FORESTRY EXTENSION NOTES

KILN DRYING OF LUMBER

The modern lumber dry kiln is a product of extensive research, testing, and development. It represents the only practical means now in wide use to rapidly season high volumes of lumber to specific moisture conditions essential for maximum serviceability. A well-designed and properly operated kiln can transform green or partially dried lumber to essentially any appropriate moisture content in a matter of several days or a few weeks. Two methods of kiln drying are conventional and dehumidification. Conventional kilns are open systems, have a high volume of production, and are more common than dehumidification kilns. Dehumidification kilns are closed systems, demand more electricity, and are slower than conventional kilns.

Wood is a hygroscopic material; it gives off or takes on moisture until the amount it contains is in balance with that of the surrounding atmosphere. Lumber is dried in a lumber kiln by manipulating the temperature and humidity of the air around it. The amount of moisture in wood at specific temperature and humidity levels is called the equilibrium moisture content.

Air seasoning can be used to remove most of the water from green lumber. FORESTRY EXTENSION NOTE F-303 (available from Forestry Extension, Iowa State University, Ames, Iowa 50011) provides guidelines for proper air seasoning of hardwood lumber. However, kiln drying is generally required to lower the moisture content to the 6 to 8 percent level appropriate for wood used inside a heated building. Solar lumber drying can be used, but high volume production and careful control are not as easy to attain. Information on solar drying is contained in FORESTRY EXTENSION NOTE F-303 which is also available from Forestry Extension.

Proper stacking of lumber is essential in any type of drying. Stack the lumber in neat layers; separate the layers with spacers called stickers positioned 12, 18, or 24 inches apart along the length of the pile. Stickers should be uniform in size (3/4 inches thick and 1 1/2 inches wide), vertically aligned, and support the ends of the boards. Figure 1 shows proper placement of pieces of random length lumber in successive layers; figure 2 shows a completed stack of lumber ready for kiln drying.

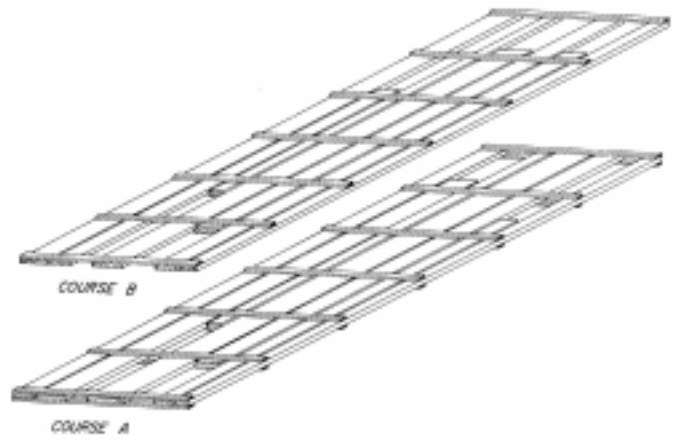

Fig. 1. Proper placement of random length boards in successive layers.

What is a kiln?

A lumber dry kiln is essentially a well-insulated chamber in which temperature, relative humidity, and air circulation can be controlled, maintained, and readily changed. Kilns may be of two general types: compartment or progressive. Compartment kilns are loaded fully at one time. The entire load remains stationary during the drying period; temperature and humidity are changed as the wood dries. In a progressive kiln, the load consists of several units each at a different stage of drying. Drying conditions vary along the length of the kiln;

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lumber loads progress from the green end to the dry end. For most situations in Iowa, compartment kilns are the best choice.

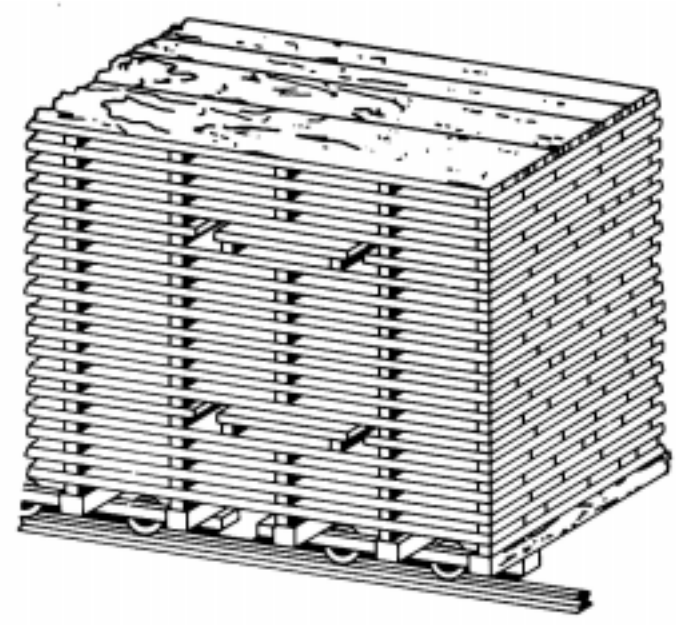

Fig. 2. Lumber stacked for kiln drying showing location of kiln samples

How is air circulated and heated?

Air is circulated within all types of kilns to carry heat from the heating unit to the lumber, to mix the air, and to carry away the moisture evaporated from the wood. Air can be circulated by natural or by mechan-ical means. In a natural-circulation kiln, air movement depends on the fact that warm air rises and cool air falls; air velo-city is usually less than 30 feet per minute. In a forced-circulation kiln, air is moved by fans or blowers; air velocities may range from 70 to 400 feet per minute. Generally speaking, the higher the air velocity through the load, the faster the drying.

Circulated air can be heated directly or indirectly. Direct-fired kilns may use gas, oil or wood residue to heat air for circulation. In indirect-heated kilns, steam or hot water is passed through radiator coils located in the kiln; air is heated as it passes over the coils. A distinct advantage of a steam kiln is that some of the steam can be used to maintain humidity in the kiln.

How are temperature and humidity controlled?

To assure proper control of drying conditions in a kiln, both temperatures and relative humidity must be accurately and continuously measured. Two thermometers are used for this purpose. One measures temperature in the usual way to generate a dry-bulb temperature. The other thermometer has the temperature sensing element covered with a constantly moist wick-like cover. Water evaporates from the moist cover at a rate determined by the dryness of the air. The dryer the air, the greater the cooling effect, and the lower the temperature recorded on the wet-bulb thermometer. This temperature reading is called the wet-bulb temperature. The difference between the dry-bulb temperature and the wet-bulb temperature is called the wet-bulb depression and is a measure of relative humidity in the air.

Conventional dry kilns operate with dry-bulb temperatures between 100° and 180°F; wet-bulb temperatures may be from a few degrees to as much as 50° lower. The temperature levels and wet-bulb depression depend upon several factors and vary during the drying period. Generally, the higher the temperature, the faster lumber will dry; low humidity levels also accelerate drying rate. In conventional kilns, vents and fresh air intakes are used to remove excess humidity, making it an open system. In dehumidification kilns humidity is removed from the air by passing it over coils that condense it into a liquid, instead of venting it out of the kiln (Fig. 3, from USDA Agricultural Handbook No. 188, Dry Kiln Operators Manual). This makes dehumidification kilns a closed system. Also because of the closed system heat is recovered which makes dehumidification kilns more energy efficient than conventional kilns. Steam or water sprays are used to increase humidity. The controls may be manual or automatic; commercial kilns typically use automatic controls.

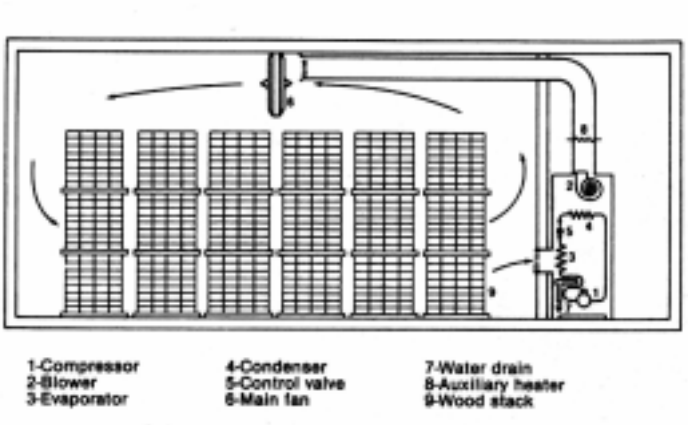

Fig. 3. View of a typical dehumidification kiln.

What is a kiln schedule?

Lumber is dried in a kiln using a kiln schedule developed and tested for the particular species, lumber thickness, initial wood moisture content, and other factors. A kiln schedule is a predetermined set of temperature and humidity conditions for different periods or stages of drying. Changes are made as the lumber is dried to specific moisture content levels. The schedule used should dry the lumber as quickly as possible while minimizing degrade (warp, checks, splits, collapse) to acceptable levels for the end product desired. Appropriate kiln schedules are available for a variety of species, lumber thickness, and end products.

An example of a kiln schedule for 1-inch thick red oak (from USDA Agriculture Handbook No. 528, Drying Eastern Hardwood Lumber) is given in table 1.

Table 1. Basic kiln schedule for 1-inch thick red oak lumber.

Moisture content at start of step Percent	Dry-bulb temp °F	Wet-bulb depression °F	Wet-bulb temp °F
Above 50	110	4	106
50	110	5	105
40	110	8	102
35	110	14	96
30	120	30	90
25	130	40	90
20	140	45	95
15	180	50	130
Equalized	173	43	130
Condition	180	10	170

How are moisture content changes monitored during drying?

As the lumber is stacked, several sample boards are selected representing the wettest and driest material in the load. At least two, and preferably four or more, samples should be used. A section at least 30 inches long should be cut from the center of the sample boards to be used as kiln samples. One-inch wafers are cut from the ends of eack kiln sample, weighed, and dried at 220°F for 24 hours or more. Moisture content is then determined for each wafer using the following formula:

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

The ends of the kiln samples are sealed, and the samples are weighed. Individual kiln samples are assumed to have the same original moisture content as the average of the wafers cut from each end. The estimated oven-dry weight of each kiln sample can then be calculated using the following formula:

$$\text{Oven-dry weight} = \frac{\text{original weight} \times 100}{100 + \text{moisture content}}$$

The kiln samples are placed in representative locations in the stack (fig. 2). As drying proceeds the samples are periodically removed and weighed. The moisture content is determined using the current weight and the calculated oven-dry weight. Adjustments in the kiln schedule are made based on moisture content of the kiln samples.

At the conclusion of the kiln schedule, the lumber will exhibit some variation in final moisture content between individual boards and may contain drying stresses. This moisture content variation and stress development are corrected by processes called equalizing and conditioning. These processes involve specific temperature and humidity conditions applied for predetermined time periods. Steam or water sprays are commonly used to humidify during these stages.

How long does it take to kiln-dry lumber?

The time required to kiln dry lumber depends upon the species, lumber thick-ness, initial moisture content, the character of the wood, the type of kiln, and the kiln schedule used. Table 2 gives the time required to dry 1-inch thick hardwood lumber to an average final moisture content of 6 percent; time required from both green and air-dry condition (20 percent moisture content) are given. These time estimates are taken from USDA Agriculture Handbook No. 528 and are generally minimum times that can be obtained in a well-maintained commercial kiln with air velocities through the load of 200 to 450 feet per minute.

Table 2. Approximate kiln-drying times for 1-inch thick hardwood lumber in conventional internal fan kilns.

Species	Days required to kiln dry from: Air-dried	Green
ash, black	4	7
ash, green or white	4	10
aspen	3	9
basswood (light color)	4	9
birch, paper	2	4
birch, yellow	5	12
butternut	5	10
cherry	5	10
cottonwood (normal)	4	8
cottonwood (wet streak)	4	10
elm, American or slippery	4	9
hackberry	4	7
hickory	4	10
maple, red or silver	4	7
maple, sugar	5	11
oak, red	5	21
oak, white	5	23
sycamore	4	10
walnut, black	5	11
willow	4	10

Summary

Proper kiln drying of lumber requires a good facility and a well-trained operator. Poor kilns and/or unskilled operators can destroy the quality of lumber. Many native Iowa hardwoods require definite skill in drying lumber quickly without developing excessive defects. Anyone interested in building and operating a lumber dry kiln should seek professional counsel and receive training.

Perhaps the best single reference is the Dry Kiln Operators Manual, Agricultural Handbook No. 188, published by the Forest Service, U.S. Department of Agriculture, and available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Another valuable reference is Dry Kiln Schedules for Commercial Woods, Temperate and Tropical, General Technical Report FPL-GTR-57, also available from the Superintendent of Documents. A listing of lumber dry kilns located in the state is given in Extension Publication F-301, "Directory of Sawmills in Iowa," available from county extension offices.

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