration of the instruments, or the location of sensing elements.

(3) If a direct-fired kiln does not have, or is not using, supplementary humidification, the wet-bulb setting of the controller does not always indicate the wet-buib temperature attained in practice.

(4) With the same scheduie of temperatures, drying rate is very dependent on air veiooity through the kiin charge and this, in turn, depends on fan veiocity, sticker thickness and uniformity of iumber thickness. These factors wiil vary much between kiins; consequently, two kiins using the same scheduie may show quite different resuits.

Kiin operators should, therefore, expect to taiior new scheduies to individual kiins, checking the quaiity of drying by extensive mc measurement of the dried iumber. Modifications should be made using the information provided in Chapter 9, with the aim of conforming to standards with a relatively iow range of mcs.

Air velocities shouid be approximateiy 250 fpm (75 m/min) for kiln temperatures up to 180°F **(80°C)**, 250 to 400 fpm (75-135 m/min) for kiins operating to 212°F (1 OO"C), and in excess of 400 fpm (135 **m/min)** for high-temperature scheduies.

Softwoods

Pine

There are three species of pine of commercial importance in western Canada — western white pine ***(Pinus monticola*** Dougi.), yeiiow or ponderosa pine ***(Pinus ponderosa*** *Laws.).* **iodgepoie pine** ***(Pinu bank-*** *siana* Lamb.). Of these, iodgepoie pine has by far the greatest commercial importance, its range extending throughout British Coiumbia, particularly in the interior, into southern Yukon and North West Territories, much of Aiberta and parts of southwestern Saskatchewan.

Aii western pines are subject to sapstain, which may occur in a iog when the timber is feiied in warm, moist weather, or when it remains too iong before sawing. if no stain has deveioped in the sapwood prior to kiln-drying, it may occur in the initiai stages of seasoning if a iow temperature is maintained in the kiin. it is, therefore, recommended that the charge be given a sterilizing period at the beginning of a run, carrying an initial temperature sufficiently high to destroy the staining organisms.

"Brown stain" or "kiin burn" is common in white pine, especially in oid trees having a condition known as "water core", which may aiso occur in the other pines. This stain is not caused by any iiving organism, but is thought to resuit from soiubie extractives in the wood, which are concentrated and oxidized by too high a temperature in the kiin. Brown stain can be avoided by using moderately iow humidities, with as high a circulation as possible, to dry and set the surface before soluble extractives, which cause the stain, can be brought to the surface by free water movement. Because of the low humidity carried under such conditions, casehardening may resuit, and when stock is to be resawn, a finai conditioning period may be required.

Because lodgepoie and jack pine are harvested, processed and marketed with white spruce, they are

Temperature (dry-bulb/wet-bulb)		Time	EMC
°F	°C	hr	%
Schedule No. 1 Western white pine and ponderosa pine 1-in and 2-in clears			
160/158	**71/70 (sterilize)**	**4**	**19.8**
130/118	**54/48**	20	11,0
140/122	60/50	24	8.7
150/126	65/52	24	7.1
150/122	65/50	to dry	6.2
160/152	71/67 (condition)	2	12.7
Estimated drying time, 1 in (25 mm) to 10% mc, 84 to 120 hr 2 in (50 mm) to **14%** mc, 120 to 144 hr			
Schedule No. 2 Lodgepole and jack pine 2-in dimension			
160/145	70/62	24	9.4
180/160	80/70	24	7.6
195/165	90/75	24	6.4
		72	
Schedule No. 3 Lodgepole pine 2 X 8-in dimension			
to 180/150	to 80/65	9	5.8
to 200/150	to 95/65	17	3.3
to 200/125	to 95/50	22	2.0
		48	
Schedule No. 4 Lodgepole and jack pine and white spruce studs			
to 180/160	to 80/70	6	7.6
180/160	80/70	6	7.6
to 220/185	to 105/85	14	4.7
220/180	105/82	9	4.2
220/160	105/70	11	2.3
		46	
Schedule No. 5 White spruce 2-in shop			
130/120	55/50	20	12.1
140/130	60/55	24	11.9
146/136	63/58	28	11.9
154/136	70/60	72	8.6
154/130	70/55	72	7.0
		216	
Schedule No. 6 White spruce 2-in dimension (high-temperature schedule for gas-fired kilns)			
230/185	**110/85**	**28**	**3.3**
Schedule No. 7 White spruce 2-in dimension (high-temperature schedule for gas-fired kilns)			
240/180	115/82	27	2.5

Temperature (dry-bulb/wet-bulb)		Time	EMC
°F	°C	hr	%
Schedule No. 8 White spruce 2-in dimension (moderate schedule with conditioning)			
168/158	76/70	10	11.3
180/158	82/70	13	7.2
190/158	88/70	28	5.3
200/158	92/70	12	4.1
182/158	83/70	11	7.2
		72	
Schedule No. 9 Douglas-fir 1 X 5-in clears			
164/152	75/68	12	10.6
164/146	75/65	12	8.5
172/146	79/65	24	6,7
180/146	84/65	21	6.7
		69	
Schedule No. 10 Douglas-fir 1 X 6 to 1 X 12-in clears			
150/140	65/60	48	11.8
157/138	70/60	12	8.2
165/138	75/60	36	6.4
		96	
Schedule No. 11 Douglas-fir 2 X 4-in clears			
160/150	70/65	24	11.5
166/146	75/65	24	7.8
172/140	80/60	24	5.5
180/140	82/60	24	4.4
190/140	88/60	48	3.3
		6 days	
Schedule No. 12 Douglas-fir 2 X 12-in clears			
160/154	70/67	24	14.2
166/152	75/67	24	7.6
172/150	80/67	24	7.3
172/144	80/65	24	6.2
172/140	80/62	72	5.5
		7 days	
Schedule No. 13 Douglas-fir 2-in random-width laminating stock			
200/195	93/90	36	14
200/185	93/85	24	8.8
200/175	93/80	24	6.2
200/170	93/77	64	5.4
200/190	93/88	12	10.8
		160	

seldom dried alone. They share with spruce the characteristics of easy, defect-free drying under all but the most severe conditions. However, the spruce dried in the same charge will have a final mc 3 to 4 percent less than the pine. Both conventional and high-temperature schedules have been successfully used, but differences between the two woods are more apparent at higher temperatures. Lodgepole and jack pine should not be dried in the same charge as alpine fir because the latter will not meet standards when dried with a pine schedule.

Spruce

The main species in western Canada are Sitka spruce [*Picea sitchensis* (Bong.) Carr.], white spruce [*Picea glauca* (Moench) Voss], Engelmann spruce (*Picea engelmannii* Parry) and black spruce [*Picea mariana* (Mill.) BSP]. Of these, Sitka spruce is the largest in size and is confined to the coastal region of British Columbia. It is most abundant in the northern portion of its range, especially on the Queen Charlotte Islands.

White spruce and Engelmann spruce occur in the interior of British Columbia and the eastern slopes of the Rocky Mountains in Alberta. The two species are not distinguished commercially and are the most important species cut in western Canada. Spruce dimension lumber is relatively easy to dry and appears not to be adversely affected by severe high-temperature schedules: it is being dried in 24 to 60 hours.

White spruce is normally dried with lodgepole pine on schedules listed under lodgepole pine. However, spruce dried on such schedules will have a final average of 10 to 11 percent when the pine is sufficiently dry to meet standards. Where spruce is being dried alone, therefore, it will conform to standards with shorter drying times than those for pine. Schedules No. 3 and 4 can be terminated at 42 hours for spruce alone. Black spruce similarly can be dried on pine schedules when harvested and milled with lodgepole or jack pine. In schedules 6 and 7, the temperature should be reached after 6 to 8 hours drying. Faster heating can result in severe degrade.

Douglas-fir

Douglas-fir [*Pseudotsuga menziesii* (Mirb.) France] is found throughout the southern half of British Columbia and Alberta in pure or mixed stands. Because of minor differences, it is sometimes segregated into two separate varieties, coast and interior Douglas-fir. These differences apparently do not affect the seasoning characteristics. Studies made at the Western Forest Products Laboratory show that both varieties season equally well by the same schedules.

In drying 1 -inch Douglas-fir, the main difficulty is to prevent the loosening of encased knots. Tests indicate that there is a marked increase in degrade owing to loosened and shattered knots during machining when ITIC is less than 16 percent. Because of the greater thickness of wood surrounding the knots in 2-inch lumber, that thickness has much less degrade from loose knots than 1 -inch lumberand a more severe schedule.

In both 1- and 2-inch dimension lumber, drying time varies greatly according to the type of logs from which the lumber is cut. Lumber from small logs contains more sapwood and has a higher mc than that cut from heartwood of large logs.

In the interior of British Columbia, Douglas-fir is frequently dried with western larch.

Larch

Two species of larch, tamarack (*Larix laricina* (Du Roi) K. Koch], and western larch (*Larix occidenta/is* Nutt.) are found in British Columbia. Both may be known locally as tamarack, but the species more commonly called by that name, *Larix laricina,* is found east of the Rocky Mountains. Western larch is found throughout the Kootenays with admixture of alpine larch (*Larix lyallii* Parl.) above 6500 ft (2000 m) elevation. Western larch is harvested, milled and marketed with Douglas-fir. Kiln schedules are usually designed for its admixtures with Douglas-fir (schedules 14 to 16).

Western hemlock

Western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] is the major lumber species on the coast and also occurs in the interior wet belts of British Columbia. On the coast, it is usually in mixed stands with Douglas-fir, amabilis fir, Sitka spruce, and western red cedar. It is in such stands that it attains its optimum growth. In the interior, it is chiefly associated with spruce, alpine fir, Douglas-fir, western red cedar, and lodgepole pine.

There appears to be no difference in the seasoning characteristics of coast and interior western hemlock lumber. When properly handled, western hemlock can be dried with highly satisfactory results. It should not be included in the same charge, however, nor dried by the same schedule as that recommended for Douglas-fir.

There is a wide variation in the mc of green western hemlock. Clears are more likely to be of high initial mc and are usually dried to a lower final mc. Construction grades vary greatly in initial mc and are normally dried to about 14 percent mc. Best results with these grades are obtained when sorting facilities permit segregation. If segregation of "sinker stock" is not possible, a longer time will be required to obtain the desired results, and a

Temperature (dry-bulb/wet-bulb)		Time	EMC
°F	°C	hr	%
Schedule No. 14 Douglss-firand larch, 2-in dimension, conventional schedule			
160/140 → 180/160	70/60 → 80/70	18	7.9
180/160 → 190/160	80/70	19	7.6
180/160	80/70 → 87/70	3	5.5
190/160	87/70	23	5.5
cooling period		6	
		69	
Schedule No. 15 Douglas-fir and larch, 2-in dimension, conventional schedule			
to 170/160	76/60	6	11.3
to 190/160	85/70	16	5.5
190/150	85/65	44	4.4
180/170	80/75	6	11.1
		72	
Schedule No. 16 Douglas-fir and larch 2 x 4-in dimension, high-temperature schedule			
225/190	107/88	12	*4.4*
240/190	115/88	9	*3.1*
205/180	96/82	3	*6.1*
		24	
Schedule No. 17 Western hemlock 1-in random width clears			
160/154	70/67	24	14.2
166/150	74/65	24	9.1
172/150	77/65	24	7.3
180/150	82/65	48	5.7
		5 days	
Schedule No. 18 Western hemlock 2-in random-width clears			
160/154	70/67	24	14.2
166/148	75/65	24	8.5
172/144	78/62	24	6.2
172/140	78/60	24	5.5
180/140	82/60	24	4.4
190/140	88/60	48	3.3
		7 days	

higher relative humidity should be maintained to prevent too low a mc in the more easily dried pieces.

Western hemlock is normally dried by conventional schedules, requiring about 4 days drying time. Some schedules have been developed to dry it in about 2 days at high temperatures. One result of some high-temperature schedules has been to give the lumber a brownish "toasted" color, particularly in the sapwood. Some operators claim to be able to dry quickly without the color change. Whether this is due to schedule or to wood characteristics is not known.

Western hemlock is frequently dried with amabilis fir, whose drying characteristics are similar.

Alpine fir

Alpine fir *[Abies **lasiocarpa*** (Hook.) Nutt.] grows in central and northern British Columbia and contiguous parts of Alberta in association with white spruce and lodgepole pine. It is harvested, milled and marketed with these woods as spruce-pine-fir. However, its very high mc, compared to spruce and pine, results in some 30 percent of "wets" when it is dried with these species. Consequently, to conform to standards it must be segregated and dried alone.

Western red cedar

Western red cedar ***(Thuja plicata*** Dorm) is found in British Columbia in the coast area and in the damper valleys of the southern and central interior, particularly in the Kootenay and Columbia drainage basins. It usually occurs in mixture with western hemlock and Douglas-fir, but is sometimes found in small pure stands. Large trees occur throughout the range of the species, though the biggest trees are generally on coastal sites.

There is no appreciable difference in the drying qualities of coast and interior western red cedar lumber, which dries better at lower humidities than those recommended for Douglas-fir.

Some western red cedar lumber is subject to collapse when kiln dried. Air drying in stickered piles for several weeks helps to prevent this condition, but in extreme cases may not be completely effective. For abnormal cedar of this type, an initial dry-bulb temperature of 120"F and relative humidity of 85 percent is recommended, followed by a relatively low temperature [e.g. 140°F (60"C)] until the fiber saturation point (fsp) has been reached. After the average mc has reached 25 percent, it is usually safe to raise the dry-bulb temperature to that maintained for normal cedar.

Another defect encountered in seasoning cedar is that known as "wet spot", in which sections of a board may be above the fsp when the rest is thoroughly dry. This condition is only relieved by extending the kiln-drying time and maintaining a relative humidity high enough to prevent excessive drying.

Yellow cedar

In Canada, yellow cedar ***[Chamaecyparis nootkatensis*** (D. Dorm) Spach] is confined to the coastal region of British Columbia from Alaska southward. It seasons readily and 1 -inch and 1 %-inch lumber can be dried successfully by the same schedules as are used for western red cedar.

Hardwoods

Hardwoods require more care in seasoning than softwoods. Because of the great variation in mc and other factors, the use of sample boards when drying hardwoods is recommended.

Hardwoods green from the saw are subject to all the forms of kiln degrade common to softwoods and also are subject to collapse in varying degrees when too high an initial temperature is used. On the other hand, if too low an initial temperature is used, mouid is apt to develop on the surface of lumber. All hardwoods should be stickered more closely than softwoods, and it is recommended that the stickers be not more than 24 inches apart.

Changes in temperature and relative humidity in the schedules which follow are determined on the basis of changes in mc of the lumber. Times shown are inserted only as an approximate guide to the points at which these changes should be made.

Red alder

Red alder ***(Alnus rubra*** Bong.) attains commercial size only in the rich bottomlands of the coastal region. It is one of the most important of local hardwoods and a considerable quantity is cut and dried for the furniture industry.

The color of the wood is affected by the temperature and humidity of the schedule.

Broadleaf maple

Broadleaf maple *(Acer **macrophyllum*** Pursh) has somewhat similar characteristics to red alder and is found on the same sites throughout the southern coastal region. It is more difficult to dry because of its tendency toward severe end checking. For this reason special care and supervision must be given when it is kiln dried.

Temperature (dry-bulb/wet-bulb)		Time	EMC
°F	°C	hr	%
Schedule No. 19 Western hemlock 1 ½ X 6-in vertical-grain shop			
160/150	70/65	15	11.5
175/150	80/65	51	6.7
190/150	88/65	72	4.4
		138	
Schedule No. 20 Western hemlock and amabilis fir 2 X 4-in dimension			
165/150	75/65	12	9.4
175/150	80/65	24	6.6
190/150	88/65	36	4.4
		72	
Schedule No. 21 Western hemlock and amabilis fir 2 X 6 and 2 X 8-in dimension			
155/150	68/65	12	15.2
165/150	75/65	24	9.4
180/150	82/65	24	5.7
190/150	88/65	24	4.4
		84	
Schedule No. 22 Western hemlock and amabilis fir 2 X 10 and 2 X 12-in dimension			
155/148	68/65	24	13.6
160/148	70/65	24	10.6
170/148	77/65	24	7.3
175/148	80/65	24	6.4
185/148	85/65	24	4.6
		120	
Schedule No. 23 Western hemlock and amabilis fir 2 X 4-in dimension, high-temperature schedule			
240/205	115/95	42	4.4
Schedule No. 24 Western hemlock 2 X 4-in studs, high-temperature schedule for gas-fired kilns			
Set controller at 240/180(115/82°C)			
240/180	115/82	3	2.2
to 240/155	to 115/68	24	1.9
		27	
Schedule No. 25 Alpine fir 2-in dimension, gas-fired kilns			
100/80 to 200/180	36/25 to 91/80	10	7.2
200/180 to 240/180	91/80 to 115/80	40	2.2
240/180 to 240/160	115/80 to 115/70	20	2.0
		70	

Temperature (dry-bulb/wet-bulb)		Time		EMC
“F	“c	hr		'3/0

Schedule No. 26 Alpine fir 2-in dimension, steam kilns

235/180	**11 0/80**	**“ 54**	**2.8**
steam		**4**	
235/1 80	**11 0/80**	**4**	**2.8**
steam		**4**	
235/1 80	**110/80**	**24**	**2.8**
		90	

Schedule No. 27 Western red cedar 1 X 4-in clears and ?4 X 5-in shop

		clears	¾-in shop	
1 90/150	88/65	24	48	4.4
1 90/140	88/60	48	60	3.3
1 90/170	88/77	4	6	7.4
		76	114	

Schedule No. 28 Western red cedar 1 X 6 and 1 X 8-in clears

172/1 52	**78/67**	**24**	7.8
180/1 52	**82/67**	**24**	6.0
1 90/150	**88/65**	**48**	4.4
1 90/170	**88/77**	**4**	7.4
		100	

Schedule No. 29 Western red cedar% X 5-in clears and 2-in shop

		Clears	Shop	
190/1 52	77/67	24	48	8.4
180/1 50	82/65	24	48	5.7
185/1 50	85/65	24	48	5.0
1 90/145	88/63	48	48	3.8
1 90/140	88/60	48	48*	3.3
1 90/170	88/77	6	10	7.4
		174	250	

Schedule No. 30 Western red cedar 2-in shop

		Days	
1 50/135	65/57	1	9.5
1 55/135	68/57	3	7.7
160/1 35	70/56	1	6.8
160/1 30	70/53	2.	5.8
165/1 25	75/53	1	4.4
170/125	78/53	3	
		11	

● For 2-in clears, use 96 hours

Temperature (dry-bulb/wet-bulb) °F	°C	Time days	EMC %
Schedule No. 31 Western red cedar 2-in shop (final mc 7 to 10%)			
170/152	77/67	2	8.4
180/150	82/65	2	5.7
190/150	87/65	2	4.4
190/145	87/62	2	3.8
190/140	87/59	2	3.3
		10	
Schedule No. 32 Western red cedar 1 X 6 to 1 X 12-in Sound tight knots (final mc 12 to 16%)			
140/132	60/56	1	13.2
144/134	63/57	4	11.9
		5	
Schedule No. 33 Western red cedar 2-in sound tight knots (final mc 14 to 19%)			
150/142	64/60	1	16.2
152/142	66/60	6	14.2
		7	
Schedule No. 34 Yellow cedar 1-in random width shop			
147/142	64/60	1	15.4
150/144	66/62	1	14.5
160/152	72/67	1	13.0
170/160	76/70	1	11.3
180/160	80/70	1	7.6
190/160	87/70	2	5.5
		7	
Schedule No. 35 Yellow cedar %-in shop			
142/136	60/57	1	14.8
152/146	67/64	1	14.5
162/156	72/69	1	14.2
172/162	78/72	1	11.3
177/162	80/72	1	9.1
182/162	83/72	1	7.6
192/162	89/72	4	5.5
		10	

Mc at start of step	Temperature (dry-bulb/wet-bulb)		Time (approx.)	EMC
%	“F	‘C	days	%

Schedule No. 36 Red alder 1 %-in to 2-in lumber; turning squares to 2%-in

—	150 steam spray	65	1Y2	—
over 40	140/132	60/56	2	13.2
40	145/135	63/57	1	11.9
35	150/135	66/57	1	9.5
30	155/135	68/57	1	8.0
25	160/135	71/57	1	6.8
20	165/137	74/59	1	6,2
15	170/140	77/60	1	5.7
10 to dry	175/135	80/57	4	4.4
Condition	180/168	82/75	·	10.2

Estimated drying time to 8% mc = 12 to 16 days.

Schedule No. 37 Red alder 2-in random-width lumber

	150 steam spray	65	1Y2	
	160/150	70/65	1Y2	11.5
	170/150	77/65	2	7.8
	180/150	82/65	8	5.7

Schedule No. 38 Broadleaf maple 1-in and 1 %-in lumber

Over 40	140/130	60/54	2	11.9
40	140/128	60/53	1	10.9
35	150/134	65/57	1	9.2
30	150/132	65/56	1	8.6
25	150/130	65/54	1	8.0
20	160/136	71/58	1	7.0
15	160/132	71/56	1	6.2
10 to dry	170/136	77/58	3	5.1
Condition	170/164	77/73	—	13.9

Estimated drying time 10 to 12 days to 7% for 1 in and 10% for 1 ¼ in.

Mc at start of step	Temperature (dry-bulb/wet-bulb)			EMC
%	“F	‘ c	days	'??0

Schedule No. 39 Trembling aspen ?4- and %-in factory lumber

Over 40	160/1 42	71 /61		8.5
40	170/1 36	77/58		4.7
30 to dry	180/1 30	82/54		3.0
Condition	180/1 71	82/77		12.6

Schedule No. 40 Trembling aspen ¾ to 3/A-in and balsam poplar ¾ to %-in factory lumber

over 40	**1 40/133**	**60/56**		**14.3**
40	**1 50/130**	**66/54**		**7.9**
30 to dry	**170/1 20**	**77/49**		**2.9**
Condition	**170/161**	**77/72**		**12.7**

Schedule No. 41 Balsam poplar ?4 to %-in factory lumber

over 40	135/1 29	57/54		15.4
40	1 40/130	60/54		12.5
30	1 50/135	66/57		9.8
25 to dry	165/1 15	74/46		2.9
Condition	165/1 56	74/69		12.9

Schedule No. 42 Black cottonwood 1 -in and 1 %-in furniture core stock

over *45*	1 70/166	77/75	7	15.8
45	175/1 67	80/75	1	12.4
40	180/1 70	82/76	'/2	11.1
30	185/1 72	85/78	'/2	9.7
20	1 90/168	88/76	½	7.2
10 to dry	190/1 60	88/71	3	5.5

Schedule No. 43 Trembling aspen and balsam poplar (mixed) 2 X 4-in dimension (steam kiln)

			hr	
	180/1 80	to 82/82	2	—
	to 250/180	121 /82	59	2.0
	off	off	2	no fan
	204/1 96	96/91	18	11.8
	250/1 80	121 /82	15	2.0

0

Broadleaf maple can be kiln dried green from the saw. The initial dry-bulb temperature, however, should not be reduced below 140°F because of the potential for moukf formation. To eliminate defects caused by a higher temperature, it is recommended that a higher humidity be carried until the final stage of drying below the fsp is reached.

Western white birch

Since the supply of western white birch ***[Betula papyrifera*** Marsh. var. ***commutata*** **(Regel)** Fern.] is restricted and log diameters are usually not large, only a limited quantity is kiln-dried, usually as flooring blanks or other narrow widths, This species occurs throughout western Canada, usually in scattered patches in the more moist sites.

The seasoning qualities of western white birch are similar to those of broadleaf maple and it may be dried by the maple schedule.

Poplar

Two species of poplar, trembling aspen ***(Populus tremuloides*** Michx.) and balsam poplar ***(Populus balsamifera*** L.) occur in abundance in the western provinces and a third, black cottonwood ***(Populus*** *trichocarpa* Torr and Gray), is restricted to British Columbia and the western part of Alberta. Two products, factory lumber and light framing lumber, represent the main channels by which this lumber is marketed.

Aspen dries relatively easily, but two serious sources of trouble must be recognized. Throughout a log, but principally at the sapwood-heartwood boundary, wet pockets are found which dry very slowly and are prone to collapse and internal checking.

The second problem source is tension wood which occurs frequently in poplars. During drying, tension wood exhibits a measurable shrinkage along the grain, i.e. in the long axis of a sawn board. Depending on where in a board the tension wood is located, this longitudinal shrinkage will cause bow, twist, or crook. To try to minimize this warp, close sticker spacings are recommended, some mills placing stickers at only 1-foot **centres.**

APPENDIX A
CONVERSION FACTORS

English	Old Metric	S1 Units
Linear Units		
1 in (inch)	2.54 cm (centimetres)'	25.4 mm (millimetres)'
1 ft (foot)	30.48 cm	304.8 mm
1 yd (yard)	91.44 cm	0.9144 m (metres)
39.37 in		l m
1.0936 yd		l m
3.28 ft		l m
0.03937 in		1 mm
Surface Units		
1 in^2 (square inch)	*6.452* cm^2 **(square centimetres)**	645.2 mm^2 (square millimetres)
1 ft^2 (square foot)	**929 cm^2**	92900 mm^2
1 yd^2 (square yard)		0.8361 m^2
1.196 yd'		1 m^2
1 acre		.405 ha (hectare)
2.47 acres		1 ha
Volume Units		
1 in' (cubic inch)	16.39 cm^3 (cubic centimetres)	
1 ft^3 (cubic foot)		0.0283 m^3
1 M fbm (thousand feet board measure)		2.3583 m^3
424 fbm		**1 m^3**
Weight Units		
102 (ounce)	28.35 g (grams)	28.35 g
1 lb (pound)	0.4536 kg (kilograms)	0.4536 kg
1 ton = 2000 lb.		0.9072 metric tonne
Pressure Units		
1 lb/in^2	0.97 kg/cm^2	6.895 kPa (kilopascals)
14.5 lb/in'	1000 mb (millibars)	100 kPa
1 in Hg (inch mercury)	0.0345 kg/cm^2	3.386 kPa
1 in H_2O (inch water)	2.538 g/cm^2	249 Pa (pascals)
1 **lb/ft^2**	0.4875 g/cm^2	47.9 Pa
19.34 lb/in^2	1000 mm Hg (millimetres mercury)	133.33 kPa

145 lb/in^2		**1 MPa(megapascal)**
1 atmosphere = 14.69 lb/in^2	1013 mb	**101.3 kPa**
0.145 lb/in’		**1 kPa**
Energy Units		
1 Btu (British thermal unit)	0.252 kg-cal	1.054 kJ (kilojoules)
1 hp-hr (horsepower-hour)	641.7 kg-cal	2.685 MJ (megajoules)
1 kw-hr (kilowatt-hour)	859.98 kg-cal	3.6 MJ
1 ft-lb	0.324 **g-cal**	1.356 J (joules)
Power Units		
1 hp (horsepower)		***746*** W (watts)
1.34 hp		1 kW (kilowatt)

‘While it is prefereable to limit multiples to 1/1000 and 1000 primary units, for convenience multiples of 1/100 (centi-) are frequently used.

APPENDIX B
GLOSSARY

A list of generally accepted definitions of some common terms used in wood seasoning is provided below. Free reference was made to U.S.D.A. Handbooks No. 188 and 402 and to Forest Products Research Society Publication 83G. For descriptions of terms relating to wood, wood structure, species characteristics and lumber grades the reader is referred to standard references such as:

British Columbia Lumber Grading Authority, 1972 and NLGA 1970

Standard Grading Rules for Canadian Lumber.

DEFINITIONS

Air velocity: The speed at which air moves through a load of lumber in a kiln, generally measured in feet per minute (metres per minute) on the leaving-air side of a load.

Baffle: A piece of material used to deflect, check, or otherwise direct the flow of air through the loads of lumber in a kiln. Improper loading and/or baffling leads to short-circuiting of the air movement.

Blanking: Presurfacing of green lumber, usually on one side only, prior to kiln drying in order to obtain uniform thickness of lumber.

Bolster (or bunk): A square timber placed between stickered packages of lumber to provide for entry and exit of the forks of a lift truck.

British thermal unit (Btu): The amount of heat necessary to raise 1 pound of water 1°F in temperature.

Bulb, control: The temperature-sensitive part of a thermostatic control system.

- **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:** A temperature-sensitive instrument that records, but does not control kiln temperatures.
- **Recorder-controller:** An instrument that records the dry- and wet-bulb temperatures within the drying chamber and automatically controls them according to some predetermined schedule.

Bulk pile: A solid-piled package of lumber.

Cam: One of two precut metal discs, one representing the pattern of dry-bulb temperatures with time, the other wet-bulb temperatures with time; used in a control instrument to provide the schedule to be automatically followed.

Casehardening: A condition of set in wood under stress. The outer fibers (face) are under compressive stress and the inner fibers (core) are under tensile stress.

Casehardening, reverse: A final stress and set condition in wood where the outer fibers (face) are under tensile stress and the inner fibers (core) are under compressive stress; the result of over-correction for casehardening.

Chamber, plenum: Conduit or space on the pressure side of a fan or blower in which the air is maintained under a small positive pressure.

Chart, recorder: A paper sheet, usually circular, on which a graphic record of kiln temperatures is transcribed.

Coil, heating:
Syn: Pipe coil.
In kiindrying a heat exchanger made up of two or more runs of plain or finned pipes in the dryer through which steam, hot water, or hot oil flows to heat the circulated air.

- **Booster or reheater:** A supplementary coil, usually located between tracks of a double-track kiln, used to add heat to air that has already cooled by moving through a truckload.

Collapse: The severe distortion of single cells which may occur in wood during the early stages of drying. Evidenced by caved-in. appearance of the surface of the lumber.

Compression wood: Abnormal wood formed on the lower side of trunks of leaning softwood trees. It shrinks londitudinally more than normal wood, causing bow, crook and twist.

Condensation: The changing of a vapor to liquid form. Steam releases 970 Btu per lb or 2.3 MJ per kg in changing to liquid water.

Conditioning: Any process designed to produce a uniform distribution (equalization) of moisture in timber and reduce drying stresses.

Controller: An instrument that automatically controls kiln temperatures.

Course: Single layer of lumber of the same thickness in a stickered pile or package.

Degrade, drying: A drop in lumber grade due to defects that result from seasoning.

Depression, wet-bulb: The difference between dry-bulb and wet-bulb temperatures.

Diffuaion: Spontaneous movement of heat, dissolved material, moisture or gas through a body or space from high points to low points of temperature, concentration or partial pressure.

Drying rate: The amount of moisture lost from lumber per hour of drying time, usually expressed as percentage decrease in moisture content per hour.

Duct, air: A rectangular, square, or circular passageway to conduct air.

End coating: Moisture-resistant coating applied to end-grain surfaces of green lumber to restrict checking and splitting resulting from rapid end drying.

Equilibrium moisture content (emc): The moisture content at which wood neither gains nor loses moisture when subjected to a given constant condition of humidity and temperature. The moisture content which wood attains when subjected to any given constant condition of humidity and temperature.

Evaporation: Conversion of a liquid to the vapor state by the addition of latent heat (970 Btu per lb of water at212“F; 2.3 MJ per kg of water at 10O”C.)

Extractives: Substances in wood, not an integral part of the cellular structure, that can be removed by hot or cokf water, ether, benzene, or other solvents that do not react chemically with wood substance.

Fiber saturation point (fsp): The stage in the drying of wood at which the cell walls are saturated with water, but the cell cavities are free from water. It is taken at normal temperatures as approximately 30 percent moisture content. At higher temperatures, its value decreases. At the boiling point of water it is approximately 19 percent.

Honeycombing: Checks, which occur in the interior of a piece of wood, usually along the wood rays, and may not be visible at the surface.

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.

Hygrometer: An instrument, usually consisting of two thermometers, for measuring the dry-bulb and wet-bulb temperatures of the air.

Hygroscopicity: The property of a substance which permits it to absorb and retain moisture.

Joule (J): Metric measure of heat or energy: 1 kJ (kilojoule) = 0.9486 Btu; 1 MJ (megajoule) = 948.6 Btu,

Juvenile wood: Low-density, fast-growing wood formed near the pith of a tree; also known as core wood.

Kiln: A chamber provided with controls for temperature and relative humidity in which lumber is dried.

Compartment: A dry kiln in which the total charge of lumber is dried aa single unit.

Progressive: A dry kiln in which the total charge of lumber is dried 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 (green) end than at the discharge (dry) end.

Multiple track: A dry kiln equipped with two or more tracks.

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 drying: Process of drying lumber under controlled conditions in a dry kiln.

Kiln run: Term applied to the drying of a single charge of lumber.

Meter, moisture: An instrument for automatically determining the moisture content of wood, equipped with electrically conducting electrodes which may be driven into the wood or which are flat and contact the wood surface. Readings must be adjusted to compensate for species and temperature of the wood.

Moisture, bound: Water in wood that is found in the cell walls and held by hydroscopic forces; preferably called “bound water”.

Moisture, free: Moisture in the cell cavities and intercellular spaces of wood, as distinguished from moisture in cell wails; preferably called “free water”.

Moisture content (me): The weight of water held in wood, usually expressed as a percentage of the ovendry weight; the percentage of moisture present in wood. The moisture may exist (a) free in cell spaces or(b) in the cell walls.

Air-dry mc: The moisture content of wood that is in equilibrium with climatic conditions,

Green mc: The moisture content of unseasoned wood that may vary from 30 to 200 percent.

Kiln-dry mc: The moisture content of wood that has been dried in a kiln. According to present standards, each piece must be less than 19 percent mc.

Ovendry: Wood that has been dried to constant weight in an oven at217 &4°F(103 ± 2°C).

Moisture distribution: The varying concentration of moisture throughout a piece of wood, usually from face to face but sometimes from end to end.

Moisture gradient: A condition of graduated moisture content between the inner and outer portions of wood due to loss or absorption of moisture.

Piling, box: A method of flat piling random-length lumber whereby both ends of a pile are square,

Piling, close: Lumber piled edge to edge with no space between courses; solid or bulk piling; the normal way in which lumber is shipped.

Piling, flat: Lumber piled so that the broad faces of boards are horizontal.

Reaction wood: Wood of more or less distinctive anatomical characteristics formed in parts of leaning or crooked stems; in hardwoods termed tension wood and in softwoods, compression wood.

Sample board: A board from which one or more kiln samples will be cut and placed in a kiln charge, so that they can be removed for examination, weighing and testing; or a board within a kiln truckload sampled for moisture content during or after a run.

Set: A localized, semipermanent deformation in wood caused by internal stresses.

Compression set: Set, occurring during compression, that tends to give 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 overcondition-ing or rewetting.

Tension set: Set, occurring during tension that tends to give wood a larger than normal dimension, usually occurring in the outer layers during the first stages.

Shrinkage: Contraction caused by drying wood below the fiber saturation point; greater in the wide face of flat-grain than in edge-grain lumber, and minimal in the longitudinal direction.

Sorting: Segregation of lumber into lots having similar characteristics, such as thickness, species, grade, initial moisture content, final moisture content, and into stacking classes by thickness, width and length.

Specific gravity: The ratio of the ovendry weight of a piece of wood to an equal volume of water at 39°F (4"C). It is normally based on the green volume of the wood.

Spray line: A plain pipe of varying sizes and lengths, drilled with holes of various sizes and spacing, through which steam or water droplets are injected into a kiln.

Stain, blue: A bluish or grayish discoloration in the sapwood of softwoods caused by the growth of certain dark-colored (staining) fungi.

Stain, brown: A brownish discoloration that may occur during the seasoning of certain softwoods (particularly white pine), apparently caused by the concentration and oxidation of extractive chemicals.

Steam: The vapor into which water is converted when heated above the boiling point.

Exhaust: Steam which has been passed through a steam engine or machine; usually of low pressure.

Live: Steam obtained directly from a boiler.

Saturated: Steam in contact with liquid water at the same temperature and pressure.

Superheated: Steam at a temperature higher than the saturation temperature corresponding to the pressure.

Sticker: A wood strip or crosser placed between courses of lumber in a pile or a unit package, at right angles to the long axis of the stock. It permits air passage between adjacent courses.

Stress, drying: An internal force, 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 shrinkage is restrained by the still-wet interior regions; also the stress in the interior layers later in drying as they try to shrink, but 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 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 relief: See Conditioning.

Stress section: A cross section of a sample that is cut into prongs of equal thickness from face to face, in order to determine the presence of stresses in the wood.

Temperature, dry-bulb: The air temperature indicated by any type of thermometer not affected by the relative humidity of the air.

Temperature, wet-bulb: The temperature of a thermometer set in a wind current, the sensitive element of which is covered by a smooth, clean, soft, water-saturated cloth.

Tension wood: Abnormal wood formed on the upper side of the trunk of leaning hardwood trees. It shrinks more than normal wood longitudinally; is subject to wet spots in drying and fuzzy surface on machining.

Treatment, antistain: A chemical applied to lumber by dipping or spraying to prevent or retard development of chemical or fungus stain mould or sapstain). It is recommended for green and close-piled underdried lumber.

Treatment, steaming: Spraying steam directly into a kiln to attain a condition at or near saturation in the initial stages of kiln drying to retard the growth of mould. It is also used to increase the rate of heating of cold lumber, but it is not the same process as conditioning.

Vapor pressure: Pressure exerted by a confined body of vapor; at saturation, the pressure is a function of temperature only.

Vent: An opening in a kiln roof or wall that can be opened or closed in order to permit escape of humidity, to assist in maintaining the desired relative humidity condition within the kiln. Most vents have automatic control.

Linkage: The adjustable, pivoted rods connecting the vent cover to an air piston which facilitates the opening and closing of the vents.

Waterpocket: A zone within green or dried lumber having excessively high moisture content; common to alpine fir, hemlock, aspen.

Water repellent: A compound designed to give temporary waterproofing to wood products in transit and storage; usually a wax emulsion applied by spraying.

Wetwood: Pockets within wood having one or more of the following characteristics: high moisture content; presence of bacteria (but not decay fungi); usually but not always with lower acidity than adjacent wood; lower permeability than normal wood. Common in poplar wood.

Moisture content, air velocity and temperature designations:

The following approximate moisture content values are important:

Lower limit of fungal growth	22?40
Air-dried lumber	12 to 16%
Exterior woodwork	**16%**
Interior joinery with central heating	6 to 8%

Temperature ranges for drying classifications:

(a) Low temperature, less than 140°F(600C).
(b) Conventional, 140-180"F (60-80"C).
(c) Elevated, 180-212"F (8O-1OO"C).
(d) High temperature, morethan212°F (1 **00°C**).

Classification of air delivery on the basis of exit air in feet per minute (fpm) or metres per minute (m per rein):

(a) Standard, up to 300 fpm (90 m per rein).
(b) Accelerated, 300-500 fpm (90-150 m per rein).
(c) High velocity, more than 500 fpm (over 150 m per rein).

Common abbreviations (see also Appendix A):

emc	=	equilibrium moisture content
fbm	=	feet board measure
Mfbm	=	1000 feet board measure
fpm	=	feet per minute
fsp	=	fiber saturation point
mc	=	moisture content
M	=	thousand (as in board feet)
psia	=	pounds per square inch absolute pressure
psig	=	pounds per square inch gauge pressure
rpm	=	revolutions per minute

APPENDIX C
PROPERTIES OF STEAM

Table C.1

Properties of Ice, Water and Saturated Steam

Temp. 'F	Saturated steam pressure psia	psig	Volume of 1 lb liquid Cu ft	vapor Cu ft	Heat content* of liquid Btu	Latent heat of evap. Btu	Total heat* content Btu
32 **(ice)**	—	—	(0.1 74)		o	—80	•- – 8 0
32 (water)	—	—	0.160		0	—	o
126	2	—	0.162	***174***	94	1022	1116
153	4	—	0.164	***91***	121	1006	1127
170	6	·	0.165	***62***	138	996	1134
183	8	—	0.165	***47***	151	988	1139
193	10	—	0.166	***38***	161	982	1'143
202	12	—	0.166	***32***	170	977	1147
210	14	—	0.167	***28***	178	972	1150
212	14.7	o	0.168	***26.8***	180	970	1150
228	20	5.3	0.168	***20.1***	196	960	1156
240	25	10.3	0.169	16.3	208	952	1160
250	30	15.3	0.170	13.7	219	945	1164
259	35	20.3	0.171	11.9	228	939	1167
267	40	25.3	0.172	10.5	236	934	1170
274	45	30.3	0.172	9.4	243	929	1172
281	50	35.3	0.173	8.5	250	924	1174
287	55	40.3	0.173	7.8	256	920	1176
293	60	45.3	0.174	7.2	262	916	1178
303	70	55.3	0.175	6.2	273	908	1181
312	80	65.3	0.176	5.5	282	901	1183
320	90	75.3	0.177	4.9	290	895	1185
328	100	85.3	0.178	4.4	298	889	1187
335	110	95.3	0.178	4.0	306	883	1189
341	120	105.3	0.179	3.7	312	878	1190

● **Above liquid stateat 32°F**
•● **Latent heat of fusion**

Table C.1 lists properties of water and steam at selected temperatures. It will be noted that at every temperature there is a specific pressure of saturated steam, and that there is a specific total heat content, made up of the heat content of the liquid (the amount of heat required to raise the liquid from 32°F to that temperature) and the latent heat of evaporation (the amount of heat required to convert the liquid to steam at that temperature). Saturated steam is associated with the presence of l'iquid water and is in equilibrium with it. Such steam results from the boiling of water or partial condensation of steam. Superheated steam cannot exist in the presence of water. It is formed after being conducted away from water and (a) heated to a higher temperature, or (b) passed through a reducing valve or throttle to reduce its pressure. "Superheat" is frequently used to describe the heat content in excess of that needed to convert all the water to steam, or it is the difference between the temperature of the steam and that of saturated steam at the same pressure.

When heat is removed from superheated steam, its temperature falls, though no steam condenses, until the temperature reaches that of saturated steam at the prevailing pressure. During this stage, approximately 0.45 Btu is released per pound of steam for each ‘F temperature drop. Further loss of heat results in condensing the steam without change of temperature. During condensation, the heat lost is the latent heat of evaporation, approximately 970 Btu per pound of water condensed.

The quantity of steam transported by a steam line for a given pressure drop is proportional to the internal area of the pipe and also to the steam pressure. Thus a pipe of 1 sq in cross-sectional area will conduct as many pounds per hour of 100 psia steam as a 2 sq in cross section will conduct of 50 psia steam.

The rate of heat transfer (Btu/hr) from a radiator (steam coils) to the kiln atmosphere is proportional to the radiator area. Consequently finned pipe transfers heat faster than unfinned pipe. The rate of transfer is also proportional to the difference between steam temperature and kiln temperature. For example, if a kiln operating at 180”F is being heated by 50 psia steam (281 ‘F), the rate of heat transfer will be proportional to the value 281 — 180 = 10l°F. If the steam pressure is then raised to 100 psia (328”F), the rate of heating will be proportional to the value 328 — 180 = 148”F, or almost 50 percent faster.

High-pressure steam is not suitable for humidifying the kiln during the conditioning period. Saturated steam at 50 psia has a relative humidity of 100 percent at 281°F. If this steam is released through an expansion valve or throttle into the kiln at 14.7 psia (atmospheric pressure), its temperature will not change greatly. For simplicity, let us assume it will remain at 281 “F, but its relative humidity will be reduced. Its value will be the saturated vapor pressure at 212°F (1 4.7 psia) divided by its saturated vapor pressure at 281‘F (50 psia) or about 30 percent. Consequently, low-temperature or desuperheated steam is required for conditioning.

APPENDIX D
SPECIAL DRYING TECHNIQUES

From time to time, a kiln operator may be asked about several special drying techniques and their application to commercial drying.

An important factor in any drying procedure is the cost: this includes depreciation of equipment, operating costs and losses due to degrade of the product. Conventional kiln drying appears to offer the best value in terms of equipment and operating costs, and the quality of the product is satisfactory for most purposes. It is only when wood of outstanding value or for specialized products is being dried, and conventional methods result in too much loss of value, that other methods should be considered. For example, the high cost of species, grades, and sizes of hardwood for bowling pins, heels of ladies' shoes, gunstocks, and wooden mementos or souvenirs, make any degrade a costly matter. If a special drying technique can reduce losses to more than balance the extra drying costs, then it can be justified for these products.

Radio-frequency and microwave drying

These drying techniques involve placing the wood in a very high-frequency radio field. Due to the action of the alternating field, the water molecules reverse (flip over) many millions of times per second, with considerable frictional losses. These losses are converted to heat, which raises the wood temperature so that the water can diffuse out and evaporate.

The particular advantage of this technique is that heat is generated in proportion to the moisture content: wet zones are heated more than dry zones and, in general, the core is heated more than the shell. As a result (refer to Chapter 9), the core can have a higher vapor pressure than the shell, while its moisture content may be only a little higher. This results in rapid diffusion and drying with relatively little drying stress and degrade. Also, little energy is lost when dry wood is in the radio-frequency field.

The disadvantages are in the high costs of the electronic equipment and energy. Energy costs are approximately twice the cost of electricity, since the radio-frequency generator is about 50 percent efficient.

In the softwood industry, this drying method has been recommended for the final stage of drying softwood plywood veneer, to ensure that there are no wet spots, which would result in blisters and loss of an entire panel of finished plywood.

Freeze drying

It is well known that wood can dry even below the freezing point. It is also known that, if the wood is placed in a vacuum where the absolute pressure is less than the vapor pressure of the wood, water will begin to evaporate from the wood. Many attempts have been made to use this process commercially, but with little success. The reason is that water requires about 1000 Btu per pound (2.3 MJ per kg) to evaporate. Since heat cannot be conducted through a vacuum, it will be taken from the wood itself, cooling the wood to the temperature where evaporation stops. Freeze drying has been used successfully in drying small laboratory samples, where it is possible to transmit heat through the container wall to the specimen. In a commercial installation, this would not be possible, and the process is not practical.

Solvent drying

One of the technical problems in drying wood, particularly large cross sections, is to transmit into the wood the large quantities of heat required to evaporate the water. If the water were "washed" out by another solvent with a lower heat of evaporation, the problem would be reduced. Since water is soluble in acetone, permeable species (where solvents will pass readily through the wood) can be dried rapidly by solvent drying, followed by evaporation of the solvent. Most of the solvent can be recovered, but even so, the cost of solvent lost is a significant part of the total cost. The method has been used for the drying of resinous species, such as the pines, in order to recover and sell the resins, and to produce a clean resin-free product. However, unless there is a substantial increase in the selling price of resin, the costs do not justify the expenses involved in the process.

Polyethylene-glycol drying

It sometimes happens that particularly beautiful pieces of wood sculpture are carved in green or partially dried wood, and are in serious danger of checking in subsequent drying. The obvious solution to the problem is to have the sculptor use properly dried and conditioned wood for his carvings. But, where the sculpture already exists, it is sometimes possible to soak the sculpture in a 50:50 mixture of polyethylene glycol and water. Polyethylene glycol, or PEG as it is often called, is a water-soluble wax that will penetrate the wood structure and reduce its shrinkage during subsequent drying. Consequently, after soaking in PEG, the wood may be dried with less danger of checking. However, checking is still possible. If the value of the piece justifies the use of PEG, it also justifies careful drying at relatively high humidities after PEG treatment to reduce the risk to a minimum.