FOOD AND AGRICULTURAL PRODUCTS RESEARCH AND TECHNOLOGY CENTER

FOOD TECHNOLOGY FACT SHEET

OKLAHOMA STATE UNIVERSITY

Fundamental Aspects of Kiln Drying Lumber

Salim Hiziroglu
FAPC Wood Products Specialist

Introduction

Wood is a hygroscopic material which gains moisture content as a result of changes in humidity. Hygroscopicity is one of the most distinctive properties of wood. Any kind of wood product absorbs and desorbs moisture from the surrounding air until it reaches equilibrium moisture content (EMC), a balance point between the wood's moisture content and that of the surrounding environment.

Because the dimensions of wood products change with fluctuation in relative humidity, kiln drying becomes one of the most important processes for the efficient use of wood products. Proper machining, gluing and finishing of wood are not possible until moisture content is reduced to an appropriate amount.

Other advantages of drying include weight reduction, increased strength properties and more resistance to biological deterioration due to fungi and insects. Therefore, lumber should be dried before use for any applications in further manufacturing.

This fact sheet summarizes the basics of kiln drying wood, the most commonly used methods, drying schedules and some drying defects.

Kiln Drying

The kiln process involves the drying of wood in a chamber where air circulation, relative humidity and temperature can be controlled so that the moisture content of wood can be reduced to a target point without having any drying defects.

The most commonly used kilns are conventional and dehumidification kilns. Vacuum and solar kilns also are used for special applications and conditions.

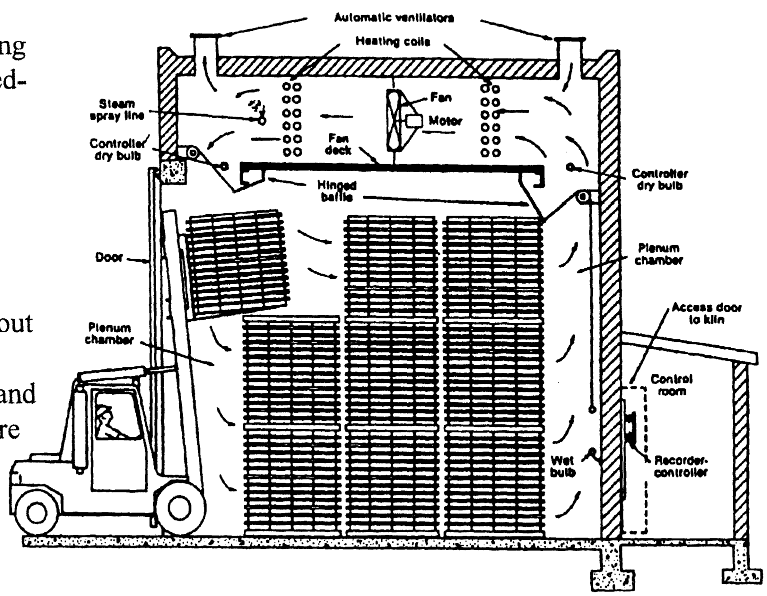
Conventional Kilns

A conventional kiln uses steam flow into the kiln through pipes and radiates heat into the kiln's atmosphere. Water content of the wood is converted into vapor by evaporation and discharged from the kiln with the hot air. Figure 1 is a schematic of a typical conventional kiln. This type of kiln requires large amounts of energy; therefore, it is neither economical nor efficient compared to dehumidification kilns.

Dehumidification Kilns

Today, dehumidification kilns are among the most commonly used kilns in the wood products industry. An advantage of using dehumidification kilns is the continuous recycling of heat within the kiln rather than the discharging of heat from the kiln as in the case of conventional kilns. The majority of water is condensed on the coils of the dehumidifier and removed as liquid rather than being ventilated to the outside of the kiln.

Figure 1. Schematic of a dry kiln. (Dry Kiln Operator's Manual. USDA, 1991)



Although dehumidification kilns use electricity, which is more expensive than gas, they are still more economical than conventional kilns because they recycle heat and also are more environmentally friendly.

The air dehumidification kiln reaches a temperature of 95 to 100°F, and the hot air is circulated over the wood. The hot, moist air is then cooled by passing over cold refrigeration coils. The evaporated moisture condenses into liquid form and is drained as cool water. Figure 2 illustrates the working principles of the dehumidification kiln.

Vacuum Kilns

The less commonly used vacuum kiln is 3 to 4 times more expensive than either conventional or dehumidification kilns because of limited drying capacity in the chamber. However, the main advantage of this system is a very high-drying speed.

Kiln Schedules

Kiln schedules are used to determine the temperature and relative humidity needed in the kiln to dry specific wood products at a satisfactory rate without causing objectionable drying defects. A typical kiln schedule is a series of temperatures and relative humidities, which are applied at various stages of drying as can be seen in Table 1.

In general, the schedule should be developed so that drying stresses do not exceed the strength of the wood at any given temperature and moisture content. Schedules vary by species, thickness, grade and intended final use of the material.

Figure 2. Dehumidification drying system. (Dry Kiln Operator's Manual. USDA, 1991

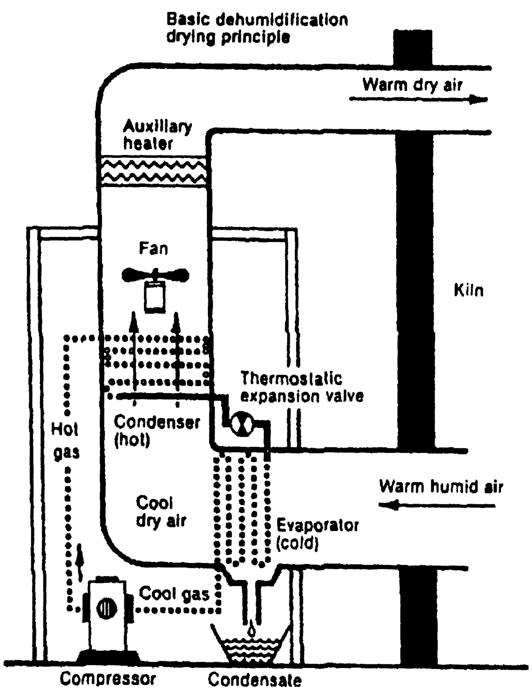


Table 1. Typical drying schedule.

Step	Moisture Content (%)	Dry bulb (°F)	Wet bulb (°F)	EMC (%)	Relative Humidity (%)
1	Above 50	110	107	19.1	90
2	50-40	110	106	17.6	87
3	40-35	110	104	15.2	81
4	35-30	110	100	12.0	70
5	30-25	120	95	8.5	40
6	25-20	130	90	4.0	22
7	20-15	140	90	2.9	15
8	15 to target	160	110	3.4	21
Equalize and condition as necessary					

For example, a typical hardwood schedule would begin at 110 to 120°F and 70- to 80-percent relative humidity when lumber is green. Temperatures could reach up to 170 to 180°F by the time lumber has a moisture content of 10 to 15 percent.

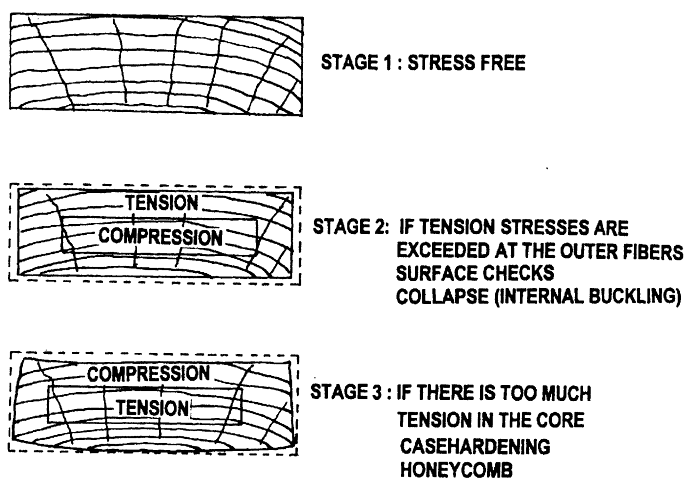
Softwood kiln schedules differ from hardwood schedules because the kiln temperature and relative humidity are decided at predetermined times rather than at moisture content levels.

Development of Drying Stresses in the Kiln

Stage 1

Wet lumber having high moisture on the outer and inner portions will be stress free. As soon as it dries, the outer portion will go below the fiber saturation point (fsp), which is 28 to 30 percent moisture content, before the inner portions reach fps.

Figure 3. Development of drying stresses during the kiln process.



Stage 2

As the atmosphere in the kiln is heated and dried, drying occurs faster on the outside, and the outer fibers will have a tendency to shrink. The interior core of the lumber will be at a moisture content of fsp and will prevent the exterior shell from shrinking as much as possible. The result will be development of tensile stresses on the outside and compression stresses on the inside of the lumber. This is called the second stage of drying as shown in Figure 3.

If the maximum tension stress is exceeded at the outer fiber, surface check occurs and is considered a drying defect. Surface check can be avoided by drying the load at a reasonably cool temperature rather than using high temperatures at the beginning of the drying process.

Also, temporarily increasing relative humidity in the kiln will help to eliminate surface check. If surface check is not handled properly, stress development in the lumber can be severe and lead to collapse, a significant drying defect at the end of the second stage of the drying process. Figure 4 illustrates an extreme surface check, oil check and collapse.

Stage 3

As drying progresses, the center of the board will lose enough moisture to pass below the fsp. As this occurs, it will tend to shrink, but the outer fibers now have a tension set different from the earlier stage of the drying process and will prevent some of the interior shrinking.

When this happens, the inner portion will become stressed in tension and the outer portion will have compression stress built up; this is called casehardening. Casehardening occurs when the surface layers of the lumber are stretched larger than they should be.

Casehardened material will exhibit severe cupping tendencies. If the surface of the lumber is wetted, any expansion will be resisted by the dry cores, and stresses will be introduced producing compression sets in place of the tension sets caused by casehardening.

If compression stresses on the face of the lumber are equalized to the previous tension set, the lumber should be stress free. Casehardening relief can easily be accomplished and may even be reversed by controlling kiln atmosphere.

Figure 4. Surface check, end check and collapse as drying defects.

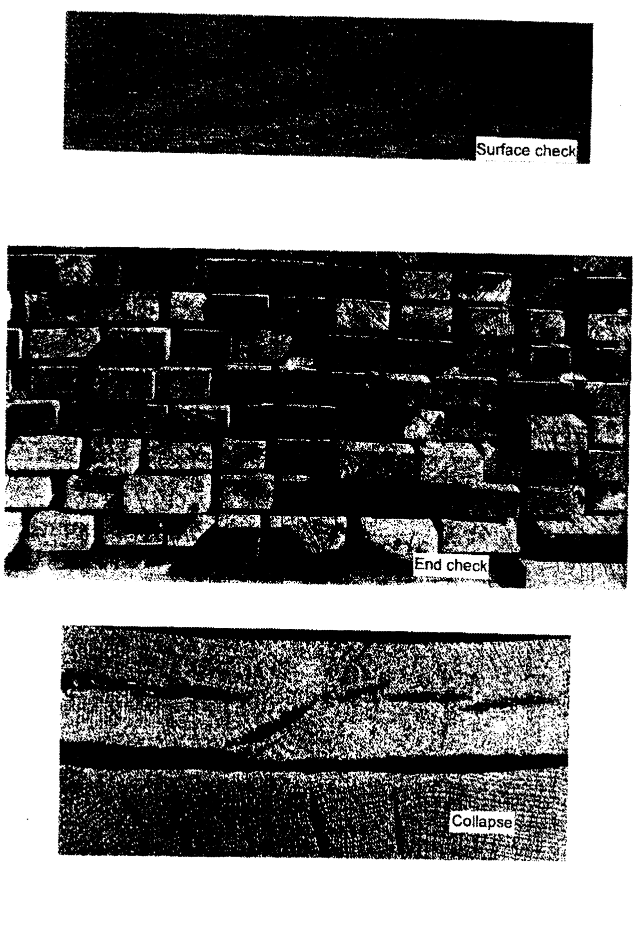
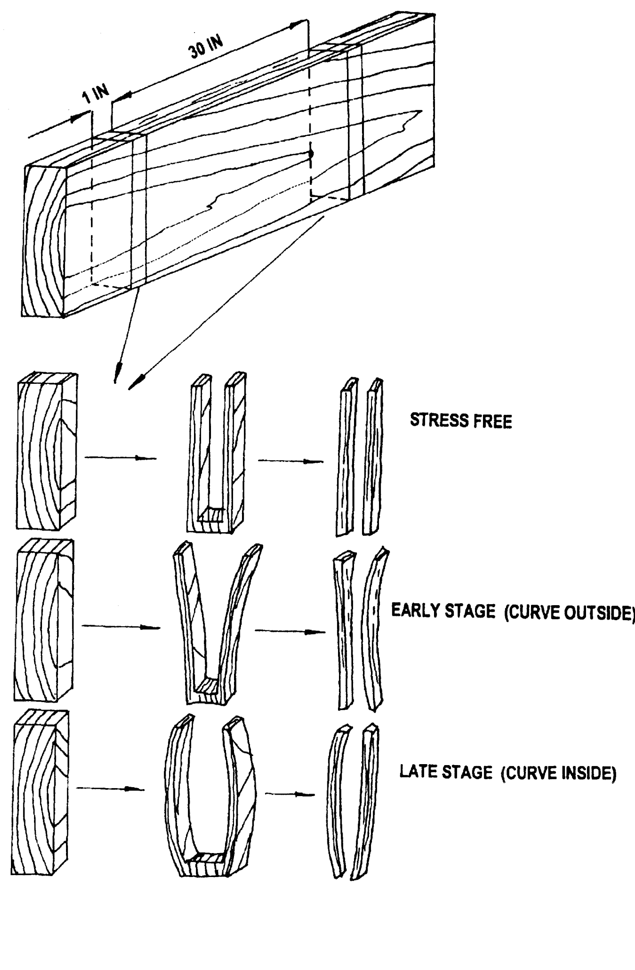


Figure 5. Preparing drying samples.



Overall kiln performance can be monitored by taking kiln samples. Samples should be selected from the kiln during stacking. The number of samples depends on the condition and drying characteristics of the wood being dried, the type of kiln and the final intended use of the material.

Usually, samples are cut from central sections of the lumber to determine moisture content, surface check and stress development as illustrated in Figure 5.

Moisture sections and stress sections are cut from each kiln sample to monitor the overall process of drying to target moisture content without any drying defects.

For More Information

The principles described in this fact sheet are important elements of the efficient utilization of wood products. Detailed information about these elements also can be found in the following references and handbooks:

Simpson, W.T. ed. 1991. Dry Kiln Operator's Manual. USDA. Forest Products Laboratory, Madison.

Wood Handbook. Wood as an Engineering Material. 1999. USDA, Forest Products Laboratory. GTR-113., Madison.

Boone, S.C., C. Bois, and E. Wengert. 1988. Dry kiln schedule for commercial woods. Temperate and tropical. USDA Forest Products Laboratory. GTR -57. Madison.

Hoadley, B. 1990. Understanding Wood. The Taunton Press, Inc. Newton, CT.

Haygreen, J. G. and J.L. Bowyer. 1996 Forest Products and Wood Science. Iowa State University Press, Ames IA.

Brown, W. 1989. The conversion and seasoning of wood. Linden publishing Inc, Fresno, California.

Rietz, R.C., R.H.Page, E.Peck, W.T. Simpson, J.L. Tschernitz, and J.J. Fuller. 1999. Airdrying of lumber. GTR-117. USDA. Forest Service, Washington D.C.

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