UNITED STATES DEPARTMENT OF AGRICULTURE

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KILN DRYING HANDBOOK

By

ROLF THELEN, In Charge, Section of Timber Physics, Forest Products Laboratory, Forest Service

CONTENTS

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CONTENTS.

PURPOSE.

The principal purpose of this bulletin is to present to the dry-kiln operator, in condensed and convenient form, the fundamental facts about the drying of wood which he must know in order to get the most satisfactory results with his kiln. The major portion of the bulletin deals with the kiln drying of lumber, but there are also included specific suggestions concerning the drying of other forms of wood. The general information is applicable to all kinds of drying.

No attempt has been made to present detailed data in substantiation of the information given. The conclusions are for the most part based on extensive investigations and experiments by the Forest Products Laboratory of the Forest Service, Department of Agriculture, Madison, Wis., tested out in commercial practice.

MOISTURE IN WOOD.

The purpose of drying or seasoning wood is to remove a certain amount of the moisture which is naturally present in it, and which if allowed to remain would interfere with its use for most construction purposes. The exact amount of moisture to be removed de-

Note.—Acknowledgement is made by the author to the members of the Section of Timber Physics, both past and present, who are largely responsible for the development of the practical technique of kiln drying described in this bulletin.

pends upon the quantity present and the purpose for which the wood is to be used. Rarely, except for test pieces, is it necessary or desirable to remove all the moisture, producing an oven-dry or bone-dry condition.

Moisture in wood is commonly called sap. There is no universally accepted definition of this word "sap," and its use causes much confusion. The moisture, or sap, in both sapwood and heartwood consists almost entirely of water. It does contain, however, small percentages of organic and mineral matter. In the sapwood these substances are principally sugars of various kinds, and in the heartwood they include tannins, coloring matter, and various other chemicals. For the purposes of this bulletin, sap will be considered to be water only.

Water occurs in wood in two distinct forms, spoken of as "free" water and "imbibed" water. The free water exists in the cell cavities and the imbibed water in the cell walls. Imagine each cell of the wood to be a small bucket of some porous or absorbent material. If this bucket is filled with water, a certain amount will be absorbed by the sides and bottom, in addition to the "pailful" inside the bucket. This pailful is free water, that absorbed by the walls is imbibed water, and the sum of the two represents all the water the bucket, or the cell, can hold. A portion or all of the free water can be removed from the cell without changing the amount of imbibed water in the walls; but when the bucket is empty further drying removes water from the walls themselves and they begin to dry out. This point at which the bucket becomes empty is called the "fiber-saturation point." It has a very important bearing upon the process of drying and will be discussed more fully later.

In most living trees there is some free water in both heartwood and sapwood. The amount varies considerably depending on a number of factors. Thus, sapwood almost always contains more moisture than heartwood. The butt may contain much more than the top, as is evidenced by the sinker stock of redwood and sugar pine. The season of year in which the trees are felled may have some influence upon the moisture in the sapwood, but this influence is not very important. There are a number of instances on record in which there was more moisture present in the sapwood in winter than in summer. The common conception is that the reverse is true.

Species and locality of growth have an important bearing upon the amount of moisture in the living tree. Species growing in swampy regions are apt to contain much more moisture and to be harder to dry than similar upland species. The oaks are an excellent illustration of this fact. On the other hand, certain species contain comparatively large amounts of water, even though growing under reasonably dry conditions. All of these variations must be taken into consideration in the drafting of drying schedules and in the actual drying operation.

MOISTURE DETERMINATION.

To dry stock successfully and to know when it has reached the proper dryness, it is essential that the operator be able to determine the amount of moisture in wood at any time. There are several methods by which the moisture content of wood may be determined, but the following is the one commonly used for moisture determinations on lumber.

Crosscut the board or stock at least 2 feet from one end, to avoid the effect of end drying, and then again about three-fourths inch from the first cut, thus securing a section as wide and thick as the original board and three-fourths inch long with the grain. Remove all loose splinters from the section and weigh it immediately on a sensitive scale. Record the weight, called "original weight." Place the section in a drying oven kept at a temperature of about 212° F., leaving it there until it no longer loses weight. This requires from 12 to 24 hours, sometimes longer. Leaving the sections in the oven longer than the required time produces an appreciable error in the result. Remove the section from the oven and again weigh it. This will be the "oven-dry" weight, the actual weight of the wood. The difference between the original and oven-dry weights is the weight of water originally in the section, and the moisture percentage is readily calculated.

Divide the difference between the two weights by the oven-dry weight, and to reduce to per cent multiply by 100. The formula is:

$$\frac{\text{Original weight}-\text{oven-dry weight}}{\text{oven-dry weight}}\times 100=\text{moisture content in per cent.}$$

Thus, if the green weight is 180 and the oven-dry weight 150, a difference of 30, the moisture percentage will be $\frac{30}{150}\times 100=20$ per cent. The moisture content so determined is based on the oven-dry weight of the wood. It is, however, possible to base it upon the original weight. This system is occasionally used for moisture determinations by those who are accustomed to use it for other purposes. Its use is not recommended for wood sections, but it is occasionally necessary to convert moistures from one system to the other. The calculating and conversion formulas are given.

$$\text{Moisture content based on original weight, in per cent}=\frac{\text{original weight}-\text{oven-dry weight}}{\text{original weight}}\times 100.$$

In this system the original weight equals 100 per cent, whereas in the other the oven-dry weight equals 100 per cent.

To convert moistures from one system to the other, use the following formula:

$$\text{Moisture based on oven-dry weight}=\frac{\text{moisture based on original weight}}{1-\text{moisture based on original weight}}.$$

BALANCES.

Any system of weights may be used, but the metric system is more convenient than the others and is preferred for this reason. The unit of this system is the gram, and weights are expressed as grams and decimal fractions thereof.

The choice of balance is a matter of personal preference and of first cost. For general use the balance should have a capacity of 1 kilogram (1,000 grams) and be sensitive to 0.1 gram. These requirements are met by the ordinary analytical type of balance in which the two pans are suspended from an overhead beam. Other types are the Harvard trip, which has the beam located under the pans and is provided with a scale beam and rider sensitive to 0.1 gram, and with a 10-gram capacity; the torsion balance, with beams below the pans; and the multiple-beam balance, with only one pan suspended from the beam, which is provided with sliding weights.

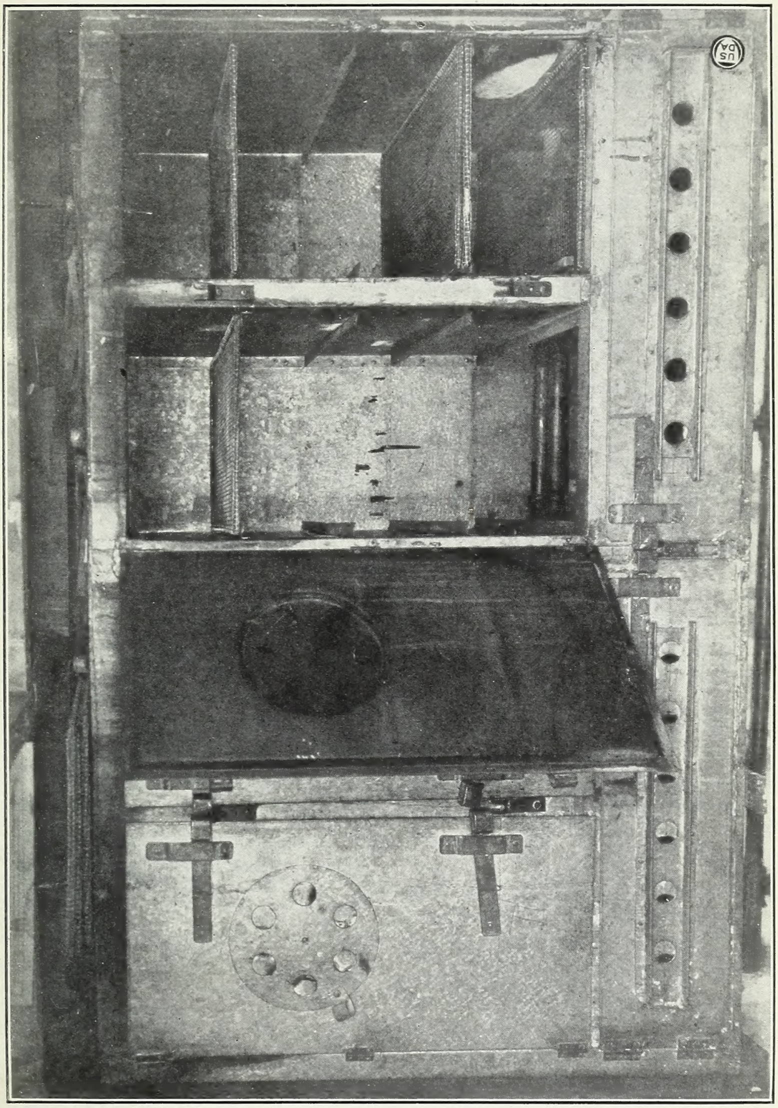
DRYING OVENS.

Several makes of drying ovens can be bought. All of these are electrically heated and provided with thermostatic control, which keeps the temperature accurately at the desired point. Steam-heated ovens are convenient and free from trouble and will be found excellent where high-pressure steam is continuously available. Ovens of this kind are usually homemade. The walls and doors can be of galvanized iron, made hollow with a $1\frac{1}{2}$-inch space filled with mineral wool, and the heating element can be conveniently made of 1-inch or $1\frac{1}{4}$-inch pipe. Ventilators should be fitted to the top, and provision made under the steam pipes for the entrance of fresh air. The temperature is usually regulated by means of a reducing valve on the steam line and dampers on the ventilators. For each cubic foot of volume above the heating coils in the oven there should be at least $1\frac{1}{2}$ square feet of heating surface and six square inches of ventilator area. Shelves should be provided for the moisture sections. Plate I illustrates one of the steam drying ovens used by the Forest Products Laboratory.

There are available various kinds of hot plates used in place of ovens for drying out moisture sections. It is customary to use very thin sections with these hot plates and to leave them on only a short time—15 to 45 minutes. These hot plates fill a need in that they are cheap and used by those who do not care to buy a regular oven, and in the hands of a skillful operator can be made to yield good results. They can not be recommended except as makeshifts.

It is very helpful, except in the simplest kinds of drying, to know how the moisture is distributed throughout the cross section of the board or stick, and for this purpose "moisture distributions" are made. The moisture section is cut in the usual manner, but instead of weighing it as a whole, it is cut or split so as to separate the core or center from the shell or outside, and separate moisture determinations are made on the core and shell. The latter will usually be in two or four pieces, which can be most conveniently weighed as a single unit. For thick stock it may be desirable to divide the sections into three units, a shell, an intermediate zone, and the core. The procedure is precisely the same as before, the pieces of the intermediate zone being weighed as a unit just as are those of the shell. To secure satisfactory results, these "moisture distributions" must be made accurately, and an analytical or torsion balance sensitive to 0.01 gram should be used. The capacity of this balance need not be over 100 grams. A larger balance should also be available for the heavier work of weighing regular moisture sections.

Figure 1 illustrates the method of cutting the moisture and distribution sections. While it is the usual practice to cut a full section and a distribution section whenever a distribution test is to be made, it is not absolutely necessary, since the average moisture content may



STEAM OVEN USED AT THE FOREST PRODUCTS LABORATORY FOR DRYING MOISTURE SECTIONS. THE THERMOMETER, SHELVES, AND A PORTION OF THE HEATING COILS CAN BE SEEN IN THE OPEN SECTIONS.

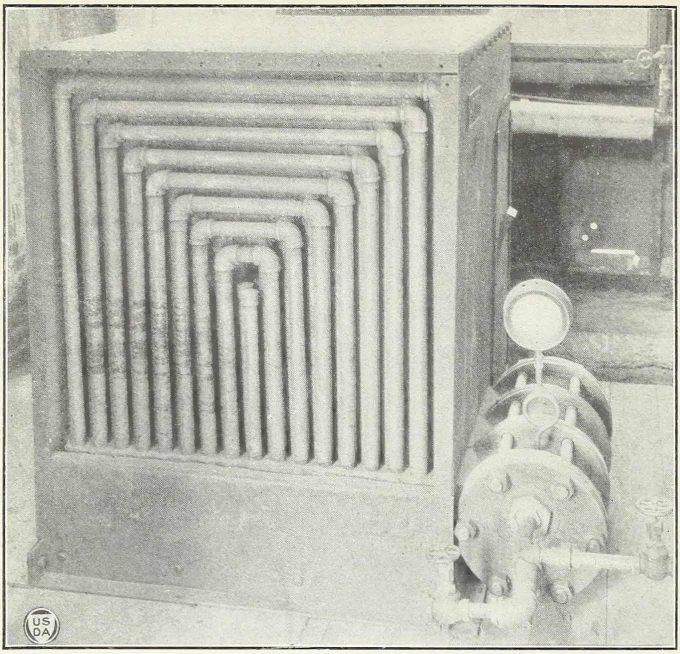


FIG. 1.—HEATER UNIT FOR EXTERNAL BLOWER.

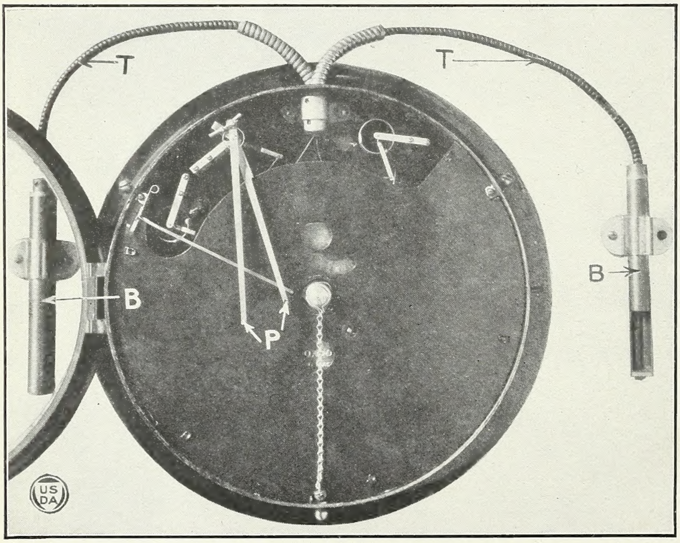


FIG. 2.—TWO-PEN EXTENSION TUBE RECORDING THERMOMETER SECTIONED AND WITH CHART REMOVED.

The bulbs *B* are connected to the instrument through the armored tubing *T* entering at the top of the case. The pens *P* and pen arms are slightly to the left of the center.

be secured with reasonable accuracy from the distribution section alone by assuming the original weights of all the pieces to be the original weight of the section, and similarly with the dry weight. The entire calculation will be as follows:

Shell.	*Core.*	*Section.*
Original weight =60	Original weight =100	Original weight =160
Oven-dry weight=50	Oven-dry weight= 80	Oven-dry weight=130
Moisture=$\frac{10\times100}{50}$	Moisture=$\frac{20\times100}{80}$	Moisture=$\frac{30\times100}{130}$
=20 per cent	=25 per cent	=23.1 per cent

GENERAL PRINCIPLES OF DRYING WOOD.

The drying of wood is a very complex process, concerning many phases of which we are still uninformed. However, it is not essential that the operator understand all of the details of the movement of

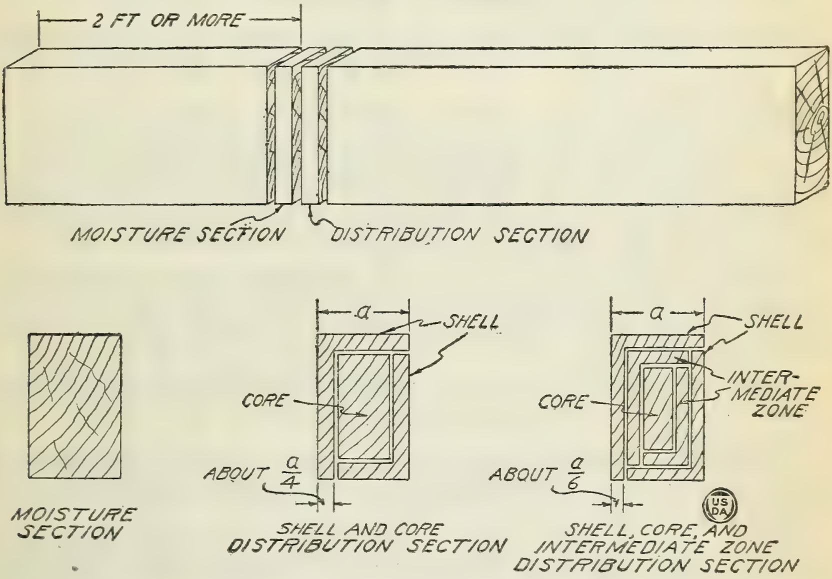


FIG. 1.—Method of cutting sections from board or plank for making moisture distribution determinations.

the moisture through the wood, and all of the attendant phenomena. Let him take it for granted, for the time being, that the moisture tends to distribute itself evenly through the wood, moving from the more moist regions to the drier ones.

This movement of moisture within the wood is affected by three controllable external factors—heat, humidity, and circulation. A constant application of these factors in proper proportion is essential to the successful drying of lumber to the moisture content required for a specific use. The regulation of the heat, humidity, and circulation is, in fact, the main problem in the successful operation of kilns.

HEAT IN THE KILN.

Heat is used in a kiln to produce rapid evaporation and to hasten the transfusion of moisture from the interior to the surface of the wood. The correct temperature to use is determined by the character of the wood and varies widely with different kinds of stock. Commercial kiln temperatures range from 100° to 250° F.

The use of temperatures above that of the surrounding atmosphere introduces a problem in the heating of buildings, and imposes an added burden upon the heating system, namely, to keep the kiln building hot and to replace the heat lost through the walls of the kiln. The higher the kiln temperature, the greater will be these heat losses. The amount of heat actually used in the evaporation of the moisture is only a small part of the total heat supplied; it is seldom over 40 per cent and frequently as low as 5 per cent, depending upon the kind of drying being done.

SOURCES OF HEAT.

Many methods have been used to heat kilns, and although most of them are obsolete or impractical, brief mention will be made of the principal ones.

Direct furnace heat.—Smoke and other products of combustion are led direct from an ordinary furnace into the kiln, from which they are exhausted by chimney or other suitable means. Kilns of this type are known as "smoke kilns." At one time it was thought that lumber dried in them was superior to steam-dried stock, but their use has been largely abandoned.

Indirect furnace heat.—As in an ordinary hot-air furnace, the air passes around the fire pot and radiators on its way to the kiln, and the products of combustion pass directly up the chimney instead of through the kiln.

Gas.—Occasionally natural or artificial gas is used to heat small dry kilns, the burners being arranged much as in an ordinary household gas oven.

Electricity.—Electric heat can be used in small kilns, although the cost of current is prohibitive, except possibly for experimental units.

Hot water.—Hot-water heat can readily be adapted to the heating of kilns which do not demand too high a temperature. A suitable hot-water supply would rarely be available, however, in the absence of steam.

Steam.—At present steam is almost universally used for heating dry kilns of all types, and a knowledge of its use is essential to intelligent kiln operation. It may be either high pressure, above 10 pounds per square inch, or low pressure, below 10 pounds. High-pressure steam is almost invariably live steam—that is, steam direct from the boilers; low-pressure steam is frequently exhaust steam, or that which has passed through engine, pump, or turbine on its way from the boilers to the kilns. High-pressure steam is much drier, as a rule, than low-pressure steam, principally because exhaust steam generally carries with it much water condensed in its passage through the engine or other unit in which it has done work. As the steam circulates through the kiln radiators the kiln air is heated and the contained lumber is dried accordingly.

PIPE COILS AND RADIATORS.

The form, construction, and arrangement of the kiln radiators is of importance. Those constructed of pipe coils are in most common use. Pipe coils are made of ordinary merchant pipe, extra heavy pipe of various kinds, and wrought-iron pipe, the last being particularly suitable for severe drying schedules. Among the advantages of pipe-coil radiators are low first cost, ease of manufacture and installation, ready adaptability to a great range of shapes and sizes, and ease of repair by the shop mechanic or millwright. There are several essentials which a good pipe coil must possess: First, it must be of such size and shape and so located that it can properly heat the air in the kiln; second, it must be mechanically strong and durable and provided with means for permitting the expansion and contraction of the individual pipes in the coil; third, it must provide for the ready escape of air and water of condensation from the entire system; fourth, it must provide for adjustment in the amount of heating surface to be used by cutting certain pipes in or out. As it is difficult to combine all these essentials in the highest degree in any one type of coil, different ones have been found best adapted for various special conditions.

A large portion of all pipe coils used for dry-kiln heating are located in the kiln proper, between or under the rails. These fall into two general classes, known as header and return-bend coils. In the former, a number of pipes spring from the same supply pipe or header and return to a similar drip pipe or header, usually but not always, located at the other end of the kiln. In the return-bend type, however, the pipes of each group are connected end to end by means of return bends or double-elbow fittings; steam enters at the front of the first or top pipe, and condensation is removed from the end of the last or bottom pipe. Figure 2 illustrates various types of header and return-bend coils.

PLAIN HEADER COIL.

The action of the two types of coils is quite different, especially when operated with a thermostat. When steam is turned on in a plain header coil with a header at each end of the kiln that end of the kiln nearest the supply header will heat up first; the other end will not heat until the front end has become hot and all the air has been exhausted from the coil. This uneven heating takes place each time the thermostat opens. If the heating surface is unduly large, as it may be when low temperatures are used, the thermostat will operate often, and there will be a marked difference in temperature between the two ends of the kiln. Another characteristic of the header system is that the large heating surface of the headers themselves causes an uneven distribution of heat by causing a "hot spot" at each header.

RETURN-BEND COIL.

In the return-bend type the top pipes in each group become hot first, since the steam must pass through them before reaching the lower ones. Each pipe runs the full length of the kiln, and heating will be practically uniform from end to end. The return-bend type also has disadvantages, among which are the first cost and the amount

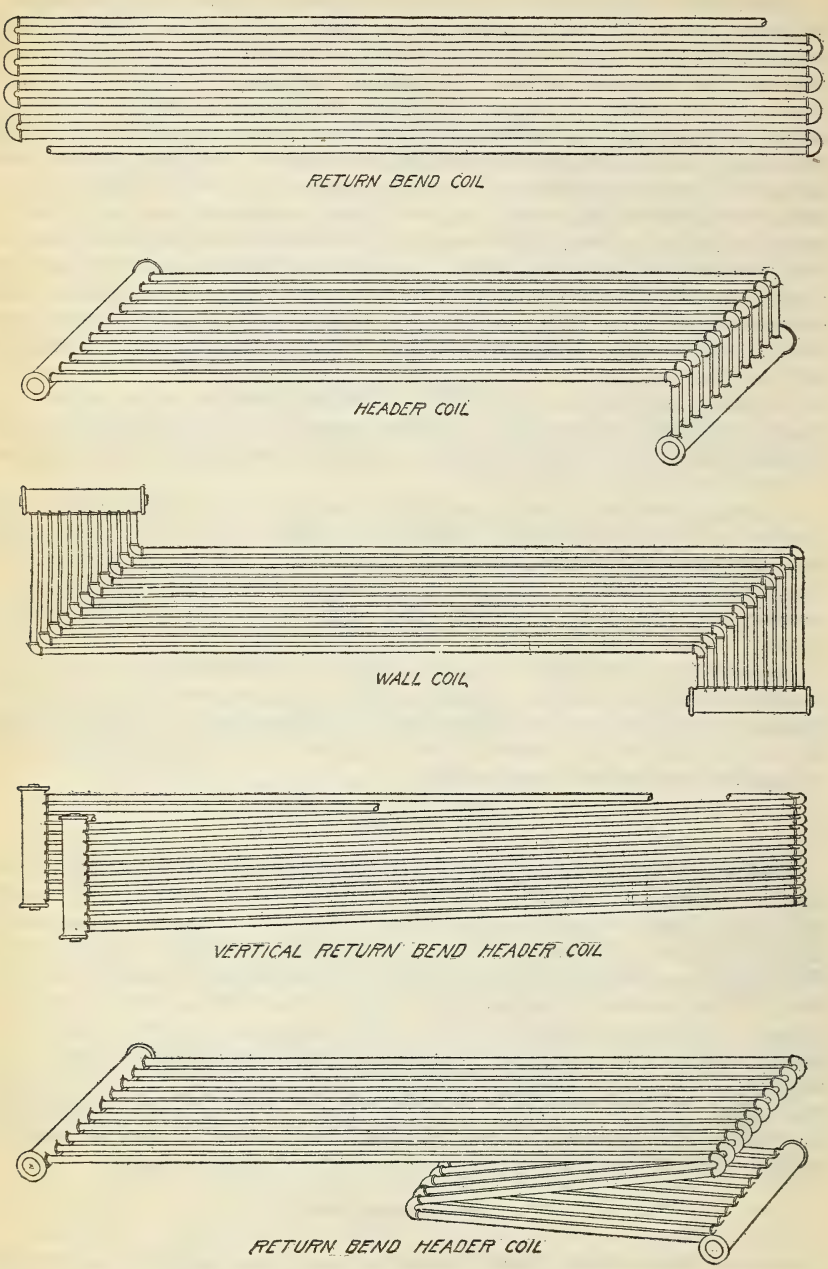


FIG. 2.—Pipe coils used for heating dry kilns. These are designed to provide for the expansion and contraction of the individual pipes and for the free flow of the condensed steam to the drain end. The wall coil may also be used as a horizontal coil, called "Z" coil.

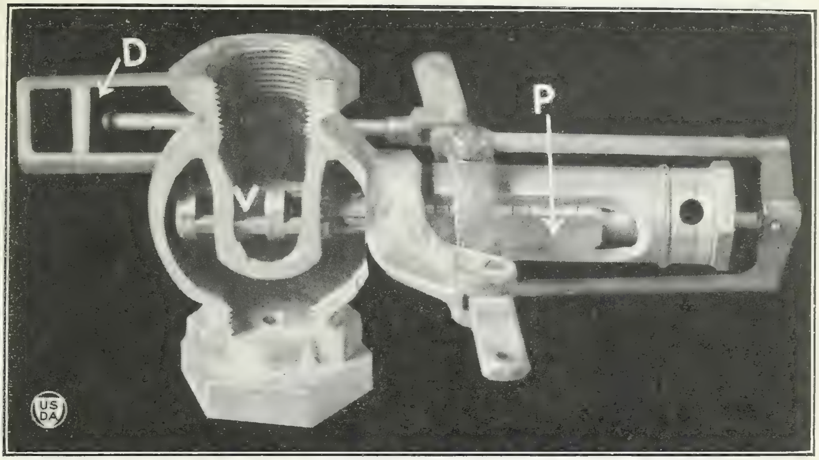


FIG. 1.—A PISTON TYPE OF BALANCED REDUCING VALVE ESPECIALLY ADAPTED TO SERVICE IN WHICH THE FLOW OF STEAM IS CONTINUOUS.

The low-pressure steam acts on the piston *P* in the cylinder and tends to close the valve *V*. Loose weights hung on the horizontal lever counteract this tendency. The dashpot *D* steadies the motion of the piston and valve, preventing bouncing.

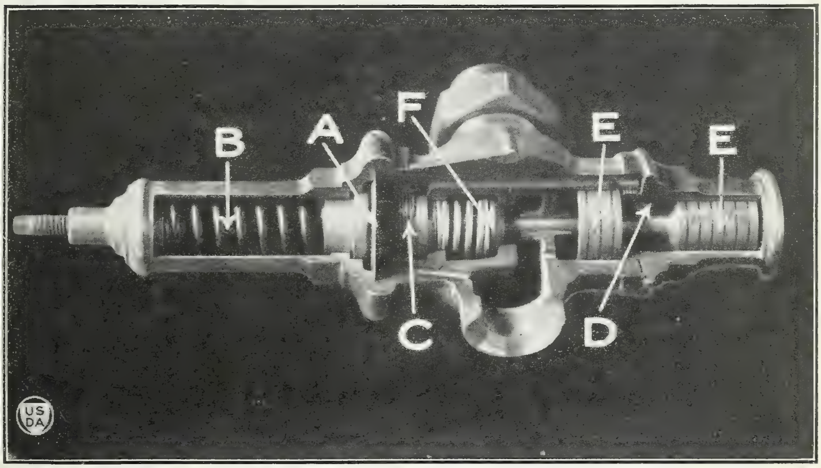
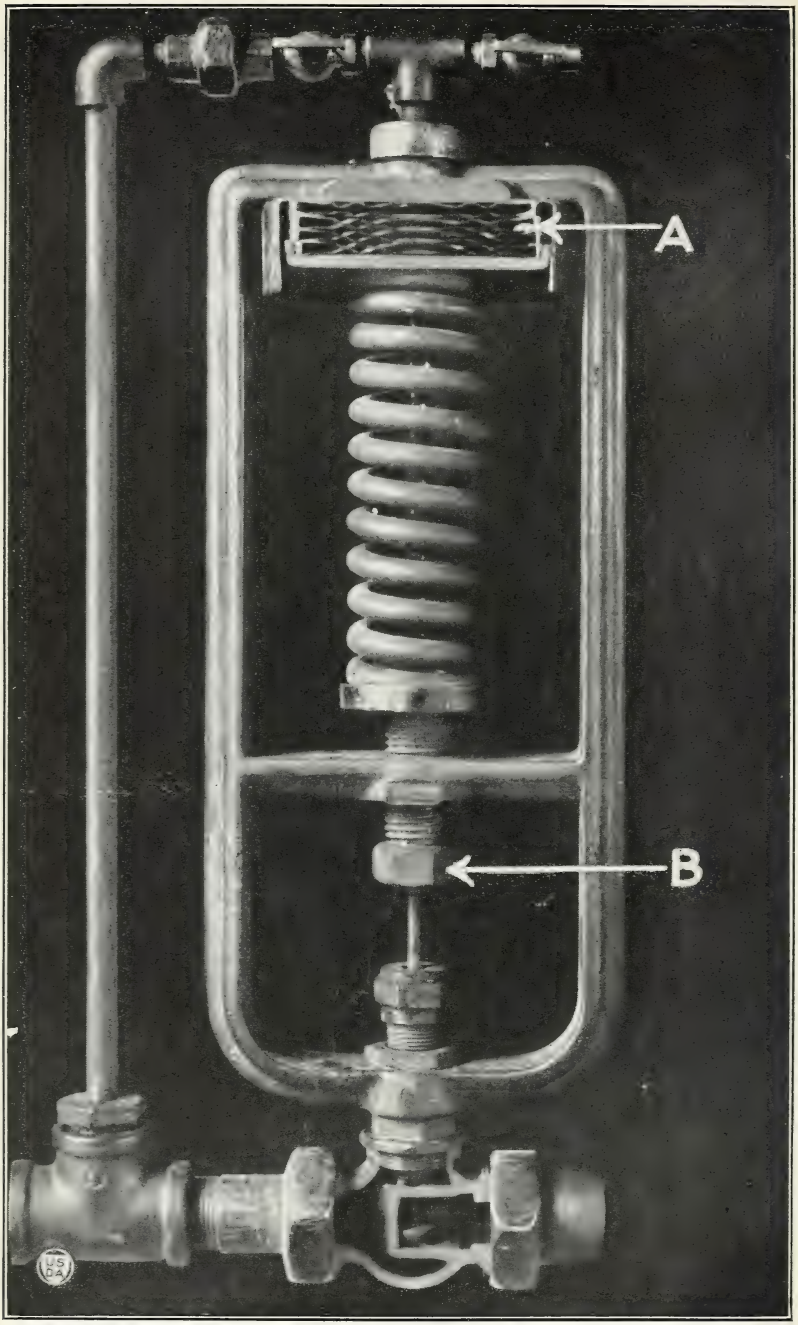


FIG. 2.—A REDUCING VALVE USED FOR A WIDE RANGE OF PRESSURES.

The reduced pressure operates the diaphragm *A* under the main adjusting spring *B*, thus opening and closing a small pilot valve *C* concealed in the plug under the diaphragm. The pilot valve controls the admission of high-pressure steam to the space *D* between the two pistons *E* in the bottom of the body; this steam forces the pistons *E* up and so opens the main valve *F*. When the pilot valve closes, the high-pressure steam on the main valve *F*, the low-pressure steam on the larger piston, and the valve spring all act to close the main valve.



A REDUCING VALVE WITH A METAL BELLOWS (A) AND AN ADJUSTING SPRING IN PLACE OF RUBBER DIAPHRAGM AND WEIGHTS. THE LOW-PRESSURE STEAM ENTERS THE BELLOWS AT THE TOP. THE DESIRED PRESSURE IS SECURED BY TURNING THE ADJUSTING NUT (B).

of headroom which the vertical arrangement of the groups of pipe demands. This headroom must be sufficient not only for the pipes and the return bends, but also for at least 0.1 inch of the downward pitch per foot from the supply to the discharge end of each group. This pitch causes adjacent pipes to form a V with each other, and the headroom required for the pipes increases rapidly with the length of the kiln. For short kilns requiring accurate temperature control and even heat distribution the return-bend coil is specially adapted.

RETURN-BEND HEADER COIL.

Various modifications of the two types have been introduced, retaining the advantages of both and eliminating the disadvantages. Among these are the return-bend header coil, with horizontal headers and two or more layers of pipe connected with return bends; and the vertical header coil, with both headers at one end of the kiln and return bends or double elbows with a short run of pipe at the other end. These compromise types have merit and will operate advantageously under conditions to which they are adapted.

WALL COILS.

Several types of kiln use pipe-coil radiators on the side walls. These radiators do not need to differ materially from those located under the lumber, and the great amount of headroom available makes it a simple matter to get rid of the water of condensation from almost any type of coil. It also permits the use of return-bend coils in long kilns without the sacrifice of the pitch required for proper drainage.

Cast-iron radiators of various kinds have recently been introduced for use in dry kilns. They can be had in a wide range of sizes and shapes adapted to practically any space or heating requirement. This type of radiation is higher in first cost than some other types, but great durability is claimed for it on account of the resistance of cast iron to rust.

Blower kilns of several types have the heating units located outside of the kiln as shown in Plate II, Figure 1. These units are usually of the standard types used in blower systems for heating buildings. Practically all of these consist of compactly arranged groups of pipes or pipe coils made up into cast headers, which form the base of the heater. Sometimes special forms of cast-iron radiators are used. It is good practice to equip the heater with valves, so that various portions of it may be used as desired. Such heaters give little trouble, since their design permits unusually easy removal of air and water and the short pipes are free from difficulties caused by uneven expansion and contraction.

In addition to the heating equipment described, some kilns are equipped with ceiling coils. These usually consist of a few runs of pipe spaced a foot or more apart and hung a few inches below the ceiling. They are connected independently and are used most or all of the time. Their function is to replace the heat lost through the ceiling and so prevent the latter from acting as a condenser. During cold weather especially, and when high humidities are used, the ceiling is likely to accumulate a great deal of condensation, which drips down upon the lumber and prevents humidity control.

CONTROL OF KILN TEMPERATURE.

The proper measurement of the temperature in the kiln is essential to proper control and deserves much more time and attention than it usually receives. Temperature-measuring instruments or thermometers may be grouped in two classes, indicators and recorders. Indicating glass-stem thermometers for kiln work are almost invariably of the mercury-filled type, though sometimes alcohol-filled ones are used.

INDICATING THERMOMETERS.

There are many kinds of mercury thermometers available, and care must be used to select reliable instruments. The very cheap ones, with separate scales stamped on metal and attached to the case, are not accurate enough for kiln work and should be avoided. A number of better grades also have separate scales, but the highest-grade thermometers have the graduations etched on the glass stem. These can be obtained with or without a metal protecting case. Occasionally it is desirable to insert the thermometer through the kiln wall, with the bulb inside and the scale outside. Industrial-type thermometers are well adapted for this purpose. These have a brass extension tube surrounding the bulb and part of the stem, and a weatherproof brass casing with a glass face protecting the scale. The extension tubes can be made 3 feet or longer, and the stem fitted on at almost any desired angle. A right-angle stem is desirable where the extension tube projects horizontally into the kiln, because it permits the scale to be vertical and therefore most easily read.

An electrical-resistance thermometer has recently been developed for dry-kiln use. This thermometer has a special panel and connecting wires, so that the temperatures at a number of places can be read from the one instrument. The temperature is indicated by a pointer moving over a graduated dial.

RECORDING THERMOMETERS.

Recording thermometers used in kiln work are almost invariably of the extension-tube type provided with 1-day or 7-day charts. In recorders of this type the sensitive element or bulb is connected to the instrument by a capillary tube of suitable length. (See Pl. II, fig. 2.) This tube is usually protected by a flexible armor and ends in a spring capsule in the case. This capsule may be any one of several different types, all of which are flexibly constructed, so that changes in internal pressure produce a movement of the capsule which is usually transmitted through a series of levers to a pen arm, which moves across a slowly revolving chart and produces a graphic record of the temperature in the kiln. The chart is rotated by a clock movement which is wound whenever the chart is changed.

There are three types of recording thermometers, the difference being in the material used for filling the bulbs. These three types are commonly known as liquid-filled, gas-filled, and vapor-filled. The choice of type depends upon the accuracy desired and the conditions under which the thermometer is to be used.

In dry-kiln work the tube and the case of the thermometer are liable to be subjected to wide variations in temperature, which influence the accuracy of the instrument, especially in the case of the mercury-filled and gas-filled types. In these the record is influenced by the bulb temperature, the tube temperature, and the case temperature. Variations in any one of the three will change the reading of the instrument, except when compensation is made for variations in case temperature. The vapor-filled instrument is nearly free from this particular defect, since the bulb is partially filled with a volatile liquid, and the pressure of gas or vapor in the tube and the capsule is virtually the vapor pressure of the liquid in the bulb at the bulb temperature. If the bulb is large and filled with the proper amount of liquid, the thermometer is practically free from errors due to case and tube temperatures, and this type is recommended for dry-kiln work.

Charts recording temperature for one-week periods are satisfactory for most purposes. It is desirable to use charts at least 10 inches in diameter. The divisions on the charts of most vapor-filled instruments are not uniform, because the vapor pressure does not vary in direct proportion with the temperature. The divisions spread as the temperature rises. This drawback has been overcome by introducing a cam movement which compensates for the lack of uniformity and produces a uniform pen movement.

The temperature in the kiln is controlled by the use of auxiliary apparatus, such as valves and thermostats. The pipe leading from the steam main to the kiln is almost always provided with a simple globe or gate valve, by which the steam supply to the kiln may be turned on or shut off. This valve can also be used for hand control of the temperature in case no other means is available. The pressure in the steam main is usually higher than necessary to furnish the desired temperature in the kiln, and it then becomes desirable to place a reducing valve (Pls. III and IV) between the steam main and the kiln. With this the pressure may be reduced to almost any desired point; the variations in this reduced pressure are less than those in the high-pressure main. If the pressure reduction is very great, from 100 pounds down to 1 or 2 pounds per square inch, it may be necessary to install two reducing valves in tandem, the first one reducing to perhaps 10 pounds and the second making the final reduction. In an installation of this kind a steam receiver or a couple of lengths of pipe should be placed between the two reducers to provide a cushion, and thus prevent the first reducer from chattering. Reducing valves should always be so installed that they can be readily removed for repairs. Whenever a battery of kilns is run part time on exhaust steam and part time on live steam it is very desirable to have a reducer between the boilers and the exhaust-steam main to the kilns, so that the live steam may be supplied to this main at about the exhaust pressure. Steam-pressure gauges should invariably be provided so that the operator may always know just what pressure he has available.

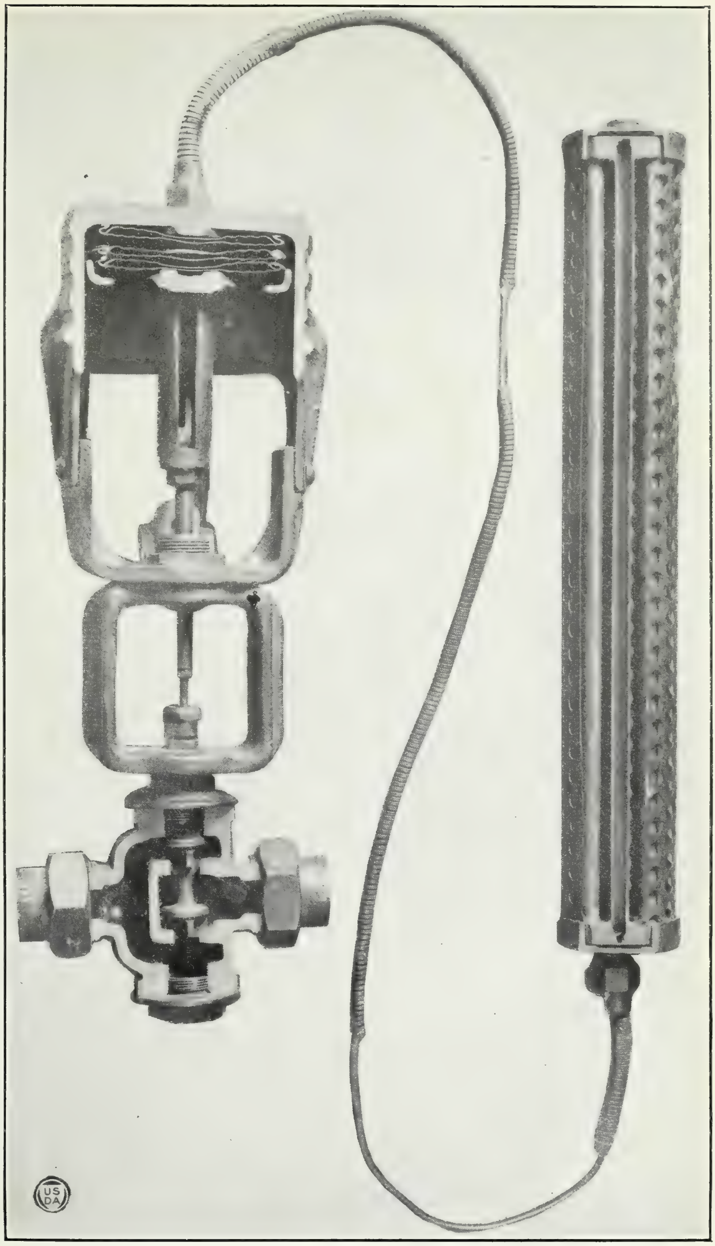
The intelligent manipulation of reducing valves assists materially in maintaining good temperature control. The pressure to the kilns may be so adjusted that it is barely sufficient to keep the desired temperature with the steam-control valve wide open. Excessive temperature rises may thus be prevented and the coils kept full of steam most of the time. Under hand control this arrangement is unusually sensitive, since a comparatively large change in the setting of the hand valve makes only a small change in the amount of steam supplied. If the kiln is provided with automatic control, the control valve will usually be located next to the kiln. The use of automatic control valves is recommended for practically all kinds of kiln drying, because a more even temperature may be maintained, injury from excessive temperatures avoided, and loss of time from unnecessarily low temperatures prevented.

AUTOMATIC TEMPERATURE CONTROLS.

There are two classes of automatic temperature control in common use in dry kilns. These are known as self-contained and auxiliary operated. The self-contained thermostats are operated by means of the direct pressure of vapor or liquid upon the valve stem. The action is very similar to that of the recording thermometers already described. A large bulb in the kiln is connected by means of a capillary tube to a diaphragm or capsule in the head of the valve located in the steam line. The temperature variations in the kiln change the pressure inside the bulb, which in turn causes corresponding pressure changes in the capsule. This results in the opening and closing of the valve, the stem of which bears upon the capsule. The valve itself is usually of balanced type to provide ease of movement. A counter force or pressure is provided by means of an adjustable spring or sliding weights, and the instrument is set for the desired temperature by changing the tension of the spring or the position of the weights. (See Pl. V.) The principal advantages of the self-contained thermostat are that no auxiliary source of power is required for its operation and that the first cost is comparatively small. This type is not so sensitive as the auxiliary operated type. The manufacturers claim regulation within 2° of the temperature for which the instrument is set, but in kiln operation the variation is often much greater than that. The auxiliary operated instruments are supposed to control with a variation of only 1° and in kiln operation usually maintain this accuracy.

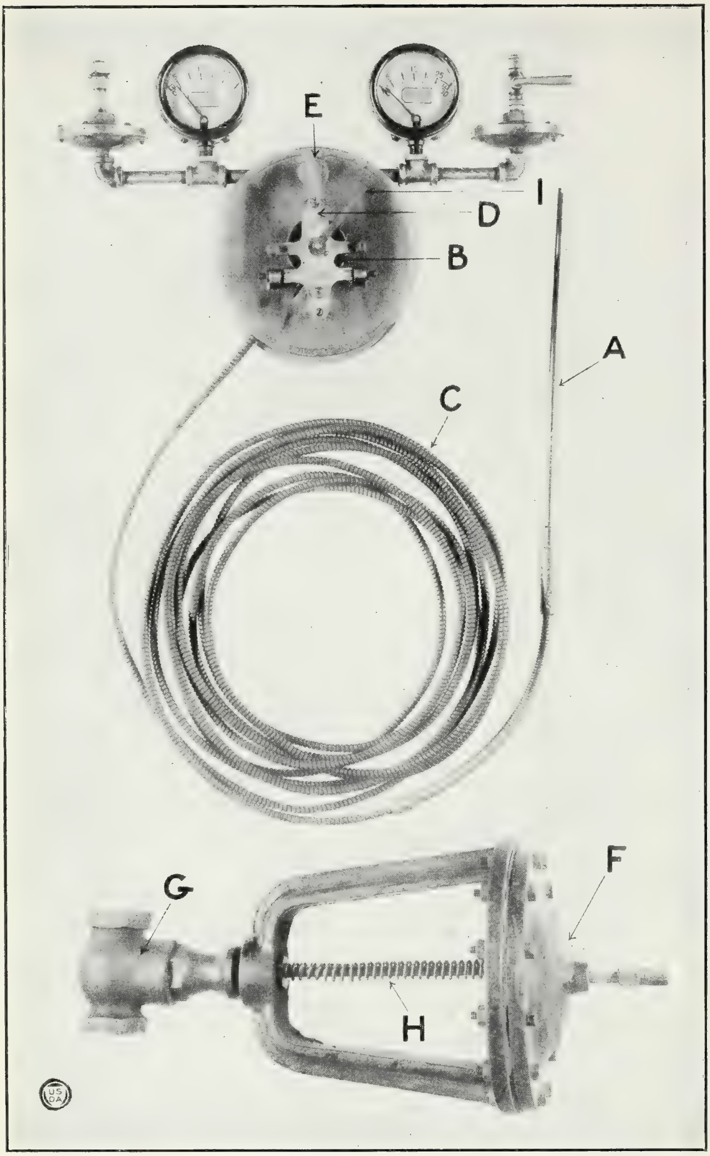
The auxiliary operated instruments using air as the operating medium are usually provided with a small bulb inserted in the kiln and connected to a capsule in the instrument by means of a capillary tube. (See Pl. VI.) The movement of the capsule top in response to temperature changes in the kiln is transmitted to a small valve connected on one side to a supply of air compressed to 15 pounds pressure and on the other side to a diaphragm-motor valve on the steam main. Sometimes a bimetallic system is used in place of the capsule to operate the air valve. This small air valve is so arranged, in instruments using direct-acting diaphragm valves, that as the temperature rises, air pressure is admitted to the head of the diaphragm-motor valve. This forces the diaphragm down, which closes the valve and shuts the steam off from the kiln. As the temperature falls, the air pressure is shut off, and a means of escape is provided for the air in the valve head. The valve then opens through spring action and admits steam to the kiln. Reverse-acting diaphragm valves are so constructed that the air pressure opens them and the springs close them. The air valve must be modified accordingly.

The advantage of the reverse-acting type is that a failure of the air supply causes the valves to shut, which prevents a dangerous rise in temperature. The same effect may be secured in a battery of



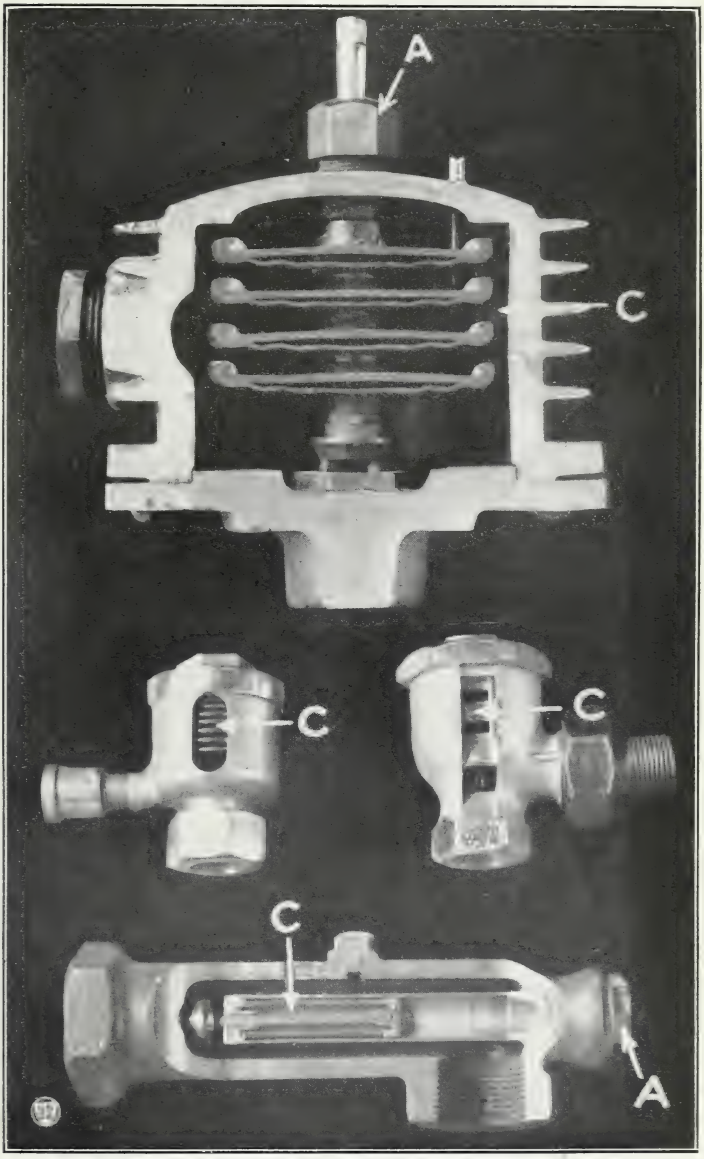
SELF-CONTAINED THERMOSTAT.

The large bulb at the right is connected through the armored tube to the bellows in the head of the valve. The lower part of the bellows is connected to the stem of the balanced steam valve, and the pressure in the bellows tends to close this valve. A weighted lever, not shown, acting through the slot below the bellows, opposes this pressure and keeps the valve open until the desired temperature is reached.



AIR-OPERATED THERMOSTAT AND DIAPHRAGM VALVE.

The bulb *A* is connected to the flexible capsule *B* through the armored capillary tube *C*. Changes in the temperature of the bulb cause changes in the pressure of the liquid or gas in the bulb. The capsule expands and contracts accordingly, and moves a pivoted lever *D*, which opens and closes a small air valve *E*. Air at about 15 pounds pressure enters the system from the left, passes to the head *F*, and closes the steam valve *G*, the stem of which is connected to the diaphragm in the head. When the air valve *E* closes, the air supply to the diaphragm is shut off, the pressure is relieved by leakage through the valve *E*, and the spring *H* opens the steam valve.



THERMOSTATIC AIR VALVES AND TRAPS.

In those illustrated the thermostatic element consists of a flexible capsule *C* and a volatile or nonvolatile liquid, the expansion of which shuts the valve. The capsules serve as springs to open the valves. The traps are provided with adjusting nuts *A* to compensate for variations in the steam pressure in the system.

direct-acting thermostats by putting a single reverse-acting valve in the steam main and connecting it direct to the air supply. Both types are equipped with dials indicating the proper temperature adjustment. Various combination instruments can be secured for different services. One type consists of a combination recording thermometer and reverse-acting air-operated thermostat. Other types are discussed below.

After the steam has passed through the various valves, it enters the steam coils proper. If the coils are in one unit, steam enters all. However, they may be divided into several groups, each group controlled by a gate or globe valve. In the latter case, enough groups should be turned on to produce a temperature only slightly in excess of that desired. Care must be exercised to select the different groups so that the kiln will be heated uniformly throughout.

When steam is first turned on, the coils are full of air and will not heat properly until the air has been removed. The use of air valves to remove the air depends upon the method employed in removing the water of condensation from the coils. An automatic thermostatic air valve should be provided near each trap unless it is of the thermostatic type, for which no air valve is needed.

Automatic air valves operate thermostatically. They remain open until a definite temperature is reached and then automatically close through the action of some element, such as a metal bar or a liquid-filled capsule, which expands with the heat. (See Pl. VII.) This action permits the cold air to be blown out of the coils and prevents the passage of the hot steam. Other things being equal, air valves should be placed near the bottom of the coil, since the air is heavier than the steam and consequently settles to the bottom. They should be mounted on fittings projecting from the top of the drip pipe, so that they will not become water bound.

THERMOSTATIC STEAM TRAPS.

Steam imparts its heat mainly through condensation. This condensed steam must be continuously removed from the heating coils, or they fill with water and become cold. Various devices are used to remove water from steam coils and several patented systems are in use. In most dry kilns steam traps which allow the escape of the water but trap the steam are used. They can be divided into two general classes, those depending upon temperature for their operation, and those depending upon the weight of the accumulated water. The first class is known as thermostatic. (See Pl. VII.) Most thermostatic traps have an operating bellows or diaphragm filled with some volatile liquid. One end of the bellows is attached to a valve stem and valve, and the motion of the bellows opens and closes the valve. The trap is connected to the lowest point in the heating system, so that the water will drain readily to it.

The coils are cold and full of air, and the trap is cold and open when steam is first turned on. The steam displaces the air which is driven out through the open trap. A certain amount of steam is condensed, and this hot water flows to and through the trap. Warmed by the water, the trap partly closes, owing to pressure from heat expansion inside the bellows, but remains partly open until all the air and water have been forced out and steam starts blowing through. The higher temperature of the steam causes a further expansion of the bellows and a complete shutting off of the trap. A screw adjustment is necessary so that the trap may be set for various steam temperatures, since the temperature of saturated steam increases with the pressure. After the trap has closed, condensed steam accumulates back of it, until the trap cools enough to allow it to open and blow out. It is desirable to locate the thermostatic traps and air valves in the operating room where they will be under better supervision and will be more sensitive, since they will cool more quickly than if they were located in the hot kiln.

Properly installed thermostatic traps are very useful in dry-kiln work, especially on coils built in groups. One installed on each group prevents trouble which arises when all the groups are operated by one trap. They also operate on coils which are controlled by auxiliary operated thermostats, allowing the coils to heat uniformly and thoroughly in a minimum time.

Several types of traps used on dry kilns are operated by the weight of the water of condensation. Among these are tilt, float, and bucket traps. The water of condensation flows into a receptacle within the trap and by its weight or buoyancy opens a valve that allows the water to be blown out, after which the valve returns to its closed position. Such traps do not, as a rule, provide for the escape of air from the coils, and for this reason automatic air valves or hand-operated pet cocks are fitted to them.

VACUUM PUMPS.

Kilns are sometimes equipped with a vacuum pump for the rapid removal of air and water from the coils. One is sufficient for a battery of kilns, each heating coil being connected through a thermostatic trap to the pump suction main. Dependence must be placed on the traps, since the pump will not work properly without them. Although the pump is very effective in removing air and water, especially on low-pressure systems, the rapid relief obtained by it is not needed in most kilns.

HUMIDITY IN THE KILN.

ABSOLUTE HUMIDITY.

Humidity or water vapor in the air is the most puzzling factor with which the average kiln operator must contend. The amount of water vapor in the atmosphere may be expressed in terms of the weight of water vapor for every unit volume of atmosphere. The unit of weight used is the grain and the unit of volume the cubic foot. The absolute humidity is the number of grains water vapor per cubic foot. This alone is no indication of the drying capacity of the air, since its capacity to hold water varies greatly with the temperature.

RELATIVE HUMIDITY.

Air containing the total number of grains of water vapor it can hold at a given temperature is saturated. The ability of air to dry any substance varies with the amount of additional moisture it can hold before becoming saturated. The amount of vapor in the air expressed in percentage of the amount held at saturation is called relative humidity, and is what is meant when the term "humidity" is used in this bulletin. The lower relative humidities represent dry air and the higher ones moist air. Air at a temperature of 125° F. can hold a maximum of 40 grains of water vapor per cubic foot. If an atmosphere at that temperature had only 10 grains of water per cubic foot it would have only ten-fortieths of the maximum amount of water vapor it could hold, or a relative humidity of 25 per cent. Air with 25 per cent relative humidity is comparatively dry. The relative humidity of air having 30 grains would be thirty-fortieths, or 75 per cent, and would be considered moist. Air at 155° F. can hold 80 grains per cubic foot, or twice as much water vapor as at 125°. At 155° air containing 10 grains of water per cubic foot would

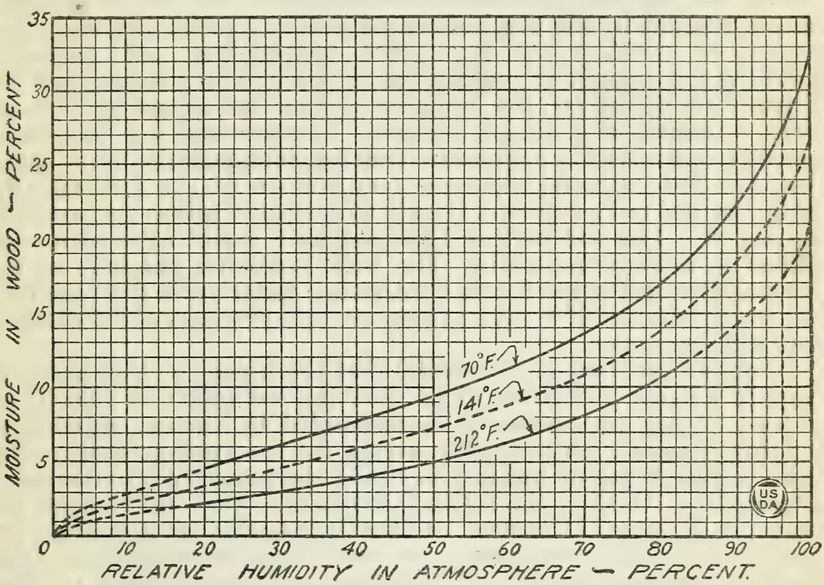


FIG. 3.—Relation between the moisture in wood and the relative humidity in the surrounding atmosphere at three temperatures. Solid lines are based on actual data.

be very dry, having a relative humidity of only 12½ per cent, and air containing 30 grains per cubic foot would still be moderately dry, having a relative humidity of 37½ per cent.

The amount of moisture in the air determines not only the rate but also the extent to which materials will dry. There is a definite balance between the humidity in the air and the moisture content of wood. All kinds of wood, if held long enough in an atmosphere of constant temperature and humidity, will come to the same moisture content. The time required for this adjustment varies with different species. The relation between humidity in the air and moisture in the wood is an important one, since it forms the basis for some drying schedules and determines the extent to which wood for use under specified conditions of temperature and humidity should be dried. Figure 3 presents curves showing the humidity-moisture relation at three temperatures. The middle curve has been interpolated, actual data having been secured for the outer ones only.

HUMIDITY MEASURING INSTRUMENTS.

Since the humidity in the air determines the drying characteristics at any given temperature, the control of humidity in the kiln is of prime importance. It is essential that the moisture be removed from the wood surface at the maximum safe drying rate. If the humidity is too low the wood will dry too fast and will be injured; if the humidity is too high the drying will be slow and expensive.

Humidity is measured by an instrument variously named a hygrometer, a psychrometer, or a wet and dry bulb thermometer. Modifications of the instrument adapted to dry-kiln use bear trade names, but the principle underlying all modifications is the same. A wet surface exposed to a breeze of nonsaturated air will be cooled a certain amount by the evaporation of water from the surface. The amount is constant for any given temperature and humidity. Knowing the amount of cooling, called wet-bulb depression, and the temperature of the air, the humidity can be determined by formula or by reference to a humidity chart. The wet and dry bulb thermometer consists of two separate thermometers, mounted on a panel. One, the dry bulb, registers the temperature of the air; and the other, the wet bulb, registers the air temperature minus the wet-bulb depression. The wet bulb is equipped with a silk or muslin wick dipped in a water reservoir. The wick surrounds the bulb of the thermometer and keeps it wet by drawing water from the reservoir. The evaporation of this water from the bulb produces the cooling or wet-bulb depression.

To obtain accuracy it is essential that the wicks be clean and that there be a brisk circulation of air over the wet bulb. A velocity of at least 15 feet per second is recommended by various authorities, but this is more than is needed, except for the most accurate work. With certain types of wet and dry bulb thermometers circulation is produced by whirling the entire instrument. Such instruments are known as sling psychrometers. Other instruments are provided with maximum-reading thermometers, so that they can be removed from the kiln and read outside. The mercury or fluid column in these thermometers must be shaken down before they are replaced in the kiln. They record only the maximum wet and dry bulb temperatures since they were last shaken down. If the temperature and humidity variations have been reasonably great during this time the readings will be deceptive.

Table 1 is a humidity chart for use with wet and dry bulb thermometers. It is based on the difference between the wet-bulb and dry-bulb temperatures. The dry-bulb temperatures are in the left-hand column and the difference between wet and dry bulb temperatures in the top row. The relative humidity is given at the intersection of the row and column. Suppose the dry bulb reads 140° F. and the wet bulb 130° F., the difference between them is 10°. By reading across the 140 row to column 10 the relative humidity will be found to be 75 per cent.

Most of the kiln humidity recorders are wet-bulb instruments with extension tubes. They differ from dry-bulb recorders (recording thermometers) in that the sensitve bulb in the kiln is provided with a wick and a water reservoir. Any type of recording thermometer

TABLE 1.—*Relative humidity table for use with wet and dry bulb thermometers.*

Temperature of dry bulb	Difference between wet and dry bulb thermometers, in degrees Fahrenheit																																						
	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	31	32	33	34	35	36	37	38	39	40
60	94	89	83	78	73	68	63	58	53	48	44	39	34	30	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
70	95	90	86	81	76	72	68	64	59	56	51	47	43	40	37	33	29	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
80	95	91	87	83	79	75	71	68	64	61	57	54	50	47	44	41	38	35	32	29	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
90	96	92	88	85	81	77	74	71	67	65	61	58	55	52	49	47	44	41	39	36	34	31	29	26	25	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
100	96	93	89	86	83	79	76	73	70	68	64	62	59	57	54	51	48	46	44	42	39	37	35	33	31	29	27	..	..	..	..	..	..	..	..	..	..	..	..	..
102	96	93	89	86	83	80	77	74	71	69	65	62	59	57	54	52	49	47	45	43	40	38	36	34	32	30	28	..	..	..	..	..	..	..	..	..	..	..	..	..
104	96	93	90	86	83	80	77	74	71	69	65	63	60	58	55	52	50	48	46	43	41	39	37	35	33	31	29	27	..	..	..	..	..	..	..	..	..	..	..	..
106	96	93	90	87	83	80	77	74	72	69	66	63	60	58	56	53	51	48	46	44	42	40	38	36	34	32	30	28	..	..	..	..	..	..	..	..	..	..	..	..
108	96	93	90	87	84	81	78	75	72	70	66	64	61	59	56	54	51	49	47	45	43	41	39	37	35	33	31	29	28	..	..	..	..	..	..	..	..	..	..	..
110	96	93	90	87	84	81	78	75	72	70	67	64	62	60	57	55	52	50	48	46	44	41	39	37	36	34	32	30	28	27	..	..	..	..	..	..	..	..	..	..
112	96	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	53	51	49	47	44	42	40	38	37	35	33	31	29	28	..	..	..	..	..	..	..	..	..	..
114	97	93	90	87	84	81	78	75	73	71	68	65	63	61	58	56	53	51	49	47	45	43	41	39	37	35	34	32	30	28	27	..	..	..	..	..	..	..	..	..
116	97	93	90	88	84	82	79	76	74	71	68	66	63	61	59	56	54	52	50	48	46	44	42	40	38	36	34	33	31	29	28	..	..	..	..	..	..	..	..	..
118	97	93	91	88	85	82	79	76	74	71	68	66	64	62	59	57	54	53	51	49	46	44	42	41	39	37	35	34	32	30	29	27	..	..	..	..	..	..	..	..
120	97	94	91	88	85	82	79	77	74	72	69	66	64	62	60	57	55	53	51	49	47	45	43	41	40	38	36	34	33	31	30	28	27	..	..	..	..	..	..	..
122	97	94	91	88	85	82	79	77	75	72	69	67	65	63	60	58	56	54	52	50	48	46	44	42	40	38	37	35	33	32	30	29	27	..	..	..	..	..	..	..
124	97	94	91	88	85	83	80	77	75	72	70	67	65	63	61	58	56	54	52	51	48	46	44	43	41	39	37	36	34	33	31	29	28	27	..	..	..	..	..	..
126	97	94	91	88	86	83	80	78	75	73	70	68	65	64	61	59	57	55	53	51	49	47	45	43	42	40	38	37	35	33	32	30	29	28	..	..	..	..	..	..
128	97	94	91	89	86	83	80	78	76	73	71	68	66	64	61	59	57	55	53	52	49	47	46	44	42	40	39	37	36	34	33	31	30	28	27	..	..	..	..	..
130	97	94	91	89	86	83	80	78	76	73	71	68	66	64	62	60	58	56	54	52	50	48	46	44	43	41	40	38	36	35	33	32	30	29	28	..	..	..	..	..
132	97	94	92	89	86	83	81	78	76	74	71	69	67	65	62	60	58	56	54	53	50	49	47	45	43	42	40	39	37	35	34	32	31	30	29	27	..	..	..	..
134	97	94	92	89	86	84	81	79	76	74	71	69	67	65	63	61	59	57	55	53	51	49	47	46	44	42	41	39	38	36	35	33	31	31	29	28	..	..	..	..
136	97	94	92	89	86	84	81	79	77	74	72	69	67	65	63	61	59	57	55	53	51	50	48	46	45	43	41	40	38	37	35	34	32	31	30	28	27	..	..	..
138	97	94	92	89	86	84	81	79	77	74	72	70	68	66	63	62	60	58	56	54	52	50	48	47	45	43	42	40	39	37	36	35	33	32	31	29	28	27	..	..
140	97	94	92	89	87	84	81	79	77	75	72	70	68	66	64	62	60	58	56	54	52	51	49	47	46	44	42	41	39	36	36	35	34	33	31	30	28	27	..	..
142	97	94	92	89	87	84	82	80	77	75	73	70	68	66	64	62	60	58	57	55	53	51	49	48	46	44	43	42	40	39	37	36	34	33	32	30	29	28	27	..
144	97	95	92	89	87	84	82	80	78	75	73	71	69	67	65	63	61	59	57	55	53	52	50	48	47	45	44	42	41	39	38	36	35	34	32	31	30	29	27	..
146	97	95	92	90	87	85	82	80	78	75	73	71	69	67	65	63	61	59	57	56	54	52	50	49	47	45	44	43	41	40	38	37	36	35	33	32	30	29	28	27
148	97	95	92	90	87	85	82	80	78	76	73	71	69	67	65	63	61	60	58	56	54	53	51	49	48	46	45	43	42	40	39	38	36	35	34	32	31	30	28	28
150	98	95	92	90	87	85	82	80	78	76	74	72	70	68	66	64	62	60	58	57	55	53	51	49	48	46	45	43	42	41	39	38	37	36	34	33	31	30	29	28
152	98	95	93	90	88	85	83	81	79	76	74	72	70	68	66	64	62	60	59	57	55	53	52	50	48	47	46	44	42	41	40	39	37	36	35	33	32	31	30	29
154	98	95	93	90	88	85	83	81	79	77	74	72	70	68	66	65	63	61	59	57	56	54	52	50	49	47	46	44	43	42	40	39	38	37	35	34	33	32	30	29
156	98	95	93	90	88	85	83	81	79	77	74	72	71	69	67	65	63	61	59	58	56	54	53	51	49	48	46	45	43	42	41	40	38	37	36	34	33	32	31	30
158	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	63	61	60	58	56	55	53	51	50	48	47	45	44	43	41	40	39	38	36	35	34	33	31	30
160	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	64	62	60	58	57	55	53	52	50	49	47	46	44	43	42	41	39	38	37	35	34	33	32	31
162	98	95	93	90	88	86	84	82	80	77	75	73	71	69	68	66	64	62	60	59	57	55	54	52	51	49	47	46	45	44	42	41	40	39	37	36	35	34	32	31
164	98	95	93	91	88	86	84	82	80	78	75	73	72	70	68	66	64	62	61	59	58	56	54	52	51	49	48	47	45	44	43	41	40	39	38	36	35	34	33	32
166	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68	66	65	63	61	59	58	56	54	53	51	50	48	47	46	44	43	42	41	39	38	37	36	35	33	32
168	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68	67	65	63	61	60	58	56	55	53	52	50	49	47	46	45	43	42	41	40	39	37	36	35	34	35
170	98	95	93	91	89	86	84	82	80	78	76	74	72	70	69	67	65	63	62	60	59	57	55	53	52	51	49	48	47	45	44	43	41	40	39	38	37	35	34	33
172	98	95	93	91	89	86	84	82	81	78	76	74	73	71	69	67	66	64	62	60	59	57	55	54	53	51	50	48	47	46	45	43	42	41	39	38	37	36	35	34
174	98	95	93	91	89	87	84	83	81	78	76	75	73	71	69	67	66	64	62	61	59	57	56	54	53	51	50	49	47	46	45	43	42	41	40	39	37	36	35	34
176	98	96	94	91	89	87	85	83	81	79	77	75	73	71	70	68	66	64	63	61	60	58	56	55	53	52	50	49	48	46	45	44	43	42	40	39	38	37	36	35
178	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	66	64	63	61	60	58	56	55	54	52	51	49	48	47	46	44	43	42	41	39	38	37	36	35
180	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	67	65	63	62	60	58	57	55	54	52	51	50	48	47	46	45	43	42	41	40	39	38	36	35
182	98	96	94	91	89	87	85	83	81	79	77	75	74	72	70	68	67	65	63	62	60	59	57	56	54	53	51	50	49	48	46	45	44	43	42	40	39	38	37	36
184	98	96	94	92	89	87	85	83	82	79	77	76	74	72	70	69	67	65	64	62	61	59	57	56	55	53	52	50	49	48	47	45	44	43	42	41	39	38	37	36
186	98	96	94	92	90	87	85	83	82	80	78	76	74	72	71	69	67	66	64	62	61	59	58	56	55	53	52	51	49	48	47	46	44	43	42	41	40	39	38	37
188	98	96	94	92	90	87	85	84	82	80	78	76	74	73	71	69	68	66	64	63	62	59	58	57	55	54	52	51	50	49	47	46	45	44	43	41	40	39	38	37
190	98	96	94	92	90	88	86	84	82	80	78	76	75	73	71	69	68	66	65	63	62	60	58	57	56	54	53	51	50	49	49	46	45	44	43	42	41	39	38	37
200	98	96	94	92	90	88	86	84	82	80	79	77	75	74	72	70	69	67	66	64	63	61	60	58	57	55	54	53	52	51	49	48	47	46	45	43	42	41	40	39

can be used equally well as a wet-bulb recorder, though sometimes it is necessary to change the shape or design of the bulb.

The wet-bulb temperature alone is of no value in determining humidity without the corresponding dry-bulb temperature. Hence, wet and dry recorders are set up side by side, or, as is much more convenient, combined in one instrument called a two-pen recorder, which records both temperatures on one chart. The space between the two represents the wet-bulb depression. For general use, two-pen recorders have the tubes and bulbs separate from each other, but when designed exclusively for use as wet and dry bulb recorders the extension tubes are frequently encased in a single protecting armor extending from the case of the instrument almost to the bulbs. The wick trough is made with two sets of brackets, one set for the wet bulb and one for the dry bulb. Instruments of this type are usually called recording psychrometers. The facts concerning recording thermometers apply to wet and dry bulb recorders.

CONTROL OF KILN HUMIDITY.

It is simpler to increase the humidity in a kiln than to decrease it. The universal method of increasing humidity is to inject steam into the kiln chamber.

Atmospheric air is usually drier than that in the wood-drying kiln and can be used only for dehumidification, a practice common with ventilated kilns. The moist air is drawn off through ventilating flues and the fresh air enters through intake flues or ducts. As the fresh air is heated its relative humidity falls while the dew point remains the same.

Moisture may also be removed from the air by condensation. The water vapor in the air condenses as it passes over a substance colder than the dew point of the air. Condenser pipes with cold water flowing through them are commonly used for this purpose. When cold water is not available, a refrigerator plant may be installed and brine circulated through the condenser pipes.

Cold-water sprays are also used to dehumidify air. The spray temperature must be below the dew point of the air passing through. If the sprays are powerful enough the air will be cooled to about the temperature of the water and will come out saturated at a temperature below its original dew point. In other words, the dew point will have been lowered. If the air be heated to its original temperature it will be drier than it originally was.

In the chemical laboratory air is dried by passing it through chemicals which have affinity for moisture. Principal among these are calcium chloride and sulphuric acid. Their use has not been developed for commercial wood drying.

The control of humidity is more difficult than temperature control, and greater attention must be given to the apparatus to secure satisfactory results. One principal reason is that a small difference in the wet-bulb temperature produces a comparatively large difference in humidity, and to secure good control requires an accurate instrument.

The controllers of greatest importance are those which depend partly or wholly upon a wet-bulb of one type or another. Temperature controllers of various types can be made into wet-bulb controllers by providing the bulb or sensitive element with a suitable wick and water supply. The Forest Products Laboratory has used with success air-operated wet-bulb controllers of both the extension bulb (vapor filled) and the bimetallic or differential expansion types. Self-contained thermostats can also be used, but their sensitiveness is not so great as that of the air-operated instruments. Wet-bulb controllers can keep the wet-bulb temperature constant. If the dry-bulb temperature is also kept constant, the humidity will remain constant. If it does not, however, the humidity will vary, even if the wet-bulb temperature is accurately controlled. To overcome this difficulty a differential type of self-contained humidity control has been developed. In this instrument there is a dry bulb as well as a wet bulb; the two bulbs are connected to their respective motor diaphragms on the body of a balanced steam valve so that an increase in the wet-bulb temperature will close the valve and an increase in the dry-bulb temperature will open it. Balance between the two is secured by a lever and sliding weights. This system provides for a constant difference between the vapor pressures in the wet and dry bulb motor diaphragms, no matter what the dry-bulb temperature may be. This results in an approximately constant difference between the wet and dry bulb temperatures.

A glance at the humidity table shows that, with a constant difference between wet and dry bulb temperatures, even quite a considerable variation in the dry-bulb temperature has but little effect upon the relative humidity.

To secure satisfactory service from wet-bulb thermostats, care and attention should be given especially to the wicks, which should be changed as often as they become hard and dirty.

Humidity controllers almost without exception operate valves controlling steam jets, just as temperature controllers operate valves upon the heating system. The same kind of valves are ordinarily used, each valve being adapted to the needs of the particular service it is to render. As the use of humidity controllers on steam-jet lines presupposes that the humidity will always need to be increased, means must be provided to insure this need. Ordinarily in ventilated kilns the fresh-air inlets and the moist-air vents are open sufficiently to require continuous humidification. If necessary in special cases, the controllers can be made to operate dampers of various sorts, and also to control the flow of water in condenser pipes. Control in the various kiln types will be considered more in detail later.

Several special types of temperature and humidity-control instruments have been designed or adapted for dry-kiln use. Among these are double-duty air-operated instruments which have two sensitive bulbs and extension tubes with but a single case, in which are housed the capsules and air valves. These instruments can be used for temperature and humidity control, or for temperature control and the removal of condensation from the heating coils. This latter use is not common in dry kilns.

The recorder regulator has already been mentioned under temperature control. This air-operated instrument provides for the control of either wet or dry bulb temperature and for a graphic record of the controlled temperature.

Time is an element in certain classes of control in which it is desirable to change the setting of the control instrument at definite intervals. To meet this need both single-duty and double-duty instruments are made with time attachments. These are usually in the form of clock-driven cams, upon which ride levers controlling the adjustment of the air valves. By providing a suitable assortment of cams and a sufficiently flexible system of gearing between the clock and the cam any desired drying schedule can be reproduced automatically.

AIR CIRCULATION IN THE KILN.

It is absolutely necessary to have a certain amount of circulation of air in a kiln to convey the heat from the steam coils or other source to the lumber and to carry away the evaporated moisture.

PRODUCTION OF CIRCULATION.

The simplest way to produce circulation is by means of chimneys or flues. This natural draft is caused by the difference in temperature of the outside air and the air in the kiln. The warm air in the kiln is lighter than the air outside and is continually escaping through the top. The cold outside air is drawn in at the bottom. There is always inleakage at the bottom and outleakage at the top of the kiln, no matter how well it may be built; and when the path of the air is made easy by providing chimneys and fresh-air intakes the circulation becomes quite brisk. The velocity in the chimneys may be 600 feet per minute or more, depending upon circumstances. A reasonable amount of draft may be secured through the chimneys, even though no air intake openings are provided. There may also be considerable draft through the intake when there are no chimneys, or when the chimney dampers are closed. Under such conditions the whole kiln acts as a chimney, and the leakage is sufficient to permit the escape or entrance of appreciable amounts of air.

Air intakes are usually placed at the bottom of the kiln and the outlets from the kiln to the chimneys at varying heights along the sides and in the ceiling. The chimneys usually, but not always, project above the roof. The higher the chimneys the more rapid will be the circulation.

It is sometimes considered advantageous to draw the air over a circuitous route through which the circulation will ordinarily not start of its own accord. This may be done by some special means to stimulate the circulation, such as the use of radiators, aspirators, or inspirators. The simplest form of radiator for this purpose is a single length of pipe running the full length of the chimney and fed with steam from the bottom. These radiators produce an upward draft of air in the chimneys by heating the air. They may be left on throughout the entire drying period if the added circulation is desirable. The heat given off by these radiators is lost, except in so far as it does useful work in producing circulation.

Condensers if properly located will assist materially in producing circulation, and will also reduce the humidity. If air is being continuously heated at one point in a confined space and continuously cooled at another point, there will be a continuous flow of heated air upward at the first point and a continous flow of cooled air downward at the second point. There will also be cross-circulation between the two points, the warmed air above flowing from the hot point to the cold one and cold air below flowing from the cold point to the hot one. Condensers may well act as the cooling agent and the steam coils as the suppliers of heat.

Water sprays, if cool enough, may likewise act as the cooling agent and, in conjunction with a suitable source of heat, produce a recirculating system. The water sprays, in addition to their cooling effect, may stimulate the circulation through the impact of the water particles upon the air. For this reason it is desirable that the sprays point downward, at a place where downward circulation is desirable and readily producible.

Water sprays may be used as either humidifiers or dehumidifiers at the time they are assisting in producing circulation. Water sprays are as a rule used only in recirculating kilns.

Steam sprays are used in many ways in kilns, and their maximum usefulness has not yet been developed. The mechanical or heat efficiency of these steam-jet blowers is not as great as that of high-grade fans, but often this fact is outweighed by other considerations.

The circulation in almost any ventilated kiln may be materially increased by the use of suitable steam jets in the intakes, the outlet flues, or both. Jets placed in the outlet flues increase the circulation through the exhaustion of air from the kiln, but if the jets are placed in the intakes, they not only induce circulation but humidify the air and preheat it by imparting some of the heat of the steam. Under most conditions the proper place for the jets is in the intakes.

Centrifugal blowers of various designs are used to produce circulation in kilns of many types. The volume of air moved per unit of time may be any desired amount within wide limits, and the direction of the circulation may be controlled and regulated to meet individual needs and conditions. Centrifugal blowers are located almost exclusively outside of the kilns and are usually arranged to recirculate the air.

Disk fans of several different types have been used for special drying problems. These fans may be either in or out of the kiln, depending upon individual design, and may be driven by shaft or belt or have direct connection to engine or motor.

MEASUREMENT AND CONTROL OF CIRCULATION.

For a particular drying condition it is possible to specify temperature and humidity, but the amount of circulation is not so easily specified. While it is true that rapid uniform circulation produces faster and more even drying and permits of better control of the drying conditions than slow, irregular circulation, it becomes increasingly difficult to secure uniformity as the speed of circulation increases; and there is an added expense to produce and maintain high circulation rates. Ventilated kilns with low rates of circulation have been in satisfactory operation for many years.

RATE OF CIRCULATION.

The Forest Products Laboratory recommends for all difficult drying work which demands uniform drying conditions a circulation of at least 25 feet per minute through the lumber piles. Where requirements are not so exacting much lower rates may be used. If only the removal of the moisture from the kiln through ventilation is desired, a very low rate may be ample. In fact, certain types of kilns are being successfully operated without any visible means of moisture removal, leakage being sufficient to keep the humidity below the desired point.

Generally high rates of circulation produce increased drying rates in wood as well as in many other substances, temperatures and humidities being the same; but actual data on the subject are meager and it is not possible at present to say how far it may be commercially feasible to go in the matter of very high circulation, and to what extent similar effects may be produced by other means.

TESTING CIRCULATION.

Much trouble in drying is caused by poor or nonuniform circulation, and it is frequently necessary to determine the amount of circulation and its direction as a preliminary to prescribing a remedy. The rate of circulation inside the average kiln is so low that most of the methods usually employed in the measurement of air velocities are not suitable. About the only method which has proved satisfactory is to watch the drift of smoke and, if desired, to time its movement over a known distance by means of a stop watch. One of the special advantages of this method is that it shows clearly the direction of movement. It is, of course, necessary for the operator to be inside the kiln during the test.

Tobacco, punk sticks, or rope may be used to provide the smoke, although it is difficult with these means to get a sufficient volume of smoke, and the fire risk is an objectionable feature. It is almost necessary, however, to use one of these methods in determining the circulation at an inaccessible point. A few punk sticks or a bit of rope can be tied to the end of a stick and poked into many places which could not otherwise be reached. Smoke from any burning substance, it must be remembered, tends to rise because of its higher temperature; hence the true circulation will not be indicated until the smoke has cooled to the temperature of the surrounding air.

A special form of smoke machine for dry-kiln work has been developed at the Forest Products Laboratory. This machine consists essentially of two small bottles and a few pieces of connecting tubing. One bottle is partly filled with hydrochloric acid and the other with ammonia. When air is blown through the bottles, fumes of the two chemicals are mixed, producing a dense fog or smoke which will drift readily with the air current.

To secure proper results in smoke tests, it is essential that all the doors be closed and that the kiln be operating in the normal manner.

For higher velocities, such as those usually occurring in the flues of ventilated kilns and in the interior of some types of forced circulation kiln, the Biram type of anemometer is suitable. This anemometer is in essence a disk fan mounted upon pivot bearings and provided with a revolution counter. This counter is ordinarily in the form of a dial and pointer, one revolution of the pointer usually representing an air movement of 100 feet. It is necessary to use a watch with the anemometer, to determine the time corresponding to a certain air movement. It is customary to let the anemometer run a definite number of minutes, and then to divide the number of feet recorded by the number of minutes, the quotient being the velocity expressed in feet per minute. It must be remembered that the velocity in any duct varies throughout the cross-section, being greatest at the center and least along the sides, and that a single reading will probably not represent a true average. For accurate results the cross-section of the duct should be divided into squares about equal to the diameter of the anemometer and a reading taken on each square. This will seldom be necessary, however, in ordinary work. In using anemometers in open places care must be exercised to set the anemometer with its axis truly parallel with the air movement. Otherwise it will register less than it should. Smoke may be used to indicate the direction of the air movement.

Anemometers are imperfect in that the speed of the fan is not truly proportional to the air velocity over the entire range of usefulness of the instrument, and it becomes necessary to apply a correction factor. This correction factor is determined by actual trial or calibration at the factory, and a curve showing the amount of correction to be applied at different velocities should accompany the instrument.

DRYING AND DRYING STRESSES.

MOISTURE GRADIENT.

The moisture in wood tends to equalize itself by flowing to areas of least moisture. If we desire to produce a flow of moisture in a piece of wood of uniform moisture content, we must first upset this uniform condition. This is done by removing some of the moisture from the surface by circulating air of proper temperature and humidity around the piece. As soon as evaporation from the surface commences, a "moisture gradient" has been established; that is, we have made the wood drier on the surface than in the interior, and have thereby started the movement of the moisture from the interior toward the surface. If we continue to remove the moisture from the surface through evaporation a moisture gradient will continue to exist. If the moisture be removed from the surface faster than it can transfuse from the interior, the moisture gradient will increase or become steeper, whereas if it be removed more slowly, the gradient will become less.

SHRINKAGE.

As the drying of green wood progresses the amount of free water in the cells gradually diminishes, and soon the cells near the surface have lost all their free water, i. e., they have reached the fiber-saturation point. It is at this point, which is a very definite one for most species, usually between 25 and 30 per cent moisture, that the changes in the properties of the wood begin to take place. As wood dries beyond the fiber-saturation point it begins to shrink, and it will continue to shrink as long as it loses moisture. In fact, this shrinkage is very nearly proportional to the amount of drying below the fiber-saturation point. Shrinkage is not uniform in all directions, however. The longitudinal shrinkage, parallel to the length of a board or vertical in a standing tree, is practically nothing, and may be neglected here. The tangential shrinkage, parallel to the circumference or rings or in a horizontal direction in the standing tree, is usually from one and one-half to three times as great as the radial shrinkage (horizontal in the standing tree, from the pith to the circumference, perpendicular to the rings and to the tangential direction). Shrinkage is more or less proportional to density or weight of wood; the heavier woods, as a rule, shrink more than the lighter ones.

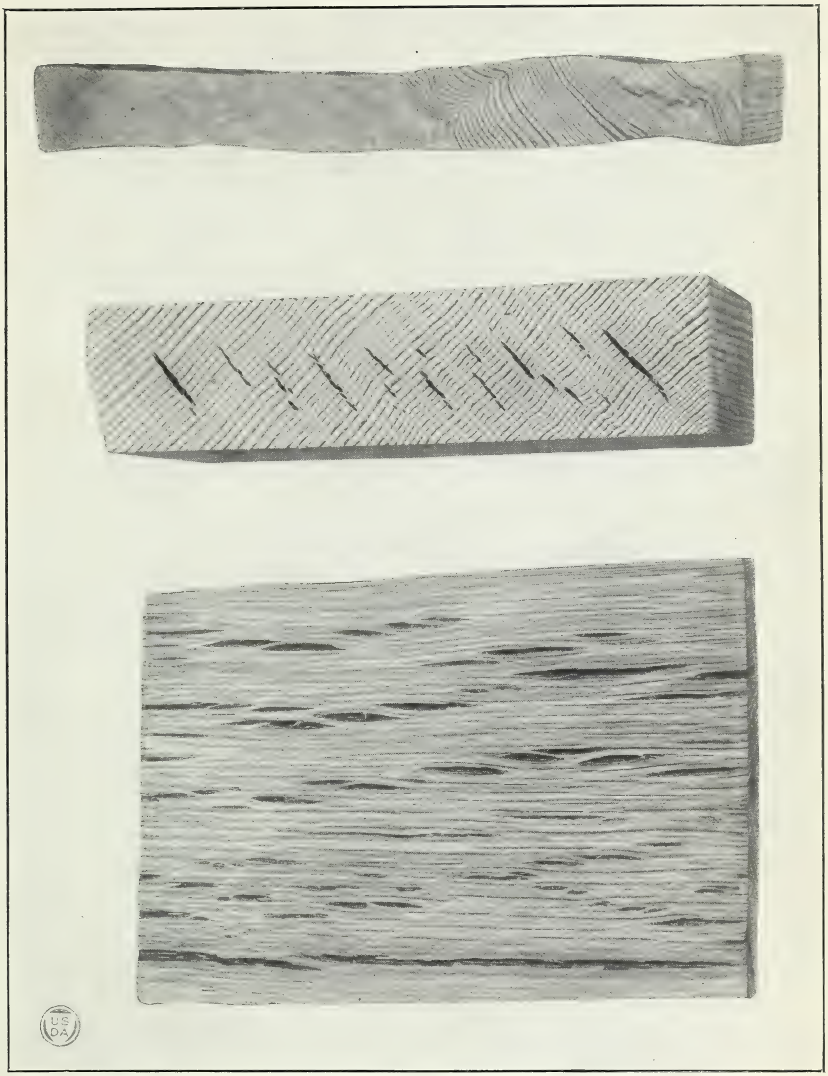
Shrinkage is accompanied by a hardening of the wood, a reduction in its plasticity, and a reduction in the rate at which the moisture transfuses through it. There are also important changes in the mechanical properties. The wood becomes stronger under stresses, such as bending, tension, and compression, and also gains in stiffness. The increase in these properties as the wood is dried from the fiber-saturation point to zero moisture may be as much as several hundred per cent of the values in the green wood.

DRYING DEFECTS DUE TO UNEVEN SHRINKAGE.

Most of the defects ordinarily classed as drying defects would not exist if it were not for uneven shrinkage and the attendant stresses set up by it. Take the simplest case, a hypothetical one, in which a board dries without moisture gradient and with uniform radial shrinkage and uniform tangential shrinkage. If the board be radial (quarter-sawed or edge grain) or tangential (plain-sawed or flat grain), it will remain flat in drying, but after drying the radial board will be thinner and wider than the tangential one if they were both of the same width and thickness when green. If, however, the board is neither radial nor tangential, but has the grain running uniformly at an angle to the sides and edges, the difference between radial and tangential shrinkage will cause "diamonding," the sides and edges no longer being at right angles to each other. In a board partly quartered and partly slash grained the difference between radial and tangential shrinkage will cause the board to cup, the edges turning away from the heart.

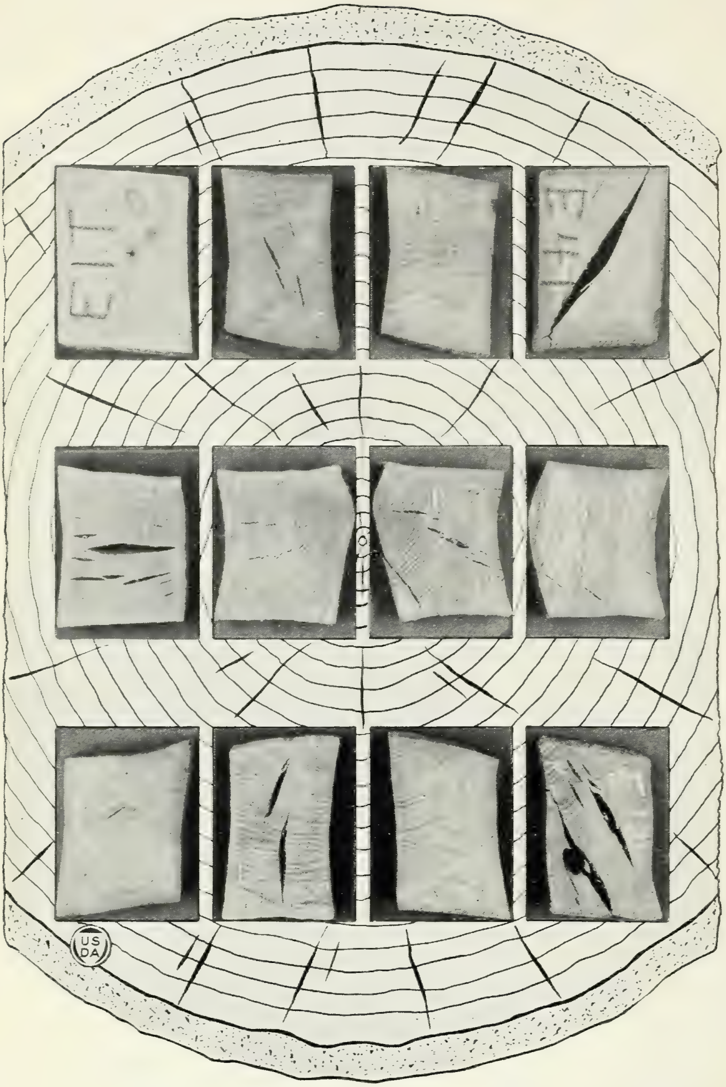
CASEHARDENING.

As the outer surfaces of the board reach and pass the fiber-saturation point they begin to shrink. In order to shrink, however, they must squeeze together all of the green wood inside, since it has not yet reached the fiber-saturation point and is therefore not ready to shrink of its own accord. The first result is that the surface layers, in trying to squeeze the inside or core, create in it a state of compression and in themselves a corresponding state of tension, or pull. Imagine a rubber band stretched across a book or bundle of papers. The band is stretched and the book compressed or squeezed. The only difference is that the tension is put into the



DRYING DEFECTS.

The upper board is a piece of redwood showing collapse; before drying the board was of uniform thickness. The piece of Douglas fir plank in the center shows honeycomb. The lower board is a resawed piece of badly honeycombed slash-sawed oak, showing the appearance of honeycomb on the tangential faces.



CROSS SECTION OF A SOUTHERN SWAMP OAK TREE CUT INTO BOLSTER STOCK AND DRIED.

The black rectangles represent the green size and exact location of the pieces in the tree. The dried pieces exhibit in exaggerated form many of the common drying defects, such as checks, honeycomb, diamonding, and even cupping. The difference between radial and tangential shrinkage and the comparatively small shrinkage of some of the sapwood are illustrated.

rubber by actually stretching it, whereas the tension is produced in the outer layers of the wood by preventing it from shrinking. The same thing occurs if a piece of wet leather is prevented from shrinking as it dries.

This drying stress will increase as the drying progresses. The outer layers continue drying and shrinking and to them are continually being added other intermediate layers which are reaching the fiber-saturation point and are ready to shrink. Layers once in compression begin shrinking and place themselves in tension. Those layers still near the fiber-saturation point are more or less plastic and able to yield to stress without too much difficulty. The outer layers, however, having yielded at first, much like the rubber band, are now getting dry, and are becoming constantly less yielding. Eventually they become sufficiently stiff and there are enough of them so that they can successfully resist the stresses placed upon them by the drying, and they are in what is known as a "set" state. Further drying results in a reversal of stresses. The shrinkage of the inner layers or core is now opposed by the "set" exterior layers, and the result is that the inner layers are in tension and the outer layers in compression. If no special precautions are taken, it is to be expected that most kiln-dried stock will be in this state of stress when it is removed from the kiln. This condition is usually described as "casehardened."

CHECKING AND HONEYCOMBING.

It has been assumed that the stresses in the board were not sufficient to cause visible damage. If, however, the strength of the wood in tension across the grain is not sufficient to resist the tensile stresses in the surface layers during the early stages of drying, it will tear open, forming surface checks of varying size and depth. Likewise, if the inner layers are not strong enough to resist the tension placed upon them during the latter stages, they will rupture, causing "honeycomb" or "hollowhorn." Because radial shrinkage is less than tangential, and because a weak plane is produced where the rays and fibers cross, checks and honeycomb more often run radially than tangentially. It not infrequently happens that surface checks formed during the early stages of drying, or, in the case of partially air-dried stock, before entering the kiln, close up and disappear during the final drying. In fact, the effect caused by the shrinkage of the core may go still farther and result not only in closing the checks at the surface, but in actually deepening them and opening them up in the center, forming honeycomb. (See Fig. 4.)

WARPING, LOOSENING OF KNOTS, END CHECKING.

There are several other drying defects due to uneven shrinkage, such as warping and twisting, which are often caused by spiral or interlocked grain, by a difference in longitudinal shrinkage between sapwood and heartwood, and by various other irregularities in structure and in the drying. (See Pls. VIII and IX.) The loosening of knots is caused by the drying-out or exudation of cementing resins and gums and by the differentials in shrinkage caused by the fact that the axis of the knot or branch is at right angles to the axis of the tree. Thus the knot shrinks away from the wood lengthwise of the board, but does not shrink appreciably in the radial direction. End checking, which is caused by the very rapid drying from the end surfaces, is discussed more fully under "Drying schedules."

COLLAPSE.

One form of seasoning defect which occurs in the green wood is the actual collapse of rows of cells, just as a rubber tire collapses when the air is let out. This defect occurs only in a few species, such as redwood, western red cedar, swamp oak, and red gum. The remedy consists in the use of low temperatures at the beginning of the kiln run.

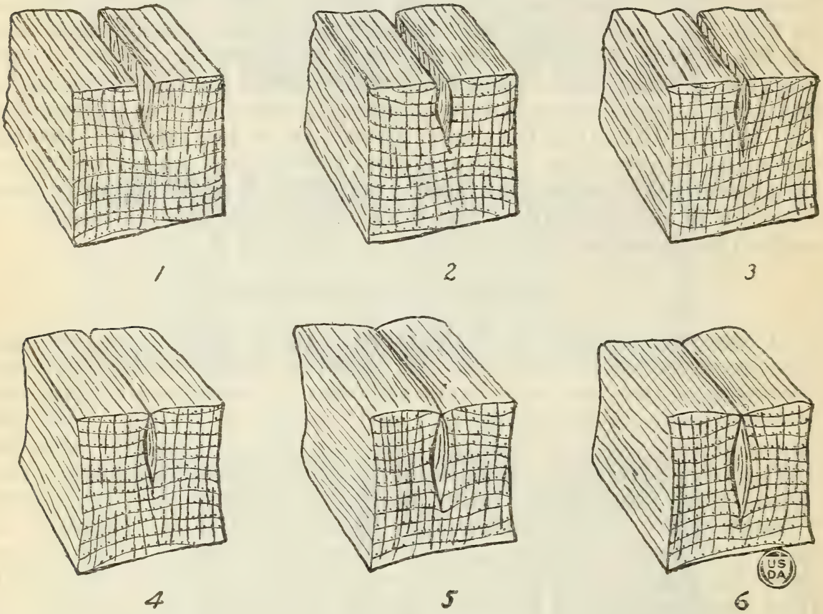


FIG. 4.—Development of a surface check into a honeycomb. 1, 2, and 3 show the check gradually closing up as the piece dries and shrinks. 4, 5, and 6 indicate how the tensile stresses deepen the bottom of the honeycomb as the casehardening becomes more severe. The depression along the center of the top, in 5 and 6, is typical of honeycomb.

STRESS DETECTION.

The detection and relief of the shrinkage stresses causing casehardening, checking, and honeycombing is one of the most important of the kiln operator's duties, and one which requires skill and close application.

The usual method of detecting the presence of these stresses, commonly called casehardening stresses, is to cut a stress section from an average board. This stress section should be cut at least 2 feet from the end of the board, and should be about 1 inch long in the direction of the grain. It is then slotted as shown in Figure 5, the number of slots depending upon the thickness of the board and upon the preference of the individual operator. Often it is desirable to cut up several stress sections with varying numbers of slots. The direction in which the individual prongs turn and the relative lengths of the various prongs tell the story. If the outer prongs turn out, it is an indication of tension in the outer layers. If they turn in, there is compression in the outer layers. Cutting the section into prongs disturbs the balanced state and allows each prong or group of layers to make a new adjustment within itself. The compression side of each prong will immediately stretch and the tension side will contract, just as a spring under tension or compression will return to its original length when the deforming pressure is removed. In doing this the prong will be bent, the amount of the bend depending upon the thickness of the prong and upon the amount of stress originally present. The side which was originally in tension will become the concave side and the one originally in compression will become the convex one. The amount and distribution of the drying stresses can be judged by the relative bending

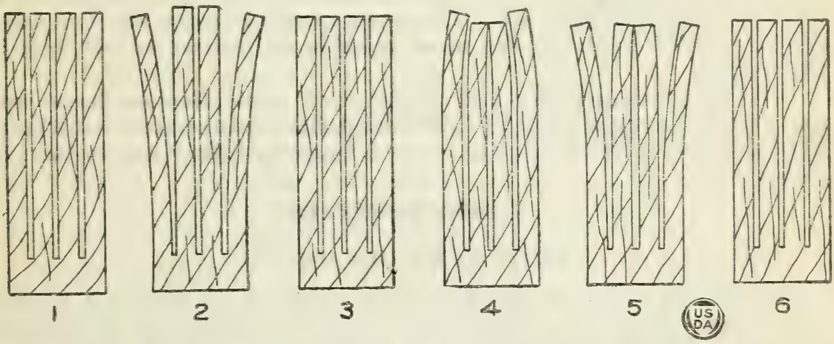


FIG. 5.—Typical stress sections. 1 represents a green board; 2 shows tension in the surface, typical of early stages in the drying; 3 shows drying has progressed farther and the shrinkage of the interior has balanced that of the surface; 4 shows typical casehardening; 5 reveals slight reversal of stresses by treatment to relieve casehardening; 6 is the finished board free from stress. The changes in the length of the prongs have been exaggerated slightly for emphasis.

of the several prongs on each side, especially when the prongs all turn outward. When they turn inward the relative bending can not be judged so well, since they interfere with each other. In such cases it may be advantageous to cut the section into a larger number of prongs, thus reducing the amount of curve in each prong and permitting comparison of the relative lengths of the individual prongs. If they are thin enough there will be but little difference in stress between the two sides of each prong, and the state of stress will be indicated by the change in its length. All prongs in tension at the time of cutting will shorten, and those in compression will relieve themselves by lengthening. The top ends of all the prongs will form a curve, and the shape of this curve will indicate clearly the state of stress. If it is convex or high in the center, it indicates tension in the outer layers and compression in the core. If low in the center, the reverse is indicated.

So far only general indications at the time of sawing the sections have been considered. If they be now set aside in a warm place they will soon dry down to an approximately uniform moisture content, the actual amount depending upon the temperature and humidity of the surrounding atmosphere; and the changes in the moisture content of the section will be portrayed by changes in the length and curvature of the individual prongs. Loss of moisture on one side of a thick section will usually be most plainly indicated by a change of shape, the prong bending toward the side that has been drying. If the prong be in the center and there is an equal loss of moisture from both sides, the only indication will be a shrinkage in the length. In thin sections this is apt to be the case anyway, because their very thinness precludes much difference in moisture between the two sides. Under ordinary circumstances, except after special treatments, the drying of stress sections will cause a contraction or an inward turning, or both, to take place in all the prongs, the amount being proportional to the amount of moisture lost from each prong. The final shape of the section, then, is a criterion by which to judge the condition of the stock in the kiln after the drying has been completed. Caution must be used, however, since the sections dry without further stress and the stock in the kiln probably does not. The more nearly dry the stock is when the stress section is cut, the more reliable an indicator will it be in this respect.

Now that the meaning and function of stress sections have been explained, it is necessary to understand the significance of the story they tell and to learn how to correct matters if they are in need of correction.

STRESS REMEDIES.

RELIEF OF SURFACE TENSION.

The first evidence of stress in green stock in the kiln is a tension in the outer shell. This is shown in the stress section by an outward turning of the prongs, and may be considered a normal condition of affairs, more or less unavoidable. If this tension becomes too severe, surface checks will result. As it is easier to watch for surface checks than to cut stress sections, the condition of the stock in the early part of the run is usually judged by the presence or absence of surface checks. Excessive tension in the surface and surface checks are caused by too steep a moisture gradient; in other words, the moisture is being removed from the surface more rapidly than the rate of transfusion from the center to the surface. The remedy is to slow down the rate of evaporation by increasing the relative humidity of the air in the kiln. The effect of a definite increase in humidity will be apparent from a study of stress sections cut before and after the change in humidity.

PRELIMINARY STEAMING OF AIR-DRIED STOCK.

Air-dried or partially air-dried stock is frequently put into kilns for further drying. Its condition upon entering the kiln should be carefully determined so that suitable subsequent treatment may be accorded. If deep surface checks are present, the fact should be noted and recorded and the drying carried on with unusual care. Casehardening is frequently present in air-dried stock, and the surface is apt to be so dry that the transfusion of the moisture is badly hampered. For these reasons, and also to warm the stock through before drying commences, it is good practice to give it a preliminary steaming treatment. This is customarily continued for from $1\frac{1}{2}$ to 2 hours for each inch of thickness, the temperature being about 15° above that at which the drying is to begin. The humidity should be kept at 100 per cent not only during the steaming but also during the subsequent cooling to the initial drying temperature. When the center of the stock is already in tension a high humidity treatment should be used instead.

RELIEF OF INTERNAL TENSION.

Assume that the stock has safely passed the first stages of drying and that the tension in the surface has passed its maximum and is now diminishing. During this period the stock is not usually liable to injury, and the only surface phenomenon is the probable closing up of any checks which may be in it. As soon as these checks have closed, or possibly even before, the tension in the surface will have disappeared and compression begun to develop. This compression will be accompanied by a corresponding tension in the core. If surface checks were originally present and have closed up, the increasing tension is apt to deepen them into honeycomb. If no surface checks were present, the stock can stand more of the internal tension which accompanies casehardening than it could otherwise. In any event, it is necessary to remedy the condition or relieve the stresses before they have reached a dangerous intensity. This is accomplished by softening the surface so that it will yield to the pull or tension of the core, thus allowing the whole piece to adjust itself by shrinkage. The amount of shrinkage is usually readily noticeable. The usual method of softening the surface is to subject the kiln charge to a steaming treatment at saturation or to a high humidity treatment at less than saturation. When the depth to which the layers in compression extend is small—that is, when the compression "zone" is shallow—steaming treatments at 100 per cent humidity are safe and satisfactory. They will produce a quick effect on the surface, which is desirable, moistening and softening only a shallow zone, which is then compressed or squeezed together by the tension or pull of the core. At the time the steaming is completed the surface will still be in compression and the core in tension, the amount of these stresses being, however, comparatively small and representing only the force required to squeeze together the wood in the compression zone, in its moistened and softened condition. Immediately after the steaming treatment, however, the surface layers will lose most of the moisture picked up during the treatment and will shrink accordingly, thus reducing all stresses and possibly even reversing them, putting the surface back into tension and preparing the stock for further shrinkage of the core.

PREVENTION OF REVERSE CASEHARDENING.

When the stock is reasonably dry and the compression zone comparatively deep, a steaming treatment may readily result in too severe an effect on the surface without enough effect toward the inner portion of the compression zone. If the treatment be continued long enough to penetrate the entire compression zone, the surface may have picked up so much moisture that the resultant great shrinkage will produce a permanent reverse casehardening, which the drying down to the desired final moisture content is not able to eliminate. This state of affairs must be avoided since reverse casehardening in dry stock can not be removed without softening up the entire piece again—a tremendously long and unsatisfactory process. It is better, therefore, to employ milder means as the stock becomes drier. Instead of steaming (100 per cent humidity), the humidity is kept at some lower point ranging usually between 60 and 85 per cent. The time required is considerably more, and the effect is correspondingly milder and more uniformly distributed through a deeper zone.

GENERAL RULES FOR STEAMING AND HIGH-HUMIDITY TREATMENTS.

It is not possible to lay down hard and fast rules for steaming and high humidity treatments; each operator will have to learn by experience just what can and must be done. The Forest Products Laboratory usually recommends that high humidity treatments be used when the core of the stock contains less than 18 per cent moisture. Above this point steaming at from 160° to 185° F. may be safely used, the period of steaming varying from one-half to three hours. These temperatures can be used advantageously also in high humidity treatments. The relative humidity will vary with the dryness of the stock. It may well be between 75 and 90 per cent when the core is between 15 and 18 per cent and between 65 and 75 per cent below that. The duration of high humidity treatments may be from 10 to 30 hours, sometimes shorter but seldom longer.

The degree to which steaming and high-humidity treatments should be used depends entirely upon the stock being dried and the purpose for which it is to be used. It may be laid down as a general rule that better results will be secured, and at less risk of damage, principally from honeycomb, if the stresses are relieved frequently by short, mild treatments than infrequently through long, severe treatments. In any event, the treatment given should be determined by the condition of the stock at the time.

Casehardening is not in itself a serious defect during the drying process, though, of course, it is undesirable and leads to various difficulties. In the finished stock, however, matters are different, and casehardening is of itself a serious defect, which results in cupping and warping, unequal shrinkage, and similar trouble, especially in resawing or in working deep patterns. It is essential, therefore, that casehardening be removed before the stock is taken from the kiln, and provision for a final treatment should be made in the drying schedule. While it is not customary to do this in the drying of most softwoods, it has been repeatedly shown that, especially for resaw stock, final relief of casehardening is very advantageous even in woods like the soft pines. There are, on the other hand, many cases, such as drying simply for shipping weight, where the financial advantage is questionable.

STEAMING TO KILL MOLDS AND WOOD-BORERS.

The kiln operator is frequently confronted with the necessity of handling stock showing evidences of decay, mold, stain, or the action of borers. Under ordinary drying conditions in the kiln, borers will be killed and the growth of decay, molds, and stains will be arrested, except possibly in the case of stains similar to the brown stain of western yellow pine. When drying is carried on at low temperatures and high humidities, however, conditions are favorable to the growth of many of these parasites, and sometimes they may cause trouble in the kiln. The growth of mold on heavy oak wagon stock during the early stages of the drying is not uncommon, and borers are occasionally found working in hickory wagon-axle stock in the kiln. The remedy usually applied is steaming for a period of about two hours at a temperature of about 180° F. This treatment may have to be repeated periodically in the case of molds, until the surface of the stock becomes dry enough to inhibit further growth.

DRYING SCHEDULES.

A drying schedule is a prescription or rule for the operation of the kiln during the drying period. Drying schedules are usually presented in the form of curves or tables showing the temperatures and humidities to be used at various stages of the drying, it being taken for granted that a kiln of suitable type, with ample and uniform circulation, etc., is available. Obviously, successful drying can not be accomplished if the kiln is incapable of doing the work required of it. The temperatures and humidities in drying schedules are based upon either the length of time the stock has been in the kiln or the current moisture content of the stock. The latter basis is used exclusively by the Forest Products Laboratory, since it is logical and of universal application.

KILN SAMPLES.

To use a drying schedule based upon the current moisture content of the stock requires a system by which this current moisture can be determined with ease and certainty. The best system so far developed depends upon the use of kiln samples. Kiln samples are short pieces of typical stock of known original moisture content, which are placed in different parts of the kiln and are periodically weighed to determine the loss of moisture. The current moisture content is computed from the original moisture content and the loss in weight, and is assumed to be the average moisture content of the stock represented by the samples.

Kiln samples are prepared as follows: Several boards, representing both fast drying and slow drying stock, are selected from the stock to be dried, and from each one or more samples about 2 feet long are cut. The sample should be cut not less than 2 feet from the end of the board, if possible, and the end 2 feet discarded. Each sample should be cut 2 inches longer than desired, a moisture section cut immediately from each end, and the moisture determination made. The average of these two moistures is assumed to be the average moisture content of the sample.

END COATINGS.

When the moisture sections have been weighed and placed in the oven the samples should be end coated. It has already been shown that wood dries out much faster from the end grain, and if the end surfaces were not protected in some suitable manner the samples would dry out from the ends, and since they are comparatively short they would soon become drier than the rest of the stock and would not represent an average.

A number of materials are being used to prevent or retard end drying under various conditions, and while some are excellent for the low temperatures encountered in air seasoning, comparatively few have proved suitable for kiln work. The most satisfactory end coating so far tested is a 213° coal-tar pitch. There are probably other pitches, asphalts, and similar materials which would serve the purpose, but additional research will be required to determine the relative efficiency of the many grades available. Materials with very high melting points are barred, since they can not be applied to the wood, and those with low melting points are unsuitable because they would flow off at the temperatures used in the kiln. Rosin and lampblack mixtures have been used with success, but their efficiency is not so great as that of coal-tar pitch, and their cost is considerably more. No coatings, liquid at ordinary temperatures, have proved so satisfactory as the hot dips.

The ends of the moisture samples are dipped into the melted pitch to a depth of about one-half to three-fourths inch. The pitch should be hot enough to produce a smooth coating approximately one-sixteenth inch thick, but not hot enough to cause any of the moisture in the wood to flash into steam and blow holes in the coating. A very thin coating is undesirable on account of lack of imperviousness, and a thick one is wasteful of pitch and at the same time causes an error in the current moisture determinations. As soon as a sample has been dipped it should be weighed immediately and the weight recorded. The average moisture content of the two moisture sections is assumed to be the moisture content of the sample. The oven-dry weight of the sample is found by multiplying the original weight of the sample by 100 and dividing by 100 plus the moisture content expressed in per cent. Thus, assume that the sample originally weighs 3.75 pounds and that the two moisture sections average 25 per cent moisture. Then the oven-dry weight of the sample equals $\frac{3.75 \times 100}{100+25}$, or 3 pounds. If the moisture content were expressed as a decimal instead of in the form of percentage, this formula would be still simpler; oven-dry weight equals $\frac{3.75}{1.25}=3$. The kiln samples are placed in convenient parts of the various truck loads or piles of lumber and allowed to dry with the rest of the stock.

Whenever a current weight is taken, the current moisture content is always calculated on the basis of the calculated oven-dry weight, just as if the sample were a regular moisture section, and the moisture content of the load is assumed to be the average of the moisture contents of the various samples. If the work has been accurately done, this method will yield excellent results, but in any case a check should be made at the end of the run, by cutting moisture sections from the samples and comparing the actual moisture with the calculated moisture. Stress sections should also be cut from the samples. Extra samples should be placed in the kiln, so that current stress and moisture determinations may be made as desired.

The use of end coatings on samples is imperative; coating the ends of all of the stock in the kiln would be desirable in most kinds of difficult drying, but is not considered economical except in unusual cases, such as in the drying of heavy vehicle parts, gunstock blanks, and shoe-last blocks. The 213° pitch is recommended for this work as well as for the samples.

USE OF DRYING SCHEDULES.

The drying schedules presented on the following pages are intended to be used with kiln samples, the changes in temperature and humidity being made as the moisture content of the samples passes the various stages. All of the schedules are safe. It is possible to obtain good results with faster drying, but the use of schedules more severe than those recommended will require most careful judgment on the part of the kiln operator.

The schedules of widest application are the hardwood schedules, originally intended for furniture stock, and the softwood schedules, which provide for drying at higher temperatures. These two series supplement each other and are numbered consecutively, No. 000 of the softwood schedules being the most severe and No. 8 of the hardwood schedules being the mildest.

Preliminary steaming has been mentioned for the relief of air-drying stresses in partly dry stock. This treatment is also recommended for green stock, not to relieve stresses, but to warm the stock thoroughly before the drying operation begins. It is not necessary to steam green stock so long as partly seasoned stock, 1 hour per inch of thickness being sufficient. The temperature may be from 10 to 15° above the starting point of the schedule.

All of the drying schedules are equally applicable to green and to partially dried stock. The moisture of the stock as it enters the kiln determines where to start on the schedule. Start on the point of the schedule corresponding to that moisture content, disregarding everything above that point, just as if the previous drying had been done in the kiln in accordance with the upper part of the schedule.

HARDWOOD SCHEDULES.

The following instructions apply specifically to the hardwood schedules in Table 2. These are intended to be used on all lumber up to about 6/4 inches in thickness. Thicker stock can be dried by using a schedule one number higher (milder) for each added inch in thickness. It is intended that only one species and one thickness be dried at a time. The wet-bulb temperature is included in the schedule merely for the sake of convenience. Schedules 3 and 4 have been modified somewhat to conform to the other schedules in the group.

TABLE 2.—*Hardwood schedules 1 to 8.*

[D=dry-bulb temperature in degrees F.; W=wet-bulb temperature in degrees F.; H=per cent relative humidity.]

Moisture per cent.	Schedule 1.			Schedule 2.			Schedule 3.			Schedule 4.		
	D.	W.	H.	D.	W.	H.	D.	W.	H.	D.	W.	H.
Initial	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
Moisture per cent.	**Schedule 5.**			**Schedule 6.**			**Schedule 7.**			**Schedule 8.**		
	D.	W.	H.	D.	W.	H.	D.	W.	H.	D.	W.	H.
Initial	120	113	80	115	109	80	110	105	85	105	101	85
40	125	116	75	120	111	75	115	109	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	111	45	130	109	50
10 to final	150	112	30	145	108	30	140	108	35	135	107	40

TABLE 3.—*Index of drying schedules to use with various hardwood species (up to 6/4 inch thick.)*

Species.	Hardwood schedule.	Remarks.	Species.	Hardwood schedule.	Remarks.
Ash	2		Holly, American	4	
Basswood	1		Hornbeam (ironwood).	4	
Beech	3	Relieve stresses often.	Locust	5	
Birch	1		Magnolia	4	
Boxwood	5	Squares or quartered stock only.	Mahogany	4	
Butternut	2		Maple (hard and soft).	3	
Cherry, black	5		Oak, red and white	6	Northern highland stock.
Chestnut	2	Relieve stresses frequently.	Do	7	Northern lowland stock.
Cotton gum (tupelo).	3		Do	7	Southern highland stock.
Cotton wood	2		Do	8	Southern lowland stock.
Elm	2		Osage orange	5	
Gum, red	2	Including "sap gum."	Persimmon	5	
Gum, black	3		Poplar, yellow	1	
Hackberry	2		Sycamore	5	
Hickory	5		Walnut, black	5	
			Willow	2	

SOFTWOOD SCHEDULES.

Because of large variations in the initial or "green" moisture content existing among the various softwoods, it has been found expedient to divide softwood schedules into several divisions, as shown in Table 4. The divisions of each schedule differ from one another only in the moisture contents at which the changes in temperature and humidity are to be made. It has also been found desirable to make specific recommendations for the drying of different grades and sizes of various species. Thus, while the basic principles in the construction and use of both hardwood and softwood schedules are identical, there is a slight difference in arrangement.

The softwood schedules are used as follows: Find in the species table (Table 5) the size and kind of stock to be dried and note the schedule and division given opposite it. Use this division without reference to any of the other divisions in the schedule. Suppose 4/4 Douglas fir is to be dried. The table shows two schedules, 000–IV and 00–IV, for 4/4 to 6/4 Douglas fir. The more severe one is for the ordinary run of stock and the milder one for wide flat-grain stock. There is also a general note at the foot of Table 4 stating that in drying vertical-grain flooring strips the temperature may be raised 10° F. higher than the schedule after the stock has dried down to 25 per cent. Therefore, if the 4/4 Douglas fir is flooring strips, use Schedule 000–IV, Table 4, raising the temperature to 200° F. at 25 per cent and to 210° F. at 13 per cent. If it is ordinary stock, use Schedule 000–IV without change, and if it is wide flat-grain stock, use 00–IV. These softwood schedules are not intended for use with low grades of stock. Schedules for low grades are being developed by the Forest Products Laboratory.

The initial entering-air humidity of 85 per cent given in the softwood schedules is an ideal which can be maintained only under the most favorable conditions. With fast-drying woods, the humidity of the air increases rapidly in its passage through the lumber and, unless the circulation be very rapid, air entering the lumber at 85 per cent humidity may become saturated before it leaves the pile. This causes uneven drying. Further, differences in temperature in various parts of the kiln cause comparatively wide variations in drying rate at high humidities. It is, therefore, impractical to use such high initial entering-air humidities in kilns which do not have very fast circulation and very uniform temperature throughout. Lower initial entering-air humidities must then be used in kilns with slow circulation and in kilns lacking uniformity in temperature. The slow circulation compensates in large measure for the lower entering-air humidity, since the humidity rises rapidly as the air passes through the pile, and only a small portion of the lumber is subjected to the low humidity.

In drying thin stock of a number of species, particularly southern pine and Douglas fir, it is possible to secure first-class results with lower initial entering-air humidities (as low as 70 per cent) even in kilns with extremely rapid circulation.

The operator will need to experiment more or less to determine the particular initial entering-air humidity which will give the best results with the particular stock to be dried and the equipment available.

TABLE 4.—*Softwood schedules Nos. 0, 00, and 000.*

SCHEDULE 0.

Moisture content at which changes should be made.			Dry bulb.	Wet bulb.	Relative humidity.
Div. I.	Div. II.	Div. III.			
Per cent.	*Per cent.*	*Per cent.*	°*F.*	°*F.*	*Per cent.*
Initial.	Initial.	Initial.	135	129	85
30	25	20	150	132	60
20	16	13	175	140	40
15	12	10	175	130	30

SCHEDULE 00.

Moisture content at which changes should be made.				Dry bulb.	Wet bulb.	Relative humidity.
Div. I.	Div. II.	Div. III.	Div. IV.			
Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	°*F.*	°*F.*	*Per cent.*
Initial.	Initial.	Initial.	Initial.	160	154	85
40	35	30	25	170	150	60
20	16	13	13	180	135	30

SCHEDULE 000.

Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	°*F.*	°*F.*	*Per cent.*
Initial.	Initial.	Initial.	Initial.	180	173	85
40	35	30	25	190	168	60
20	16	13	13	200	150	30

Temperatures for vertical-grain flooring strips may be 10° higher than those in the schedule after the stock has dried to a moisture content of 25 per cent.

TABLE 5.—*Index of drying schedules for use with various species and thicknesses of softwood lumber.*

Species.	Size.	Softwood schedule.	Remarks.
Cedar, Port Orford	4/4–6/4	00–III	
	7/4–9/4	00–IV	
Cedar, western red	4/4–6/4	00–IV	Wide, clear (after sinkers are removed).
	4/4–6/4	0–III	Sinker.
	7/4–9/4	00–III	Free from sinkers.
	7/4–9/4	0–III	Sinker.
	10/4–12/4	0–III	
Cedar, white	4/4–6/4	00– II	Flat grain.
	7/4–9/4	00–III	
	10/4–12/4	0– II	
Cypress, bald	4/4–6/4	00– I	
	7/4–9/4	00– II	
	10/4–12/4	0– I	
Douglas fir	3-1/2–4-1/2	00–IV	Cross arms.
	4/4–6/4	000–IV	
	4/4–6/4	00–IV	Wide, flat grain.
	7/4–9/4	00–IV	
	10/4–12/4	0–III	

TABLE 5.—*Index of drying schedules, etc.*—Continued.

Species.	Size.	Softwood schedule.	Remarks.
Fir, balsam	4/4–6/4	000– I	Wide flat grain.
	7/4–9/4	000– II	Do.
	10/4–12/4	0– I	
Fir, lowland white	4/4–6/4	000– I	
	4/4–6/4	00– I	Do.
	7/4–9/4	000– II	
	7/4–9/4	00– II	Do.
	10/4–12/4	0– I	
Fir, noble	4/4–6/4	000–III	
	4/4–6/4	00–III	Do.
	7/4–9/4	000–IV	
	7/4–9/4	00–IV	Do.
	10/4–12/4	0–III	
Fir, white	4/4–6/4	000– I	
	4/4–6/4	00– I	Do.
	7/4–9/4	000– II	
	7/4–9/4	00– II	Do.
	10/4–12/4	0– I	
Hemlock (eastern)	4/4–6/4	00– I	Uppers.
	7/4–9/4	00– II	Do.
	10/4–12/4	0– I	
Hemlock, western	4/4–6/4	000– I	
	7/4–9/4	000– II	
	10/4–12/4	0– I	
Larch, western	4/4–6/4	00– II	Do.
	7/4–9/4	00–III	Do.
	10/4–12/4	0– II	
Pine, Norway	4/4–6/4	000– II	
	7/4–9/4	000–III	
	10/4–12/4	0– II	
Pine, southern yellow	4/4–6/4	000– I	
	7/4–9/4	00– I	
	10/4–12/4	0– I	
Pine, western yellow	4/4–6/4	000– I	
	7/4–9/4	00– I	
	10/4–12/4	0– I	
Pine, white (eastern and western)	4/4–6/4	00– II	Do.
	7/4–9/4	00–III	Do.
	10/4–12/4	0– II	
Redwood	4/4–6/4	00– I	Free from sinkers.
	4/4–6/4	0– I	Sinker.
	7/4–9/4	00– II	Free from sinkers.
	7/4–9/4	0– II	Sinker.
	10/4–12/4	0– I	
Spruce, Engelmann	4/4–6/4	00– II	
	7/4–9/4	00–III	
	10/4–12/4	0– I	
Spruce, red	4/4–6/4	00–III	
	7/4–9/4	00–IV	
	10/4–12/4	0–III	
Spruce, Sitka	4/4–6/4	000– II	
	4/4–6/4	00– II	Wide, flat grain.
	7/4–9/4	000–III	
	7/4–9/4	00–III	Do.
	10/4–12/4	0– II	
Spruce, white	4/4–6/4	000–III	
	4/4–6/4	00–III	Do.
	7/4–9/4	000–IV	
	7/4–9/4	00–IV	Do.
	10/4–12/4	0–III	
Tamarack	4/4–6/4	00– II	
	7/4–9/4	00–III	
	10/4–12/4	0– II	

The hardwood schedules and the softwood schedules together cover almost the entire temperature range commonly used in kiln drying. They range from an initial temperature of 105° F. in hardwood schedule 8, Table 2, to a final temperature of 210° F. for vertical-grain flooring strips in softwood schedule 000, Table 4. While most drying can be reasonably well done by the use of the proper one of these 11 schedules, it has been found advantageous to develop special schedules for certain purposes. A number of these follow.

COMMON GRADES OF DOUGLAS FIR.

The kiln drying of Douglas fir common is a problem quite different in several respects from most seasoning problems. One of the most important considerations is to keep the knots from falling out, and another is the fact that it is not necessary to dry the stock lower than about 15 per cent. This latter makes it much easier to keep the knots from falling out, but brings the added complication that it is very difficult to dry a load of mixed heart and sap to a uniform moisture content as high as 15 per cent. To prevent excessive shrinkage of the knots, it is necessary to maintain a high humidity throughout the drying. The maximum temperature is more or less definitely limited because it is undesirable to use temperatures high enough to melt the resin from around the knots. The need for reasonable uniformity in moisture content at the end of the run and the use of high humidity make it necessary to have a very rapid and uniform circulation readily reversible in direction, and an accurate control of temperature and humidity.

Douglas fir common schedules were developed in a semicommercial unit of the Forest Service internal-fan kiln, and this is the only type which can at present be safely recommended for this class of work. A constant temperature of 175° F. may be used throughout the entire drying period. In the case of 1 by 6, 1 by 8, 2 by 4, and 2 by 6 inch stock the humidity may be kept constant at 70 per cent. For 1 by 10, 1 by 12, 2 by 8, 2 by 10, and 2 by 12 inch stock, it is better to use a humidity of 80 per cent for the first half of the run, dropping then to 70 per cent. The drying time will vary considerably with the size and shape of the stock. For 1 by 8 inch material it should be about 32 hours, with a final average moisture content of 15 per cent.

AIRCRAFT STOCK.

It has been proved by many kiln runs and by many thousands of strength tests that the aircraft schedules given below, if carefully followed, will produce stock that is just as strong in every way as the most carefully air-seasoned stock. These schedules were prepared by the Forest Products Laboratory, and since 1917 they have been the standard for the Army and Navy air services. They are intended to be used on stock 3 inches or less in thickness. For thicker stock the temperature is to be lowered 5° F. for each inch increase in thickness.

TABLE 6.—*Aircraft Schedule I.*

Stage of drying.	Drying conditions.		
	Maximum dry-bulb temperature.	Minimum relative humidity.	Wet bulb.
	° *F.*	*Per cent.*	° *F.*
At the beginning	120	80	113
After fiber saturation is passed (25 per cent)	125	70	114
At 20 per cent moisture	128	60	112
At 15 per cent moisture	138	44	112
At 12 per cent moisture	142	38	112
At 8 per cent moisture	145	33	110
Final	145	33	110

SPECIES FOR WHICH AIRCRAFT SCHEDULE I IS APPLICABLE.

Ash, white, blue, and Biltmore.
Birch, yellow.
Cedar, incense.
Cedar, northern white.
Cedar, western red.
Cedar, Port Orford.
Cypress, bald.
Pine, sugar.
Pine, white (eastern and western).
Spruce, red and white.
Spruce, Sitka.

TABLE 7.—*Aircraft Schedule II.*

Stage of drying.	Drying conditions.		
	Maximum dry-bulb temperature.	Minimum relative humidity.	Wet bulb.
	° *F.*	*Per cent.*	° *F.*
At the beginning	105	85	100
After fiber saturation is passed (25 per cent)	110	73	101
At 20 per cent moisture	117	62	103
At 15 per cent moisture	129	46	106
At 12 per cent moisture	135	42	109
At 8 per cent moisture	135	40	107
Final	135	40	107

SPECIES FOR WHICH AIRCRAFT SCHEDULE II IS APPLICABLE.

Cherry, black.
Douglas fir.
Mahogany.
Oak, white, and red.
Walnut, black.
Maple (hard and soft).

OAK WHEEL BLANKS.

Several schedules have been developed for oak artillery-wheel stock—club-turned spokes and bent rims. Since oak is extremely variable in its drying characteristics, extreme care must be exercised in using these schedules. Steaming of bent rims must be done with caution, since over-steaming will relieve the set caused by the bending, thus allowing the stock to straighten out. Steaming for from 1 to 2 hours at 160 to 180° F. may be done periodically after the outer one-half inch has dried below 25 per cent.

TABLE 8.—*Drying schedule for 56-inch artillery wheel spoke blanks, oak, 2¾ by 2¾ by 26 inches.*

Moisture content.	Dry bulb.	Wet bulb.	Relative humidity.
Per cent.	°*F.*	°*F.*	*Per cent.*
80	105	100.5	85
60	106	100.5	82
40	107	100.5	79
30	110	101.5	74
25	115	102	63
20	120	102	54
15	131.5	104	40
10	142	106	30

TABLE 9.—*Drying schedule for 60-inch artillery wheel spoke blanks, oak, 3¾ by 3¾ by 26 inches.*

Moisture content.	Dry bulb.	Wet bulb.	Relative humidity.
Per cent.	°*F.*	°*F.*	*Per cent.*
80	100	96	85
60	101	96	82
40	102	96	80
30	105	97	75
25	110	98	64
20	115	99	55
15	127	101	40
10	140	103	29

TABLE 10.—*Drying schedule for 56-inch artillery wheel rims, bent oak, 3½ by 3½ by 56 inches.*

Moisture content.	Dry bulb.	Wet bulb.	Relative humidity.
Per cent.	°*F.*	°*F.*	*Per cent.*
70	90	83	75
65	95	88	75
60	100	93	75
55	105	97	75
50	110	102	75
35	115	105	70
30	120	105	60
20	130	106	45
15	140	108	35
10	150	107	25

TABLE 11.—*Drying schedule for 60-inch artillery wheel rims, bent oak, 3¾ by 3¾ by 60 inches.*

Moisture content.	Dry bulb.	Wet bulb.	Relative humidity.
Per cent.	°*F.*	*F*°.	*Per cent.*
70	85	78	75
65	90	83	75
60	95	88	75
55	100	93	75
50	105	97	75
35	110	100	70
30	115	100	60
20	125	102	45
15	135	104	35
10	145	104	25

WALNUT GUNSTOCKS.

Walnut for gunstocks is usually cut in the form of rough blanks, steamed to darken the sapwood, and then shipped to the gunmaker for drying. All stocks to be kiln dried should be end dipped in hot pitch before loading into the kiln. A schedule that has been used successfully in the drying of many thousand blanks is given in Table 12.

MAPLE SHOE-LAST BLOCKS.

Maple shoe-last blocks, end dipped and piled on stickers, can be dried successfully under hardwood schedule 7.

PENCIL CEDAR.

Pencil cedar, the southern juniper used for pencils and cedar chests, is quite difficult to dry and care must be used to prevent the shelling off of the streaks of sapwood which will result from too steep a moisture gradient and too severe casehardening. A special schedule (Table 13) has been prepared for the drying of 1-inch boards of this species; it covers about the same range as hardwood schedule 3.

The cedar oil present in this wood causes a variable error in making moisture determinations, since it is driven off with the moisture in the drying oven, resulting in a calculated moisture content higher than the actual. This error is usually not more than 2 or 3 per cent, though it may be as great as 5 per cent.

TABLE 12.—*Drying schedule for black walnut gunstock blanks.*

Moisture content.	Dry bulb.	Wet bulb.	Relative humidity.
Per cent.	*°F.*	*°F.*	*Per cent.*
Initial.	110	102	75
35	113	102	68
20	115	104	67
15	117	103	62
10	130	105	43
8 to final.	140	107	34

TABLE 13.—*Drying schedule for 1-inch pencil cedar.*

Moisture content (heart samples).	Dry bulb.	Wet bulb.	Relative humidity.
Per cent.	*°F.*	*°F.*	*Per cent.*
Initial.	140	128	70
20	150	127	50
15	155	124	40
10 to final.	160	115	25

PLYWOOD PANELS.

The drying of plywood panels is a special problem in which simplicity of control and operation are important. Panels can be dried successfully under widely varying conditions of temperature and humidity, largely because the original moisture content is low. However, the effect of the drying schedule upon the properties of the glue must be taken into consideration. It has been found possible to dry panel stock at a constant temperature and a constant humidity, the latter corresponding to a moisture content about 3 per cent below that to which the panels are to be dried. Thus, if the panels are to come down to 10 per cent, a humidity corresponding to about 7 per cent would be used. (See Fig. 3.) At a temperature of 125° F., which is considered suitable for this work, the humidity corresponding to 7 per cent moisture is about 43 per cent. A temperature of 125° F. and a humidity of 43 per cent will dry the average half-inch panel down to 10 per cent moisture in a few hours; and if the stock be left in the kiln considerably longer, no particular damage will result, since the drying rate below the desired 10 per cent will be increasingly slow.

BENT STOCK.

Bent stock of various kinds may be dried according to the lumber schedules applying to species and thickness, but caution must be exercised in the matter of steaming, since the excessive use of steam in the early stages of the drying is very apt to result in straightening out the stock.

SUPERHEATED-STEAM DRYING.

All of the schedules so far presented are adapted to use in "air" kilns. It is possible to accomplish drying in superheated steam, and several types of superheated-steam kilns are now in use. Live steam superheated by means of coils carrying high-pressure steam is turned into the kiln. The degree of superheat, or the temperature above the boiling point at atmospheric pressure, governs the drying rate, and no further humidity control is needed. Drying temperatures usually range between 225° and 240° F., depending upon the class of wood being dried and upon the boiling point at atmospheric pressure. Sometimes an unusual amount of air is mixed with the steam in the kiln, with the result that the drying capacity of the atmosphere is correspondingly increased. Such cases are indicated by a wet-bulb reading below the boiling point, and so a lower degree of superheat must be carried.

Species now being dried commercially by superheated steam are principally Douglas fir and western hemlock. Other species for which it may be suitable are western yellow pine, sugar pine, eastern white pine, southern yellow pines, most of the spruces, and some of the true firs. In some of these woods a certain amount of darkening of the surface, especially of the sapwood, may be expected.

DRYING PERIODS.

The extreme variability of the drying time with individual lots of stock and with different types of equipment, added to the variable time consumed in steaming and conditioning treatments, makes a tabulation of drying time of doubtful value. About the fastest drying time for lumber of which the Forest Products Laboratory has record is the drying of 1 by 4 inch Douglas fir flooring strips in 24 hours; the slowest, the drying of some southern oak wagon bolsters, which were in the kiln almost a year, and then were not drier than 15 per cent.

The average periods required to dry several common hardwoods are presented in Table 14. While these drying rates can readily be secured in kilns with high velocity of circulation, it does not necessarily follow that they can be duplicated under all conditions.

TABLE 14.—*Average drying time for 1-inch stock, green from the saw to 5 per cent moisture.*

Species.	Original moisture content.	Drying time.	Species.	Original moisture content.	Drying time.
	Per cent.	*Days.*		*Per cent.*	*Days.*
Yellow birch	80	21	Oak, red and white:[1]		
Red gum	100	26	Northern highland stock	80	40
Sugar maple	80	23	Northern lowland stock Southern highland stock	80	48
Mahogany	80	22			
Black walnut	80	30	Southern lowland stock	80	56

[1] Plain sawed only; quartered takes about one-third longer with the same schedule.

Maple last blocks can be dried in about 60 days, and walnut gunstock blanks in about the same length of time. Heavy oak wagon stock takes from one and one-half to two months per inch of thickness to dry down to 15 per cent moisture. The common drying times for 1-inch softwoods, such as Douglas fir, the southern yellow pines, and the white pines, run from two to four days, there being exceptions in both directions. Quartered stock may usually take a higher schedule, and thus make up for some of its natural slowness in drying. It has already been mentioned that certain woods, like redwood, western red cedar, and cypress, are subject to collapse at high moisture and temperatures. The hardwoods, as a rule, are more plastic when hot and moist than the conifers, and in consequence are more easily bent. This fact is taken advantage of in the drying of red gum, for instance, which has a natural tendency to warp, but seems plastic enough at high temperatures to overcome this tendency, drying with but little trouble if properly "stickered."

FINAL MOISTURE CONTENT.

As has been stated, the final moisture content should be slightly lower than that which the finished product would naturally have after it had been in service for some time. The first thing to consider, therefore, is the ultimate use to which the finished product is to be put and the climatic conditions at the point of use. Whether the product is for use indoors or outdoors also is a determining factor. Sometimes it is desired to have the stock swell after it is put in service, and in these cases it is dried lower than it otherwise would be.

A study of the weather reports for various parts of the country shows that the average atmospheric temperature and humidity conditions vary greatly in the different regions and that they also have important seasonal variations in each place. The relative humidities for a number of cities are given in Table 15 to show these variations.

While it is not possible to lay down any hard-and-fast rules for proper final moistures, the information in Table 16, based on average conditions in the East and Middle West, may serve as a guide in the drying of stock for specific purposes.

TABLE 15.—*Mean relative humidities at various points in the United States.*

City.	Mean relative humidity, per cent.				
	Winter.	Spring.	Summer.	Fall.	Annual.
Cleveland, Ohio	77	72	70	74	73
Denver, Colo	54	51	49	46	50
El Paso, Tex	45	27	41	46	40
Galveston, Tex	84	82	79	78	81
Madison, Wis	82	80	71	75	74
Memphis, Tenn	74	69	75	71	72
New Orleans, La	79	75	78	77	77
New York, N. Y	73	70	74	75	73
Pensacola, Fla	80	77	79	75	78
Phoenix, Ariz	47	32	32	41	38
Portland, Oreg	84	72	67	79	75
San Diego, Calif	74	78	81	78	78
Spokane, Wash	82	61	47	67	64
Wilmington, N. C	78	78	83	81	80

TABLE 16.—*Final moisture content of stock for various uses.*

	Final moisture, per cent.
Furniture	5 to 7
Interior woodwork	6 to 8
Vehicle stock, except wheel and box parts	15 to 18
Vehicle wheel and box parts	8
Gunstocks	6 to 8
Aircraft (Army)	8
Aircraft (Navy)	12
Outdoor sporting goods (bats, golf sticks, tennis rackets, polo mallets, etc.)	10
Musical instruments	5 to 7
Softwoods for long freight shipments	12 or less
Miscellaneous outdoor material	12

NOTE.—Thoroughly air-dried wood ranges from 12 to 18 per cent moisture content, depending on local climatic conditions.

MOISTURE SPECIFICATION.

Much of the trouble experienced in the use of lumber results from improper seasoning, and many disputes arise from a misunderstanding of the use or meaning of broad and loose terms, such as "kiln dried" or "air dried," or even "thoroughly kiln dried" or "thoroughly air dried." These terms are so indefinite that they really are without significance. There is now no universally accepted standard moisture specification, and each purchaser must draw his own. A moisture or seasoning specification is fully as important as a grade specification—sometimes much more important—and it is essential that the purchaser know that he is getting stock properly seasoned for his use.

A number of wood users throughout the country are now specifying the amount of moisture that the stock shall contain at the time of shipment or receipt, which is excellent in every way. It is not always enough, however, since there may be a vast difference as to seasoning between two lots of stock dried down to the same moisture. The specification should include a clause concerning the presence of drying stresses, based upon the use of stress sections. To be complete and accurate such a clause would be quite lengthy and cumbersome, and therefore more or less impractical. However, a simple statement that the wood shall be free from injurious drying stresses, while very broad, affords reasonable protection to the purchaser.

STORAGE OF KILN-DRIED STOCK.

Whenever possible, the stock should be cooled before it is removed from the kiln, since exposure of the hot stock to the cool air is liable to cause checking. All of the boards in the kiln are not of the same moisture content at the end of the drying period. It is therefore necessary that they be held in storage until both dry and moist boards have the same moisture content. The required time for storage varies with conditions. Where little accuracy is needed, as with softwood, the stock need be stored but a short time. One week is considered long enough for furniture stock, and two weeks are specified for aircraft stock. Careful conditioning in the kiln reduces the required time of storage.

Dimension stock and finished wood products which have to be stored should be held in the proper atmospheric conditions, or they will absorb or lose too much moisture. Later, when the stock is manufactured and put into actual use, this loss or gain may damage its serviceability. Stock taken from damp, unheated storerooms into heated shops is too moist for the best utility. The moisture is unevenly distributed not only in the individual pieces of stock but in the entire pile. The boards on the sides and top have a different moisture content from those in the pile. Products made from such stock may be end-checked or distorted. Short stock with large end surfaces warps when stored in a damp atmosphere. Such stock used in chair seats of the common saddle style, if dried too rapidly, shows end checks and open glue joints.

KILN TYPES.

Dry kilns for wood may be grouped in two general classes, commonly known as progressive and compartment. Progressive kilns are sometimes called "continuous" kilns, and compartment kilns are known as "box" or "charge" kilns. The differences between the two types depend on the method of handling the stock through the kiln. In the progressive kiln (Fig. 6), the stock enters at one end and moves progressively through to the other end, emerging, presumably dry, at the proper time. The stock is fed in and removed periodically, and the process is continuous. In the compartment kiln the entire kiln is loaded at one time, and the charge remains in place throughout the drying period. In the progressive kiln the temperature and humidity at any point remain constant, but the kiln is hotter and drier at the discharge end than at the receiving end; in the compartment kiln the temperature and humidity are as nearly uniform as possible throughout the kiln at any given time, and are changed from time to time as the stock dries.

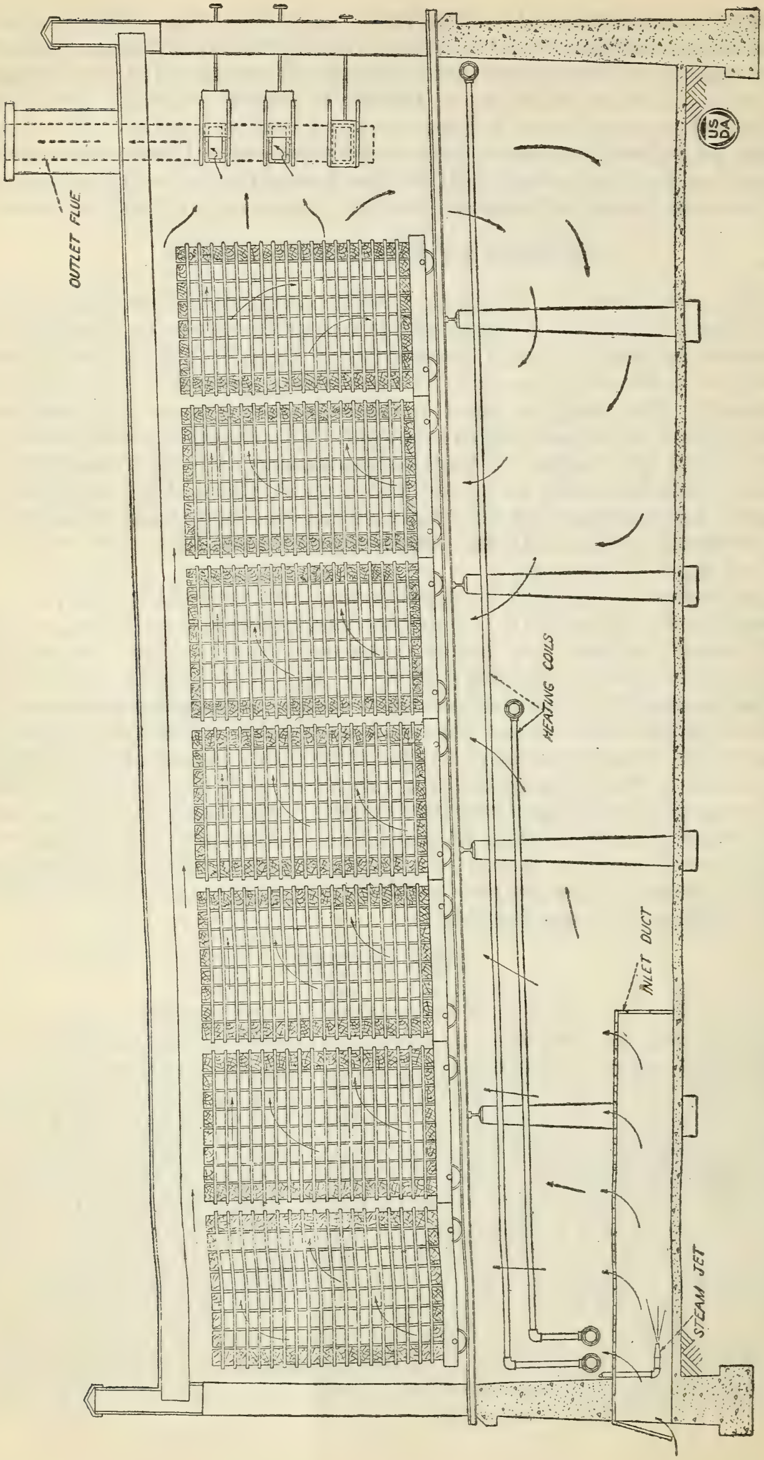


FIG. 6.—Longitudinal section of progressive kiln. The lumber moves from right to left, and the general air circulation is from left to right.

Since the temperature and humidity vary from end to end in a progressive kiln, the circulation of air must, in part at least, be longitudinal; the circulation in a compartment kiln may be in almost any desired direction but is usually some kind of cross circulation.

The progressive kiln finds its greatest field of usefulness in those places where drying requirements are not exacting and quantities of the same class of stock are to be dried continuously. The compartment kiln is adapted to all classes of drying. The heat efficiency of the progressive kiln is generally greater than that of the compartment type, but its accuracy of control and its flexibility are much less.

PROGRESSIVE KILNS.

Almost all progressive kilns are of the natural-draft type, although a number of progressive blower kilns have been built. The air usually enters through ducts at the discharge or dry end of the kiln, is heated by steam coils under the lumber, and humidified by means of a steam jet. It then passes upward through the lumber, horizontally the length of the kiln, and finally out into the atmosphere at the green end through chimneys provided for this purpose. As it progresses through the kiln it becomes cooler and more moist, the cooling itself increasing the relative humidity and the moisture evaporated from the wood adding its share. Thus the severity of its action is automatically reduced as the air reaches the greener lumber. The extent of this reduction depends upon the individual kiln design, upon outside atmospheric conditions, and upon the kind, thickness, and initial moisture content of the stock being dried. The longer the kiln the more moist and the cooler will be the air at the green end. Very wet, easily dried stock, or a reduction of heating surface at the green end will have the same effect. A reduction of the rate of circulation may have a similar effect. To adjust conditions so that moisture and humidity are in accordance with the drying schedule throughout the length of the kiln is usually very difficult, since ordinarily the temperature and humidity can each be regulated at one point only. They can both be controlled at one end or at opposite ends, as seems best under the circumstances. Occasionally steam jets can be fitted along the length of the kiln to increase the humidity as the air moves toward the green end, and in some kilns vents are provided along the length so that some of the air can be exhausted before it reaches the green end. There is seldom any provision, however, for regulating the temperature along the length of the kiln.

The methods of producing circulation and ventilation vary considerably among the kiln manufacturers, just as details of the heating elements differ. The general principles and operation are, however, much more nearly alike than would appear at first sight.

Progressive kilns are always provided with tracks, and the lumber is rolled through on trucks or bunks. To provide for preliminary steaming, in many ventilated progressive kilns a steaming chamber can be formed by dropping a curtain between two trucks near the green end. Steaming in this curtained-off space is apt to upset the conditions in the kiln, increasing the humidity throughout. Further-more, trouble may result if the steamed stock is not carefully cooled in saturated air to the drying temperature before the curtain is rolled up and drying resumed.

VENTILATED COMPARTMENT KILNS.

Ventilated compartment kilns also vary considerably in detailed design. Most of them, however, are arranged for cross circulation,

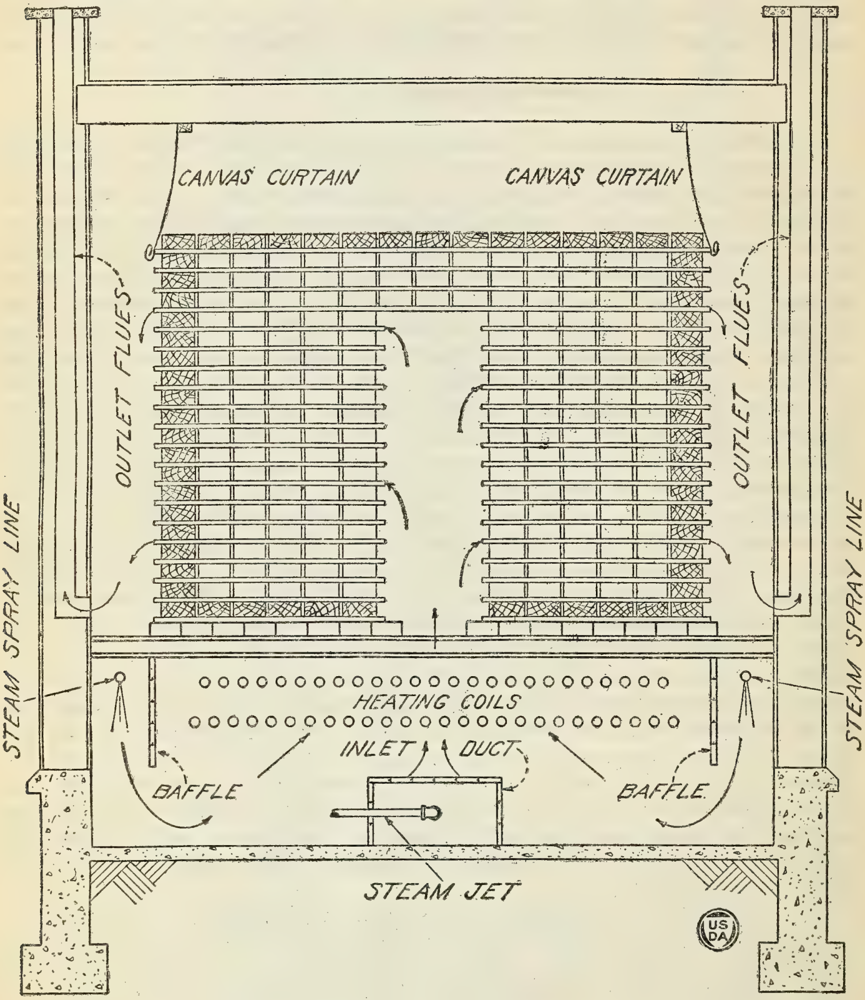


FIG. 7.—Cross section of ventilated compartment kiln.

and the fresh air is usually brought in at the bottom and distributed throughout the length of the kiln by means of ducts under the lumber. Ventilating flues are usually provided along the length of the kiln on both sides, and outlets to these made at various heights and in various manners, in accordance with the ideas of the individual manufacturer. The entire possible range of locations for these outlets is represented in commercial practice, at least one manufacturer drawing the air from under the lumber on the floor of the kiln, and another having the vents located in the roof. Almost as wide a range is to be found in the location of the inlet openings in the kiln; although the air may be brought into the kiln in ducts running along the floor, several kiln designers carry it up in risers at various points along the length of the kiln and deliver it at convenient heights above the rails. While it is usual to provide considerable outlet flue area, there is a wide difference in the amount of inlet area. One maker provides none at all, another allows about a square foot for a kiln 70 feet long, and a third insists upon at least 4 or 5 square feet for a similar kiln only 40 feet long.

The cross circulation in most ventilated compartment kilns depends largely on the draft of the chimneys or vents. It may be assisted by steam jets placed in air intakes or outlets, and even by the steam used in the kiln for humidification. If the circulation caused by the cooling of the air as moisture is evaporated from the wood can be made to augment the draft of the chimneys, the maximum circulation and the most satisfactory drying will be secured. Figure 7 shows the general construction of a ventilated compartment kiln. This figure is a composite representing no particular make of dry kiln. While it is not offered as a scale drawing for an ideal kiln, very good results can be obtained from kilns built upon the principles illustrated.

The principles of the kiln can best be understood by following the arrows which indicate the air flow. The air enters through the inlet duct, which has suitable openings along its length. The steam jet located in the inlet duct where it enters the kiln increases the rate of flow. The air from the duct passes over the heating coils and into the chimney or flue in the center of the lumber pile, thence outward and downward. Some is exhausted through the flue outlets and some returns past the steam-spray line and the baffles to the heating coils and around again. The downward-pointing steam sprays are always used for steaming and high-humidity treatments, and may be used to assist the steam jet or to act in its place during the drying period. The baffles prevent the air from rising in any passages except the chimney, thus assisting materially in producing and maintaining the desired air flow. They also prevent the steam from spraying against the lumber or the heating pipes. The floor boards under the lumber pile protect the lower layers from direct radiation and prevent the short-circuiting of the air through them.

WATER SPRAY AND CONDENSER KILNS.

The water-spray kiln was invented and developed at the Forest Products Laboratory. As ordinarily designed it embodies the principles of the condenser kiln, and the two may be described together. Figure 8 is a cross section of a typical water-spray kiln. The circulation is similar to that in Figure 7, although there are no intakes or outlets. The baffles at the bottom of the spray chambers prevent spray or mist from passing along with the air and thus increasing the humidity beyond the desired point. The condensers and the water sprays are located close together, and both serve to regulate the humidity and increase the circulation. The sprays and condensers are usually used for high and low humidity, respectively. When the sprays are in use the air is cooled to the dew point each time it passes through the circuit; but with the condensers no attempt is made to do this, and condenser water just sufficient to keep the humidity down to the desired point is used. A kiln designed for the use of condensers only, need have neither sprays nor baffles, and the height of the condensers may be varied to meet individual requirements. Water-spray and condenser kilns require a supply of cold

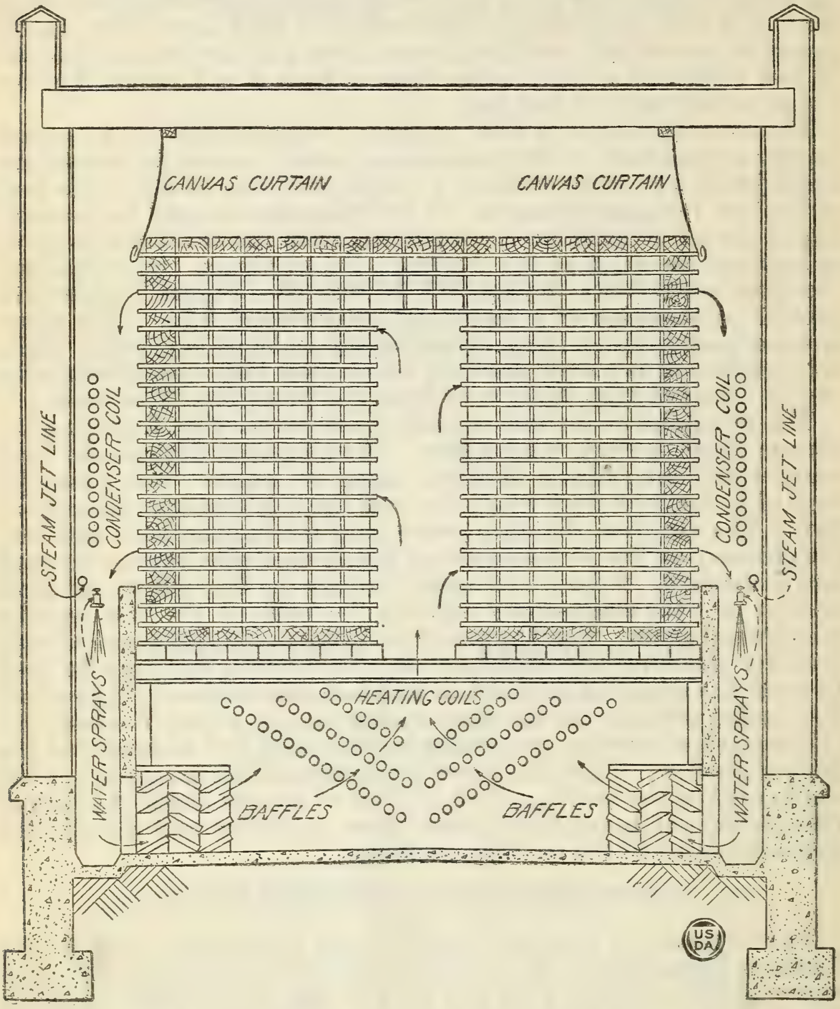


FIG. 8.—Cross section of water-spray compartment kiln.

water in addition to the steam or other source of heat. In the condenser kiln the water is ordinarily run out as waste after passing through the coils, but in the water-spray kiln it is usually returned from the spray chambers and recirculated by means of pumps, enough cold water being added to bring the temperature down to the desired point. The humidity in the water-spray kiln, when using the sprays, is controlled by regulating the water temperature; and since the air leaving the sprays and passing through the baffles is at its dew point, a recording thermometer is usally placed in the baffles. This thermometer shows the dew point rather than the wet-bulb temperature, and for convenient use in water-spray kilns, the drying schedules should be modified to show the dew-point temperature as well as the wet-bulb temperature.

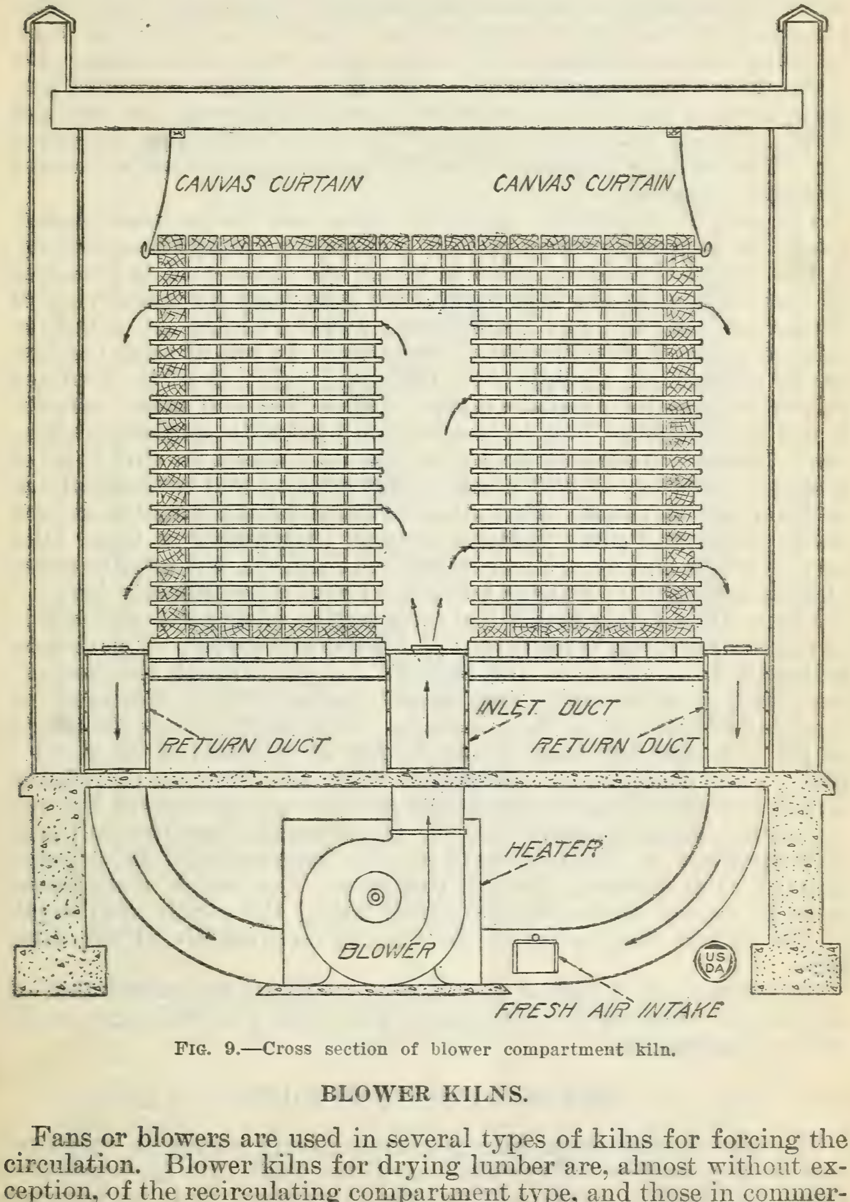


FIG. 9.—Cross section of blower compartment kiln.

BLOWER KILNS.

Fans or blowers are used in several types of kilns for forcing the circulation. Blower kilns for drying lumber are, almost without exception, of the recirculating compartment type, and those in commercial use are mostly of the external-blower type. Figure 9 is a diagrammatical cross section of a blower kiln and illustrates the path of the air through the system. The blower is usually placed outside the kiln in an operating room at one end, discharging and returning through ducts running the full length of the kiln. The heating units may be in a box located at the blower, or they may be arranged in almost any desired form in the kiln proper. Humidity may be increased by means of a steam jet located in the return duct and decreased by opening a fresh-air intake also in the return duct. One manufacturer prefers to decrease the humidity in his blower kilns by using canvas curtains to form the outer walls of the flues. Between these curtains and the side walls of the kiln are ventilated passages about a foot wide. Moisture transfuses through the curtains from the inside out, and is carried away on the ventilating current of air. This air may be drawn from the operating room and exhausted through a chimney.

The rate of circulation in blower kilns may be increased indefinitely, but beyond a certain point it is difficult to maintain unformity. A few forced-circulation kilns in which the circulation is produced by fans located in the kiln itself have been used for the drying of lumber and veneer; and several such types of kilns are being developed at the Forest Products Laboratory. In one of these the fans are all mounted on a single shaft running lengthwise of the kiln and driven by a motor located outside. Office fans and other self-contained motor-driven fans have also been used with considerable success. There are several points of special interest in this type of forced circulation, of which ease of installation and reversal of circulation are foremost. Periodical reversal of the circulation produces faster and more uniform drying. Humidity in these kilns may be controlled by any one of several methods, but usually steam alone is sufficient, as leakage keeps the humidity sufficiently low.

Figure 10 is a diagrammatical cross section of an internal-fan kiln of the compartment type, arranged for flat-end piling. The double-pointed arrows illustrate the path of the air through the lumber; the direction of air travel may be reversed at will by reversing the direction of rotation of the fan shaft. This shaft extends the length of the kiln and has fans mounted upon it at intervals of about 7 feet. These fans are so housed that when the direction of rotation is such that the air movement is upward through the central flue and downward along the side walls, the air enters the fans through suitable openings in the side walls of the housings and is deflected upward after passing through the fans. The double distributors serve to distribute the air uniformly along the width and length of the central flue, reducing the velocity appreciably at the same time.

Recent tests have shown that a very uniform, fast circulation of air may be obtained in this type of kiln with a surprisingly small power consumption.

SUPERHEATED-STEAM KILNS.

The superheated-steam kiln is comparatively simple in construction and operation. Provision must be made for high-pressure steam for heating coils and jets; the circulation must be reversed periodically; and the kiln must be designed for short travel of the steam through the lumber. One type of superheated-steam kiln was invented and developed at the Forest Products Laboratory. Figure 11 illustrates in a general way the principles of construction. The heating coils are conveniently mounted on the side walls, and a steam-jet line runs along the top and bottom of each wall. The two left lines operate simultaneously, and likewise the two right lines. The arrows indicate the direction of the circulation when the left lines are open. With the right lines open the circulation will be reversed.

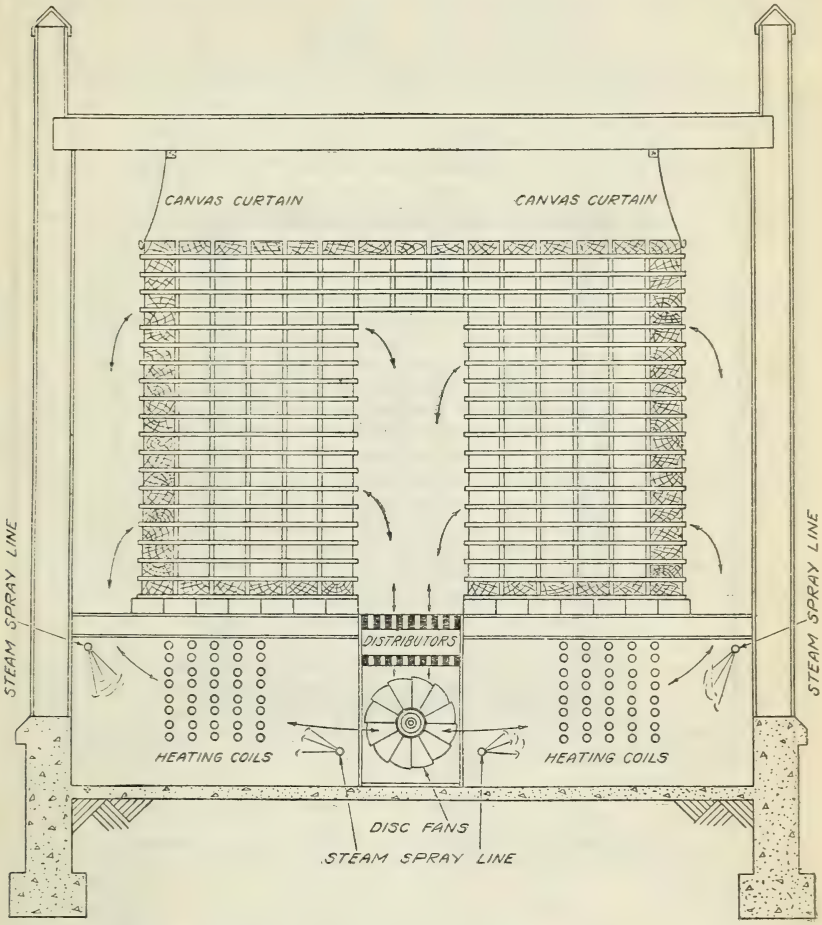


FIG. 10.—Cross section of internal-fan kiln. A number of disk fans are mounted at intervals upon a shaft extending the full length of the kiln.

PILING LUMBER FOR KILN DRYING.

Lumber to be kiln dried is usually piled in layers with strips or stickers between each two layers. Sometimes short stock, like spoke billets, handles, and shoe-last blocks, is simply dumped into the kiln without any attempt at orderly arrangement. This method is apt to produce irregular drying unless only small amounts are dried at a time. The piling and sticking of the lumber should provide suitable air passage between the boards in each layer and between layers, and furnish support to the lumber during drying so that it will be as straight as possible when dry.

For drying in a progressive kiln, the lumber is always loaded on trucks or bunks and run through the kiln on rails, which are usually pitched down toward the dry end, so that gravity will assist in moving the trucks. Large compartment kilns are usually provided

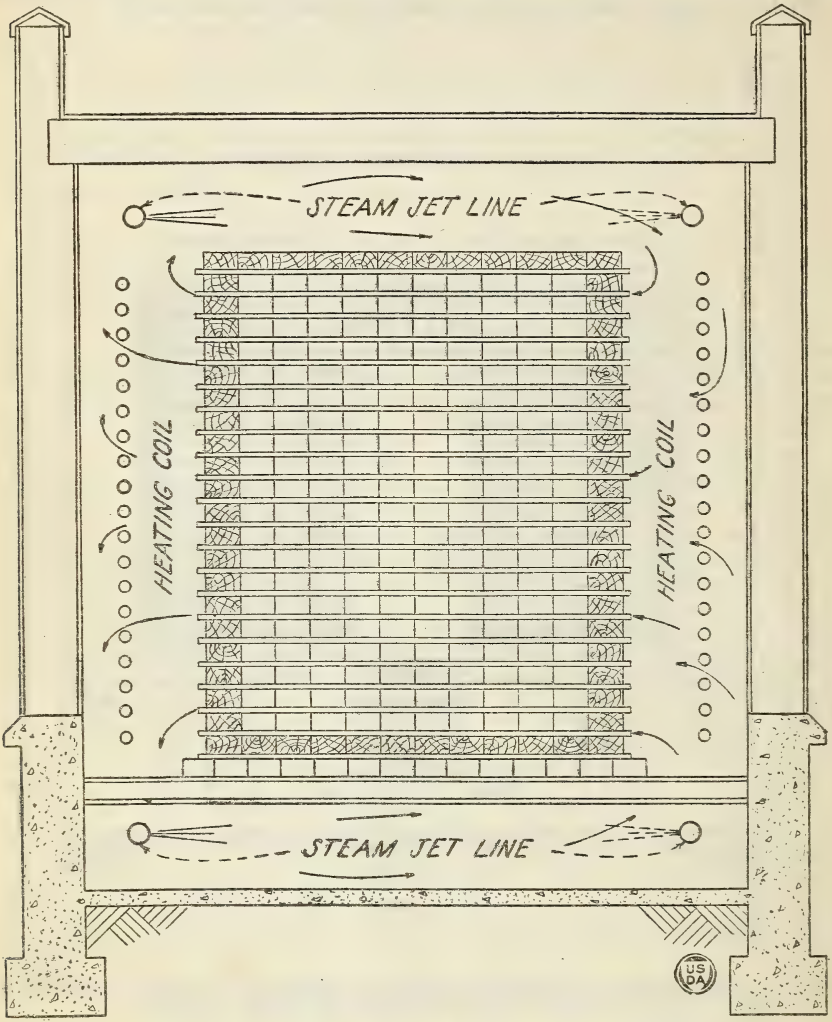


FIG. 11.—Cross section of superheated-steam compartment kiln.

with rails, so that the lumber can be run in on trucks; but many small kilns have no such provisions, and the lumber is piled on horses or other supports.

The two general kinds of piling used for lumber are vertical or edge piling, and horizontal or flat piling. Each of these may be divided into cross and end piling. In cross piling, the boards run crosswise of the kiln, and in end piling they run lengthwise of the kiln.

FLAT PILING.

Cross piling (Pl. X) is most suitable for kilns with longitudinal circulation, and end piling for kilns with cross circulation. This is determined by the arrangement of the stickers. In cross piling they extend lengthwise of the kiln, thus aiding longitudinal circulation. In the same way, end piling (Pl. XI) favors cross circulation. A large number of kilns are, nevertheless, being operated contrary to these principles, particularly cross-circulation ventilated compartment kilns with cross piling. These methods are not absolutely essential, but better results are obtained by following them.

The spacing of the boards in the layer has an important bearing upon circulation, especially in ventilated kilns, and manufacturers of this type frequently recommend a wide spacing. This assists in permitting a freer circulation, especially in cross-circulation kilns with cross piling. The amount of space to leave in any particular case is a matter of judgment and depends upon the circulation. Ordinarily 1-inch spaces do very well for almost all kinds of stock when there is ample circulation; when the circulation is poor, and uneven drying results, the spaces may be enlarged to 3 or 4 inches for wide boards. For narrow boards there is less need for widening the spaces.

The thickness of the stickers may vary with local conditions; however, they should all be straight and of uniform thickness. Seven-eighths-inch stickers are commonly used for most classes of stock, except in edge-stacking, when the requirements of the stacking machine may determine the thickness. If stickers are made about one and one-half times as wide as they are thick, they will lie flat and not tend to roll when the boards are laid on them.

The spacing between rows of stickers should be reasonably close. Four feet should be the maximum distance for most hardwoods and 6 feet for easily dried softwoods. If the boards show a tendency to twist and warp, a closer spacing should be used, and great care must be exercised in the actual piling. To obtain best results, material dried at one time should be of the same species and thickness and with moisture content as nearly uniform as circumstances permit. The supports for the lumber should be firm and even and arranged with one under each row of stickers. These rows should be kept perfectly vertical; otherwise there will be a tendency to warp the boards. The ideal is to have boards of only one length in each pile; but where this is impossible the piles should be made long enough to cut down the number of projecting ends, and the short boards should be brought flush alternately at both ends of the pile. In the case of cross-piled progressive kilns it is especially desirable that the piles should take up the full width of the kiln, so that there may be as little opportunity as possible for the short circuiting of the circulation around the lumber. For the same reason, the piles should extend the full length of the trucks.

VERTICAL PILING.

Under certain conditions vertical or edge piling is considered to be somewhat cheaper than flat piling, and is being used by a number of big mills in the softwood regions. (See Pl. XII.) Several different automatic stacking and unstacking machines have been developed for this work. While they differ in operation, the resulting piles are very much alike, except in the width and thickness of the stickers. The layers of boards and the stickers are vertical, and there is no space between the boards in each layer. As the lumber dries and shrinks there is a tendency for the piles to become loose and to lean. To avoid this trouble several take-ups have been devised. These take-ups are intended to squeeze the load together sidewise as the boards shrink and thus keep it always tight. A serious objection to most of them is that they increase the weight of the bunk very considerably; this is important where the bunks have to be handled by hand.

The principal direction of circulation with vertical piling must be upward or downward through the lumber. In ventilated kilns it is upward, in blower kilns either upward or downward, and in superheated steam kilns both upward and downward.

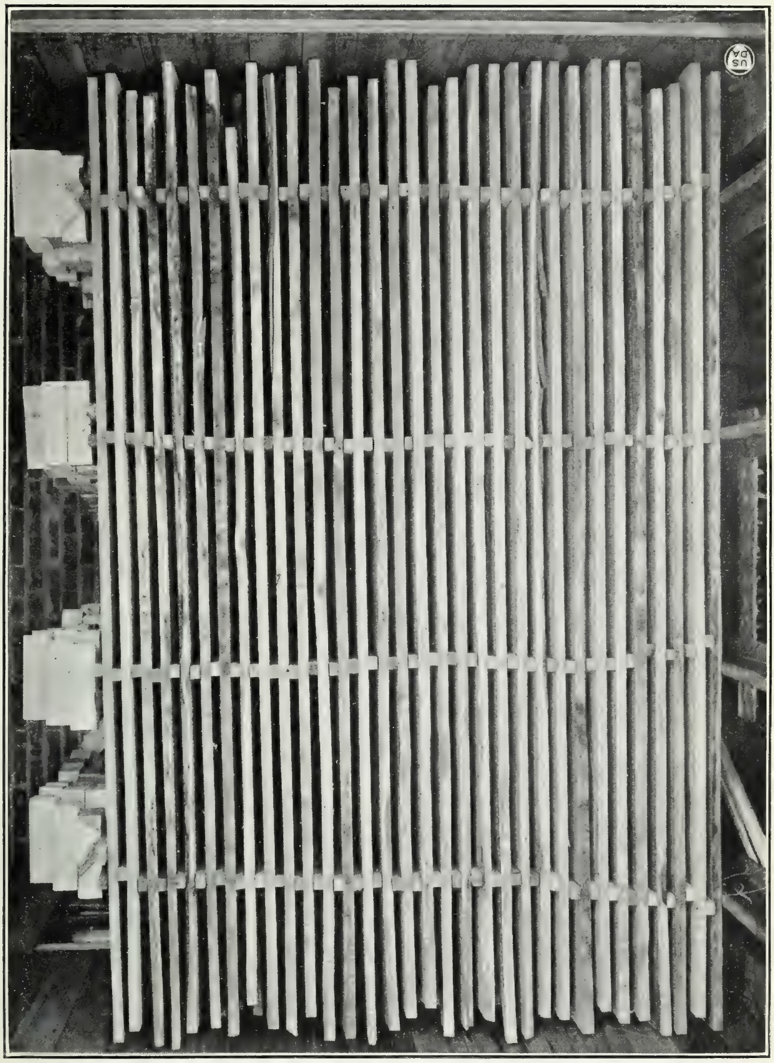
Vertical stacking would seem, at first sight, to permit much better circulation than flat piling. The unimpeded passage of the hot air from the heating coils underneath up through all the straight, open, vertical spaces between the layers of boards seems very simple. However, it is not so simple as it appears. Trouble is experienced in keeping the air in the lumber piles hot, it cools as soon as it strikes the lumber, and then begins to descend and interferes with the air trying to come up. Further, there is usually a space on either side of the kiln and other spaces between the trucks through which the air can rise more easily than through the piles. Another peculiarity which may cause trouble, especially in superheated steam kilns, is that the length of travel through the pile is comparatively great, causing a large difference in drying conditions between the entering air and leaving air sides of the pile. These points indicate why it is necessary with vertical piling to use a specially designed kiln instead of using a kiln designed for flat piling.

DETAILS OF KILN OPERATION.

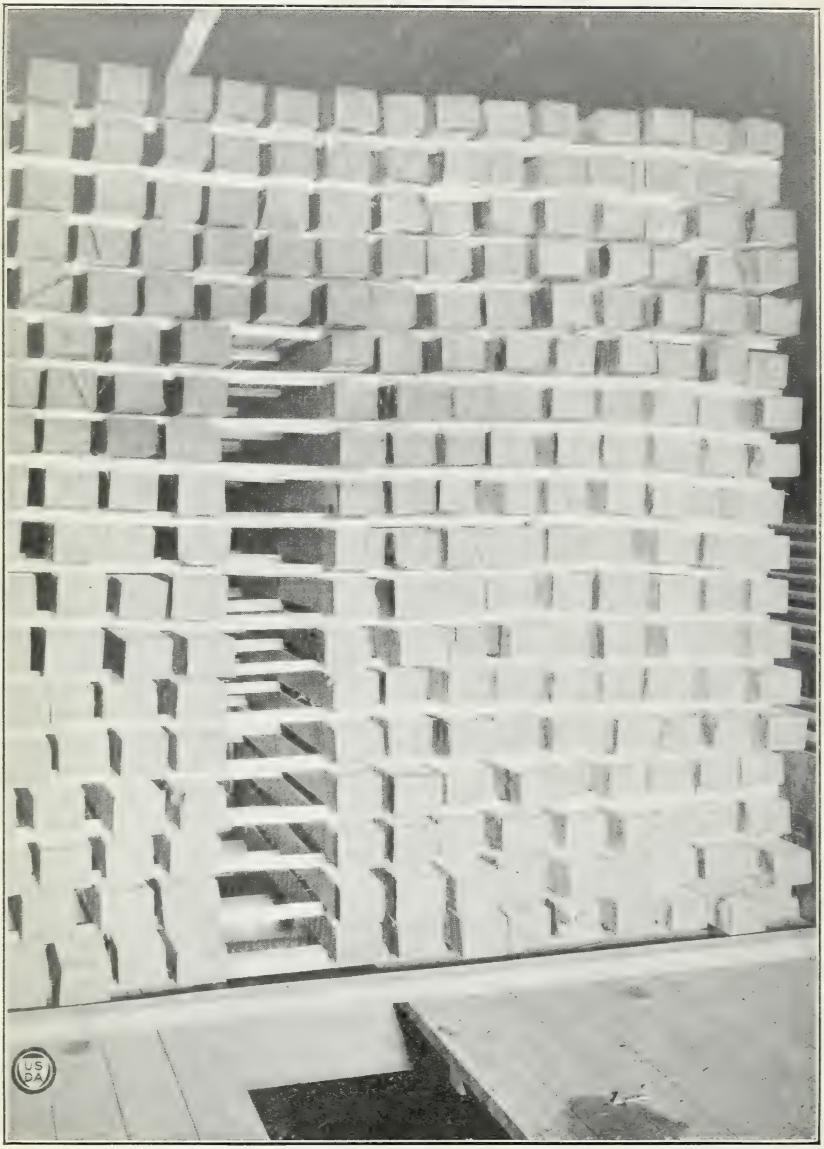
The successful operation of dry kilns requires constant care and attention. The results secured depend in a large degree upon the operator, and he should be impressed with his responsibility to bend every effort to turn out perfect stock. The operator must first familiarize himself with the kilns under his supervision. Before making the first run in a kiln, he should make a careful inspection to assure himself that it is mechanically safe, that the heating coils, traps, etc., are in proper working order, and that the instruments have been checked, calibrated, and properly located.

INSPECTION OF KILN.

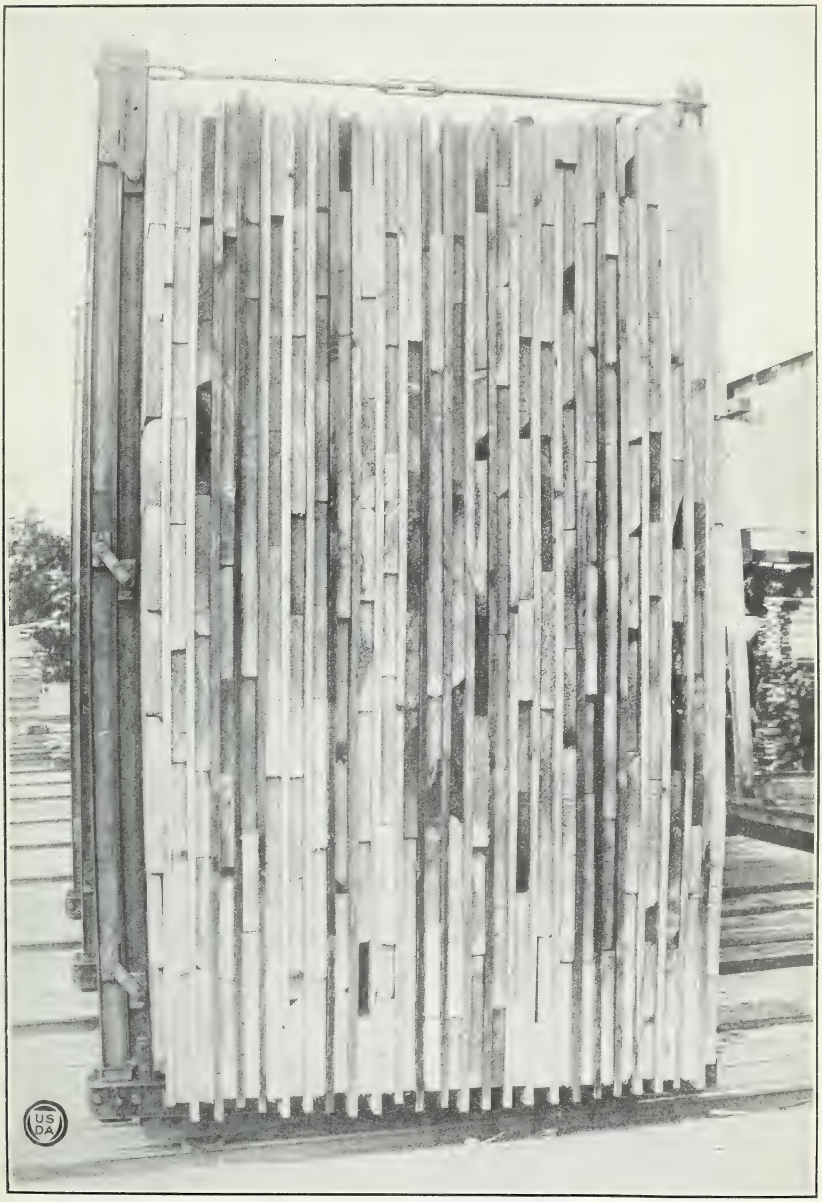
The kiln building should be kept tight and mechanically safe and sound. Interior surfaces should be painted with a good kiln paint. Doors should be kept in good repair and fitting tightly; poor doors allow a great deal of heat to escape and upset the drying conditions. Rails and rail supports should be inspected periodically and the fastenings checked over. Pipes should be kept in proper repair, and their pitch to the drain end maintained to allow free flow



HORIZONTAL CROSS PILING.



HORIZONTAL END PILING.



VERTICAL CROSS PILING.

of the condensed water to the traps. Suitable gratings or runways should be provided, so that the men entering the kiln can do so with safety and without walking on the pipes. The interior iron work and pipes should be protected by a good kiln paint, or the pipes can be painted while hot with a mixture of cylinder oil and graphite, if preferred. The coils should be inspected occasionally to make sure that they are all working, and the traps should be observed every day.

CALIBRATION AND ADJUSTMENT OF INSTRUMENTS.

Success in all except the easiest kind of kiln drying depends upon the accuracy of the instruments and apparatus used in the regulation of the kiln and in the determination of the moisture content. It is therefore essential that the apparatus be maintained in an accurate operating condition. Most important is the matter of temperature indicating, recording, and regulating instruments, since through them both temperature and humidity are determined and controlled.

THERMOMETERS.

The simplest and most satisfactory way to calibrate indicating and recording thermometers is to compare them at different temperatures within their range with a standardized or calibrated thermometer of known accuracy. Each operator should have at least one such standard thermometer. The type recommended is a 12-inch glass chemical thermometer, with graduations in degrees Fahrenheit etched on the stem, and having a range of 30° to 220° correct for ordinary purposes. Such a thermomoter can be purchased for about $3 list price; and a brass protecting sleeve or case, recommended for use in kilns, can be had for about $1.50.

The usual laboratory method of calibration by comparison with a standard thermometer consists in immersing the standard and the thermometers to be calibrated in a vessel of water, which is constantly stirred to keep the temperature uniform throughout. The water is gradually heated, and the thermometers are read at intervals of a few degrees. The difference between the reading of any thermometer and the standard at any temperature is the error of that thermometer, and a correction of this amount must be applied to the reading to give the correct temperature. If the standard reads higher, call the correction plus (+) and add it to the reading of the thermometer, and vice versa. This method is applicable to glass-stem thermometers and other portable types. Wet-bulb thermometers are calibrated this way also, the wicks being removed during calibration. Once every six months should be sufficient for the calibration of glass thermometers.

Recording thermometers require more attention than other types on account of the comparative ease with which they may become deranged. They should be calibrated in water, as described for glass thermometers, the bulb and about a foot of the tube being immersed. This calibration will give a good idea of how the error, if any, varies throughout the operative range of the instrument. After calibration the instrument should be mounted in place in the kiln and then checked up at several points in its range by comparison with the standard thermometer hung close beside its bulb. These comparisons can well be made during the run, if care be taken to read the instruments only after the temperature has been practically constant for 10 minutes, to allow the recorder bulb to overcome its natural lag. A full correction curve can then be plotted for the entire range, and the pen arm of the recorder adjusted to reduce this correction to the minimum. For making this adjustment there is usually provided a small screw at or near the pen-arm pivot, the turning of which moves the pen over the scale.

Wet-bulb recorders should be calibrated similarly, preferably without the wick, and double-pen instruments should have both bulbs calibrated, dry, at the same time. An occasional check with a wet and dry bulb thermometer will show whether the wet bulb is really recording the wet-bulb temperature. It must be kept in mind that a reasonable amount of circulation past the bulb is necessary to secure enough evaporation to bring the bulb temperature clear down to the actual wet-bulb temperature.

Recorders should be calibrated in place at least once every two months, and oftener if they show a tendency to fluctuate abnormally. They should be handled carefully, in accordance with the manufacturer's instructions, special care being taken in changing charts not to bend the pen arm, and when filling the pen not to spill ink down the pen arms. Instruments should be returned to the manufacturer when other than the clock mechanism needs repair. Competent jewelers can keep the clocks in order.

Although recorders can be obtained in weatherproof cases which need no special protection from the elements, it will be found advantageous to mount them in the operating room in some place which is readily accessible and as free from temperature changes as possible.

THERMOSTATS.

Thermostats do not as a rule require any calibration except to determine whether in the case of the wet bulb there is enough circulation past it to insure proper depression. This can be done by comparison with a wet-bulb thermometer placed right at the regulator bulb. It should be read first without fanning and again after vigorous fanning. The drop in temperature will indicate the extent to which the regulator bulb represents the actual wet-bulb temperature.

It is necessary, however, to give the thermostat regulators occasional attention. In self-contained instruments which have a stuffing box on the valve stem a small quantity of oil and graphite applied occasionally on the stem at the box will help to reduce friction and make the instrument more accurate. The stuffing box should be tightened only enough to prevent leakage. In the air-operated type the small valves in the regulator head must be kept free from the oil which is apt to be carried by the air. An occasional washing of the head, by disconnecting the air lines and pouring gasoline through it, will keep the parts clean and prevent sticking.

DRYING OVEN.

The drying oven needs no particular attention, except to make sure that it is maintaining a temperature of 212° F. and not varying over 2° or 3°. Variations in the oven temperature will make an appreciable difference in the moisture-content determinations. Steam ovens are easily regulated by means of a reducing valve in the steam main, and electric ovens by an adjustable thermostat operating on the heating circuit.

SCALES AND BALANCES.

Scales for weighing samples and sections should be sensitive to the smallest quantity which they are intended to weigh; if they are not, they should be repaired or returned to the factory. The absolute accuracy of the scales is not, however, of paramount importance, so long as all the readings are in proportion. Thus, suppose that a scale is 5 per cent in error; this error will apply just as much to the original and the current weights as to the oven-dry weight, and the moisture percentages will be just the same. This assumes, of course, that all the weighings are made on the same scale. This illustration is given simply to show that it is not absolutely necessary to have a set of standard weights for calibrating the scales. It is necessary, however, to be assured that the indicated weights are always in proportion. If, for instance, one sample weighs twice as much as another, the scales must show this. Specifically, this means that all of the weights and the poise must be in proper proportion. This can be readily determined on platform scales by any scheme which allows the same piece or quantity of material to be weighed with the different loose weights and the poise. To illustrate: A 200-pound silk scale has a single poise and beam graduated to 2 pounds by hundredths of a pound and loose counterpoise weights of 100, 50, 20, 10, 10, 5, 3, and 2 pounds respectively. This scale can be checked up as follows: Balance the beam accurately, set the poise at 2 pounds, and place just enough weight on the platform to balance. Then return the poise to zero and put the 2-pound loose weight on the counterpoise. The beam should balance again. If it does not, it can be brought to balance by adding to or removing weight from the platform and then weighing again with the poise. Having checked the 2-pound weight against the poise, check the 3-pound weight by putting enough additional weight on the platform to balance at 3 pounds with the poise set at 1 pound and the 2-pound weight on the counterpoise. Remove the 2-pound weight, return the poise to zero, and place the 3-pound weight on the counterpoise. This scheme of comparisons may be continued through the entire capacity range of the scale. It is most convenient, in securing the final balance of the beam at the different weights, to use a pan of shot, sand, or water.

Balances using loose weights can be checked simply by interchanging the contents of the two pans. If they were in balance in the first place and remain so, the balance arms must be of equal length. If the arms are not of equal length, the balance can still be used, by always placing the weights on the same pan. The individual loose weights may be checked against each other by placing the same nominal weight on each pan.

STEAM GAUGES.

Steam-pressure gauges, if used simply to give a general idea of the amount of pressure available or to check the operation of a reducing valve, need not be very accurate. However, the operator should know how to calibrate them so that he may do so when necessary. There are two general methods in common use; in one the gauge is compared directly with a standard test gauge and in the other the pressure to which the gauge is subjected is actually weighed by means of standard weights placed on a piston of known diameter.

In both cases the test pressure is produced by means of a small hand pump filled with oil, and provided with connections for the gauges. Pressures throughout the range of the gauge being tested are produced and the errors noted. Adjustment can be made by pulling the gauge hand from its pivot and putting it back again in the proper position. Testing equipment of this sort is carried by all boiler inspectors. If none is available, comparisons can often be made with other gauges, such as those on the boilers, and a fair idea of the accuracy obtained.

LOCATION OF INSTRUMENT BULBS.

The drying schedules in this bulletin are based on the assumption that the temperature and humidity are measured and controlled at some point where the air enters the lumber pile. The conditions at such points are the most severe, since the air becomes cooler and more moist as it travels through the lumber.

Only a thorough examination by means of the smoke test and thermometers hung in different parts of the kiln will determine where the recorders and regulator bulbs must be hung to be exposed to conditions which correspond to those of the entering air. Corrections can then be made in the setting or reading of the instruments. It is usually necessary, in single-width progressive kilns and in other single-width cross-piled kilns, to hang the bulbs on the wall, since it is not considered worth while to remove and replace them each time the kiln charge is moved. Further, the circulation is frequently such that no definite "entering air" side can be determined.

In compartment kilns, such as the one in Figure 7, the bulbs can be placed in the central flue, and this is the proper place for them. They should be at least 15 feet from the end of the kiln and 6 feet above the heating coils, unless they are shielded from direct radiation.

In the water-spray kiln illustrated in Figure 8, the thermostat and dry-bulb recorder bulbs should be located in the entering air flue and the dew-point thermometer in one of the baffle boxes. In the external blower kiln, the bulbs can be located on the side of the pile at which the air enters. When the heating coils are in the kiln, the bulbs must also be located in the kiln and on the entering-air side of the pile.

In the superheated-steam kiln illustrated in Figure 11 the bulbs can be located in the center of the top passage, as indicated, or in the center of the lower passage. These locations are best, because they are free from direct radiation, out of the way, and subject to the same conditions, no matter which pair of jet lines happens to be open. The instruments, however, if so placed should be carefully checked against standard thermometers located on the entering-air side and properly shielded from direct radiation, since the temperature will undoubtedly be higher there than in the upper and lower passages.

PLACING OF SAMPLES.

The placing of samples is of prime importance, and a large number, 10 or 12, should be used for each run until the behavior of the kiln is well determined. Samples should be so placed in the piles of lumber that they will receive exactly the same drying treatment as the lumber itself. They should be located on both entering-air and leaving-air sides of the piles, high, low, and halfway up, so that the relative drying effects can be determined. In case of erratic circulation or trouble from uneven drying, samples can also be placed in the middle of the piles; on these there will be nó intermediate weighings possible. In progressive kilns, or any type operating at high temperatures, the obtaining of intermediate weights on any of the samples is often a difficult matter. When the kiln has been loaded steaming can start immediately. A full supply of high-pressure steam should be available, so that the steaming temperature may be reached quickly and full saturation of the air assured. Care must be used to prevent possible injury to the instruments as the kiln is heated; the steaming temperature will probably be higher than that for which the regulators are set, and if these are of the liquid-filled type the excessive pressure developed may strain the bulbs or diaphragms or cause the valve to stick on its seat.

After the drying conditions have been established a study should be made of the circulation. This study can well be supplemented by the use of a number of wet and dry bulb hygrometers scattered throughout the kiln, preferably near the various samples. The readings of these will give a good idea of the relative drying conditions at these points. The readings should be tabulated and the relative humidity determined. The variations in the relative humidity are a good indicator of the variations to be expected in the drying rate throughout the kiln. In progressive kilns the matter is more difficult, and more reliance must be placed upon circulation tests and upon the moisture content of the samples in the dry stock. If wet and dry bulb hygrometers are used in progressive kilns to determine uniformity of drying, they should all be placed on a single truck at a time, since variations from end to end are to be expected.

The samples should be weighed frequently enough so that there will be at least 5 determinations for the kiln run; in the case of runs extending over more than 10 days, the samples should be weighed every day. The moisture per cent should be calculated immediately, and a chart should be maintained, showing graphically the loss of moisture day by day. On this same chart may be plotted the daily temperatures and humidities. This can then be compared with the drying schedule and differences noted and corrected. If preferred, the temperature and humidity of the schedule may be plotted on the same sheet, thus giving a useful comparison between the schedule and the actual run. (See Fig. 12.)

KILN RECORDS.

In addition to this chart, it is desirable to keep a permanent record of the details of each run. Forms for this purpose are provided by some of the kiln companies and can well be used wherever they are applicable. It frequently happens, however, that the operator prefers to make up his own form, possibly combining chart and tabulations on the same sheet.

The runs for compartment kilns should each be numbered and all the data on each run kept together. For progressive kilns the records can be kept by days for each kiln, and other modifications can be made to suit. All of the following information should be provided for on the form: (1) Company name; (2) operator's name; (3) run number; (4) kiln number; (5) thickness and species

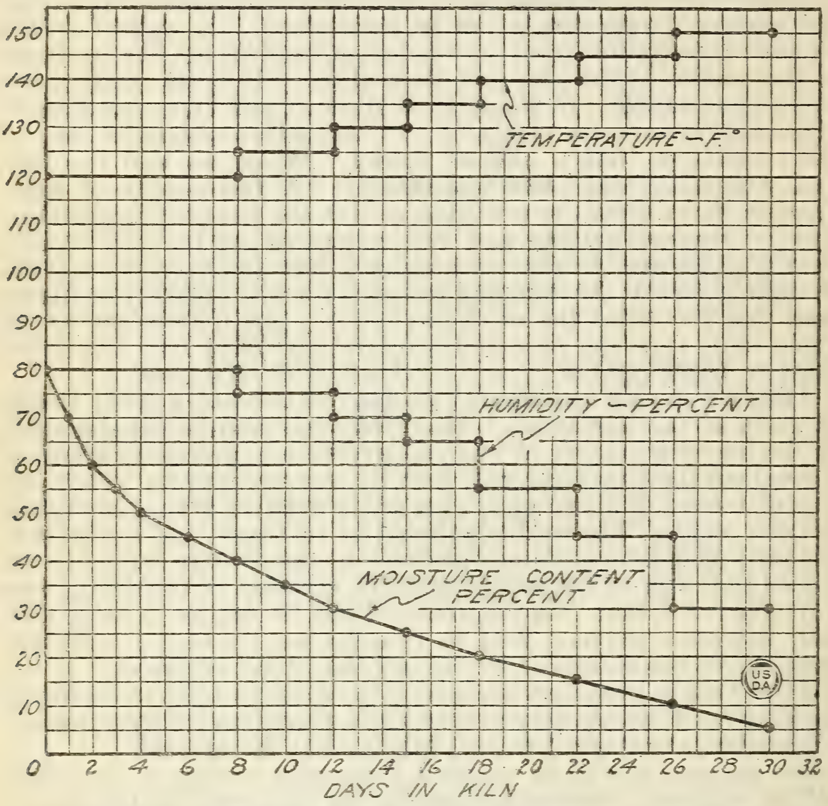


FIG. 12.—Hardwood Schedule 5 plotted against an average drying time of 30 days.

or kind of stock; (6) amount on each truck; (7) locality in which stock was grown; (8) date of arrival at yard, condition, and time of seasoning when ready for kiln; (9) appearance of stock as to seasoning defects; (10) use to which put; (11) final moisture content desired; (12) original and final weights and moisture content of moisture section from samples; (13) original weight, moisture content, and calculated dry weight of each sample; (14) running record of current weights and calculated moisture content for each sample; (15) weights and moisture content of each moisture section cut from the samples at the end of the run; (16) running record of temperatures and humidities taken once or twice a day at least; (17) corrections on recording and indicating thermometers used in the run; (18) running record of appearance of stock, stress determinations, and steaming and high humidity treatment; (19) final condition of stock.

The charts from the recorders, with run number, dates, and corrections plainly indicated on each, should be filed with each run report, and final-stress sections can frequently be kept to advantage, at least until the stock has been worked up. To make the marking of kiln samples simpler, it is suggested that each one bear the run number and an additional individual serial number. Thus, if there are four samples in run 32, they should be numbered 32–1, 32–2, and 32–3, 32–4, respectively. Moisture sections cut from the sample should bear the sample number and also an individual identifying number or letter. The two sections first cut from 32–1 might be 32–1A and 32–1B and the final section 32–1C.

ESSENTIAL APPARATUS.

In order to work effectively, every operator should have certain apparatus described in this handbook, and a suitable room or office in which to keep and use it. The following list represents the minimum compatible with efficient work:

One standard-grade etched-stem glass chemical thermometer, 30° to 220° F., graduated in degrees.

Six wet and dry bulb hygrometers, 60° to 220° F., graduated 2 degrees.

One balance or trip scale for weighing moisture sections, capacity 1 kilogram (1,000 grams=2.2 pounds, about) sensitive to 0.1 gram, with sliding poise on arm for weights up to 5 grams. Brass weights, 1 gram to 1,000 grams in box.

One platform scale or balance for kiln samples. Platform balance capacity 100 pounds, sensitive to 1/100 pound. Beam graduated to 1/100 pound; or—

Solution scale, capacity 20 kilograms, sensitive to 1 gram; 2 scale beams, one graduated to 100 grams in 1-gram units, the other graduated to 1,000 grams in 100 gram units; counterpoise and loose weights.

One drying oven (electric or steam) inside dimensions at least 10 by 12 by 10 inches. Thermostatic control on electric oven sensitive to 2° F. To operate at 212° F.

One 10-inch slide rule.

One smoke box with concentrated ammonia and hydrochloric acid.

Two flash-lamps; spare batteries and lights.

One gas plate and kettle for heating pitch.

Miscellaneous tools, such as saw, screw drivers, hammer, rule, etc.

AIR SEASONING.

It is not within the province of this bulletin to discuss the air seasoning of wood, except in so far as a knowledge of it is essential to the kiln operator. Much of the lumber dried in kilns, especially hardwood lumber, is first air dried, either at the sawmill or the manufacturing plant, and the quality of the finished product depends in no small measure upon the care taken in the preliminary air seasoning.

The following general rules apply in piling the stock in the yard for seasoning:

Foundations for piles should be firm and solid, level in one direction and properly pitched in the other, well above the ground and free from weeds and decay.

Stickers should be of uniform size, not over 2 inches wide nor less than seven-eighths inch thick, free from decay, and planed on two sides. The practice of using boards from the pile for stickers should be avoided.

Care and accuracy in piling are essential. Boards of only one length should be piled together. The pile should pitch forward about 1 inch per foot. There should be a row of stickers over every foundation sill (about 4 to 6 feet for hardwoods and 6 to 8 feet for softwoods), and these rows should run up parallel to the front of the pile. Front and rear rows of stickers should be flush with the ends of the boards.

All piles should be carefully roofed, preferably with a double layer of boards projecting over the pile, front and rear. Roofs should be fastened down to prevent the wind from blowing them off.

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