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Optimum Drying Temperature to Prevent Oxidative Stain in Soft Maple

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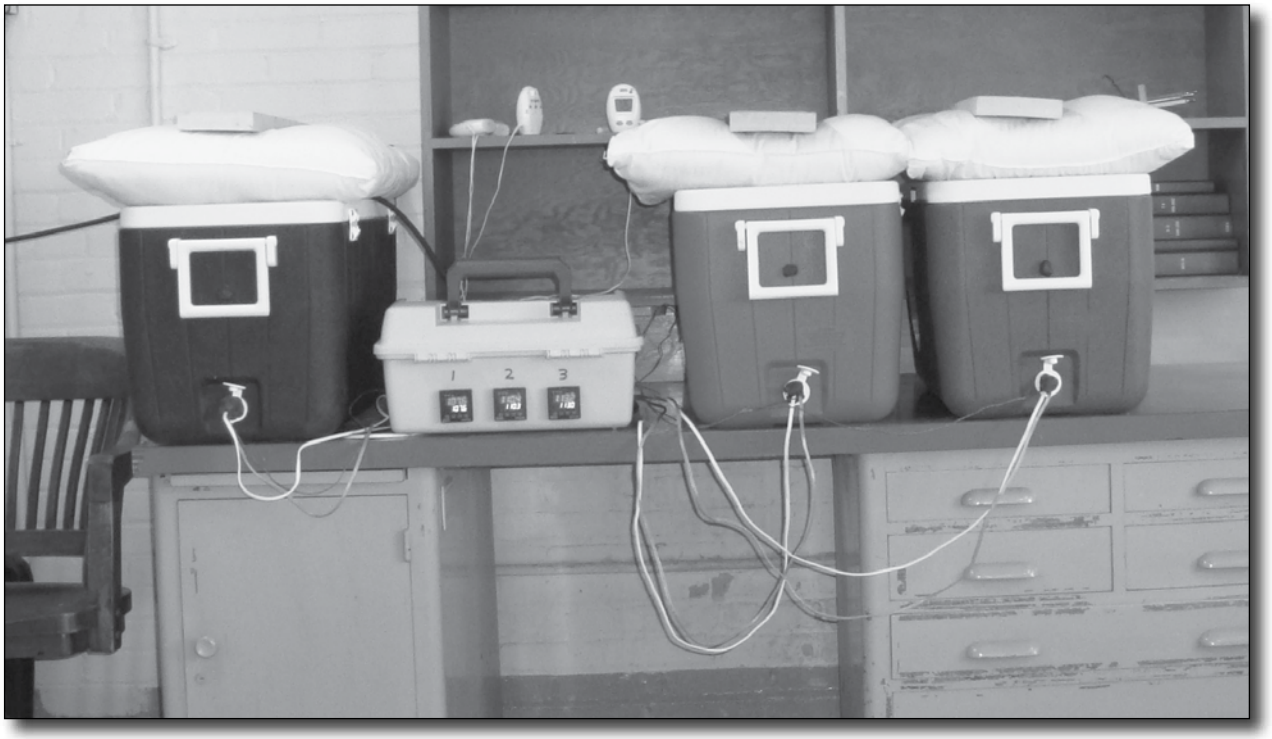

Abstract

The objective of this paper is to determine the kiln conditions necessary to avoid interior enzymatic oxidative discoloration in soft maple. Three drying chambers were designed and constructed to control temperature and relative humidity of maple test samples. The tests showed that drying as soon as possible after harvest at temperatures below 42 °C will greatly reduce drying discoloration in soft maple.

Keywords: drying temperature, enzymatic, gray, interior, oxidative stain, soft maple

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Contents

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Optimum Drying Temperature to Prevent Oxidative Stain in Soft Maple

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Introduction

As a result of previous research on soft maple (*Acer rubrum* L.), we hypothesized that oxidative stain commences and becomes more severe when the wood temperature increases across the range of 41–51 °C. If this is true, then an ideal drying temperature schedule might reduce or eliminate stain in soft maple and Bolivian ochoó (*Hura crepitans* L.), another species that has this problem. This paper reports the results of conditioning soft maple at carefully controlled temperatures to determine the temperature at which discoloration begins. The research will be repeated using ochoó to determine if discoloration can also be eliminated by temperature control in this species as well.

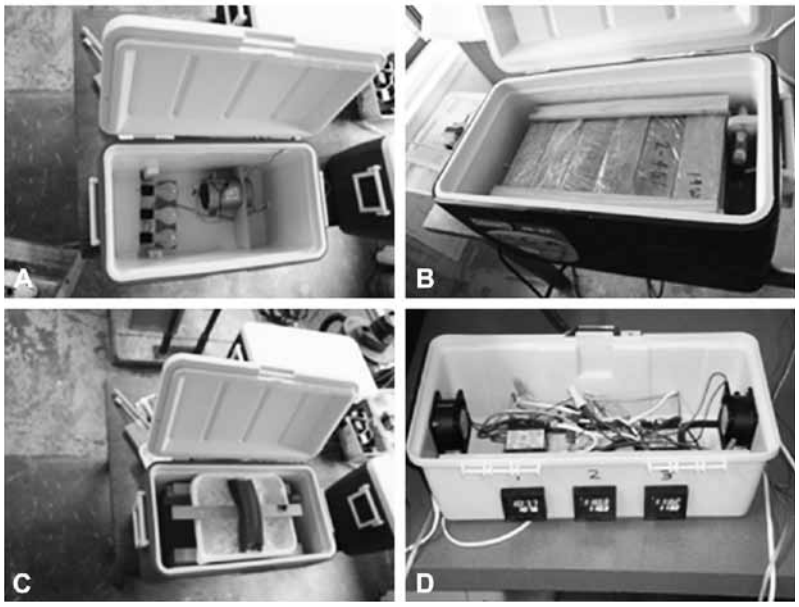

Fig. 1. Conditioning chambers showing incandescent bulbs and fan assemblage (A) loaded with plastic-wrapped samples, with yellow thermometer protruding from a hole in the left side and a data logger on the right side, (B) with a salt pan installed and foam spacer to divert air flow, (C) and control box showing three control assemblies with temperature readouts visible in front (D).

Procedure

Three chambers (selected to meet air transportation limits, because we intend to use the apparatus in Bolivia) were rigged as transportable conditioning chambers using incandescent bulbs, temperature controllers, fans, and pans containing salt (NaCl) to maintain a constant relative humidity (RH) of 74% to 75% (Fig. 1). We will refer to these as chambers A, B, and C.

On June 8, 2010, we obtained six freshly sawn nominal 2.5-cm-thick (260-cm-long) sapwood soft maple boards, 14–18 cm wide, from Kretz Lumber Co., Inc., in Antigo, Wisconsin. These boards were tightly wrapped in plastic and transported to the Forest Products Laboratory (Madison, Wisconsin), where they were stored at 2 °C, 82% RH. On June 9, a 92-cm-long segment was cut from each of the six boards, as shown in Figure 2. The remainders were re-wrapped in plastic and re-stored at 2 °C, 82% RH.

The 92-cm segments were sawn as shown in Figure 2, labeling the 2-cm-long moisture content samples 1–48 and 36 25-cm-long test pieces 1A–6Cw. The sawing sequence was as follows:

1. Each segment was ripped down the center of the face.

2. Each half of each segment was ripped to 6-cm-wide strips and outer portions were discarded.

3. Beginning at the right end, 2-cm-long moisture content samples and 25-cm-long test pieces were sawn and labeled, and the 4-cm-long outer piece was discarded. This yielded eight moisture content samples and six test samples per board. The matching test samples were labeled with the board number (1–6), the piece letter (A–C), and a "w" if the test sample was to be wrapped in plastic wrap (Fig. 1B). All the moisture content samples and test samples were weighed immediately, and the moisture content samples were placed in a drying oven set at 103 °C. The 18 test samples marked "w" were completely sealed with plastic wrap.

The "A" test samples were then placed into chamber A, the "B" samples into chamber B, and the "C" samples into chamber C. The temperature controllers were set to 41 °C, 46 °C and 51 °C for chambers A, B, and C, respectively. Chamber temperatures were measured using thermometers (two per chamber, one on the upstream end, the other on the

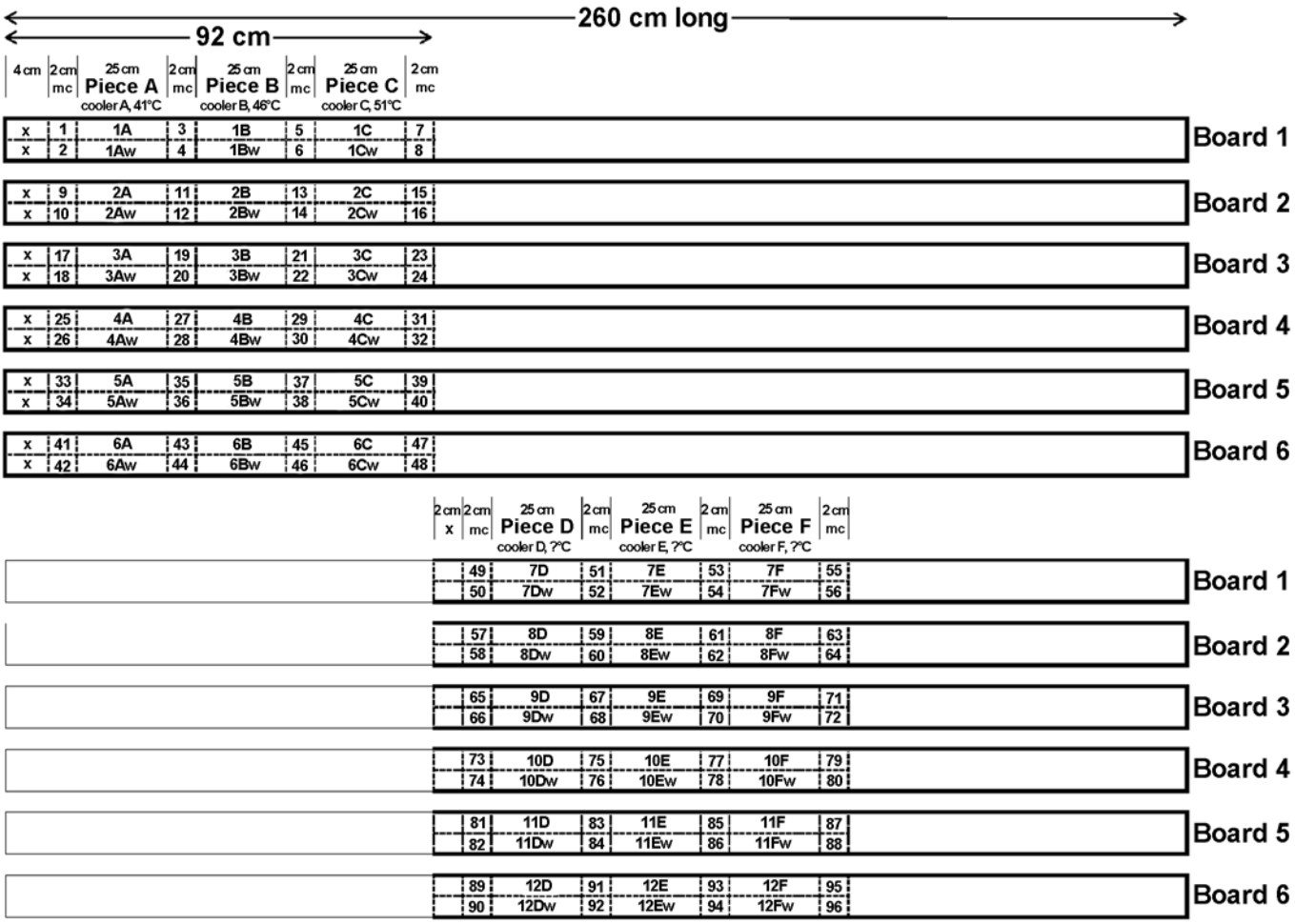

Fig. 2. Sampling pattern. Moisture content samples numbered 1–96. Test pieces 1A–6Cw (first run), 7D–12Fw (second run), labelled w if wrapped in plastic.

downstream end) inserted into holes drilled through the ends of the chambers. Temperature and relative humidity were recorded continuously using USB-502-LCD data loggers from Measurement Computing Corporation (Norton, Massachusetts), one in each chamber. The cover illustration shows the three chambers topped by weighted pillows to reduce heat loss; the control box is between two of them. Figure 1 shows the setup and use of the chambers: the heating incandescent bulbs and fan assembly are shown in A, a loaded chamber (wrapped samples are topped by stickers) with a yellow thermometer protruding (left) and a data logger in a wooden holder (right) is shown in B, loaded chamber with salt pan and foam rubber baffle is visible in C, and a plastic box containing three controllers and two cooling fans is located in D.

The moisture content samples were removed from the drying oven after 24 h and immediately weighed. Their initial moisture contents were calculated and used to calculate the ovendry weight of each test sample. The data loggers recorded the temperature and RH in each chamber once every 5 min throughout the run. The unwrapped samples were weighed daily, and the experiment was run until at least two-thirds of the samples reached moisture contents of 20% or lower. This occurred after
5 days, at which time all the test samples were removed (on June 14), the wrapped samples were unwrapped, and every test sample was weighed. They were then placed in a 27 °C, 30% RH room to air dry for a day.

The test samples were cut in half and separated into two matching groups with the sample numbers hidden. The discoloration of each half-sample was evaluated with each group scored independently, then the scores were compared to arrive at consensus scores. Based on amount of discoloration, the samples were ranked in order from 1 (least stain) to 36 (most stain), and separated into four categories (1 is no discoloration, 4 is severe discoloration) (Fig. 3). Based on the evaluations, the next settings of the chambers were determined such that the new (more limited) temperature range included the transition from no discoloration (or minimal) to severe discoloration.

The controls on the chambers were set to the new temperatures (42 °C, 43.5 °C, 45 °C), and the chambers

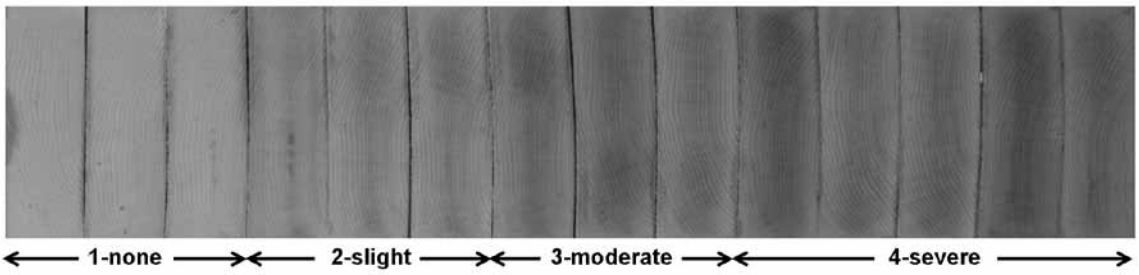

Fig. 3. Discoloration levels.

were re-labeled D, E, and F, respectively. On June 16, the preparation of moisture content and test samples was repeated as shown in Figure 2 (test pieces 7D–12Fw); the moisture content samples and test samples were immediately weighed, the moisture content samples were placed in the 103 °C drying oven, and the test samples were placed in the appropriate chambers. The moisture content samples were removed and weighed after 24 h, and their moisture contents were used to calculate initial moisture contents of the test samples. The test samples were removed after 5 days, the wrapped samples were unwrapped, all samples were weighed and then air dried in the 20 °C, 30% RH room for a day. They were then cut in half and their discoloration was evaluated as before. All 72 test samples (the two groups together) were then ranked least (1) to most (72) discolored.

All of the discoloration data were analyzed and plotted to determine the threshold temperature that results in discoloration and the effect of wrapping on level of discoloration.

Results and Discussion

The data loggers indicated that temperatures within the chambers were stabilized within 1 h, and relative humidity stabilized quickly then dropped gradually from about 80% to 75% over the course of the runs. The thermometers indicated that the temperature at the downstream end of each chamber was about one-half degree Celsius cooler than the upstream end where the controller thermocouple was located, although this varied with temperature setting and drying stage. The initial moisture contents of the test samples varied from 42% to 64% for the first run and from 48% to 66% for the second run. The calculated moisture contents of the samples at the time that they were removed from the chambers and cut in half was 41%–63% for the wrapped samples of the first run, from 48% to 64% for the wrapped samples of the second run, from 13% to 26% for the unwrapped samples of the first run, and from 11% to 25% for the unwrapped samples of the second run. These moisture content results indicate that there was no consistent moisture content effect between the two runs. Wrapping the samples effectively kept them from drying; unwrapping the samples and conditioning them in the 30% RH room for a day resulted in a rapid loss of weight.

Table 1 shows the distributions of discoloration categories for the two runs separately and for all of the samples taken together. The data of this table show that the additional storage time between the two runs affected the total percentage of samples that were not discolored: 28% for the first run versus only 11% for the second run. Storage time, however, did not affect the percentages of samples with the highest level of discoloration (22% for the first run versus 20% for the second run). For all of the samples taken together, each discoloration category contained a substantial percentage of samples (20–33%) (Table 1).

Table 1—Samples in each discoloration category

Discoloration category	First run (%)	Second run (%)	All samples from first and second runs combined (%)
1	28	11	20
2	19	47	33
3	31	22	26
4	22	20	21

The evaluation of the samples into discoloration levels was somewhat arbitrary, which is why we ranked all of them together from least discolored to most discolored. Figure 4 shows that for the samples exposed to temperatures greater than 43 °C, aged (second run) samples had greater discoloration ranges than their corresponding first run samples. This was also true for the samples exposed to temperatures lower than 43 °C; i.e., the second run samples had a wider discoloration range, with half the samples with discoloration exceeding 20, than the first-run samples, which all had discoloration scores less than 20 (Fig. 4).

Overall discoloration was lower for samples exposed to temperatures lower than 43 °C, and was lowest for the first-run samples exposed to a temperature of 41 °C (Fig. 4). Wrapping the samples gave inconsistent results. At some temperatures (42 °C, 45 °C, 46 °C, 51 °C), wrapping seemed to slightly increase the amount of discoloration, but at others (41 °C, 43.5 °C), wrapping seemed to decrease the amount of discoloration (Fig. 4), so exclusion of oxygen by wrapping did not seem to consistently affect the amount of discoloration.

Two of the 43.5 °C unwrapped samples of the first run had exceptionally high discoloration scores of 70 and 71 (Fig. 4). These samples, 12E and 11E, respectively, came from different boards (6 and 5, respectively; Fig. 2), but

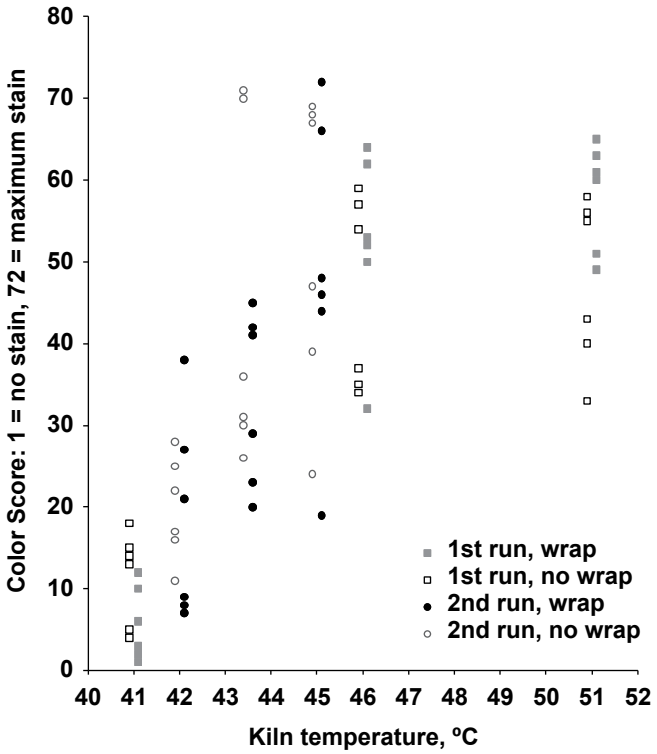

Fig. 4. Evaluation of the discoloration of the samples after exposure to the indicated temperatures. Squares represent samples from first run, circles represent samples from the second run. Closed symbols represent wrapped samples, open symbols represent unwrapped samples. The samples with the greatest discoloration were from the aged (second run) set. Note the marked decrease in discoloration at exposure temperatures lower than 43 °C.

their placement in the 43.5 °C cooler could not be reconstructed. It might be that the two samples were located in a "hot spot" and therefore responded like samples conditioned in the warmer coolers.

Conclusions

1. Maintaining a conditioning temperature below 43 °C reduces the amount of discolored wood in soft maple.

2. In soft maple, immediate exposure to normal drying temperatures results in less discoloration than exposure after storage, even if the storage time is only 1 week and the storage temperature is near freezing.

3. Excluding oxygen does not consistently reduce discoloration.

Next Steps

This drying test will be repeated using maple samples known to be from separate logs. The location of the test samples in the coolers will be randomized. Sample locations within coolers will be mapped to facilitate the evaluation of possible outliers.

This experiment will be then be tried on Bolivian ochoó (*Hura crepitans* L.) to determine if the severe discoloration that occurs in this species can be reduced or eliminated by rapid processing and low temperature drying. In Santa Cruz, Bolivia, however, high ambient temperatures and relative humidities might make it impossible to achieve sufficiently low wet-bulb temperatures for conventional dry kilns, necessitating the use of dehumidification kilns.