DELTA T AND YOUR LUMBER DRYING OPERATIONS

Stewart Holmes
Oregon State University
Corvallis, Oregon

INTRODUCTION

Most of you in the lumber-drying business would like to improve the quality of lumber and increase the quantity of lumber going through your dry kilns. Most of you would like to reduce your drying energy costs. DELTA T may be able to help you do both. In this paper I'll explain how.

Most of you probably have heard about DELTA T control in lumber drying. DELTA T as a means of monitoring and controlling dry kilns has become widely visible only recently even though it's been studied and used for nearly 60 years. I'll mention some of that history and talk about the key principles and considerations that have been found out.

Why use DELTA T? Control of lumber drying is ideally based on adjusting kiln conditions to the estimated moisture content (MC) of some part of the lumber. DELTA T is a method for estimating that MC. I'll explain how it works.

Some lumber driers today are using DELTA T to monitor and control drying. I explain how you can too, either manually or automatically.

GOAL AND OBJECTIVES

My goal is to explain how you can use DELTA T to improve the quality and increase the quantity of lumber dried, and perhaps also to save on your energy costs.

My objectives are to:

1. Explain what DELTA T is and what causes it.
2. Talk about others who've used and studied DELTA T,
3. Describe how changes in kiln conditions can affect DELTA T,
4. Outline some possible control strategies using DELTA T, and
5. Discuss how you can apply the DELTA T principles in your lumber-drying operations.

WHAT IS DELTA T?

DELTA T is the difference in air temperature between the entering and the leaving sides of a drying load of lumber. DELTA T is a method for estimating the rate of moisture movement out of drying lumber. "DELTA" means "difference" and "T" stands for "temperature". DELTA T refers to the same thing as Temperature Drop Across the Load, or TDAL.

WHAT CAUSES DELTA T?

During drying, air enters a load of lumber at a temperature called the "dry-bulb temperature" and with a certain MC defined in terms of relative humidity (RH). Under most conditions, when that same air comes out the other side of the load it's at some lower dry bulb temperature and it's at a higher relative humidity. These changes occurred because heat energy from the air was picked up by the wood and water. The wood heated up and some of the water evaporated. The drop in dry-bulb temperature across the load is what's called DELTA T or Temperature Drop Across the Load.

When drying starts, lumber is usually cool and has a high moisture content. DELTA T under these conditions will be large since a lot of heat will be picked up by the wood and water. As drying progresses the wood and water heat up and will pick up less heat from the air. And because the lumber is drier there will be less water to evaporate. Therefore, DELTA T will become progressively smaller unless the kiln conditions are changed.

The rate at which moisture moves from inside the lumber to the surface where it can evaporate into the air stream, depends in large part on the diffusivity and permeability of the lumber. These properties vary from piece to piece, even within a single species, and can change as the drying process progresses.

In general, in lumber that has a high permeability like Southern pine, and/or has a high rate of diffusion, moisture will move freely to the surface where it can evaporate. When drying this lumber you may find a large DELTA T due to the heat absorbing character of the water as long as the water is moving freely. Conversely, in lumber that has a low permeability or low diffusivity, moisture will not move freely. When drying this lumber you may find a smaller DELTA T.

HISTORY OF DELTA T

The following is an overview of who's used and studied DELTA T. While not complete it shows how and for how long the principles of DELTA T have been recognized and used.

What I want you to get from this overview is an understanding of what others have found to be the key considerations when using DELTA T. These same considerations will pertain to your operations and will make or break your successful use of DELTA T.

1930

In 1930 operators at a mill drying ponderosa pine measured DELTA T and used it to control conditions to prevent brown stain. The operators knew they had to maintain a certain DELTA T to prevent brown stain and they used that information to control the entering-air dry-bulb temperature. This same control strategy could be automatically implemented today with a computer controller.

1940

In 1940 Torgeson studied the relative effects of various aspects of the drying process on drying time. He found the difference in total drying time for different width stacks greater than expected based on the average DELTA T.

He noted that while entering air temperatures and humidities were relatively uniform, the leaving-air conditions were not. He also noted that as the air passed through the stack the flow became less rapid and less uniform. This resulted in varying amounts of heat loss to the wood and water within different parts of the stack and thereby differences in the leaving air conditions.

He concluded that anything that resulted in poor air flow patterns through the stack would adversely affect DELTA T. Therefore, for DELTA T to be effective operators must do a good job of preparing lumber for drying and must know what the kiln conditions are "in fact".

1943

In 1943 Voorhies and Loughborough evaluated the state of kiln control in some Pacific Northwest kilns drying lumber for aircraft. They installed thermocouples in the plenums and stacks of lumber and measured several variables including DELTA T.

DELTA Ts typically would vary from 1-1/2 to 4 F depending on which heat coils were used. Uneven heating from malfunctioning heat coils, and uneven air flow from poor stacking and baffling practices, lead to uneven drying and DELTA Ts that varied throughout a kiln. The authors concluded that knowledge of DELTA T "...plays a very important role in the successful drying of aircraft lumber."

1956

In 1953 Stevens, Johnston and Pratt studied heat transfer, something that can cause DELTA T, during the constant rate period of drying using a range of air velocities while holding other parameters constant. They found a linear relationship between heat transfer and air velocity.

That type of relationship could be used in a drying control strategy to calculate the optimum air speed for drying rate and conditions development.

1957

In 1957 Stevens and Johnston used their data and other's to calculate DELTA T and drying rates with and without fan reversals. They found that the rate of temperature drop is great in the first few feet into the stack and drops off rapidly after that. They also found how significant fan reversals can be in maintaining a relatively greater drying rate.

The relationships could be used to calculate the optimum air speed at different times in the drying schedule and the timing of fan reversals.

1969

In 1969 Dedrick described the relationships among air velocity, dry- and wet-bulb temperatures, and wood temperatures and MC in commercial kilns with special regard to constant rising temperature-controlled kilns. He talked about how DELTA T was a good indicator of the rates of drying and heat absorption by lumber. DELTA T is the **KEY** to the CRT process-control strategy.

1972

In 1972 Malmquist described the control strategy of a commercial, progressive kiln. He stated that DELTA T was the

"...appropriate and simple measurement of the drying rate..." used in their kilns for control.

1984

In 1984 Oliveira described the theory and practice of using DELTA T to control drying of Southern yellow pine. His tests showed that during the first 10 hours of drying, DELTA T was nearly constant. During the second 10 hours of the 20-hour schedule, DELTA T dropped off at a constant linear rate. The change was constant enough from one test to another that this relationship could be used in a drying-control strategy. Since control of drying conditions with Southern pine is minimal most driers probably would use DELTA T only to determine when the load was dry.

1987

Finally, in 1987 Kimberly described a now-patented kiln control system that uses DELTA T as part of its control strategy. He called this strategy "evaporative rate control". The strategy allows using DELTA Ts throughout all or parts of a schedule to prevent stress- and moisture-related degrade caused by too-fast or too-slow drying.

In zone-controlled kilns, by controlling DELTA Ts they could adjust drying rates so that all the lumber in the kiln dried to the same final MC at the same time.

HOW KILN CONDITIONS CAN AFFECT DELTA T

Now that we know what causes DELTA T in general and how that can be used to control kilns, let's focus more closely on how kiln conditions can affect DELTA T. I'll discuss air temperature, humidity, and circulation characteristics since these are the kiln functions most operators are familiar with and can do something about.

Temperature/Heat

Temperature is a measure of the amount of heat energy in something. Heat moves from where there's more of it to where there's less and the greater the temperature difference the greater will be the movement of heat.

In drying, that heat usually comes from the air. As the air passes over the lumber the heat moves from where it's hotter, the air, to where it's cooler, the lumber's surface. Some heat goes to heat the water and wood.

Some heat goes to evaporate water. That evaporation energy is needed to overcome the forces holding the water to the wood. When water evaporates from the surface of lumber it takes with it some energy. When it does that, that loss of energy results in a cooling of the lumber's surface.

So, one reason for DELTA T to exist is a temperature difference between the air moving through the lumber load and the lumber itself. That difference, the DELTA T between the air and lumber, is a good measure of the amount of drying force available in the system.

Relative Humidity/Air Moisture Content

In lumber drying the MC of air circulating in the kiln is usually expressed as "relative humidity". As with temperature, moisture moves from where there's more of it to where there's less.

As I mentioned, to dry lumber you must get the water to move from the lumber into the air. One way to do that is to make the surrounding air less moist than the lumber. Under these conditions water will move from where there's more of it, the lumber, to where there's less, the air.

As the water evaporates it will take with it its latent heat of evaporation. The effect will be to cool the lumber. As the hot air stream passes over the lumber heat will move from the air to the lumber thus cooling the air stream causing a DELTA T.

So, another cause of DELTA T is a MC difference between the air moving through the lumber load and the lumber itself. If the air is saturated no water will evaporate though there may still be heat transfer between the air and lumber.

Circulating Air Characteristics

Air serves to carry heat to the lumber and to carry water away. The turbulence of the air stream, the velocity, and the volume of air circulating through the drying lumber load are all important in the development of a DELTA T. In general, air streams that are more turbulent, have a higher velocity, and a greater volume, all will be able to carry more heat to, and moisture away from, drying lumber.

Several other factors can significantly affect air flow. Stickering can affect flow by causing or preventing turbulent flow. Improper stickering can even result in reversed air flow in some parts of a load. Some automatic sticker machines may create "chimneys" within a stack that can allow a lot of air to flow vertically in the stack instead of horizontally.

Thicker stickers can result in lower velocities but greater volumes of flow. Thinner stickers can result in higher velocities but lower volumes. Too thin stickers can cause slowing or blockage of air passages within and between stacks.

The use or not of baffles can have an enormous influence on the development of DELTA T. Baffles must be properly placed and in the same locations every time the kiln is loaded in order for there to be consistent DELTA Ts developed from one run to the next.

Because all these factors affect air flow, all must be considered when designing a control strategy based on DELTA T. Without consistency of air flow through the stack from one kiln charge to the next no control strategy using DELTA T can be effective consistently.

DRYING CONTROL STRATEGIES BASED ON DELTA T

Now that we know more specifically how air temperature, humidity and circulation characteristics can affect DELTA T, let's examine how we can use that information to implement drying control strategies based on DELTA T.

The following are guidelines for some strategies that could be based on the DELTA T principle. While these strategies would most likely be part of a computer-controlled drying system, they could also be used to plan when and how to make changes manually.

As I explained at the start, DELTA T is only a measure of the rate of heat pickup by lumber from the air stream as that air moves through the lumber stack. That lumber consists of both wood, and water in the wood. While water can absorb and hold more heat than wood, keep in mind that bone dry but cold wood will also pick up heat and create a DELTA T. For that reason, any strategy based on DELTA T should be able to compensate for these factors during the changing stages of the drying process.

DELTA T can be measured in one or many zones or areas in a single or double track kiln. In a double track kiln where the booster or center coils can be independently controlled from the ceiling coils, temperatures would normally be taken on both sides of the loads on both tracks. This would allow controlling DELTA T independently for each load.

Strategy #1 = DELTA T Only Used To Determine The End-Point In Drying

In Strategy #1 DELTA T would only be used for determining the end-point in drying. Temperature setpoints would be determined on another basis. That is, the continual changes in DELTA T are not as important as the actual size of DELTA T or the duration of a lack of significant change in DELTA T.

In the first scenario DELTA T would diminish to a certain amount at which time drying would be considered done. This strategy might be used with a fast-drying species like Southern pine where you simply turn on the heat and maybe not even control humidity. Probably not many species could be dried using this strategy due to the lack of sufficient permeability allowing moisture to keep moving fast enough.

In the second scenario DELTA T would diminish to a certain level and then not change for a given period of time after which drying would be considered done. This strategy might be used with most other species.

Strategy #2 = DELTA T The Only Basis For Setpoint Determination

In Strategy #2 setpoint control is based on DELTA T with only a relatively high limit placed on entering air temperature. Operators might use this strategy if they needed to control stain by maximizing the rate of evaporation especially during the early stages of drying.

This strategy has the potential drawback of allowing entering-air temperatures to rise very high with the possible result that lumber on the entering air side will be degraded due to too-fast drying.

Strategy #3 = DELTA T And Entering-Air Conditions The Bases For Setpoint Determination

The difference in strategy between #3 and #2 is that both DELTA T, and entering-air temperature and humidity, may place limits on the drying rates.

This strategy has the drawback of probably limiting the rate of drying to less than what it could be if inlet-air conditions were not limiting. On the other hand, this strategy allows optimal control of defect development. Using this strategy it would be possible to control humidity where a certain wet-bulb depression might be necessary, for example, to control color set or development.

Strategy #4 = A Combination of Strategies

In Strategy #4 drying might be started using Strategy #3 until DELTA T diminished to a certain low value at which point another strategy would be invoked. From then until the end of drying perhaps only the dry-bulb/wet-bulb temperatures would be the source of control. The end of drying then could be determined using Strategy #1.

Difficulties In Implementing Strategies

What are some factors likely to cause difficulties in implementing DELTA T-based strategies?

Very wet or cold lumber at startup.--When lumber has a high green MC, has been wetted by rain or snow, is very cold or frozen, or for some other reason will cause a very large DELTA T, then DELTA T control may have little or no practical sense. Under these conditions control would have to be based on some other parameters until DELTA T diminished to a meaningful level.

Saturated air coming out of the first load in a double-track kiln.--A similar problem on startup in double-track kilns is when air coming out of the load on the first track is saturated. Even though that air is reheated by the booster coils the RH is still much higher than it was going into the load on the first track so drying is slower than in the first load.

Fan reversals.--Under most drying scenarios, as drying proceeds kiln conditions get progressively drier causing lumber on the entering-air side to dry more than lumber on the leaving-air side. In fact, at the outset, lumber on the leaving-air side can pick up moisture from the air stream. When the direction of air circulation is reversed, kiln conditions that were suitable for the relatively-drier lumber on the old entering-air side are now unsuitably dry for the relatively-wetter lumber on the new entering-air side. The longer the time between fan reversals the greater this difference can become. Also, DELTA T will tend to be greater after a fan reversal.

A "smart" strategy might call for a decrease in the severity of kiln conditions immediately after a fan reversal, especially at the start of drying, with the rate of increase in severity after that being tied to the DELTA T noticed after that or to some other factors.

Changes in air flow.--If the fans are slowed to conserve energy the type of air flow might change. Turbulent flow might become laminar causing a decrease in the amount of heat and moisture transfer between the air and lumber. The volume of air flowing through the load will decrease, which will provide for less heat and moisture transfer. Both of these will change DELTA T. Control strategies must take these changes into account and vary other kiln conditions like temperature and/or humidity to maintain the desired DELTA T.

All these factors are made more difficult to compensate for if the fans are not equally efficient in both directions.

Small DELTA T near the end of drying.--Near the end of drying DELTA T might become so small, or the amount of variation around the small value so great, that the precise determination of DELTA T might not be possible by most inexpensive means. No DELTA T-based control of kiln conditions probably would be possible. In this case operators might have to determine by experience how many hours drying should continue after that DELTA T is reached, and then stop drying based on that criterion.

HOW CAN YOU IMPLEMENT DELTA T CONTROL?

How can you implement DELTA T control in your operations? In a real sense all you have to do is measure temperatures on both sides of a drying load of lumber and use that information in your decision making. The cheapest way to do that is to buy a hand-held electronic thermometer and a roll of thermocouple lead wire. You solder the ends of the wire to make the thermocouple junction and lead the wire from the control room, through the kiln wall into the kiln, and attach it to the wall but sticking out into the plenum. Do this on the opposite side of the kiln in the same location. By keeping track of DELTA T in this way you can make changes in kiln conditions to achieve the desired results. On the downside, although not expensive nor particularly difficult to implement, this method would not allow practical realtime control since the method only works when you are there to take the readings and make the appropriate changes.

In a practical sense you must work with a commercial kiln controller manufacturer. In the last few years many of the large controller manufacturers have developed their own versions of DELTA T control strategies. If you would like to know more about using DELTA T in your kilns you should contact the manufacturers.

CONCLUSION

I've covered a lot of topics in these 30 minutes. I talked about what DELTA T is and what causes it; who has used and studied DELTA T; how changes in kiln conditions affect DELTA T; possible control strategies based on DELTA T; and how you can apply DELTA T in your lumber drying operations.

The key points I want to leave you with are:

1. DELTA T can be a reasonably accurate measure of the rate and timing of moisture and heat transfer in drying, and by that I mean the rate of drying,

2. DELTA T exists in your drying operations and can be used to monitor and control those operations,

3. DELTA T affects and is affected by lots of factors in the average dry kiln so it can be difficult to measure and control well,

4. Some form of DELTA T control, along with the equipment needed to make it automatic, will almost certainly guarantee you a fast payback in terms of
   .....Improved lumber quality,
   .....Increased lumber throughput, and
   .....Lower drying costs.

REFERENCES

Anon. 1930. Various figures showing data from a number of drying runs at a ponderosa pine mill. Figures and information about the work were provided by Charlie Kozlik.

Dedrick, D. 1986. "Some Comments on Air-Wood Temperature Gradients and Temperature Drops Across the Load as They Relate to Drying Rate." Proc. 27th Annual Western Dry Kiln Assoc. Pp. 74-81.

Dedrick, D. 1969. "Accelerated Kiln Drying by Control of Air to Wood Temperature Differential." Proc. 20th Annual Western Dry Kiln Assoc. Pp. 9-12.

Kimberly, T.H. 1987. "A New Approach to Management and Control of the Traditional Lumber Drying Process." Proc. 28th Annual Western Dry Kiln Assoc. Pp. 63-82.

Malmquist, L. 1972. "Lumber Dryer of the Seventies." SF Review, Industrial Edition 1972.

Ogura, T. 1955. "On the Drop of Dry-Bulb Temperature at the Constant Rate of Drying of Wood." J. Japan Wood Res. Soc. 1(2):74-75.

Oliveira, L. C de S. 1985. "Mathematical Model for Control of High Temperature Drying of Southern Yellow Pine Dimension Lumber." Ph.D. Dissertation. Virginia Tech., Blacksburg, VA.

Stevens, W.C. and D.D. Johnston. 1957. "Temperature Drop Across a Pile of Green Timber and Its Effects of Air Speed on the Transference of Heat from Air to Water." Timb. Tech. 64(2208):537-539.

Torgeson, O.W. 1940. "The Drying Rate of Sugar Maple as Affected by Relative Humidity and Air Velocity." USDA, Forest Service, Forest Products Lab., Rpt. No. R1264.

Voorhies, G. and W.K. Loughborough. 1943. "The Performance of Pacific Northwest Kilns in the Drying of Aircraft Lumber." USDA, Forest Service, Forest Products Lab. Proj. L-142-24.