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COMPARISON OF TWO KILN-DRYING SCHEDULES FOR TURKISH HAZEL (*Corylus colurna*) LUMBER OF 5-CM THICKNESS

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ABSTRACT

Turkish hazel (*Corylus colurna*) lumber with a nominal thickness of 5 cm from the Kastamonu region, Turkey, was dried through conventional kiln drying using two different programs, a non-protective drying schedule and a protective drying schedule. The goal of the study was to obtain a kiln schedule that would maintain wood quality and also save drying time until a final moisture content of 8 ± 2% was reached. The intensity of warping (twisting, bowing, cupping, crooking), superficial, internal, and end checks, residual stresses, drying rate, and moisture gradient of the dried woods were measured, and the results were evaluated according to the classification of the European Drying Group. The results showed a more homogeneous moisture profile, fewer occurrences of superficial checks, and an absence of internal checks when using the protective drying schedule due to low warping values compared with those for the non-protective drying schedule. From the point of view of energy efficiency, by saving 60 h of drying time, the non-protective schedule reduced electricity by 960 KWh and was therefore more profitable by $105,60 in this trial. Therefore, it seems that the protective drying schedule should be recommended as the optimum program for drying Turkish hazel lumber from the Kastamonu region at the commercial scale.

Keywords: Drying quality, drying rate, moisture gradient, residual stresses, wood warping.

INTRODUCTION

There has been a continuous increase in the demand for wood products in Turkey, as in many other countries of the world. As a result, the gap between wood supply and demand has been widening rapidly. The general approach used to solve this problem is to establish large wood plantations consisting of fast-growing trees. Additionally, some researchers (Eşen *et al.* 2005, Ünsal and Kantay 2009) have indicated that attributes of wood quality should be considered for special end uses when the plantation approach is used. In general, plantation programs and research in Turkey have focused on native fast-growing and widely distributed species, but research on native species that have excellent wood quality attributes has been neglected because of the limited growing stock of these species. Turkish hazel (*Corylus colurna*) is a good example of such a neglected species.

Turkish hazel is a native species distributed mostly in southeastern Europe and southwestern Asia. It covers an area ranging from the Balkans through northeastern Turkey. The height of the tree may reach 35 m, and the trunk is stout, with a diameter as large as 1,5 m. The species grows well in well-drained chalky soils. The fine wood has a pinkish-brown color and excellent finishing characteristics (Yaltirik and Efe 2000). Hazelnut wood is under-utilized, although it has limited use in the manufacture of veneers, furniture, decorative inlays, and novelty items. The improved characteristics of kiln-dried hazelnut wood would increase the desirability of wood from this species for manufacturing value-

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added products and thereby create other potential opportunities (Sevim Korkut *et al.* 2008, Korkut and Hiziroglu 2009).

The goals of the wood drying process are maximum wood quality at minimum drying time and cost. Although there are a number of commercial drying methods, conventional kiln drying is the method most commonly used (Ünsal and Kantay 2009, Oltean *et al.* 2011, Shahverdi *et al.* 2012a).

The need to dry lumber quickly while simultaneously avoiding the development of defects in the dried wood has prompted researchers to develop wood-drying schedules to achieve the desired objectives. These programs involve a set of wet-bulb and dry-bulb temperatures that characterize the temperature and relative moisture content of the gas environment in the kiln. The selection criterion for the temperature and relative moisture content of a wood-drying program is a suitable drying rate that considers wood quality during the drying process. The application of optimal wood-drying schedules results in savings at the kiln due to reductions in time and energy consumption and improved use of the dried woods due reduced losses and better preservation of wood quality during processing (Shahverdi *et al.* 2012b). In addition, the determination of a proper wood-drying program to control the wood-drying process is considered an inevitable and unavoidable issue.

Several studies have investigated the design of wood-drying programs for species other than Turkish hazel (Korkut *et al.* 2007, Korkut and Güller 2007, Korkut *et al.* 2010). However, in Turkey, no study has considered the development of a program for proper drying of Turkish hazel, indicating the importance and the novelty of this study.

The objectives of this research project were to investigate the quality of the lumber produced from small-diameter (30-35 cm) hardwood logs and to evaluate the quality characteristics of Turkish hazel lumber dried in a kiln using different drying schedules.

MATERIALS AND METHODS

Five trees with diameter at breast height (DBH; 1,3 m above ground) of 30-35 cm were obtained from Kastamonu Forest Enterprises. The area from which the trees were harvested has an elevation of 1290 m and a slope of 30%. Sample lumbers 50 mm in thickness and 200 cm in length were cut by through-sawing at a private sawmill (Oney Wood Veneer Industry and Trade, Inc.). In total, 30 samples were used in the study.

An automatic drying kiln with a capacity of 1 m^3 and electrical heating was used for the trials (Figure 1). The kiln had three lumber moisture content sensors, an environmental temperature sensor, and an environmental equilibrium moisture sensor. The lumber moisture content sensors were mounted by drilling a 1,6-mm-diameter hole to the depth of measurement. In addition to these sensors, the kiln had an automated flap valve and an automated humidifying valve as measurement tools and accessories. These were all connected to the command panel. To determine appropriate drying schedules, pre-trials were carried out based on data from the existing literature (Boone *et al.* 1988, Simpson 1991, Simpson 1996). The drying process consisted of heating, main drying, and conditioning and cooling periods. The temperature and relative moisture content of the kiln were controlled automatically. The air speed was 3 m/s. Air was provided by a fan on the side of the kiln, and air circulated horizontally inside the kiln. The lumber drying oven had two ventilation chambers.

Figure 1. Drying kiln used for the trials.

Two different drying schedules, protective and non-protective, were used for the trials. Fifteen boards that had been dried from green to a target moisture content of 8% were used for each drying experiment. Detailed information about the schedules is presented in Table 1 and Table 2.

Table 1. Non-protective drying schedule for Turkish hazel lumber.

Wood type: Turkish hazel (*Corylus colurna* L.) Lumber thickness: 50 mm Oven dry density: 0,636 g/cm^3 Initial moisture content: 75% Final moisture content: 8%				Temperature T1: 48,9; T2: 75 Drying gradient: 4				
1	2	3	4	5	6	7	8	9
Drying Period	Moisture content of lumber (%)	Drying gradient	Equilibrium moisture content (%)	Dry-bulb Temperature (°C)	Wet-bulb Temperature (°C)	Wet-bulb depression (°C)	Relative moisture content (%)	Approximate duration (h)
Heating	Pre-heating	-	-	-			100	
	Superficial heating	-	-	-			. . . . . .	7
	Deep heating	-	-	48,9				
Main drying	75–40	-	17,7	48,9	46,9	2	90	
	40–35	2,43	16,4	48,9	45,9	3	84	
	35–30	2,59	13,5	48,9	44,9	4	80	
	30–25	2,91	10,3	54,4	47,4	7	68	508
	25–20	4,16	6,0	60,0	45	15	44	
	20–15	7,14	2,8	65,6	39,6	26	21	
	15–8	4,41	3,4	75,0	47	28	23	
Equalizing	8	-	8	75,0	65,0	10	63	45
Kiln type: Metal Air speed: 3 m/s Daily operation duration: 24 h								

Table 2. Protective drying schedule for Turkish hazel lumber.

<table>
<tr><td colspan="5">Wood type: Turkish hazel (Corylus colurna L.)
Lumber thickness: 50 mm
Oven dry density: 0,636 g/cm³
Initial moisture content: 75%
Final moisture content: 8%</td><td colspan="4">Temperature
T1: 43; T2: 70
Drying gradient: 4</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td></tr>
<tr><td>Drying period</td><td>Moisture content of lumber (%)</td><td>Drying gradient</td><td>Equilibrium moisture content (%)</td><td>Dry-bulb temperature (°C)</td><td>Wet-bulb temperature (°C)</td><td>Wet-bulb depression (°C)</td><td>Relative moisture content (%)</td><td>Approximate duration (h)</td></tr>
<tr><td rowspan="3">Heating</td><td>Pre-heating</td><td>-</td><td>-</td><td>-</td><td></td><td></td><td rowspan="3">100
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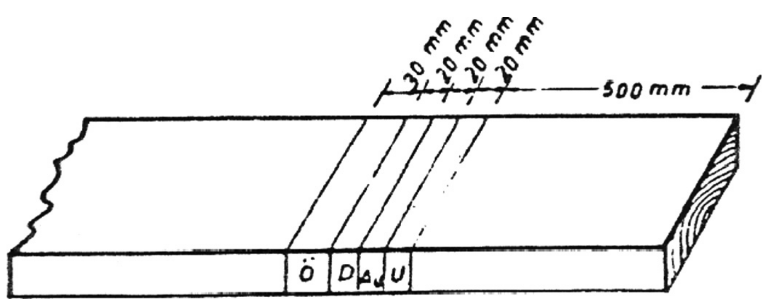
.
.
92</td><td rowspan="3">9</td></tr>
<tr><td>Superficial heating</td><td>-</td><td>-</td><td>-</td><td></td><td></td></tr>
<tr><td>Deep heating</td><td>-</td><td>-</td><td>43,0</td><td></td><td></td></tr>
<tr><td rowspan="7">Main drying</td><td>75–40</td><td>-</td><td>19,3</td><td>43,0</td><td>41,0</td><td>2</td><td>90</td><td rowspan="7">563</td></tr>
<tr><td>40–35</td><td>2,25</td><td>17,7</td><td>43,0</td><td>40,0</td><td>3</td><td>87</td></tr>
<tr><td>35–30</td><td>2,28</td><td>15,3</td><td>43,0</td><td>39,0</td><td>4</td><td>81</td></tr>
<tr><td>30–25</td><td>2,45</td><td>12,2</td><td>48,0</td><td>43,0</td><td>5</td><td>72</td></tr>
<tr><td>25–20</td><td>3,52</td><td>7,1</td><td>54,0</td><td>41,0</td><td>13</td><td>44</td></tr>
<tr><td>20–15</td><td>7,21</td><td>2,8</td><td>60,0</td><td>34,0</td><td>26</td><td>15</td></tr>
<tr><td>15–8</td><td>4,41</td><td>3,4</td><td>70,0</td><td>44,0</td><td>26</td><td>22</td></tr>
<tr><td>Equalizing</td><td>8</td><td>-</td><td>8</td><td>70,0</td><td>59,0</td><td>11</td><td>58</td><td>48</td></tr>
<tr><td colspan="9">Kiln type: Metal
Air speed: 3 m/s
Daily operation Duration: 24 h</td></tr>
</table>

The target final moisture content was set to 8% because the final indoor moisture content was 10 ± 2% due to the central heating that was used. The drying results were evaluated by quality control (characterization) tests (Boone *et al.* 1988, Simpson 1991, Simpson 1996). As recommended by the European Drying Group (EDG 1992), samples for testing were taken from a transverse section of the final quality control sample lumbers. The sampling positions were at least 500 mm from the end of the lumber (Figure 2).



(U) Final moisture content testing sample
(ΔU) Moisture content difference testing sample
(D) Case hardening testing sample (prong sample)
(Ö) Density testing sample

Figure 2. Sampling for final quality control.

Samples that were the same size as the final moisture content testing samples were cut into five slices. The moisture content of each slice was found by the drying method, and the moisture content difference between inner and outer layers was determined by the following formula using outer layer samples 1 and 5 and inner layer sample 3, as shown in Figure 3 (TGL 21504, 1969).

$$\Delta U = U3 - \frac{U1 + U5}{2} \quad (\%)$$

ΔU = Moisture content difference between inner and outer layers (percent)
U3 = Moisture content in inner layer (percent)
U1 and U5 = Moisture content in outer layers (percent)

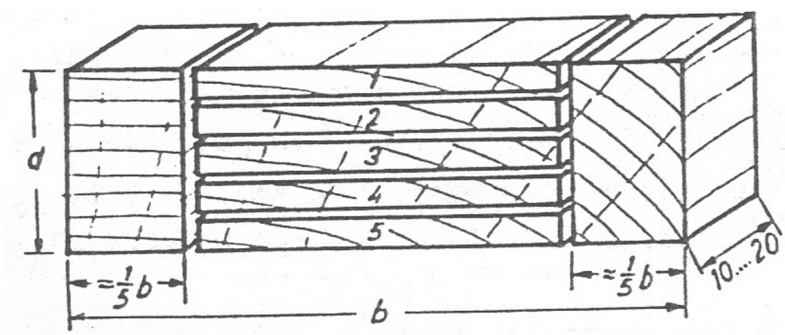


Figure 3. Samples used in the determination of the moisture content distribution within the transverse section (Lempelius 1969, Kantay 1978).

Prong samples (Figure 4) were prepared, and the TRADA pattern (Figure 5) was used to determine drying tensions at two stages, i.e., just after drying and 24 h after drying.

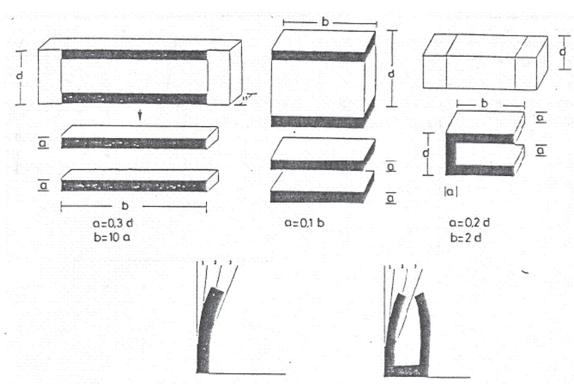


Figure 4. Preparation and utilization of prong samples (EDG 1992).

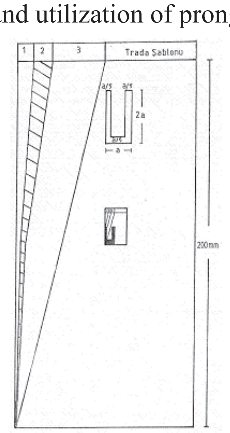


Figure 5. TRADA pattern (Unsal 1994).

Before drying, defects of the final quality control sample lumbers were determined, and checks were marked on the lumbers. At the end of the drying process, the final quality control samples, which had been marked and numbered previously, were examined in a step-by-step process according to the following criteria (EDG 1992): moisture content (average moisture content, distribution of moisture content in each lumber and in the kiln in general, acceptable distribution width), drying checks (surface checks, inner checks, and end checks), drying tension/case-hardening, collapses, and deformations. Quality classes were determined by comparing the data obtained with the tolerance values of the EDG (Table 3).

Table 3. Tolerance values of drying quality (EDG 1992).

<table>
<tr><th colspan="4">Criteria</th><th>S (Standard)</th><th>Q (Quality dried)</th><th>E (Exclusive)</th></tr>
<tr><td colspan="2" rowspan="2">Maximum deviation between target final moisture content (%) and average moisture content</td><td colspan="2">d ≤40 mm</td><td>+ 2,0 / - 3,0</td><td>+ 2,0 / - 2,0</td><td>+ 1,5 / - 1,5</td></tr>
<tr><td colspan="2">d >40 mm</td><td>+ 3,0 / - 3,0</td><td>+ 2,5 / - 2,5</td><td>+ 2,0 / - 2,0</td></tr>
<tr><td colspan="2" rowspan="2">Maximum deviation between target final moisture content (%) and separate moisture content measurements</td><td colspan="2">d ≤40 mm</td><td>+ 4,0 / - Unlimited</td><td>+ 3,0 / - 3,0</td><td>+ 2,0 / - 2,0</td></tr>
<tr><td colspan="2">d >40 mm</td><td>+ 6,0 / - Unlimited</td><td>+ 4,0 / - 4,0</td><td>+ 3,0 / - 3,0</td></tr>
<tr><td rowspan="2">Case hardening</td><td rowspan="2">Prong sample testing</td><td colspan="2">First measurement</td><td>Moderate (2)</td><td>Light (1)</td><td>Light (1)</td></tr>
<tr><td colspan="2">Measurement after 24 hours</td><td>Severe (3)</td><td>Moderate (2)</td><td>Light (1)</td></tr>
<tr><td colspan="4">Collapse (reduction of thickness) (in 10% of the samples)</td><td>Max. 6 mm</td><td>Max. 3 mm</td><td>Max. 2 mm</td></tr>
<tr><td colspan="2" rowspan="4">Checks</td><td colspan="2">Surface checks (on each surface)</td><td>Max. depth 5 mm</td><td>Max. depth 3 mm</td><td>Max. depth 2 mm</td></tr>
<tr><td colspan="2">Internal checks</td><td>in 10% of the samples</td><td>in 5% of the samples</td><td>in 2% of the samples</td></tr>
<tr><td rowspan="2">End checks (in 90% of the samples)</td><td>d ≤40 mm</td><td>Max. length 200 mm</td><td>Max. length 100 mm</td><td>Max. length 50 mm</td></tr>
<tr><td>d >40 mm</td><td>300 mm</td><td>200 mm</td><td>100 mm</td></tr>
<tr><td colspan="4">Deformations</td><td colspan="3">Deformations caused by shrinkage and anisotropy of shrinkage and those caused by inherent wood properties are allowed.</td></tr>
</table>

The electrical energy consumption of the kiln was previously known. A comparison of the electricity consumption and cost of the two schedules was calculated using equation (1) (2):

$$ECon = KEC * DT \qquad (1)$$

$$ECost = Econ * EUP \qquad (2)$$

where ECon is electricity consumption (kWh), ECost is electricity cost (USD), KEC is kiln electrical energy consumption (16 kWh), DT is drying time (h), and EUP is unit price of electricity (0,110 \$/kWh).

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RESULTS AND DISCUSSION

Drying Turkish Hazel Lumber using the Non-protective Drying Schedule

Drying the lumbers from an initial moisture content of 75% to a target final moisture content of 8% took 560 hours in total: 7 h for heating, 508 h for main drying, and 45h for the equalizing stage. At the final moisture content measurements, the maximum moisture content was 12,5% and the minimum was 5,5%. With the average moisture content, the standard (S) quality level was approximately reached. Based on the moisture-content gradient measurements (12% maximum and 5,5% minimum), the quality level Q was obtained. Moderate case hardening was determined in the first (immediate) measurement, and severe case hardening was determined in the second (24h later) measurement. According to these results, the S quality level was achieved. Collapse was observed in 5% of the samples. The maximum collapse width was 3,2 mm. Quality level S was achieved, but the 10% limit on the ratio of collapse was exceeded. In all of the samples, some deformations (warping), such as cupping, bowing, and crooking, were observed. The tree's shrinking anisotropy, rather than stacking faults, is most probable reason for this defect. Cross sectional and surface splits occurred in all samples. Quality level S for the maximum length of the splits was achieved (Figure 6).

Figure 6. Lumbers dried with the non-protective drying schedule.

Drying Turkish Hazel Lumber using the Protective Drying Schedule

For the protective schedule, the total drying time was 620 hours: 9 h for heating, 563h for main drying, and 48h for the equalizing stage. The final moisture content measurements showed that the maximum moisture content was 11% and the minimum was 5%. With regard to the average moisture contents, the exclusive (E) quality level was attained. Based on the moisture-content gradient measurements (10,4% maximum and 6% minimum), the quality level E was achieved. In measurements with finger samples, light case hardening was determined at the first (immediate) and second (24h later) measurements. According to these results, the quality level E was attained at both the first and second measurements. Collapse was observed in 1% of the samples, and the maximum collapse width was 1,2 mm. According to these results, the E quality level was obtained. Discolorations and splits were not found in the samples. Additionally, there were no warps, such as bowing, crooking, or twisting (Figure 7).

Figure 7. Lumbers dried with the protective drying schedule.

The protective drying schedule resulted in fewer end cracks and no superficial checks because of less warping and the lower moisture-content profile compared with the non-protective drying schedule. Therefore, this program is recommended as the optimum drying schedule for Turkish hazel (*Corylus colurna*) coming from the Kastamonu region at the industrial scale.

This result is consistent with the results reported by other researchers (Kantay 1978, Khorsandalam 2001, Kantay *et al.* 2002, Ünsal 1994, Korkut and Güller 2007, Korkut *et al.* 2007, Unsal and Kantay 2009, Korkut *et al.* 2010, Rahimi *et al.* 2011, Rrezaei and Hoseinpour 2012, Tenorio *et al.* 2012, Korkut *et al.* 2013, Tari and Madhoushi 2013). According to these researchers, a protective schedule should be used to obtain better quality lumber and prevent serious defects. Furthermore, when initial moisture content is high, an intense schedule may cause defects.

CONCLUSIONS

Although acceptable results were obtained and drying time was shortened by 60 h using the non-protective drying schedule, the protective drying schedule yielded better results in drying Turkish hazel lumber compared with the non-protective schedule by several criteria, including final moisture content, moisture gradient, and especially, drying tension.

From the point of view of energy efficiency, the non-protective drying schedule reduced the drying time by 60 h and the electricity use by 960 kWh relative to the protective schedule. The total savings for this trial were $105,60.

To optimize crucial factors in the drying process, such as temperature and relative moisture content, additional research pertaining to other thicknesses at this growing site as well as to the same thickness at other growing sites is needed. Given the importance of conditioning treatment and its role in removing internal drying stresses, its implementation in future studies is recommended to obtain a desirable time for this process.

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