Lumber Drying Theory

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INTRODUCTION

FRANK CONTROLS (1986) LTD.

Frank Controls is comprised of a group of individuals dedicated to the continual development of process technology to achieve optimum efficiency in kiln drying. Other areas of process development include machine automation in other manufacturing and industrial applications.

FOREWORD

The subject of kiln drying lumber is probably one of the most hotly debated subjects in the forest industry today. It seems that there are as many theories about how lumber should be dried as there are people involved in kiln drying.

This is an indication of the complex nature and the many factors that influence the removal of moisture from wood.

In the following pages we will pace the FC method under a microscope. The intention is to provide the kiln operator with all the information necessary to obtain a complete understanding of the FC method.

As with any successful project the FC method is supported by years of research and scientific information. Countless hours have been spent analyzing the scientific information from the various research organizations in Canada and U.S.A.

GENERAL INFORMATION

This section on the scientific aspects of water, stress, heat etc., is not intended to be a lesson in physics but is however a useful tool in analyzing the behavior of wood as it dries.

As everybody knows, wood is an organic compound made up of cells and these cells have a nature of holding water in their green state. It is this water we are trying to remove so the lumber can be at the desired moisture content.

Structure and Properties of Wood

As mentioned previously, wood is an organic, porous compound. It acts like an insulator and because of this it is quite difficult to dry. If we took out all the water from a piece of wood we would be left with a board of wood cells; this is called fibre.

So the total weight of a board = fibre weight + amount of water the board holds. Ideally, the fibre weight could be determined by the density (expressed in g/cc). However different species of wood have different densities. Standard density measures are taken at specific moisture contents (say 15%). If we progress along these lines it is quite obvious the moisture content of wood can be determined by its weight.

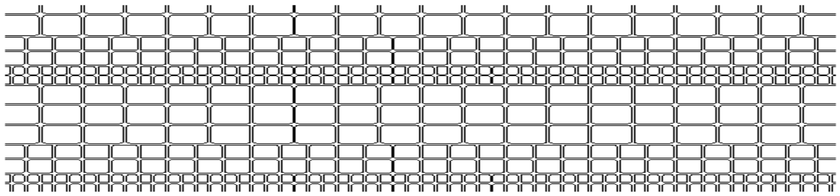
For example:

The density of oven dry pine is .38 g/cc
One board foot = 2,359.737 cc
From this, we may assume one board foot weighs:
2,359.737 x .38 = 896.7 g = 1.9768 lb

Because the lumber is dressed at 3/4" and not 1"
the weight is only 75% = 1.4826 lb
The oven dry weight of 1000 board feet would be 1482.6 lb,
then with 15% MC it would weigh 1704.99 lb.

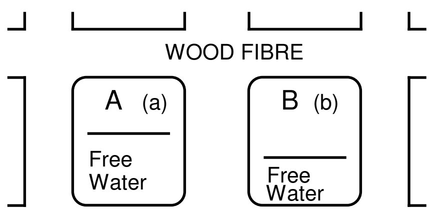
The anatomy of wood is shown in the next illustration. Basically it is comprised of a collection of large and small cells. The small cells are the last growth in the fall. In the spring when the tree starts to grow it grows large cells and later in the mid-summer they grow smaller. As the summer gets closer to the fall the cells get smaller. In the fall the cells are quite small and they form the outside of the tree.

* see diagram next page



In the diagram, there are different types of cells. The large cells hold most of the free water. Free water is the easiest to remove. Free water as a general rule disappears when wood reaches its fibre saturation point which is about 27% moisture content. Once you have reached the fibre saturation point (27%), bound water only is left. Bound water is found in the cell walls. To understand how bound water might move (flow) out we need to understand some basic biology. The question we have to ask ourselves is how do cells absorb or give up water?

Below are two cells which are adjacent to each other. Cell "A" has a certain amount of water [a] and Cell "B" has a certain amount of water [b]. The transport of water from cell "A" to cell "B" is determined by the amount of water in each cell.



If A is higher than B, water will move from cell "A" to cell "B". IF A is lower than B, water will move from cell "B" to cell "A". This is called Cellular Transport.

When most of the free water is gone the concentration of water is in the fibre. This is the fibre saturation point, it is at this point we start to remove the water in the fibre. This is where the problem starts because the water in the fibre flows slowly. As the water starts to move from the fibre, the fibre starts to shrink. This is the basic problem in the occurence of case hardening.

When we think of kilns; the energy of the system is the amount of energy being generated or going into the kiln, and the heat of the kiln is the actual temperature being measured by the temperature probes. The temperatures are expressed in Fahrenheit and the energy is in units of BTU (British Thermal Unit).

By definition:

1 BTU = the energy required to raise 1 lb of 4 degree C water, to 1 degree Fahrenheit.

It takes just under 970 BTU to boil away one pound of water, or to change to vapour from water at sea level (212°F). It takes one BTU per degree F to raise the water temperature to the boiling point. For that reason it is not only the 970 BTU that was used to boil the water away but also the energy that was required to raise the water to the boiling temperature. To evaporate one pound of water at 170 degree wet bulb it takes 1030 BTU - plus the BTU to raise to 170. It takes more energy to evaporate water at a lower temperature, this is the advantage to using a higher wet bulb temperature.

It takes approximately 1200 BTU to evaporate one pound of water, including the heat up of wood fibre and water in the lumber. Therefore if you know how much water you have to remove and your heat output in BTUs, it's easy to calculate how long it should take to dry. This can only be done if you are able to use all the energy for that period of time.

Example:

250,000 lbs of water to be removed.
Energy output is 10 million BTU/hr

Fomula:

(250,000 lbs of water) x (1,200 BTU) divide by 10,000,000 = 30

It should take approx. 30 hours to remove the necessary water.

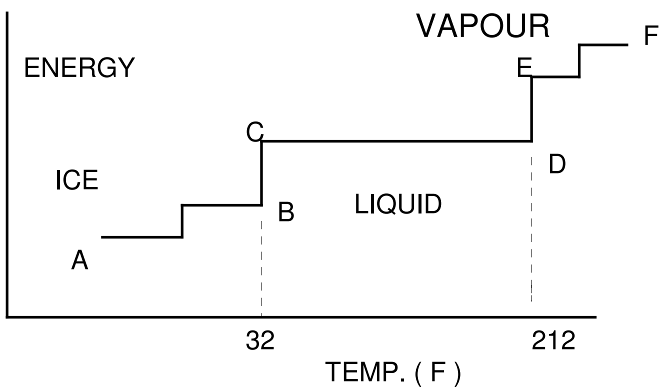
This figure is assuming 100% efficiency. There is usually a 25 - 45% heat loss factor to be taken into account, which depends on the outside temperature. This is why it takes longer to dry in the winter than in the summer, and this will depend on the amount of water needed to be removed. The initial moisture content of wood can change drastically from day to day.

Properties of Water

Water is a very unique compound. It's atomic structure is comprised of two atoms of hydrogen and one atom of oxygen (H20). Water exists in three different states:

a) Solid (ice)
b) Liquid
c) Gas (steam)

All states are determined by the temperature of the water. This is better illustrated by the following graph:



The state of water that we are concerned with is the steam state. By definition, the boiling point of water is the point at which the vapour pressure of water equals the atmospheric pressure acting on the liquid. Standard pressure is taken to 1 atm. (atmosphere) or 760 mm of Hg. This implies that if the atmospheric pressure is greater than one atmosphere this would affect the boiling point of water, which is entirely correct. The boiling point of water can be reduced by reducing the pressure around it, and conversely, if the pressure was increased, the boiling point would be increased. Another factor that can affect the boiling point of water is the amount of impurity in the water, called the solvent. If other compounds are mixed in with the water this tends to drive the boiling point to a much higher value.

Since water exists in different phases, this means the properties of water also change depending on what state is being observed.

Here are some typical properties:

Heat of vaporization	(212 F)	540 calories/g
Heat of fusion	(32 F)	80 calories/g
Specific heat	(solid)	0.49 calories/g C
Specific heat	(liquid)	1.00 calories/g C
Specific heat	(gas)	0.44 calories/g C

Water vapour is measured in terms of relative humidity and this is defined by the following equation:

RELATIVE HUMIDITY (RH) = (P1/P2) X 100%

Where P1 = partial pressure of water in air
P2 = equilibrium vapour pressure of water at the same temperature

The equilibrium vapour pressure increases as temperature increases. If the partial pressure of the water falls below or equal to the equilibrium pressure of water then the RH will be 100% and condensation would occur. Measuring partial pressures can be quite difficult in a kiln so that is why a dry bulb and a wet bulb are used. A more convenient formula is stated below.

RH = 100 / (D/W) ^ 4

where D = dry bulb temperature
W = wet bulb temperature

In comparison to dry air, humid air has the ability to carry much more energy due to the high specific heat of water. A good example to illustrate this point is the sauna. If you are in a sauna which has a temperature of 200F it would feel comfortable. However, if you threw some water on the rocks, the energy content in the air would rise quickly due to the moisture. This leads to the conclusion that the high humidity results in air with a high energy content.

As we try to heat up lumber inside a dry kiln high humidity is a desirable result we wish to achieve. The high humidity also has other effects on the drying process.

A) Able to use more energy in the drying process. This reduces drying times as opposed to manual drying schedules.

B) Carry heat further through the charge without condensation occurring.

C) Minimizes twist and warpage.

D) Better grouping of moisture content.

It should be noted that to benefit from the characteristics of high humidity, lumber must be heated up properly so as not to create any internal stress in the wood. Therefore the heatup must be accurate and dynamic.

Factors Influencing Seasoning

The following scientific information and laws of physics are the foundation to the understanding of how wood dries. This information is the basis to the FC method. The intention is not to rewrite the many publications with this same information, but to provide all pertinent information for quick reference material. Following are numerous quotations from the various publications on the kiln drying of lumber.

A. Air flow (Circulation)

1. A constant movement of air is necessary in kiln drying to carry heat to the lumber being dried, and to carry the evaporated moisture away. (1)

2. The air movement over the surface of the lumber should be sufficiently rapid that the limiting factors in drying will be the rate at which the moisture diffuses from the interior to the surface of the wood. (2)

3. Air will always seek the path of least resistance, (around the ends or top of the load). (1)

4. The latent heat given up by the air, to cause evaporation, cools the air. (3)

B. Heat and Temperature

1. The main reason for using heat in drying is found in the physical behavior of lumber, the movement of moisture through wood being more rapid at high temperatures than at low temperatures. (2)

2. Heat increases the rate of moisture movement so that a high humidity may be maintained without unduly slowing up the rate of drying. (2)

3. Wood is more plastic at high temperatures, and because of this increased plasticity, yields more readily to any stress imposed. (2)

4. In wood, the rate at which the interior moisture can be brought to the surface determines the rate of drying. This rate of drying cannot be

exceeded without impairing the physical structure of the wood. Drying cannot be controlled by temperature alone. (2)

(1) (2) (3) See bibliography on p.18

5. One BTU is the energy required to raise the temperature of one pound of water one degree Fahrenheit. (1)

6. Heat is a form of energy associated with and is proportional to the molecular motions of a substance. These molecular motions are determined by the heat capacity of a substance. Heat capacity is the change of energy divided by the change of temperature at a constant volume. Heat is measured in BTU or Calories.

7. Temperature is a measure of the degree of heat in a body. Temperature is measured in degrees Fahrenheit or degrees Centigrade. (1)

8. Specific heat - is the amount of energy (BTU) it takes to raise one pound of substance one degree Fahrenheit. This energy is then stored in the substance. Specific heat of water is equal to one, since it takes one BTU to raise one pound of water one degree Fahrenheit. In comparison to dry air, humid air has the ability to carry much more energy due to the high specific heat of water. A good example to illustrate this point is the sauna. If you are in a sauna which has a temperate of 100C it would feel comfortable. However, if you threw some water on the rocks, the heat content in the air would rise quickly due to the moisture. This leads us to the conclusion that the high humidity results in air with high heat content.

C. Energy

Energy has the capacity for doing work and for overcoming inertia. While work is the transference of energy from one body to another resulting in motion or displacement of the body acted upon.

Work = Force x displacement

In kilns, the heat of the atmosphere is the actual temperature of the kiln while the energy of the system is the amount of gas being burned to make up heat loss and energy used for evaporation.

D. Heat transmission

The main method of heat transfer in drying wood is in the form of convection. "Convection" is the movement of masses of hot gases and vapor, either by natural displacement currents or by mechanical means. (1)

(1) See bibliography on p. 18

E. Thermal Conduction

Heat transfers by conduction which is determined by three factors.
a) Temperature gradient in a substance.
b) Coefficient of conductivity
c) Amount of area

Mathematically, (dQ/dt) = -K(dt/dx)

(dQ/dt) = flux of thermal energy of energy transmitted across unit area per unit time.
K = constant of conductivity. Different substances have different conductivities due to their nature.
(dt/dx) = temperature gradient.

The above equation implies that energy does not simply enter one end of a substance and proceed to the other end in a straight path, but rather diffused through the substance suffering collisions within it. If the energy could go directly from one end to the other, then it would be dependent on the difference of the temperatures of the two ends, regardless of the length of the specimen.

One might ask why conductivities change when comparing one substance to another? As stated earlier, heat is proportional to the molecular motions in a substance. These molecules have some movements due to their individual energy levels called the mean free path. The mean free path is principally determined by geometric scattering within the lattice structure. Other effects are imperfections within the substance like dislocations. In summary, the mean free path is affected by internal processes that occur in the structure (processes are quite numerous and complicated). Conductivity is dependent on the mean free path present.

K = 0.33vl

C = heat capacity
v = average velocity of particle between collisions
l = average mean free path

** above equation is an approximation **

Wood is comprised of cells and water. Therefore, since the amount or percentage of water is not constant the conductivity will be different. This is due to the fact there is water in the wood.

F. Quick points on Relative Humidity

1. Air will hold more water when its temperature increases.

2. Air holds less water as its temperature decreases.

3. As temperature increases (with the same amount of water) the air's RH% will decrease, since there will be more room in the air for water.

4. As temperature decreases (with the same amount of water) the RH% of the air will increase. If it goes up past 100%, water will be lost from the air through condensation.

5. RH of 100% is called the dew point. Any drop in temperature or addition of water will force water to drop out of the air.

6. A higher RH means a higher density, which in turn gives a higher specific heat.

7. Venting air with a high RH releases more water per cubic foot than air with a low RH. Therefore venting at a high RH is much more efficient.

8. Benefits of high RH.

   Manual controls generally run in the range of 10 - 30% relative humidity. Relative humidity is dependant on temperature, it is the percentage of water in the air, compared with the maximum amount of water the air could hold at a specific temperature. If you have an RH of 38.5% at 150 degrees, that means that the air could hold 61.5% more water at that temperature. When air has an RH of 100% the air is saturates with water at that temperature. If any water is added or the temperature is dropped (less room in the air for moisture) water particles will begin to condense out of the air, producing precipitation in the form of rain. The important point to note is that the heat content of the air in a manually controlled kiln is very small compared to the 50% RH maintained by the computer. The 50% RH has double the heat content of 25% RH at a maximum operating temperature of 210 degrees. With high humidity more heat is available at the same temperature to heat the wood and evaporate the water as it comes out of the lumber.

Benefits of high RH as the FC method sees it:

1) Able to use more energy in the drying process. This reduces drying times as opposed to manual drying schedules.

2) Carry heat further through the charge without condensation occurring.

3) Minimizes twist and warpage.

4) Better grouping of moisture content.

It should be noted that to benefit from the characteristics of high humidity, the lumber must be heated up properly so as not to create any internal stress in the wood. Therefore the heat up must be accurate and dynamic.

For each species and size of lumber, there is a definite drying temperature and relative humidity which will accomplish the drying at the fastest possible rate without the development of checking, case hardening or other defect. (2)

(2) See bibliography on p. 18

G. <u>Wood</u> <u>Stresses</u>

Wood dries through a gradual loss of moisture using surface evaporation to remove water. As wood is heated in a kiln, the surface becomes hot. As the moisture at the surface of the wood is absorbed by the air, the moisture flows to the surface in a wicking action. It is important this wicking action is not broken. This drying mechanism is extremely important. Any condition which prevents the wick action will break the flow of water to the surface. There are two primary conditions which break this flow within the wood.

1) Removing the surface water faster than water is moving from the core. This dries the surface layer, then seals the pores. The shrinking of the fibres at the surface closes the cells. This sealing process is called CASE HARDENING. ***Once lumber is case hardened it takes more energy and time to dry, lumber must then be dried with low humidity, requiring a lot of venting.***

2) Removing the surface water slower than water is flowing from the core, water puddles on the board. The interior of the wood becomes almost as hot as the surface and there is no incentive for the water to flow anymore. The wood becomes hot and soggy. An indication would be collapse and compression marks which appear at the stickers causing skip at the planer.

3) Reverse CASE HARDENING occurs during rapid heat up in hi-humidity conditions. Example: Injecting steam at start of a charge. This rapid heat up with hi-humidity makes the surface of the wood hot and soggy, allowing the surface fibres to stretch and elongate the cells. As the humidity is then lowered and the wood dries, the surface fibres and cells do not return to their original shape. The interior of the wood shrinks more than the surface causing honey combing.

The rate the lumber is heated up is calculated by the controller, based on the temperature and initial moisture content. The correct heat up is critical to insure quality drying.

H. Metering Wood

Checking the moisture content of the lumber after the kiln is finished drying is very important when setting up a computerized process control. It can provide a lot of useful information on what the computer is doing, and which direction to move the parameters. It is therefore also very important to meter accurately, and remove the errors involved with this measurement. Most commonly used meters measure the resistance of the wood. The amount of water in the wood affects this resistance. Unfortunately moisture isn't the only thing that affects the resistance of wood, the temperature also affects it. The problem is to separate these two factors and obtain a good idea of what the wood's actual moisture content is. Further complicating matters is the fact that you never really know what the real internal temperature of the wood is.

M.C. READING INCREASE WITH TEMPERATURE INCREASES

Determining the core temperature of the wood within a few hours after shutdown can be very difficult. To accurately determine the moisture content of a load after drying, the kiln operator must determine the wood temperature, then convert the meter readings with the use of a conversion chart usually supplied by the meter manufacturer.

It is strongly recommended that insulated needles be used in all metering. Insulated needles give readings for the wood between the tips, deep within the wood, rather than just an average of the surface and points in between. Another advantage when using insulated needles is testing for case hardening. If the needles are slowly pushed into the wood, 1/16th inch at a time, the readings should not change more than 4%. If they do, the wood is case hardened.

It is recommended to meter the lumber while it is still in the kiln, right after shutdown if possible. Using the wet bulb temperature as the conversion temperature will be fairly accurate. Safety precautions must be taken by venting the kiln adequately before entering. Vents and doors should remain open while any one is inside a dry kiln. Leaving a load for less than 24 to 48 hours, then using the outside temperature, is extremely inaccurate.

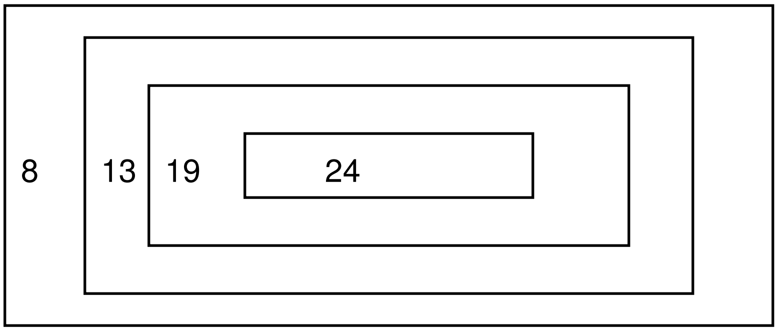
At Frank Controls, we have found that when wood is dried by the FC process, the actual moisture content can be determined without using the temperature correction. This is done by using long insulated needles and looking at the moisture gradient through the board.

The first step is to first bury the tips of the needles in the wood: this gives you the outside moisture content. Slowly hammer the needles in 1/4" at a time. The dial readings will increase gradually until the needles are all the way in.

Remember the moisture content should increase linearly, if it doesn't, this means some case hardening has occurred. The MC content is determined by a simple formula

$$MC\% = \text{outside reading} + \left[\frac{\text{Highest inside reading} \text{ minus } \text{outside reading}}{3} \right]$$

Consider a sample board of wood



The moisture gradient is roughly linear so the formula can be used.

The outside MC + 8%
The highest inside reading = 24%
Actual MC% = 8 + (24-8) / 3 = 8 + 5.3 = 13.3% or 14%

By using the small needles (5/8") the average of the board is done automatically. The actual reading is the MC< but due to the temperature, the MC will drop approximately 1%.

A small temperature gradient in the wood gives an indication of a slow heatup, and a large gradient indicates that the heatup may have been too fast.

Since many companies have their own procedures to follow, and if they do work well, there is probably no need to change.

All sides available in a kiln should be measured carefully. This includes the two inside - as well as the two out sides in a twin track kiln. The information from the middle will demonstrate problems like condensation and bypass air. From accurate metering, meter the middle three or four lifts on each side, avoiding the ends which are usually drier.

Kiln Structure Conditions

There are many conditions which may be present, yet overlooked in kilns using manual controllers, that will stop the computer from working properly. Hours of pointless frustration trying to fix physical kiln problems with computer adjustments will be avoided if basic kiln operation is in order before setting up a computer. The following list should help to evaluate the condition of the kiln and loading procedures.

1. Fans: Are any fans not working? Are any blowing in the wrong direction? It is easy to reverse the fan direction when installing new blades or motors. This condition is fairly serious as it affects the air flow through the wood. At best it will result in wet spots in the kiln, at worst if the fans are near the bulbs the controls will not work. The pitch on the fan blades,

and amperage on the fan motors, should be checked periodically, to ensure that maximum efficiency is obtained without overloading the system.

2. Baffling: Top and bottom baffles should be in good shape, making contact with the load. Overhead baffles must be lowered until all baffles are resting on the top of the load. The crank should be given another turn to ensure that there is enough slack in the baffle cables to allow the baffles to move down as the lumber shrinks. The height of the load should be the same along the length of the charge. If the top of the loads are uneven, the baffles will not seal the top properly.

Like the fans, the baffling must be particularly good around the probes or the temperatures fed back into the computer will be wrong, and the control will not work properly.

3. Loading: If the tracks are two lifts wide, the space or chimney between the loads should be a minimum of two inches and a maximum of six inches if the lifts are not spaced. The spaces between tiers will not line up giving very poor air flow. Some mills have prevented this by inserting a 2x4 or metal pipe vertically into the cart to ensure even spacing. All packages should be butted up as tightly as possible to reduce bypass air cutting across the kiln without going through the load. If split length packages are used (two different lengths piled in the same lift), one end of the lift should be even, with the length difference all on one edge. The charge is then loaded even ends together. Uneven ends jam into each other. The uneven ends will allow the most bypass air, and should be kept as far from the probes as possible.

4. Vents: Vents should be inspected for leakage, plus sticking open and closed. Make sure each individual vent is adjusted to close properly. Monitor some venting to see if the vents are opening when they are activated and closing when turned off. Proper operating of the vents is critical for the computer to exactly control the conditions within the kiln.

5. General Leakage: If leakage from the kiln is severe, the computer will not be able to maintain the required levels of humidity in the kiln. In other words the kiln would be leaking at a faster rate than it would vent the kiln. Problem areas are vents, doors and safety windows. A well sealed kiln will give much better performance than a kiln that leaks too much, not requiring the vents to open.

6. Bulb Placement: Bulbs must be place in direct air flow, not around wall obstructions causing turbulence. Generally, the further the probes are placed from the wall, the more reliable they will be. The wet bulb must have a constant supply of water and a clean sock. If the sock becomes clogged with resin and dirt, it will begin to read too high, giving a false

picture of the humidity in the kiln. Wet bulb socks should be regularly checked and replaced for reliable results.

7. Burner: The burner should be in good working condition, capable of putting out its maximum rated BTU level. If an extremely small burner, or a large one, which doesn't give its maximum rating, is used, it will be more difficult to get optimum results from the computer.

In general, any clear paths for air to flow from one side of the kiln to the other must be blocked. As much air as possible must go through the load of lumber. Good air velocities are important both for drying and for proper wet bulb readings.

J. Moisture Gradients

The difference between wood moisture content inside the wood and the moisture content on the board surface creates the driving force during drying. It is the object of a correct drying process to adjust this wood moisture content gradient so that the drying process proceeds at an optimum. It is disadvantageous if the wood moisture content gradient is too great, since the moisture content then flowing from the inside of the board to the surface is disturbed ("the moist fibers are torn"). Case hardening is the result. Case hardening means that the surface layers are too dry and the inside more or less wet.

If the moisture content gradient is too small during drying, then the resulting drying times are uneconomical. In a kiln, the possibility exists of controlling the climate so that an optimum wood moisture content gradient is present. (4)

Moisture trys to achieve equilibrium in wood. It tends to distribute itself equally throughout the piece by moving from areas of high to areas of low moisture content. When green lumber begins to dry, the evaporation of moisture lowers the surface moisture content below that of the interior. As drying progresses the moisture from the interior moves outward to the area of lower moisture near the surface. This difference in moisture content between the interior and the surface of a board is termed the moisture gradient. The surface moisture content is controlled by the temperature, relative humidity, and circulation of the surrounding air. (2)

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FRANK CONTROL DRYING PROCESS

The process control, designed by Frank Controls, carefully monitors kiln conditions, then uses heat and venting to obtain and maintain the optimum drying environment. The computerized control dries every load differently depending on its requirements. This is analogous to cutting a different cam for each charge; the wood determines its own schedule. Manual and other programmable controls dry every load with the same schedule, usually over-drying, under-drying, and degrading a large amount of wood. It is extremely rare that any two charges have the same initial condition or moisture content.

The FC Controller require an accurate set of dry and wet temperatures from the kiln. The temperature probes are the only source of information the computer has to work with. (From this point on, conventional controllers using a capillary tube system, or newer electronic programmable fixed cycle systems will be referred to as manual controls.) Obviously any condition which influences the probe data will have an adverse effect on the operation of this kiln control. A manual control, on the other hand, will plod on despite inaccurate temperature information, since the schedule is fixed and will not change significantly.

One of the computer laws, "garbage in - garbage out", applies in this case as well. Therefore, where a kiln is in poor condition, yet functioning with a manual control, it may be necessary to do some maintenance, before optimum performance is achieved with the computer. Many differences exist between the computerized controller and the manual controller.

Many difficulties will be created if the computer is forced to behave like a manual control.

It operates on a different principle, and old conventions of traditional drying do not apply.

Objective - to minimize energy consumption, while drying lumber in the fastest most economical possible way, without case hardening or degrading the lumber in any way.

General Information

The Frank Control drying process has two main objectives:

1. To heat up the lumber in such a way so the moisture of flow starts to move freely. The purpose of the controlled heatup is to set up this flow according to the condition of the wood inside the kiln. The heatup has to be dynamic due to the fact that wood conditions do change and the control must be able to compensate for these changes.

2. Once the heatup has been achieved the next objective is to use the available heat to dry the wood. This is done in conjunction with the heatup. As the moisture starts to flow in the kiln more energy is required as the relative humidity increases. We want to set up the flow in such a way to utilize all or a large portion of the burners output. An important aspect which affects that, is the kiln's internal airflow through the wood.

Airflow is very crucial to the kiln's operation and there is a direct correlation between airflow and the amount of energy that is available for drying. As the air heats up the efficiency of the fans decrease roughly around 40% so at low temperature it is desirable to have high airflow. The higher the airflow the more energy is available for use in drying.

Usually kilns which have cold readings between 360 ft/min and higher work well. The reason behind this is due to the nature of the two different types of airflows which are:

A) Laminar Airflow

B) Turbulent Airflow

Of the two types of airflow it is turbulent airflow that we need in order to dry wood.

ANALYSIS OF HEATUP

The structure of the heatup is divided into two distinct and very important parts. They are:

A) Preheat Side (Forward Fans)

B) Heatup Side (Reverse Fans)

PREHEAT SIDE

To understand the heatup it is divided into two parts one has to realize that facts are more efficient in one direction than the other. If a person would measure the air velocities of the two directions; one side would be approximately 20% higher that the other.

** This aspect of the kiln is the first thing that has to be determined. This can be done by measuring the airflows (with heat fan running) or by observing what happens when the kiln reverses. This will be looked at later in more detail. **

The side which exhibits the highest airflow is the preheat side and is the first side the control goes on. The control calls this the forward direction of the fans. The control heats up the preheat side to 110 F then reverses the fans to the opposite side of the kiln called the reverse side or heatup side.

The control has two different modes an operator can use, to control the heatup.

A) Dry bulb control mode

B) Wet bulb control mode - uses relative humidity

These modes are used only to predetermine the temperatures for each side of the heatup.

Preheat side -----> 110 °F
Heatup side -----> 125 °F

In the dry bulb mode, the parameter that governs how the preheat is applied, is performed by parameter 45. This is called the PREHEAT KILN FACTOR DETERMINANT.

Suppose parameter #45 = 115. The control adds 60 to parm.# 45 so parm. #45 is 175. This means that the temperature will rise to 100 F at 17.5 degrees per hour. When it reaches 110 F the program looks at the temperature drop and stores this value into parameter #21 - called the PREHEAT KILN FACTOR.

In the wet bulb control the same procedure occurs except that a different parameter is used. In this case parameter #37 denotes the relative humidity desired at 100 F where the PREHEAT KILN FACTOR is set.
** The wet bulb mode control is used only if the wet bulb is reliable and the readings are accurate. Generally the wet bulb is accurate at high temperatures, but seems to be erratic at lower temperatures. As a consequence for most kilns

the dry bulb mode is used on heatup, while the wet bulb is used for calculating the moisture content. If the wet bulb is used for heatup a humidity correction is available, but its use is determined by the kiln. **

The purpose of the preheat is to pull the surface moisture off the wood, which tends to drop the relative humidity inside the kiln. If the wet bulb reading is good, values of around 35% to 38.5% RH is a good baseline to be at 110 F. This depends on the airflow and the position of the wet bulb inside the kiln. In the winter since the wood is frozen a THAW OUT may be required. By setting kiln parameter #24 to 1 the fans will reverse on the preheat section of the heatup to thaw out the wood. (according to time set in parm.#25)

HEATUP SIDE

The heatup side of the HEATUP is probably the most important part that sets up the flow in the lumber.

After the preheat reaches 110 F, the fans reverse direction to the reverse side (heatup side) which is characterized by the low airflow. This side is brought up to 125 F where the control sets up parameter #20 as did for #21 in the preheat section.

In the dry bulb mode, the rate the temperature is advanced is controlled by parameter #46. While in the wet bulb mode parameter #36 controls this.

** Important to note that the values in parameters #36, #37 are the RH X 2. **

Example: Suppose the RH wanted - 35% on preheat section therefore Parm #37 = 35 X 2 = 70

Once the heatup has reached 125 F the control sets up parameter #20. From this point, parameter #20 is used in combination with the CURVE PARAMETERS.

The curve parameters include parameter #22 - #30. The idea behind the curve is to compensate for changes in the kiln airflow. The curve adds absolute degrees to parameter #20 depending on its parameter. The incremental degree addition to #20 is done by parameters #23 - #30. Each parameter is responsible for a different part of the heatup. Parameter #22 controls the main slope of the curve, parameter #44 gives the operator the choice of whether to use the absolute degree adjustment or the percentage of parameter #20 adjustment. We find that the percentage adjustment tends to push the heat up a little too fast.

For Gas Systems: Parm #22 - (50 - 90)
Heat Exchangers: Parm #22 - (30 - 70)

GAS	HEAT EXCHANGERS
23 - 5	23 - 3
24 - 7	24 - 5
25 - 9	25 - 7
26 - 12	26 - 9
27 - 15	27 - 11
28 - 25	28 - 20
29 - 35	29 - 30
30 - 100	30 - 100

There are two main points in adjusting the heatup curve. As the wood heats up, one needs to look at the percentage of heat being used and the rate the temperature is climbing.

Assume at around 125 F the temperature rate is 15 degrees per hour and the burner output is 60%. As the temperature increases one would hope to observe a gradual decrease in the rate of temperature rise, and increase in the amount of energy being used. This would indicate that as the moisture starts to move more energy is required to pick up the moisture. As a result the relative humidity would be gradually increasing. Around 195 F the rate of temperature rise is very small (depending on the moisture in kiln). At this point it is usually about 2 - 3 degrees per hour. This is called the STALL OUT.

Thermodynamically, the stall out tells us the flow of water from the wood is coming at such a rate in which all the energy of the kiln is being used. This happens when the kiln is running at its best capability; the lower the stall out point of the kiln the better the heatup. If the lumber can be heated up so that the water flow can absorb all the energy this means minimal case hardening has occurred.

Normally the stall out occurs in the temperature range of 195 - 205 F but there are factors that determine this.

1. Energy output of kiln. Kilns which have a low energy output will stall out at lower temperatures.

2. Amount of airflow. The higher the airflow the lower the stall out temperature.

3. Amount of water in the wood.

4. How the wood was heated up.

The stall out temperature is an indication of the heatup performance. The lower the stall out the better the heatup.

FINE ADJUSTMENTS FOR WOOD QUALITY

Fine adjustment can be broken down into two categories. It is assumed that the control is already shutting off at the desired moisture content. The two categories are:

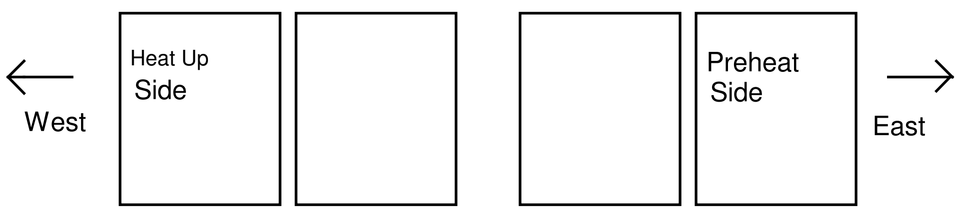
A) Twisting

B) Moisture Content

ADJUSTING FOR TWIST

Since the heatup is divided into two parts it is important to know which side the preheat is on and which side the heatup side is on.

For example - the sides are as follows:
(expressed below as a twin track dry kiln)



Presume the control is using the dry bulb control mode, so parameter 45 controls the preheat while parameter 46 controls the heatup side. After a charge has been dried, go outside and look at the top tier to see if there is any twist. At this point it becomes necessary to tell the difference between compression wood and twist. As you look across the load the important thing to see is if all the boards are lifted upwards or twisted sideways. If only one board is twisted it is more likely to be a form of compression wood. If all the boards have some twist then an adjustment is required. This can be done by adjusting parameter 45 or 46 according to where the twist is. If the heatup side is twisted adjust parameter #46. If the preheat is twisted adjust #45 but remember the preheat does have an influence on the heatup side.

Presume.. Parameter 46 = 115 and the heatup side is twisting.

If you adjust parm #46 higher, do so about 2 - 3 points. If you adjust #46 by an increment of 3 then the new value for parameter 46 is 118. If you feel parameter 46 needs to be decremented by 3 then the new value becomes 112. At this time you are probably asking how can you tell which way to adjust the parameter if twist can occur in both fast and slow heat ups?

This can be done by looking at two main factors.

A) Moisture Grouping
B) Moisture Gradient through the board

Since twist is adjusted first it is important to realize that the above factors can help determine which way to change the parameter (higher or lower).

As a general rule:

Adjust higher:

1. Moisture gradient through board is small.
2. Grouping varies over a wide range.
3. Twisting occurs.

Adjust lower:

1. Moisture gradient is too large. Typical gradient usually is about 8% on outside to 25% in centre.
2. Grouping varies over a wide range.
3. Twisting occurs.

If you decide to push the parameter higher and it gets worse then you need to go the other way. Once you find the direction you need to go on the parameter, keep going in the direction until the twist is gone.

** *In most cases the heatup needs to be slowed down. That is done by lowering parameters.* **

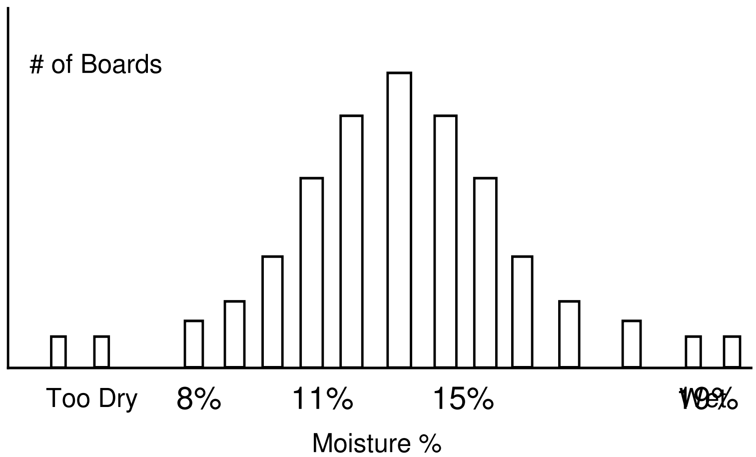
ADJUSTING MOISTURE CONTENT GROUPING

Once you have managed to eliminate the twist it is now important to work on the moisture content grouping. Ideally we want to obtain a tight bell curve distribution. To get the twist down you have to adjust a parameter in a certain direction. Since it improved, continue in this direction to tighten up the grouping. As you continue you will reach a point where the wood will get worse. This is called the borderline. At this point it is necessary to back off on the parameter since you are very close. This gives you minimal twist and good moisture content grouping.

There are certain considerations when adjusting for moisture content grouping. All are relative to the kiln's performance. The biggest problem is that the airflow is not even throughout the kiln. If you measure the airflow through the wood from the top of the kiln to the floor of the kiln you will notice that the top air flow is about twice than that of the bottom (in most kilns). This tends to over-dry the top of the charge while the bottom is not as dry. Therefore there will be a deviation of moisture content from top to bottom.

When adjusting the grouping, do so until twist starts to occur then back off from that point. From this you receive close grouping while keeping the twist down to a minimum.

The histogram below is an illustration of the grouping :



To determine the average MC - add up all the boards MC readings and divide this number by the number of boards measured.

$$\text{AVERAGE MC} = \frac{\text{[Sum of MC readings]}}{\text{Number of Board}}$$

Major Differences : Manual & FC Method

1. Heat up
   FC Method - Heat up is usually done in two stages, depending on species, outside temperatures, and initial moisture content. The preheat is designed to establish a moisture and temperature gradient on one side of the kiln. The highest airflow direction is referred to as the preheat or forward fan direction.

Moisture and heat gradients are established initially on the heat up side or reverse fan direction. The control then continues the heat up based on humidity levels, and the kiln environment at any given time heat is only increased if optimum conditions exist.

Results - Controller reacting to the lumber responses eliminates stresses and establishes the most efficient drying rate. Prevents case hardening and reverse case hardening.

Manual Method - Heat up is usually set for maximum heat output and temperature rise possible until the maximum kiln temperature is reached. Some controllers raise temperatures as fast as possible to a certain point, then control by means of a physical or electronic cam regardless of the kilns environment or the lumbers response to the conditions being created.

Results - Most lumber stresses are created in the early stages of drying and are magnified as the cycle continues.

2. Humidity

FC Method - Humidity levels of 55 - 75%, depending on species, is very common.

Results - More energy is carried with high humidity levels, making more energy available for the removal of moisture from the wood. *High humidity levels prevent case hardening.* It also conserves energy by removing large amounts of moisture with each vent.

Manual Method - Levels of 20 - 30% are usually the highest levels reached.

Results - Less energy per cubic foot of air is available for the removal of moisture. Low humidity levels case harden lumber very early in the cycle. More heat and less moisture is removed with each vent. These factors result in longer cycles and reduction in lumber quality.

3. Energy Utilization

FC Method - Energy sources are generally used to capacity for most of the cycle time. When optimum conditions are created, energy consumption may be at the maximum capacity, but a very slow rise in temperature.

Results - Energy sources are used to capacity for moisture removal from the lumber, not to increase kiln atmospheric temperature. Maximum amounts of moisture are removed in minimum time, reducing cycle times.

Manual Method - Energy sources are generally used to capacity for 2 - 6 hours during the heat up. After this the heat is used to maintain the kiln temperature.

Result - This results in case hardening lumber, which reduces moisture flow, increases cycle times and decreases lumber quality.

4. Fan Reversals

FC Method - Generally only two fan reversals are used, one after the preheat, and one after a calculated moisture content of 21% is reached. The number of reversals depends on species moisture content and outside temperature conditions.

Results - Moisture flow and temperature gradient once established are maintained, resulting in uninterrupted drying. Reversals are used when thawing out lumber, to protect the surface layers while utilizing large amounts of energy in the thaw out phase. Reversals are used in some high moisture species or delicate species to maintain a heat gradient. These reversals are not time based but are responses to humidity levels and heat output.

Manual Method - Fan reversals are usually time based between 2 and 8 hours apart.

Results - Moisture flow is constantly being interrupted resulting in lower efficiency and longer cycle times.

5. Venting

FC Method - Venting is kept to a minimum in order to keep humidity levels high. The amount of venting increases or decreases depending on kiln condition, energy source (gas or hot oil) and lumber moisture content. With high humidity levels, large amounts of moisture are removed with the air escaping around the doors and any other holes that may be present. Increased vapor pressure, increased heat, burner combustion air, positive and negative pressures created by the circulating fans are all reasons for air exchange and moisture loss from the kiln.

Results - With high humidity levels, large amounts of moisture are lost with the escaping air due to the pressures on the kiln atmosphere mentioned above. These factors combine to reduce the need for venting with the Frank method. *Energy is conserved by not venting usable heat.*

Manual Method - Small amounts of moisture are removed with each vent when low humidity levels are maintained. Low humidity levels must be maintained due to the moisture flow restrictions caused by case hardening in the early stages of drying.

Results - A large amount of venting is necessary when expelling low amounts of moisture as the air is exchanged. This increases energy consumption.

6. <u>Shutdown</u>

FC Method - Final moisture content is calculated based on humidity levels.

Results - Once the Frank method has been set up, the shutdowns have proven to be very accurate and reliable. Only inaccurate wet bulb or dry bulb readings as a result of negative physical conditions will vary the results of this calculation.

Manual Method - Shutdown is usually time based or arrived at by counting the number of vent cycles within a given time period.

Results - Erratic shutdowns and final moisture contents when wood conditions change. Large amounts of heat are lost by venting when not necessary.