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Full Length Research Paper

Drying schedules calculation of Camiyani Black Pine (*Pinus nigra* Arn. subsp. *pallasiana* var. *pallasiana*) by computer programming

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In this study, computer aided drying schedules were developed for Camiyani Black Pine (*Pinus nigra* var. pallasiana) lumber for less than 30 mm thick, between 30-60 mm thick and larger than 60 mm. Schedules were calculated on drying gradient basis. In this software (named KILNBRAIN), users can find more then one hundred other species' data (density, fiber saturation point, temperatures for warming up and drying periods, drying gradients for moisture contents above and less than 20%). Users can choose lumber thickness, initial and final moisture content, kiln type, air velocity and drying quality. One of the advantages of KILNBRAIN is that the drying schedule can be operated manually according to this data. Moreover, possible total drying duration can be predicted.

Key words: Camiyani Black Pine, computer software, drying schedule.

INTRODUCTION

The wood of a living tree contains large quantities of water. When this wood is converted to lumber, it requires the removal of some of the water to enhance the attributes and physical properties of the lumber. This in turn increases the value of the lumber.

This increased value may allow the seller to obtain a higher selling price or provide entry into otherwise inaccessible market segments. If the value can be enhanced to the point where the total cost of delivering dried lumber is less than the difference in the selling price between green and dry lumber, a net contribution to profit can be realized. Drying may still be warranted even if a net contribution is not realized. If drying opens up new market segments, a zero or short-term negative contribution to profit may be forgiven in favor of the long-term viability of the operation (Peter, 2001).

Increasing the value of lumber requires improving its usefulness while minimizing quality losses. Usefulness can be increased through drying by improving the:

- resistance to biological attack by insects, bacteria, and fungus
- volume/weight ratio
- strength and stiffness
- appearance
- gluing properties
- finishing properties
- machining and assembly properties
- dimensional stability
- phyto-sanitary reasons stable product to store and ship

Although wood has many advantages, it also has some unwanted properties. Because of being organic material, it decays and burns easily. If it is dry it can absorb water (absorption) or if it is wet it can lose water (desorption) and change its dimensions depending on its environment (Kantay, 1993). Between 0 and 25-33% relative humidity levels described as hygroscopic humidity level, dimensions of wood material can change, swelling occurs as a result of absorption of water and shrinkage happens because of drying (Kantay, 1993; Ucuncu, 1992; Ors, 1986).

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Many methods have been developed to eliminate the unwanted properties of wood. Modern wood technology, such as, drying steaming, preservative treatment and finishing techniques are used to enhance some of the properties of wood (Ors, 1986).

Drying of wood is a process that involves taking out the liquid inside the wooden material. The advantages of properly dried wood are as follows (Aytekin et al., 1999):

1. Properly dried wood will not deteriorate if its moisture content is kept at the same levels as drying conditions. Fungi being responsible for the decay need moisture, moderate temperature and oxygen. If one of these is kept under control, occurrence of decay can be prevented.
2. The dimension change in properly dried wood is very limited. The occurrence possibility of checks, twists and warp is decreased.
3. Proper drying can ease woodworking applications, getting smooth surfaces and dimensions.
4. Better results in wood bonding applications can be obtained by properly dried wood.
5. Success rates of surface and preservative treatments can be maximized by proper drying methods.
6. Strength, hardness, nail withdrawal strengths and paint quality of lumber are increased with drying.

Generally wood can be dried by two essential methods: which are air drying and kiln drying. However there is also accelerated air drying method in between. Air drying is the drying of timber by exposing it to the atmospheric conditions and not changing the external factors affecting drying process.

This type of drying is not suitable for wooden materials used indoors and centrally heated places in terms of the final moisture content obtained. However, with kiln drying desired final moisture content can be achieved by changing and adjusting drying factors. Thus, lower final moisture content can be easily obtained (Berkel, 1978; Ors, 1986).

Cronin et al. (2003) examined the effects that a single set-point drying schedule and a double set-point drying schedule had on the distribution of final moisture contents for Irish Sitka Spruce. The dry and wet-bulb temperatures were not altered in the single set-point schedule. On the other hand, the dry and wet bulb temperatures were modified in a stepwise fashion during drying for the double set-point schedule. The probabilistic drying models used in this work involved the development of empirical expressions that predict the mean and standard deviation of the board moisture contents as a function of time.

Trial and error has been used for the development of kiln drying schedules in the past (Campbell, 1980; Mills, 1991). Thereafter, more rational approaches have been undertaken for the optimization of kiln drying schedules. Optimized kiln drying schedules have been developed from simulations (Cronin et al., 2003) that have only considered the variability of final moisture contents. Continuous kiln drying schedules (Booker, 1994; Alexiou, 1993; Langrish et al., 1997) have also accounted for stress, strain, and checking/cracking. Pordage and Langrish (2000) developed a kiln drying schedule that considered the variability of timber properties, using very limited data on variability from Doe and Innes (1999). The remaining challenges in optimizing kiln drying schedules include getting sufficient data on the variability of timber properties, and optimizing both to minimize cracking and to minimize the range of final moisture contents.

Different methods for optimizing drying schedules to minimize checking or cracking have been applied in the past. Key features of previous work include using acoustic emissions, and trial and error (Booker, 1994; Alexiou, 1993). The study of more specific stages during the drying process, for example the conditioning phase (Salin, 2001) to reduce the development of cracking or internal checking, using average timber properties as a basis for optimization (Langrish et al., 1997), and optimized drying schedules that allow for a representative mixture of sapwood and heartwood (Carlsson and Tinnsten, 2002). However, the methods mentioned were either applied only to a particular timber species, e.g. the work of Booker (1994) for Tasmanian eucalypt, Alexiou (1993) for blackbutt, and Langrish et al. (1997) for ironbark, or required validation because they were only predictions, e.g. Salin (2001) or lastly, were simulations that were based on assumptions that are improbable in practice, e.g. Carlsson and Tinnsten (2002), with the assumption that drying started from fibre-saturation point. Most importantly, the variability in timber properties was not accounted for in these previous works.

Booker developed the program SMARTKILN from Oliver's (1991) KILNSCHED program to develop optimum drying schedules based on the calculated surface instantaneous strain (Booker, 1994). KILNSCHED is based on a diffusion model. KILNSCHED simulates arbitrary drying conditions, allowing the user to experiment with different kiln schedules, and understand the fundamental process of timber drying.

SMARTKILN control begins with a simple drying schedule. SMARTKILN, like KILNSCHED, then uses data logged real time drying conditions to simulate the drying behavior of the sample boards in the kiln, by solving Fick's Law of diffusion for mass transfer and the Fourier equation describing heat conduction for heat transfer. The process of moisture transfer was assumed to be a nonlinear, one-dimensional flow of moisture and heat from the centre to the wide surfaces because sufficient data on edge-drying were not yet available (Booker, 1994). Stress/strain theories were also applied in the model, where the instantaneous strain was the strain component compared with the failure criterion. Overall, these optimized drying schedules calculated by SMARTKILN prevented collapse (shrinkage which occurs above fiber saturation point, usually 30% moisture content), reduced drying time from 1430 to 1320 h, and controlled the strain on the surface of the boards. The work of Booker (1994), therefore, shows that AE measured within timber can be used to optimize kiln drying schedules to reduce cracking, but he did not try to minimize the dispersion of final moisture contents. Langrish et al. (1997) showed that optimizing drying schedules to minimize cracking using average timber properties gave improvements compared with conventional schedules (Campbell, 1980) based on trial and error. An optimized kiln schedule for Australian Ironbark timber (*Eucalyptus paniculata*) was based on a simple Fickian diffusion model for drying, and stress/strain models. The resulting optimized drying schedule set gentler drying conditions, smaller wet-bulb depressions during the initial stages of the drying process, and more aggressive conditions towards the end of drying compared with the conventional schedule. The drying time for the optimized drying schedule was reduced by 10% (122 h) compared with the conventional one (137 h) for a target average moisture content of 15%.

Alexiou (1993) developed an optimized kiln drying schedule for 50 mm thick blackbutt timber boards based on trial and error. The final, optimized drying schedule was developed based on data regarding strain gradients, moisture gradients, and on the amount of checking obtained from two conventional kiln runs, and from a first attempt at an accelerated drying schedule.

The success rate of kiln drying directly depends on the drying schedule or program. The adjustment of drying conditions of sawn wood from initial to final stages and management strategies are clearly determined in drying schedules. For a successful drying operation, wood species and properties, and thickness should be taken into account and a drying program proven with previous trials is needed (Aytekin, 1997).

Drying schedules are prepared according to drying gradient. The average moisture content of lumber is divided by chosen drying gradient value and equilibrium moisture content applied on that moisture level obtained. Dry bulb and wet bulb temperatures are adjusted according to this calculated equilibrium moisture content (Table 1) (Keylwerth, 1950; Kantay, 1980; 1993).

The software developed in this study is named KILNBRAIN. This software can prepare drying schedules of more than hundred tree species automatically. In order to test the capabilities of this software Camiyani Black Pine lumber was kiln dried and the drying parameters were compared to schedule created by this software.

MATERIALS AND METHODS

Material

Camiyani Black Pine (*Pinus nigra* Arn. subsp. pallasiana var. pallasiana) grows naturally in Yenice Region, Turkey. It is determined that the heartwood ratio for Camiyanı Black Pine is more than 50% in comparison to the sapwood in Yenice region. Camiyanı Black Pine grows naturally in Elekdag, Dursunbey, Tosya, Daday, Tavsanli and Yenice regions of Turkey with the total area of 30,000 ha. The average habitat altitude is 866 m and prefers calcareous with stone and sandy-clay soils. It is a primary forest tree species with an average of 30 m height, rarely reaching 50 m (Berkel, 1970; Gunduz, 1999).

This species is preferred in the forest industry because of its relatively large and distinct heartwood in comparison with other pine species. The reason for this is that the color of the heartwood darkens with time and becomes more decorative. Camiyanı Black Pine was in the endangered species list in 1986 by the government. Camiyanı Black Pine has been used for utility poles, veneer, fences, railroad ties, building foundations and beams, marine applications, bridges and trusses, and boardwalks (Gunduz, 1999).

Three trees with a diameter at breast height diameter (DBH. 1.3 m above ground) of 68–88 cm were obtained from Yenice-Zonguldak Forest Enterprises. The area from which the trees were taken was at an elevation of 1330 m and had a slope of 25–30%. Lumber from the logs was prepared by AKE Sawmill Ltd.

Method

The adjustments between lumber moisture content and equilibrium moisture content were made according to drying gradient.

Determining equilibrium moisture content

The lumber industry defines moisture content as the weight of water held in the wood expressed as a percentage of the weight of the oven-dry wood. It can be calculated as the difference between the initial (wet) weight and the oven-dry weight, divided by the oven-dry weight and multiplied by 100%.

Drying gradient (∇_d) is the ratio of average moisture content (r) of a lumber to be dried to equilibrium moisture content occurred inside the kiln which depends on temperature and relative humidity (r_d). Drying gradient expresses the intensity of drying and it is unitless. Drying gradient can be calculated from this formula:

$$\nabla_d = \frac{\bar{r}}{r_d} \tag{1}$$

For the development of drying schedules, equilibrium moisture content under fiber saturation point was found using this formula.

Drying gradient should always be kept constant during drying. For quality drying, drying gradient can be 1.5 for hardwood lumber having less than 30 mm thickness and 2 for softwood lumber. The recommended drying gradient during faster drying of lumber having more than 30 mm thickness with less quality can be 2-3 for hardwood lumber and 3-4 for softwood lumber. Usually the lesser drying gradient was chosen down to 20% moisture content and bigger one was chosen under 20% moisture content. This type of drying applications needs more attention since equilibrium moisture content decreases more rapidly.

Table 1 was prepared for determining relative humidity and equilibrium moisture contents according to dry bulb temperature and wet bulb depression (psychrometric difference).

Calculation of drying period

By this date many graphical and mathematical methods were developed to find out approximate drying period. Drying period (Z_t) is a sum of Heating period (Z_h), main drying period (Z_d) and condi-

Table 1. Psychrometric dry bulb temperatures and relative humidity and equilibrium moisture contents according to wet bulb depression (Kollman, 1955).

Depr.	Dry bulb temperature (°C)															
	20	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**105**
2	17.0	17.9	18.0	18.1	18.2	18.1	17.9	17.6	17.1	16.8	16.3	15.9	15.5	15.2	14.0	14.6	
	82	86	87	88	89	90	90	90	91	92	92	92	93	94	94	95	
3	14.2	15.4	15.8	16.0	15.9	15.8	15.6	15.3	15.0	14.7	14.4	14.1	13.8	13.0	13.2	13.0	
	73	79	80	82	83	84	85	86	87	88	88	89	89	89	90	90	
4	12.2	13.4	13.9	14.0	14.2	14.1	14.0	13.8	13.6	13.3	13.1	12.8	12.5	12.3	12.0	11.8	
	68	73	75	77	78	80	80	82	83	83	84	84	84	86	86	87	
5	10.6	11.8	12.1	12.4	12.6	12.7	12.7	12.5	12.3	12.1	12.0	11.6	11.4	11.1	11.0	10.8	
	60	67	70	73	74	75	77	77	78	79	79	80	81	82	83	83	
6	9.2	10.6	11.0	11.2	11.4	11.5	11.5	11.4	11.3	11.1	11.0	10.7	10.5	10.2	10.1	9.9	9.8
	51	60	64	67	69	71	73	74	75	76	76	77	77	78	79	80	81
7	8.2	9.6	10.0	10.3	10.6	10.7	10.7	10.6	10.5	10.3	10.1	9.9	9.7	9.5	9.3	9.1	9.0
	45	55	59	63	64	66	68	70	71	73	73	74	74	75	77	78	79
8	7.2	8.8	9.2	9.5	9.7	9.8	9.9	9.8	9.7	9.6	9.5	9.3	9.1	9.0	8.8	8.6	8.5
	38	50	54	56	60	63	64	66	66	68	69	71	72	72	73	74	75
9	6.1	8.0	8.4	8.8	9.0	9.2	9.3	9.2	9.1	9.0	8.8	8.7	8.5	8.4	8.2	8.1	7.9
	30	45	49	53	55	58	60	63	64	65	65	67	69	69	70	72	73
10	5.0	7.2	7.7	8.2	8.5	8.6	8.7	8.7	8.5	8.5	8.3	8.2	8.0	7.9	7.7	7.5	7.5
	25	40	45	48	52	54	57	58	60	63	63	65	66	67	68	68	70
11	4.0	6.1	7.2	7.6	8.0	8.0	8.1	8.1	8.0	8.0	7.8	7.7	7.5	7.4	7.3	7.1	7.0
	18	35	40	44	47	50	54	55	57	58	58	62	63	64	65	66	67
12	2.9	5.8	6.5	7.0	7.4	7.5	7.6	7.7	7.5	7.5	7.3	7.2	7.1	7.0	6.9	6.7	6.7
	12	30	37	40	44	46	50	53	54	55	55	59	60	62	63	63	64
13	1.7	5.0	5.9	6.4	6.8	7.0	7.1	7.2	7.1	7.0	7.0	6.8	6.7	6.6	6.5	6.4	6.3
	5	25	33	36	40	43	46	49	51	53	53	56	57	58	60	61	62
14		4.3	5.3	5.9	6.3	6.6	6.7	6.7	6.7	6.7	6.6	6.5	6.4	6.3	6.2	6.0	5.9
		20	27	33	36	40	43	46	48	50	50	53	55	56	58	58	60
15		3.6	4.7	5.3	5.9	6.2	6.3	6.4	6.4	6.4	6.3	6.2	6.1	6.0	5.9	5.8	5.7
		16	24	29	33	37	40	44	45	47	47	51	53	54	55	56	58
16		2.9	4.1	4.9	5.4	5.7	5.9	6.0	6.0	6.0	5.9	5.9	5.8	5.7	5.5	5.5	5.4
		12	20	26	30	34	38	40	43	45	46	49	50	52	53	53	55
18		1.1	3.0	3.9	4.5	4.9	5.2	5.4	5.4	5.4	5.4	5.4	5.3	5.2	5.1	5.0	5.0
		5	13	19	24	28	32	34	37	39	39	43	45	47	49	49	51
20				3.0	3.8	4.2	4.6	4.8	4.8	4.9	4.9	4.9	4.9	4.8	4.8	4.7	4.6
				13	19	24	27	30	33	35	35	39	41	43	43	46	47
22				1.8	2.9	3.5	3.9	4.2	4.3	4.4	4.4	4.4	4.4	4.4	4.4	4.3	4.3
				8	13	18	23	25	28	31	33	35	37	38	40	42	43
24						2.8	3.3	3.7	3.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9
						13	18	22	24	27	27	32	33	34	36	38	39
26						2.1	2.7	3.1	3.4	3.5	3.6	3.7	3.7	3.7	3.7	3.6	3.6
						9	13	18	21	23	26	28	30	32	33	35	37
28	*Eq. moisture cont (%) =*					1.4	2.2	2.6	2.9	3.1	3.2	3.2	3.3	3.3	3.3	3.3	3.3
	Relative humidity (%) =					5	9	13	17	20	23	26	27	28	30	32	33
30							1.5	2.1	2.4	2.7	2.8	2.9	2.9	3.0	3.0	3.0	3.0
							6	10	13	18	20	23	23	26	27	28	31

tioning period (Z_c).

$$Z_t = Z_h + Z_d + Z_c \qquad (2)$$

Calculation of pre-heating period (Z_h)

Calculation of heating period is calculated according to a basic

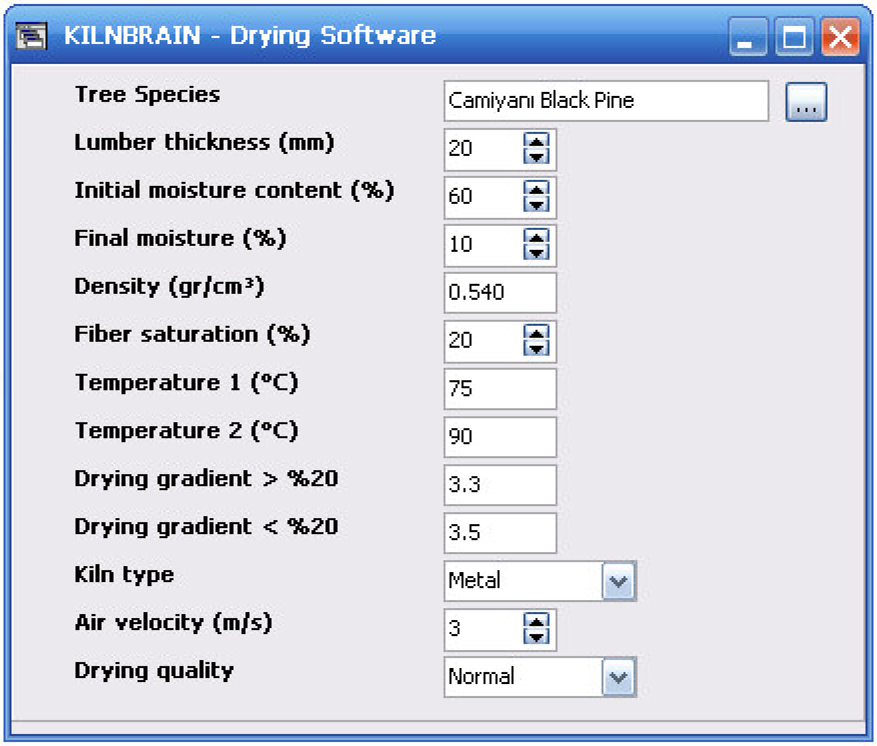

Figure 1. Data entry window.

formula. The thickness of the lumber to be dried is multiplied by f_h coefficient which is 0.1 average.

$Z_h = e.f_h$

Where e = thickness of a lumber (mm), and f_h= 0.1 (h/mm). However, for the refractory species f_h should be 0.15 (h/mm).

Calculation of main drying period (Z_d)

Kiln drying professionals generally use the formula given below.

$$Z_d = \frac{1}{\alpha}(\ln r_b - \ln r_s)(\frac{e}{25})^{1.5}\frac{65}{T}(\frac{1.5}{v})^{0.6} \qquad (3)$$

In this equation 1/α is a coefficient depending on the specific gravity of the species and r_b and r_s are the initial and final moisture contents of lumber (%). T is temperature (°C) and v is the velocity of air (m/seconds) between stacks.

Main drying period usually is a two part application. One is for above fiber saturation point and the other one is for below fiber saturation point to final moisture content. Thus, two periods are calculated separately.

Calculation of conditioning period (Z_c)

Calculation of conditioning period is calculated according to formula given below:

$$Z_c = Z_d \cdot f_c \qquad (4)$$

In this equation, Z_d main drying period (hours), f_c is a coefficient which depends on the quality of drying and the structure of kiln whether it is masonry or metal.

Metal Kilns; f_c = 0.2 – 0.6
For quality (protective) drying f_c = 0.4
Masonry kilns; Air velocity if v>2 m/s then f_c = 0.2 – 0.45 and if v<2 m/s then f_c = 0.1 – 0.3

RESULTS AND DISCUSSION

According to previous studies, computer software was developed and a special drying schedule program was prepared for Camiyani Black Pine lumber for three different thicknesses. The screen comes when the related computer software is started (Figure 1). First, when the species and thickness are entered, necessary information such as temperature, fiber saturation point, etc. is shown.

During the entry of wood species, if there are similar species in the list they also appear with their Latin and commercial trade names. In this section, fiber saturation point should be determined because this indicates the transition to second stage of drying period. If there is no such information in the database fiber saturation point should be 28%. Similar applications should be performed to other variables and average values can be given. Moreover, if proven data about that species are acquired, KILNBRAIN - Drying Software

	Lumber moisture content	Drying Gradient	Equilibrium moisture content	Dry Bulb Temperature	Wet Bulb Temperature	Psychrometric difference	Relative Humidity
1				45	44.0	1.0	95.0
2				55	53.5	1.5	93.0
3				65	63.0	2.0	91.0
4			15.3	75	72.5	2.5	90.0
5	60-20		15.3	75	72.5	2.5	90.0
6			14.1	80	77.0	3.0	89.0
7			13.8	85	82.0	3.0	89.0
8			12.7	90	86.5	3.5	87.5
9	20	3.3	6.1	90	75.5	15.0	55.0
10	19	3.5	5.4	90	73.0	17.0	49.5
11	18	3.5	5.1	90	71.0	19.0	45.0
12	17	3.5	4.9	90	71.0	19.0	45.0
13	16	3.5	4.6	90	69.0	21.0	40.5
14	15	3.5	4.3	90	67.0	23.0	36.0
15	14	3.5	4.0	90	67.0	23.0	34.0
16	13	3.5	3.7	90	65.0	25.0	33.0
17	10		10.0	90	83.5	6.5	77.1

Figure 2. Window showing the drying schedule.

KILNBRAIN - Drying Software

Periods	Time (h)
Pre-heat	2.0
Drying I	12.9
Drying II	6.8
Conditioning	7.9
Total	29.6
	1 day 6 hours

Figure 3. Window showing drying periods and durations.

the data set can be changed manually. When the necessary information are entered, F5 button should be pushed to create appropriate drying schedule. Thus, drying schedule about the lumber species and given thickness is determined (Figure 2).

When the time button was clicked or F3 button is pushed drying duration of given species are easily calculated. Preheat, drying and conditioning durations are calculated and shown separately in a window (Figure 3).

Schedule 1 (for 20 mm thickness)

The first schedule was prepared for 20 mm thick Camiyani Black Pine lumber. The details are given as follows. The initial moisture content was estimated as 60%, the final moisture content was 10%. The temperature values were 75 and 90°C, drying gradients were 3.3 and 3.5, respectively (Table 2). Drying durations are given in Table 3.

Schedule 2 (between 30 and 60 mm)

The second schedule was prepared for 50 mm thick lumber. Initial moisture content was estimated as 60%, final moisture content was 10%. Temperature values were 65 and 80°C, and drying gradients were 3.1 and

Table 2. 20 mm thick Camiyanı Black Pine drying schedule.

Lumber thickness	: 20 mm		T_1 :			75°C
Initial moisture content	: %60		T_2 :			90°C
Final moisture content	: %10		DG_1 :			3.3
Density	: 0.543 gr/cm^3		DG_2 :			3.5
Lumber moisture content	**Drying Gradient**	**Equilibrium moisture content**	**Dry Bulb Temperature**	**Wet Bulb Temperature**	**Psychrometric difference**	**Relative Humidity**
			45	44.0	1.0	95
			55	53.5	1.5	93
			65	63.0	2.0	91
		15.0	75	72.5	2.5	90
60-21.1		15.0	75	72.5	2.5	90
		14.0	80	77.0	3.0	89
		14.0	85	82.0	3.0	89
		13.0	90	86.5	3.5	88
20.1	3.3	6.1	90	75.5	15.0	55
19.1	3.5	5.5	90	73.0	17.0	50
18.1	3.5	5.2	90	71.0	19.0	45
17.1	3.5	4.9	90	71.0	19.0	45
16.1	3.5	4.6	90	69.0	21.0	41
15.1	3.5	4.3	90	67.0	23.0	36
14.1	3.5	4.0	90	67.0	23.0	36
13.1	3.5	3.7	90	65.0	25.0	33
12.1	3.5	3.5	90	63.0	27.0	30
11.1	3.5	3.2	90	61.0	29.0	27
10.1	3.5	2.9	90	61.0	29.0	27
9.1	3.5	2.6	90	61.0	29.0	27
8.1	3.5	2.3	90	61.0	29.0	27
10.0		10.0	90	83.5	6.5	77

Table 3. Drying durations for 20 mm thick Camiyanı Black Pine Lumber.

Periods	Time (h)
Pre-heat	2.0
Drying 1	16.5
Drying 2	8.7
Conditioning	10.1
Total	37.2 (1 day 13 h)

3.3, respectively (Table 4). Drying durations are given in Table 5.

Schedule 3 (over 60 mm)

For this schedule the lumber thickness was 65 mm, initial moisture content was 60%, final moisture content was 10%. Temperature values were 60 and 75°C, and drying gradients were 2.8 and 3.0 (Table 6). Drying durations are given in Table 7.

Conclusion

Drying schedules that aim for both a reduction of checking/cracking and a small dispersion of final moisture contents have been further developed. The use of drying simulations has proved feasible to optimize drying schedules. However, more information regarding the material properties of the timber boards, and the covariance between the parameters, is required, so that the information will be considered in the optimization procedure, and possibly increase the robustness and flexibility of optimized kiln drying schedules. It is important for saw millers to have robust drying schedules because they are under pressure both to increase throughput and reduce wastage (Langrish et al., 1997; Korkut and Guller, 2007), especially when dealing with the increased amount of variability in the timber properties for hardwood plantation timber.

This program allows the user to control or change the conditions in the kiln manually. However, if manual operation exceeds the limits for that species, software warns the user about the exceeding temperatures. For example, if there is a serious collapse formation danger

Table 4. Drying Schedule for 50 mm Thick Camiyanı Black Pine.

Lumber thickness	: 50 mm	T_1 :	65°C
Initial moisture content	: %60	T_2 :	80°C
Final moisture content	: %10	DG_1 :	3.1
Density	: 0.543 gr/cm^3	DG_2 :	3.3

Lumber moisture content	Drying Gradient	Equilibrium moisture content	Dry Bulb Temperature	Wet Bulb Temperature	Psychrometric difference	Relative Humidity
			40	39.0	1.0	94
			45	43.5	1.5	92
			55	53.0	2.0	90
		16.0	65	62.5	2.5	89
60-21.1	3.1	16.0	65	62.5	2.5	89
	3.3	15.0	70	67.0	3.0	88
	3.3	14.0	75	72.0	3.0	88
	3.3	13.0	80	76.5	3.5	87
20.1	3.3	6.5	80	65.5	15.0	52
19.1	3.3	5.8	80	63.0	17.0	46
18.1	3.3	5.5	80	63.0	17.0	46
17.1	3.3	5.2	80	61.0	19.0	41
16.1	3.3	4.9	80	59.0	21.0	37
15.1	3.3	4.6	80	59.0	21.0	37
14.1	3.3	4.3	80	57.0	23.0	34
13.1	3.3	4.0	80	55.0	25.0	30
12.1	3.3	3.7	80	53.0	27.0	27
11.1	3.3	3.4	80	53.0	27.0	27
10.1	3.3	3.1	80	51.0	29.0	25
9.1	3.3	2.8	80	51.0	29.0	25
8.1	3.3	2.5	80	51.0	29.0	25
10.0		10.0	80	74.0	6.0	77

Table 5. Drying durations for 50 mm thick Camiyanı Black Pine Lumber.

Periods	Time (h)
Pre-heat	3.0
Drying 1	34.9
Drying 2	17.9
Conditioning	21.1
Total	77.0 (3 days 5 h)

like *Eucalyptus*, the drying conditions should be below 60°C.

Users can save the successful drying operation data for further use. So then, for the same tree species in the same or different thickness of timber drying is concerned, this program will be loaded into memory and can be applied again. This software includes information about 150 different wood species. As mentioned earlier, if there is no record for a specific kind or species, average values can be used. After successful drying operation, drying data can be stored and used for further operations. Moreover, drying durations for any given species can easily be calculated.

In this study 3 different drying schedules were developed for Camiyani Black Pine lumber. Stacking makes a big difference for drying operations. If any developed drying schedule is successful for one batch, it does not mean that the software is going to be successful for all operations. This issue should not be ignored. This empirical study was prepared for users to have an idea and to use the kilns more efficiently. The results of KILNBRAIN and traditional drying results were compared,

Table 6. Drying Schedule for 65 mm thick Camiyanı Black Pine Lumber.

Lumber thickness	: 65 mm	T_1 :	60℃
Initial moisture content	: %60	T_2 :	75℃
Final moisture content	: %10	DG_1 :	2.8
Density	: 0.543 gr/cm^3	DG_2 :	3.0

Lumber moisture content	Drying Gradient	Equilibrium moisture content	Dry Bulb Temperature	Wet Bulb Temperature	Psychrometric difference	Relative Humidity
			40	39.0	1.0	94
			45	43.5	1.5	92
			50	48.0	2.0	90
		16.0	60	57.5	2.5	88
60-21.1		16.0	60	57.5	2.5	88
		15.0	65	62.0	3.0	87
		15.0	70	67.0	3.0	88
		14.0	75	71.5	3.5	86
20.1	2.8	7.2	75	62.5	13.0	54
19.1	3.0	6.4	75	60.5	15.0	49
18.1	3.0	6.0	75	59.5	16.0	47
17.1	3.0	5.7	75	58.0	17.0	43
16.1	3.0	5.4	75	56.0	19.0	37
15.1	3.0	5.0	75	56.0	19.0	37
14.1	3.0	4.7	75	54.0	21.0	34
13.1	3.0	4.4	75	52.0	23.0	30
12.1	3.0	4.0	75	52.0	23.0	30
11.1	3.0	3.7	75	50.0	25.0	27
10.1	3.0	3.4	75	48.0	27.0	25
9.1	3.0	3.0	75	46.0	29.0	22
8.1	3.0	2.7	75	46.0	29.0	22
10.0		10.0	75	67.5	7.5	72

Table 7. Drying durations for 65 mm thick Camiyanı Black Pine Lumber.

Periods	Time (h)
Pre-heat	4.0
Drying 1	53.8
Drying 2	27.6
Conditioning	32.5
Total	117.9 (4 days 22 h)

and they are found quite similar.

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