

## FROM UNEVEN AIR CIRCULATION TO UNEVEN DRYING

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### INTRODUCTION

One of the most persistent features and problems of the lumber drying process today is that at the end of a kiln run there is a large variation and wide scatter in the moisture contents of the individual pieces within the kiln charge. There are no general standards and rules governing variations and scatter in final moisture contents, although these may be specified in individual instances between producer and purchaser. For softwood dimension lumber, the only regulation is that not more than 5 percent of a shipment should exceed the stated moisture content for dry lumber, namely 19 percent moisture content.

Almost all complaints regarding the moisture content of lumber are that it is too high, seldom that it is too low. Yet one does hear complaints about warp, checking, splits, etc., and all of these are shrinkage-related degrade. Shrinkage is directly related to moisture content reduction below fiber saturation point, therefore, the more that lumber is dried the more it shrinks, and the more it shrinks the greater is the probability of degrade.

The production of a large proportion of lumber that has a final moisture content well below the target moisture content should be regarded as just as undesirable as the production of a large proportion of wet lumber. An important aim in drying research therefore is to improve the uniformity of moisture contents in charges of kiln-dried lumber.

The proposition presented here is that, all other things being equal, any non-uniformity in the delivery of heat to wet lumber and in the removal of evaporated moisture from the surface of the lumber, will result in non-uniform drying rates throughout the load. Of course all other things are not equal, even assuming the kiln to be loaded with only one species and size of lumber, the rate of moisture removal from the wood is influenced by factors including green moisture contents, proportions of heartwood and sapwood, and proportions of edge-sawn and flat-sawn boards. Nevertheless, there are some factors over which we can exert some control and the effects of one of them, air circulation and distribution, are the subject of this paper.

### PARAMETERS

The two most important parameters to be considered are the air velocity (feet per minute) and the volume of air circulated (cubic feet per minute). Air velocity is measured directly with velometers or anemometers and air volume is calculated as the product of the air velocity and the cross-sectional area through which it flows. An obvious question for a kiln operator to ask is what air velocity should he have in his kiln. Perhaps he should ask what air volume should he have, and the reasons for this will be dealt with later.

The relationships between air velocity, air volume and the size of the air slots (determined by the sticker thickness) are important in this discussion. If a fan is delivering a given volume of air through a number of air slots between rows of lumber in a kiln and the sticker thickness is reduced, (a) the volume of lumber in the kiln is increased, and (b) allowing some simplifications, the velocity of air through each of the increased number of slots is higher but the volume of air passing through each of the slots is lower than before.

#### BOUNDARY LAYERS

In a lumber stack, the lumber surfaces separated by the stickers form a number of small rectangular ducts. It can be shown that particularly at low air speeds, the temperature and humidity of the circulating air vary considerably from the middle of the duct to the lumber surface. This effect can be traced to a sluggish layer of air near the wood surface tending to produce a barrier to the free transfer of heat and moisture. This barrier is known technically as the 'boundary layer' and it is essentially a film acting as an insulating layer between the surface of the wood and the free air stream.

Flow within the boundary layer can be laminar or turbulent. In the laminar area there is very little mixing of a large number of individual layers through which heat can travel only by conduction and through which moisture can move only by diffusion. At a critical distance from the leading edge of the slot (dependent upon velocity and slot-size) a transition from laminar to turbulent flow may take place. The turbulent flow region may be pictured as a random churning action with chunks of fluid moving to and fro in all directions.

The thickness of the turbulent boundary layer is actually greater than that of the laminar layer but rather than increasing the insulating effectiveness, the thicker turbulent layer actually allows more heat transfer because of the irregular pattern of flow within the boundary layer. If the assumption is made that maximum rates of heat and mass transfer are desirable in lumber drying, then the boundary layer should be the turbulent rather than the laminar type.

The type of flow that exists in a given situation, or the characteristics of that flow, can be described by reference to a dimensionless parameter known as the Reynolds Number (Re). To calculate Re it is necessary to know the thickness and distance of separation of the stickers (gives slot "diameter"), the velocity of the air flow through the slots, and constants for the temperature and humidity of the air (give values for fluid density and viscosity):

$$Re = \frac{\text{fluid density} \times \text{velocity} \times \text{slot "diameter"}}{\text{dynamic viscosity}}$$

The value obtained for Re is an indication of whether the flow of the slot is laminar or turbulent. Up to a given value for flow in particular situations, e. g., over a flat plate or through a tube or duct, flow is laminar. Increasing the value past a transition point changes the flow from laminar to turbulent. It should be noted that to increase Re it is necessary to increase air velocity or slot size which in practical terms means increasing sticker thickness. However, to increase velocity through slots of a given size means a great increase in the power

required to drive the fans, and to increase the sticker thickness means reducing the volume of lumber held in the kiln.

It can be shown that turbulence, and therefore heat and mass transfer, can be increased by artificially roughening the surfaces of material over which a fluid flows. This would be an impractical approach to take with green lumber.

Meroney and Hsi (1975) demonstrated that inserting delta-wing-shaped vortex generators in the entrances of the air slots at the edge of a lumber pile in a kiln created intense turbulence along the length of the slots. In laboratory tests, reduced drying times were obtained but to date there are no records of this idea being tested in large-scale industrial trials.

#### TEMPERATURE VARIATIONS ACROSS A LOAD

Particularly in the earlier stages of drying, much of the heat contained in the circulating air is transferred from the air to the water and the wood a relatively short distance in from the leading edge of the stack. Therefore there is a very rapid drop in the dry-bulb temperature of the air over that length of travel. One consequence of this is that only wood at the leading edge of a stack is subjected to air at the temperature and humidity that a drying schedule calls for.

If the preset wet-bulb depression is low, and particularly if the volume of air circulated is low, it is possible that the dry-bulb temperature can fall to the wet-bulb temperature part way through a load. From that point to the exit side of the load, no drying can occur because the air is fully saturated.

Periodic fan reversals may help to promote overall uniform drying rates, however, they can also promote degrade. If wood that has undergone little or no drying is suddenly subjected to hot dry air, then rapid drying and shrinkage of the surface layers can cause checking.

#### VARIATIONS IN AIR VELOCITY AND VOLUME IN KILNS

By taking account of factors involved in kiln drying, e. g., air velocity, air volume circulated, sticker thickness, temperatures and temperature drops across loads, it should be possible to predict with some accuracy how a kiln load of lumber is going to dry. However, this is made impossible by variations in some of these factors throughout the kiln and usually variations in one factor cause variations in at least one other. Stacking and loading are the usual sources of variations in air circulation. In general, any spaces larger than the air slots between stickers and rows of lumber offer less resistance to air flow. Disproportionately large volumes of air pass through the larger spaces and air flow through the lumber is reduced.

The baffle systems fitted to modern kilns can perform well in reducing air losses or short-circuiting to a minimum if they are used correctly. Tests made by the Western Forest Products Laboratory some years ago on a number of kilns showed that causes including missing or inadequate baffles could allow an average of 42 percent of the circulating air to by-pass the lumber and therefore make no contribution to drying. The total comprised average losses of:

- 8 percent through missing floor baffles
- 9 percent through missing end baffles
- 18 percent through missing top baffles or low loads
- 7 percent through gaps between loads comprised of mixed lengths.

Air velocity values in individual air slots in a well piled, well baffled load are sometimes found to be much lower than the average for the load. This is usually due to localized obstructions to flow in these slots, for example, warping in the unrestrained length of a board between the stickers, or severely torn or raised grain on the surface of a board.

## DISCUSSION

All of the factors mentioned here can interact to play a role in causing a kiln load of dried lumber to have a wide scatter in final moisture contents. For example, consider a kiln operating under fairly normal industrial conditions with only average quality of baffling. Some areas of the load will receive relatively low air velocities and air volumes while others will receive high velocities and volumes.

In the air slots through which velocity and volume are low, there is likely to be poor drying for two reasons: (a) There is insufficient heat in the volume of air passing through the slots to dry the wood all across the width of the load. If the volume is too low then even fan reversal may not be adequate, and boards near the edges of the load will dry very much more than those in the centre. (b) Because the air velocity is low, flow will tend to be laminar rather than turbulent thereby reducing heat and mass transfer.

Conversely, in those areas of the load where the air velocity and volume are high, heat and mass transfer rates should be greater than the average throughout the load due to the quantity of heat carried in the air and the turbulence intensity of the air. Moisture contents of lumber in these slots should be considerably lower than the average for the kiln charge.

These factors that contribute to uneven drying have been recognized at least individually by most people involved in drying. However, almost without exception, they are discussed and considered only in general terms as have been outlined here. There is no information readily available on just how much each source of variation in air circulation contributes to non-uniformity of final moisture contents. This gap in our knowledge of kiln drying should be filled. For example, it should be possible to predict how great a drop in air velocity or volume through some slots in a load can be tolerated before there is a likelihood of lumber in those areas still being wet at the end of a schedule. Similarly, we should know how uniform air circulation rates should be to yield a given degree of uniformity in final moisture contents.

In the same context, it is not adequate to present time-based kiln schedules only in terms of dry- and wet-bulb temperatures. The dry-bulb temperature distribution through a load is dependent on the volume of air circulating through the air slots and the length of the air slot, i. e., the width of the load, through which it must pass. Type of

schedule should, therefore, at least state a desirable air velocity through air slots formed by stickers of a given thickness.

A research study is presently underway at the Western Forest Products Laboratory to supply some of these quantitative data, and of considerable importance to industry, to assess the monetary losses incurred in producing under-dried and over-dried lumber.

#### LITERATURE CITED

Meroney, R.N. and A. Hsi. 1975. Vortex enhancement of parallel plate heat and mass transport. *Wood Science* 7(4):328-335.