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Comparing Vacuum Drying and Conventional Drying Effects on the Coloration of Hard Maple Lumber

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Abstract

Vacuum kiln-drying, using low temperature in a low oxygen environment, produces light-colored hard maple in a significantly shorter drying time, and with less variability, than does conventional steam kiln-drying. To avoid chemical staining and to maintain light color, drying hard maple requires the use of high air flow at low temperature and relative humidity soon after being sawn. This study compared the color and drying times of hard maple dried in both types of kilns. Paired samples of 1-in. (25.4-mm) flat-sawn boards were dried in either a conventional kiln or a vacuum kiln, and lumber color of each board after drying was measured with a spectrophotometer. Vacuum drying produced industry-acceptable white maple faster than did conventional drying. On average, there were no visual differences in color between the two drying methods but color among boards from the vacuum kiln was more uniform.

Keywords: vacuum drying; hard maple; spectrophotometer; wood color

Contents

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Comparing Vacuum Drying and Conventional Drying Effects on the Coloration of Hard Maple Lumber

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Introduction

In 1904, Alexander Gray received a U.S. patent for a wood drying process he invented. This process involved the use of heat and vacuum cycling (Gray 1904). Historically, this technology was primarily used to dry specialty or niche wood products. However, in recent years, the use of vacuum technology to dry wood has seen renewed interest. Because this process has been shown to produce quality lumber, at faster drying rates, and at decreased operating costs, more wood products manufacturers are considering this technology. Vacuum drying allows wood to dry at a lower temperature than does conventional drying. Drawing a vacuum causes the boiling point of water to be decreased and the drying time to be shortened significantly. In conventional drying, color change mostly occurs when higher temperatures are used while the lumber is above the fiber saturation point. One potential advantage of vacuum drying is that it uses lower temperatures in a low-oxygen environment. This helps to produce lighter-colored wood and to preserve natural color in certain species (Chen and Lamb 2004, Espinoza and Bond 2016).

Hard Maple Color Importance

The sapwood of hard maple, called white hard maple, is valued for its bright color and clean grain. It is especially desired by consumers for a variety of products and demands a premium price. Lighter woods are generally viewed by consumers as modern and modest (Bumgardner and Bowe 2002). In general, hard maple requires drying with the use of high air flow at lower temperature and relative humidity soon after being sawn. If this is not done, the wood is prone to chemical staining (McMillen 1968, Wengert 1992). To compete with the increasing quality of products that resemble natural wood, such as luxury vinyl tile, lumber must be uniform and replicable in color (McMillen 1975). Several studies examined factors that may be used to achieve white maple color, such as harvest times; lumber storage times; end coating logs; chemical, physical, and mechanical treatments; and decreased temperature conventional kiln schedules (McMillen 1968, 1976; Yeo and Smith 2004; Rappold and Smith 2004; Wiemann and Knaebe 2008; Wiemann and others 2009, 2011, 2014).

Understanding the Color Measurement System

Paper making, coatings, and textile manufacturers use specialized color detection equipment to replicate color, such as a colorimeter or spectrophotometer. Colorimeters use light combined with a series of filters and photo detectors to quantify color, whereas spectrophotometers operate by illuminating a surface and measuring the amount and wavelength of light reflected from it (Beckwith 1979). Past studies (Smith and Montoney 2000, Smith and Herdman 1998) that have examined color variation in hard maple have used both types of equipment for the assessment. In the hardwood lumber manufacturing industry, color of wood is determined visually before and after drying. Value-added or secondary wood manufacturers, such as flooring and furniture manufacturers, assess wood color after surfacing.

Color tolerancing systems are used to describe the color analysis, which can differ based on the equations and techniques used to assess color. These systems are set apart from one another by how they use equations and techniques to assess color. The CIE L*a*b* model, from the International Commission on Illumination (abbreviated CIE from its French name), was defined in 1976 and is the universally accepted colorimetric reference system for quantifying and communicating color. This system expresses color as three values: L* for the lightness from black (0) to white (100), a* from green (–) to red (+) (+a* implying red and –a* implying green), and b* from blue (–) to yellow (+) (+b* implying yellow and –b* implying blue). This model quantifies color based on the opponent theory of color vision, which states that colors cannot be perceived as both green and red at the same time, nor blue and yellow at the same time. Colors are perceived as combinations of green and blue and of red and yellow (Billmeyer and Saltzman 1981). Figure 1 shows this relationship among the colors in this model. Smith and Montoney (2000) determined that customers preferred a white color for hard maple with the following spectrophotometer data ranges of color values: L* = 79 to 88; a* = 3 to 7; b* = 14 to 19. These data were used for comparison purposes in this study.

Dawson-Andoh and others (2004) found that discoloration in hard maple was attended by a decrease in brightness (L*) and increases in both redness (a*) and yellowness (b*). Conventional drying in a steam-heated kiln at lower temperatures is known to produce whiter lumber. A reasonable hypothesis is to compare coloration after vacuum drying (low temperature) with that after a conventional steam drying (higher temperature) schedule.

Research suggests that vacuum drying preserves the color in wood and produces a brighter product (Espinoza and Bond 2016, Chen and Lamb 2004, Harris and others 1984). Vacuum drying using similar temperatures to a conventional steam kiln schedule may produce whiter hard maple lumber than the steam kiln. It is reasonable to expect that drying at a low temperature and in a low-oxygen atmosphere in a vacuum kiln may produce much whiter lumber than conventional drying. This study investigated these expectations.

Objectives

The objective of this study was to compare the color of hard maple lumber dried in a vacuum kiln with that of hard maple lumber dried in a conventional steam kiln.

Methodology

Five #1 grade hard maple logs 8 ft 6 in. (2.6 m) long with diameters of 14 to 16 in. (360 to 410 mm) at the small end were chosen for the study. These logs were harvested during the week of September 16, 2019, in Langlade County, Wisconsin. Logs were not end-coated and were sawn on October 3, 2019. The sawmill used a circular headsaw and horizontal band resaw to produce 1-in.- (25.4-mm-) thick flat-sawn boards, which ranged from 4 to 9 in. (100 to 230 mm) wide.

Seven to nine boards were selected from each of the five logs based on the following criteria: all sapwood, clear, and free from discoloration. Each board was cut in half, and the halves were separated into two groups (Fig. 2). One group (half of each board) was dried to 7% moisture content (MC) in a SII conventional steam kiln (SII Dry Kilns, Lexington, North Carolina, USA), and the second group (the other half of each board) was dried to 7% MC in a VacuPress vacuum kiln (Vacutherm, Inc., Barre, Vermont, USA). In total, 206 board feet (0.49 m^3) of lumber were used in the study.

Because this study was conducted during a warm humid week, the researchers chose to operate the conventional steam kiln with the T1-C5 schedule developed by the USDA Forest Service, Forest Products Laboratory, for achieving the whitest color during summer months (Denig and others 2000) (Table 1). The vacuum kiln used the VacuPress medium drying schedule shown in Figure 3.

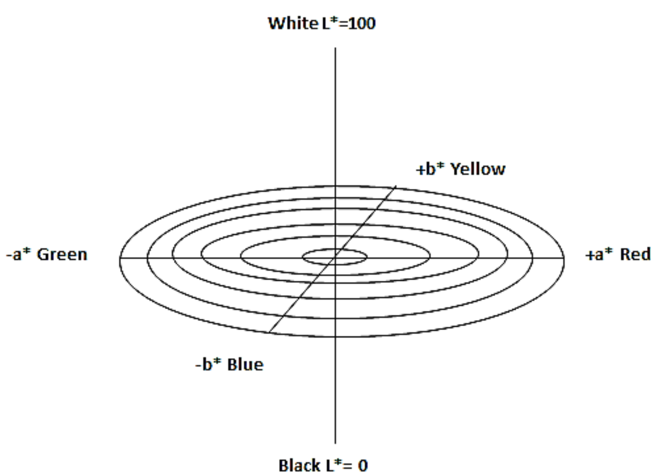

Figure 1. International Commission on Illumination (CIE) L*a*b* color space coordinates. L* for the lightness from black (0) to white (100), +a* implying red and –a* implying green, +b* implying yellow and –b* implying blue.

Figure 2: Left, Board sample halves are stacked on stickers prior to processing in the conventional steam kiln; right, board sample halves are stacked on heating platens prior to processing in the vacuum kiln.

Table 1—White maple drying schedule (T1-C5)

Step	Moisture content (%)	Equilibrium moisture content (%)	Relative humidity (%)	Dry-bulb (°F)[a]	Wet-bulb depression (°F)[a]
1	Above 30	11.8	68	100	10
2	25 to 30	9.8	58	105	14
3	20 to 25	7.6	44	105	20
4	15 to 20	4.1	22	115	35
5	<15	3.3	17	120	45

[a]°C = (°F – 32)/1.8.

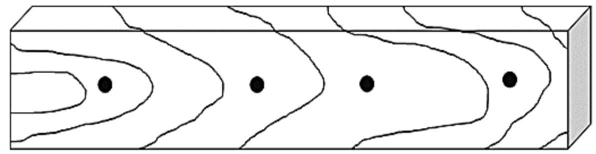

Figure 4. Diagram showing best judgement sampling of clear areas on a tangential surface.

Because dried wood appears brighter when surfaced, surface preparation of the sample boards for color analysis was performed with an industrial planer and drum sander to remove 3/16 in. (4.8 mm) from one surface of each board. The drum sander used 150-grit sandpaper to smooth the surfaces of the sample boards for easier interpretation with the spectrophotometer.

A Color Master CM2 spectrometer (X-Rite, Inc., Grand Rapids, Michigan, USA) with a D65 light source illumination was used to measure sample color numerically as L*a*b* values, and the data were downloaded and analyzed by X-Rite Color Master software. The sampling protocol detailed by Rappold and Smith (2004) was followed. Four spectrometer readings of 13-mm-diameter spots were taken using best judgement from clear areas, between the growth rings, of both tangential board faces, for a total of eight readings per sample board (Fig. 4). Figure 5 shows the sample boards being measured using the spectrometer method described.

Sample statistics and paired sample *t*-tests were run for each of the three variables measured with the spectrometer. The eight readings taken by the spectrometer for each variable were averaged for each sample board. The 40 paired sample averages were compared.

Results and Discussion

Samples in the vacuum kiln were dried in 58 h using a vacuum of 10 cmHg with a hold of 140 °F (60 °C) for 8 h, at which point the temperature was raised. The charge was completed when a wood core temperature of 160 °F (71 °C) was reached (Fig. 3). Samples in the conventional steam kiln were dried in 288 h using the T1-C5 schedule. The conventional steam kiln-dried the lumber using two 2-horsepower (1,492-watt) fans that averaged 500 ft (152.4 m) per minute during the kiln schedule, along with an electric steam boiler. This drying time difference is significant, with vacuum drying nearly five times faster than conventional steam drying. Kiln samples were used in both kilns to monitor moisture content during the drying process.

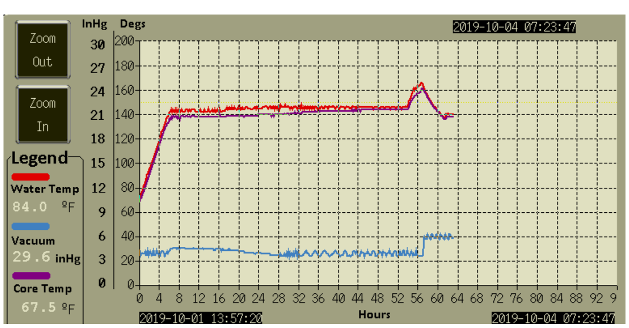

Figure 3. Vacupress (Vacutherm, Inc., Barre, Vermont, USA) drying schedule, medium setting.

Table 2 shows that the mean values for the 40 paired sample averages were very similar. No significant differences were shown for brightness (L*), a* (green–red), or b* (blue–yellow) scales.

Figure 6 shows that both methods of drying produced an industry-accepted lightness value range of white hard maple

Figure 5. Measurement of a sample board using the Color Master CM2 spectrometer (X-Rite, Inc., Grand Rapids, Michigan, USA) with a D65 light source illumination.

Table 2—Average L*a*b* values for surfaced wood samples from each drying schedule and *P* values for *t*-test: paired two sample for means

Drying schedule	L*	a*	b*
Vacuum	83.51	4.43	17.01
T1-C5 (conventional)	84.25	4.24	16.75
$P(T \leq t)$ one-tail	0.00	0.004	0.002

(L* = 79 to 88) as defined by Smith and Montoney (2000) and Smith and Herdman (1998).

Because the CIE L*a*b* model is three-dimensional, it is difficult to visualize actual differences in color values. One way to examine these color differences is to combine measured variables into a single measure called the colorimetric difference. The colorimetric difference can be defined as the distance between point L*a*b for sample 1 to point L*a*b for sample 2. Colorimetric differences of less than 3 are considered indistinguishable to the human eye.

Calculated colorimetric differences

$$\Delta E^*_{ab} = \sqrt{\left(\left(L^*_1 - L^*_2\right)^2 + \left(a^*_1 - a^*_2\right)^2 + \left(b^*_1 - b^*_2\right)^2\right)}$$

or the Euclidean distance between two colors, L*1a*1b*1 and L*2a*2b*2, specifically between drying methods are listed in Table 3. Our results showed that all samples, except for sample 2.6, had a colorimetric difference of less than 3. A value greater than 3 suggests a perceivable color difference when evaluating color in hard maple.

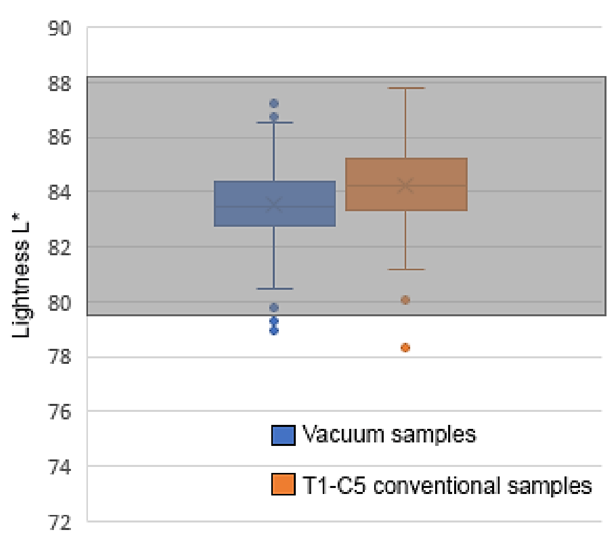

Figure 6. Average and range of lightness color values after surfacing. Shaded area is lightness range of industry-accepted white maple defined by Smith and Montoney (2000) and Smith and Herdman (1998).

Table 3—Calculated colorimetric differences between vacuum drying and conventional kiln schedule (T1-C5)[a]

Log.Board #	ΔE^*_{ab}	Log.Board #	ΔE^*_{ab}
1.1	1.5	3.5	0.6
1.2	0.9	3.6	0.9
1.3	0.9	3.7	0.2
1.4	0.9	3.8	0.9
1.5	0.3	4.1	0.8
1.6	1.6	4.2	2.7
1.7	1.4	4.3	0.8
2.1	1.9	4.4	1.0
2.2	1.6	4.5	0.9
2.3	2.3	4.6	1.3
2.4	1.1	4.7	0.3
2.5	0.8	4.8	1.4
2.6	**4.1**	5.1	0.6
2.7	1.5	5.2	0.4
2.8	1.8	5.3	0.4
2.9	1.9	5.4	0.3
3.1	1.7	5.5	0.8
3.2	0.8	5.6	1.3
3.3	0.5	5.7	0.5
3.4	0.6	5.8	1.0

[a]A value greater than 3 (in bold) indicates that the two sets of color value coordinates being compared were distant enough from one another that visually perceivable color differences are possible. Log.Board # refers to the five maple logs with seven to nine boards each, as described in the Methodology section.

Conclusions

In summary, there was no visual difference in color between the two drying methods, although the vacuum kiln did produce tighter variances in color measures compared with the conventional kiln. It is worth noting that the conventional steam kiln was a small research kiln with good control; therefore, the air flow, temperature, and relative humidity control were probably more accurate, with less variability, than would be found in a typical commercial kiln. Drying times were nearly five times faster in the vacuum kiln. However, loading and unloading a vacuum kiln is significantly more labor intensive. The results of this study have demonstrated that vacuum drying can produce industry-acceptable white hard maple that is comparable with a known white hard maple conventional kiln schedule.

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