SHOULD AIR VELOCITY BE INCREASED OR DECREASED?

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We hear a lot of talk these days about speeding up the air velocity in the kiln to accelerate or improve drying, and at the same time we hear about the merits of saving energy by slowing down the fans. These two thoughts appear to be in conflict, however, that is not the case.

Most people using some type of variable speed fan control, rely on a time basis to adjust fan speed. Although the **"time basis"** may be satisfactory, it may not necessarily provide the optimum velocity at the proper time.

This presentation will review some of the effects of air velocity, and I hope provide some basic understanding of when the air velocity should be increased and when the air velocity can be decreased.

Mike Milota has provided copies of several papers he has collected on the subject, and I have drawn some information from them. "The effects of air movement in kiln drying," by W.C. Stevens, and G.H. Pratt. "The effect of air speed and flow direction on the drying of pile timber," by W.C. Stevens and G.H. Pratt. "Temperature drop across a pile of green timber and its effects on drying rates," by W.C. Stevens and D.D. Johnston. Another source of information on this subject is "Quality control in lumber drying," Chapter 13, written by Dean Huber. Yet another source is "Utilization of the Southern Pines," by Peter Koch. The data relating to "The Mechanism of Drying" was taken nearly verbatim from work done by C. Arthur Hart and North Carolina State University, 1965.

What I have attempted to do is review these sources of information and sort out the points that relate to our subject "Should air velocity be increased, and when can the fans be slowed without having adverse effects on the drying."

In order to better understand the subject we should know a few of the terms used.

TEMPERATURE DROP ACROSS THE LOAD

The resulting drop in dry bulb temperature associated with the moisture being absorbed from the lumber. For a known volume of air, and a known drop in temperature between the entering side to the leaving side, the amount of water evaporated can be determined.

The psychrometric chart shows this process as the condition of the air backs up the wet bulb line, loosing dry bulb temperature and gaining moisture.

In 1988, Dr. Dallas Dedrick spoke to us from the audience on this very subject. He cautioned us about reading too much into the "temperature drop across the load."

Fred Taylor expressed similar thoughts yesterday, in his presentation of "The Use of Charge Weight to Control Drying."

T.D.A.L. necessarily assumes that the air velocity (and thus air volume) is constant throughout the load. This calculation also assumes that the entering and leaving air temperatures are measured directly at the entrance and exit of the sticker openings. Usually, neither of these assumptions are true.

Air velocity (and therefore volume) is very much affected by the thickness uniformity of the lumber and stickers, the use of the baffles, and how well the lumber is stacked.

Usually the sensing bulbs are mounted on the wall. The temperatures sensed are very much influenced by air which passes through the bolster openings, air which by-passes around the end of the load, air which due to bad stickering may have an excessive temperature drop, or the proximity of the sensing bulb to the load.

BOUNDARY LAYER

That layer of air directly in contact with the fibers and surface of the board is known as the boundary layer. The water travels through the board to the surface, where the air absorbs the water. The surface of the board consists of cut and broken fibers which were turned up during the sawing process. These fibers and splinters no doubt help in dispersing the water into the air stream. However, we could also assume that these splinters and fibers also tend to offer resistance to the air movement and slow the air velocity at the surface of the lumber. This also contributes to the boundary layer effect.

We all know that higher air velocity will help dry the lumber faster, but are we really sure why? There are two primary reasons.

The first reason is that the higher velocity tends to scrub away the boundary layer and expose the course of lumber to larger wet bulb depressions.

The second reason relates to the "Temperature drop across the load." We know that as the air passes through the sticker openings, it looses dry bulb temperature as it absorbs moisture from the surface of the lumber. The slower the air velocity (or the smaller the volume of air) the larger the temperature drop across the load. As the dry bulb temperature decreases, it gets closer and closer to the wet bulb temperature, and the wet bulb depression is reduced. Thus, the ability of the air to absorb water is reduced, and drying is diminished.

The advantages of higher air velocity are much more pronounced when free water is available at the surface, as in the early phases of drying. During this period the drying rate is limited by rate of evaporation from the surface of the lumber. Therefore, higher air velocity will pass a larger mass or volume of air over the surface of the board and evaporate more water.

As the surface dries below fiber saturation, the rate of drying becomes limited by the diffusion of the water through the fibers of the cell wall. As this occurs, the drying rate is said to be diffusion limited, and is not appreciably improved by higher air flows.

Koch and Hart state it this way:

> ...if the surface of the wood remains relatively wet, the rate of drying may be substantially increased by increasing air flow.
>
> On the other hand, when the surface has approached the E.M.C., the rate of drying is almost completely dependent upon the rate of moisture movement from the interior to the surface, and an increase in air velocity is ineffective and wasteful.
>
> In either case, while the wet-bulb temperature of the air moving across a charge of lumber remains constant, its dry-bulb temperature drops in proportion to the quantity of moisture evaporated, reaching the wet-bulb temperature if the air becomes totally saturated.
>
> Thus it is desirable to use sufficient air velocity to maintain a reasonable drying capacity on the exit-air side of the charge.

Koch and Hart also offer this "Rule of Thumb": If removal of moisture from the wood surface is the limiting factor, drying time is directly proportional to wet-bulb depression and approximately inversely proportional to air velocity over the surface.

The effect of this is shown in Figures 1 and 2 taken from "Quality Control in Lumber Manufacturing" pages 166, 167 and 168.

Figure 1 shows the effect of air velocity on temperature drop toward middle of the kiln load. Dean informs us that these figures are based on an initial M.C. of 130%, and an intermediate moisture content of 105%. These conditions are similar to what you would find in a pine kiln during the first several days of the drying schedule. During this time there would be free water at the surface.

In Figure 1 we see that with entering air temperatures of 120 degrees dry bulb and 105 degrees wet bulb, the temperature drops are very significant for all air velocities shown. You will note that as the air becomes more saturated, the slope of the line is reduced. The additional drop in temperature is reduced, indicating the amount of moisture evaporated is also reduced.

Figure 2 shows the effect of air velocity on drying time. Quoting from Dean Huber,

> As the air becomes (more) saturated and lower in temperature, the drying time increases. The magnitude of the difference in drying time is much larger than might be expected from the difference in temperature....
>
> Control of the drying quality requires control of the air velocity. Variation due to kiln design is difficult to change. But the system by which air is moved - fans, motors, baffles, stickers, piling practices, and so forth - must be maintained at a constant level of performance. If not, the quality of lumber will be seriously affected.

In discussing this graph with Dean, we find that the drying time is shown in dimensionless units. The scale is relative, for example, with 300 fpm, it would take 4.6 units of time to reach a M.C. of 105 percent at 2' into the load. It would take about 72% longer or 5.9 units to reach the same M.C. at 3' into the load.

Now, let's look at air velocities of 300 fpm and 500 fpm. At 4' into the load, we find that 300 fpm requires 11.9 units of time to attain a M.C. of 105 and 500 fpm requires 7.9 units of time. This is approximately 50 percent longer time for this first step of the drying schedule.

As you can see, these figures are for only 4' of lumber, we can only imagine what the conditions would be like passing through an 8' crib. At this point in the schedule we are only drying through the first 2'-3'. Probably, some of the moisture being evaporated in this first 2'-3' is being condensed in the last 2'-3' of an 8' crib.

I have seen water actually flowing down the side of the cribs, puddling on the floor, and then draining out the doors in several kilns drying sugar pine and red alder. When this occurred, we assumed it was a steam condensate leaking on the floor. However, it turned out to be vapor from the air condensing on the lumber and dripping to the floor.

The impact of velocity on the drying time would become less dramatic as the surface of the lumber continued to dry. Then referring back to Koch and Hart, "when the surface has approached the E.M.C., the rate of drying is almost completely dependent upon the rate of moisture movement from the interior to the surface, and an increase in air velocity is ineffective and wasteful."

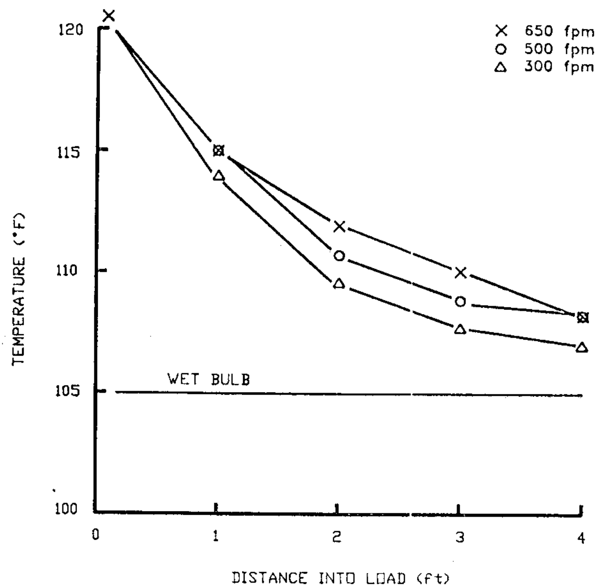

Figure 1. Effect of Air Velocity on Temperature

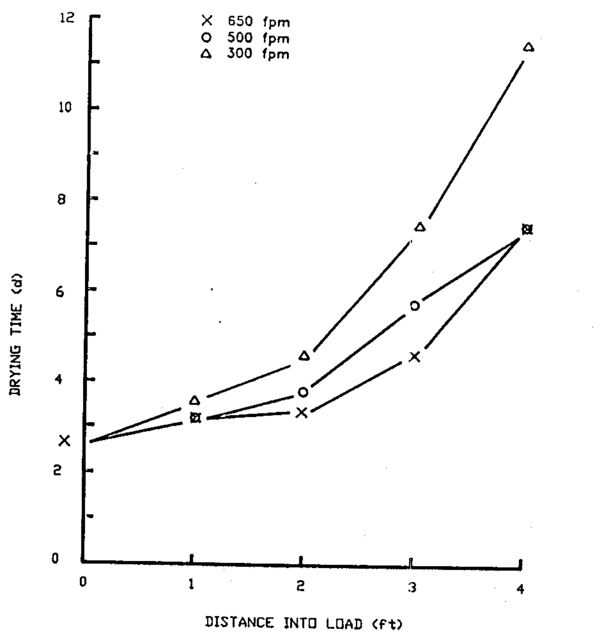

Figure 2. Effect of Air Velocity on Drying Time

There are many factors to consider before making changes to your fan system, or your air velocity. However, I would like to offer these following points for thought, discussion, criticism, and further study, in an effort to help the industry develop the background and foundation for the proper control of air velocity.

1. The higher the moisture content of the entering lumber, the higher the potential for decreasing drying time by increasing air velocity.

2. Drying schedules which reduce the moisture gradient in the board between the surface and interior, as with higher temperature, narrow depression conditions, would appear to keep the surface above fiber saturation for the longer period of time and thus enhance potential for decreasing drying time by increasing air velocity.

3. No matter what phase or step of the drying schedule is being considered, it is desirable to use sufficient air velocity to maintain a reasonable drying capacity on the exit-air side of the charge.

   I interpret this to mean a large enough depression, or low enough E.M.C. so that drying will not be retarded. Figures 1 and 2 indicate that wet-bulb depressions of less than about 7 degrees, (E.M.C. of 15 or more) dramatically extend drying time.

4. At the beginning of the schedule, when free water near the surface is abundant, higher air velocities offer good potential of reducing drying time.

5. Near the end of the schedule, when there is no free water and the process is diffusion limited, higher air velocities are ineffective and wasteful.

6. There must be a transition period between these two phases when some type of control over air velocity would be desired.

Ideally we want to match the rate of evaporation from the surface of the board with the rate at which the water is reaching the surface. Thus the surface of the board stays near fiber saturation until the "optimum amount" of the free water from the board's interior has been removed.

The conditions controlling your drying process need to be analyzed carefully. However, most drying schedules offer potential for reducing drying time and improving uniformity through increased air velocity, as well as decreased electrical consumption through decreased fans speed.

I hope this has helped to raise the level of awareness of how small differences is temperature, air velocity, and depression, can and do have a dramatic influence on drying time.