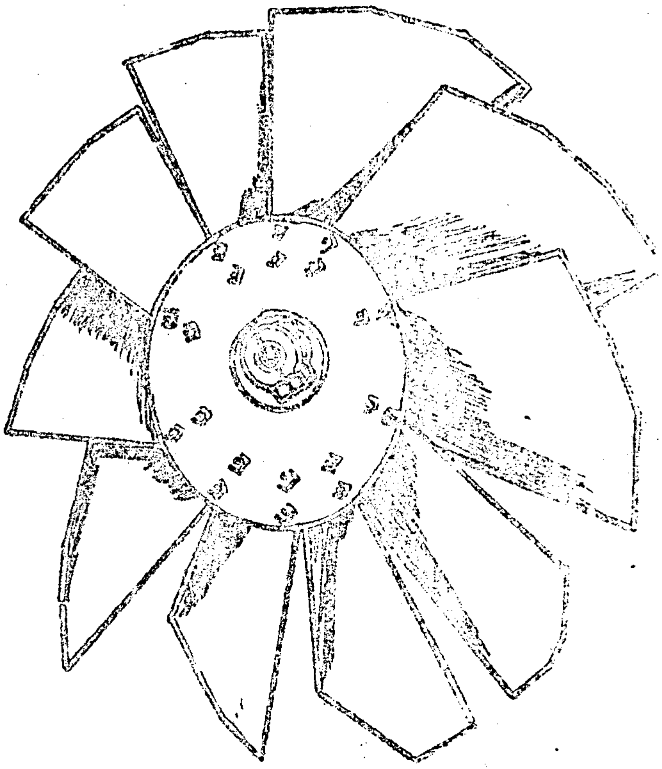
# WHAT THE KILN OPERATOR CAN DO ABOUT



# AIR CIRCULATION

By The

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## AIR CIRCULATION IN LUMBER DRY KILNS

The drying of lumber in Dry Kilns consists of two separate problems. One deals with the means of moisture evaporation and the other with the physical conditions involved in the extraction of the moisture from the lumber with a minimum of injury to the material.

The aims of this report will be limited to the air circulation in dry kilns and the factors affecting the rate of uniformity of the air flow.

The problem concerned with the extraction of the moisture from the lumber will be touched on here only briefly to bring out its connection with the air circulation.

### I. FLOW OF MOISTURE IN THE WOOD

When the particles of water in wood are at rest they do not move if:
(a) The moisture is uniformly distributed throughout the wood and --
(b) The temperature of the wood is uniform.

When the above conditions of balance are upset the moisture inside of the wood begins to move. It moves from the point of higher moisture content to the points of lower moisture content, and from the point of higher temperatures to the points of lower temperatures. The rate of increase of moisture content of temperature from point to point in the wood is called respectively, the "Moisture and Temperature Gradients". The presence of either the temperature or moisture gradient is necessary to set moisture in motion. The moisture flow due to the temperature difference is termed - "Thermo Diffusion". The surface of the board in the dry kiln is in contace with the hot air and its temperature is therefore higher than the temperature of the board core. Consequently, the "Thermo Diffusion" has a tendency to retard the moisture flow toward the board surface. Its influence, however, does not affect this flow much, but yet its presence dictates the necessity to keep the temperature gradient across the boards at a possible minimum. The flow of moisture due to the moisture gradient is a very important factor in the drying of woods. This gradient is usually produced by the evaporation of moisture from the board surface. In other words, the wood is made drier on its surface and thereby, a flow of moisture from the interior toward the surface takes place. Usually, but not always, the steeper the moisture gradient the faster the moisture moves to the board surface.

### II. THE WORK ASSIGNED TO THE AIR CIRCULATION

Air is hygroscopic; that is, it has the ability to hold moisture. The higher the air temperature the more moisture the air is capable of holding. The amount of water in pounds or grains in a cubic foot of air is called the absolute humidity. The ratio of the water vapor in pounds present in a cubic foot to the weight of the vapor which one cubic foot will hold when fully saturated, is called the relative humidity of the air, and often is expressed in terms of percent. It is obvious that the relative humidity is the measurement of the drying power of air.

Wood is also hygroscopic material and will absorb or give up the moisture according to the nature of its surroundings, which we will call the drying conditions. If placed in relatively dry air the wood will give up part of its moisture until the state of equilibrium is reached. The wood is then at the equilibrium moisture content.

The moisture brought to the surface of the board must be removed at a rate sufficient to maintain the desired moisture gradient in the lumber. This is done by the evaporation of moisture from the board surface. Approximately 1000 BTU's are required to evaporate one pound of water at atmospheric pressure. These BTU's are furnished by high air velocity which is in contact with the boards. To do this work of evaporation the heat content of the air must obviously be sufficiently high to maintain the desired rate of evaporation.

The heat supply is not the only task assigned to the air. It must also be capable of absorbing the evaporated moisture and carry it away, because the replacement of air is also essential to the continued drying. Thus air must circulate through the lumber. If there were no circulation the air would absorb the moisture from the wood until it was saturated, and then the drying would cease.

The absorbing "drying power" of the air depends upon its temperature and relative humidity, that is, on the dry and wet bulb temperatures.

Compared with a drying process where the moisture removed is the only factor (drying of the sand for example), the kiln drying of the wood is a complex process, because if drying conditions (temperature, relative humidity, and air circulation) are not properly controlled, the material may be injured and its value depreciated.

Circulation of air is the means of maintaining uniform drying conditions throughout the lumber load for the removal of the evaporated water. Only if the air circulation is uniform and ample is it possible to maintain the even drying conditions so important within the lumber load.

## III. WHY THE AIR CIRCULATION MUST BE REVERSIBLE

The air enters the load at a dry bulb temperature and relative humidity as required by the drying schedule. It flows through the lumber ducts made by the stickers. On its way it picks up evaporated moisture from the lumber and is cooled. The cooling effect is due to the fact that the air uses a portion of its heat needed for the evaporation of the moisture. The process of the moisture removal from the lumber is not, however, so simple.

The evaporation takes place at a temperature which is lower than the dry bulb temperature of the air. When the surface is wet the temperature of the lumber is equal to the wet bulb temperature and it gradually goes up as the lumber dries out. But it never becomes equal to the air dry bulb temperature because the transfer of the heat from the air to the board is possible only when there is a difference of temperatures. Heat always flows from the points of higher temperatures to the points of lower temperatures. Therefore, the temperature of the lumber must always be lower than that of the air if the heat is flowing toward the lumber. Consequently, the temperature of the water vapor leaving the lumber and entering the air stream is below the dry bulb temperature of the air. Hence the cooling action of the evaporation. Temperature drop across the load decreases as the schedule progresses. With the vapor there is also furnished all of the heat of the liquid which before the evaporation was part of the total heat of the load.

If the air is made to travel continuously in one direction through the lumber load, the side where it enters the load will begin to dry more rapidly than that where it leaves the load, because the air has cooled and become more humid in passing through it.

In order to secure more uniform drying of lumber in all parts of the lumber load with a consequent reduction of drying time and lumber spoilage, the direction of the air circulation must be periodically reversed.

In the kiln with internal fans the direction of the air circulation is changed by reversing the electric motors that drive the fans. In the blower type kiln the reversing circulation is accomplished by adjusting a series of damper levers.

The lag in the drying of lumber at the side of the load can also be decreased by the increase of the air flow. Then the moisture coming off the load will be distributed in the larger volume and therefore the relative humidity, the dry bulb temperature, and thus the drying power of the air, are more uniform across the load.

## IV. THE IMPORTANCE OF THE AIR FLOW VELOCITY

The air is flowing through the passages left in the lumber load by the stickers.

When the air velocity is low the air particles move in a straight parallel line; (see Figure 1.)

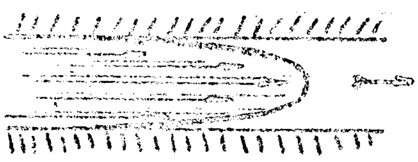


FIGURE 1

The air velocities across the flow, however, are not the same. The velocity reaches its maximum at the center of the flow and is very close to zero at the lumber surface. This is due to friction of the air against the board sides. The air flow just described is called the "streamlined or lamina flow."

If the average velocity of the air flow is sufficiently high, the flow becomes turbulent; (see figure 2.).

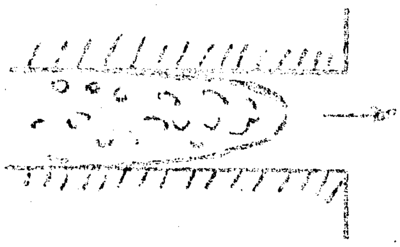


FIGURE 2

Because of the pressure of the innumerable eddies in the central portion of the flow, this type of flow is described as "Turbulent Flow."

In both types of air flow, the thin film of air in contact with the lumber is relatively stagnant as a result of the friction. The thickness of this film cannot be clearly defined but the thickness decreases with the increase of the turbulence and the average velocity of the air flow. The air of the film is particularly saturated with the water vapor at the temperature of evaporation.

This air film, as we shall see, has a definite bearing on the rate of evaporation. In other words, on the drying of lumber.

The particles of air flowing through the passages left in the lumber load contact the above air film and get saturated and therefore, lose their drying power. The chance of these particles to get in contact with the other particles of air flow and thus get rid of a portion of their moisture load, obviously depends upon the degree of flow turbulence. The more the air flow approaches the lamina type, the less the particles have the chance to contact the air film and at the same time distribute their load among the unsaturated particles. As a result the dry bulb temperature and relative humidity of the air flow varies considerably across the load. The air will move in layers and the central layer will do no drying work at all. This phenomenon is called "Air Stratification". All measures which can increase the turbulence of air flow are welcome here. The stratification of the air at the lower average velocities of the flow can be minimized. For example, by the separating of the boards in the lumber loads so that their edges will interfere with the lamina air flow. When the average velocity of the air flow is high enough to produce the turbulent flow, the air stratification is decreased and the dry bulb temperature and the relative humidity across the air flow become more uniform. Consequently more moisture is absorbed from the wood.

The degree of air turbulence increases with the increase of air velocity but not in direct proportion to it. Eventually a point of diminishing returns is reached. (See Figure 3).

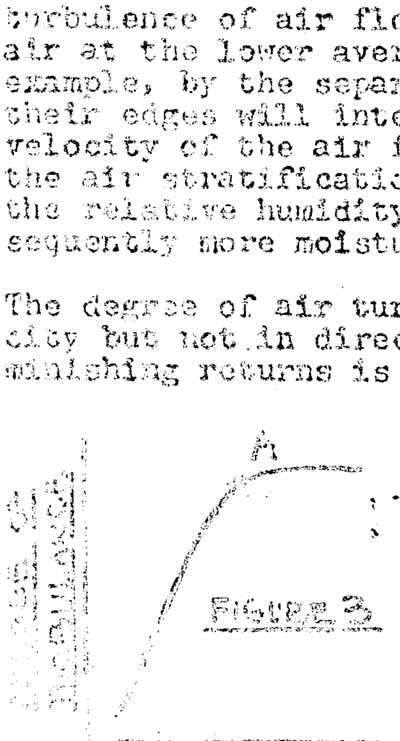



FIGURE 3

The thickness of the air film at the board surface affects the heat transfer from the air to the lumber very much. The film of practically stagnant air insulates the boards and reduces the transfer of heat needed for evaporation of the moisture. The insulating effect of the film is governed by the film thickness and its thickness in turn, by the air flow turbulance and velocity.

Thus the high air velocity through the lumber gives the following advantages in speeding up the drying.

(1) -- The heat transfer from the air to the water in the lumber becomes easier.

(2) -- The dry bulb temperature and the relative humidity across the flow are more uniform because more air particles are taking part in the absorption of the moisture from the lumber.

## V. THE ECONOMICAL AIR CIRCULATION

There are two basic methods to increase the velocity of the air flow. The velocity can be increased:

(a) -- By circulating more air through the lumber load.

(b) -- By decreasing the cross section of the air flow, that is by use of thinner stickers.

The increase of the volume of air circulation cannot be done without the increase of power input which goes up much faster than the gain in the velocity.

According to the laws of fan performance the air delivery of the fans working against unchanged systems is approximately directly proportional to the RPM, but the power input changes approximately as the cube of the RPM. In other words, if we increase the RPM twice, it would double the air delivery if the system was not changed, but the power required would go up eight times.

The gains in the drying ability of the air do not increase in direct proportion to the velocity. When Point A, in Figure #3, is reached, the further increase of the flow turbulence with the increase of velocity, becomes very small. The criterion by which the efficiency of the air velocity is to be judged, is the cost of the lumber drying with the effect of the higher velocity on the economy in mind. The question arises as to what constitutes the economical velocity. In figuring the economical velocity for the individual dry kiln, the gains obtained with the higher air velocities must be weighed against the first cost of the installations, return of such investment, steam costs, labor costs, etc... The Western Pine Association, for example, after tests run in an experimental kiln in 1937, came to the conclusion that the most economical air velocity for the drying of 4/4 Ponderosa Pine Sap Lumber, load 9 feet wide and 11 feet high, was equal to 300 feet per minute. The air circulation was periodically reversed and the lumber was stacked with 15/16" stickers.

As to the possibility of increasing velocity of the air flow in existing kilns by reducing thickness of the stickers, the following factors must be considered first before we will be able to give an intelligent answer.

The above problem involves the knowledge of relations existing between the air velocity and the lumber load ducts created by the stickers of the various thicknesses and the resistance of the air flow. The air flow between the two points is impossible if the pressure at these two points are equal. Only the pressure difference will produce air flow. This pressure difference is called the total head. Part of the total head, called the velocity head, is spent to make the air move; that is, to produce air velocity and the balance bulging the sides of the channel is called static pressure; and is that pressure that is required to overcome the resistance offered to the flow. Roughly speaking, the total resistance to the air flow is composed of the resistance required to overcome the friction and a pressure loss due to shock, caused by the changes of direction of the air flow, or due to the sudden enlargement or contractions of the air flow.

The lumber load openings can be considered as a number of rectangular duct channels in parallel. The static head which is necessary to overcome the resistance of the air flow through these lumber openings is a sum of the pressure required to cover the friction loss plus the pressure required to offset the entrance loss.

Both the entrance and the friction losses vary with the square of the velocity and increase with the decrease of the sticker thickness, broadness of the boards and the width of the load. The effect of the sticker thickness on the velocity is for the velocity to increase with the decrease of the sticker thickness and for the entrance pressure losses to increase as the sticker thickness is decreased. The decrease of sticker thickness evidently will also increase the overall resistance of the air circulating system in the kiln; that is, the total static pressure the fans are working against; and that fan air delivery as a rule becomes smaller. That means that the volume of air passing through the lumber decreases with the sticker thickness regardless of how low or high the air speed may be. The above factors entering the problem do not leave any possibility to give the direct answer. Each case must be analysed separately, because the drying rate is governed not only by the air velocity but by the air circulation as well, and therefore the increase of the air velocity at the expense of the air volume is often a step in the wrong direction.

There are other possibilities to increase the air flow in the kilns.

1. The disc fan of larger diameter, turning slower, delivers more air per horsepower than the smaller fan running faster to create the same air flow in the kiln. That is why C. M. LOVSTED & CO., INC., manufacture disc fans with diameters up to 84".

2. It was very important to develop a new reversible disc fan which would be able to deliver more air per horse power, working in the same system as fans now used. C. M. LOVSTED & CO., INC. is manufacturing these more efficient fans now and they are already in operation.

## [illegible] THE [illegible] AND THE UNIFORMITY OF

## AIR CIRCULATION

### VI--1 BOOSTER COIL

The rate of air circulation in cubic feet per hour or in pounds per hour, depends upon the length of the air travel through the lumber load. If the load is too wide, the air can become saturated before it reaches the end of travel. The saturated air does not have any drying power. We can increase the air flow sufficiently high to offset the above trouble but it would be connected sometime, with the appreciable increase of power input. The same result could be obtained, however, without changing the air circulation if we divide the width of the lumber load into two halves, spread these two halves apart, and install a booster coil between. As soon as the air is laden with moisture and leaves the first half of the load, it blows through the booster coil which raises the temperature of the air and thus increases its holding capacity. Thus two, or even more booster coils must be used when the load is very wide. Thus the booster coils help the air to do its drying job along the whole path through the lumber. In all existing dry kilns with very wide lumber loads and inadequate circulation, the installation of booster coils will be a good improvement and of great importance.

### VI--2 THE KILN VENTILATION

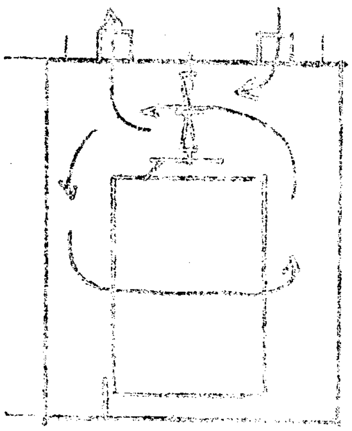


Fig. 4.

In all modern dry kilns, the inlet and exhaust vents are installed very close to the fan partition, flat or zigzag. The one row of roof vents is on the fan suction side and the other on the fan pressure side. That is done to obtain adequate kiln ventilation without extra equipment. Thus, good ventilation is obtained at the expense of air circulation. Ventilation is governed by the drying rate and when it is very high, the air circulation in the dry kiln must be specially designed to provide at the same time, both the required air flow through the lumber and for fast ventilation.

### VI--3 AIR JETTING

When the space between the load and the kiln wall is narrow, the air enters this space from the top, for instance, with very high velocity.

The energy accumulated in the air stream because of this high velocity strongly resists any attempt to change its direction. Therefore, the air will jet down to the floor and then flow through the bottom [illegible] of the load, subject to higher flow than that through the top [illegible]. When jetting of the air takes place, the static pressure drops down to provide for the increase of velocity pressure head.

The drop in the static pressure sometimes is so great that the air flow through the top courses is reversed. The uniformity of air flow can be improved by the use of thinner stickers or by increasing the distance between the load and the wall, or by installation of sloping baffles at the wall, which helps to deflect the air to the spaces between the loads. The difference between the load and the wall should never be smaller than 1/2 of the sum of the space between the lumber layers of the full kiln load made of 4/4 stock. For example, in a load of 4/4 stock on 1" stickers, 72 courses high, there are 72 spaces 1" high each. The minimum distance from the load to the wall should not be less than $\frac{72}{2}$ = 36 inches. This space, however, must never be less than 24 inches.

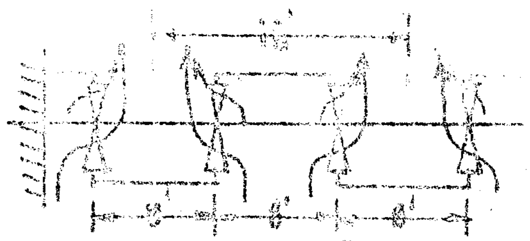


FIGURE 5

FIGURE 6

Here is another example of air jetting. In the dry kiln with so called Mueller Type Circulation System, the fans are mounted on one longitudinal shaft and the zigzag fan partition is used to deflect the air crosswise. (See Figure 5). The fans are usually spaced on 8 foot centers. In other types of air circulation systems, the fans are facing crosswise, and deliver air in the same direction.

This type of kiln, (Figure 6), we call, -- "Direct-Flo" Type.

Fig. 6.

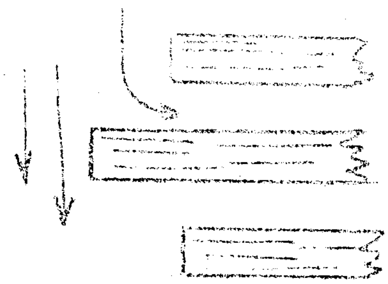
The advantages of the "Direct-Flo" Type Dry kiln, if it is compared with the Mueller Type Kiln, are as follows:

A. Less power is required to create the same air flow.

B. More uniform circulation can be produced in the Dry Kiln. In the Mueller Type Dry Kiln, when fans are delivering the same amount of air, the air is leaving the deflecting duct system in jets spaced 16 feet apart. This jetting of the air affects the uniformity of the air circulation as we now know, and it does it very, very much.

We are very enthusiastic about the potentialities of the "Direct-Flo" principle of air circulation and feel there is still very much ground for improvement and are leaving no stone unturned in our effort to obtain information that will be beneficial to the people who are interested in drying operations.

## VI--4. PROJECTING EDGES ON THE ENTERING AIR SIDE

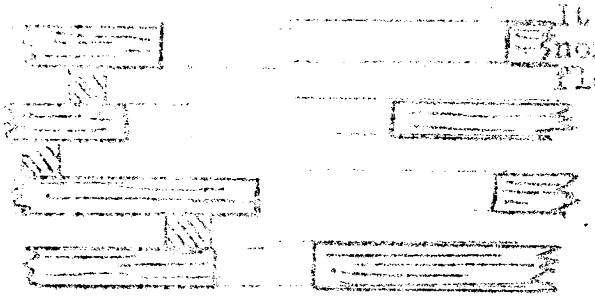


The projecting edges on the entering air side, when the air is moving down in the space between the wall and the load, deflect the air into the spaces immediately above them, and decrease the air flow to the spaces immediately below them, as shown in Fig. 7. In all cases the uniformity of air circulation can be improved by properly aligning the entering edges.

Figure 7.

## VI--5 SHORT CIRCUITING

When lumber of unequal lengths is piled on kiln trucks, voids are created, as shown in Figure 8. A lot of air will by-pass the lumber through the voids because the resistance of the air flow is smaller there. The air velocities through the portions of the lumber adjacent to the voids drops down and will impair the drying very much.



It must always be remembered that air under normal conditions (no jetting) will always flow along the path of least resistance.

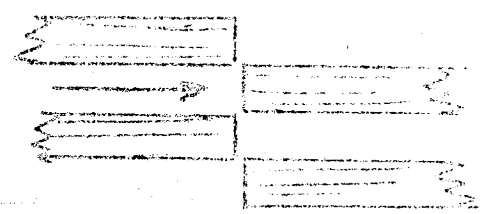
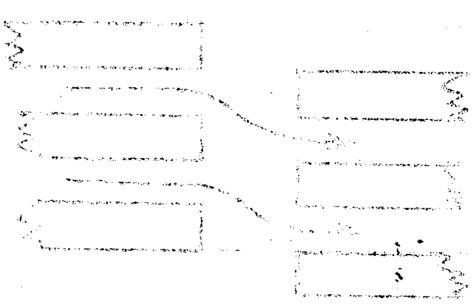


Figure 8.

FIGURE 9

## VI--6 BLOCKING OF THE AIR PASSAGES IN THE LUMBER LOAD



When the lumber is loaded on the Dry Kiln Trucks in packages a horizontal clearance of at least 6" must be left between the packages to avoid the blocking of the spaces created by the stickers in one package by the boards of the adjacent package as shown on Figure 9. The clearance left between the packages will give the air flow room to change direction of flow as shown in Figure 10.

Figure 10.

## VII. SUMMARY

In this report we have endeavored to give you some of the technicalities of air circulation in conjunction with heat and heat transfer, moisture and moisture transfer, uniformity, etc.. We have covered all of them in a technical nature and it probably would be [illegible] [illegible] [illegible] language.

(A) Always stack your lumber in square uniform packages, and be sure that these packages are stacked on your kiln trucks so that all packages are even in both horizontal and vertical planes.

(B) Segregate your lumber for length so that you have a minimum of voids at the one end of the load which is one of the greatest factors for short circuiting and air flow reduction in the kiln. These voids being the path of least resistance, the air flows through them and not through the stickered lumber.

(C) Segregate your lumber for light and heavy boards.

(D) Be sure that your loads are baffled at the top and at the bottom so the air does not have a chance to take the path of least resistance and flow through a large opening rather than the opening which is set up for you by the thickness of the stickers.

(E) It would be wise to baffle the ends of your load so that the air cannot bypass around the ends of the load at the door of the kiln

(F) If you are experiencing wet spots in your lumber or uneven drying even after following the above four points, it would be well to go inside of your kiln and install sloping baffles at points that will deflect the air to enter and pass through ducts and areas of the load that are coming out in a wet and uneven condition.

(G) Check to be sure that you have sufficient air volume from your fans to give you ample uniform air flow. The slightest degrade due to improperly stacked lumber, sloppy baffles, etc., can multiply into a huge loss to a company.

Let us take a few minutes to look at figures on degrade in the dry kilns and what a small percentage of trim can amount to over a short period of time in dollars and cents. We will use a 1 x 4 board, about the smallest board dried in a kiln. There are 188 - 16 foot - 1 x 4 boards in one thousand board feet. Suppose that we trim 2 feet of end check from five (5) boards in each thousand board feet and each dry kiln has a holding capacity of 50,000 board feet. 50 x 5 = 250 pieces, 2 x 1/3 x 1 x 250 = 166 board feet per charge. On a three day schedule, 120 charges a year, this will amount to 20,000 board feet of lumber and at $60.00 per thousand, a loss of $1,200.00 with only a 2-1/2% degrade.

From this you can easily see that your losses through degrade could be considerable, when only a 2-1/2% degrade on 1 x 4 for 120 charges of 50,000 board feet, each, amounts to $1,200.00. It doesn't take much figuring to see that this degrade could easily and in [illegible] run well into a five figure loss. How high does your controllable degrade loss run a year?

[illegible] dry kiln [illegible] $1,000,000.00. That's a lot of money — a big investment. A dry kiln operator runs an expensive piece of equipment and processes thousands of dollars worth of his company's product.

A Dry Kiln Operator should be a high salaried employee, ranking with the Logging Superintendent, and Mill Superintendent, but, the Dry Kiln Operator must assume the responsibility and attain the knowledge of the drying cycle from green chain to customer in order to assume his proper position with his Company with commensurate pay. You can qualify for this job if you are willing to spend the time to study and learn. It's hard work; it's important work. How far you go and the progress you make depends upon how much you want to put into it.

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