A Comparison of the Blower Type Kiln, the Cross-Circulation Kiln, as Designed by Moore Dry Kiln Company, and the Cross-Circulation Kiln as Designed by Herbert Fryer

by

Carl Froude

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ABSTRACT

The world in which we live demands that work be done with speed and efficiency, yet it must be done effectively and at low cost. The Drying operations of any sawmill is confronted with just such a problem. Present day requirements are for lumber that is low in moisture content and low in price. With this in mind this investigation, the results of which follow, was made.
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INTRODUCTION

Objective: This thesis is a comparison of the three types of dry kilns that are used in the Pacific Northwest. A comparison which was to find out whether the blower type, the cross-circulation, kiln as designed by the Moore Dry Kiln Company, or the cross-circulation kiln as designed by Herbert Fryer was more efficient.

During the course of investigation, the author found that it is very difficult to find the necessary data. First, very few mills using dry kiln keep the data necessary to make a comparison of this type. Secondly, mills that do keep data, do not have data for just one lumber class—for example; a mill will keep a record of the amount of steam consumed during one month. During this month they will dry stock from one inch strips four inches to stock three inches thick and eighteen or twenty-four inches wide. Naturally, the thicker stock takes much longer to dry than the thin stock and it will require much more steam and electric power. Therefore, in order to make a fair comparison the data acceptable must be limited as to specie, thickness, grade, and locality in which the timber was cut.
The schedule used to dry the lumber should also be the same as this is one of the most important factors in determining the efficiency of a dry kiln. In other words, it would almost be necessary to make the study at one mill having all three types of kilns. (Note should be made of the fact that when a mill has all three types of kilns, none of them are of the same age—in other words they have a 1920 model of kiln "A", a 1930 model of kiln "B", and a 1940 model of kiln "C"—it is hardly fair to compare a 1920 model "T" Ford to a 1940 model Ford V-8.)

These introductory paragraphs are added to make it clear that it is very difficult if not impossible to make a fair comparison as to efficiency of different types of kilns because it is almost impossible to have the different types operating under the same conditions.
CHAPTER 1

GENERAL

1. Purpose of seasoning lumber  The term, seasoning, in this case means, "to make fit for use", thus when applied to lumber, means to make lumber fit for use. In its reference to lumber it invariably means the removal of at least some water, that is the drying of lumber. There are two main methods of drying lumber: (1) by air seasoning, and (2) by using a kiln. The trend for the past years has been to use dry kilns more and more, and the recent stimulus of the National Defense Program has acted as the proverbial "shot in the arm". Kiln dried lumber is coming into prominence more and more, because lumber can be dried from its green state to a moisture content that will make it suitable for any use, inside of a comparatively short time when compared to the old method of air seasoning.

The following are the main objectives of drying lumber regardless of whether the natural elements or the artificially heated kiln is used to dry the material.

1. To reduce the weight of lumber for shipping.
2. To prepare the wood for whatever use it is to be applied: that is to improve the quality of the product, to reduce the shrinking, warping, and checking after it is put into use, and to make it less subject to decay, stain, mold, and attack by insects.
2. **Reasons for using a dry kiln**  The kiln drying of lumber may be defined as the process of seasoning lumber under artificially induced and controlled conditions.

There are several reasons for using dry kilns in preference to air seasoning of lumber:

1. To speed up the rate of drying—from six to thirty times. This means a quick turnover of capital, a more flexible operation, less capital tied up in the yards, and lower insurance costs and taxes.

2. To reduce the moisture content of the lumber to a point lower than is attainable by mere air drying. This is to insure a minimum of shrinkage in buildings after the lumber is being used, to prevent the opening up of cracks, checks and joints. This is especially noticeable in those parts of the country in which buildings have to be heated.

3. To reduce the amount of degrade that results from the drying of lumber. Stain, warping, checking, and case-hardening often result from air drying and these can be prevented by proper kiln drying.

4. To bring the orders up to the saw. That is, it is often of strategic advantage to be able to fill orders and accept contracts without carrying a large stock of sawed lumber in the yard. This means bringing the order right up to the saw and meeting competition.
5. To set pitch. This is done by using a temperature high enough to evaporate or harden the pitch that runs or oozes from the lumber after the lumber has been put into use.

6. One other important purpose of kiln drying green lumber is to sterilize it against insects and stain.

The problem of drying wood

If drying wood were simply a matter of evaporating the moisture, there would be no problem there, since it would consist merely of supplying the necessary heat to evaporate the water. However, this is not the case.

Shrinkage of the wood is responsible for a multitude of the troubles encountered when trying to kiln dry wood. (1) The shrinkage of wood as it dries is not uniform, therefore, as it dries it sets up stresses within the piece of lumber that may result in what is known as casehardening, checking, honeycombing and warping. (2) Another form of excessive shrinkage known as "collapse" is quite common in drying green lumber of certain species at a high temperature. (3) The wood may become discolored. For example, maple sapwood, some western yellow pine sapwood, and sugar pine turn brown under certain conditions. (4) The lumber may become mouldy in a kiln if dried at a comparatively low temperature and a high humidity. (5) The lumber may dry unevenly so that part of the kiln charge becomes dry and is ready to be taken from the kiln before the rest of the charge is dry. (6) The lumber may become too dry. If the lumber
does become too dry it has a tendency to loosen the knots, thereby lowering the grade of lumber. Extremely dry lumber is harder to work, then too, after the dry lumber is put into use and picked up a little moisture it will swell, causing trouble. These are a few of the difficulties, not mentioning those due to the mechanical make-up of the kiln.

The Economic Significance of Kiln Drying Lumber Properly

"Considered from the standpoint of the country as a whole, the proper operation of dry kilns is of considerable economic significance. There is no question but that a large amount of waste or degrade that now occurs in the drying of lumber either outdoors or in kilns can be prevented by the intelligent operation of kilns.

"By drying lumber to a low moisture content at the mill, the freight charges on the lumber can be reduced considerably. It is estimated that in 1922 the country's freight bill on lumber was $250,000,000. A reduction in weight of two per cent in addition to what is already accomplished would mean a saving of approximately $5,000,000 in transportation alone. On many shipments a reduction of from five to ten per cent would be within the range of practical possibilities, and occasionally a reduction of over thirty per cent could be possible. Furthermore, within reduced weights more lumber could be loaded onto a car and some rolling stock released for other purposes.

"The time that could be saved by cutting down the length of drying periods at some plants by remodeling the kilns, installing modern equipment, and operating the kilns so that the lumber will dry in the minimum of time without serious degrade is considerable. It is possible in some cases to increase the kiln capacity over twenty-five per cent by merely improving present practices. On the other hand, many manufacturers try to dry lumber in so short a time as to make good results impossible. One manufacturer found that by lengthening the drying time of each charge the degrade was greatly reduced. As a result, he did not need to dry anywhere near so great a quantity as before, and his kilns which previously were crowded afforded ample capacity.

"Wood dried uniformly, to the right moisture content, and without serious internal stresses, will give more satisfaction while passing through the shop, and in the finished product, than when improperly dried. Lumber satisfactorily
dried means less culls in the shop, fewer replacements, less return of goods for repair or adjustment, and a better reputation for the manufacturer or the builder than lumber dried in a haphazard way. Examples of lumber, small dimension stock, or finished sizes, warping, checking, or shrinking to undersize while passing through the shop are common. The checking of wooden products, the opening up of joints, and the misfit of drawers or doors after they leave the factory are fruitful sources of complaint which can often be traced back to the kiln. Any elimination of waste, whether of time, money, or materials, means cheaper production and lower selling prices, which are essentials in improving the economic condition of a country.

"A reduction of degrade and waste of lumber means that less lumber needs to be cut, furnishing one of the means of prolonging the rapidly diminishing supply of timber. Furthermore, most of the 20,000,000,000 feet of lumber that are kiln dried each year consists of the upper grades. If the degrade caused by seasoning the upper grades could be reduced to 2 per cent, not only would less high grade lumber need to be cut but some of the lower grades that are the natural accompaniment of high grade lumber and much of the low grade produced by the improper kiln drying would not be thrown on a market already flooded with low-grade lumber. This would afford the lumberman a better opportunity to dispose of the legitimate lower grades and hence encourage closer utilization.

"The timber in this country is now being cut four times as fast as it grows. Any reduction of the drain on the forests, especially when it can be accomplished without curtailing the industries, is a step toward the efficient conservation of one of the most important natural resources."
Early types of dry kilns  The fact that outdoor drying of lumber was not sufficient for cabinets, furniture, and other articles for interior use, or wherever tight joints are necessary was realized early in the woodworking trades. Very likely their first attempts at seasoning wood was to pile it in open piles in a warm room—perhaps in the workshop or above the workshop until it was thoroughly dry or until it was needed. However, the lack of proper kiln drying methods is evidenced by the open joints of the furniture that is to be found in museums or in the furniture that has been handed down as heirlooms. The earliest kilns used for drying lumber by using heat were probably developed in Europe. They consisted of a chamber with a perforated floor beneath which a fire was built. The smoke and heat passed through the lumber that was piled openly on the floor above and out through a vent in the ceiling. During this time it was considered advantageous to burn green branches of the same species of wood as was being dried—if the best results were to be secured. The smoke had the added effect of darkening the wood and was supposed to harden poplar and other soft textured woods. Later some of these kilns were furnished with a firebox or furnace over which a basin of water was kept to humidify the air.
In this country an even less elaborate kiln, known as the "smoke kiln" or "Arkansas kiln" was developed. This kiln is still used in some of the southern states. This kiln consists of a platform set on posts, boarded in on three sides. The lumber (usually pine, as it is the principle species dried in this way) is piled on the platform and the fire built underneath it, the smoke and heated gases passing through the lumber pile. The lumber, of course, is blackened by the smoke except where the stickers cross. The discoloration is dressed off later.

Developed from these simple forms, the dry kilns has passed through a number of modifications. Several decades ago the advantage of drying lumber by using moist air began to be appreciated, so the manufacturers of certain kilns obtained much favorable advertising by calling their kilns "moist-air" kilns. These kilns did not differ fundamentally from the other kilns but were usually equipped with some comparatively simple device for keeping more or less moisture in the air.

The idea of drying wood "artificially" by means of dry kilns is of comparative recent origin, dating back not much beyond the 1860's. It is a noteworthy fact that The United States is far ahead of all other countries in the development of this practice. This fact is undoubtedly due to the rapid exploitation of the forests and the enormous consumption of wood per capita in the development and settlement of this country.
Why not dry lumber as cloth or other hygroscopic materials are dried? In times past the process of kiln drying was discussed entirely from the standpoint of the evaporation of so much water without consideration of the behavior of the wood itself. In other words, the thermodynamics of the process were taken into consideration without giving a thought to what was taking place in the wood itself. This is very similar to studying food problems by simple chemical analysis without paying any attention to the physiological processes involved. When the problem of what takes place inside the piece of wood being dried is considered, the other side of the question, namely, heat consumption and rate of evaporation sinks into relative insignificance.

In the drying of cloth or sand or other loose materials, all that is needed is a means for supplying the heat and carrying away the water vapor that is evaporated. A circulation of air that comes in contact with all the surfaces of the material will fulfill this demand very simply.

When water is contained in a substance such as wood or almost any other organic substance (leather, gelatine, etc.), an amount of heat in addition to the latent heat of evaporation is required. This heat is called the heat of adsorption. The amount of heat of adsorption required varies with the
substance. In the case of wood it is approximately 135 BTU per pound of water to be evaporated. This applies only to the moisture below the fiber-saturation point; the free water in the wood does not require this extra amount of heat.

So far, the drying of wood and the drying of cloth have been very similar. Here is where the difference comes in:

1. Cloth is a very flexible substance and water moves through it readily, while wood on the other hand is an inflexible substance and water moves through it with great difficulty, especially in the case of heartwood. 

2. Then as the wood dries it shrinks sometimes causing great stresses which result in "honeycombing".

3. As the wood dries under stress it takes a severe set, or changes dimensions, this being known as "casehardening".

4. Wood as it dries below the fiber-saturation point hardens and stiffens greatly.

5. To remove moisture below the fiber-saturation point a moisture gradient is necessary. This gets involved when thought is given to the fact that wood is not a homogeneous substance and, therefore, does not shrink equally in all directions.

6. In pervious woods, as the sapwoods of most species, the freewater moves readily by capillarity somewhat like oil in a wick, or water through blotting paper, and is evaporated as it comes to the surface. In this case the wood is easily dried without injury. In impervious woods, such as heartwood, the free-water moves with difficulty and often acts as though "bottled up" in the cells. In such cases it may pass out not as liquid flow but only by a process of diffusion just as the hygroscopic moisture does, which is a very slow operation.
Water in wood Wood, under ordinary conditions, contains water. The growth of the tree takes place in those parts of the tree that are well supplied with water, the cambium layer, and during the green condition of the cells they continue to be comparatively wet. Water is a natural associate of wood, in fact, the two have a great affinity for each other and are not easily separated. Water exists in wood in two distinct forms. First as free water and secondly as imbibed water. If each cell is thought of as a bucket made up of some absorbent material it is very easy to show the relationship of the two types. That water contained in the bucket is called free water while that absorbed by the walls of the bucket is called imbibed water. All of the free water may be removed from the cell cavity without taking any of the imbibed water from the cell. As soon as all the water is removed from the cell cavity then, the additional water that is removed comes from the cell walls and they begin to dry out. The condition that exists when the cells are empty and the cell walls are completely saturated is known as the fiber-saturation point. This situation exists when the wood contains about 25 per cent moisture content (based on oven dry weight).

"In the living tree, the amount of moisture in the wood may range from 250 per cent of its oven dry weight to 30 per cent. The heartwood of conifers is usually near to its fiber-saturation point, containing about 30 per cent of moisture, but the sapwood which contains much free water, often has from 100 to 150 per cent. No wood in a healthy condition in the living tree is dryer than its fiber-saturation point. Dry wood is, therefore, in an abnormal condition, when considered from a physiological standpoint."
Early theories about lumber drying. A single cause for the poor results obtained by the early types of dry kilns can not be found, because the causes were many. In the first place it was a new field and little, if any, was known about it. For example one of the theories advanced, instead of being a step forward, was a step in the opposite direction. It was claimed that wood dries from the inside to the outside, that is, the interior became dry first. This was accomplished by heating the lumber thoroughly, clear into the interior; the high temperature is then supposed to have driven the moisture out. A little thought would show that it is impossible for the interior of a substance to become dry before the exterior is at least equally dry. Then too, if the high temperature was going to drive the moisture anywhere it would first drive it towards the center of the piece being dried. Then as the whole piece became dry the moisture would not move in any direction because the whole piece was the same temperature.

Another theory, is that moisture moves away from heat. Thus when straight heat is applied to a piece of wood the moisture moves towards the center of the piece where it is hard to remove. If we accept this theory it is not hard to understand that if at certain times during the heating process the temperature of the surface of the lumber is suddenly reduced to a point considerably lower than the interior of the wood, then the moisture in the interior
of the lumber will tend to flow towards the cooler surface. The type of kiln manufactured by the National Dry Kiln Company makes use of this theory.

H. D. Tiemann, in his booklet entitled "Lessons in Kiln-Drying" publishes what he calls the "A. B. C. of Kiln-Drying" a copy of which follows:

A. "Control of humidity at all times."
B. "Ample circulation at all points."
C. "Uniform and proper temperatures."

Physical Conditions

1. "Wood is soft and plastic while hot and moist, and becomes "set" in whatever shape it dries. Some species are more plastic than others."

2. "Wood substance begins to shrink only when it dries below the fiber-saturation point, at which it contains from 25 to 30 per cent moisture based on its dry weight. Eucalyptus and certain other species are (appear to be) exceptions to this law. The overall size and shape of the block may change, however, before this point is reached, due to collapse. This accounts for the apparent exceptions mentioned."

3. "The shrinkage of wood in general is about twice as great circumferentially as in the radial direction; lengthwise it is very slight."

4. "Wood shrinks most when subjected, while kept moist, to slow drying at high temperatures."

5. "Rapid drying at high temperatures produces less shrinkage than slow drying but is apt to cause casehardening and honeycombing, especially in dense woods."

6. "Casehardening and honeycombing result directly from conditions 1, 2, 4, and 5. Honeycombing in dense impervious woods is largely due to collapse of the inner portion after the surface has hardened."

7. "Brittleness is caused by carrying the drying process too far or by using too high temperatures. Safe limits of treatment vary greatly for various species."
8. "Wood absorbs or loses moisture in proportion to the relative humidity in the air, the proportional amount varies slightly with the temperature. This property is called 'hygroscopicity'."

9. "Hygroscopicity and working are reduced but not eliminated by thorough drying."

10. "Moisture tends to transfuse from the hot towards the cold portions of the wood."

The Process of Drying

A. "The evaporation from the surface of a stick should not exceed the rate at which the moisture transfuses from the interior to the surface."

B. "Drying should proceed uniformly at all points, otherwise extra stresses are set up in the wood causing warping."

C. "Heat should penetrate to the interior of the lumber before drying begins."

D. "The humidity should be suited to the condition of the wood at the start and reduced at the proper ratio as the drying progresses."

E. "The temperature should be uniform (i.e. with reference to position and not to time) and as high as species under treatment will stand without excessive shrinkage."

F. "Rate of drying should be controlled by the amount of humidity in the air and not by the rate of circulation, which should be ample at all points."

G. "Best results in drying woods and hardwoods are obtained at comparatively low temperatures; rapid drying at high temperatures, such as results from preliminary steaming at slight pressures and for short periods, is satisfactory for woods which will stand this treatment without honeycombing or collapse."

H. "The degree of dryness attained should conform to the use to which the wood is to be put."

I. "Proper piling of lumber, and weighting to prevent warping are of great importance. The pile should be so arranged especially when green, so as to permit the air to pass through in a somewhat downward direction, never upward, as the spontaneous cooling produced by the evaporation increases its density."
J. "In woods subject to collapse the temperature must be kept low until the free-water has passed out of the fibers in the interior."

These statements by H. D. Tiemann, the foremost authority on kiln-drying in the United States, constitute the most modern theories on Kiln-drying of lumber.

Requirements of a kiln:

From the standpoint of the requirements of the lumber there are just three factors of importance, namely: (1) Proper air circulation: Huge sums of money and an immense amount of research have been devoted to the study of aerodynamics, especially in its relationship to the airplane. The subject has been found to be a very complicated one. Never-the-less, in the case of dry kilns this subject has been taken-for-granted. It is safe to say that in dry kilns, in a large number of cases, the air actually moved in the opposite direction from what it was supposed to! In natural circulation kilns the air went down through the piles instead of up, even when the heating coils were directly the piles and ventilators in the roof directly over the piles. In kilns provided with chimneys the air often went down the chimney instead of up; and in blower kilns a suction was often created instead of anticipated pressure. When the fact that both the other important elements in kiln drying, humidity and temperature, are largely dependent upon circulating, the seriousness of the situation becomes apparent. Even a slight change in air circulation, in the kiln, will alter the temperature of a given point several degrees!
A single stick of lumber could be heated by radiation until it was dry. There would be no circulation of air except that caused by the heat rising—convection currents. However, this is obviously impractical in drying a pile of lumber. Exceptions to the general rule that circulation is necessary when drying wood are: the Nickel Kiln in which pipes are placed between the layers of lumber, the Merritt Veneer Kiln in which wood is dried by placing it in contact with heated platens, and veneer kilns which make use of the same principle as used in the above mentioned Nickel Kiln.

By using tables it is a simple matter to compute the amount of air that must pass through a given pile of lumber in the required time to produce a given rate of drying, remembering that good drying practice calls for a minimum drop in temperature and rise in humidity while passing through the lumber. The conclusion is inevitable that for the proper drying of lumber, some kind of forced ventilation is essential.

At this time it would be well to point out that there is such a thing as having too high a velocity of circulation air. This is not good as it will inevitably lead to stagnation of air flow and cessation of drying in certain places. What is wanted is a bulk movement of air. A movement in all parts of the pile. This is not likely to occur when there are high velocities of air.

The required velocity depends upon the kind of drying. For example, in one inch refractory, green, hardwoods, such as oak, an air movement of one half to one foot per second
is ample if the pile is from five to six feet wide. For thicker material it may be even less, provided it is positive, for the thicker the material the less will be the amount of evaporation taking place. On the other hand, for rapidly drying, green, pervious, conifers, velocities as high as 240 feet per minute (4 feet per second) have proved to be desirable. (From the latest information available it seems that velocities up to 600 feet per minute are desirable.)

To find if the velocity in kilns is uniform and adequate, the best method is to note the drop in temperature of the air in passing across the pile. This drop in temperature should never be great, because much drop means an even greater rise in humidity. A large drop is especially bad at the beginning of a run, when a uniform temperature throughout the pile, in order to get the lumber thoroughly heated, is desirable. In order to make a check and find if the circulation is adequate it is best not to rely upon the conventional recorder instruments when they are fixed in place. The temperature reading should be taken at various places along the charge. (2) Control of humidity: To anyone not familiar with peculiar behavior of wood while drying, it must seem paradoxical to maintain a high temperature, in a kiln, to hasten the evaporation of moisture, and at the same time maintain a humidity which reduces the rate of evaporation. However, the problem in drying lumber is not one of securing rapid evaporation, it is one of obtaining a rapid transfusion
of moisture from the interior of the lumber to the surface of the lumber without injuring the lumber. The following are the principal reasons for maintaining a humidity or for occasionally steaming the lumber in the kiln:

(1) To aid in the prevention, or reduction of surface and end checking. Checking is usually due to internal stresses which are caused by uneven drying. The ends and surface of the boards tend to dry faster than the interior, so when the rapid drying is slowed down to the speed at which the interior is drying, the tendency to check is removed.

(2) To prevent casehardening and to aid in relieving casehardening if it does occur.

(3) To speed up the transfusion of the moisture from the center of the board to the surface of the board. When the surface of the board becomes dry, the water will not pass from the interior to the surface of the board as rapidly as if the surface were not so dry.

(4) To even up the moisture content. Steaming lumber at high temperatures tend to even up the moisture content rapidly.

(5) To regulate the dryness of the lumber. If a certain relative humidity and temperature is maintained in a kiln, the moisture content of the wood will not drop below a certain point (moisture equilibrium). It is most advisable, as a rule, to maintain a final humidity corresponding to the desired final moisture content, because the final stages of drying will become very slow. It is better to have the relative humidity slightly lower to speed up the rate of drying.
Consideration was given to humidity in some of the earliest kilns. Various and sundry devices were used to add moisture to the air or to retain at least part of the moisture evaporated from the wood. Trays of water were often used. As far back as 1862, Oliver, of New Haven, Connecticut, patented a kiln in which live steam was used and in 1866 a patent was granted by the Colony of Victoria, (Australia) to Richard Turnbridge for a steam pipe kiln in which free steam was admitted to the drying chamber. In 1910, John House of Melbourne, Australia, was granted a patent on a kiln which used trays of water. These trays also contained charcoal or some other absorptive material, presumably to give greater evaporation surface. Early patents granted in England also include humidification.

In the United States, between the time of the earliest kiln and the kilns of recent design, the need for regulation of humidity seems to have been over-looked. This was probably due to the opening up of vast resources of softwoods that are found in the South and the Northwest. These softwoods could be dried (to reduce freight costs) with little loss due to degrade, with little or no attention to humidity. However, the need for controlled and regulated humidity became more apparent when the losses due to degrade from lumber cut from western larch, "sinker" redwood, and some of the other more difficult species to dry, became enormous.
Attempts were made to retain some of the moisture given off by the wood by closing the kiln tight or by using weighted dampers which would open only when the pressure inside the kiln, developed by the vapor, exceeded the atmospheric pressure outside of the kiln. Others made use of chimneys in such a way that only the excess moisture near the bottom of the kiln was allowed to escape. Tightly closed kilns with condensers (some were made of canvas, pipes, glass, or metal( for the removal of the excess moisture) were very much in style at one time. By using these condensers properly a fairly good control of the humidity could be attained. None of these kilns had any direct positive humidity control.

It will be good to mention at this time, that for good drying constant temperature and humidity is not necessary. A smooth line on the recorder chart does not mean that good drying conditions are being attained. The essential thing is that all parts of the charge be subjected to the same conditions. The conditions should be uniform as to location, but not as to time.

Direct methods for positive humidity control had been used in air conditioning for some time previous to this era. In fact, some of the patents were so old at this time that they had expired. However, none of them had been applied to the kiln drying of lumber. After a period of time, during which considerable experimenting was done, the desired result was attained. The first commercial size kiln of this type was erected at Berkeley, California.
The popularity of this Water Spray Kiln continued to grow until the end of World War I. During this time over three hundred of these kilns had been installed in various parts of the country.

Rapid development followed in the improvement of the other makes of commercial kilns, until today all kilns attempting to do technical drying have adopted some form of positive humidity control.

In the majority of the recently designed dry kilns, the humidity is regulated automatically by the injection of live steam into the air stream. The amount of steam allowed to enter at any time is controlled by a thermostat which is operated by the wet bulb, often called a "hygrostat" to distinguish it from the instrument controlling the dry bulb temperature. Usually the two bulbs are combined into one instrument, which is also a two-pen recorder.

One disadvantage of using this method of raising the humidity is that it also raises the temperature of the kiln. This is particularly objectionable where a very low temperature is required during the early stages of drying humidification. Other disadvantages to using this method are: (1) Usually high pressure steam is injected into the kiln to produce a thorough mixing of the air and steam. Due to the vapor-saturation-temperature curve of steam, when dry steam at boiler pressure is allowed to escape into the atmosphere, it becomes super-heated, even though it does cool. The amount
of super-heating can readily be computed, by means of a well known formula, provided the steam is dry or the degree of wetness known. Because of this super-heating effect, the injection of boiler pressure steam into the air is likely to produce a reduction in the humidity rather than a desired increase. This is the reason that "steaming" lumber at a high temperature, to condition it, sometimes fails to accomplish its objective. Instead of moistening the surface of the lumber by increasing the humidity, it may actually intensify drying conditions by decreasing the moisture content at the surface. Sometimes reducing valves are resorted to in an attempt to overcome this super-heating effect but they are really useless in this respect unless the supply line cools off the steam before it reaches the kiln. In the whole, injection of wet steam is probably the most practical. (2) Other disadvantages to using this method are that in all kilns controlled by the wet bulb, the relative humidity, not the moisture equilibrium of the wood, is what is determined. Never-the-less, it is the moisture equilibrium condition and not the relative humidity that is of importance. The two are not the same, and their relation varies considerably with the temperature. Experimentally it has been found that the moisture equilibrium is very nearly (but not quite) proportional to the wet bulb depression within the normal range of kiln drying conditions. Since it is the moisture equilibrium that we are interested in, it is logical that the depression of the wet bulb should serve not only as a
measure of the moisture equilibrium condition of the wood but also to control the drying intensity of the kiln, irrespective of temperature. (By drying intensity we are concerned merely with describing the atmospheric condition producing a certain rate of drying from a free water surface, irrespective of the material being dried or of its immediate condition.) Very efficient "hygrostats" are made which utilize this principle of temperature difference between the wet and dry bulb. The only drawback to these "hygrostats" is that they are attached to a sample in the kiln. Should this sample be fast drying, the whole charge is subjected to severe treatment. On the other hand, if it should be a slow drying piece, the progress of the whole charge is slowed down. A method should be devised that would measure the moisture equilibrium condition of at least a larger share of the charge, if not the whole charge, so that the kiln drying conditions could be closely regulated.

Control of Temperature: Why Heat is necessary:

Why is temperature necessary at all? The first answer that comes to one's mind naturally, is that it takes heat to evaporate moisture and therefore it is necessary to supply heat to evaporate the moisture. In reality this is no answer. The same amount of heat could be supplied at any temperature. In fact, heat and temperature are not the same thing! The same amount of B.T.U.'s could be supplied at almost any temperature if the circulation of the air was
low enough to permit evaporation. The heat available to produce evaporation is the amount of heat contained in the atmosphere above its wet bulb temperature, and this is available at either high or low temperature, although it is perhaps easier to maintain the wet bulb depression at a higher temperature. Heat serves several purposes in a dry kiln, including:

(1) The most important reason for using heat is that the rate of diffusion or water movement through the wood itself increases with temperature. That is, the coefficient of moisture diffusion increases with the temperature. It is very obvious that evaporation from the surface cannot proceed faster than the moisture can transfuse from the inside to the surface. There are only two means of influencing the rate of transfusion, namely, temperature and steepness of moisture gradient. Since steepness of moisture gradient effects, directly, the amount of stress in the wood (the amount of set, casehardening, etc., produced) we must use temperature if we are to make the rate of transfusion faster.

(2) Heat is always necessary to evaporate the moisture that comes to the surface of the lumber. Because evaporation consumes heat, heat must be supplied if the rate of evaporation is to be kept constant.

(3) Heat is required to separate the moisture from the wood below the fiber-saturation point. This heat requirement is small, about 34 BTU per pound of wood dried. (from saturation to complete dryness).
(4) An increase in the amount of air also increases the capacity of the air for carrying moisture. However, this advantage is offset to a large extent by the fact that when higher temperatures are used, a higher relative humidity must also be used.

(5) High temperatures similar to those used in a kiln, prevent decay, blue stain, and mould during the drying operation. The temperatures usually used towards the end of the drying process are high enough to sterilize the wood against these fungus growths, so that the wood must be infected again before it will decay.

(6) If a temperature of 1300°F. or over is maintained for an hour and one half, or longer, powder-post beetles will be killed, and very likely ordinary kiln drying conditions are fatal to all insects that may be in the lumber at the time it is dried.

(7) Heat makes wood plastic; thereby reducing its internal stresses as it dries and shrinks, and tends to cup and warp. In other words, wood that is dried at a high temperature is more apt to remain straight than wood dried at lower temperatures.

It should be added that wood kept in a kiln at temperatures above 150°F. for any length of time is not so strong as that dried at lower temperatures. The amount it is weakened varies with the temperature and the length of time the high temperature was maintained.
How Heat is Supplied  There are three ways that heat can be supplied to any object, namely: (1) By conduction, that is, by means of direct contact with the source. This method when used in kilns is practical only in the case of veneer dryers. (2) By radiation; by direct passage of the heat rays from the source of heat. This method is also impractical when large quantities of lumber are to be dried. (3) By convection; by heated currents of vapor. This is the only practical means of drying large quantities or piles of lumber.

The most popular method of heating dry kilns is by means of steam pipes. The most important consideration, as far as the process of heating a kiln goes, is that of uniform distribution of the heat, particularly between the two ends of the kiln. This is far more important than having the ability to maintain a constant temperature. The distribution of heat is largely dependent upon the arrangement of the heating pipes, and whether or not they are functioning properly.

I will not take time in this article to point out the various piping systems. These systems can be found in any book on dry kilns or in the dry kiln catalogue.
CHAPTER IV

From the preceding three chapters, it is easily seen that the three main essentials of a dry kiln are: air circulation, humidity, and heat. When the question of supplying these elements arises there seems to be a multitude of correct answers. In years previous to this time, it was thought that the natural draft kiln was the answer to most kiln operator's prayers. Then as the kilns using forced ventilation came into being, the natural draft kiln was sadly outmoded. Now the question arises as to which of the forced ventilation kilns is the most effective, that is, which is the most economical to operate, which dries lumber in the fastest manner without producing an excessive amount of degrade, which is the most efficient? This question is a most difficult one to answer because of the difficulty encountered when trying to gather data from which to make a fair comparison.

In order to insure a fair comparison, correspondence was carried on with the manufacturers of dry kilns and with the kiln operators of several of the larger mills in this region. These men seemed to think that it would be impossible to secure data that would be accurate enough, and data that would provide a fair basis from which to make a comparison. The reasons for this, are: (1) The large difference in conditions under which the different mills operate. (2) Very few, if any, would have the three makes of kilns operating in their mills that were manufactured
in the same year. (3) The difference in drying schedules
used at the different mills.

However, under these circumstances, the author will
endeavor to make a comparison of the mechanical make-up
of these kilns and shall try to show that much progress
has been made during the last decade in improving the
lumber dry kiln.
**BLOWER TYPE KILN**

**Edge Stacked lumber**

When the air goes up to the top of the kiln it goes down between the boards.

Air is delivered into the kiln through this duct.

Air is removed from the kiln by suction thru this pipe.

Heating coils

Steam spray

Air circulates straight up the sides of the kiln.

Air is delivered into kiln thru this duct.
Top of Center Air Chimney Closed to Force Air to Circulate Through the Lumber

Tapered Center Chimney to allow air to jet to all parts of the load.

Air Delivery and air Return pipes

Heating coils

Steam spray

Air Circulates across the load

Air Jetting from the fan

Tapered Delivery duct

Mixing of air and steam takes place in this chamber

May use steam turbine, electric motor, etc., to drive fans.

FIGURE 2
THE BLOWER TYPE KILN

If the reader will refer to figures 1 and 2 during the description it will aid him in understanding the discussion.

The power, to operate the fans, may be supplied by means of electric motors, steam sturbines, gas engines, etc., thus, greatly aiding in making the kiln adaptable to any location.

The steam coils to be used in heating the kiln are located in the heater casing outside of the kiln. The air, as it circulates, is passed through these coils in order to heat it to the required temperature. If the humidity of the air is too low steam is added as the air passes through the heater casing on its way back through the fan and into the kiln. As the air leaves the fan it passes into tapered ducts that extend the entire length of the kiln. Air is delivered into the chamber in which the lumber is located, by means of slots that are located on the top of the tapered duct. These slots are adjustable, that is, the size of each slot may be regulated so that only a certain amount of air will pass through it. In this way uniform circulation is secured for the entire length of the kiln. The air passes from these slots and follows the path indicated by the arrows on the sketch. As it comes from the lumber on the kiln car it is drawn by means of suction, generated by the fans, back into the duct that leads the air to the heater casing where it is
again "conditioned" so that it can be re-circulated through the kiln.

As the air passes through the lumber it picks up moisture. After a short time it contains all the moisture it can carry at the given temperature. It is then necessary to have the vents so that the saturated air can be allowed to escape from the kiln and to allow fresh air to enter the kiln. The exhaust vents are located (not shown on the sketch) along the top of the kiln at suitable intervals. The fresh air intake vents are located so that the air as it is drawn in to the kiln will be heated and humidified before it reaches the lumber. This is necessary if the proper drying conditions are to exist in the kiln. These vents can be operated either manually or automatically.

The rate of circulation in this type of kiln usually does not exceed 180 or 200 feet per minute. This in itself is an undesirable feature because recent experiments have shown that higher velocities will produce faster drying rates. In fact, air speeds of 600 feet per minute seem to be approaching the maximum for economical drying. In a kiln of this type it would require too large an amount of power to drive the fans to make it feasible to attempt to attain air speeds of this velocity.

However, when the slots of the air ducts are properly adjusted this kiln does a good job of drying the woods that are dried in the Pacific Northwest.
THE CROSS CIRCULATION KILN (Moore Type)

The power in this type of kiln may be supplied by any device that will produce controlled rotary motion, that is, will produce a definite number revolutions per minute. Usually electric motors, or steam turbines are used. The kiln is usually designed to fit the power that is cheapest in the locality in which the kiln is to be used.

Heat is supplied by means of banks of pipes or coils that run the entire length of the kiln (return bend coils are usually used as they produce a more uniform distribution of heat throughout the kiln). These coils may be made of black iron pipe, black iron pipe with fins on the pipe, copper pipe, and copper pipe with fins. The pipes equipped with fins have greater heating surface and therefore increase the efficiency of the coils in their ability to throw off the heat that is contained in the steam in the pipe. However, it is believed that the fins increase the resistance offered to the air as it circulates past the pipes.

Humidity is supplied in the kiln by means of a steam spray line. (Usually only one line runs the entire length of the kiln.) The steam is admitted to the kiln through small nozzles that atomize the steam, and spread it in diverse directions. The primary reason for having the nozzles is to insure a more even mixing of the steam with the air as it is circulated through the kiln.
The main difference between this type of kiln and the others is in the way that the air is put into motion and directed through the pile. The fans are mounted on a longitudinal shaft that runs the entire length of the kiln. The fans are evenly spaced. Because of the fact that they are mounted on one long shaft they necessarily set the air in motion parallel to the shaft.

![Diagram of kiln](image)

**Figure 3**

However, it is desirable that the air circulate at right angles to this direction and air movement in this direction is brought about by a series of baffles (see figure 3). These baffles are so placed that they direct the air in an upward crosswise motion that forces the air to circulate across the load. (When the fans are located below the drying chamber—downward, when the fans are above the drying chamber.) Just how much these baffles effect the ability of the fans to deliver air in
Cross Circulation Kiln

FIGURE - J-B
motion in the kiln chamber is not known. O. W. Torgeson in his report "Uniformity of Air Distribution in a Lumber Dry Kiln" says: "Baffles causing sudden changes in the direction of air movement result in considerable increases in power consumption and decreases in fan delivery."

From this statement by one of the engineers in the United States Forest Products Laboratory it is evident that all these baffles do have a very detrimental effect. (4)

The efficiency of a fan increases when it has lower pressures to work against, that is, it delivers a larger volume of air when it is working against lower pressures. The static pressure in the drying chamber of a Moore Kiln usually runs from 0.012 to 0.3125 inches of water, a relatively low pressure. Recently Professor Hughes of the Mechanical Engineering Department of Oregon State College has run some experiments and collected data that should aid in improving the performance of fans used in the modern dry kilns.

Note should also be made of the width of the plenum chambers on each side of the lumber pile as it stands in the kiln. In the older style Moore kilns this chamber was about eighteen inches in width, in the modern kilns it is about thirty six inches. The widening of this chamber has a tendency to make the air flow through the pile more uniform, it also decreases the amount of power necessary to maintain higher velocities of air as it passes through the chamber.
THE FRYER TYPE CROSS CIRCULATION KILN

The power is supplied to the Fryer Type kiln usually by means of electric motors. This kiln differs from the other types discussed in this article in that each fan is powered by a single motor instead of being operated by one motor to the whole kiln. The motor is located inside the kiln right next to the fans (see figure 4) instead of outside the kiln and down in the operating room. This has one disadvantage. The insulation of the motor windings is affected by the heat and moisture that is always present in the kiln when it is operating. The motors will "short" and cause slight delays because of the repairs to the motors that are necessary. However, this trouble may shortly be eliminated by the recently announced insulation for wiring that is not affected by heat and humidity.

The reason for having individual motors for each fan becomes apparent when the subject of air circulation is brought up. The fans instead of facing the length of the kiln face across the kiln. When faced in this direction they blow the air directly across the load without the aid of baffles to change the direction of the air. (see figure 4).

Another very noticeable difference in the design of this kiln when compared to the two other types is the size of the plenum chamber. The latest Fryer Kilns maintained a width of six feet on each side of the load.
The purpose of this chamber is to have a more uniform circulation through the load. Another advantage that comes as this chamber is widened is that the fans have a lower static pressure to work against—it ranges below 0.01 inches of water. Thus the fans are able to deliver more air without increasing the amount of power. In other words higher velocities of air are attained without increasing the amount of power. Just exactly how much these static pressures affect the ability of the fan to deliver air is difficult to say because of the lack of information available on the operation of fans of this nature against such low static pressures.

**SUMMARY**

All three types of kilns described in this thesis make use of the three essentials (heat, humidity, and air circulation) of a dry kiln. The methods of supplying these requirements, in some cases, are very similar while in others they differ widely. For instance, they all use steam to humidify the kiln, they all use steam to supply the heat required to dry the lumber. The largest difference occurs in the type of fan use to set the air in motion, in the location of the fan, and the direction in which the fan is faced (the immediate direction in which the air is moved).

The multivane fan used in the blower type of kiln is more efficient working against the static pressures that are found in this particular type of kiln than the disc fans that are used in the other two kilns. The only
disadvantage is that with a kiln designed as this one is, it is not practical to try to make them produce air speeds that are becoming more and more into demand.

The disc fan used in the other two types of kilns described is better fitted to this use, for obvious reasons, than the multivane fan. The disc type fan delivers more air using less power when it works against lower static pressures, therefore, the lower the static pressure found in kilns of this type the more effective the fan is. Because of this reason the Fryer type kiln is more efficient in its power utilization than is the Moore kiln. The static pressure being less in the Fryer kiln.

The baffling system found in the Moore type kiln does not aid in a more efficient performance of this type of kiln. However, the mere fact that the Fryer type of kiln does not use baffles, does not make it the most efficient kiln.

The single factor that makes the Fryer type kiln more efficient than the the other types mentioned is the large plenum chamber that is located on each side of the lumber as it stands inside of the kiln. (1) This chamber makes the static pressure inside of the kiln lower than the static pressure in the other types of kilns mentioned. (2) It makes the airflow through the load much more uniform. (all parts of the pile receive the same amount of air) The first of these two factors cuts down the amount of power that must be put into the fan assembly to move
the required amount of air. The fans are more effective when working against low static pressures. The second factor, more even circulation through the lumber pile, is due to the fact that the velocity of the air is less in the kiln with the wide plenum chamber. That is, the volume of air that circulates through the lumber pile is greater because the velocity of the air is lower.

When air is circulating at high velocities, it tends to follow the easiest pathway through the lumber, when it is traveling at lower velocities it "diffuses" through the whole lumber pile more evenly because it is not traveling at a higher velocity. The resistance of air due to friction increases with its velocity, therefore a rapid current of air necessitates more power for, and gives rise to a smaller output of, the fan.

Among the advantages that the blower type kiln and the Moore type kiln have when compared to the Fryer type of kiln is the fact that they make use of only one power unit. This means less maintenance cost, and less trouble and delay because of failure of the motors to function properly.
CHAPTER V

RESULTS OF STUDY

Because of the scarcity of material and data, it was possible to find information concerning the relative performance of these three types of kiln in only one publication. Probably the best way to sum up the results of this study is to quote directly from the article as it was published recently in one of the trade journals. In the October, 1939 issue of the WEST COAST LUMBERMAN an article by Hubert Hamilton entitled "Kiln Drying at McCLOUD" was published. In this report he tells of the remodeling of the dry kilns at his plant. The kilns were changed from blower type and "other types of internal fan kilns" to the Fryer type of kiln. The results of the change at this mill are similar to the results obtained throughout this area.

The following are quotations from his article:

"Each double track unit is equipped 12-60inch reversible fans, and these are direct connected or mounted on an individual 3-hp. Pacific General Electric gear motor turning over at 305 revolutions. All units are designed for an ambient temperature of 200 degrees F., and require when the kilns are up to heat, a total of 25-hp. for each double track unit, as compared to the 30-hp. per single track used in other types of internal fan kiln that this company has used, and with 15 to 30-hp. per track in the blower kilns.

"The fan units are set in the wall between the two kilns, under the rail, and of course are designed for reversing. At such periods as required by the operator, either by hand or automatic control; at present we are reversing at four hour cycles, but this may be varied. The fans produce a circulation of about 400 to 500 feet per minute through the lumber."
per minute through the lumber and with the spacing provided for above and below the loads we have obtained a positively uniform circulation in every course varying not over fifty feet per minute. There are no air ducts so that all resistance has been eliminated and it is impossible to show any static resistance by pitot tube measurements. Under such conditions, as is characteristic of disc fans, we were able to obtain maximum efficiency from our air units, getting as a result maximum air flow per horsepower, and absolutely uniform air flow from one end of the kiln to the other without a trace of end drift, which has always been a problem.

"The heating system is split into three groups, longitudinally, of the kiln and also into three groups across each side of the kiln, each cross group being hand controlled so that the proper amount of radiation can be cut in or out to meet the load demand, and thereby get close control for either or both loads.

"The entire operation has now been carried to the point that we have complete information as to power and steam requirements. An analysis of power shows that we are now drying from three to four times the footage of lumber per horsepower per hour than we do in our old units, and are using the same amount of steam in one double track unit as we formerly used in one single track for the same capacity.

"In general, drying times have been reduced from forty to fifty per cent, and with a resultant improvement in quality that has been very noticeable, especially in shop and better items. We have much better uniformity and have eliminated a great deal of the warp and twist."
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