

# KILN CHARACTERISTICS CAN INFLUENCE DRYING TIME AND MOISTURE UNIFORMITY IN HIGH-TEMPERATURE-DRIED LUMBER

Bruce L. Herzberg and Fred W. Taylor  
Mississippi State University  
Mississippi State, MS

Howard N. Rosen  
North Central Forest  
Experiment Station  
Carbondale, Illinois

## Introduction

Attempts to dry softwoods at temperatures above the boiling point of water started in the United States in 1867, but the practice was not widely adopted as a commercial method of drying softwood lumber in the U.S. until the late 1960's. Prior to 1970, there were just a few high-temperature kilns in operation, but presently, approximately 370 have been built (9). The principle reasons for the adoption of high-temperature drying were the increased production capabilities of lumber producers and rising energy costs. Due to the increased production capacity, bottlenecks occurred because the existing kilns could not dry lumber fast enough to keep up with the sawmill output. Also, high-temperature kilns were less expensive than conventional kilns of equal drying capacity and used less energy (6).

A serious problem encountered in high-temperature drying is the variation in moisture content of dried lumber (2,6). This high variation makes it difficult to dry a high percentage of the lumber charge to meet grademark specifications (15 to 19 percent moisture content) without severely overdrying some of the boards. Overdrying not only increases energy costs, it also increases degrade.

Although a few studies (1,3) show trends in stack width, sticker thickness and air velocity effects on drying uniformity, they do not indicate whether these factors have a statistically significant effect. Because of the high moisture content variation within kiln charges dried at high temperatures, definitive studies of the factors that affect the uniformity of drying and drying rate are necessary to design kilns that dry more uniformly or to modify existing kilns to improve drying uniformity. A replicated study with controlled conditions is justified to evaluate approaches to increasing final moisture content uniformity and rate of drying.

The purpose of this study was to determine the effect of stack width, sticker thickness, air velocity, and fan reversal conditions on drying time and moisture content uniformity within the stack of southern pine 2 x 6's dried at high temperatures. Data developed by this study may lead to innovations in drying technology or provide evidence for recommending process changes that would improve drying.

## Drying Equipment

The experimental kiln at the Mississippi State Forest Products Utilization Laboratory was used to dry 45 consecutive

charges of lumber. Each charge consisted of 80 southern pine 12-foot 2 x 6's. The kiln (12 x 12 x 6 feet) was heated by four sets of steam coils with 120 psi steam. Dry-bulb and wet-bulb temperatures were controlled and recorded by a Foxboro automatic controller. Circulation was provided by two 36-inch propeller-type fans powered by a 3-HP continuously variable electric motor.

The kiln was instrumented to measure several variables during the drying process. These variables were static air pressure drop across the lumber charge and the fans, air velocity through the lumber charge and the fans, and weight loss of the lumber charge during drying.

Static air pressure drop and air velocity were measured with a pitot-static tube placed on each side of the fans and on each side of the lumber charge. These four pitot-static tubes were connected to a magnehelic gauge individually to measure air velocity on the leaving side of the fans and lumber charge and connected in pairs to measure static air pressure drop across the fans and across the lumber charge. Weight loss of the charge (which was used to determine the moisture loss of the lumber) was measured with compression load cells placed under each corner of the lumber carriage.

#### Drying Methods

The study was divided into two phases. The first phase tested the effect of stack width, sticker thickness, and air velocity on drying time and moisture content uniformity of southern pine lumber charges dried at high temperature. Charges of lumber were dried in packages of three different stack widths (4, 6 and 8 feet), two different sticker thicknesses (9/16 and 1-1/8 inches), and three different target air velocities (500, 1000, and 1500 feet per minute). Each lumber charge consisted of a combination of one stack width with one sticker thickness at one target air velocity. There were two replications of each combination for a total of 36 lumber charges for the first phase. Factors held constant were temperature (245°F dry-bulb and a maximum of 170°F wet-bulb) and a fan reversal of 3 hours.

The second phase of the study investigated the effect of fan reversal on drying time and moisture uniformity within the lumber charge. Based on the results of the first phase, a stack width of 8 feet with a sticker thickness of 9/16 inch and an air velocity of 1000 feet per minute were kept constant over three different fan reversal conditions. The direction of air flow was reversed at 3-hour intervals, 6-hour intervals, and without reversal. Each fan reversal condition was replicated three times for a total of nine lumber charges in the second phase.

Static pressure drop, temperature drop, air velocity, and weight loss were monitored during both phases of the study. Each board was weighed before it was stacked and dried in the kiln. There was no equalization or conditioning period in the kiln after drying, but the charge was immediately removed from the kiln, restacked on stickers and allowed to cool at room temperature for 24 hours. After cooling, each board was again weighed and its moisture content was measured with a resistance type electronic meter.

Drying time and moisture content uniformity were defined as follows: Drying time was the time in hours that it took a green lumber charge to reach a relative moisture content of 10 percent ( $E = 0.10$ ). This is the point at which the lumber charge contains only 10 percent of its original moisture content. Relative moisture content is not equivalent to average moisture content based on dry weight, but it is close because the southern pine used in this study had an average green moisture content of 115 percent. Moisture content uniformity was calculated by two methods. The first used the total variation of moisture content within the whole charge and the second used the variation between the average moisture content of the vertical tiers across the stack. Variation was defined in terms of a statistical variance which is the sum of the squares of the difference of each board's moisture content from the average moisture content of the lumber charge. Thus, the larger the variance, the less uniform the moisture content was within or across the lumber charge.

## Results and Discussion

### First Phase: Drying Time

The time necessary to high-temperature dry a charge of 80 pieces of 2 x 6 southern pine from its green condition to a relative moisture content of 10 percent was significantly affected by air velocity through the lumber charge, the width of the lumber charge, and the thickness of the stickers. Air velocity accounted for 82 percent of the difference in drying time, stack width accounted for 10 percent, and sticker thickness, an additional 2 percent.

Figure 1 compares the drying curves for the combination of factors that led to the most and least rapid drying. The drying curve is much steeper and the drying time less than half as long for a 4-foot wide stack with 1-1/8-inch stickers and a measured air velocity of 1000 feet per minute than it is for an 8-foot wide stack with 9/16-inch stickers and an air velocity of 500 feet per minute.

Multiple regression equations, developed from the data, show drying time decreasing with an increasing air velocity and sticker thickness, and a decreasing stack width (Figure 2).

Other studies have also concluded that an increased air velocity reduces drying time (4,5,7). Kollmann (5) showed that in high-temperature kilns, drying rates for low and very high circulation velocities did not become equal until the moisture content of 6.5 percent was reached. Kollmann also states that even though power consumption increases with the third power of velocity, velocities as high as 1575 feet per minute may be justified due to increased drying rates. In an unreplicated study, Price and Koch (7) concluded that thicker stickers and increased air velocities reduced drying time.

### First Phase: Moisture Uniformity

After accounting for variance caused by differences in the final average moisture content between each lumber charge, we

found that stack width, sticker thickness, and air velocity had no significant effect on the moisture uniformity within the entire lumber charge. However, when variance was measured between the average moisture content of each vertical tier of boards across each stack, the final average moisture content and stack width had a significant effect on moisture uniformity. The difference in the final average moisture content between the lumber charges accounted for 73 percent of the moisture variance and stack width accounted for an additional 5 percent.

Using a multiple regression equation with the final average moisture content held constant at 12 percent, an increase in stack width from 4 to 8 feet caused a 90 percent increase in moisture content variance across the stack (Figure 3). Although not statistically significant, multiple regression equations developed from the data showed the variance for the entire stack increased slightly as sticker thickness decreased from 1-1/8 inch to 9/16 inch, but variance between vertical tier averages across the stack decreased as sticker thickness decreased. The vertical tiers with the higher average moisture contents tended to be in the center of the lumber charges with the drier vertical tiers on the outer edges of the lumber charges.

Grading rules for moisture content state that less than 5 percent of the boards may be above the 15 percent moisture content limit (2,8). Only those charges with a final average moisture content of 11.8 percent or below, regardless of stack width, sticker thickness, or air velocity, met this requirement.

## Second Phase: Drying Time and Moisture Uniformity

The results of the second phase showed that there was no significant difference in drying time based on the different fan-reversal conditions. The average drying times for the no fan reversal, 6-hour, and 3-hour reversal conditions were 19.6 hours, 19.3 hours, and 20.0 hours, respectively. Also, there was no significant difference in moisture content variance measured for the stack as a whole or measured across the stack using the variance between the vertical tier averages. Also, the results showed that as the time between fan reversals decreased from no reversal to 6 hours to 3 hours, the portion of the stack with the highest moisture contents shifted from the leaving air side of the stack toward the center of the stack.

## Summary

Drying time was significantly influenced by air velocity and stack width. The drying time was reduced by more than one-half for combinations of narrow stacks, thick stickers, and high air velocities. Fan reversal had no significant effect on drying time.

Also, air velocity, sticker thickness and fan reversal had no significant effect on moisture content uniformity but stack width did have a limited effect. As stack width increased, variance between the average vertical tier moisture contents also increased, but no significant increase in moisture content

variance was shown in the entire lumber stack. The most significant factor, accounting for 73 percent of the variance in moisture uniformity, was the final average moisture content of the lumber charge. All lumber charges with a final average moisture content above 11.8 percent failed to meet the allowable grademark limit of only 5 percent of the charge above 18 percent moisture content.

#### Literature Cited

1. Bassett, K.H. 1975. Sticker thickness and air velocity. Proc. 25th Ann. Mtg. West. Dry Kiln Clubs. pp. 40-45.
2. Culpepper, L. and G. Wengert. 1981. Looking for causes of moisture content variation in kiln drying southern pine 2 x 4's. Unpublished report, Department of Forest Products, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.
3. Gough, D.K. 1974. High temperature drying in 24 hours. Australian Forest Industries Journal 40(10):9-11.
4. Koch, P. 1972. Drying southern pine at 240°F--Effects of air velocity and humidity, board thickness, and density. Forest Products Journal 22(9):62-67.
5. Kollmann, F.F.P. and A. Schneider. 1961. The effect of the flow velocity on the kiln drying of timber in superheated steam. Holz als Roh-und Werkstoff 19(12):461-478.
6. Page, R.H. 1973. High temperature versus conventional methods of drying southern pine lumber. Georgia Forest Research Paper No. 73, Univ. of Georgia, School of Forest Resources, Athens, Georgia.
7. Price, E.W. and P. Koch. 1981. A note on effects of stick thickness and air velocity on drying time of southern pine 2 x 4 and 2 x 6 lumber. Wood and Fiber 13(2): 115-119.
8. Southern Pine Inspection Bureau. 1977. Grading Rules. pp. 32-35.
9. Wellford, W. 1983. Personal communication via Dr. Fred W. Taylor.

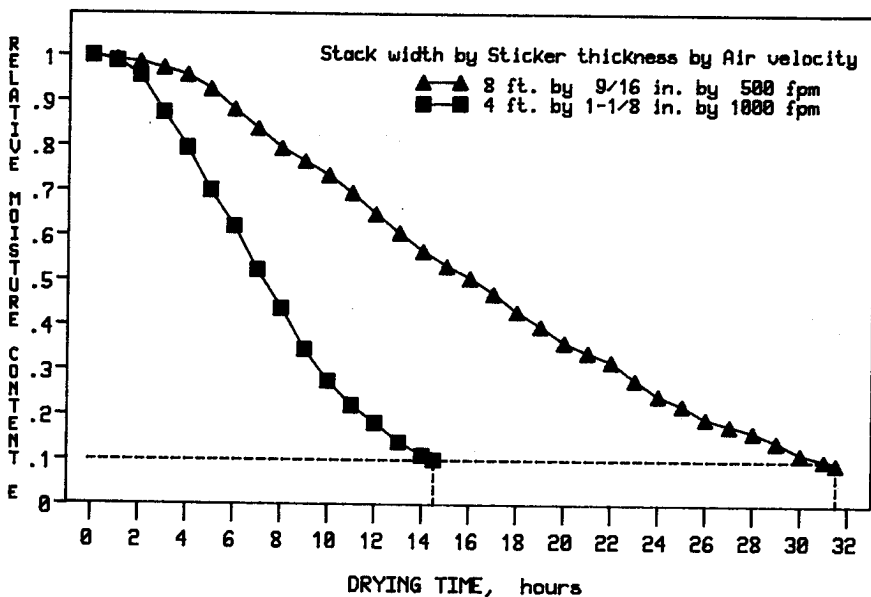


Figure 1. Comparison of the drying curves from the most and least rapid drying conditions.

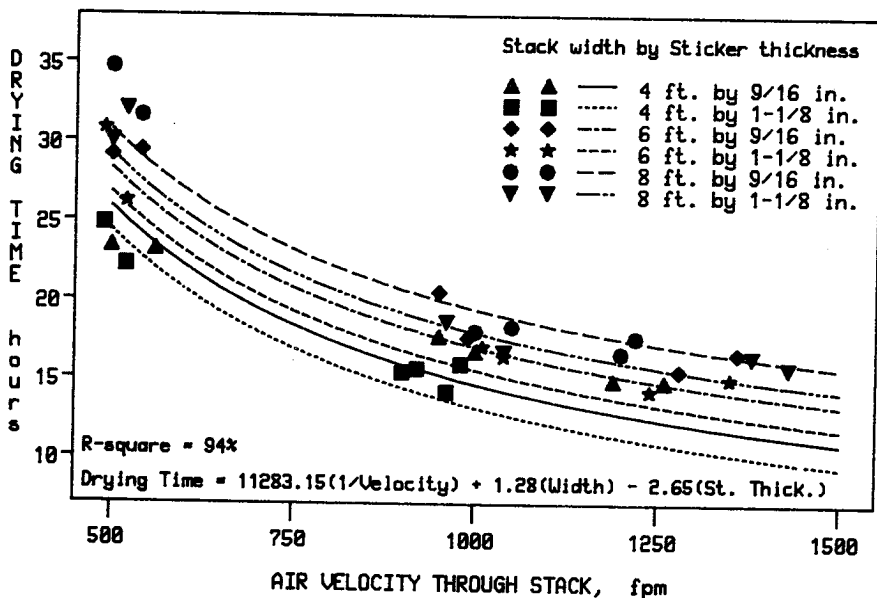


Figure 2. Regression of drying time vs. air velocity, stack width, and sticker thickness.

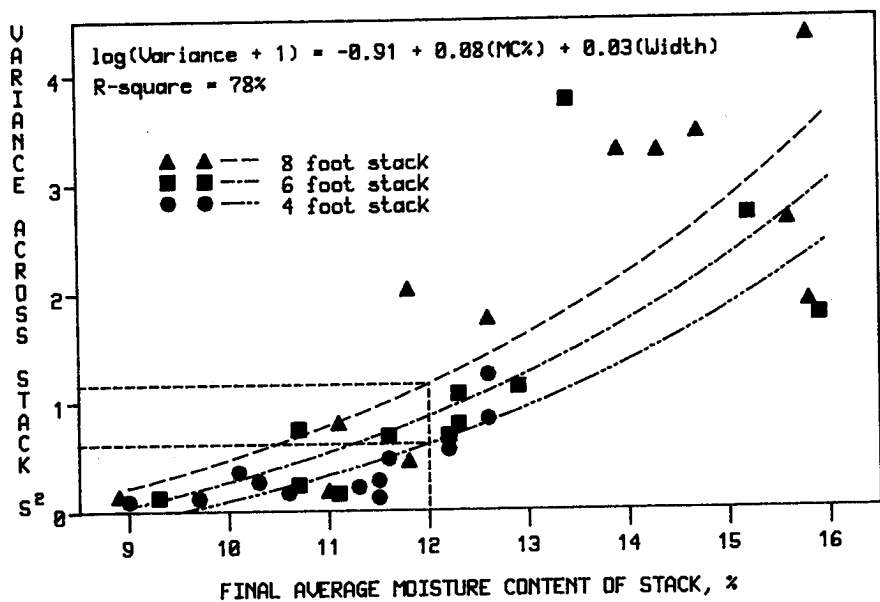


Figure 3. Regression of vertical tier variance across the stack vs. final average moisture content and stack width.