MECHANISM OF AIR CIRCULATION IN LOVSTED DRY KILNS

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LOW-STEM LUMBER DRY KILNS

INTRODUCTION

The brisk and uniform air circulation in the kilns is the keynote to successful drying of lumber on a commercial scale.

There is definite trend in modern lumber drying toward the use of high air velocities.

In this report, however, no attempt will be made to discuss effect of air velocity on drying rate of lumber in dry kilns. This report will be principally one covering mechanism of air circulation in modern kilns. Moreover the dry kilns with internal disc fans, and crosswise circulation will be considered only.

All problems involved will be treated from the standpoint of those engaged in the manufacture of dry kiln equipment.

AIR TRANSMITTING SYSTEM IN DRY KILNS

In any dry kiln one will find an airway, or duct provided for air circulation. In modern disc fan kilns with air recirculation this duct is not straight, but forms a ring circuit to return air to the fans. At a certain point of this duct there is always a partition installed across the duct with fans in the openings (see Fig. 1).

This partition can be either of straight or zigzag pattern. Sometimes even it is built with more complication -- it all depends on design. But it is important that this partition be built in all kilns with disc fans.
AIR FLOW IN THE DRY KILNS

When the fans are standing still in a cold kiln the air pressure in the duct is the same throughout. But when the fans begin to force air through the openings in fan partition, they build up pressure on one side of this partition and vacuum on the other side.

The air in the kiln starts immediately to move from points of higher pressure to the points of lower pressure.

The total pressure difference across the fan is termed "total head" and this total head is necessary to start and maintain the air flow.

The total head consists of two components:

(1) Static head, which is spent on pressure drops required to overcome resistances to air flow in the air transmitting system.

(2) Velocity head, which is the portion of total head required to produce velocity of flow.

THE STATIC AND VELOCITY HEADS ARE MUTUALLY CONVERTIBLE

The velocity head depends on the square of the velocity of flow. Velocity of flow in its turn depends on cross-section of flow. If, for instance, the cross-section of a duct is increased twice, the velocity will decrease in its magnitude twice also.

Let us assume that velocity $V_1 = 600$ FPM (see Fig. 1) and velocity $V_2 = 300$ FPM. The velocity heads are different also. The velocity head in duct enlargement "D" will be four times smaller than in duct portion marked "C". The difference will be converted into static head. Conversely, when the area is reduced, the static head is partially converted into velocity head. This conversion, however, as it will be shown later, is always accompanied by a certain amount of static head loss.

THE STATIC VELOCITY AND TOTAL HEADS ARE MEASURED IN INCHES OF WATER COLUMN

These heads may be readily measured by water gauges communicating with the duct in the manners shown in Fig. 2.

![Diagram](image-url)
As it was explained before, the velocity head makes the air move, and static pressure is spent to force air through the system obstructions. For a particular flow, in other words a definite pressure drop is required to get air through the system and back to the fans. The pressure drops in the air transmitting system are due to the friction losses and dynamic losses.

(1) The friction losses are the result of friction of air particles against duct walls and internal friction between air particles.

The pressure drop required to overcome the friction loss increases with velocity head, roughness of duct walls, length of duct, and decreases with increase of duct cross-section.

(2) The dynamic losses are caused by sudden changes of direction of flow, or its velocity, and by eddy formations.

The pressure drops compensating for dynamic losses in the system are usually expressed as multiples of velocity head (7/4000)². The actual losses, are of course losses of static head. The velocity head, as we know now, for a given air flow, depends entirely upon the cross-sectional area of duct.

The following are approximate pressure drops due to the different dynamic losses.

(a) Pressure drop due to abrupt turn at 90°

| 90° elbow or rectangular cross-section |
| ASHVE Guide 1961 |

The combined dynamic and friction losses due to an elbow are usually expressed as equivalent to the friction loss in a length L₀ of similar straight duct.

(b) Pressure drop due to dynamic losses when two air streams are directed against each other and then abruptly turned at 90°

("Briera" by Birgerman)
The pressure drop in this case is expressed in numbers of velocity heads lost across this obstruction.

\[ \Delta P_2 = 2.5 \left( \frac{V_2}{1000} \right)^2 \text{ INCH. OF WATER.} \]

**FIG. 4**

(c) Pressure drop due to dynamic losses when air stream is divided into two halves, and each half is abruptly turned 90°

("Modern Air Conditioning, Heating and Ventilating" by Carrier, Churns and Grant)

The pressure drop in this case is expressed in numbers of velocity heads lost in this obstruction.

\[ \Delta P_3 = 1.25 \left( \frac{V_2}{1000} \right)^2 \text{ INCH. OF WATER} \]

**FIG. 5**

(d) Pressure drop due to sudden duct enlargement

(ASHE Guide, 1951)

**EDDY FORMATIONS**

When \( V_2/V_1 = 0.8 \) \& \( P_4 = 0.04 \left( V_1/4000 \right)^2 \text{ inch.} \)

- \( V_2/V_1 = 0.6 \) \& \( P_4 = 0.16 \) \( \text{ inch.} \)
- \( V_2/V_1 = 0.5 \) \& \( P_4 = 0.25 \) \( \text{ inch.} \)
- \( V_2/V_1 = 0.4 \) \& \( P_4 = 0.36 \) \( \text{ inch.} \)
- \( V_2/V_1 = 0.2 \) \& \( P_4 = 0.64 \) \( \text{ inch.} \)

**FIG. 6**

(e) Pressure drop due to sudden duct contraction

(ASHE Guide, 1951)

**EDDY FORMATIONS**

When \( V_1/V_2 = 0.2 \) \& \( P_5 = 0.37 \times \left( V_1/4000 \right)^2 \text{ inch.} \)

- \( V_1/V_2 = 0.4 \) \& \( P_5 = 0.29 \) \( \text{ inch.} \)
- \( V_1/V_2 = 0.5 \) \& \( P_5 = 0.24 \) \( \text{ inch.} \)
- \( V_1/V_2 = 0.6 \) \& \( P_5 = 0.19 \) \( \text{ inch.} \)
- \( V_1/V_2 = 0.8 \) \& \( P_5 = 0.09 \) \( \text{ inch.} \)

**FIG. 7**
(1) Muller type Dry Kiln -- Two track kiln with overhead fans shown

Reversible R.H. and L.H. disc fans on one long shaft installed lengthwise. Fans are equally spaced and their size and number depends upon required circulation.

Fans facing lengthwise of the kiln blow air directly into one another and zigzag fan partition turns air flow crosswise. Then air flow makes two 90° turns, goes through both lumber leads, and again turns 90° twice to get back to the fans.

Shaft with fans may be located either below the lumber leads, or at their sides, or above them, as shown.
Reversible R.H. and L.H. fans on one shaft mounted lengthwise. Fans are equally spaced, and their size, and number depend upon required circulation.

Two fans of right and left hand are installed in openings of fan housings which in their turn are fastened to horizontal baffles and over rectangular holes in the baffle. These fan housings serve the same purpose as fan partitions in other kiln types.

The fans build up pressure in the housings and the air moves through holes in the baffle downwards into the space between the loads. Here the air stream is divided into two halves.
One half flows through load "A" and the other through load "B" and then both halves return to the fans.

When direction of fan rotation is reversed there is vacuum in the fan housings and pressure above horizontal baffle. Due to these pressure changes circulation reverses its direction.

Shaft with fan can be located either above, or below the lumber loads.

(3) "Direct-Flo" Type Kiln

Reversible fans in this type of kiln are facing crosswise. Each fan is mounted on its own shaft and is driven by individual motor.

Uniform and ample circulation is obtained by having disc fans properly spaced the full length of kiln building. Size and number of fans are governed by required circulation.

In this type of kiln the fans move air crosswise.

Air streams do not collide as in previous two types, but are parallel. All these insure uniformity of air circulation.

The fans may be located on the side, above or below the lumber loads.

We build single track, two track, and three track compartments.

COMPARISON OF LOVSTED AIR CIRCULATION SYSTEMS

Any air circulation system in dry kiln must meet the following requirements:

(a) Adequate air flow through the lumber courses must be obtained with the smallest power input.

(b) The air flow through the lumber must be uniform.

Thus, the best air circulation system is the system which is capable of producing economically the same but more uniform air flow through lumber load in dry kiln.
(1) Power input required to produce air circulation

Certain laws govern the performance of fans. The air delivery of a given fan, as well as its necessary power input, depends upon the static pressure against which the fan is working and also on the fan's RPM.

In order to compare air circulation systems in Lovsted's three types of dry kilns, let us assume:

(a) That kiln lengths in all cases are the same and equal to 40 ft.

(b) In each kiln there are 5 - 60" dia. disc fans installed on 8 ft. centers.

(c) Each fan is driven with speed necessary for delivery 16,000 CFM of air against obstructions to air flow in each system.

The pressure drops in systems, as they are shown on Fig. 8, 9 and 10, are tabulated below:

<table>
<thead>
<tr>
<th>Pressure drops because of</th>
<th>Muller type</th>
<th>Double Track Kiln with single Track Performance</th>
<th>&quot;Direct-Flo&quot; Kiln</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friction losses............</td>
<td>0.0502&quot;</td>
<td>0.00185&quot;</td>
<td>0.0503&quot;</td>
</tr>
<tr>
<td>Dynamic losses due to change of air flow direction, and deceleration and acceleration of flow.</td>
<td>0.0801&quot;</td>
<td>0.0201&quot;</td>
<td>0.0921&quot;</td>
</tr>
<tr>
<td>Due to fan arrangement...</td>
<td>0.1068&quot;</td>
<td>0.1068&quot;</td>
<td>None</td>
</tr>
<tr>
<td>Total pressure drop</td>
<td>0.2371&quot;</td>
<td>0.1268&quot;</td>
<td>0.1336&quot;</td>
</tr>
</tbody>
</table>

NOTE: Lumber load 8 ft. wide x 10 ft. high, 4/4 stock on 1" stickers

The smallest pressure drop is in the air circulation system of Double Track Kiln with Single Track performance, but the velocity of air flowing through lumber courses is one-half of that in the Muller and "Direct-Flo" kilns. In the last two kilns the air velocity through the lumber is exactly the same.

If we increase air velocity through the lumber in a double track kiln with single track performance to get it equal to the velocities in the other two kiln types the pressure drop will go up, from 0.126" to approximately 0.516" of water. The pressure drops due to friction and dynamic losses in Muller and "Direct-Flo" kilns are practically the same. The total pressure drop in Muller kiln as well as in Double Track kiln with single track performance is increased much by the item called "Fan arrangement".
In estimating dynamic losses on pressure side of fans we have used method shown on Fig. 4 but reduced coefficient in formula from 2.5 down to 1.725 to allow for possible velocity component normal to direction of air flow produced by fans. This was done because any disc fan does not produce pure axial air flow. Total pressure drops shown in the above tables are also the static pressures fans are working against. They are as follows:

- Muller type kiln: 0.24" of water
- Double Track Kiln with Single Track Performance: 0.13"
- "Direct-Flo" Kiln: 0.14"

In each case fan must deliver 16,000 CFM.

There are 5 fans in each kiln and required circulation = 16,000 x 5 = 80,000 CFM per kiln according to fan performance curve:

(a) In Muller type kiln 60" d. disc fan, at 300 RPM delivers 17,100 CFM against static pressure = 0.24", with power input = 2.6 HP.

In this particular example 17,100 CFM is greater than the 16,000 CFM figure that was assumed. Because of this these fans will slightly increase air flow in the kiln and static pressure as well as power input will go up also until an equilibrium point is reached.
(b) In Two Track Kiln with single track performance, 60" diameter disc fan at 250 RPM will deliver 16,000 CFM against static pressure = 0.13" with power 1.34 HP. However, to bring velocity through lumber to the same magnitude as in Muller and "Direct-Flo" kilns fan RPM must be increased up to 500 RPM with power input = 5.26 HP.

(c) In "Direct-Flo" kiln 60" diameter fan at 300 RPM delivers 21,500 CFM against static pressure = 0.15" with power input = 2.1 HP.

In other words, 4 - 60" fans in "Direct-Flo" kiln will produce the same circulation as 5 - 60" fans in the Muller type kiln. Thus --

"Direct-Flo" kiln  - 4 x 21,500 = 86,000 CFM
Muller type kiln  - 5 x 17,100 = 85,500 CFM

Total power input for kilns 40 ft. long, when the same velocity through load maintained in all three kilns, and efficiency of V-belt drive is equal to 0.85, are as follows:

"Direct-Flo" kiln  - 2.1 x 4/0.9 x 9.33 = 9.33 HP.
Muller type kiln  - 2.6 x 5/0.9 = 14.4 HP.
Double track kiln with single track performance  - 5.26 x 5/0.9 = 26.3 HP.

The above figures prove that air circulation system of "Direct-Flo" kiln is the best system from the standpoint of required power input.

The Double Track Kiln with single track performance requires the greatest power input. Therefore this type of kiln is usually used only on modernization jobs, when it is necessary, with minimum cost, to change natural circulation in old narrow two track kilns to forced circulation. In this case even halved velocity will improve kiln performance very much.

(2) Uniformity of air circulation

In "Direct-Flo" kiln fans face crosswise of the kiln and produce air flow in the same direction. The air streams created by fans are parallel.

In the Muller Kiln and Two Track Kiln with single track performance fans face longwise of the kiln, and blow air directly into one another. Then air flow is compelled crosswise.
Mr. Greenhill of Australian Forest Product laboratory, who studied dry kilns in U.S.A., states:

"The cross-shaft internal-fan dry kiln is the most efficient type of commercial kiln in operation today both in regard to uniformity of circulation, and quantity of air circulated through timber per unit of power consumption of the fans."

CONCLUSION

During the past few years considerable research has been carried on by various organizations in an attempt to reduce time required for lumber drying. There is now a definite tendency to increase air velocity through lumber load in the kilns, or, in other words, the volume of air circulation. This could be done by speeding up the kiln fans, because fan delivery is directly proportional to the fan RPM. However the required power input increases in proportion to the cube of RPM, creating power cost entirely out of proportion to the benefits obtained.

Therefore, there is imperative demand now for a more efficient reversible disc fan.

The fan air delivery per H.P. of power input can be increased as follows:

(1) More air can be delivered against comparatively small given static pressures for the same power input by using a larger fan and turning it slower.

This explains why in our North Coast kilns we are using new 84" diameter disc fans.

(2) Stationary shroud ring installed in fan opening around the fan increases air flow for the same power input or obtains the same air flow for about 10% less power cost.

The width of stationary shroud ring depends on number of blades in the fan, and projected width of fan at blade tips.

(3) Considerable data is available on the design of uni-directional axial fans, but there is definite lack of information that could be directly applied to the reversible disc fans.

C. M. Lorence and Company, Inc., have undertaken a special project to find out the factors affecting efficiency of reversible disc fans.

The tests are run under air flow condition comparable to those under which they usually operate in dry kilns.

We hope that in the near future we shall be in a position to put on the market a new, more efficient, reversible disc fan.

Peter V. Richolt