UNIFORMITY OF AIR DISTRIBUTION IN A LUMBER DRY KILN

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UNIFORMITY OF AIR DISTRIBUTION IN A LUMBER DRY KILN[1]

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The advantages of optimum rates of air circulation in a lumber dry kiln are often lost by permitting nonuniformity of air flow through the load. Any pronounced irregularity of air flow will cause a lag in drying in some areas and will govern either the drying time or the uniformity of moisture content.

Recently the Forest Products Laboratory started a study of aerodynamic problems within a kiln which included a few experiments to determine the degree to which certain factors influence the uniformity of air flow through a pile of 1-inch boards. Three factors were studied: (1) width of entering air space, (2) projecting edges on the entering air side, and (3) thickness of stickers. Factors (1) and (2) were determined simultaneously so that the results presented here portray the combined effect rather than the independent effect of these two factors.

The kiln used is 18 feet long and 8 feet wide, and is equipped with three 36-inch overhead disk fans. These were driven by individual 1.5 hp. motors at a speed of 550 revolutions per minute. No heat was supplied and all air velocity readings were taken at ordinary room temperatures by means of a velocity meter equipped with an 18-inch duct jet.

(1) Width of Entering Air Space

The lumber pile in this test consisted of 1-inch lumber 16 feet long piled on 1-inch stickers to a width of 3 feet and a height of 7 feet. The entering air edges projected or recessed from zero to three-fourths of an inch. A movable partition was placed in the entering air space and shifted so as to provide entering air spaces 6, 12, 18, 24, and 30 inches wide, respectively. Another position was provided by resting the top of the partition against the kiln wall and the bottom against the

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pile, thus forming a deflecting baffle with an entering air space 30 inches wide at the top and 1 inch wide at the bottom. The leaving air space was 24 inches wide throughout the series of tests.

Velocity readings were taken in every sticker space along three veritcal lines on the leaving air side of the load. For each position of the partition, an average of all readings was obtained and in addition readings above and below this grand average were averaged separately, the difference between these latter representing, approximately, the range between which 50 percent of the readings fell. This range was divided by two to obtain the plus and minus average variation from the grand average.

The results are given in table 1. These indicate that the width of the entering air space and the resulting air velocity within that space greatly influenced the uniformity of air velocity through the load of lumber. Apparently the sloping position of the partition was best. Under this condition the air entered the pile at approximately the same velocity from top to bottom and was partly deflected into the openings between layers. As will be illustrated later, much of the variation was caused by the projecting edges, but when the circulation was reversed and the entering air edges were even, yet considerable variation occurred.

Table 1.--Effect of width of entering air space on uniformity of air flow

Width of entering air space (1)	Average downward air velocity in upper area of entering air space (2)	Average air velocity through lumber pile (3)	Average variation through lumber pile above and below average velocity (includes approximately 50 percent of readings) (4)	(5)
Inches	Ft.per min.	Ft.per min.	Ft.per min.	Percent
6	1,840	269	225	84
12	860	251	170	68
18	620	272	123	45
24	490	286	90	32
30	390	286	69	24
30 - top 1 - bottom	400	294	57	19

Column 2 of table 1 gives the velocity of the air as delivered from the fans into the space between the kiln wall and lumber pile. The velocity within this space has a direct and most important effect upon the uniformity of air flow throughout the lumber pile. With a constant volume of air delivery, the entering air velocity is inversely proportional to the width of this space. Even with the comparatively ample width of 18 inches, the uniformity of air flow left much to be desired, being less than half of that secured with the 30-inch space and the sloping baffle.

Column 3 gives the average air velocity, which is a measure of the total air delivery of the fans. Eliminating the average for the 6-inch width, where slight errors of measurements may have been caused by turbulent flow, and using the average for the 12-inch width as a base, the fan delivery was increased 8 percent using an 18-inch space, 14 percent using 24 or 30-inch spaces, and 17 percent when the side wall sloped from a width of 30 inches at the top to 1 inch at the bottom. These added amounts of air, plus greater uniformity, indicate the desirability of using an entering air space at least 24 inches wide.

One other effect, not shown in table 1, is that with the 6-inch space the highest velocities were through the lower layers, but as the width increased the distribution vertically changed until at the 30-inch width the highest velocities were through the top layers.

(2) Projecting Edges on Entering Air Side

Much of the nonuniformity shown in table 1 was due to projecting edges, which deflected air into the spaces above and prevented air from entering the spaces below. In some cases the direction of flow in the spaces below was reversed, that is, air returned from the leaving air side to the entering air side. In many other cases the air in spaces below projecting edges was practically stagnant. This effect was very pronounced when the air velocity downward in the entering air space was high, but became very much less as this velocity decreased.

Figure 1 shows layers 16, 17, and 18 (numbering from the top) and the relative position of their entering edges. The air velocities obtained under entering air space widths of 6 and 24 inches, respectively, are given in the separate sketches "A" and "B."

In case "A" it is apparent that, in drying, the lower surfaces of layer 17 will lag behind the upper surface resulting in uneven moisture content and increased warp. In case "B," with an entering air space 24 inches wide the uniformity of air flow is much better, but even here the air velocity in the space below the projecting edge is only 76 percent of that in the space above.

In other words, uniformity of air circulation is increased considerably when the air flows through a lumber pile having the entering edges even; and this effect becomes more pronounced as the air velocity in the entering air space increases.

(3) Thickness of Stickers

The pile arrangement and the procedure for this study were practically the same as for the studies on entering air width and projecting edges, except that in this case the entering air edges were vertically aligned and the sticker thicknesses used were 1/2, 3/4, 1, and 1-1/4 inches. The width of both entering and leaving air spaces was 30 inches. The air velocities were read on the leaving air side in each sticker space at five locations along the length of the load.

The following results favor the use of thin stickers: first, the kiln capacity is increased. Second, the air velocity is increased due to the decrease in total air space between layers. This increased air velocity may produce a faster drying rate. Third, the uniformity of air flow is increased, as shown by the data presented in table 2.

Table 2.--Effect of sticker size on uniformity of air flow

Thickness of stickers	Average air velocity through lumber pile	Average variation through lumber pile above and below average velocity (includes approximately 50 percent of readings)	
Inches	Ft. per min.	Ft. per min.	Percent
1/2	454	41	9
3/4	389	49	13
1	367	60	16
1-1/4	330	75	23

One objection to the use of thin stickers is the additional back pressure caused by the entrance and frictional losses and the resulting effect of air delivery and power consumption. It might be thought that with more lumber in the kiln more air would be needed to provide heat for the additional amount of evaporation and to replace the amount lost due to increased resistance. With a possible increase in drying rate and a more uniform distribution of air, however, the time needed to obtain a given uniform moisture content might not be increased even if no additional air is supplied. The economics of the use of thin stickers has not been determined, but in this particular study an estimate of the power and air delivery losses was obtained by the use of a watt-hour meter and an inclined manometer and pitot tube.

Readings of pressure difference were taken on each side of one fan at a point 6 inches away from the blades and 5 inches in from the rim. These readings of pressure differences are comparable within themselves, but are only approximately correct because of the turbulence of flow especially on the discharge side where the air is turned abruptly by a baffle.

Readings were taken when the kiln was empty and when completely baffled as representing the two limits of air delivery and power consumption. Additional readings were taken with the lumber pile in place and piled on 1/2-inch and 1-1/4-inch stickers, respectively, as representing the two extremes of the stickers used. The results are given in table 3 and indicate that by using 1/2-inch in place of 1-1/4-inch stickers (thus increasing the kiln capacity 52 percent) the air delivery was reduced 16 percent and the power consumption increased 1 percent. Under these conditions, the capacity of the fans would have to be increased 68 percent to provide the same amount of air per board foot as available to the lumber when piled on 1-1/4-inch stickers.

Table 3.--Effect of sticker size on total air delivery and power consumption

Thickness of stickers	Static pressure difference across fan	Total air delivered	Total power consumption
Inches	Inch of water	Cubic feet	Kilowatts
1/2	0.26	13,200	3.45
1-1/4	.24	15,700	3.41
Kiln empty	.23	18,000	3.37
Kiln fully baffled	.52	1,000	4.10
		(estimated leakage)	

It is obviously not possible, from the data at hand, to determine the proper sticker thickness for any given set of conditions. The very evident advantages of greater kiln capacity and greater uniformity of air flow resulting from the use of thin stickers must be balanced against decreased air moving efficiency. A reasonable balance for one set of drying conditions may be far different from a reasonable balance for an entirely different set of drying conditions.

In regard to the fan delivery and power consumption, one other item of interest was disclosed during these tests. The kiln used has a baffle which deflects the air from the fan 180° upward causing it to make another 180° turn before reaching the lumber below. With the kiln empty, the dropping of this baffle caused the static pressure difference to drop from 0.23 to 0.09 inch of water, the power consumption to drop from 3.37 to 2.83 kilowatts, and the air delivery to increase from 18,000 to slightly over 20,000 cubic feet per minute. This shows the importance of keeping any sudden changes in air direction to a minimum.

Summary

The following conclusions are applicable only when conditions are similar to those of these experiments.

1. The width of the entering air space should not be less than 24 inches. A tentative rule might be set up that the width of the entering air space

should not be less than one-half of the sum of the spaces between the layers of boards of a full kiln load of 1-inch lumber. This minimum width of space needs to exist only at the top of the load and from there down a sloping baffle is beneficial by deflecting the air into the spaces between the boards.

2. Projecting edges deflect large volumes of air into the spaces immediately above them and cause local variations in air velocity even to the point where the direction of air travel is reversed through the spaces immediately below them. The higher the air velocity down the entering air space the greater was this action, but in all cases good returns in uniformity can be secured simply by aligning the entering air edges.

3. Uniformity in air distribution was improved by reducing the thickness of stickers. This procedure has the added advantage of increasing the kiln capacity with only a negligible increase in power consumption. It is believed that these advantages overbalance the fact that some reduction in air delivery is caused by the additional frictional losses.

4. Baffles causing sudden changes in the direction of air movement result in considerable increases in power consumption and decreases in fan delivery.

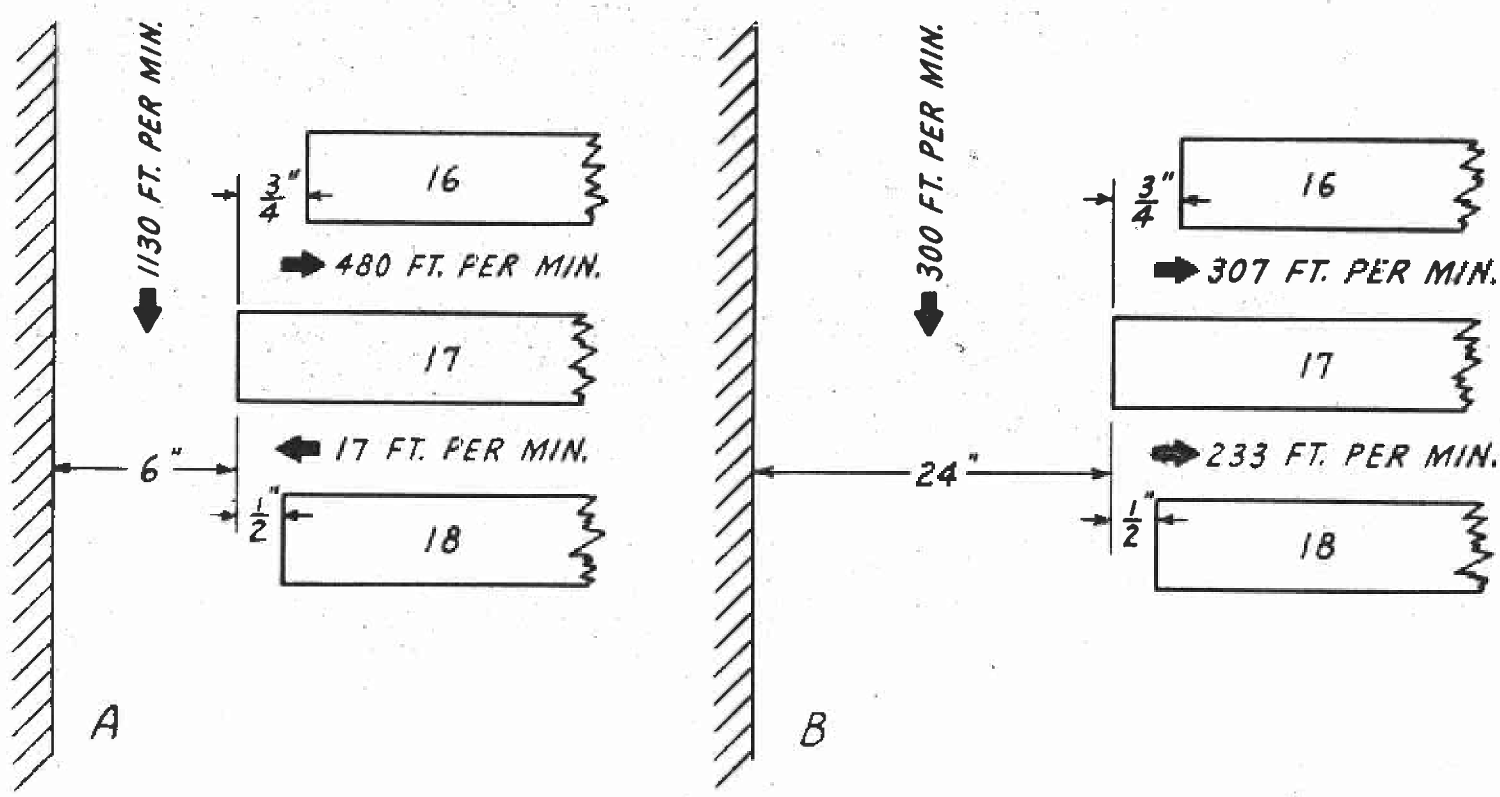

FIG. 1

EFFECT OF PROJECTING EDGES ON ENTERING AIR SIDE OF LAYERS 16, 17 AND 18 OF 1-INCH LUMBER AT TWO VELOCITIES. LOCATION OF THESE LAYERS IS 0.4 THE TOTAL HEIGHT FROM THE TOP OF THE PILE.

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