THE EFFECT OF AIR VELOCITY ON DRYING LUMBER - THEORY AND PRACTICAL RESULTS

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Everyone who dries lumber is well aware of the effects of temperature and humidity on the rate of drying. On the other hand, air velocity, which is as important as relative humidity, is often overlooked and misunderstood. This paper looks at the effects of velocity, both for an individual piece of lumber and for the entire load, first from a theoretical viewpoint and then from a practical viewpoint.

THEORY: DRYING A SMALL PIECE OF WOOD

When wood is dried at atmospheric pressure at a given temperature, relative humidity, and velocity, the air carries energy from the heat supply to the wood, and the air carries evaporated moisture away from the wood. The air, due to its viscosity, flows at a reduced speed near the surface of the wood. The region of reduced speed (the velocity is 99% or slower of the free steam velocity) is called the boundary layer (Figure 1). Initially, the boundary layer has the air flowing in parallel path, called the laminar region. However, further down the flow path, the air flow pattern often becomes turbulent. The distance when lanimar becomes turbulent is dependent on the velocity (higher velocities result in a quicker transition), among other variables.

The transfer of energy within the boundary layer is approximately equal to the square root of velocity in a laminar region (i.e., quadruple the velocity to achieve a doubling of heat transfer rates) and proportional to the velocity to the 0.8 power in the turbulent region (i.e., quadruple the velocity and achieve about three times better heat transfer).

The boundary layer can be considered as an insulating layer of air that resists drying. The higher the air speed, the less the resistance. As a generalization, the resistance of the boundary layer when drying lumber can be represented as:

	Resistance
Nearly Still Air	50
Laminar Flow	0.5
Turbulent Flow	0.05

These values are not dependent on wood MC.

When drying wood, there are two resistances to drying--the boundary layer (as above) and the wood itself. These two resistances are added to obtain the total resistance. The resistance of the wood varies with moisture content. When the wood is soaking wet, the resistance offered by the wood is very small--water molecules are at or very near the surface. As the wood dries, water is evaporated deeper within the wood. The wood then offers resistance to the movement of this water, as the molecules wiggle their way to the surface. The thicker the wood, the greater the resistance as the wood dries. As a generalization, the resistance of wood to drying is:

	Resistance	
	Wet wood	Dry wood
Thick Lumber	0.008	8
Thick Lumber	0.008	3
Thick Veneer	0.008	0.08

At this point, it is helpful to consider the total resistance in drying for a turbulent boundary layer.

	Overall Resistance*	
	Wet Wood	Dry Wood
Thick Lumber	0.058	8
Thin Lumber	0.058	3
Thin Veneer	0.058	0.013

*Obtained by summing the boundary layer and wood's resistance

These values are then examined for the factor -- boundary layer or wood -- that provides the dominant resistance.

	Wet Wood	Dry Wood
Thick Lumber	B.L.	Wood
Thick Lumber	B.L.	Wood
Thin Veneer	B.L.	B.L. & Wood

Considering wet wood, the boundary layer is of key importance, meaning that velocity of the air will be critical in controlling drying. For dry wood, the boundary layer (and therefore velocity) is not an important factor in the drying rate of lumber, but is still important for thin veneer.

PRACTICAL RESULTS FOR A SMALL PIECE OF WOOD

One of the more illustrative sets of data on the effect of velocity on drying lumber was collected by Torgeson in 1957. A summary of his work for soft maple at 130° F is presented in Figure 2. Notice first the top curve, labeled 60% MC. As velocity increases, this curve rises (meaning faster drying), just as predicted by the theory.

Now, note the 20% MC curve. What is the change in drying rate as the velocity increases? The change is negligible, which again agrees with the theory that predicts at low MC's the major controlling resistance is in the wood itself, not the boundary layer.

The implications of this graph are many. One conclusions is that at high MC's, slights variations in kiln velocity will significantly affect drying rates. At low MC's, because velocity is not significant and because high velocities cost more money to generate than low velocities, it is easy to understand that low velocities, perhaps using a frequency invertor, will save substantial energy without affecting drying time!

Another result of Torgeson's data is presented in Figure 3 for soft maple at 130° F and 60% MC. The interaction of velocity and humidity can be seen by looking at the 2% MC loss per hour line and noting the different combinations of RH and velocity that are possible in order to achieve a 2% loss--the higher the velocity, the higher the humidity required. [It is interesting, however, that almost all kiln schedules in use today specify a temperature and humidity (or wet-bulb) and do not indicate the velocity options. This omission is an important oversight.]

VELOCITY EFFECTS ON AN ENTIRE LOAD

Up to this point, I have discussed what happens at a point. Now consider what happens as the air goes through the load--as it supplies energy to the wood, the air cools. With this cooling, there is also an increase in relative humidity. (This is sometimes called the integral effect of velocity.) As an example, consider a 20-foot wide load of a load of pine (Figure 4) air drying on an 85° F day with 43% RH (8% EMC). The air blows through the pile at 5 MPH. On the exit side of the pile, the temperature is 72° F, which gives a 65% RH (12% EMC). The lumber on the entering side will dry very well, but the lumber, as the air progresses through the load, will dry slower and slower as the RH increases.

In a commercial kiln, air velocity direction is frequently reversed. As a result, it is common to see both edges dry fairly quickly, while the center of the load dries more slowly. As an example of this effect, consider a load of oak lumber 24-feet wide (three 8-foot packs) dried at and 400 fpm velocity with 6 hour velocity reversal (Figure 5). The upper curve is the MC in the center of the load, while the lower curve is the MC at the edges. At 200 fpm the MC spread is larger than 400 fpm. It is therefore correctly concluded that at higher MC's, higher velocities result in more uniform drying.

Further, exploration of the effect of velocity shows that narrower loads have less variation from edge to center. Further, because the average humidity in a narrow load is lower than in a wide load, narrower loads will dry faster. (Going one step further, this integral velocity effect is why it is difficult to extrapolate drying results from narrow loads of lumber (one or two pieces wide) dried in research kilns to full size kilns. Conditions in a full size kiln cannot be simulated in a research kiln. A full size kiln, for example, may run at entering conditions of 40% RH and exit conditions of 70% RH -- the lumber is exposed to RH's from 40% to 70%. When the fans reverse, the lumber exposed to 40% RH before reversal is now exposed to 70% RH (and vice versa). In a research kiln with a narrow load, the lumber is always exposed to approximately 40% RH, even when the fans reverse. Narrow load drying is more severe!)

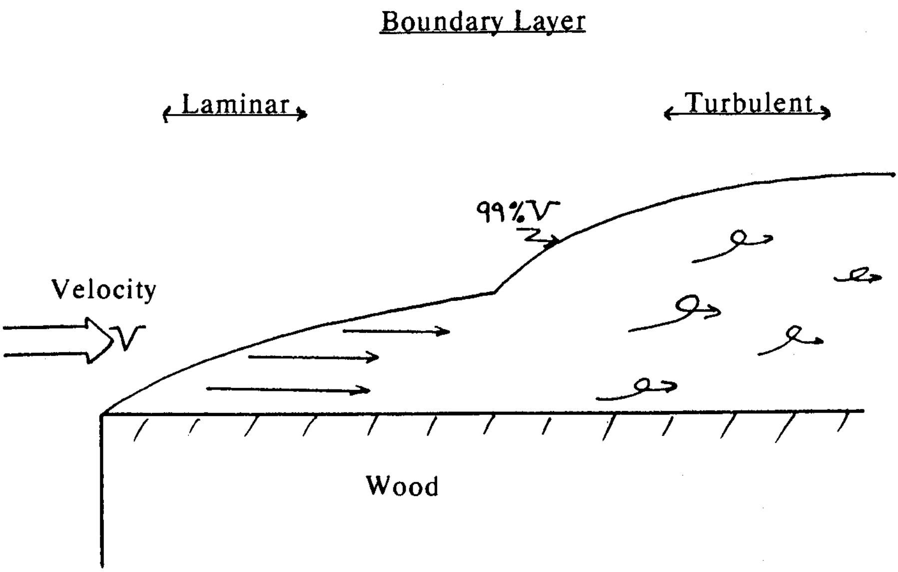


Figure 1. The boundary layer across lumber, illustrating the laminar and turbulent regions.

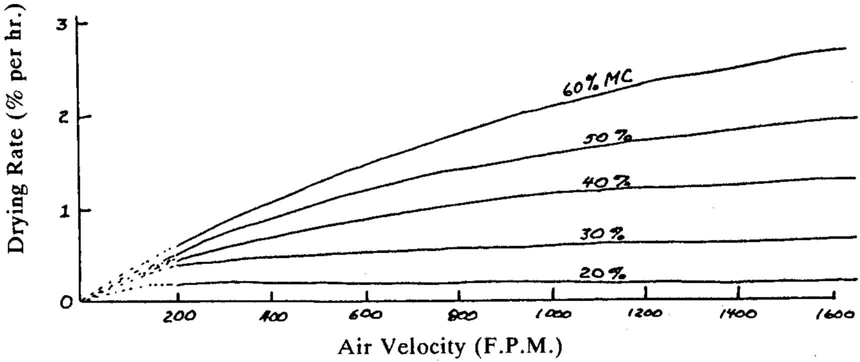


Figure 2. The effect of velocity on drying rates at different MC's for soft maple dried at 130° F.

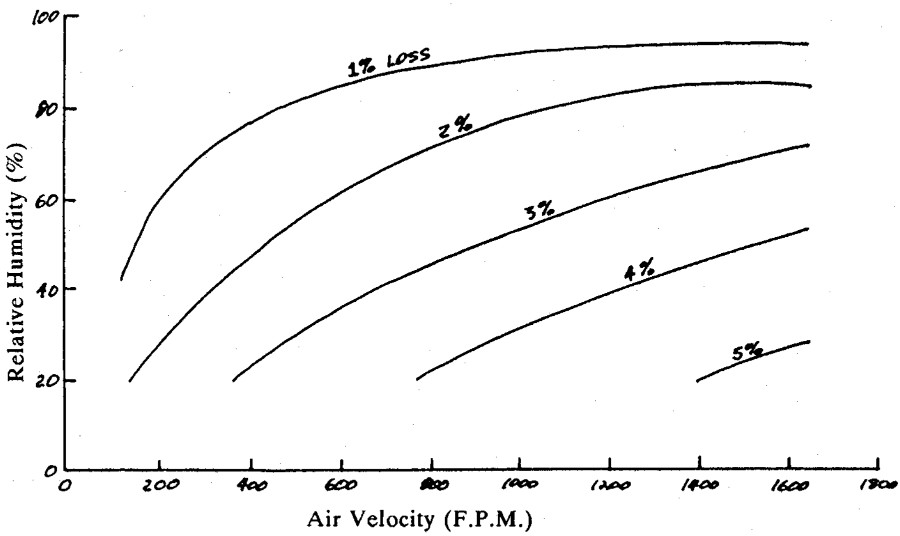
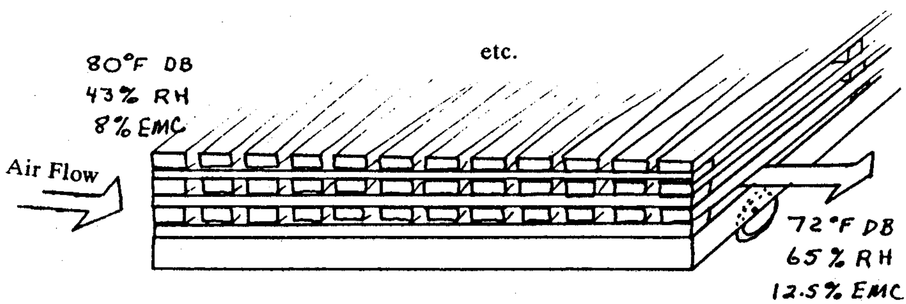
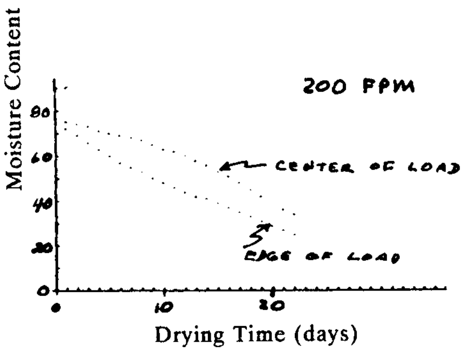


Figure 3. The effect of velocity and RH on the drying rate of soft maple dried at 130° F.



Variation Across the Load

Figure 4. The drop in temperature and increase in humidity through the load.



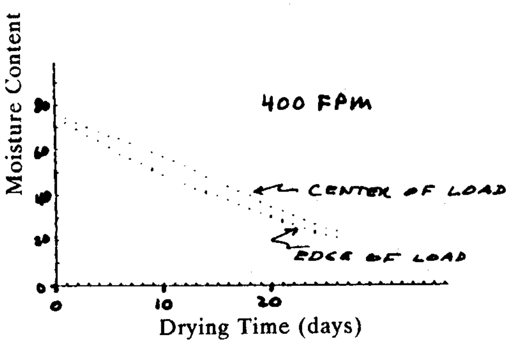


Figure 5. The effect of velocity on drying uniformity.