Delta T
Kiln Control Technology

CONTROL OF Steam-Heated Multi-Zone Kilns Processing Southern Pine

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By

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CONTROL OF STEAM-HEATED MULTI-ZONE KILNS

<u>I. INTRODUCTION:</u>

A) THE NEED FOR CONTROLLED DRYING:

Freshly cut Southern Pine lumber (SPL) contains, on the average, about 100% MC (dry basis). Natural air drying of the wood commences immediately and continues through the green lumber stage since the water content in the wood is not in equilibrium with the moisture content of the ambient air. Air drying, of course, is not suitable for today's more demanding production and quality requirements; therefore, the more rapid and controlled atmosphere of a kiln must be employed to dry the lumber to the target moisture content (MC). Drying, by any means, creates stresses in the wood that may lead to production of lower quality lumber. Consequently, care must be taken in controlling the drying process to minimize these stresses.

B) THE COST OF POOR KILN CONTROL:

To reduce shrinkage or swelling in place, the MC of lumber exiting a kiln must, of necessity, be controlled to a target MC value that is suitable for the product's end-use and the environment in which it will be used. Additionally, the standard deviation should be reduced as much as practicable to minimize degrade losses from overdried lumber. Studies[1 conducted] in the mid-eighties determined that for every 1% MC below the target value, degrade losses were approximately $3/MBF. The potential savings from having a true zone-control system that is capable of: (1) accurately and consistently drying lumber to the target MC, and (2) capable of reducing the standard deviation of the MC to the lowest practicable value is sufficient to warrant careful comparison of control systems being offered.

C) VARIABLES IN KILN DRYING:

Some of the variables that a kiln control system must be able to handle are:

a) Stratification of initial MC in kiln,

b) Relative differences in drying rates of wood,

c) Effect of pressure drop across the load on airflow,

d) Differences in heat transfer rate from the coils,

e) Differences in top and bottom drying rates due to uneven air flow.

II. ZONING FOR BETTER KILN CONTROL:

A) DEFINITIONS:

1) ZONE: A segment of lumber for which the temperature of the circulating hot air may be manipulated for control purposes. It may be a portion or the whole kiln.

2) MULTI-ZONE KILN: A lumber kiln that has been divided into independent control segments (zones) for the purpose of controlling MC of the lumber in each zone.

B) **RATIONALE FOR ZONING;**

Quality and profit suffer if there is wide MC variation in the finished lumber. Standard deviation of the lumber MC can be reduced significantly by dividing the kiln into zones and forcing each zone MC toward the target MC. However, simply dividing the kiln into zones does not assure success. The kiln control system must include an accurate and reliable method for comparing individual zone MCs.

C) SELECTION CRITERIA FOR A TRUE ZONE CONTROL SYSTEM:

The following capabilities should be included in any true zone control system selected:

(1) A reliable and simple method for monitoring MC;

(2) A reliable method for comparing zone-to-zone drying; and

III. EFFICACY OF ZONE CONTROL:

Wood is non-homogeneous and during the drying process presents problems in obtaining uniform MC. It is impossible to directly control some of these variables, e.g., initial MC, wood density, air flow rate, etc., therefore indirect means must be employed for improving control. The most effective method for improving moisture control is to divide the kiln into zones. Proof that zoning will improve control is illustrated by figures (1-3).

A) MC DISTRIBUTION WITHOUT ZONING:

Figure (1) shows the lumber MC distribution from a kiln without zoning. The mean MC value may be close to the target value but its standard deviation is rather wide.

FIGURE 1
MC DISTRIBUTION - KILN WITHOUT ZONING

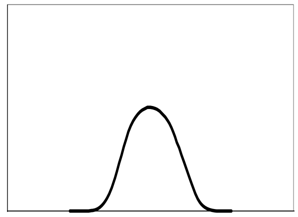
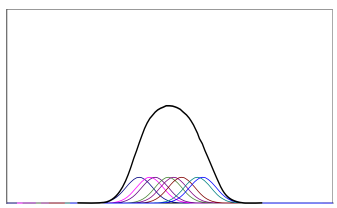


Figure (2) shows the same MC distribution divided into several imaginary zones that make up the overall distribution of a non-zoned kiln. Each zone would be expected to have ***different means*** but similar standard deviations.

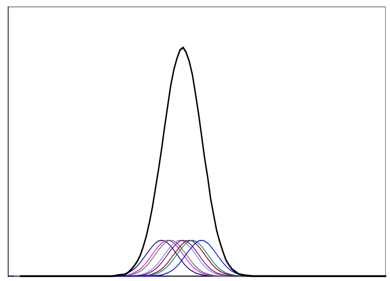
FIGURE 2
MC DISTRIBUTION OF INDIVIDUAL ZONES



B) MC DISTRIBUTION OF A ZONED KILN:

Figure (3) shows the overall MC distribution and the distributions for the individual zones for the kiln segregated into zones. The mean MC of each zone has been individually controlled toward the target MC value. Even if the standard deviations of the individual zones MC are not reduced significantly (they probably are), the overall standard deviation of the kiln load will be reduced below that of the non-zoned kiln as seen by a comparison of figures (1) and (3). The reason for this is that as the mean value of each zone is forced toward the target, the individual distributions tend to cluster closer to the target value and as such, the overall kiln standard deviation is reduced below that of the non-zoned-zoned kiln.

FIGURE 3
MC DISTRIBUTIONS FOR A ZONED KILN



This demonstrates that the kiln should be divided into zones to take advantage of the reduction in downgrade resulting from a lower overall standard deviation for the zoned kiln.

IV. KILN CONTROL METHODS:

In any automatic kiln control system, there must be an effective method for on-line measurement of the lumber MC in the kiln. Two of the most popular for controlling (SPL) are:

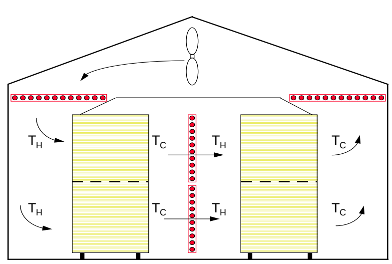
(1) Temperature Drop Across the Load (TDAL)

(2) Electrical properties of wood.

A) TDAL CONTROL METHOD:

At the present time, the most widely-used method for the control of kilns drying Southern Pine is TDAL. Figure (4) illustrates this method.

FIGURE 4
TEMPERATURE DROP ACROSS THE LOAD



1) BASIS OF TDAL: THE DELTA T MODEL:

The mathematical basis for the TDAL method is the DELTA T model.[2, 3, 4]

$$\mathbf{MC = K_1(\Delta T)^p - K_3(D_t)^r} \qquad \mathbf{(1)}$$

The model relates the lumber moisture content (MC) to: (1) the temperature drop of hot air after contact with the wet lumber; and (2) the drying time (D_t). Constants k and exponents, p and r are peculiar to a given kiln.

2) TDAL METHOD INTRODUCES ERROR:

Serious error (ε) is introduced when using TDAL for comparing individual zones of a kiln. For the above model to hold, two conditions must be met for each zone of a multi-zoned kiln:

(1) Entering air temperatures to each zone must be equal

(2) Air flows to each zone must be equal.

Since these two conditions are seldom if ever met in a kiln, TDALs are not comparable between zones and should not be used as the basis for multi-zone kiln control systems. An additional observation that TDAL is not an accurate indicator of lumber MC has been reported.[5] This is reinforced by Table I illustrating the ± error associated with attempting to compare individual zone drying using the Temperature Drop Across a kiln zone.

TABLE I

TDAL + ERROR (ε) IN EACH ZONE

$\Delta T_1 \pm \varepsilon_1$	Apparent MC in Zone 1
$\Delta T_2 \pm \varepsilon_2$	Apparent MC in Zone 2
$\Delta T_3 \pm \varepsilon_3$	Apparent MC in Zone 3

$$\varepsilon_1 \neq \varepsilon_2 \neq \varepsilon_3$$

This is further illustrated by Table II, where three adjacent zones of a hypothetical kiln with equal average MC values exhibit different TDALs because of differences in air flow or entering air temperature.

TABLE II
EFFECT OF TEMPERATURE AND AIR FLOW
ON TDAL READINGS

TIME	AIRFLOW	AIR TEMP. F	TDAL	% MC APPARENT	% MC ACTUAL
0	1000	350	8	18	18
0	1200	350	10	16	18
0	1000	325	6	16	18

The error involved in each zone is caused by differences in air flow and/or entering air temperatures between zones.

3) QUESTIONS TO ASK THE KILN CONTROL MANUFACTURER:

If you are contemplating installation of a new kiln or a new control system for an old kiln, and you want the advantages of a true zone controlled kiln, you should ask the equipment suppliers these three important questions

1) What method will be used for on-line sensing of lumber MC?

2) What basis will be used for comparing zone-to-zone MC?

3) How do you propose to accomplish zone-to-zone control?

If the answer to any one of these questions is Temperature Drop Across the Load (TDAL), you will not be obtaining true zone control.

B) THE DRYING RATE CONTROL METHOD:

If the error (ε) in comparing zone MCs, inherent in the TDAL control method, could be eliminated, a ***true multi-zone control system*** would be available. The error can be eliminated by taking the partial derivative of the DELTA T model (equation 1) with respect to time as follows,

$$\partial(\mathbf{MC})/(\partial\theta) = (\mathbf{K_4})\partial\Delta\mathrm{T})/(\partial\theta) \qquad \mathbf{(2)}$$

to obtain the drying rate, (**∂(MC)/($\partial\theta$)), which** is comparable between zones because the error (ε) value is removed during the mathematical calculation. As a result, drying rates are much more effective than TDALs in comparing drying between individual zones of a multi-zone kiln.

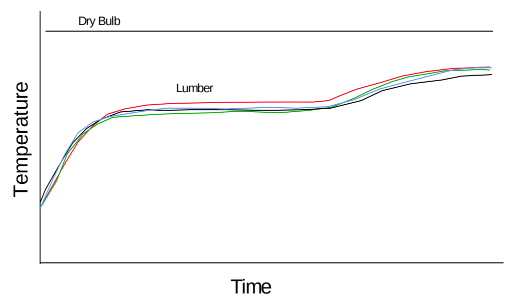
V) A CONTROL SYSTEM USING DRYING RATES:

A) LUMBER DRYING:

1) WARM-UP AND CONSTANT RATE DRYING:

Figure (5) depicts the temperature of the lumber during warm-up, and subsequent constant rate drying period for drying lumber in a kiln.

FIGURE (5)
TEMPERATURE OF LUMBER DURING KILN DRYING



After the warm-up period, the drybulb operating temperature is reached. At this point, the surface temperature of the lumber remains essentially at the wet bulb temperature since there is sufficient free moisture on the lumber surface. Drying proceeds at a constant rate and is limited by the amount of heat that can be transferred. Heat transfer during constant rate drying varies directly with the air velocity parallel to the board. As a rule of thumb, air velocities flowing parallel to the lumber should be at least 1000 fpm.   Studies[1] show that air velocities above 1200 fpm removes the effect of wider piles and thinner stickers but require more energy for conveying the air.

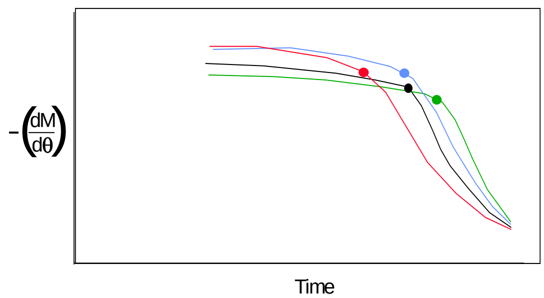
2) FALLING RATE DRYING PERIOD:

As the lumber continues to dry, the MC at which essentially all of the free water is removed from the lumber surface (approximately 25-- 30 %) is reached.   At this point, the lumber is essentially at the Fiber Saturation Point (FSP) and drying enters the falling-rate period. This period of drying is controlled by the rate at which the internal moisture can reach the lumber surface and be removed. As expected, the heat transfer rate requirement is not as great during the falling rate period. If variable speed fans are designed into the system,   energy can be conserved by reducing the air velocity across the lumber. More energy conservation could be realized during conventional drying than for drying with High Temp kilns.   Energy conservation by fan speed control is discussed below.

B) DRYING RATES FOR COMPARING ZONE DRYING:

Figure (6) is a plot of drying rate Vs time for each zone of a multi-zone kiln.

FIGURE 6
DRYING RATES VS TIME FOR
MULTI-ZONE LUMBER KILN OPERATION



In practice, drying rates are calculated and plotted continuously. The first zone drying rate curve to fall or break from (see figure 6) the constant (horizontal) pattern is concluded to be the fastest drying or the lowest MC zone, and it becomes the basis upon which to control the remaining zones. The dry bulb temperature entering this first zone is not changed. As the remaining zones break or reach the FSP they are forced toward the drying rates of the first or base zone by increasing the drybulb temperatures (within limits) to these zones. In this manner, drying in those zones that are slower in reaching the FSP are speeded up by increasing the drybulb temperature to that zone. The result is that the drying rate in each zone is forced toward the same faster drying rate value. Since drying rates are comparable and TDALs aren't, moisture control is improved as well as productivity.

In contrast, a control method using TDAL would use the average of all the zone TDALs and either force those smaller and larger values toward the average or simply allow the average TDAL value to reach a setpoint value then the kiln would be shutdown. Since error is included in the TDAL values, the method might shutdown at the average MC ***but control of individual zones would not be accomplished and the MC standard deviation would be greater than for a true zone control system.***

C) CONTROL PROCEDURE:

The use of drying rates as the basis for comparing and controlling drying in each zone of a multi-zoned kiln is described in the following procedure for startup, operation and automatic shutdown of a kiln. The kiln is loaded with green lumber, the doors are closed, steam valves are open and the fans are ready to be started.

1) The drying schedule has been pre-selected and includes:

a) Selection of one or more shutdown parameter from a menu of 10.

b) Dry bulb and wet bulb temperature setpoints are set.

c) Vents are opened before starting fans.

d) Time between fan starting and vent re-opening is set.

2) Vents open and positioner feedback must indicate they are actually open.

3) Control is initiated by placing cursor on computer at START and clicking.

4) Fans start - All at once or sequenced.

5) Steam valves are wide open or ramped for boiler protection.

6) Kiln heat up period.

8) Dry bulb temperature controlled to setpoint.

9) When the drybulb temperature setpoint is reached, drying proceeds in constant rate period of drying.

10) When all the free water is removed, drying enters falling rate drying period which is essentially at the FSP. The drying rates are plotted.

11) The first zone to reach the FSP becomes the base for zone drying comparison.

12) Dry bulb temperatures to the remaining zones are increased to drive them toward the first zone.

VI) AUTOMATIC SHUTDOWN OF KILN AT TARGET MC:

In addition to good zone control, a kiln system must include a reliable method for automatically shutting down the kiln when the target MC has been reached. Many methods have been devised over the years. Some work at particular locations but do not work so well at other locations. For this reason, a menu of ten selectable shutdown parameters is offered as shown in Table III.

TABLE III
SELECTABLE PARAMETERS USED FOR
AUTOMATIC KILN SHUTDOWN

DRYING RATE	WET BULB CHANGE
DRYING RATE CHANGE	ABSOLUTE HUMIDITY
R.H.	TDAL
R.H. CHANGE	SURFACE TEMPERATURE
WET BULB	TIME

One or more of the parameters of Table III may be pre-selected as the basis for automatic shutdown of the kiln when the average MC has reached the target MC. For example, if relative humidity, which is proving to be popular as a shutdown parameter and time, are selected, the kiln will shut down when the relative humidity has reached the proper value and the total drying time is within a specified range. Or, alternatively, the kiln can be made to automatically shutdown when one or more of the above parameters reach pre-set values. Each mill can select the parameter(s) that works best for them. This has nothing to do with zone control; it simply offers a selection of bases for determining when the target MC has been reached.

VII) MULTI-ZONE KILN CONFIGURATIONS:

Figures (7) and (8) depict two steam-heated, double track, multi-zoned kiln configurations.

FIGURE 7
CROSS-SECTION OF A KILN .WITH 3 VALVE-4 ZONE CONFIGURATION

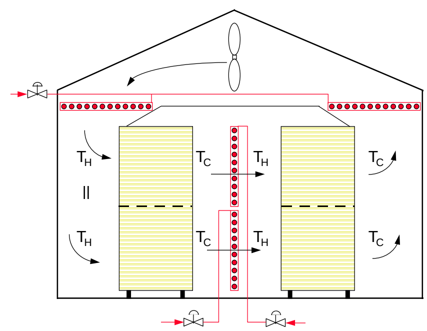
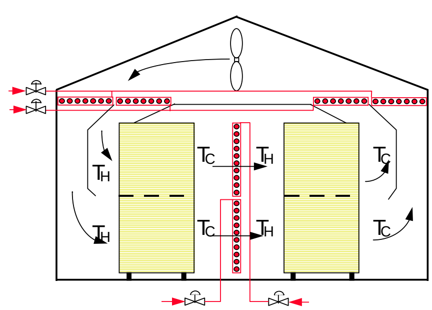


FIGURE 8
CROSS-SECTION OF A KILN WITH 4 VALVE-4 ZONE CONFIGURATION



Figures (7) and (8) are cross-sections of a kiln showing the relative number and position of zones and valve requirements for a double-track kiln. The length of the zone may vary dependent upon total length of the kiln and other reasons. Typically, for multi-zoned kilns, zone lengths range from 20 -- 40 feet per zone.

VIII. KILN CONTROL SYSTEM HARDWARE:

Normally, a PC with Windows is included. I/O modules wired to an I/O panel box located in or near the control room. The I/O signals may be processed either by a PLC linked to the PC, or by individual I/O modules. The preferred steam valves continue to be air-operated. I/P transducers may be mounted on the valves or at the I/O box. An adequate flat-screen with keyboard or touchscreen is used along with a printer. More than one kiln may be controlled using one computer if desired.

IX. OPTIONAL FEATURES:

A) STEAM MANAGEMENT

It is a simple matter to include a steam management system in a kiln control system. This can be done without the use of steam flow sensors simply by using steam header pressure. Should the steam pressure fall, a hierarchical steam management method would allocate steam to each kiln based on where they were in their respective schedules. Those kilns in constant rate drying would be deferred to those in the falling rate period of drying. Additionally, on startup, steam could be ramped to prevent damage to the boiler.

B) ENERGY SAVINGS USING VARIABLE FAN SPEED

With this new method of multi-zone control, it is now possible to determine the point when drying leaves the constant rate period and enters the falling rate period (FSP) by the use of drying rates. As the FSP is reached for each zone, the fan speed could be reduced because the thermal energy input rate is significantly reduced. Since horsepower is proportional to the $(\text{fan speed ratio})^3$, installation of variable speed fans should pay out in a short period of time. For example, a fully loaded 30 HP motor at a fan speed of 700 rpms, when reduced to 350 rpms, would pull only 17.3 HP which is a 43% decrease. For High Temperature kilns the fans might be slowed over about 30 - 35% of the entire schedule. For conventional kilns, the savings would be greater due to the longer duration of the schedule.

C) MODEM COMMUNICATION

A modem is included in the PC used in Delta T Kiln Control Systems. Plant personnel can dial in for remote access or Drying Technology, Inc. service engineers can call in for Service and Support:

1) Over-the-shoulder look at control system operation.

2) Downloading new or upgraded programs.

3) Troubleshooting hardware or software problems.

This feature saves expensive service calls.

X. SUMMARY:

It has been demonstrated that zoning a kiln will reduce the MC standard deviation and consequently reduce degrade. However, the benefits of zoning may be partially or completely negated by the method used for comparing zone drying. Further it is demonstrated herein that the popular control method, TDAL, actually introduces errors in the process of comparing zone drying. However, the use of drying rates as the basis for comparing zone drying makes possible a true multi-zone control system that eliminates these errors.

Automatic shutdown of the kiln when the MC has reached the target is a necessity in any good control system. This new method separates zone control from the shutdown decision by including a menu of ten selectable shutdown parameters. The most popular method among kiln operators to date is the use of relative humidity. We convert relative wet bulb and dry bulb temperatures to elative humidity which would appear to be a superior means for indicating endpoint moisture content. However, we provide a selectable menu of endpoint moisture indicators in order for the mill to decide which is best for their needs.

References:

1) Wengert, Eugene M. & Beckwith, Julian R. III, "Drying Southern Pine Lumber," Southeastern Lumber Manufacturers Assoc., Forest Park, GA.
2) Robinson, J. W., "A New Drying Model," Proc. North American Drying Symposium, MS. Forest Products Util. Lab, MS State, MS, p. 78 - 84, (Nov. 27-28, 1984).
3) US Patent No. 4,701, 859, Method & Apparatus for Controlling Dryers for Wood Products, Fabrics, Paper and Pulp.
4) US Patent No. 4,777, 604, Method and Apparatus for Controlling Batch Dryers.
5) Taylor, F. W. & Landoch, David, "TDAL Profiles of Southern Pine lumber During Drying', Vol. 40, No. 10, Oct. '90, pp 47 - 50.