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LUMBER DRY KILNS

And Their Operation

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EAST LANSING

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Lumber Dry Kilns and Their Operation

BY A. J. PANSHIN

Freshly cut wood contains considerable quantities of moisture; it is said to be *green*. Green lumber can seldom be used satisfactorily for any purpose, except when placed in constantly damp situations. For most uses at least some water must be removed from the wood prior to placing it in service. The process of the removal of moisture from the wood is called drying or, more commonly, seasoning of lumber. This is accomplished either by piling lumber and other wood products outdoors and exposing them to the atmospheric conditions, in which case it is called *air seasoning*, or by placing the wood in a heated chamber called a *kiln*. Lumber dried in such a chamber, at temperatures higher than those of the outside air, is said to be *kiln dried*.

Well air-seasoned lumber contains from 12 to 18 percent of moisture, depending on the part of the country and the season at which the moisture content is determined. Wood can be kiln dried to any moisture content, but in general the term *kiln-dried lumber* implies that the wood contains less than 10 percent moisture. It should be pointed out at the outset that the process of kiln drying involves more than mere removal of water from wood. To operate a kiln successfully it is necessary to understand the effect that temperature, relative humidity, air circulation and methods of piling have on the quality of the final product. Each of these factors is discussed in the pages that follow.

REASONS FOR SEASONING WOOD

WHY WOOD SHOULD BE SEASONED

Wood is made up of innumerable minute, hollow units, called cells (Fig. 1).[1] Each cell, when separated from the adjoining units, will be found to consist of a cell wall enclosing a cavity. These cells are held together by a cementing substance, called intercellular material, somewhat as bricks are held together by the mortar. The majority of wood cells are much longer than they are broad, and are arranged vertically

[1]Dr. C. C. Forsaith, of the New York State College of Forestry, Syracuse, has calculated that one cubic foot of spruce wood contains roughly 10 to 14 billion cells; if placed end to end, they would more than encircle the earth at the equator.

When wood dries, the free moisture is removed before any bound moisture can be withdrawn from the cell wall. The reverse is of course true when dry wood is allowed to absorb moisture, i.e., no free moisture can form within the cell cavities until the cell walls have been completely saturated. Technically this state, when there is no free moisture in the cells but the cell walls are fully saturated, is known as the *fiber saturation point.*

The removal of *free moisture* is not accompanied by any important physical changes in the wood. Any upward or downward fluctuations in the amount of moisture within the cell wall *(bound moisture)* are, however, accompanied by corresponding changes in the dimensions of a piece of wood; shrinking if the moisture is reduced and swelling if it is increased. These dimensional changes due to drying of bound moisture may be associated with formation of seasoning defects, such as warping, checking and casehardening.

Reduction in the amount of bound moisture results in an improvement of most of the strength properties of wood. This gain in strength due to drying is, however, of relatively minor practical significance.

Seasoning of wood leads to a considerable reduction in weight, owing to the loss of water, thus facilitating handling and helping to reduce freight charges, when lumber is shipped by rail. Finally, reduction in moisture content below the fiber-saturation point decreases the danger of development of decay and stains, and improves the machining, painting and gluing characteristics of the wood.

EQUILIBRIUM MOISTURE CONTENT

Wood will absorb or lose moisture until it reaches a balance with the humidity conditions of the air at a given temperature. When wood has attained such a moisture balance with the surrounding atmosphere it is said to have reached *equilibrium moisture content.* After that, no matter how long it is allowed to remain exposed to the particular temperature and humidity combination, no further changes in its moisture content will occur until these conditions are disturbed. For example, if the temperature is 90°F. and relative humidity 50 percent, the wood will eventually stabilize at 9-percent moisture content, and remain at that moisture content until either the temperature or the relative humidity, or both, are changed.

REASONS FOR KILN DRYING LUMBER

From this discussion of the equilibrium moisture content principle it follows that when wood is allowed to dry outdoors its moisture content can be decreased only to a point determined by the prevailing weather conditions. In Michigan, for example, in the summer wood left outdoors may dry to about 12 percent moisture, and in the winter months to between 14 and 18 percent. If lumber of a lower moisture content is desired, it cannot be obtained through air seasoning, no matter how long it is allowed to remain outside. In general, moisture content of less than 12 percent can be attained only by drying wood indoors. The most practical way of doing this on a large scale is by means of kiln drying, i.e., by subjecting wood to controlled humidities, and to temperatures higher than those normally encountered outdoors. Kiln drying of lumber, to any moisture content, is much more rapid than air seasoning; it can be controlled as desired, and when properly done results in a lesser amount of degrade than is common in air seasoning. These advantages of kiln drying must be weighed against the necessary capital investment in a kiln and kiln equipment, the cost of fuel, and other operating expenses.

METHODS OF MOISTURE CONTENT DETERMINATION

Since the satisfactory performance of wood in service is dependent to a large degree on its moisture content, it is imperative to know how to determine this quantity. It is also essential to know the moisture content of wood in order to follow the progress of its drying. There are two widely used methods by which the moisture content in wood can be determined: the oven drying method, and the electrical meter method.

THE OVEN DRYING METHOD

This method involves cutting of a small sample, about ¼ to ½ inch thick and the width of the board, weighing and then drying it in an oven (generally electrically heated) at a constant temperature of 212° to 221°F. (Figs. 22 and 23-C.) The sample is re-weighed periodically until it reaches a constant weight, which indicates that all the moisture has been removed from it. The moisture content of the sample, expressed in percentage, is then determined by subtracting the last weight (oven dry) from the original (green) weight, dividing the difference by the oven dry weight and multiplying the result by 100.

This operation may be expressed as, $MC = \frac{W-D}{D} \times 100$

Where MC signifies moisture content in percent; W is the original weight of the sample and D its oven dry weight.

The same formula can be expressed as, $MC = \left\{ \frac{D}{W} - 1 \right\} \times 100$

For example, if the original weight of the sample was 120 grams and the oven dry weight 80 grams, then

$$MC = \frac{120-80}{80} \times 100 = 50 \text{ percent, or}$$

$$MC = \left\{ \frac{120}{80} - 1 \right\} \times 100 = 50 \text{ percent}$$

The accuracy of the moisture content determination depends largely on the accuracy of weighing the samples. A thin section of a green wood tends to lose moisture rapidly when exposed to the air. The first weighing, therefore, should be done without any delay. Similarly, since oven-dried wood tends to absorb moisture from the air it must be weighed immediately after it has been removed from the oven. The samples used for determining the moisture content should be cut a foot or more away from the ends of the board. This is because the end grain dries faster, and therefore samples cut from the ends that were exposed to previous drying will not indicate the correct moisture content of the remainder of the board.

MOISTURE METER METHOD

The moisture content in wood may also be estimated with the aid of an electrical meter. There are two basic types of such instruments available: the resistance type and the capacity type.

The operation of a resistance type of meter is based on the fact that the electrical resistance of wood varies widely with changes in the amount of moisture in the cell walls. The resistance increases as the bound moisture decreases. The resistance meters are accurate only for the range of moisture content between 6 and 30 percent. Corrections in readings must also be made for the various kinds of wood.

The capacity meters[2] are designed to take advantage of the fact that the electrical capacity of wood varies directly with the amount of moisture present in it, throughout the entire range of moisture content, i.e., from green to oven dry state. It is not possible, however, to convert the weight of water into percent without knowing the weight or the specific gravity of the wood itself. Neither of these can be determined quickly and, therefore, in practice average specific gravity for the species of wood is assumed. Each reading of the meter, therefor, introduces an error proportional to the differences between the actual and the assumed specific gravity of the piece.

Although much less accurate than the oven drying method, electrical meters, when used intelligently, provide a rapid method for evaluating moisture content in the wood. They furnish the only practical means for estimating moisture content when cutting of samples for oven drying is either inconvenient or impractical. To obtain reasonably accurate results, the manufacturer's instructions accompanying a meter must be strictly followed. Moisture meters are not recommended for checking moisture content during kiln drying, because the inherent inaccuracies of measurement may lead to serious errors in choosing proper drying conditions.

FACTORS AFFECTING DRYING OF WOOD

The removal of moisture from wood is controlled by the temperature and the humidity of the air that surrounds the wood, and the uniformity and speed of air circulation. Insofar as understanding the part each of these factors plays in drying of wood is essential to successful operation of a dry kiln, a brief discussion of each follows.

HEAT

Heat is required in wood seasoning to evaporate the moisture from it. The higher the temperature that can be used without injuring the wood, the faster is the rate with which moisture moves from the interior of the piece toward the surface. Heat is also required to raise the temperature of colder air admitted into the kiln to replace heated air lost through ventilation, and to maintain the air

[2]More recently moisture meters, described by the manufacturers as radio-frequency, power-loss type have also been made available. Since these appear to operate on the same principle as the capacity type and are subject to the same faults, they are not treated separately.

in the kiln at a predetermined temperature. A certain amount of heat is rquired to pull the bound moisture from the cell walls. Finally, heat helps to produce circulation within a kiln, since warm air tends to rise and cold air to sink.

Sources of Heat

Although heat for a kiln can be supplied in a variety of ways, steam is employed almost universally. Other sources of heat include direct and indirect furnace heat. When direct furnace heat is used, a fire is built in an open fireplace, and the products of combustion are allowed to pass through the lumber; this method of heating is not only extremely dangerous but also results in excessive degrading of lumber.

Indirect furnace heat is obtained by burning fuel in a furnace and conducting the heat through pipes or ducts extending from the firepot through the kiln (Fig. 8).

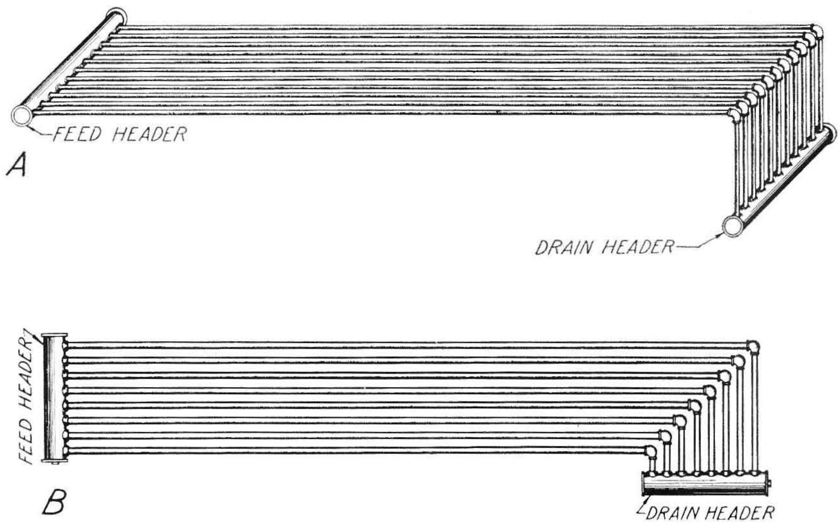
Heating Systems

When steam is available three kinds of heating systems can be used, depending on the design of the kiln. These are radiators, unit heaters and pipe coils; pipe coils are the most commonly used.

Radiators, either cast iron of the type commonly used in houses, or the light weight "extended surface" type made of steel or copper, can be used for heating lumber kilns. Such radiators, however, are more expensive than pipe, and when low pressure steam is used tend to become air bound, unless special care is taken to provide proper air-venting.

Unit heaters are used principally in the external-blower kilns, in which the blower and the heating units are located outside of the kiln. If several unit heaters are used each unit must be equipped with a separate hand valve, on both the feed and the drain lines; this is to enable the operator to shut off some of the units when the kiln is operated on low temperatures. In one type of external-blower kiln all unit heaters are in constant operation, but the temperature within the kiln is regulated by controlling the amount of air that is allowed to pass through the heaters.

Pipe coils used in the kilns fall into two general classes: the plain header type and the return bend variety. The plain header coils may be either horizontal or vertical (Fig. 2). The coils of this type consist of a cast iron supply header, into which a number of "runs" (long

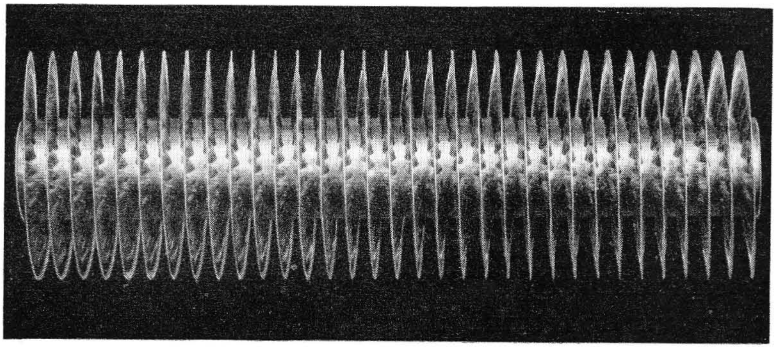


(Drawing—U. S. Forest Products Laboratory)

Fig. 2. Plain header coils. A—horizontal coil; B—vertical coils.

pipes) are threaded, and a drain header attached either directly to the opposite ends of runs or through short springer-type pipes of a smaller diameter. The latter arrangement is preferred to minimize the danger of cracking the header through unequal expansion of the runs. For ease of removal the springer pipes are threaded with a left-hand thread on one end and a right-hand on the other.

The runs are either plain pipe, generally 1 inch in diameter, or fin pipe (Fig. 3). The latter type is equipped with thin circular or square metal collars along its length, spaced about 1 inch apart. The fins increase the radiating surface of the pipe and, therefore, less



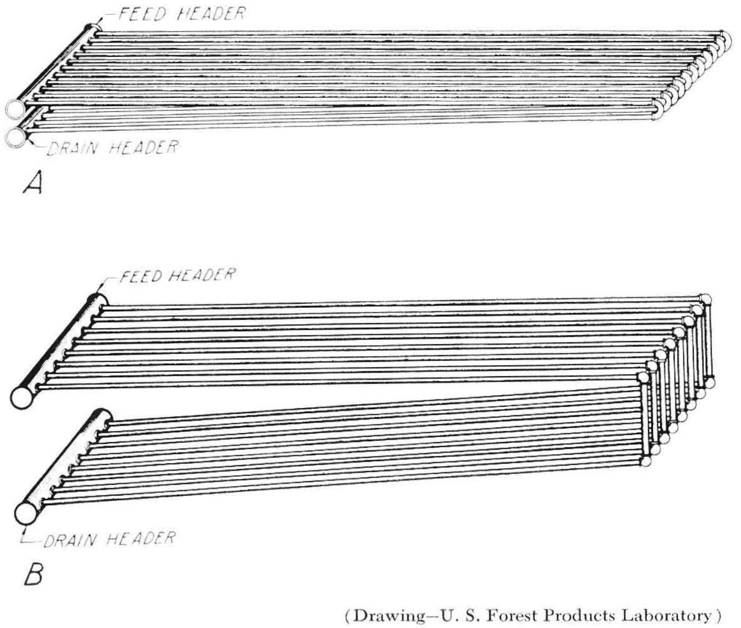
(Photo—Aerofin Corporation)

Fig. 3. Fin pipe.

pipe is required to provide the necessary radiation. On the other hand, fin coils are more expensive, and the only saving resulting from their use is due to fewer fittings required and somewhat lower cost of installation.

The plain header coils have the disadvantage of producing non-uniform temperatures through the length of the kiln. This is due to the fact that the runs are hottest at the supply end, the temperatures falling off gradually toward the drain end.

Return-bend header coils, illustrated in Fig. 4, may be either of a single or a multiple type. The single-return type is usually horizontal, while the multiple-return bend coils are mostly vertical. These types of coils produce more uniform temperatures throughout the length of the kiln.



(Drawing—U. S. Forest Products Laboratory)

Fig. 4. Horizontal return-bend header coils. A—horizontal return-bend header coil using return-bend elbows; B—using 90° elbows and connecting nipples.

In double-track kilns of the forced circulation design it is customary to place a single vertical row of coils between the loads to raise the temperature of the air as it leaves one load of lumber and before it enters the other. Such coils are called "booster" coils (Fig. 6).

General Recommendations in Regard to Steam Coils

Regardless of the method of assembling the coils to achieve uniform heating the system should be so designed that there is steam in them all the time the kiln is in operation. To achieve this the following points should be observed as closely as possible:

Use single return-bend type coil in preference to the plain header kind.

Use as short runs as possible. This generally means that the length of runs in return-bend coils should be less than 40 feet.

Design the heating system in such a manner that the amount of radiation can be controlled, so that at any given time it is just adequate to supply the requirements of the drying schedule for heat. A radiation surface greatly exceeding the current requirements of the kiln leads to water logging and air binding of the coils; this, in turn, causes non-uniform heating. The nearly ideal situation prevails when an almost constant flow of steam through the coils can be obtained. This condition is easier to achieve when the steam coils are split into a number of separate banks, each containing only a few runs, and each equipped with individually operated hand valves. This arrangement permits varying the radiating surface as the demand for heat changes in the course of drying a charge of lumber.

Install coils with a downward pitch of ⅛ to ¼ inch per linear foot of pipe, to facilitate the removal of condensate. To prevent sagging of pipes, that might lead to localized clogging through accumulation of condensate, support the coils at intervals of 6 to 8 feet.

Provide an adequate and properly installed trapping system. Unless the trapping system is adequate to remove all the condensate from the heating coils, water will remain in the pipes. An improperly designed trapping system may cause condensate from the discharge pipes to be drawn into the coils. A trap of inadequate capacity will not be able to discharge the condensate promptly as it forms.

Either thermostatic- or gravity-type steam traps may be used in the dry kilns. Important considerations in selecting an adequate steam trap are sufficient capacity for handling the condensate and the operating pressure for which the trap has been designed. A trap designed to operate at a specific pressure will not perform satisfactorily if other pressures are employed. Trap location is also important; it must be protected from freezing, and whenever possible so installed that the condensate in the coils will flow to it by gravity. All traps should be periodically cleaned to remove the accumulation of dirt that may prevent the trap from closing, or may cause air-binding.

The best designed heating system will not function properly unless steam pressure is kept fairly constant. For instance, a coil that will supply the correct amount of radiation at a steam pressure of 20 pounds will give off more heat at higher pressures and not enough at lower. For accurate control of temperature in the kiln the steam pressure should be kept from fluctuating more than $\pm$ 5 pounds. When the steam pressure in the supply line varies more than that amount a reducing valve should be placed in the feed line, near the control valves.

Location of Coils

The location of coils is determined by the design of the kiln, particularly by its circulation system, and by the size and shape of the building. Most commonly the coils are located either below or above the lumber, although they may also be placed along the sides or between the loads. When booster coils are used in the double-track kilns, these invariably are located between the loads.

Calculation of Radiation Surface Requirements

Accurate calculation of radiation surface is difficult because:

1. Heat demands in a kiln vary throughout the drying of a charge.

2. Heat requirements are affected by the air velocity employed. The faster the air movement, the more heat will be transferred from a coil. It follows that the faster the air circulation, the less radiation surface is needed to maintain a given temperature.

3. Heat requirements are affected by heat losses through ventilation, and through the doors, walls and ceiling. Therefore construction of the building, and the building materials used, have a direct bearing on the size of the radiating surface.

4. Heat demands depend on the species of wood and moisture content of the lumber that is being dried. A species that dries rapidly (such as pine or basswood) will place greater demands for heat than a slower drying wood, and therefore will require a larger radiation surface.

5. The steam pressure available affects the required radiation surface. The higher the steam pressure the fewer coils are needed.

6. The diameter and the type of coils affect the size of the radiation surface required to supply the amount of heat needed.

Because of the effect these variable factors have on the heat demand, most dry kilns have an excess of radiation. If the services of a competent heating engineer are not available, approximate calculations of the necessary radiation can be made as follows:

First, the amount of moisture to be evaporated per 1000 b.f. of lumber is calculated. For instance, if green hard maple with an initial moisture content of 75 percent is to be dried to 8 percent, it means that 67 percent of moisture must be removed. The specific gravity of hard maple is approximately 0.56. To convert this value into weight per cubic foot it must be multiplied by 62.4, weight of one cubic foot of water.

Therefore the weight of 1000 b.f. oven-dry hard maple is

$$\frac{.56 \times 62.4 \times 1000}{12} = 2912 \text{ pounds}$$

And the weight of 67 percent of water to be evaporated is:

$$2912 \times .67 = 1951 \text{ pounds}$$

Assuming that it takes 10 days to dry hard maple from 75 to 8 percent of moisture, approximately 8 pounds of water will be evaporated on the average every hour. In practice, of course, more water is evaporated at the beginning of the run when the wood is green, than later on. For the sake of this example it is assumed that 12 pounds of water per hour per thousand b. f. will be the maximum amount evaporated.

The number of square feet of radiation required to evaporate this amount of water can be found from the following formula:

$$N = \frac{A}{K \times T},$$

where, N is the number of square feet of radiation

A is the number of Btu required to evaporate a given amount of water. It is assumed that because of the loss of heat from the kiln, and for other reasons, it takes about 3 pounds of steam to evaporate 1 pound of moisture, or approximately 3000 Btu per pound of evaporated moisture.

K is a constant that depends on the speed of air circulation. In the commercial, forced circulation kilns K equals approximately 6. For the natural draft kilns it is approximately 2.7.

T is the difference between the temperature of the steam, which in turn depends on the steam pressure used, and the kiln temperature at which a maximum of steam is consumed. Since more heat is demanded when the greatest amount of water is evaporated, the starting kiln temperature should be used. For example, if steam at 5 pounds gauge pressure is used, its temperature is approximately 228°F. (For other steam pressure-temperature values see Table 1.) The starting temperature in drying green maple is about 130°F. Therefore,

$T = 228° - 130° = 98°F.$

Substituting these values, we find that

$$N = \frac{12 \times 3000}{6 \times 98} = 61.2 \text{ square feet of radiation per 1000 b.f.}$$

of lumber.

The square feet of radiation surface can be converted into linear feet of pipe by referring to Table 2.

TABLE 1—*Temperature of steam at various gage pressures*

Gage pressure, pounds	Temperature, °F.	Gage pressure, pounds	Temperature, °F.
0	212.00	40	286.74
2	218.47	45	292.37
5	227.16	50	297.70
8	234.78	60	307.30
10	239.41	70	316.03
15	249.73	80	323.89
25	266.85	90	331.16
30	274.08	100	337.86
35	280.64	110	344.22

TABLE 2—*Square feet of radiating surface per linear foot of pipe*

Diameter inches pipe	Radiating surface per linear ft. in sq. feet
¾	0.275
1	0.346
1¼	0.434
1½	0.494
2	0.622
2½	0.753
3	0.916

If one-inch pipe is used, then $\frac{61.2}{0.346} = 177$ linear feet of 1-inch pipe is required for each 1000 b.f. capacity of the kiln. If fin pipe is used, the manufacturer's recommendations must be sought to determine the necessary footage of pipe.

HUMIDITY

The drying capacity of air depends on the amount of moisture it already contains and the quantity of moisture it can hold before becoming saturated. The water holding capacity of air is greatly affected by its temperature, i.e., the warmer the air the more moisture it can hold. For instance, a cubic foot of air at 60°F. can hold a maximum of 5.8 grains of moisture[3], while at 120°F. it will hold 34 grains and at 180°F. it will contain 138 grains, before becoming saturated. To increase the speed of drying, therefore, it is desirable to use temperatures as high as is consistent with good drying results.

Humidity in the air may be expressed in two ways: as absolute and as relative humidity. Absolute humidity is the weight of water vapor per given quantity of air, as for example 25 grains per cubic foot. Relative humidity is the ratio of the amount of water vapor present in the air to the maximum amount of water vapor the air can hold at a given temperature, expressed in percent. For instance, at 120°F. air can hold a maximum of 34.0 grains of water. If at that temperature it contains only 17.0 grains of water vapor its relative humidity is

$$\frac{17}{34} \times 100 = 50 \text{ percent}$$

At 120°F. and 50 percent relative humidity each cubic foot of air can pick up another 17 grains of vapor, before reaching the saturation point. Air at 60°F. and 50 percent relative humidity will contain only 2.9 grains of water, and it can pick up only 2.9 grains before reaching the saturation point.

The difference between the amount of water vapor present in the air and the maximum quantity it can hold is called the drying power of air or the saturation deficit. At any given temperature the rate at which water can be evaporated from the wood depends to a large extent upon the relative humidity of the surrounding air; the drier the air (i.e. the lower its relative humidity) the greater is its drying power, and hence, the more rapid is the evaporation of water. It follows that, other things being equal, at the same relative humidity the drying will be faster at a higher temperature. For example, if two kilns are operating at 70 percent relative humidity and 120°F. and 140°F. temperature, respectively, lumber will dry faster in the kiln with the higher temperature, even though the relative humidity is the same in both cases; this is due to the greater drying power of air at 140°F.

[3]One pound (avoirdupois) contains 7000 grains.

More is involved in the operation of a dry kiln, however, than the mere removal of water, since improper operation leads to formation of drying defects, such as warping, checking and casehardening (see p. 55). Therefore, rather accurate control not only of temperature but also of relative humidity at each given temperature is necessary.

Although great quantities of water are evaporated when green lumber is dried this moisture may not be adequate to maintain the required relative humidity. At the beginning of the drying the rapid evaporation of water from lumber may raise the humidity of the air in the kiln above that desired. The excess of humidity can be reduced then by replacing the humid air in the kiln with the drier air from the outside. In all the kilns, however, considerable quantities of vapor also escape through the cracks in the building, and especially around the doors. As the lumber dries, less and less water is evaporated. Soon a point is reached when the evaporated moisture is not sufficient to maintain the relative humidity at the desired level. Additional vapor must then be supplied.

Moisture in a kiln may be added in several ways. In the kilns heated by steam this is accomplished by allowing steam to enter the building either through steam jets or through a perforated pipe, called a spray line, connected to a steam supply line. Spray lines are generally made of plain pipe, 1 to 2 inches in diameter, in which holes ⅜ to ¼ inch in diameter are drilled every 2 to 3 feet apart. In the internal-fan and in the natural-circulation kilns the spray lines extend the length of the kiln. In the fan kilns they are generally located near the fan, so that the spray is thoroughly mixed with air before it passes through the lumber. In the natural-circulation kilns the spray lines, or spray jets, are located below the rails in such a manner that steam will not spray directly on the steam coils. In the external blower kilns the spray lines are located near the heating units, generally in the return air ducts; either the spray lines or the jets can be used in this type of kiln.

When steam is not available, open troughs containing water or water sprays may be used to add vapor to the air. Humidification by such means is difficult to control, and hence such systems are less satisfactory than steam spray.

Determination of Relative Humidity

The most practical way of determining relative humidity is by means of a wet and dry bulb hygrometer (Fig. 24). The simplest type of this kind of instrument consists of two suitably mounted thermometers, similar in every respect except that the bulb of one is surrounded by a wick that is kept constantly wet. If sufficient circulation is present to cause evaporation of moisture from the wick, the wet bulb becomes cooler than the dry. The difference in temperature reading between the dry and the wet bulb is called *wet bulb depression*. The drier the air, the greater will be the wet bulb depression.

If dry and wet bulb temperatures are known, the relative humidity can be found by reference to Table 3. For example, if the dry bulb reading is 150°F. and the wet bulb temperature is 130°F., the wet bulb depression is 20°F. The corresponding relative humidity (57 percent) can be found at the intersection of the vertical column representing 20°F. wet bulb depression and the horizontal line representing a dry bulb temperature of 150°F.

The principle of determination of relative humidity remains the same when mercury-filled thermometers are replaced by metallic bulbs filled with mercury, gas or vapor, such as are employed in recording and controlling instruments.

CIRCULATION AND VENTILATION

In addition to controlled heat and humidity, it is necessary to have a certain amount of air movement in a kiln, in order to obtain satisfactory drying results. Air movement is required to carry the heat from its source (coils, radiators, furnace pipes) to the lumber, and to carry away moisture evaporated from the surface of the boards. Although vapor can diffuse through the nearly still air, the diffusion is so slow that it cannot be relied upon in kiln drying of lumber. The efficiency of the heating system is also increased by air circulation, since steam coils give up heat more readily as the air movement is increased.

Air movement in the kiln is of two different kinds: ventilation and circulation. The two should not be confused since they perform different functions in drying lumber.

Ventilation

Ventilation is the passage of air into and out of the kiln to dispose of the excess of the evaporated moisture. Ventilation is needed to maintain the desired relative humidity conditions within the kiln, when otherwise the evaporated moisture will tend to raise the humidity of the air.

In natural-circulation kilns ventilation is the chief means of air movement. In the modern forced-circulation kilns ventilation repre-

TABLE 3—*Relative humidity and equilibrium moisture content table. For use with dry bulb temperatures and wet bulb depressions.*

Temperature dry bulb (°F)	Wet-bulb depression (°F)																																					Temperature dry bulb (°F)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	32	34	36	38	40	45	50	
30	89	78/15.9	67/12.9	57/10.8	46/9.0	36/7.4	27/5.7	17/3.9	6/1.6																													30
35	90	81/16.8	72/13.9	63/11.9	54/10.3	45/8.8	37/7.4	28/6.0	19/4.5	11/2.9	3/0.8																											35
40	92	83/17.6	75/14.8	68/12.9	60/11.2	52/9.9	45/8.6	37/7.4	29/6.2	22/5.0	15/3.5	8/1.9																										40
45	93	85/18.3	78/15.6	72/13.7	64/12.0	58/10.7	51/9.5	44/8.5	37/7.5	31/6.5	25/5.3	19/4.2	12/2.9	6/1.5																								45
50	93	86/19.0	80/16.3	74/14.4	68/12.7	62/11.5	56/10.3	50/9.4	44/8.5	38/7.6	32/6.7	27/5.7	21/4.8	16/3.9	10/2.8	5/1.5																						50
55	94	88/19.5	82/16.9	76/15.1	70/13.4	65/12.2	60/11.0	54/10.1	49/9.3	44/8.4	39/7.6	34/6.8	28/6.0	24/5.3	19/4.5	14/3.6	9/2.5	5/1.3																				55
60	94	89/19.9	83/17.4	78/15.6	73/13.9	68/12.7	63/11.6	58/10.7	53/9.9	48/9.1	43/8.3	39/7.6	34/6.9	30/6.3	26/5.6	21/4.9	17/4.1	13/3.2	9/2.3	5/1.3	1/0.2																	60
65	95	90/20.3	84/17.8	80/16.1	75/14.4	70/13.3	66/12.1	61/11.2	56/10.4	52/9.7	48/8.9	44/8.3	39/7.7	36/7.1	32/6.5	27/5.8	24/5.2	20/4.5	16/3.8	13/3.0	8/2.3	6/1.4	2/0.4															65
70	95	90/20.6	86/18.2	81/16.5	77/14.9	72/13.7	68/12.5	64/11.6	59/10.9	55/10.1	51/9.4	48/8.8	44/8.3	40/7.7	36/7.2	33/6.6	29/6.0	25/5.5	22/4.9	19/4.3	15/3.7	12/2.9	9/2.3	6/1.5	3/0.7													70
75	95	91/20.9	86/18.5	82/16.8	78/15.2	74/14.0	70/12.9	66/12.0	62/11.2	58/10.5	54/9.8	51/9.3	47/8.7	44/8.2	41/7.7	37/7.2	34/6.7	31/6.2	28/5.6	24/5.1	21/4.7	18/4.1	15/3.5	12/2.9	10/2.3	7/1.7	4/0.9	1/0.2										75
80	96	91/21.0	87/18.7	83/17.0	79/15.5	75/14.3	72/13.2	68/12.3	64/11.5	61/10.9	57/10.1	54/9.7	50/9.1	47/8.6	44/8.1	41/7.7	38/7.2	35/6.8	32/6.3	29/5.8	26/5.4	23/5.0	20/4.5	18/4.0	15/3.5	12/3.0	10/2.4	7/1.8	5/1.1	3/0.5								80
85	96	92/21.2	88/18.8	84/17.2	80/15.7	76/14.5	73/13.5	70/12.5	66/11.8	63/11.2	59/10.5	56/10.0	53/9.5	50/9.0	47/8.5	44/8.1	41/7.6	38/7.2	36/6.7	33/6.3	30/6.0	28/5.6	25/5.2	23/4.8	20/4.3	18/3.9	15/3.4	13/3.0	11/2.4	9/1.7	4/0.9							85
90	96	92/21.3	89/18.9	85/17.3	81/15.9	78/14.7	74/13.7	71/12.8	68/12.0	65/11.4	61/10.7	58/10.2	55/9.7	52/9.3	49/8.8	47/8.4	44/8.0	41/7.6	39/7.2	36/6.8	34/6.5	31/6.1	29/5.7	26/5.3	24/4.9	22/4.6	19/4.2	17/3.8	15/3.3	13/2.8	9/2.1	5/1.3	1/0.4					90
95	96	92/21.3	89/19.0	85/17.4	82/16.1	79/14.9	75/13.9	72/12.9	69/12.2	66/11.6	63/11.0	60/10.5	57/10.0	55/9.5	52/9.1	49/8.7	46/8.2	44/7.9	42/7.5	39/7.1	37/6.8	34/6.4	32/6.1	30/5.7	28/5.3	26/5.1	23/4.8	22/4.4	20/4.0	17/3.6	14/3.0	10/2.3	6/1.5	2/0.6				95
100	96	93/21.3	89/19.0	86/17.5	83/16.1	80/15.0	77/13.9	73/13.1	70/12.4	68/11.8	65/11.2	62/10.6	59/10.1	56/9.6	54/9.2	51/8.9	49/8.5	46/8.1	44/7.8	41/7.4	39/7.0	37/6.7	35/6.4	33/6.1	30/5.7	28/5.4	26/5.2	24/4.9	22/4.6	21/4.2	17/3.6	13/3.1	10/2.4	7/1.6	4/0.7			100
105	96	93/21.4	90/19.0	87/17.5	83/16.2	80/15.1	77/14.0	74/13.2	71/12.6	69/11.9	66/11.3	63/10.8	60/10.3	58/9.8	55/9.4	53/9.0	50/8.7	48/8.3	46/7.9	44/7.6	42/7.3	40/6.9	37/6.7	35/6.4	34/6.1	31/5.7	29/5.4	28/5.2	26/4.8	24/4.6	20/4.2	17/3.6	14/3.1	11/2.4	8/1.8			105
110	97	93/21.4	90/19.0	87/17.5	84/16.2	81/15.1	78/14.1	75/13.3	73/12.6	70/12.0	67/11.4	65/10.8	62/10.4	60/9.9	57/9.5	55/9.2	52/8.8	50/8.4	48/8.1	46/7.7	44/7.5	42/7.2	40/6.8	38/6.6	36/6.3	34/6.0	32/5.7	30/5.4	28/5.2	26/4.8	23/4.5	20/4.0	17/3.5	14/3.0	11/2.5	4/1.1		110
115	97	93/21.4	90/19.0	88/17.5	85/16.2	82/15.1	79/14.1	76/13.4	74/12.7	71/12.1	68/11.5	66/10.9	63/10.4	61/10.0	58/9.6	56/9.3	54/8.9	52/8.6	50/8.2	48/7.8	45/7.6	43/7.3	41/7.0	40/6.7	38/6.5	36/6.2	34/5.9	32/5.6	31/5.4	29/5.2	26/4.7	23/4.3	20/3.9	17/3.4	14/2.9	8/1.7	2/0.4	115
120	97	94/21.3	91/19.0	88/17.4	85/16.2	82/15.1	80/14.1	77/13.4	74/12.7	72/12.1	69/11.5	67/11.0	65/10.5	62/10.0	60/9.7	58/9.4	55/9.0	53/8.7	51/8.3	49/7.9	47/7.7	45/7.4	43/7.2	41/6.8	40/6.6	38/6.3	36/6.1	34/5.8	33/5.6	31/5.4	28/5.0	25/4.6	22/4.2	19/3.7	17/3.3	10/2.3	5/1.1	120
125	97	94/21.2	91/18.9	88/17.3	86/16.1	83/15.0	80/14.0	77/13.4	75/12.7	73/12.1	70/11.5	68/11.0	65/10.5	63/10.0	61/9.7	59/9.4	57/9.0	55/8.7	53/8.3	51/8.0	48/7.7	47/7.5	45/7.2	43/7.0	41/6.7	39/6.5	38/6.2	36/6.0	35/5.8	33/5.5	30/5.2	27/4.8	24/4.4	22/4.0	19/3.6	13/2.7	8/1.6	125
130	97	94/21.0	91/18.8	89/17.2	86/16.0	83/14.9	81/14.0	78/13.4	76/12.7	73/12.1	71/11.5	69/11.0	67/10.5	64/10.0	62/9.7	60/9.4	58/9.0	56/8.7	54/8.3	52/8.0	50/7.8	48/7.6	47/7.3	45/7.0	43/6.8	41/6.6	40/6.4	38/6.1	37/5.9	35/5.6	32/5.3	29/4.9	26/4.6	24/4.2	21/3.8	15/3.0	10/2.0	130
140	97	95/20.7	92/18.6	89/16.9	87/15.8	84/14.8	82/13.8	79/13.2	77/12.5	75/11.9	73/11.4	70/10.9	68/10.4	66/10.0	64/9.6	62/9.4	60/9.0	58/8.7	56/8.4	54/8.0	53/7.8	51/7.6	49/7.3	47/7.1	46/6.9	44/6.6	43/6.4	41/6.2	40/6.0	38/5.8	35/5.5	32/5.1	30/4.8	27/4.4	25/4.1	19/3.4	14/2.6	140
150	98	95/20.2	92/18.4	90/16.6	87/15.5	85/14.5	82/13.7	80/13.0	78/12.4	76/11.8	74/11.2	72/10.8	70/10.3	68/9.9	66/9.5	64/9.2	62/8.9	60/8.6	58/8.3	57/8.0	55/7.8	53/7.5	51/7.3	49/7.1	48/6.9	46/6.7	45/6.4	43/6.2	42/6.0	41/5.8	38/5.5	36/5.2	33/4.9	30/4.5	28/4.2	23/3.6	18/2.9	150
160	98	95/19.8	93/18.1	90/16.2	88/15.2	86/14.2	83/13.4	81/12.7	79/12.1	77/11.5	75/11.0	73/10.6	71/10.1	69/9.7	67/9.4	65/9.1	64/8.8	62/8.5	60/8.2	58/7.9	57/7.7	55/7.4	53/7.2	52/7.0	50/6.8	49/6.7	47/6.4	46/6.2	44/6.0	43/5.8	41/5.5	38/5.2	35/4.9	33/4.6	31/4.3	25/3.7	21/3.2	160
170	98	95/19.4	93/17.7	91/15.8	89/14.8	86/13.9	84/13.2	82/12.4	80/11.8	78/11.3	76/10.8	74/10.4	72/9.9	70/9.6	69/9.2	67/9.0	65/8.6	63/8.4	62/8.0	60/7.8	59/7.6	57/7.3	55/7.2	53/6.9	52/6.7	51/6.6	49/6.4	48/6.2	47/6.0	45/5.7	43/5.5	40/5.2	38/4.9	35/4.6	33/4.4	28/3.7	24/3.2	170
180	98	96/18.9	94/17.3	91/15.5	89/14.5	87/13.7	85/12.9	83/12.2	81/11.6	79/11.1	77/10.6	75/10.1	73/9.7	72/9.4	70/9.0	68/8.8	67/8.4	65/8.1	63/7.8	62/7.6	60/7.4	58/7.2	57/7.0	55/6.8	54/6.5	52/6.4	51/6.2	50/6.0	48/5.8	47/5.7	45/5.4	43/5.2	40/4.8	38/4.6	35/4.4	30/3.8	26/3.3	180
190	98	96/18.5	94/16.9	92/15.2	90/14.2	88/13.4	85/12.7	84/12.0	82/11.4	80/10.9	78/10.5	76/10.0	75/9.6	73/9.2	71/8.9	69/8.6	68/8.2	66/7.9	65/7.7	63/7.4	62/7.2	60/7.0	58/6.8	57/6.6	56/6.4	54/6.2	53/6.0	51/5.9	50/5.7	49/5.5	46/5.3	44/5.0	42/4.8	39/4.5	37/4.4	32/3.8	28/3.3	190
200	98	96/18.1	94/16.4	92/14.9	90/14.0	88/13.2	86/12.4	84/11.8	82/11.2	80/10.8	79/10.3	77/9.8	75/9.4	74/9.1	72/8.8	70/8.4	69/8.1	67/7.7	66/7.5	64/7.2	63/7.0	61/6.9	60/6.6	58/6.4	57/6.2	55/6.0	54/5.9	53/5.7	52/5.6	51/5.4	48/5.2	46/4.9	43/4.7	41/4.5	39/4.3	34/3.8	30/3.3	200
210	98	96/17.7	94/16.0	92/14.6	90/13.8	88/13.0	86/12.2	85/11.7	83/11.1	81/10.6	79/10.0	78/9.7	76/9.2	75/9.0	73/8.7	71/8.3	70/8.0	68/7.6	67/7.4	65/7.1	64/6.9	63/6.8	61/6.5	60/6.3	59/6.1	57/5.9	56/5.8	54/5.5	53/5.4	52/5.3	50/5.1	47/4.8	45/4.6	43/4.4	41/4.2	36/3.7	32/3.2	210

NOTE: RELATIVE HUMIDITY VALUES ABOVE AND EQUILIBRIUM MOISTURE CONTENT VALUES BELOW DIAGONAL LINES

(Table—U. S Forest Products Laboratory)

sents only a small part of the total air movement; in such kilns greater reliance for air circulation is placed on the action of fans and blowers.

Ventilation, as the sole means for producing air movement in a kiln, is very wasteful, since it is dependent on a constant venting of heated and conditioned air and replacing it with an equal amount of relatively cold and dry air from the outside.

Circulation

Circulation refers to the movement of air within the kiln, or more properly to the rate of air movement through the load of lumber. To avoid wasteful ventilation, as much air movement within the kiln as possible should be provided by recirculation of the conditioned air through the stacks of lumber.

It is important to remember that it is mainly through circulation that drying conditions in the kiln can be kept uniform; otherwise some parts of the lumber stack will dry more slowly than others. The needed rate of circulation depends on how fast the moisture moves (diffuses) from the interior of the board toward the surface where it can be evaporated. The rate of circulation should be sufficient to evaporate moisture as rapidly as it reaches the surface.

In the initial stages of drying, i.e., when the lumber is green, the movement of moisture through the wood is more rapid than when the moisture content of the lumber is reduced to 20 percent or less. Therefore, a faster rate of circulation is desirable when lumber with high moisture content is being dried. In the modern forced circulation kiln the rate of air flow through green lumber is somewhere between 250 and 400 feet per minute, measured through the load. Faster circulation may improve drying conditions still further, but special equipment and the increased consumption of power make such speeds uneconomical in commercial installations. Circulation of 100 to 150 feet per minute is considered adequate in kiln drying air-dried lumber. The ideal situation would be variable-speed fan motors; such equipment, however, is seldom used in the commercial kilns.

Methods of producing circulation

In the kilns not equipped with fans or blowers the chief reliance for air movement within the kiln is on gravity. Circulation resulting from the action of gravity is called *natural circulation.* It is due to the rising of hot air, which becomes lighter as it expands when heated, and the downward flow of heavier cooler air. To facilitate natural circulation of air the kilns utilizing this method of achieving internal air movement are equipped with vents or chimneys for letting out the conditioned air, and a series of intake flues for admitting colder air into the kiln. Although in actual practice the vents and flues have been located in almost any conceivable place in the building, the best locations are those which take into account the physical laws of air movement. Accordingly, the intake flues should be located along the bottom part of the structure and the exhaust vents along the top (Fig. 5).

In the modern kilns circulation is produced by means of fans located within the kiln (Figs. 6, 7 and 9), or by blowers placed outside. In the latter case the air is recirculated through a series of supply and return ducts extending the length of the kiln (Fig. 10).

The fan capacity required for a kiln of a certain size can be calculated by assuming the maximum rate of circulation desired in the kiln. For instance, assume a kiln with a capacity for one stack of 4/4″ lumber 8 feet wide, 16 feet long and 10 feet high. The stickers used for separating the layers of lumber are one inch thick. It is desired to have a 350-feet-per-minute circulation through the lumber pile. The air that does the actual drying must pass between the courses of lumber, i.e., it must pass through the channels in the lumber stack made by the stickers. Each of these openings measures 1″ x 16′, or 1⅓ square feet. In a stack of lumber 10 feet high there are 60 such openings. Therefore the total area occupied by the open spaces through which air can move is $1\frac{1}{3} \times 60 = 80$ square feet.

Since a rate of circulation of 350 feet is required,

$80 \times 350 = 28{,}000$ cubic feet of air needed to produce this circulation.

The number of fans required to obtain uniform circulation throughout the kiln is determined largely by the length of the building. For a kiln measuring 18 x 20 feet, three fans will be desirable, although two fans can be used. In choosing fans, losses in delivery, due to static pressure and the tendency of some air to go around rather than through the load, should be compensated by increasing the required delivery rate by about 33.3 percent. For instance, if each fan is expected to deliver 9,333 cubic feet of air through the load (a total of 28,000 cubic feet per three fans), the rated capacity of each fan should be 33.3 percent greater, or approximately 12,500 cubic feet.

To provide uniform drying it is best to install reversible type fans, so that air can be blown alternately through one and then the other side of the load. The direction of circulation is reversed periodically, every 4 or 6 hours, by changing the direction of fan rotation. Such reversal of air movement in the kiln tends to minimize the differences in the drying rate between the entering and the leaving sides of the load.

Disk fans are most commonly used in the internal-fan kilns. Their location in the kiln is determined by the kiln design (see pages 27-30).

DRY KILNS

A lumber dry kiln may be defined as a chamber in which drying conditions can be regulated by either manual or automatic controls. Lumber dry kilns now in use, or available for installation, are of many different designs. On the basis of construction and the method of operation, they are generally classified as either progressive or compartment kilns. Each class, in turn, can be further broken down into natural and forced circulation types.

PROGRESSIVE KILNS

Progressive type kilns are buildings 80 to 200 feet long in which drying conditions are so graduated that one end of the kiln, called the green end, is comparatively cool and moist. The temperature rises and the humidity decreases gradually from the green end toward the opposite, or the dry end of the kiln. When in full operation the kiln is filled with lumber trucks, all in various stages of dryness. Periodically one or more loads of lumber are removed from the dry end, the remaining trucks advanced, while an equal number of trucks containing green lumber is charged in the green end of the kiln.

Progressive types of kilns are suitable to conditions where a continuous flow of lumber of the same species and thickness, or of species comparable in drying requirements, is available. Furthermore, such kilns operate satisfactorily only when the final moisture content need not be uniform or the dried lumber stress-free. The progressive kilns find their greatest application at the sawmills cutting softwoods, such as Douglas fir and ponderosa pine, at large planing mills and at plants utilizing large quantities of a small number of easily dried woods. They are not considered practical for drying refractory hardwoods, or for plants using a number of different woods in relatively small quantities.

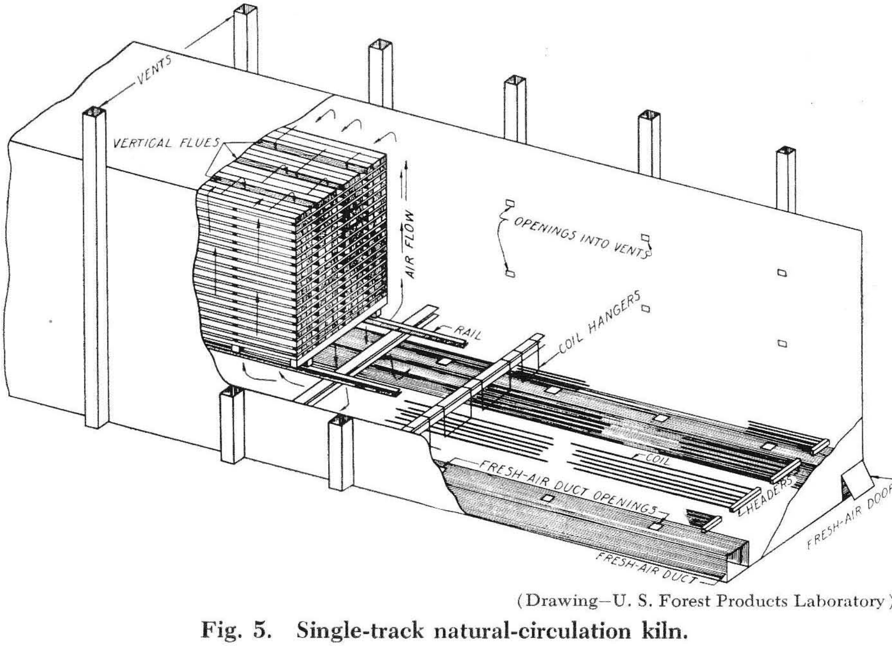
COMPARTMENT KILNS

In compartment kilns drying conditions are maintained as nearly uniform as possible throughout the building; the drying conditions are modified from time to time as drying progresses. The kiln is loaded to capacity at one time and all the lumber remains in the kiln until dry. Since the drying conditions can be varied at will, compartment kilns are more flexible than the progressive types. Wood of any species or thickness can be dried to a uniform moisture content and free from stresses; compartment kilns are also more suitable for plants using a number of different woods and lumber of different thicknesses. Most modern kilns are of the compartment type, and since this type of kiln is more suitable for Michigan conditions, only compartment kilns are discussed in this bulletin.

Compartment kilns are generally classified on the basis of the method of circulation they employ, as natural-circulation and forced-circulation types. Forced-circulation kilns, in turn, may be further separated into water-spray, internal-fan and external-blower designs.

Natural-circulation Compartment Kilns

In this kind of kiln (Fig. 5), the air circulation is produced by natural means, i.e., circulation is due to the tendency of hot air to rise



(Drawing—U. S. Forest Products Laboratory)

Fig. 5. Single-track natural-circulation kiln.

and cool air to sink. Most natural kilns are arranged for cross circulation, i.e., air is traveling from side to side of the kiln. The fresh air is usually brought in at the bottom of the kiln through fresh-air ducts, and is heated by steam coils located below the tracks on which the lumber carts are located. The humidity of the air is raised, if necessary, by admitting steam into the kiln through perforated pipes or steam jets. Vertical ventilation flues are provided at intervals along the sides of the kiln. These flues have outlets at various heights opening into the kiln, through which hot and moist air can escape. Actual arrangement of intake and discharge vents and flues varies considerably in accordance with the notions of different manufacturers and designers.

To facilitate the passage of air upward vertical flues are generally provided in the lumber stacks. The effectiveness of these flues, however, is greatly minimized by the fact that the hot air which rises and the cold air which sinks tends to neutralize each other, with the result that most of the circulation occurs around the lumber pile. This leaves lumber in the center of the stack much wetter than that on the outside of the pile. The air movement in the natural circulation kilns is very sluggish at best (generally considerably less than 50 feet per minute) and as a consequence the drying is slower and much less uniform than in the kilns with forced circulation. Well designed natural-circulation kilns perform best in drying air-seasoned lumber, since such lumber can be dried successfully with relatively low rates of circulation; they seldom perform adequately in drying green lumber, especially in the case of slow-drying species of wood. The only advantage of the natural-circulation kilns over those employing forced-circulation principles is that they are relatively cheaper to install.

Forced-circulation Compartment Kilns

There are many designs of forced-circulation compartment kilns, the most important of which are described in the following pages.

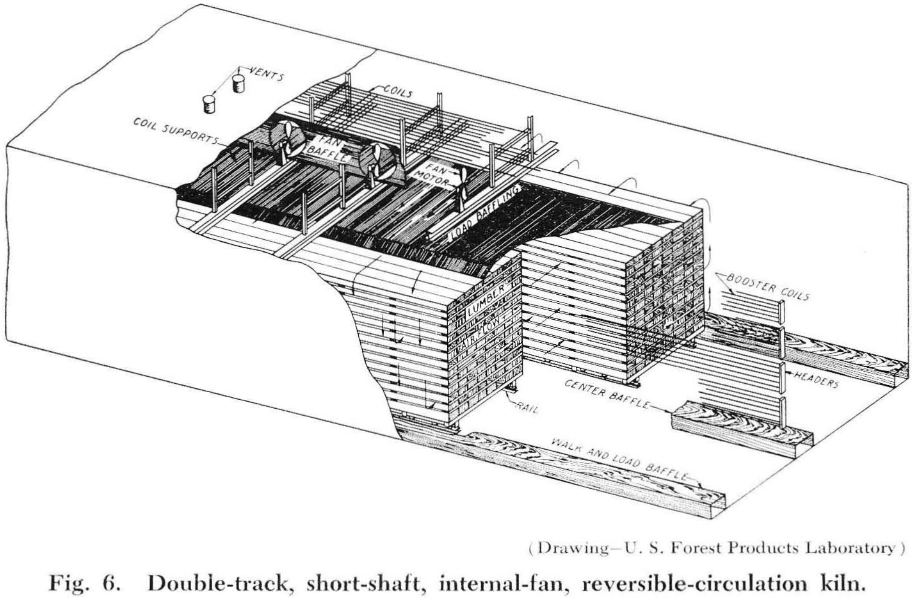
a. **Water-spray kilns**—The first water-spray kiln was designed at the Forest Products Laboratory, prior to World War I. A few of these kilns are still in operation. Although none has been built in recent years, a brief discussion of this type of kiln is included because it presents possibilities for a small plant where an extra outlay for fans or blowers is not justified.[4]

[4]More detailed information on water spray kilns can be obtained by writing to the Forest Products Laboratory, Madison 5, Wisconsin.

A water-spray kiln is provided with jets located in the spray chamber. The mechanical action of the water spray moves the air through the baffles and then through the heating coils located underneath the lumber, and upward into a central flue in the lumber stack. From the central flue the air passes through the lumber laterally to each side of the kiln; it then drifts downward between the lumber stack and the kiln walls, aided by the spray. The water used in spraying is returned to a tank, in which the temperature of the water is regulated in accordance with the temperature requirement of the kiln. In a kiln of this type the water spray not only induces circulation but also controls the humidity. This is accomplished by controlling the temperature of the water used for spraying. A single row of condenser steam coils, placed on each side of the kiln, helps to remove excess moisture from the air in the kiln. Uniform air circulation can be obtained in a kiln of this design; the velocity, however, is low, approximately 25 feet a minute.

b. **Internal-fan kilns**—Kilns using internally located fans may be divided into two classes: a) short-shaft types and b) long-shaft kinds.

Short-shaft, internal-fan kilns. In this type of kiln the fans may be located above the load or under it (below track level). The latter location of fans is common in the older kilns or in remodelled natural-circulation kilns, in which heating coils are generally located in a pit

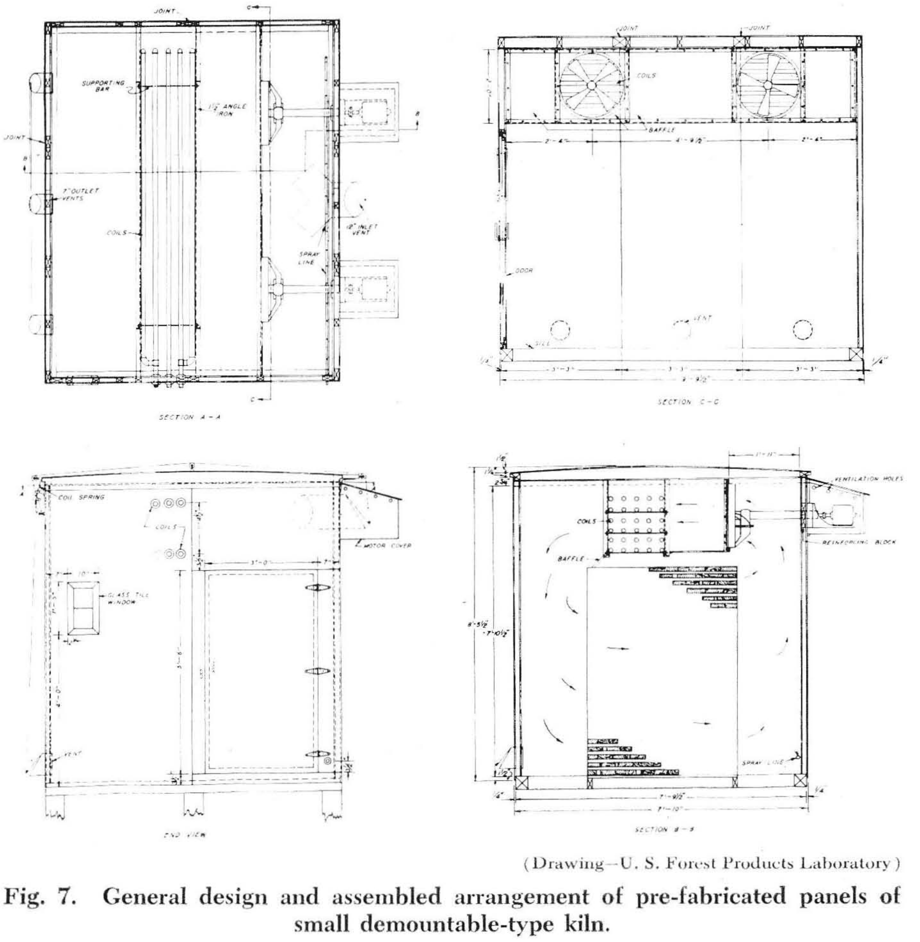


(Drawing—U. S. Forest Products Laboratory)

Fig. 6. Double-track, short-shaft, internal-fan, reversible-circulation kiln.

below the track level. In the newer kilns the overhead-fan installation is favored, because of the lower initial cost involved.

End-piled lumber stacks are preferred with any type of internal-fan circulation system to those of cross-piled type. The typical arrangement of fans and heating system for a double-track, reversible-circulation, end-piled kiln is shown in Fig. 6. To prevent the air from short-circuiting over the top and under the load, a series of baffles are provided. The air is deflected downward by the kiln walls and across the load through the spaces in the lumber pile provided by the stickers. The air is then drawn upward by the fans. When the fans are reversed the air movement is in the opposite direction. The space between the kiln wall and the lumber pile should be at least 18 inches wide; a wider space (up to 3 feet) is desirable since the wider



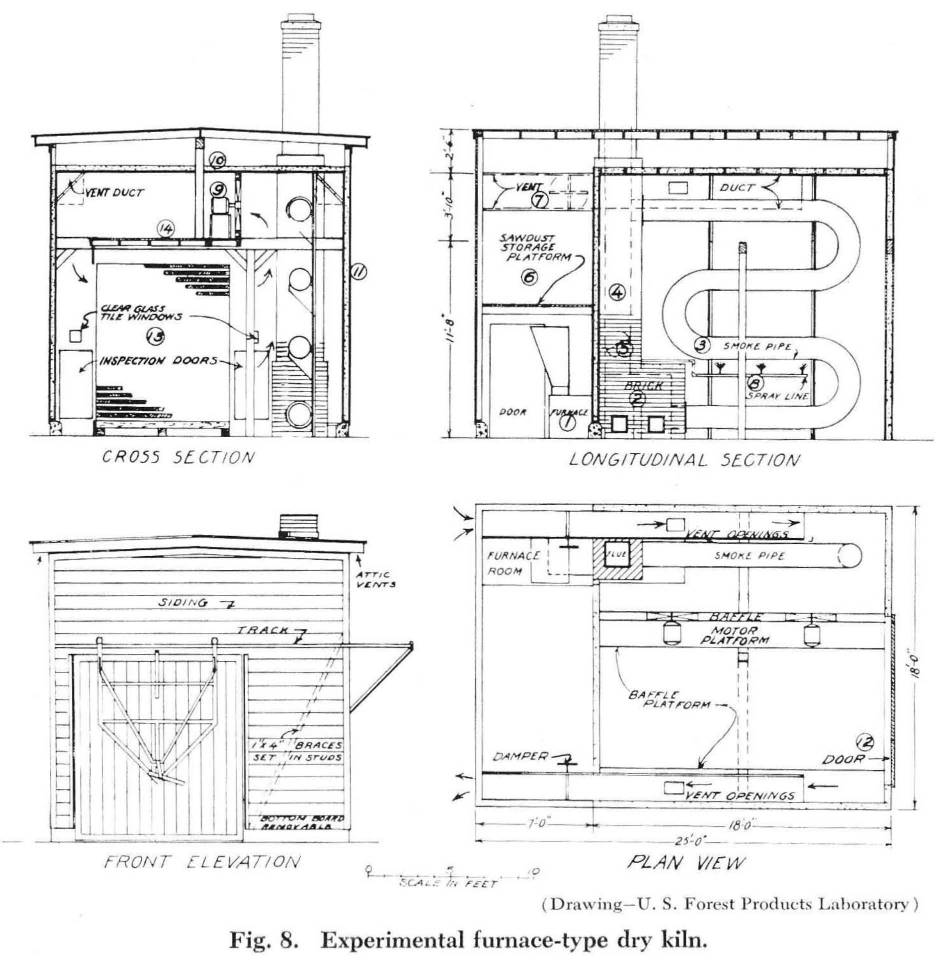
(Drawing—U. S. Forest Products Laboratory)

Fig. 7. General design and assembled arrangement of pre-fabricated panels of small demountable-type kiln.

passage (plenum chamber) tends to produce more even air distribution.

A row of booster coils is also shown in the drawing. As previously mentioned, the addition of booster coils is desirable, especially when fast-drying species are seasoned. The purpose of these coils is to reheat the air after it has passed through one load and before it enters the second stack. This reduces the differences in temperature between the entering and the leaving sides of the kiln. The kiln is ventilated through vents located on the roof.

A similar, one-load, short-shaft kiln, originally designed by the Forest Products Laboratory for experimental purposes but suitable for any small wood working plant, is shown in Fig. 7. In this kiln the fans are located overhead but to one side of the load. Although designed



(Drawing—U. S. Forest Products Laboratory)

Fig. 8. Experimental furnace-type dry kiln.

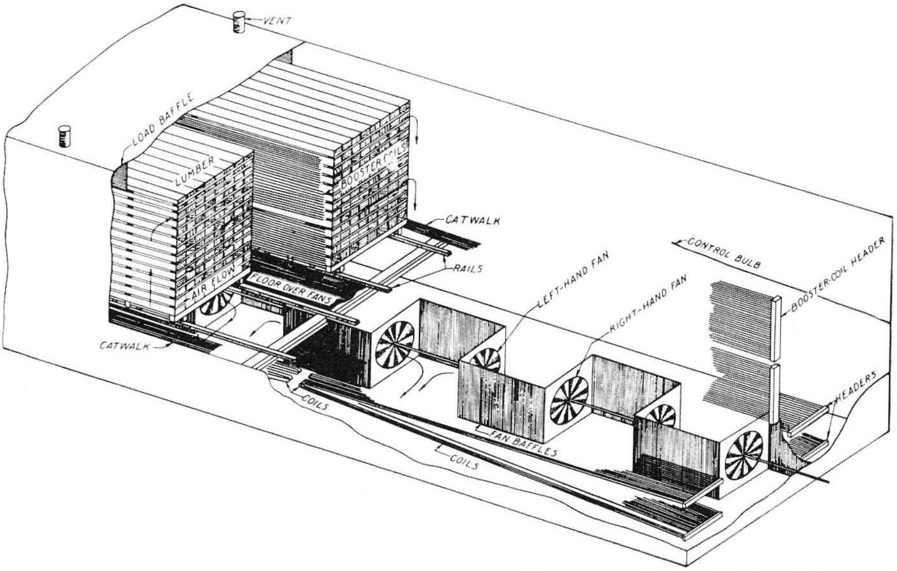
as a portable kiln to be dismantled and moved from plant to plant, similar kiln equipment can be placed in a permanent building.

The fans used in short-shaft compartment kilns are disk type, generally driven by individual motors located outside or inside of the kiln; in the latter case, special glass-wound, moisture-resistant motors must be used. A number of fans, however, can also be operated from the outside by a single motor by means of pulleys and shafts.

Furnace-type, internal-fan kiln. An internal-fan kiln in which heat is supplied by a furnace located outside the kiln is illustrated in Fig. 8. The hot air is carried into the kiln through a large smoke pipe extending through the length of the kiln. Relative humidity is maintained by a steam-spray line which can be operated manually or automatically.[5]

Long-shaft, internal-fan kilns. In this type of kiln the fans are mounted on a shaft extending through the length of the kiln; the shaft is driven by a motor located outside the kiln. The fans and the heating units may be placed either above or below the lumber.

The air is deflected to the sides of the kiln by a system of baffles, similar to the one shown in Fig. 9. Certain amount of longitudinal air



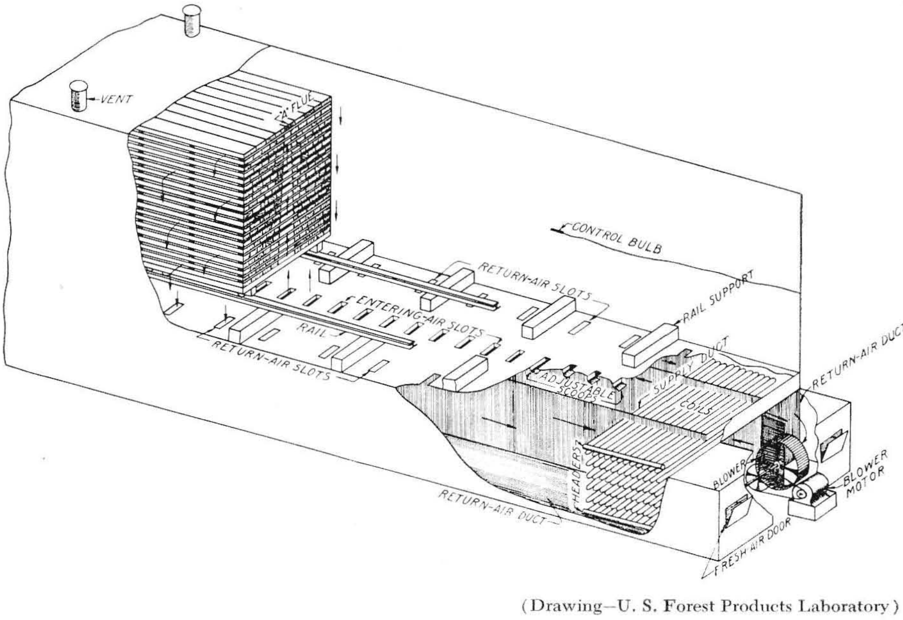
(Drawing—U. S. Forest Products Laboratory)

Fig. 9. Double-track, long-shaft, internal-fan, reversible-circulation kiln with alternately opposing fans.

[5]Further information on details of construction and operation of this kiln, may be obtained by writing to the Forest Products Laboratory, Madison 5, Wisconsin.

movement that is produced by the fans is broken up by mounting the fans in such a way that to one side of the longitudinal center they are left handed, while on the other side they are right handed. This causes the opposing fans to blow air against each other, thus breaking up the longitudinal drift of air. The direction of cross-wise circulation of air is reversed by reversing the rotation of the motor.

c. **External-blower kilns**—There are a number of different designs of kilns with the external-blower system now in operation; some of these are patented. One type of single-track, external-blower kiln is illustrated in Fig. 10. The blower and the heating coils are located at one end of the kiln. The blower forces the air across the coils and into a tapering supply duct that extends the length of the kiln. The top of the supply duct is level with the floor of the kiln and is provided with slots spaced about 1-foot apart. Each slot is equipped with an adjustable scoop, directing the air into an "A"-shaped flue in the lumber pile. The adjustment of scoops controls the volume and the direction of air flow. The air which enters the flue in the lumber pile passes through the lumber stack and outward in the space between the load and the kiln wall on each side of the load. From there it is drawn into return air ducts which conduct it back to the blower for reconditioning.



(Drawing—U. S. Forest Products Laboratory)

Fig. 10. Single-track external-blower kiln.

d. Size of the compartment kilns—The size of the compartment kilns is determined by the considerations of design, requirements of the plant, the type of material to be seasoned, and the space available for construction of the kiln. In general, the smaller the kiln the more uniform drying conditions can be obtained. A battery of smaller kilns, likewise, gives a greater flexibility of operation than one or two large kilns.

The length of a one-load kiln is determined by the length of the longest boards to be dried. Usually 12 to 18 inches of additional space is allowed at each end of the kiln. The width of the load varies from 6 to a maximum of 10 feet, 8 feet being the most common width. A space of 18 to 36 inches should be added on each side between the load and the kiln wall. It is customary to pile the lumber about 10 feet high. Adequate space should be allowed above or below the load for installation of fans and heating equipment.

Kilns of greater capacity are built proportionally larger. They can be constructed for either a single or double track. The most common sizes for commercially built compartment kilns are one-, two-, four- and six-load capacities.

LUMBER PILING FOR KILN DRYING

Lumber to be kiln dried is usually stacked flat, and each course of lumber separated by stickers. Stickers can be made of any kind of lumber, but they must be straight, uniform in thickness, free from decay and well dried. For hardwoods, stickers should be about ⅞ to 1 inch thick and 1½ to 2 inches wide. Stickers up to 4 inches in width are commonly used for softwoods.

The spacing of stickers depends on the tendency of the wood to warp during seasoning. With green hardwoods stickers are commonly spaced 2 to 4 feet apart; even closer spacing may be used for woods with warping tendencies, such as elm, and gums. When air seasoned stock is kiln dried, the stickers are spaced 3 to 4 feet apart. With softwoods the stickers, as a rule, are spaced 4 to 6 feet apart.

To avoid warping it is very important that all the stickers be of uniform thickness and properly aligned above each other. A support, strong enough to prevent sagging, should be placed under each row of stickers; these supports should be at least 4 inches thick.

In the older kilns lumber has frequently been cross-piled with respect to the length of the kiln. With forced circulation, such method of piling interferes with circulation, and therefore almost invariably the new kilns are built for end-piling.

In natural circulation kilns lumber should be piled in such a manner as to allow the hot air to rise through unobstructed vertical flues. It is customary to leave two to three flues, 4 to 6 inches wide, every 12 to 18 inches apart. In some cases, in addition, an "A"-shaped flue, 8 to 12 inches at the base and tapering to 4 inches at the top, is also provided.

In internal-fan, end-piled kiln, there is no necessity for leaving any space between the boards, if adequate circulation of at least 250 feet per minute, is provided. In the cross-piled kilns, however, spaces of 2 to 3 inches must be left between the boards.

In the external-blower kilns the piling is determined to a large degree by the design of the kiln, and particularly by the location of the air ducts. When the ducts are located beneath the load an "A"-flue must be left in the stack.

Box Piling

Since any projecting surfaces tend to deflect the air from the course it is following, it is essential to pile the lumber so that no boards stick out on the sides or the ends of the load. When lumber of different lengths is to be kiln dried it should be "box-piled" (Fig. 11). In this method of flat piling the longest boards are placed on the outside of the pile and the shorter pieces are brought even with the ends of the longer boards at one end of the pile, or alternately at the opposite end of the stack. If enough long boards are available these can be scattered through the pile. Enough stickers should be used so that no ends of the shorter boards remain unsupported. Small blocks should be inserted between the stickers to support them in the absence of boards.

CONSTRUCTION OF DRY KILNS

Although dry kilns have been constructed of many different kinds of materials, experience has shown that the most suitable materials are wood, cinder block, hard brick and hard terra-cotta tile. Combinations of materials, such as wood combined with asbestos or fibre board, are also used. In general, materials employed in construction of kilns should have high heat and vapor insulating characteristics, and be able to withstand wide fluctuations in temperatures and humidities, as well as the corrosive action of acid vapors. A measure of fire resistance is

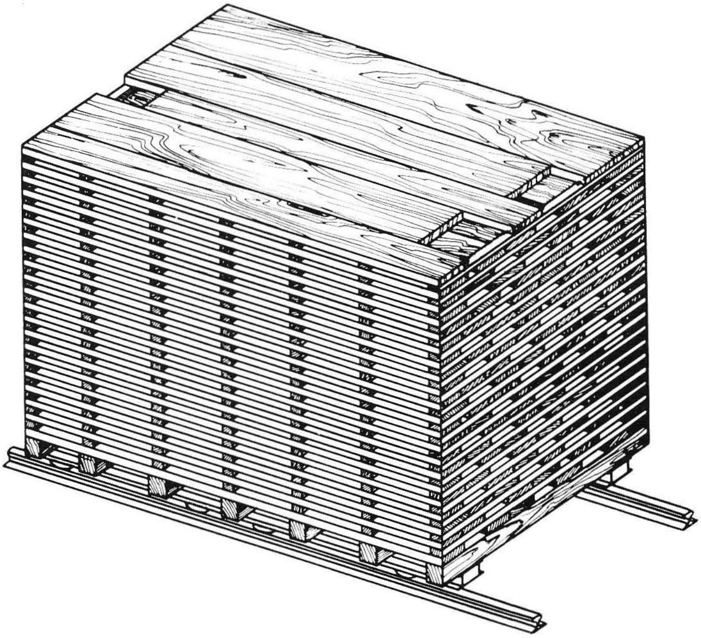
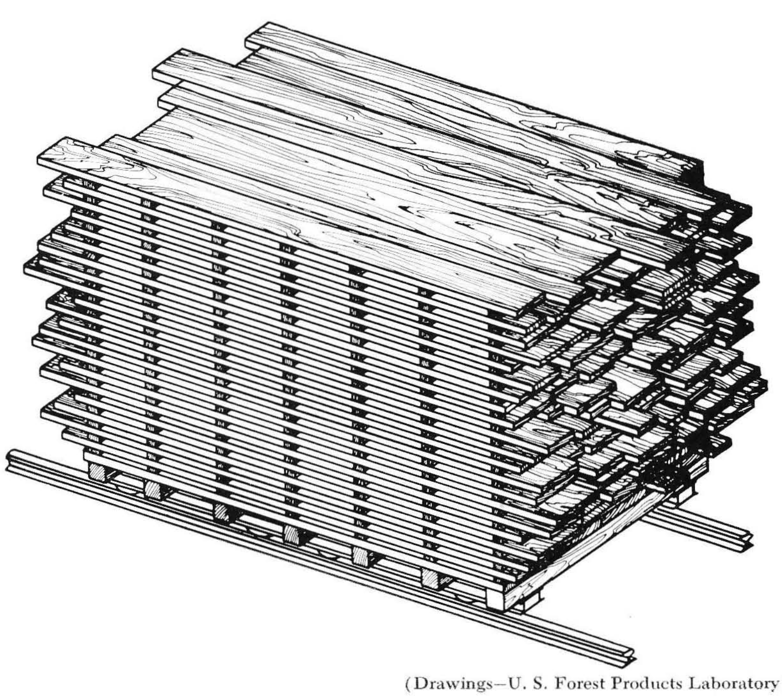


Fig. 11. A. Correct—Box-piled kiln car.



(Drawings—U. S. Forest Products Laboratory)

Fig. 11. B. Wrong—Kiln car piled with overhanging ends.

also desirable and in some localities is made mandatory by the local building codes.

No one material meets the above-mentioned requirements entirely and since dry kilns are relatively short-lived structures, the major consideration in selecting structural materials for a kiln, aside from a reasonable degree of permanency, is their cost and availability.

Foundation

Any part of the kiln wall below the grade is generally made of poured concrete, although cement blocks are sometimes also used. The sub-foundation (footings) should extend well below the frost line and be substantial enough to prevent settling. Any misalignment resulting from settling may lead to cracking of the walls and misplacement of tracks, and of heating and ventilating equipment. Foundation walls above the footings generally extend 6 to 12 inches above the ground. They should be 10 to 12 inches in thickness, if wood walls are used above the grade, and of the same thickness as the wall, if masonry is used.

Floors

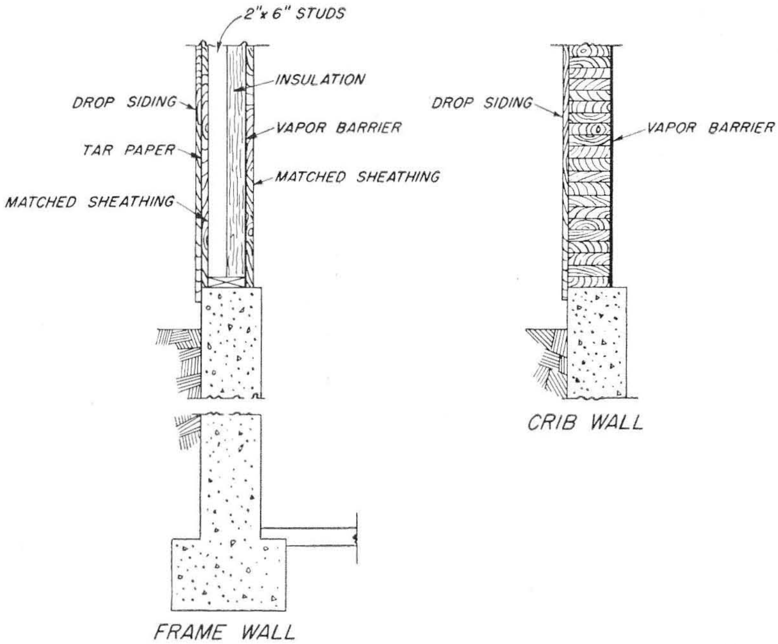
Concrete floors 4 to 6 inches in thickness are most satisfactory because of the ease with which they can be kept clean of debris. In many kilns, however, especially those built on dry ground, dirt floors are left uncovered; if the ground is clay a layer of cinders or sand is desirable.

Walls

Requirements for a good kiln wall are 1) sufficient strength to support the roof and any of the kiln equipment that may be resting on the walls, 2) good heat-insulating qualities and 3) resistance to vapor transmission.

Although masonry walls have proven the best for long service, wooden walls when properly constructed give satisfactory service for shorter periods; wood walls are also cheaper to construct.

a. Wooden walls—Two types of wooden wall construction in the kiln structure are commonly used; these are the standard frame construction and the crib construction (Fig. 12).



(Drawings—U. S. Forest Products Laboratory)

Fig. 12. Wood wall types.

When *standard stud construction* is used, 2 by 6-inch studs on 16-inch centers should be used, sheathed on the inside and outside with 1-inch lumber. Inside sheathing should be either shiplap or matched lumber. An exterior moisture barrier, in the form of good roofing paper, or aluminum foil should be applied vertically over the face of the studs, under the interior sheathing. The sheathing itself should be protected with a good kiln paint. It is recommended that all wood exposed to kiln conditions be nailed with two nails to each stud, one at the center and one at the bottom of each board; this will allow for changes in dimension due to shrinkage and swelling.

Asbestos cement boards ¼- to ½-inch thick, fastened to the studs, may be substituted for the vapor barrier and the wood sheathing. The interior face of boards should be well covered with an approved kiln paint for protection against acid vapors (APPENDIX TABLE 4).

Exterior walls are generally constructed of shiplap, covered with drop or beveled siding. For heat insulation sheathing paper may be used between the exterior siding and sheathing, but it must be of waterproof and not vaporproof type. Slater's felt or tar paper are suitable for this purpose.

To provide good protection against heat loss, the space between the studs may be filled with loose insulation. If insulation is used it is important that a good vapor barrier be installed on the inside wall.

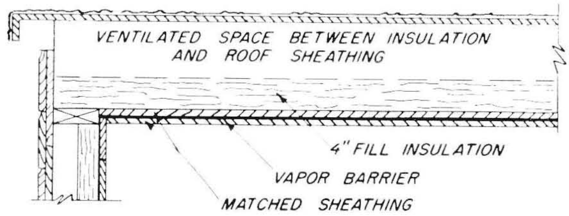
Crib walls have been used in the past in kilns built at sawmills, particularly on the West Coast. The walls are constructed by laying surfaced 2 x 6-inch stock flat, one on top of another, nailing each piece solidly. The resulting wall is strong, and has good insulating properties, if constructed of dry stock. However, if built of green lumber, the resulting shrinkage leads to formation of cracks and distortion of door frames. Further improvement in insulating characteristics of the crib wall may be obtained by facing the wall with one or more layers of roofing paper and wood siding. Crib walls are also classed as the "slow-burning" type and therefore command better insurance rates than a standard form of construction.

b. Masonry walls—Masonry walls in dry kilns are generally constructed of cinder block, brick or terra-cotta tile. Poured concrete walls are seldom used, because of the high cost and the low insulating properties. Brick used for kiln walls should be either hard burned, common or face type. The outside walls should be about 13 inches thick, and the partitions 8 to 10 inches. Terra-cotta tile must also be of the hard-burned, load-bearing type; the usual size used in kiln construction is 12 x 12 inches. The mortar used in laying the masonry must contain little lime, since this will quickly disintegrate from the action of acids in the vapor, leaving numerous openings through the mortar joints. Any kind of masonry wall must be protected on the inside with one or two coats of kiln paint.

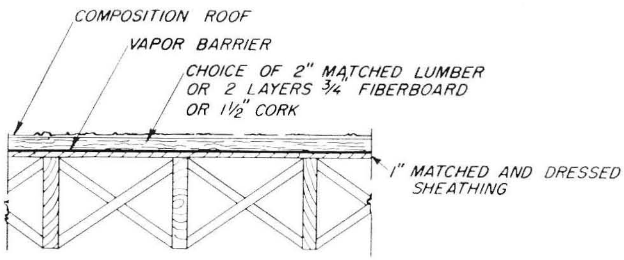
Roof and Ceiling

A satisfactory kiln roof must be weatherproof and well insulated against heat losses. If the roof is poorly insulated it will tend to cool the kiln air to the dew point. The resulting condensation will drip from the ceiling on the top layers of lumber. These boards, when later subjected to lower humidity, will check and warp. Leaky roofs or ceiling likewise makes it difficult to maintain constant humidity and temperature conditions within the kiln.

Kiln roofs are generally built flat on the underside (the ceiling side) and nearly flat, with a pitch of ¼ to ½ inch per foot, on the upper surface. Dry kiln roofs are constructed either of wood, reinforced concrete or tile and concrete.



WOOD JOIST WITH CEILING BELOW



STANDARD JOIST CONSTRUCTION

(Drawings—U. S. Forest Products Laboratory)

Fig. 13. Roof types.

a. **Wooden roofs**—These are either crib, laminated, or the conventional joist type. Crib construction is used only when lumber is cheap, and when a slow-burning building is desired. The crib-type roof is made either of 2″ x 6″ or 2″ x 8″ stock, laid on edge and spiked together. The stock should be well seasoned to minimize the danger of decay and formation of cracks due to shrinkage.

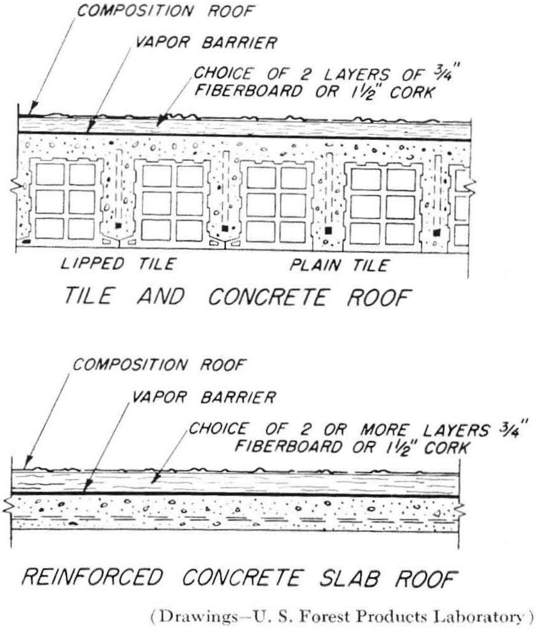
The joist roofs are made of 2″ x 10″ or 2″ x 12″ hard pine or Douglas fir, spaced 16 to 24 inches on centers and well bridged. Even the best constructed wooden roofs are subject to decay.

Experience has shown that the best results are obtained when the roof is constructed as follows: a layer of 1-inch sheathing is nailed on top of the joist and covered with a vapor barrier, such as composition or roll roofing mopped with asphalt. This is covered either with 2-inch sheathing or two thicknesses of ¾-inch fiberboard, and finished with composition roofing (Fig. 13).

In some cases a ceiling, nailed to the lower side of the joists, is also provided (Fig. 13). If this is done, a vapor barrier (roll roofing or aluminum foil) should be placed either between the two layers of sheathing forming the ceiling or applied directly to the underside of the joists and then covered with the sheathing. Asbestos boards attached with brass screws to the outside of the sheathing boards, would also make a good moisture barrier. The space between the joists can be partially filled with loose insulation, allowing for adequate ventilation of the space. The roof above the joists should be made as already described, except that the vapor barrier is omitted. If possible, wood used in kiln roofs should be pressure treated with creosote; when construction costs are high the added cost of such treatment may be justifiable because of the much longer life of the roof.

b. Reinforced Concrete Roofs—These must be well insulated because of the poor heat insulating value and low water resistance of concrete. If economical, a concrete aggregate made with an insulating product will reduce heat losses appreciably. The concrete slab must be thick enough to be structurally safe, and provided with expansion joints.

The finished concrete slab must be covered with a vapor barrier consisting of several layers of roofing felt mopped down with asphaltum or pitch; several inches of gravel or slag are usually spread on top of the finished roof. If further insulation is desired, 2 or 3 inches of cork board, or three or more thicknesses of fiberboard could be laid on top of the concrete slab and then covered with roofing, as previously described (Fig. 14).



(Drawings—U. S. Forest Products Laboratory)

Fig. 14. Roof types.

c. Terra-cotta Roofs—A very satisfactory kiln roof can be made of terra-cotta tile, separated by reinforced concrete beams. For the Michigan climate it is recommended that 12-inch tile be used. The roof is finished with a vapor barrier insulation and roofing felt, as described in the previous section on reinforced concrete roof. Expansion joints must be provided (Fig. 14).

d. Ceiling Condensation—In kilns in which the heating system is located below the lumber, condensation may form if the roof is not adequately insulated. In this case special ceiling coils should be installed to heat the roof independently of the rest of the kiln. Generally, 1-inch pipes, suspended below the ceiling and spaced 2 or 3 feet apart, are used. When fans and heating system are installed above the load, no such special ceiling coils are required.

Doors

Construction of satisfactory dry kiln doors, which are strong, light, easy to handle and high in insulating properties, is very difficult.

The most satisfactory doors are those made of aluminum and insulated, or of asbestos paneling fixed to a steel frame. Good wooden doors can be made of cypress, redwood or creosoted wooden slats about ¾ to 1 inch thick, built into a steel frame and covered with asphaltum paper or aluminum foil on the outside.[6]

Most of the kiln doors are moved on patented hangers; hinged doors are much less satisfactory.

It is desirable to build into the kiln door a small inspection door, so that the operator can enter the kiln during the operation of the kiln without opening the large door.

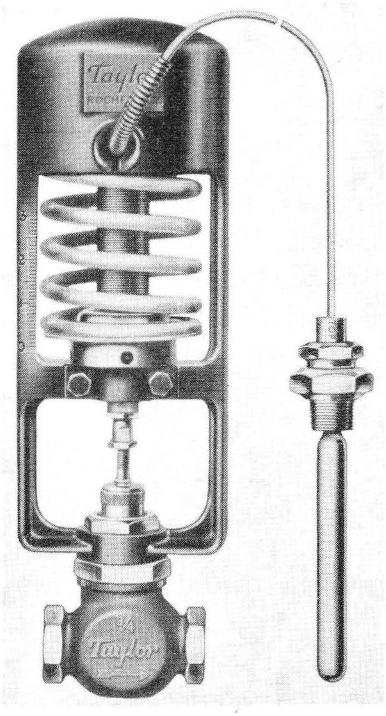
TEMPERATURE MEASURING AND CONTROLLING DEVICES

The temperature-measuring devices employed in dry kilns are either indicating or recording thermometers. Visual indicating thermometers are usually of the mercury filled glass type, with graduations in degrees either etched on the glass stem or marked on a separate metal strip, to which the thermometer is attached; the former type is more accurate. Both temperature and humidity can be determined by means of indicating thermometers. If humidity is to be determined two thermometers are employed, one of which is provided with a wick placed in water, while the other is dry.

[6]Further information on construction of dry kiln doors may be obtained from the Dry Kiln Door Carrier Company, Indianapolis, Indiana, or dry kiln manufacturers. (See Appendix Table 1).

Recording thermometers used in kiln work are of the extension-tube type. They consist of a sensitive element, called a bulb, which is connected to the instrument by a capillary tube. The bulb is filled either with mercury, gas or vapor. In dry kiln work the vapor-filled type is the most suitable. As in indicating thermometers, both temperature and humidity can be determined by using instruments with two bulbs, one of which is covered with a cloth wick or a porous sleeve kept constantly moist.

In some kilns tmperature and humidity are controlled entirely by manual operation of the valves; however, because of the fluctuation in the outside temperatures it is impossible to maintain constant drying conditions with hand controls. Most of the modern kilns, therefore, are equipped with automatic controls. The two types of automatic controls employed in kiln drying are the self-contained and auxiliary-operated kinds.



(Photograph—Taylor Instrument Co.)

Fig. 15. Self-contained controller.

Self-contained Controllers

These controllers do not require an outside source of power to operate them. The pressure inside of the bulb located in the kiln is transmitted through the capillary tube to a diaphragm in the motor head, in the valve. The expansion of the diaphragm causes the stem of the valve in the steam line to move. This movement of the valve stem is opposed by a constant counter-pressure provided by an adjustable spring or sliding weight. The instrument can be set to operate on any desired temperature by changing the tension of the spring or the position of the weights (Fig. 15).

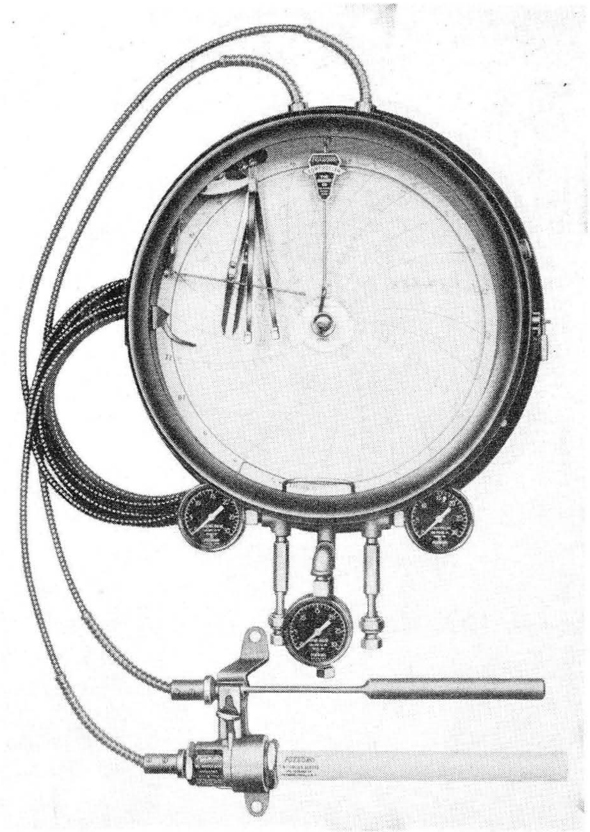
The principal advantage of this type of instrument is its lower initial cost, compared with that of the auxiliary operated controllers, and the fact that no auxiliary power is required for its operation. Self-contained instruments, however, are less sensitive, do not respond quickly to changes in temperature and do not perform well under conditions requiring wide fluctuations in the amount of steam needed. This type of controller, therefore, is seldom used in the compartment kilns.

Auxiliary Operated Controllers

This type of controllers requires an outside source of power for their operation; this can be either electricity or compressed air. In dry kilns the air-operated type is the most commonly used, but where compressed air is not available, electrically operated thermostats are quite satisfactory.

Recorder-controllers

These are auxiliary operated instruments which combine a thermostat (a controller) and a recorder (Fig. 16). The types most suitable for dry kilns are those that have vapor-filled bulbs. In the kilns using reversible circulation it is desirable to have a recorder-controller equipped with two dry and one wet bulb. The dry bulbs are located on either side of the lumber stack. This arrangement allows the dry bulb that is located on the entering air side (the hotter side) to operate the controlling instrument. When the circulation is reversed, the bulb on the other side of the load (now the entering air side) controls the instrument.



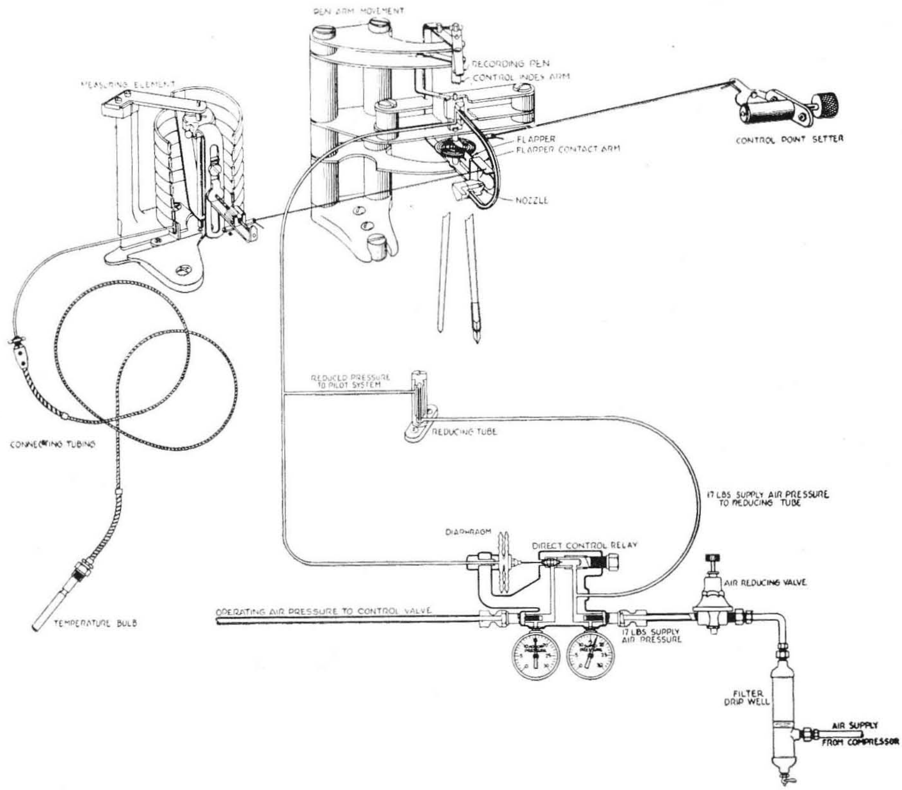
(Photograph—The Foxboro Co.)

Fig. 16. Auxiliary operated recorder-controller.

Some controller-recorders also operate an automatic vent system. In such a case the controlling mechanism for the vents is attached to the wet bulb control and works in the opposite direction from it, i.e., when the wet bulb temperature is exceeded due to the excess moisture evaporated from the wood, the vents are opened, allowing some moist air to escape. This lowers the humidity within the kiln. When the humidity is reduced to that corresponding with the setting on the instrument, the vents close.

Location of Recording and Controlling Instruments

The bulbs of the recording and controlling instruments are relatively small. Unless drying conditions are uniform throughout the kiln,

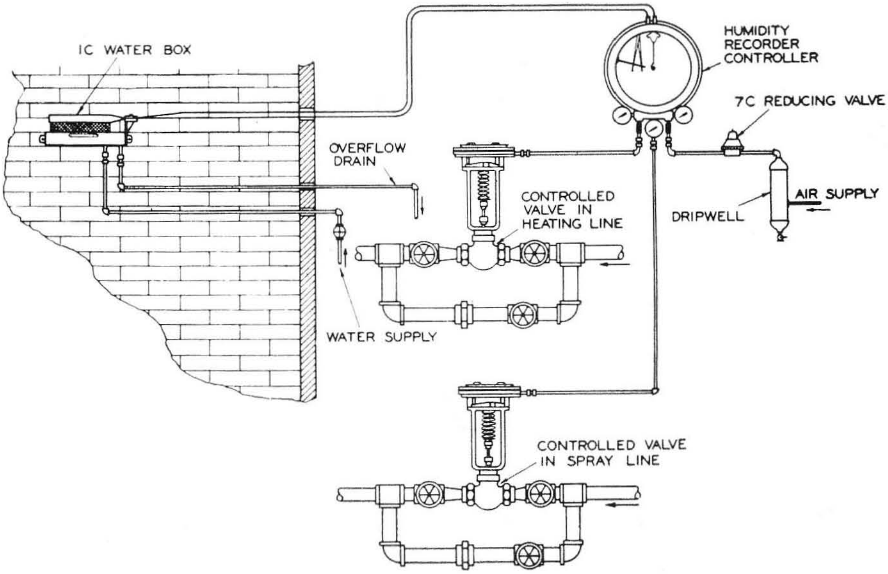


(Drawing—The Foxboro Co.)

Fig. 17. Details of pneumatic temperature control system.

the bulbs will register only the temperature prevailing in a small portion of the kiln. Since even in the best kilns some variations in temperature and humidity exist throughout the building, the bulbs should be located in the hot zone of the kiln. If the bulbs cannot be located at a point where the temperature is the highest, the instrument should be underset by the difference in reading between the hottest spot and the point where the bulbs of the instrument are located.

As a matter of convenience, since water is required for the wet bulb, the bulbs are located on a side wall of the kiln (Fig. 18). The bulbs can be mounted so that they extend either parallel or perpendicular to the side wall; they should be placed, however, as far from the wall as possible to eliminate the effect of wall temperature and to provide adequate circulation around them. The correct and incorrect ways of mounting bulbs are illustrated in Figs. 19 and 20.



(Drawing—The Foxboro Co.)

Fig. 18. Typical arrangement of dry kiln controller and automatic valves.

Calibration of Recording and Controlling Instruments

Recorder-controllers can easily become deranged and, therefore, require frequent calibration. Manufacturers' recommendations for calibration of their instruments should be consulted, but in general the procedures are as outlined in the following paragraphs.

a. Calibration of recorders—Recorders are calibrated by placing the bulb, a foot or more of the tube and a standard glass thermometer in a vessel of cool water. The water is gradually heated to 200°F.; it should be stirred to keep the temperature uniform throughout the container. Readings of the standard thermometer and those on the face of the recording thermometer are noted simultaneously, at an interval of several degrees of temperature. Any discrepancies in the readings of the two thermometers are carefully noted. These discrepancies may be of two kinds: constant and cumulative.

Constant errors are those in which the pen readings of a recording thermometer are off, plus or minus, the same amount throughout the whole range of temperatures. A constant error can be corrected by resetting the pen arm the correct distance by means of a small screw at or near the pen-arm pivot. *Cumulative errors* are those which gradually increase or decrease over a range of temperatures. Adjustments

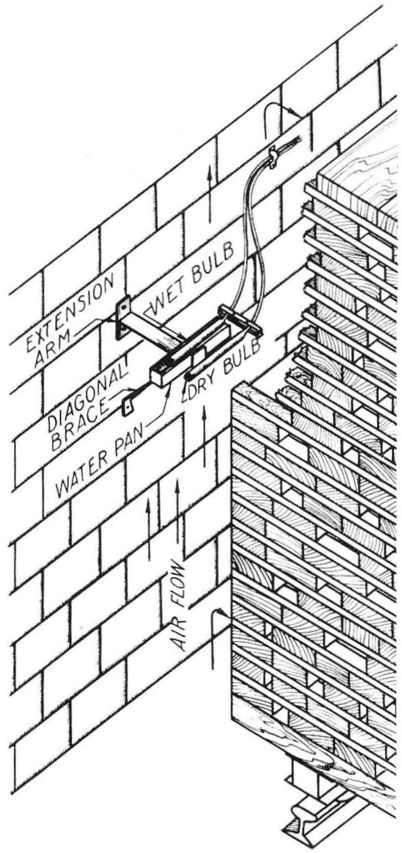
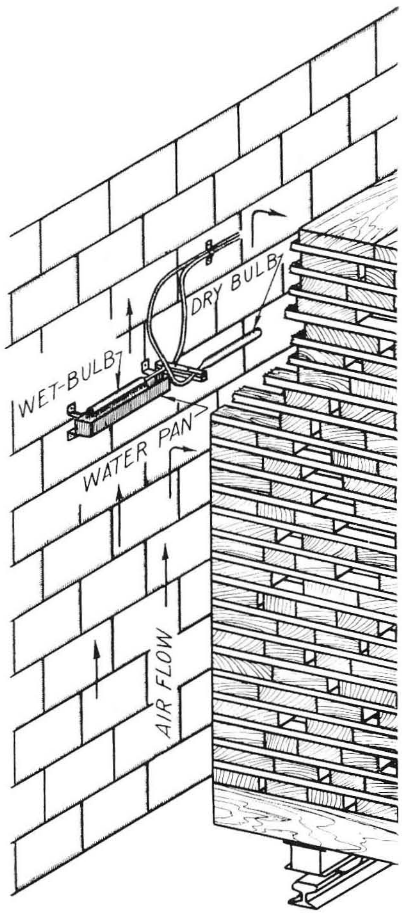


Fig. 19. Method of placing control bulbs on kiln walls so that the bulbs are far enough from the kiln wall to be in the entering air stream.



(Drawings—U. S. Forest Products Laboratory)

Fig. 20. These bulbs are located too close to the wall to permit circulating air to contact them properly.

required to correct cumulative errors are rather intricate and the work should be done by an authorized representative of the instrument manufacturer. The wet bulb of the instrument in calibrated in the same manner; the wick or the porous sleeve must be removed during calibration.

b. Calibration of recorder-controllers—The recording mechanism of a recorder-controller is calibrated in the same manner as has just been described for the recorder. To check the accuracy of the controller (i.e. the arms used for setting the dry and wet bulbs) the bulbs must be tested in their permanent location in the kiln, and the air pressure and steam turned on. The checking should be done at a temperature within the operating range of the instrument. First move the setting arm below the position indicated as being the temperature of the bulb, then begin to advance it until the steam line opens. Note the position of the arm. Now move the setting arm in the opposite direction until the valve closes. Again note the position of the arm. Place the setting arm half the distance between the two recorded points, and adjust the pointer until it corresponds to the temperature indicated by the recording pen.

OPERATION OF THE KILN

Even the most modern kiln will not perform satisfactorily without intelligent supervision of drying operations. The regulation of drying conditions means, in general, following a prescribed schedule for drying lumber. The object of all dry kiln schedules is to promote as rapid drying as possible without allowing the development of seasoning defects.

AVERAGE MOISTURE CONTENT SCHEDULES

Most of the schedules now in use are based on the average moisture content of lumber. These schedules (Table 4) indicate the wet and dry bulb temperatures which should be used at any given moisture content. Such schedules are simple to use and give satisfactory results when lumber of one thickness and of the same drying characteristics is seasoned. However, since these schedules depend on determination of the average moisture content, appreciable error may be introduced if considerable discrepancies exist in the moisture content of different boards in the kiln load.

TABLE 4

(Forest Products Laboratory)

GENERAL HARDWOOD SCHEDULES 1 TO 4

Stock moisture content	Schedule 1			Schedule 2			Schedule 3			Schedule 4		
	Dry bulb temp.	Wet bulb temp.	Rel. hum %	Dry bulb temp.	Wet bulb temp.	Rel. hum %	Dry bulb temp.	Wet bulb temp.	Rel. hum %	Dry bulb temp.	Wet bulb temp.	Rel. hum %
45	140	132	80	135	128	80	130	123	80	125	118	80
40	145	135	75	140	130	75	135	126	75	130	121	75
30	150	137	70	145	133	70	140	128	70	135	123	70
25	155	136	60	150	132	60	145	128	60	140	123	60
20	160	135	50	155	131	50	150	127	50	145	122	50
15	165	127	35	160	124	35	155	124	40	150	120	40
10 to Final	170	116	20	165	112	20	160	115	25	155	111	25

GENERAL HARDWOOD SCHEDULES 5 TO 8

Stock moisture content	Schedule 5			Schedule 6			Schedule 7			Schedule 8		
	Dry bulb temp.	Wet bulb temp.	Rel. hum %	Dry bulb temp.	Wet bulb temp.	Rel. hum %	Dry bulb temp.	Wet bulb temp.	Rel. hum %	Dry bulb temp.	Wet bulb temp.	Rel. hum %
45	120	113	80	115	108	80	110	105	85	105	101	85
40	125	116	75	120	111	75	115	108	80	110	104	80
30	130	119	70	125	114	70	120	111	75	115	107	75
25	135	121	65	130	116	65	125	112	65	120	109	70
20	140	120	55	135	116	55	130	112	55	125	110	60
15	145	119	45	140	115	45	135	110	45	130	109	50
10 to Final	150	112	30	145	108	30	140	108	35	135	107	40

INDEX OF GENERAL SCHEDULES FOR KILN DRYING HARDWOOD LUMBER

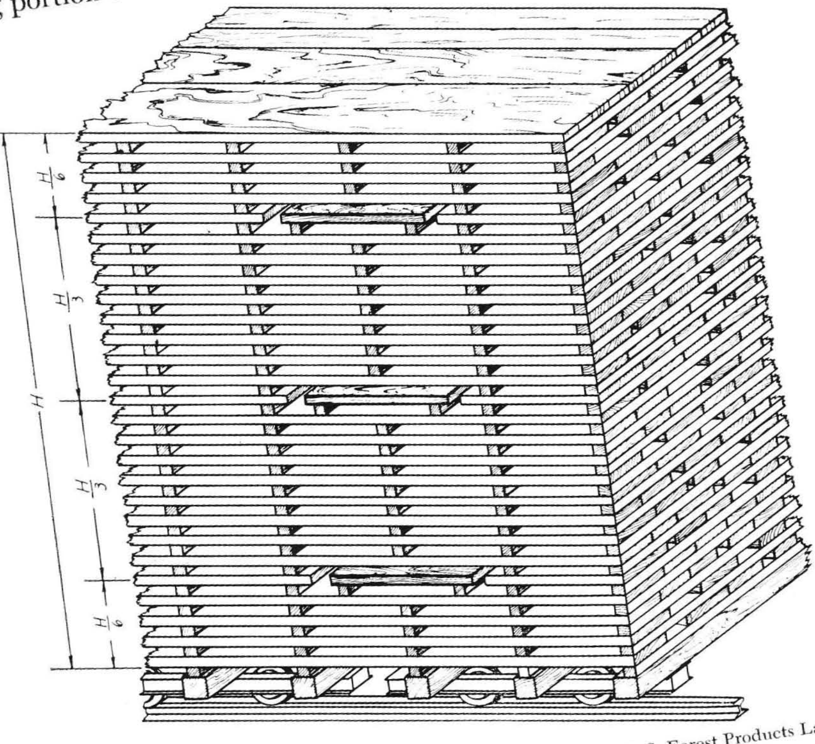
(Up to 6/4 inch in thickness)

Species of wood	*Schedule*	*Remarks*
Ash	2	
Basswood	1	
Beech	3	
Birch	1	
Boxwood	5	Squares or quartered stock only
Butternut	2	
Cherry, black	5	
Chestnut	2	
Cottonwood	2	
Elm	2	
Gum, red	2	For special schedule for sap gum write to Forest Products Laboratory
Gum, black, and tupelo	3	
Hackberry	2	
Hickory	5	
Holly	4	
Hop-hornbeam (ironwood)	4	
Locust	5	
Magnolia	2	
Mahogany	4	
Maple, silver and sugar	3	
Oak, red and white	6	Northern highland stock
	7	Northern lowland stock
	7	Southern highland stock
	8	Southern lowland stock
Osage, orange	5	
Persimmon	5	
Poplar, yellow	1	
Sycamore	5	
Walnut, black	5	
Willow	2	

NOTE: These schedules are very conservative. In the modern, forced circulation kilns more severe drying conditions can be employed. The operator should attempt to develop his own schedules as he becomes more skilled in operation of the kiln.

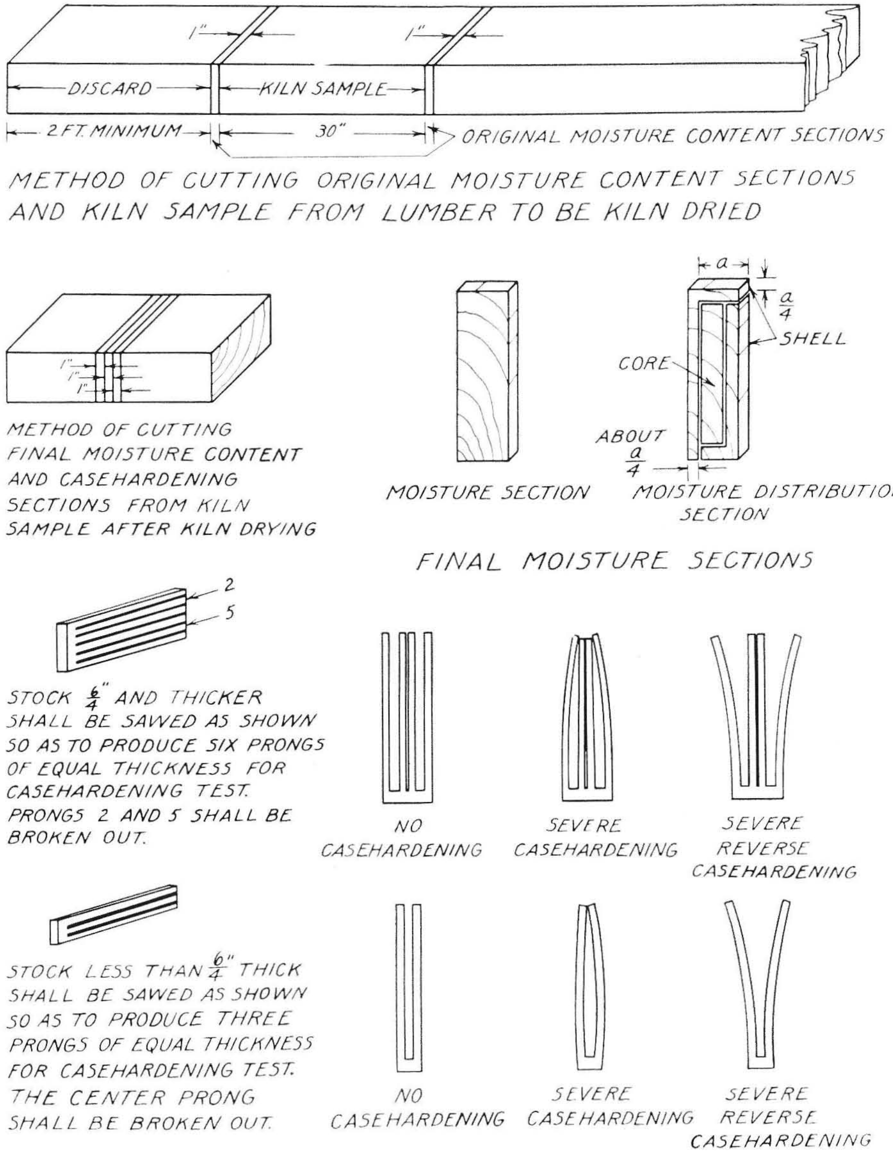
The application of the average moisture content schedule is dependent on the use of kiln samples. These samples are short boards, 2 to 3 feet long, of a known moisture content. They are placed in the kiln with the lumber and are weighed periodically (usually twice a day) to determine the changes in the moisture content of the lumber being dried in the kiln (Figs. 21 and 22).

These sample boards are prepared as follows: at the time the kiln is loaded several boards representing the thickest and the wettest stock are set aside. These boards should contain a high percentage of heartwood, unless sapwood only is kiln-dried. From each of these boards a section 2 to 3 feet in length is cut, at least 2 feet away from the end of the board. A thin section, about ½ to 1 inch in thickness is sawed off from each end of the kiln sample board and immediately weighed and placed in the drying oven (Figs. 22 and 23). The remaining portion of the kiln sample board should be end-coated without



(Drawing—U. S. Forest Products Laboratory)

Fig. 21. Placement of three kiln samples in recessed areas built in the side of an end-piled load of lumber.



(Drawing—U. S. Forest Products Laboratory)

Fig. 22. Preparation of moisture content and casehardening samples: section to be room dried before conclusion is made as to casehardening.

delay with a dry kiln or aluminum paint, and placed in the space left for it in the kiln load (Fig. 21).

After the thin sections in the oven have reached a constant weight, the moisture content of each is computed (see page 8) and averaged.

It is then assumed that the moisture content of the kiln sample from which these sections were cut is the same as the average found by drying the thin sections. It is now possible to determine the oven-dry weight of the kiln sample. For instance, assume that sections cut from the kiln sample weigh as follows:

	Green weight	Oven-dry weight	M.C.%
Section 1	52.5 grams	35.0 grams	50
Section 2	62.0 grams	41.0 grams	51.2
		Average	50.6

The kiln sample weighs 4.6 kilograms green, and on the basis of the moisture content determinations just performed, its moisture content is 50.6 percent. Therefore its oven-dry weight can be determined as follows:

$$\text{Oven dry weight} = \frac{(4.6\text{-x})}{\text{x}} \times 100 = 50.6$$

$$\text{or, x} = \frac{460}{150.6} = 3.05 \text{ kilograms}$$

Now since the oven dry weight of the kiln sample is known, its moisture content, as it dries, can easily be determined. For instance, if on the second day after the kiln has been started, it is found that the sample has lost 0.4 kilograms, its weight is then 4.2 kilograms, and its new moisture content is

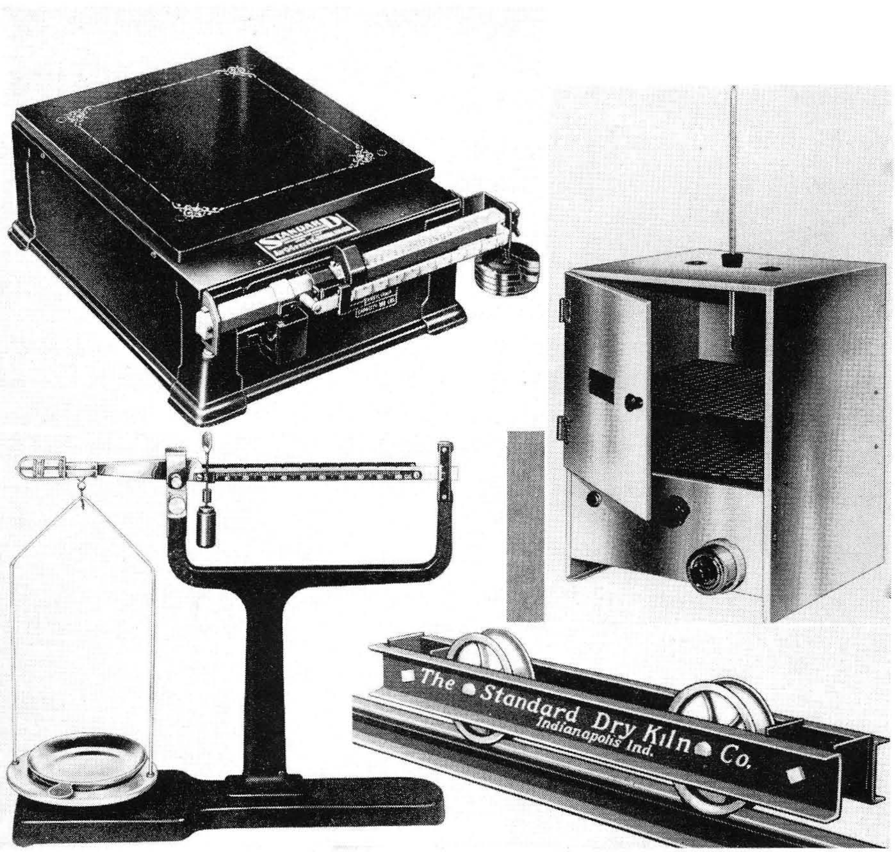
$$\frac{4.2\text{-}3.05}{3.05} \times 100, \text{ or } 37.7 \text{ percent}$$

In this way the progress of drying can be followed and the necessary changes in the drying schedule made.

It is advisable to have more than one kiln sample for each load of lumber. When possible three samples should be used, placed in the lower third, along the center line and in the upper third of the load (Fig. 21).

Use of Kiln Samples During Operation of the Kiln

The kiln samples should be removed from the kiln once or twice a day at the same hour, reweighed, and the new moisture content recalculated. When high humidities and high temperatures are used,

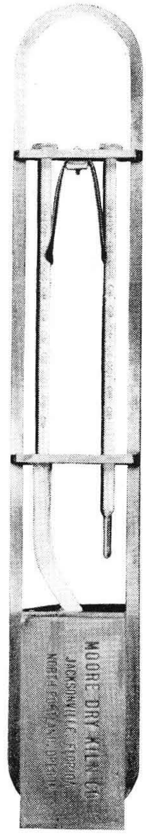


(Photograph—Standard Dry Kiln Co.)

Fig. 23. (top, left) Platform scale for weighing large kiln samples. (top, right) Electric drying oven suitable for drying test samples. (bottom, left) Triple-beam scale for weighing small test samples. (bottom, right) End-wise piling kiln trucks.

the fans and the spray lines should be turned off before one enters the kiln. As a further measure of precaution the inspection door should be left open, and if possible a second person stationed outside the kiln. Asbestos clothing and a mask are desirable when a great many samples must be handled.

After each sample is weighed it should be immediately returned to the same place in the kiln. If there is an appreciable variation in the moisture content of the samples the drying should be based on the moisture content of the sample boards with the higher moisture content. Changes in the temperature and relative humidity are made as indicated in the schedule being followed.



(Photograph—Moore Dry Kiln Co.)

Fig. 24. A hand hygrometer.

When the kiln samples indicate that the lumber has been dried to the desired moisture content, a further check on dryness of the lumber should be made by pulling out a board from the load and cutting a moisture content sample (about 1 inch thick), 2 feet from the end of the board.

TIME SCHEDULES

After the operator becomes thoroughly familiar with the kiln and the drying characteristics of the species of wood he is drying, it is possible to substitute time schedules in place of the average moisture content schedules.

In this type of schedule the kiln is operated for a predetermined number of hours at a given temperature and humidity. The drying conditions are then changed for another period of time, and so on until drying is completed. No tests for moisture content are made except at the end of the run as a check. Time schedules must be worked out separately for each kiln and each kind of wood from the information obtained by plotting the data obtained from the kiln samples. Once established, however, time schedules present distinct advantages over average moisture content schedules.

CONDITIONING AND EQUALIZING TREATMENTS

As wood dries, changes in the moisture content distribution within a board set up internal stresses. The development of such stresses is a normal occurrence that cannot be entirely avoided. It is only when stresses in dry lumber are severe that this condition may be undesirable, particularly if the lumber is to be resawn, or planed more on one side than on the other. When so treated lumber with internal stresses will cup.

Kiln-dried lumber with pronounced internal stresses is generally referred to as being *casehardened*. This term is unfortunate since casehardened lumber is not harder on the surface (it may be softer), nor does it mean that such wood is appreciably drier on the surface and wetter inside. The term refers to lumber which has dried without shrinking the full amount. As a result, the shell, i.e., the outside layers of wood, is in compression and the core, or the interior of the piece, is in tension. When such a piece is resawn (parallel with the wide surface of the board) the layers under tension (inside) become shorter and the layers in compression (outside) will elongate (Fig. 22).

The test for determining the presence and severity of casehardening must be performed after the lumber has dried within about 2 percent of the final moisture content. At that time two sections, each about 1 inch thick, should be removed from a board or from a kiln sample, after discarding at least 1 foot from the end of the board, or 6 to 8 inches from the kiln sample. One section should be used immediately for determination of moisture content, while the other is resawn parallel to the wide face of the board into prongs of equal thickness. This section should be allowed to stay in a heated place (65 to 80° F.) for an hour or two, and the behavior of the prongs observed. If the prongs turn in and stay that way after room drying, or bow in after room drying, the lumber is casehardened. The severity of casehardening can be judged by the amount of shortening of the inner prongs, and the extent of "pinching" (Fig. 22).

The Removal of Casehardening

Casehardening can be relieved by removing the stresses that cause it. The treatment involving removal of casehardening is called conditioning treatment. Two methods of relieving casehardening are in common use. One employs as high humidity (approaching 100 percent) as possible to obtain in the kiln. This treatment is therefore frequently referred to as a "steaming" operation. In this method the dry bulb temperature is set 10° to 20° F. above the previous setting, and the steam spray line is opened until the air becomes nearly saturated. The treatment is continued until, in the judgment of the operator, the outside layers of wood (the shell) have absorbed enough moisture to relieve stresses. Since there is no exact way of determining this while steaming is carried on, the treatment may or may not be sufficient to accomplish the purpose. If it was not sufficient, the treatment may be repeated. There is, however, always the danger of "oversteaming", i.e., allowing the surface fibers to absorb more moisture than is necessary to relieve the stresses. When this happens a condition known as "reverse casehardening" will occur, and the lumber will cup and warp when resawn, only in the opposite direction from that of casehardened stock (Fig. 22). Reverse-casehardening is almost impossible to relieve and, therefore, it is even more undesirable than the original casehardening.

The second method of reconditioning casehardened lumber involves a treatment at temperatures of 160° F., or higher, and at relative humidities which will do away with the difference in moisture content between the center and the surface of each board. Such treatment, to be effective, must be continued for a period of 20 to 30 hours in case of 1-inch lumber, and longer for greater thicknesses.

The following schedule for the relief of casehardening is recommended by the Forest Products Laboratory:

Moisture Content of Lumber (percent)	Temperature (°F.) Hardwoods	Softwoods	Relative humidity (percent)
10-12	160°-180°	180° and up	80-85
6-8	160°-180°	180° and up	65-75

An even more scientific method for relieving casehardening is based on the use of the equilibrium-moisture-content principle. The fundamental rules to be followed in this method are:

1. The relative humidity at which the treatment is given must be so chosen that the surface fibers will be raised to the maximum mois-

ture content in any part of the cross-section of the board; this generally means raised to the moisture content found midway between the broad faces of the board.

2. The treatment should be continued until the moisture content throughout the cross section is the same as the one at midthickness.[7]

Equalizing Treatment

Whether casehardening is to be relieved or not, an "equalizing" treatment at the end of the run is beneficial for diminishing the differences in moisture content among the boards. The equalizing treatment consists of changing the drying conditions in such a way that the equilibrium moisture content conditions of the drying atmosphere correspond to the average moisture content of the wood. For instance, if the average moisture content of hard maple is 9 percent, the equalizing treatment may be given at 170° F., dry bulb, and 156° F., wet bulb. The corresponding equilibrium moisture content is 9 percent (See Table 3). The treatment should be continued for 24 to 48 hours, during which period the boards which had less than the average moisture content will pick up some moisture, and the wetter boards will lose some. No board can, however, dry below 9 percent. A treatment to relieve casehardening may then be given following the completion of the equalizing treatment.

KILN DEFECTS

In addition to casehardening, a number of defects may develop in lumber in the course of kiln drying. These are: stain, collapse, checking, and warping.

STAIN

Stains that may develop in kiln drying are of two kinds: *organic*—caused by fungi, and *chemical*—arising as a result of chemical changes in the materials held in the wood cells. Both kinds of stains are most likely to develop at the beginning of the drying.

The principal stain caused by fungi is the blue sap stain, which, as the name indicates, develops in the lumber containing sapwood. This type of stain occurs when green lumber is kiln dried at low temperatures and high humidities, and when circulation in the kiln is sluggish. In the modern kilns, with adequate circulation, sap stain seldom oc-

[7]Further information on the use of these principles for the relief of casehardening may be obtained by writing to the Forest Products Laboratory, Madison 5, Wisconsin.

curs, except when the steam pressure falls below normal, making it impossible for the operator to maintain the desired temperature.

If evidence of blue stain or mildew (mold) is noted, these can be stopped from further development by raising the temperature in the kiln to about 150° F. and raising the relative humidity near the point of saturation for 1 to 2 hours. Following this treatment the drying conditions should be reduced to the original setting. This treatment should destroy the organisms (fungi) that cause stain and mildew.

The chemical stains, chiefly brown in color (sometimes also called *kiln burns*) are confined mostly to softwoods. The cause of this type of stain is still poorly understood, though it is believed due to oxidation of materials present in the cell sap. No effective measure of control has been found.

COLLAPSE

This defect occurs principally in the heartwood of such woods as oak, cottonwood and red gum. It is indicated by what appears to be an irregular shrinkage, giving the surface of the board a corrugated (washboard-like) appearance. This is due to actual collapsing of the cells, somewhat as rubber tubing will collapse if air is removed from it. This defect occurs before all free moisture is removed, i.e., above the fiber-saturation point. The danger of collapse is increased if high initial temperatures are used. Therefore lumber subject to collapse should be dried at low temperatures and relatively high humidities until all free moisture is removed.

CHECKING

As soon as the lumber has dried close to the fiber-saturation point, i.e., as soon as most of the free moisture has been removed, the danger of stain and collapse is eliminated, but checking, casehardening and honeycombing become a problem.

Checks are of two kinds: end and surface. Either type is caused by too rapid evaporation of moisture from the surface. Therefore, checking may be minimized, or altogether eliminated, by slowing down the rate of evaporation. The best way to accomplish this is to raise the relative humidity, if evidence of checking is discovered. Surface checking, if severe, may develop into honeycombing.

HONEYCOMBING

Honeycombing is a form of severe internal checking, which generally is not evident from the surface. It is closely associated with the development of casehardening and with formation of surface checking. This defect is particularly important when the stock is resawn or heavily dressed, because then the honeycombing becomes evident as wide surface checks. Honeycombing occurs most frequently in the species with large rays, such as oak and beech. Honeycombing may be minimized by the use of milder drying schedules, such as will not produce severe internal stresses and surface checking. Once it has occurred, honeycombing cannot be corrected.

WARPING

The cause of warping of lumber in kiln drying cannot always be attributed to the drying conditions. Much of the warping is a result of diagonal or cross grain caused by sawing, or arising from natural causes. Poor piling of lumber, poor alignment of the stickers, an insufficient number of stickers, or unsupported stickers, are the very common causes of bent and snaky boards. Cupping of wide, slash-grained boards is generally the result of one side of the board being more quarter-sawn than the other side. The two sides do not shrink the same amount, and the resulting stresses lead to cupping.

Warping, however, may sometimes be caused in straight-grained and well piled lumber by too rapid or uneven drying, especially when it is carried to a very low moisture content. The resulting stresses may frequently lead to twisting of the boards.

Warping can be minimized by paying greater attention to the proper piling of lumber, especially in regard to the stickers. Uniformity of drying conditions throughout the kiln and the use of a less severe drying schedule are other factors that help to reduce warping.

Some of the warp may be eliminated in the reconditioning. During high humidity treatment wood becomes plastic and the stresses are eliminated to a large extent. On the other hand, in some kinds of wood, for instance in red gum, any high humidity treatment (steaming) at the end of the run, may increase the extent of twisting and warping.

KNOTS

Checking and loosening of knots is more difficult to prevent than either end or surface checking. Knots check easily because they are in effect short blocks of wood with the end grain exposed. They dry, therefore, more rapidly than the surrounding wood, and since the grain in the knot is more or less at a right angle to that of the board, stresses are set up when the wood of the knot and that of the board begin to shrink. Checking and loosening of knots may be minimized by the use of milder drying schedules. However, since boards with large knots are of lower grades, such slow drying cannot always be justified, except when the low grades can be remanufactured into some higher form of finished product, for instance, paneling or flooring.

KILN RECORDS

Keeping adequate kiln records is part of a successful dry kiln operation. The drying data, i.e., a record of wet and dry bulbs, moisture content changes, condition of the lumber when dry and any special treatment given to it, form the foundation for development of better schedules and elimination of seasoning defects. Dry kiln records also provide a documentary reference in case any trouble develops during a run, or any question arises as to the condition of any particular lot of lumber.

There are many different forms for keeping dry kiln records. In fact, any experienced operator generally develops his own form, most suitable for conditions prevailing at the plant. In general, all dry kiln forms make provision for the following information: wet and dry bulb readings; current moisture content of the kiln sample boards; condition of lumber as shown by periodical tests and observations; record of conditioning and equalizing treatments; final moisture content as checked by actual tests on the lumber. A sample sheet of dry kiln records is shown in Fig. 25.

Some operators prefer to plot the drying data, i.e., keep records of the current moisture content against time, on graph paper.

A chart from the recorder-controller for any given run should also be appended to the permanent record.

TAKING CARE OF KILN DRIED LUMBER

It is not always sufficiently appreciated that wood absorbs or loses moisture, depending on its own dryness and the temperature and relative humidity of the surrounding air. Lumber, kiln dried to a low moisture content, tends to absorb moisture when exposed to outside conditions. It is useless, therefore, to dry lumber to 6 percent, for instance, and then leave it unprotected outside. It will then quickly absorb moisture until it comes to equilibrium with the outside air.

DRY KILN RECORD of ________________ Co

Kiln No. ______ Run No. ______ Contains ______ ft. of ____ /4 ______

Condition ______ Loaded on Kiln Trucks ______ from Yard Pile No. ______ Ry. Car ______

Shipper	Kind	Amount	Sample	1	2	3	4	5
			Species-Thick					
			Green Wt.					
			Oven Wt.					
			Loss-Water					
			% M.C.					
			Control Wt.					
			Cal. Dry Wt.					

Date	Days	Remarks:	Wet Bulb	Dry Bulb	Rel. Hum. %	Weight	% M.C.	Weight	% M.C.	Weight	% M.C.	Weight	% M.C.	Weight	% M.C.
	Start														
Final Cut Test 1/2" Disc.															
Average															
Core															
Shell															

(Record—Standard Dry Kiln Co.)

Fig. 25. A sample dry kiln record.

This may mean anywhere from 10 to 15 percent moisture content, depending on the section of the country and the season of the year.

Kiln-dried lumber should always be stored in an enclosed building, which can be heated through the cold and wet months of the season to at least 60° F. It is always beneficial to stack kiln-dried lumber solid, i.e., to bulk-pile it without stickers. This not only minimizes the changes in the moisture content, but helps to even up the inequalities in the moisture content that may exist among the different boards; it also keeps the lumber flat and relieves the stresses.

TABLE 5—*Recommendations for initial moisture content of lumber for dwellings (U. S. Forest Products Laboratory)*

Use of lumber	Moisture content (percent of weight of oven-dry wood)					
	Dry Southwestern States		Damp Southern Coastal States		Remainder of the United States	
	Average	Tolerance	Average	Tolerance	Average	Tolerance
Interior finish woodwork and flooring.	6	4–9	11	8–13	8	5–10
Sheathing, framing, siding and exterior trim . . .	9	7–12	12	9–14	12	9–14

REFERENCES

Henderson, H. L. The air seasoning and kiln drying of wood. Published by the author. N. Y. State College of Forestry, Syracuse, N. Y. 1947.

Koehler, Arthur and Rolf Thelen. The kiln drying of lumber. McGraw-Hill Book Co., New York. 1926.

Tiemann, H. D. Lessons in kiln drying. Pitman. New York. 1937.

U. S. Forest Products Laboratory. Numerous mimeographed reports dealing with various phases of kiln drying. Madison, Wisc.

APPENDIX

For the convenience of the users of this bulletin a list of dry kiln designers and the manufacturers of dry kiln equipment is included in this appendix. These lists were compiled by the U. S. Forest Products Laboratory. The inclusion of names in the lists implies no endorsement of any products or services by either the Forest Products Laboratory or Michigan State College.

APPENDIX TABLE 1—*A partial list of dry kiln manufacturers and dry kiln engineers in the United States*

The following numbered key has been employed in order to facilitate the tabulation of terms and services offered.

1. Natural circulation kiln.
2. Internal fan kiln.
3. External blower kiln.
4. Progressive kiln.
5. Compartment kiln.
6. Firms or engineers who stock or supply some or all kiln equipment.
7. Firms or engineers prepared to furnish complete kiln plant.
8. General engineering advice.
9. Detailed kiln drawings and specifications furnished.
10. Supervise construction.
11. Test kiln performance and instruct kiln operator.
12. Kiln accessories such as lumber lifts, power storage and transfer cars, lumber stackers and unstackers, doors, door carriers, etc.
13. Steam jet blower.

DRY KILN COMPANIES WHO STOCK OR SUPPLY KILN PARTS AND ACCESSORIES

Drying Systems, Inc. 1800 Foster Ave. Chicago 40, Ill.			3		5	6	7	8	9	10	11	
Imrie Dry Kiln Co. Grand Rapids, Mich.	1	2	3		5	6	7	8	9	10	11	12
Industrial Air Co. 20 Chestnut St. Needham, Mass.		2	3	4	5	6	7		9		11	
C. M. Lovsted & Co. 2212-16 First Ave., S. Seattle, Wash.	1	2	3	4	5	6	7	8	9	10	11	12
Moore Dry Kiln Co. Jacksonville, Fla.	1	2	3	4	5	6	7	8	9	10	11	12
Moore Dry Kiln Co. North Portland, Ore.	1	2	3	4	5	6	7	8	9	10	11	12
Perfection Dry Kiln, Inc. 121 W. Fourth St. Jamestown, N. Y.	1			4	5	6	7	8	9	10	11	12
Standard Dry Kiln Co. Harding & McCarty Sts. Indianapolis, Ind.	1	2	3	4	5	6	7	8	9	10	11	12

DRY KILN ENGINEERS

Herbert Fryer............ Carnation, Wash.	1	2	3	4	5			8	9	10	11		
Kiln Supply & Mfg. Co.... 5825 Oak Ave. Indianapolis 1, Ind.	1			4	5	6	7	8	9	10	11		
The National Engineering Co. P. O. Box 1475 Indianapolis 6, Ind.						6*		8	9			12	
Redman Engineering Service High Point, N. C.	1	2	3	4	5	6	7	8	9	10	11	12	
Robert W. Risser......... P. O. Box 91 Little Rock, Ark.	1	2		4	5	6	7	8	9	10	11		
Hiram L. Henderson...... Syracuse University Syracuse, N. Y.		2			5			8	9		11		13

*Parts stocked are largely repair parts for National Kilns.

APPENDIX TABLE 2—*A partial list of suppliers of temperature and humidity recorders and controllers and also dry kiln doors and door hardware*

TEMPERATURE AND HUMIDITY RECORDERS AND CONTROLLERS

	Recorders	*Controllers*
Barber-Colman Company Rockford, Ill.		x
The Bristol Company Waterbury 91, Conn. or The Bristol Company 221 E. Cullerton St. Chicago, Ill.	x	x
Brown Instrument Company Wayne and Roberts Avenues Philadelphia 44, Pa.	x	x
Foxboro Company Foxboro, Mass.	x	x
The Fulton Sylphon Co Knoxville, Tenn.		x
The Kiln Supply & Mfg. Co 5825 Oak Avenue Indianapolis 1, Ind.		x
Manning, Maxwell & Moore, Inc Bridgeport 21, Conn.	x	x
Minneapolis-Honeywell Regulator Co 2753–4th Ave., So. Minneapolis 8, Minn.		x
Moore Dry Kiln Co Jacksonville 1, Fla., and North Portland, Oregon.	x	x
Powers Regulator Company 2720 Greenview Avenue Chicago 14, Ill.	x	x
Sarco Co., Inc 475 Fifth Avenue New York 17, New York		x
C. J. Tagliabue Division, Portable Products Corporation Park & Nostrand Avenues Brooklyn 5, N. Y.	x	x
Taylor Instrument Companies Rochester 1, N. Y.	x	x

Recorder and control apparatus can also be secured through most of the kiln manufacturers and kiln engineers.

DRY KILN DOORS AND DOOR HARDWARE

The Dry Kiln Door Carrier Co., 1117 Cornell Ave., Indianapolis, Ind., make a specialty of manufacturing dry kiln doors and door hardware. Such equipment can be obtained also from most of the dry kiln manufacturers and dry kiln engineers.

APPENDIX TABLE 3—*Makers and dealers of electrical moisture meters*

Makers and dealers	*Trade name*	*Type*
L. R. Bradley & Co. 25 W. 45th St. New York, N. Y.	Bradley Electronic Moisture Meter*	Resistance
Colloid Equipment Co., Inc. 50 Church St. New York, N. Y.	Delmhorst Moisture Detector	Resistance
Delmhorst Instrument Co. 117 Cornelia St. Boonton, N. J.	Delmhorst Moisture Detector	Resistance
Hart Moisture Gauges, Inc. 126 Liberty St. New York 6, N. Y.	Hart Moisture Gauge and Kaydel Moisture Meter	Resistance
Hart-Moisture-Meters 1948 Grand Central Terminal Bldg. New York 17, N. Y.	Hart Moisture Meter	Resistance
Industrial Instruments, Inc. 156 Culver Ave. Jersey City, N. J.	Megohm Bridge	Resistance
C. M. Lovsted & Co. Seattle, Wash.	Tag-Heppenstall and Moisture Register	Resistance Radio-frequency power-loss
Measurements Corporation Boonton, N. J.	Delmhorst Moisture Detector	Resistance
Moisture Register Co. 133 N. Garfield Ave. Alhambra, Calif.	Moisture Register	Radio-frequency power-loss
Moore Dry Kiln Co. Jacksonville 1, Fla. also North Portland, Ore.	Tag-Heppenstall Moisture Meter and Moisture Register	Resistance Radio-frequency power-loss
National Engineering Co. P. O. Box 1475 Indianapolis 6, Ind.	Tag-Heppenstall Moisture Meter and Moisture Register	Resistance Radio-frequency power-loss
Standard Dry Kiln Co. Indianapolis 6, Ind.	Moisture Register Tag-Heppenstall Moisture Meter	Radio-frequency power-loss Resistance

*This meter was designed especially for determining the moisture content of wood and plaster prior to painting.

APPENDIX TABLE 3—*Makers and dealers of electrical moisture meters (Cont'd)*

Makers and dealers	*Trade name*	*Type*
C. J. Tagliabue Mfg. Co. Park & Nostrand Avenues Brooklyn, N. Y.	Tag-Heppenstall Moisture Meter	Resistance
George E. Zwelfel 1123 N.W. Gilson St. Portland, Ore.	Moisture Register	Radio-frequency power-loss
Thwing-Albert Instrument Co. Penn St. & Pulaski Ave. Philadelphia 44, Pa.	Thwing-Albert Electronic % Meter	Resistance

APPENDIX TABLE 4—*A partial list of dry kiln paint distributors*

Black Cat Corporation, Hattiesburg, Mississippi
Carbozite Corporation, Pittsburgh, Pennsylvania
Tropical Paint and Oil Company, Cleveland, Ohio
Moore Dry Kiln Company, Jacksonville, Florida
Standard Dry Kiln Company, Indianapolis, Indiana
Ohmlac Paint and Refining Company, Chicago, Illinois

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