IMPORTANCE OF THICKNESS VARIATION IN KILN DRYING RED OAK LUMBER

William Simpson and John Tschernitz
Forest Products Laboratory
U.S. Forest Service
Madison, Wisconsin

Introduction

It is well known in the lumber industry that the drying time of lumber increases with thickness. Furthermore, the increase in drying time with thickness is more than a one-to-one relationship--that is, doubling thickness more than doubles drying time. We also know that in the manufacture of lumber, thickness variation occurs in sawing, which can affect drying time as well as volume recovery. Undersize, target, and oversize lumber will dry at different rates. Oversize lumber will require longer drying time than target or thinner lumber, and energy consumption and drying costs will thus be affected. The purpose of this paper is to present an analysis that will provide some estimates of the significance of thickness variation on kiln drying oak lumber. Even though the analysis is limited to oak, the concept may be important for other species.

To conduct an analysis such as this, it is necessary to know the drying rate at various thicknesses and at the temperatures and relative humidities encountered in drying. The general method of analysis includes both an experimental and analytical approach. Drying rate data were developed experimentally at several combinations of drying temperature, relative humidity, and board thickness. A mathematical model was then developed so that estimated drying times could be calculated for any combination of drying temperature and relative humidity, board thickness, and initial and final moisture content.

Estimating Drying Rate

The objective of the experimental portion of this study was to determine the drying rate of red oak lumber as a function of temperature, relative humidity, and thickness. Fresh, green logs, 9 feet long and 16 inches in diameter, were obtained from southern Wisconsin. Their initial moisture content was 85 percent and specific gravity 0.56. Enough 1-1/8-inch-thick boards were sawn from the logs to prepare specimen material for the nine planned combinations of temperature and relative humidity (120°, 150°, and 180°F at 20, 50, and 80 percent relative humidity). All boards were as nearly flatsawn as possible. They were machined to 1 inch thick, 6 inches wide, and 44 inches long. Each of the nine groups consisted of 20 of these boards. Drying was done in a laboratory kiln with an air velocity of 500 to 600 feet per minute.

Another experiment was conducted at fixed drying conditions of 150°F and 50 percent relative humidity to determine the effect of thickness on drying rate. Boards 1 inch, 1-1/2 inch, and 2 inches thick were dried.

To make the drying rate data more generally applicable and to use it at any conditions other than those of the experiment, it is desirable to mathematically describe the relationship between drying rate, temperature, relative humidity, and thickness. The basic assumption in establishing an empirical relationship is that drying rate is proportional to average moisture content:

$$\frac{d\overline{W}}{dt} = -k\overline{W}$$

where $\overline{W}$ = average moisture content at time t, and k is a constant of proportionality. Carrying through the analysis (3):

$$E = \frac{\overline{W} - W_e}{W_o - W_e} = \exp\ (-bt/x^n) \qquad (1)$$

where

W_e = equilibrium moisture content (percent)

W_o = initial moisture content (percent)

b = empirical coefficient experimentally established for red oak

t = time (days)

x = board thickness (inch)

n = empirical thickness coefficient

The coefficient b describes the effect of temperature and relative humidity on drying rate. Within the normal range of temperatures used in conventional kiln schedules, b was found to be very nearly linear with the vapor pressure of water, and can be estimated by

$$b = 0.0575 + 0.00142\ p$$

where p = vapor pressure of water in mm of mercury, which can be related to temperature (within the range of 110^o-180^oF) by p = exp (20.41-5132/T) where T is degrees Kelvin. The thickness coefficient n was found in this experiment to be 1.52.

With estimates of b and n, equation (1) can be put into a more useful form to estimate the drying time of red oak lumber at each step in a kiln schedule:

$$t = \frac{-x^{1.52}}{b}\ \ell n\ \frac{\overline{W} - W_e}{W_o - W_e} \qquad (2)$$

Effect of Thickness Variation on Drying Time

Oak lumber is commonly dried in nominal thicknesses of 4/4, 5/4, 6/4, and 8/4 which, in terms of rough green lumber, correspond to 1-5/32, 1-7/16, 1-11/16, and 2-1/4 inches, respectively. Oak is sometimes kiln dried from the green (approximately 80 percent moisture content), and quite often receives varying degrees of air drying before kiln drying. Kiln schedules vary somewhat between different operators, but the schedules recommended by the U.S. Forest Products Laboratory (2) can be considered representative of those used commercially.

Using equation (2) and a typical oak schedule, it is possible to estimate kiln drying time for any thickness of lumber. Stepwise and total kiln drying times of 4/4, 5/4, and 6/4 red oak lumber from initial moisture contents of 80, 50, and 30 percent (Table 1) illustrate the use of equation (2). Figure 1 gives a good overall view of the effect of thickness and initial moisture content on kiln drying time.

Thickness standards for lumber produced under various grading rules are summarized by Lunstrum (1), and the stipulated minimum, recommended target set, and recommended maximum thicknesses for hardwood lumber are given for nominal thicknesses of 3/4 to 8/4. Table 2 shows estimated drying times for minimum, target, and maximum thicknesses for nominal 4/4, 5/4, 6/4, and 8/4 lumber kiln dried from 80, 50, or 30 percent to 7 percent moisture content. As an example, the time to kiln dry the target thickness of nominal 4/4 (37/32 inch) from 50 percent to 7 percent moisture content is estimated at 13.2 days. The time required for the recommended maximum thickness of nominal 4/4 (40/32 inch) is 14.8 days--over a day and a half longer. The difference in time between stipulated minimum and recommended maximum is even greater--over 3 days. These estimated differences in drying time are large enough that we should take a further look at what they mean in terms of such important factors as energy consumption and drying costs.

Effect of Thickness Variation on Energy Consumption

Figure 2 shows the overall effect of thickness on the energy required to kiln dry northern red oak from 80, 50, and 30 percent to 7 percent moisture content. The energy consumption includes such elements as energy to heat the lumber and kiln structure, energy to evaporate water from the lumber, vent losses, and heat losses through the structure.

The estimates are based on a 40,000-board-foot-capacity kiln operated year 'round in Madison, Wisconsin. The major factor that increases energy consumption with thickness is the increase in heat losses through the kiln. As drying time increases, heat losses also increase. Estimates are given (Table 3) of energy consumption for minimum, target, and maximum thicknesses for nominal 4/4, 5/4, 6/4, and 8/4 lumber kiln dried from 80, 50, and 30 percent to 7 percent moisture content. Continuing the same example of kiln drying nominal 4/4 from 50 percent to 7 percent, energy consumption increases by 150,000 BTU per MBF between target and maximum thicknesses, and by 280,000 BTU per MBF between minimum and maximum thicknesses.

Effect of Thickness Variation on Kiln Operating Costs

Total kiln drying costs are a major concern to those involved in lumber drying, and it is here that any effects of thickness variation take on particular interest. These effects are summarized for nominal 4/4 lumber (Figure 3). For example, if nominal 4/4 red oak lumber were kiln dried from 50 percent to 7 percent moisture content in a kiln where the operating costs were $3/day/MBF, it would cost $34.80 per MBF to dry at the minimum thickness, $39.30 at the target thickness, and $44.40 at the maximum thickness.

The practical effects of thickness variation on kiln drying time are controlled by the selection and use of kiln samples. Certain boards are selected to represent the drying rate of the entire load and, because they control drying time in the practical sense, it is the thickness and thickness variation of these boards that is important. The generally accepted method of selecting kiln samples is to choose some that represent the slower-drying material in the load (thicker, wetter, heavier, wider) and some that represent the faster-drying material (2). Hardwood schedules are usually controlled on the half of the kiln samples that dry more slowly, so that drying defects are minimized. Thus, in most hardwood drying operations, the thicker boards caused by sawing variation will control the drying time.

Literature Cited

1. Lunstrum, S. J. 1972. Circular sawmills and their efficient operation. U.S. Dep. Agric., For. Serv., State and Private Forestry, Southeastern Area, Atlanta, Ga.

2. Rasmussen, E. F. 1961. Dry kiln operator's manual. Agric. Handbk. 188. U.S. Dep. Agric., Washington, D.C.

3. Tschernitz, J. L., and W. T. Simpson. 1977. Solar kilns: Feasibility of utilizing solar energy for drying lumber in developing countries. FPL-AID-PASA TA(AG)02-75. For. Prod. Lab., Madison, Wis.

Table 1.--Estimated kiln drying time of red oak by schedule T4-D2 (2) for 4/4, 5/4, and 6/4 lumber

Initial MC of step, W_o	Temperature	EMC in kiln, W_e	Final MC of step, $\bar{W}$	Estimated drying time for nominal thicknesses of 4/4	5/4	6/4
%	°F	%	%		Days	
80	110	17.5	50	5.44	7.57	9.66
50	110	16.2	40	2.92	4.06	5.19
40	110	13.3	35	1.73	2.41	3.07
35	110	9.9	30	1.85	2.57	3.28
30	120	5.4	25	1.49	2.08	2.65
25	130	2.0	20	1.30	1.81	2.31
20	140	2.6	15	1.45	2.02	2.58
15	180	3.3	7	2.39	3.33	4.25
Total drying time from 80%				18.6	25.9	33.0
Total drying time from 50%				13.2	18.3	23.3
Total drying time from 30%				6.6	9.2	11.8

Table 2.--Range of kiln drying time[1] between stipulated minimum, target, and recommended maximum thickness for red oak lumber

Initial MC in kiln	Schedule T4-D2									Schedule T3-D1		
	4/4			5/4			6/4			8/4		
	Minimum (34/32)	Target (37/32)	Maximum (40/32)	Minimum (43/32)	Target (46/32)	Maximum (49/32)	Minimum (51/32)	Target (54/32)	Maximum (57/32)	Minimum (68/32)	Target (72/32)	Maximum (76/32)
%	Days											
80	16.2	18.6	20.8	23.1	25.9	28.2	30.0	33.0	35.7	51.7	55.7	59.1
50	11.6	13.2	14.8	16.4	18.3	20.0	21.4	23.3	25.2	37.6	40.2	42.8
30	6.0	6.6	7.5	8.4	9.2	10.2	10.8	11.8	12.7	19.7	21.1	22.3

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[1] Final MC in kiln, 7%.

Table 3.--Total energy consumption in kiln drying red oak lumber[1/]

Initial MC in kiln	Schedule T4-D2									Schedule T3-D1		
	4/4			5/4			6/4			8/4		
	Minimum (34/32)	Target (37/32)	Maximum (40/32)	Minimum (43/32)	Target (46/32)	Maximum (49/32)	Minimum (51/32)	Target (54/32)	Maximum (57/32)	Minimum (68/32)	Target (72/32)	Maximum (76/32)
%	Million BTU/MBF											
80	6.14	6.35	6.55	6.77	7.00	7.20	7.33	7.51	7.72	8.60	9.05	9.47
50	4.38	4.51	4.66	4.80	4.94	5.09	5.20	5.39	5.57	6.20	6.44	6.67
30	2.80	2.90	3.00	3.09	3.19	3.29	3.36	3.45	3.55	3.95	4.15	4.36

[1/] Final MC in kiln, 7%.

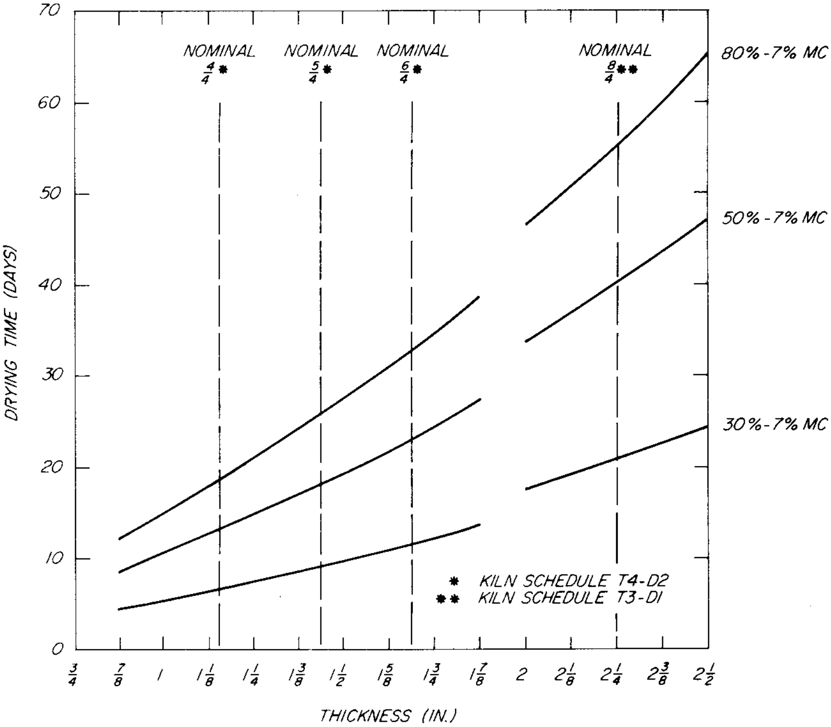

Figure 1.--Effect of thickness and initial moisture content on the kiln drying time of red oak lumber.

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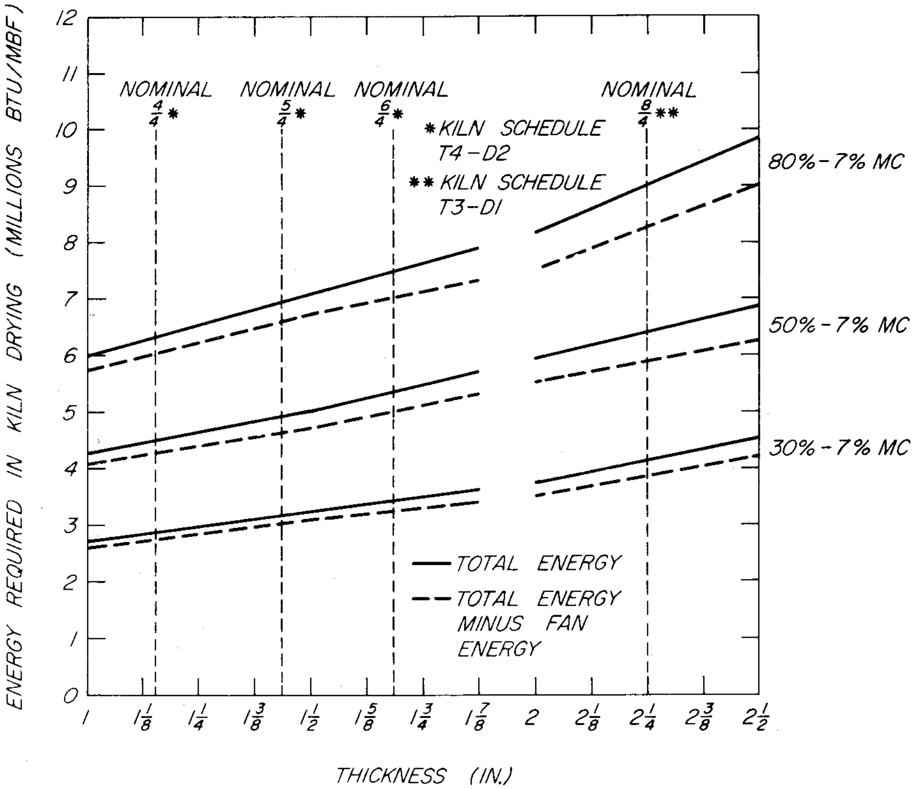

Figure 2.--Effect of thickness and initial moisture content on the energy required to kiln dry red oak lumber.

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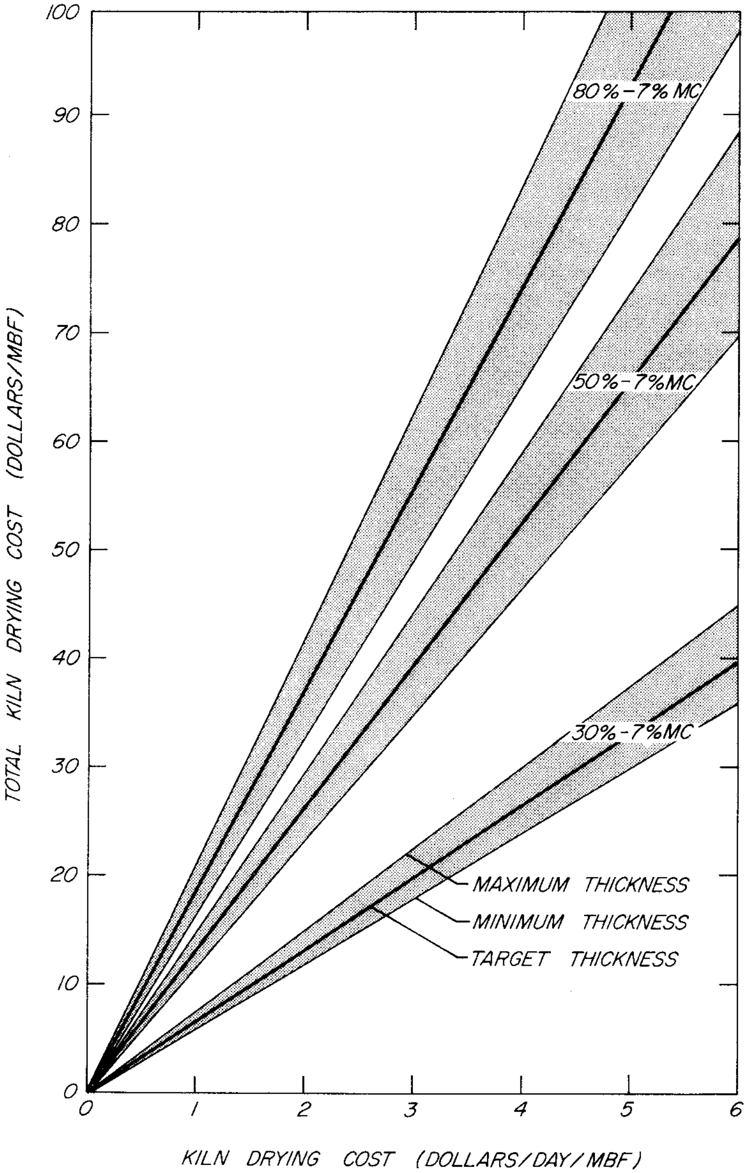

Figure 3.--Effect of sawing variation and initial moisture content on kiln drying costs of nominal 4/4 red oak lumber.

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