

STRATEGIES FOR DRYING CANADIAN SOFTWOOD DIMENSION LUMBER

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Abstract:

Thin Spruce-Pine-Fir (SPF) lumber (96x42x2440mm) was conventionally dried aiming to reduce the drying time without affecting lumber quality. The following approaches were tested: (1) lower dry-bulb temperature during the earlier stages of drying combined with higher wet-bulb depression (2) higher wet-bulb depression throughout the entire drying process (3) incremental increases in dry-bulb temperature during the final stages of the drying process. The drying time was reduced from 48 to 38 hours without affecting lumber quality or the standard deviation of final moisture content. In addition to reduced drying times, it is estimated that up to 20% energy reduction and emitted greenhouse gases (reduced CO₂ emissions generated by the drying times), can be achieved.

Key words: SPF lumber; drying time; energy reduction.

INTRODUCTION

The spruce-pine-fir (SPF) species group is the most important softwood species commercialized in British Columbia and Alberta – interior Canadian provinces. The species group denoted SPF corresponds to white or Engelmann spruce (*Picea glauca* or *engelmannii*), lodgepole pine (*Pinus contorta*), and subalpine fir (*Abies lasiocarpa*). Length of dimension products vary from 8 to 24 ft and cross sections from 2x4" to 2x12". In view of increasingly quality requirements, competitiveness and the need for reducing production costs, Canadian mills manufacturing SPF dimension products face a significant challenge to produce more efficient drying schedules to reduce energy consumption, lower environmental impact and, of course, improve the quality of the final product.

Simpson 1983, and Tomad *et al.* 2012, suggested that softwood drying can be more uniform and the check defect can be minimized if air temperatures and relative humidity (RH) are dropped in the early stages of the drying schedule. Low initial RH will increase the drying rate and cause a lot of tension set in the outer shell of the wood which will help to hold the lumber flat in later stages of drying. The increase in drying rate will also result in an additional cooling down of the surface (Simpson 2002) and thereby cause wood surface layers to exhibit higher MOE when compared with core regions of the wood. The increased tensile stress will lower the quantity of moisture held on surface and additionally strengthen the surface. Such phenomenon is more evident at low temperatures (Lenth and Sargent 2008).

HYPOTHESIS

The hypothesis behind this study was: "Lower relative humidity and temperature during the early stages combined with more aggressive conditions thereafter will decrease drying times without adversely increasing the defects".

MATERIALS AND METHODS

Eight hundred and thirty-six (836), 2.44 meter long, 96x42mm (cross section) pieces of green "wet sort" Engelmann's Spruce (*Picea engelmannii*) and lodgepole pine (*Pinus contorta*) mix was obtained from a BC interior sawmill. General drying-related properties for the species mix used in this study are as follows:

(1) Engelmann Spruce has an average green MC of 55% and a basic density of 300 – 400 kg/m³ (USDA 1999). It dries faster than lodgepole pine but should be dried at lower temperatures (between 54 and 77°C) to minimize the occurrence of drying defects. Cupping of flat sawn lumber can be an issue because of the large differential between radial (4.2%) and tangential shrinkage (8.2%);

(2) Average MC of lodgepole pine is 50% with a basic density higher than spruce 330 – 470 kg/m³ (USDA 1999). Cupping is usually not a concern because of the small differential between radial (4.6%) and tangential shrinkage (6.8%). It can be kiln dried at higher temperatures (Garrahan *et al.* 2008) without substantial degrade (between 77 and 93°C).

The objective of the study was to compare drying times and quality at the end of drying for a conservative drying schedule for SPF to a modified drying schedule for which temperature and RH would be slightly reduced at the beginning of the drying process followed by an increase in temperature and drop in RH during the last drying steps. The control drying schedule, a conservative design, used in this study is listed in Table 1. For all runs the fan speed was constant at 3m/s.

Table 1

Drying parameters for the Control run (conservative)

Step #	Description	Ramp time	Step duration	Elapsed time	DBT	WBT	EMC	Fan reversal
		(hrs)	(hrs)	(hrs)	(°C)	(°C)	(%)	(hrs)
1	heat-up	6		6	60	60	25	3
2	d1	10		16	71	68	16	3
3	d2	8		24	82	78	12	3
4	d3	1		25	88	79	9	3
5	d4		11	36	88	79	9	3
6	d5	12		48	91	76	6	3

Three experimental strategies were assessed. Details for Run 1 are shown in Table 2. For Run 1 the temperature was slightly increased towards the end of the drying process and the EMC drastically dropped during all drying steps. Strategies for the other runs (Run 2 and 3) are shown in Table 3 and 4.

Table 2

Drying parameters for Run 1

Step #	Description	Ramp time	Step duration	Elapsed time	DBT	WBT	EMC	Fan reversal
		(hrs)	(hrs)	(hrs)	(°C)	(°C)	(%)	(hrs)
1	heat-up	4		4	60	57	16	2
2	d1	8		12	60	52	10	2
3	d2	8		20	82	72	8	12
4	d3	1		21	91	81	8	
5	d4		7	28	91	81	8	12
6	d5	9		37	93	79	6	9

Table 3

Drying parameters for Run 2

Step #	Description	Ramp time	Step duration	Elapsed time	DBT	WBT	EMC	Fan reversal
		(hrs)	(hrs)	(hrs)	(°C)	(°C)	(%)	(hrs)
1	heat-up	4		4	60	57	16	2
2	d1	8		12	60	47	7	2
3	d2	8		20	82	63	5	4
4	d3	1		21	91	72	5	
5	d4		7	28	91	72	5	4
6	d5	8		40	93	75	5	4

Table 4

Drying parameters for Run 3

Step #	Description	Ramp time	Step duration	Elapsed time	DBT	WBT	EMC	Fan reversal
		(hrs)	(hrs)	(hrs)	(°C)	(°C)	(%)	(hrs)
1	heat-up	4		4	60	57	16	2
2	d1	8		12	60	47	7	2
3	d2	8		20	82	63	5	4
4	d3	1		21	88	69	5	
5	d4		7	28	88	69	5	4
6	d5	8		36	91	72	5	4

All experiments were performed in a pilot kiln located at FPInnovations Vancouver laboratory capable of holding a lumber charge of 2.44m by 2.44m by 1.8m (approximately 10.5m³). The charge rests on a scale so that the change of weight and therefore MC of the whole charge could be monitored over time. The stickers were 19mm thick.

At the beginning and completions of each run, each specimen was weighed and visually evaluated for surface, end-checking and shape distortions. After drying, MC for each specimen was evaluated at three positions (0.3, 1.2 and 2.1m) using a Wagner capacitive moisture meter (Model L612). Initial moisture content MC_o (in %) was estimated by:

$$MC_o = \frac{(1 + MC_{kd}) \cdot W_o - W_{kd}}{W_{kd}} \quad (1)$$

where:

MC_{kd} is the average MC (based on measured positions) at the end of drying (%), W_o initial specimen weight (kg) and W_{kd} specimen weight at the end of drying (kg).

In terms of evaluating the drying stresses at the end of the drying process there are several methods available. These can be either destructive tests, like measuring the deformation of a prong or small wood slices and correlating the released strain with a stress value (Peck 1940, Kuebler 1960) or based on internal stress sensor indications (Kang *et al.* 2007). Under short time loading, stresses below a certain limit (called the proportional limit) produce strains which substantially disappear when the load is released. If the stress is higher and for a longer period of time, the final shrinkage value can be used to indicate stress level (Lazarescu *et al.* 2010). While it is difficult and time consuming to calculate the exact stress values, the method may be used as a tool for comparing several drying schedules in terms of drying stresses i.e. the higher the shrinkage value the lower the stress during drying.

The apparent thickness and width of 110 flat sawn specimens, roughly evenly distributed among the runs, were measured before and after drying with a digital caliper (± 0.01 mm). The shrinkage in both tangential and radial directions was calculated by dividing the difference between green and dry dimensions (dL , in mm) to the initial green dimension (L , in mm):

$$S_{kd} = \frac{dL}{L} \cdot 100 \quad (2)$$

Since the measured specimens ended at different MC's normalization to 15% was made using a well-known empirical equation:

$$S_{T,R} = S_o \left(\frac{28 - MC_{kd}}{28} \right) \quad (\text{USDA 1999}) \quad (3)$$

where:

$S_{T,R}$ (%) is the shrinkage from green conditions to target MC (less than 28%) and S_o is the total shrinkage for a particular structural direction specific to each species (%).

The MC loss over time was fitted using the following equation:

$$MC = MC_{emc} + (MC_{initial} - MC_{emc}) \cdot e^{-\alpha t^\beta} \quad (4)$$

where:

t is time, in hrs, MC_{emc} is the equilibrium MC, $MC_{initial}$ is the initial MC at the beginning of the drying run, in %, and α and β are regression coefficients.

At the end of the each drying run, if the measured MC was below or above the Control (15.5%) the drying times were adjusted based on the drying rate – the reported times are the times required to reach exactly the MC of the Control.

RESULTS AND DISCUSSION

The estimated average initial MC (IMC) for all specimens was 93.6% with a standard deviation of 33%. Fig. 1 illustrates the distribution of these values. Numerical data and final MC (FMC) distributions for all runs are depicted in Fig. 2 and Table 5.

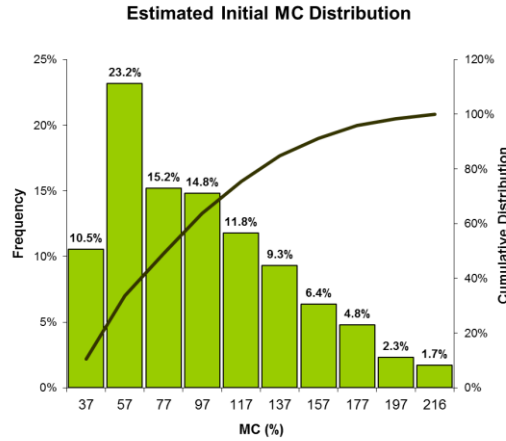
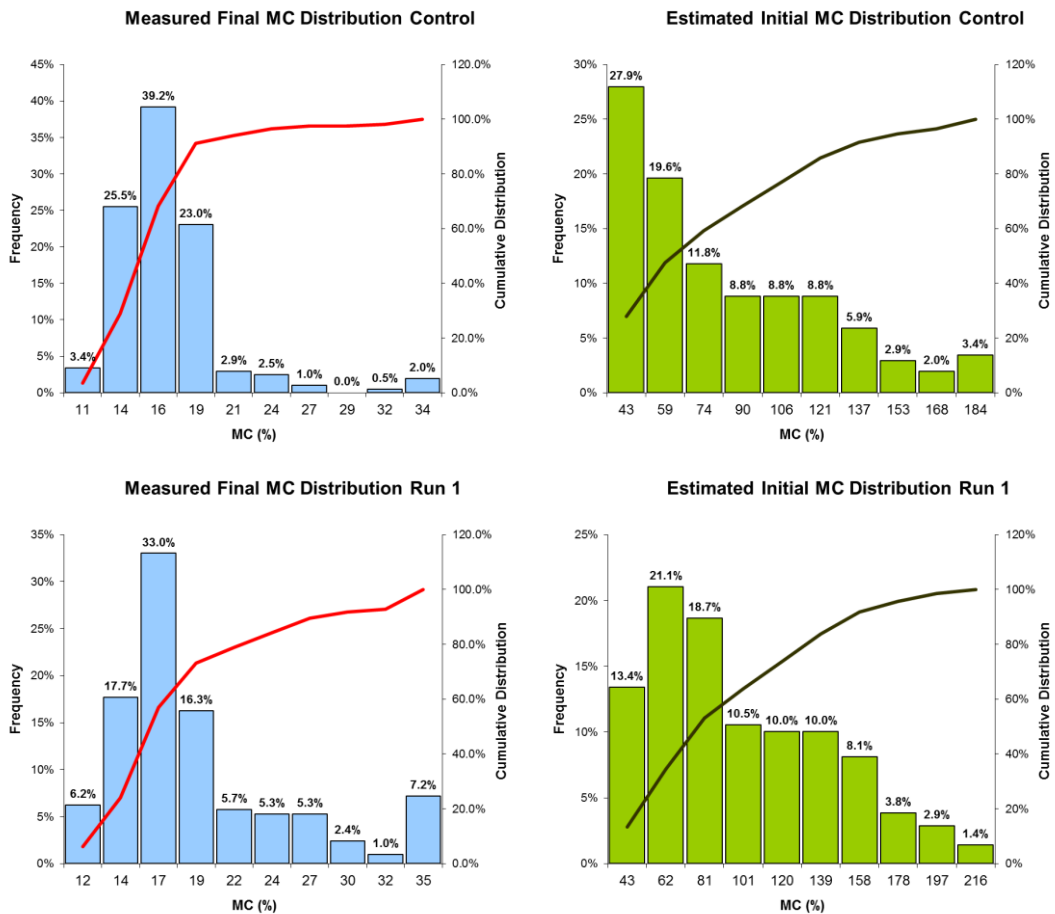


Fig. 1.
Distribution of initial moisture content for all runs.

The IMC was higher than expected for a spruce-pine population, possible explanations including either a very high percentage of sapwood – high quality wood from the tree core was used for larger cross sections and the remaining was used for 96x42’s – or subalpine fir may have been present in the mix.



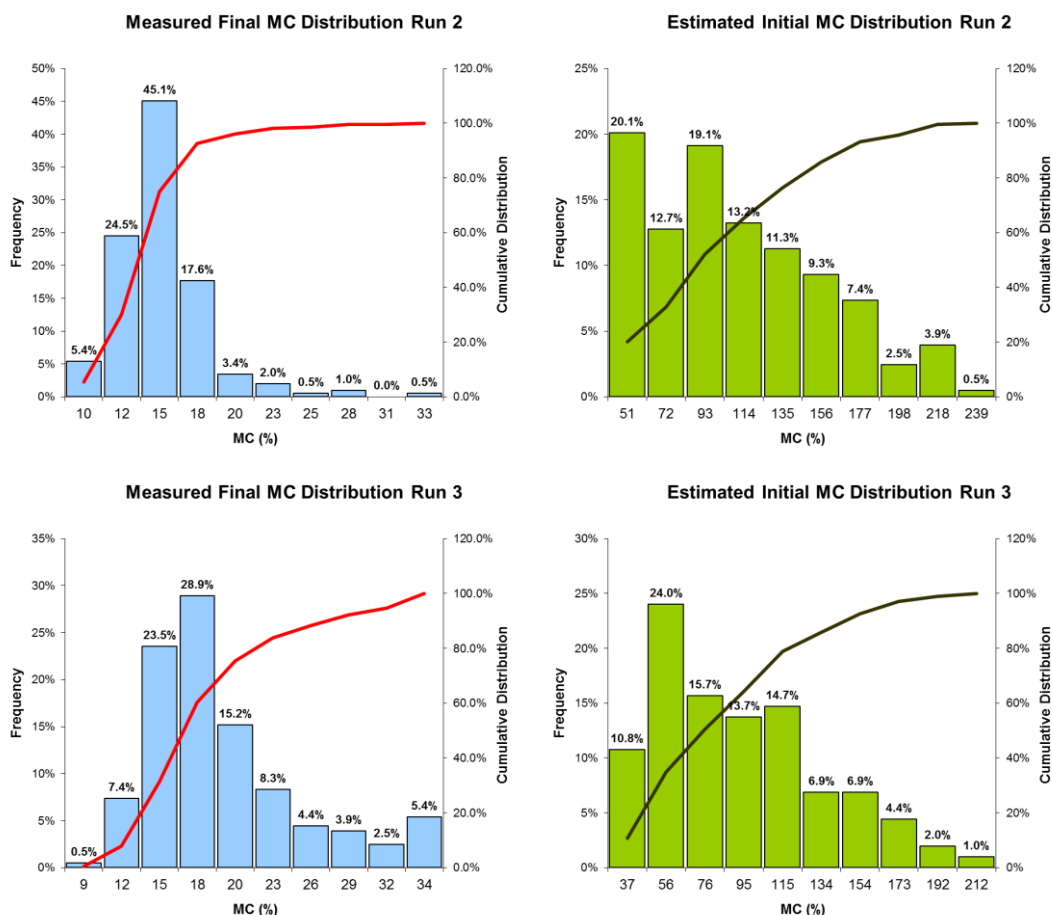


Fig. 2.
Distribution of initial and final MC in each run.

Table 5

Moisture content data for all runs

Drying run	Actual time (h)	Adjusted time* (h)	IMC/SD** (%)	FMC/SD (%)	Drying defects	Defect type (percentage)	Time reduction
Control	48.0	48.0	73.6/39.4	15.5/3.9	1.4%	crooking (1.4%)	0.0 %
Run1	37.0	39.0	89.2/44.3	18.1/6.1	2.8%	bowing (1.4%) checking (1.4%)	18.7%
Run2	40.0	38.0	99.3/47.9	13.9/3.2	6.7%	bowing (4.8%) twisting (1.9%)	20.8%
Run3	36.0	38.5	80.2/43.0	19.9/5.7	4.8%	bowing (3.9%) checking (0.9%)	19.8%

* Time estimated to reach the Control average MC=15.5%

** Standard deviation

Decreases in drying times and increases in bowing and checking appear to be correlated. Bowing is most of the time caused by uneven dimensional changes (wood properties) and can be controlled, in the lower layers in a package, by the pressure exerted by superior layers (not available in current lab set-up) or, through mechanical restrains (weight placed on top of loads). Many of the surface checks, if they are not too deep and the specimens did not shrink excessively, are usually eliminated by planing. In Run2, when an additional decrease in air EMC towards the end of the drying process was used, more defects were noticed. This high number may be attributed also to over-drying and a higher value, when compared with the other runs, of the initial MC.

To exclude the drying time difference caused by the initial MC and final MC variability between runs, the drying rate functions were fitted for a readjusted initial MC of around 72% ($\pm 2\%$) and final MC of 15.5%. The results are shown in Fig. 3.

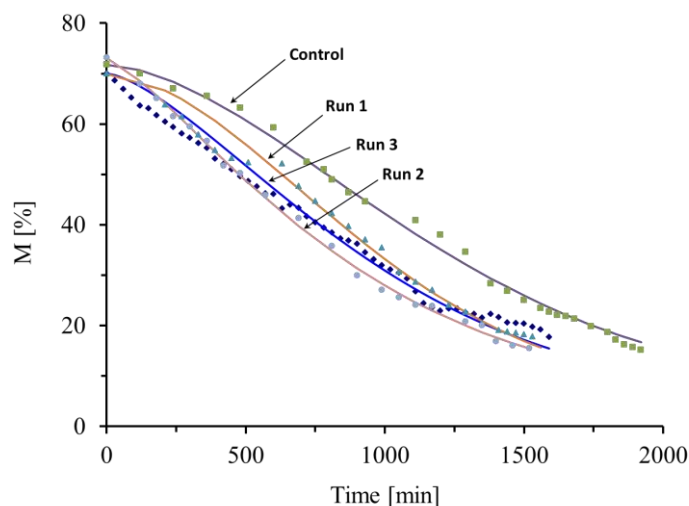


Fig. 3.
Experimental and fitted MC evolution in each run.

6. The regression coefficients used to model the drying rate calculated with eq. 4 are displayed in Table 6.

Table 6

Regression coefficients used to model the drying rate

Drying run	Alpha (1/min)	Beta
Control	4.66E-06	1.703
Run 1	3.76E-06	1.785
Run 2	1.38E-04	1.298
Run 3	3.36E-05	1.479

Between the two regression coefficients, alpha (α), characterizes the slope of fitting function while beta (β), compensates for the beginning of the process. High values for α resulted in sharp curves which ended in a small period while small values represented a smooth dehydration process. Run 2, the most aggressive tested drying schedules, had an α coefficient 100 times higher than Control and Run1. The α parameter has also shown to be significantly influenced by temperature and the EMC of the environment (Lazarescu *et al.* 2009) while little difference may be noticed between β coefficients.

The average dimensions of the cross sections were 96.41x41.98mm with a standard deviation (SD) of 2.03mm in width and 0.97mm in thickness. Average tangential and radial values for all runs are illustrated in Fig. 4.

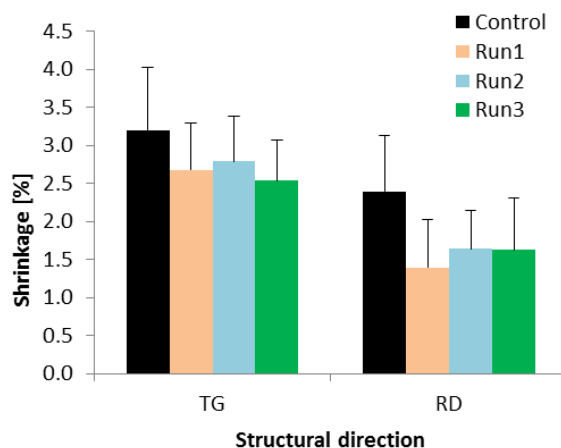


Fig. 4.
Average tangential (TG) and radial (RD) values ($\pm 1SD$) for all runs.

There was a significant difference in shrinkage value between the drying runs in both structural directions, radial and tangential. One-way ANOVA test results are shown in Table 7.

Table 7

ANOVA test for shrinkage measurements

ANOVA one-way		Tangential			Radial		
Source of Variation	df	F	P-value	F crit	F	P-value	F crit
Between Groups	3	4.67	0.004	2.69	9.99	7.45E-06	2.69
Within Groups	106						

According to these results the tension set created in the outer shell at the beginning of the drying process restricted the shrinkage process throughout the entire drying process. This stress is reflected in reduced shrinkage values. The shrinkage restriction may lead to a potential decrease in green dimensions by approximately 1%.

CONCLUSIONS AND RECOMMENDATIONS

Based on the experience gained through several drying tests on a 2x4 population of spruce and pine, the following observations can be made:

- A drop in the equilibrium moisture content at the beginning of the drying resulted in a tension set which restricted the shrinkage process throughout the entire drying process;
- There was an increase in number of drying defects, particularly bowing and checking. However, these defects can be minimized in typical large industrial kilns equipped with mechanical restraining devices or by planning, also for certain construction grades this type of defects are considered acceptable;
- The reduction in drying times was between 18 to 21% equivalent with a similar reduction in emitted greenhouse gases (reduced CO₂ emissions generated by the drying times);
- The analysis of drying rate function revealed that the process is characterized by a combination between a constant parameter and one activated by a combination between equilibrium moisture content and temperature;
- Shrinkage restriction may lead to a potential decrease in green dimensions by approximately 1%.

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