THE DEVELOPMENT OF CONTINUOUS-CHANGE SCHEDULES[1]

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Introduction

Softwood and hardwood lumber has, for the most part, largely been dried using empirically derived schedules, i.e., on a trial and error basis. These schedules are applied to the kiln through manual-set controller-recorders, which are non-reactive. That is, they do not respond automatically, schedule wise, to changes in the drying characteristics of the charge. Such schedules represent a combination of discrete changes in dry and wet-bulb temperatures and can be termed step-form type schedules. In hardwood drying where the use of kiln samples is much more common, the schedules might be viewed as semi-reactive since the predetermined step-form schedules are changed in response to the periodic measurement of the kiln sample's moisture content. In recent years there has been an increased interest in using schedules that continually change with respect to time or continuous change schedules.

The ideal case would consist of a fully reactive control system capable of sensing the charge drying rate and/or quality and which would change the schedule in a continuous fashion. The various types of possible lumber drying schedules are summarized in Table 1.

Cam controllers which are presently used in a number of kilns are non-reactive but permit the schedule to be changed on a continuous basis. A problem that we have observed when operations first begin using cam controllers and which is true for any other continuous change control system is how to develop a suitable schedule.

TABLE 1

General Classification or Types of Drying Schedules

A. Non-reactive or time schedules
   1. Discontinuous change - manual set step form
   2. Continuous change - automatic, ramp form, etc. (cam or programmable)
B. Semi-reactive-moisture content based schedules
   1. Discontinuous change - manual set step form
   2. Partial continuous change - Kil-mo-trol, kiln scan, etc.
C. Reactive
   1. Continuous change - schedule based upon change in charge weight, moisture content, ΔT, stress development, etc.

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Objectives

The general or overall objective of this research is to determine if kiln drying efficiency can be significantly improved through the use of automatic continuous change or ramp-form schedules rather than manual set discontinuous step-form schedules.

The specific objectives are:

1. To identify problems with developing and using continuous-change type schedules.
2. To develop a rational basis for developing continuous-change schedules from previously known manual set step-form schedules and,
3. To experimentally establish if continuous-change schedules lead to improved drying efficiency as expressed by total drying time, final moisture content variation and, drying stress and defect development.

This paper will only discuss the second of these objectives, that is the methodology we suggest kiln operators use in initially developing continuous-change schedules from an already available manual set step-form schedule.

Methods for Developing Continuous Change Schedules

The easiest method to convert a step-form schedule into a continuous-change schedule is to simply alter the step-form schedule using <u>linear</u> changes in temperature with respect to time. This gives a ramp-form type of schedule. This approach is shown for the dry bulb portion of a schedule in Figure 1, with the wet bulb temperature changes in Figure 2.

Three different approaches for making linear changes become apparent and these are to alter a schedule by using the

1. maximum temperature point of a time step
2. mid-points of a time step or
3. the minimum points

This method is most easily understood by examining Figs. 1 and 2 again. Unfortunately, the use of any three of these methods does not necessarily insure that the new schedule is going to give the same end result as the original step-form schedule.

It seems intuitively clear, for example, that a schedule based upon straight line connected maximum dry bulb temperatures and minimum wet bulb temperatures would yield the most severe new schedule. Conversely, using minimum dry bulb temperatures and maximum wet bulb temperatures gives the least severe temperatures. The kiln operator or anyone else working with schedules is hence faced with a most difficult dilemma, which is how to design a new schedule that gives the same or better result than the original schedule.

Drying Effort

Fortunately a method is now available that lets us numerically represent the severity of a schedule or any portion of it. This method developed by Bramhall (1975) involves expressing schedule severity in terms of a factor called drying effort. For a given species, grade and thickness combination, any two schedules having the same calculated drying effort will dry from the same initial moisture content to the same final moisture content in the same amount of time.

More exactly, the things one needs to know to calculate drying effort are:

1. The dry bulb temperatures used
2. The wet bulb temperatures used
3. The length of time each setting is used
4. The saturation vapor pressure of water in millibars at different temperatures.

The dry and wet bulb temperatures and time present no problem but the saturation vapor pressure of water is somewhat more complex. Data on the saturation vapor pressure of water can be found in steam tables or handbooks of physics or chemistry. The saturation vapor pressure of water in millibars is:

$$\underset{\text{(millibars)}}{\text{saturation vapor pressure}} = \frac{\text{saturation vapor pressure of water at some given temperature (in Hg)}}{\text{29.92 (in Hg)}} (1000)$$

Bramhall (1975) gives this data in tabular form.

Drying effort for a given step in a schedule is then:

$$\underset{\text{(millibar-hr)}}{\text{Drying effort}} = \left(\begin{array}{c}\text{Saturation vapor}\\ \text{pressure at the}\\ \text{dry bulb tempera-}\\ \text{ture (mbar)}\end{array} - \begin{array}{c}\text{Saturation vapor}\\ \text{pressure at the}\\ \text{wet bulb tempera-}\\ \text{ture (mbar)}\end{array}\right) \text{X} \begin{array}{c}\text{Length of time}\\ \text{in hours these}\\ \text{settings were}\\ \text{used}\end{array}$$

The total drying effort for an entire schedule is simply the sum of the drying efforts for each step change or time interval during which the dry and wet bulb were constant or:

$$\underset{\text{(mbar-hr)}}{\text{Total drying effort}} = \sum \left(\begin{array}{c}\text{DBT saturation}\\ \text{vapor pressure}\end{array} - \begin{array}{c}\text{WBT saturation}\\ \text{vapor pressure}\end{array}\right) \text{X Time}$$

Application to Several Different Schedules

This technique and the concept of linear schedule changes using maximum, mid-point and minimum values were applied to three different schedules which varied not only in total drying time but in the dry and wet bulb temperatures used.

That is the drying effort was originally calculated for the original step-form schedule and then again three more times when the schedules were altered to a continuous change basis using linearly changing temperatures. The following three temperature combinations were used:

1. Maximum dry and wet bulb temperatures at a given time
2. Mid-point dry and mid-point wet bulb temperatures
3. Minimum dry and wet bulb temperatures

The results for a schedule (Fig. 3) for 12/4 ponderosa pine shop and better (Knight, 1970) are given in Table 2. Note that the total drying effort for the manual set step-form schedule is 39,528 millibar-hr. When this schedule is converted to a continuously changing linear schedule using the maximum dry and wet bulb temperatures, the drying effort is 34,510 mbar-hr or 12.7%

less. This altered schedule is, therefore, approximately 13% less severe and would lead to considerable undrying. The drying efforts for mid-point and minimum dry and wet bulb temperature combinations were 38,800 and 38,300 mbar-hr, respectively, or less severe by 1.8 and 3.1%.

The results for a shorter schedule (Fig. 4) 4"x6" white fir decking (Knight, 1970) are presented in Table 3. Drying effort for the manual set step-form schedule was in this case approximately 49,100 mbar-hr. Note that although this schedule is projected to be 336 hours shorter in total drying time than the previous 12/4 pine schedule, it employs almost 10,000 more drying effort units. This is a result largely of the lower diffusivity and greater thickness of the white fir. The drying efforts for the maximum, mid-point and minimum temperature schedule alterations were 44,760, 45,891 and 44,604 mbar-hr, respectively. All of these schedules would be less severe than the step-form schedule with the mid-point type schedule having the lowest difference or 6.6%.

A similar approach was used for 8/4 Douglas-fir dimension lumber (Rasmussen, 1961) (Table 4 and Fig. 5). In this case, the drying effort for the step-form schedule was 6,656 mbar-hr. The use of maximum and mid-point temperatures lead to greater drying efforts than the original schedule, just the opposite of the previous two examples. Use of the minimum temperatures had, as before, less total drying effort. The mid-point method again had the lowest difference being only +1.0%.

Based upon thee analyses we conclude that the use of the mid-point temperatures is the overall most accurate method for developing new continuous-change schedules from previously known step-form time schedules. Anticipated differences in total drying effort from the manual schedule ranged from +1.0 to -6.6%, which would appear to be acceptable. It should be pointed out that with some practice these schedules could be adjusted so that they had equal or nearly equal drying efforts as the original schedules.

Experimental Procedures

It was decided to test the validity of these conclusions using 8/4 Douglas-fir lumber. Four different kiln charges were dried in a small expeimental micro-kiln; two charges using the manual set step-form schedule of Figure 5 and two charges with the linearly changing mid-point temperatures (Fig. 5). A total of 24, 20-inch long end-coated samples were dried in each charge. The samples in each charge were end-matched from an original set of 24 green mixed heart-sapwood stud grade pieces.

The micro-kiln used has both a conventional manual set controller and a cam-type controller for continuously changing schedules. The entire 24 sample boards were suspended from an externally mounted load cell which permitted the charge weight to be determined on a continuous basis. After drying all 24 pieces were oven-dried to constant mass to obtain an accurate oven dry mass and hence an accurate assessment of final moisture content.

Results and Discussion

The results of these four kiln runs are summarized in Table 5.

TABLE 2

Calculated Drying Efforts for 12/4 Ponderosa Pine Shop and Select (total drying time 552 hours)

Type of Schedule	Total Drying Effort (millibar-hr)	Change from Step-Form Schedule
Manual-step form	39,528	-
Continuous		
1. Maximum dry and wet-bulb temperatures	34,510	-12.7%
2. Midpoint dry and wet-bulb temperatures	38,803	-1.83%
3. Minimum dry and wet-bulb temperatures	38,300	-3.11

TABLE 3

Calculated drying efforts for 4" x 6" white fir decking (total drying time 216 hrs)

Type of Schedule	Total Drying Effort (millibar-hr)	Change from Step-Form Schedule
Manual-step form	49,114	-
Continuous		
1. Maximum dry and wet-bulb temperatures	44,760	-8.9%
2. Midpoint dry and wet-bulb temperatures	45,891	-6.6%
3. Minimum dry and wet-bulb temperatures	44,604	-9.18%

TABLE 4

Drying Efforts for 8/4 Douglas-fir Dimension (total drying time 72 hrs)

Type of Schedule	Total Drying Effort (millibar-hr)	Change from Step-Form Schedule
Manual-step form	6,656	-
Continuous		
1. Maximum dry and wet-bulb temperatures	7,238	+8.7%
2. Midpoint dry and wet-bulb temperatures	6,724	+1.0%
3. Minimum dry and wet-bulb temperatures	6,296	-5.4%

TABLE 5

Comparison of Results for Charges of 8/4 Douglas-fir Dried by a Manual Set Step-form Schedule and a Continuous Change Schedule Using Mid-Point Dry and Wet Bulb Temperatures

Run No.	Type of Schedule	Initial Moisture Content (%)	Drying Time to 12% M.C. (hr)	Drying Effort to 12% M.C. (mbar-hr)
1	Manual step-form	40.5	68	6,072
2	Manual step-form	39.3	80	8,142
Average		39.9	74	7,107
3	Continuous-change	40.0	72	6,438
4	Continuous-change	40.7	76	6,953
Average		40.4	74	6,695

The initial moisture contents of the four runs were essentially equal. Drying times to a final moisture content of 12% were obtained from plots of the drying curve for each run. While total drying times for the individual changes varied somewhat the average total drying time for the step-form and continuous change schedule were both 74 hours as the drying effort theory predicts it should be. In actuality the step-form schedule employed sightly more total drying effort (7,107 mbar-hr) than the continuous change runs (6,695 mbar-hr) but this was not considered significant.

Summary and Conclusions

1. Continuous change kiln schedules can be developed from step-form schedules without trial and error using the Bramhall drying effort method.
2. Use of linearly changing dry and wet bulb mid-point temperatures would appear to give the least difference in anticipated drying as indicated by any difference in drying effort from that of the step-form schedule.
3. For three schedules varying significantly in total drying time and temperatures used this difference ranged from +1.0 to -6.6%.
4. These conclusions were verified using drying tests on four different charges of 8/4 Douglas-fir lumber.

Literature Cited

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Knight, E. 1970. Kiln-drying western softwoods. Bull. No. 7004. Moore Dry Kiln Co., Portland, Oregon.

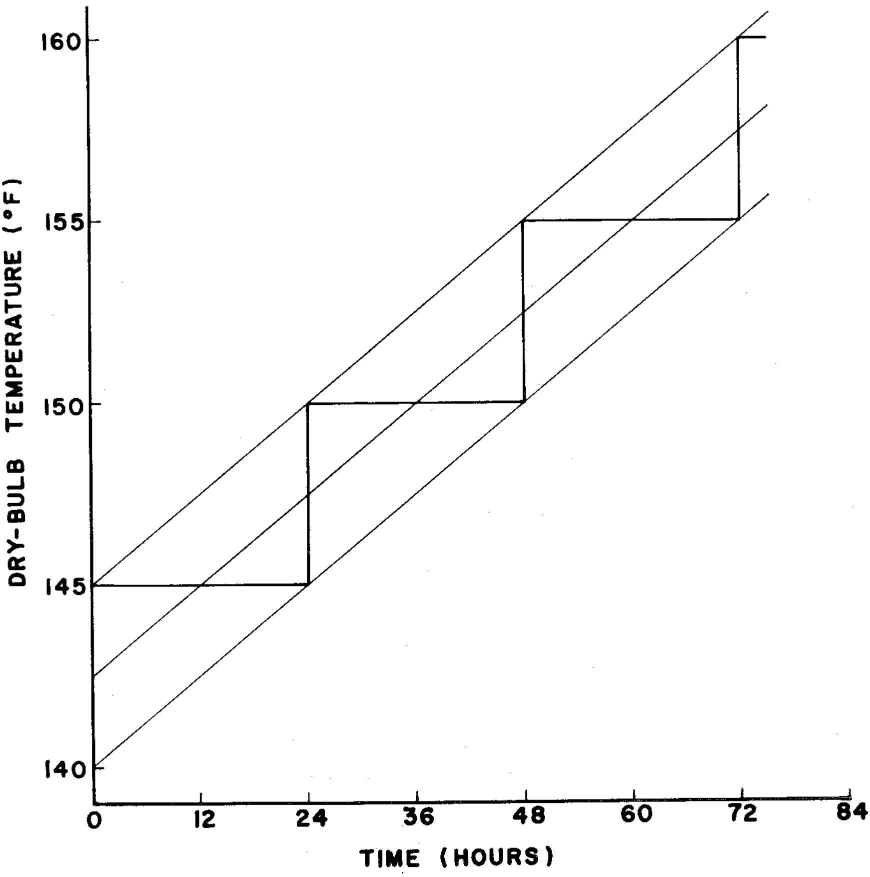

Figure 1. Typical step-form dry bulb temperature schedule with superimposed ramp-form schedules using maximum, mid-point and minimum temperatures.

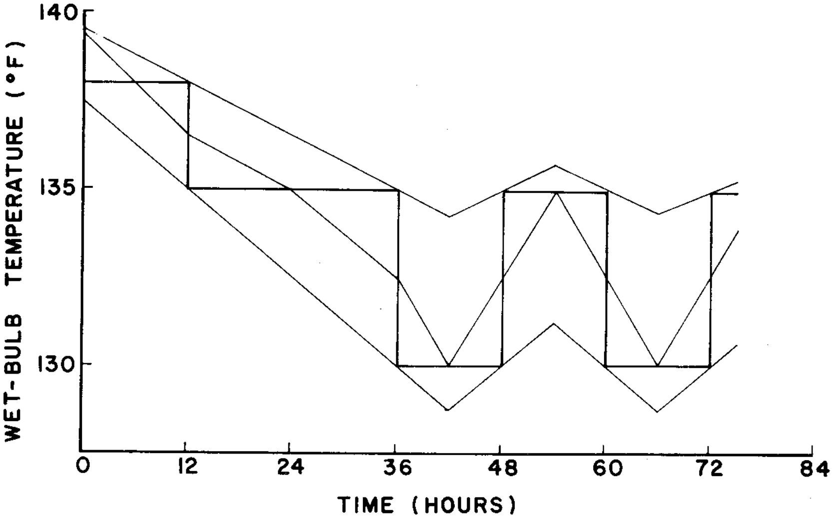

Figure 2. Wet bulb temperature schedule indicating three types of ramp-form schedule changes.

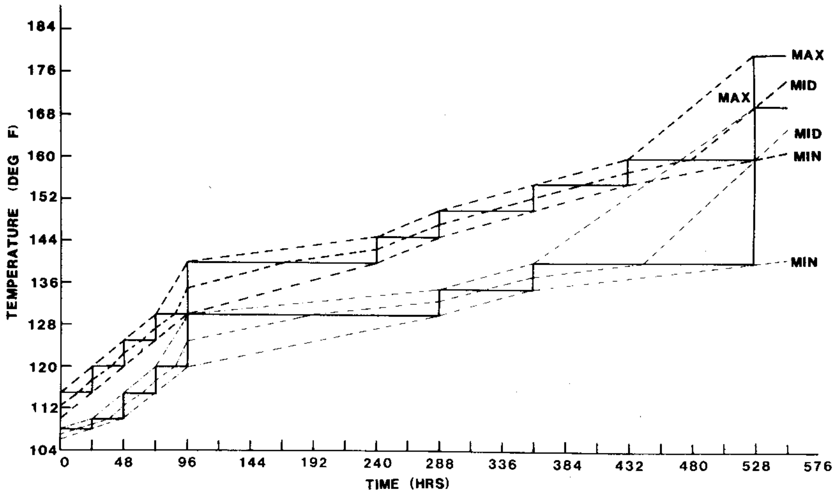

Figure 3. Step-form and mid-point continuous change schedules for 12/4 ponderosa pine shop and better lumber.

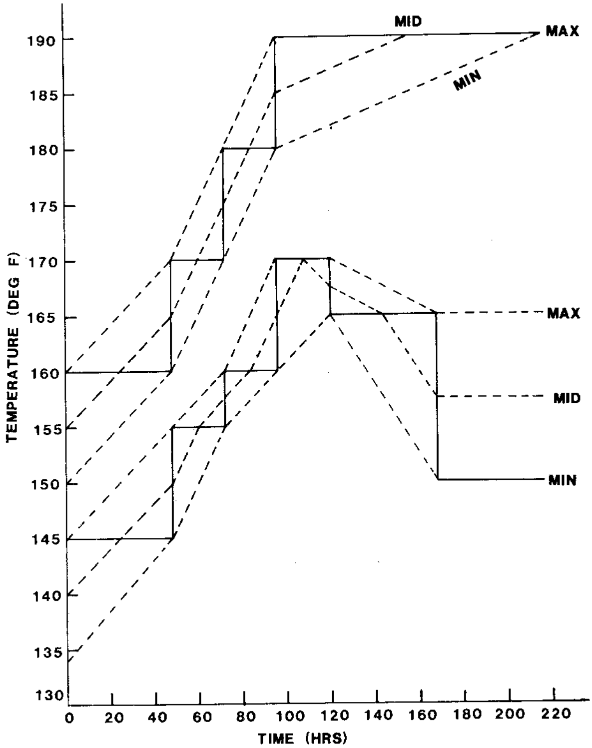

Figure 4. Step-form and maximum and minimum mid-point continuous change schedules for 4" x 6" white fir decking.

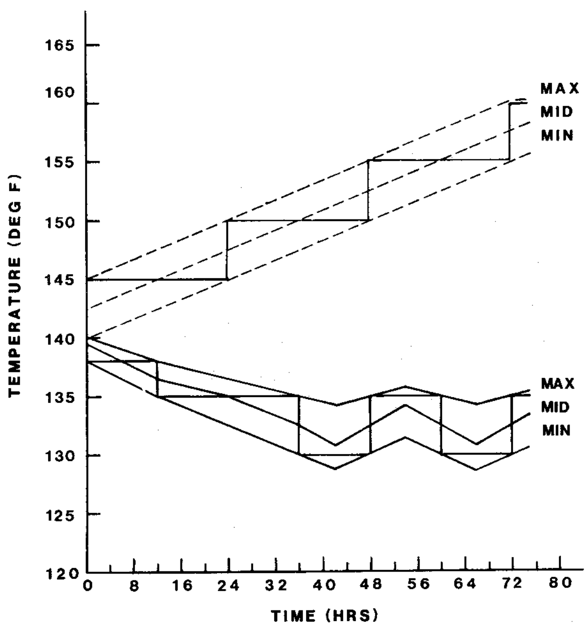

Figure 5. Step-form and mid-point continuous change schedule for 8/4 Douglas-fir dimension lumber.