SOME THINGS I WISH I KNEW

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It has been my good fortune to have been associated with a basic drying program conducted within the Weyerhaeuser Company for many years both as an employee and as a consultant. During those years I have been permitted to test many concepts and to develop those which appeared to be promising. Some worthwhile and economically favorable results were obtained and I feel justifiably proud to have been associated with them. There is no question but that the concept of the use of continuously rising entering air dry bulb temperature represents a forward step which has significant economic merit in the drying of most dimension lumber, particularly Douglas fir, western hemlock and the Southern yellow pine species. This is attested by statements by Weyerhaeuser management that corporate adoption of CRT in the drying of softwood dimension lumber is netting the Company in excess of six million dollars per year.

The potential of establishing kiln conditions by specifying drying rates in terms of the dry bulb temperature drop across the load of lumber is exciting, and I hope to have the opportunity to assist in solving the kiln design and instrumentation problems to permit kiln control by the so-called Delta I method.

As every research man knows, the results of his studies may be divided into three groups. First, there are the many failures resulting from ideas that didn't quite pan out. Second, there is that one success or promising result. And third, there is the list of questions that has accumulated during the study--generally questions that could not have been asked at the beginning because of lack of familiarity with the field. In many cases, the accumulated questions represent the most important result of the research because these questions determine the next stages of the study.

I should like to share with you some of the questions that have occurred to me. I feel that some of these questions, at least, have a bearing on the bettering understanding of the mechanism of drying, and that their answers might be applied to more economical drying practice.

I wish to be clearly understood at the beginning that I do not lay claim to have been the first person to have asked these questions. Neither do I believe that because I do not know the answers, no one else does. Lumber drying has been the subject of intensive study by many capable individuals in federal and state forest products laboratories, educational institutions and industry. Several of the more productive researchers in the field are in attendance at this meeting. It is highly probable that my questions have been asked by others and that perhaps many of them have been answered in the laboratory--or proven to be irrelevant.

Some of my questions are shared by the research staff of Weyerhaeuser Company where work on basic drying continues and are therefore proprietary. Others relate to confidential problems of clients. Among permissible topics for open discussion are the following.

Hydrolysis: I have assumed for many years that a principal cause of degrade during accelerated drying was loss of strength due to chemical degradation by means of hydrolysis. To arrive at this assumption I have reasoned from analogy. It is well known in carbohydrate chemistry that long chain high molecular weight carbohydrates are broken down into lower molecular weight shorter chain units by treatment with water at high temperature in the presence of hydronium ions as a catalyst. This is the mechanism of the Scholler process in which cellulose is broken down to simple sugars which can then be attacked by yeasts to produce ethyl alcohol by fermentation. Certainly these same process elements are present in significant degree in the dry kiln. Wood contains high percentages of carbohydrate and water and also most woods are significantly acidic in reaction. Upon the application of heat it would be expected that the carbohydrate bonds would be broken by hydrolysis. The strength and continuity of the wood structure should therefore be reduced and degrade enhanced.

I would like to have positive evidence concerning the validity of the hypothesis and concerning the extent to which the chain lengths are reduced under different drying conditions if the hypothesis is true. I have justified as one of the principal merits of CRT the idea that there is less hydrolysis at lower temperatures when the moisture content is high near the start of drying and therefore there is less degradation of wood during the drying. However, it would be reassuring to have positive proof of the validity or non-validity of the hypothesis.

Thermal Expansion: Anyone who has ever walked into a dry kiln immediately after the doors have been opened and the system is beginning to cool remembers the popcorn popper sound. This noise is probably due to the relative motion between the boards and the stickers. However, it must be due to the fact that the wood is shrinking as it cools. Data from reference books for coefficients of shrinkage show that the values for wood are of the same order of magnitude as for metals which have densities many times as large. For example, the coefficient of linear expansion for pine parallel to the grain is 3×10^{-6} inches per inch degree and for pure copper 9.2×10^{-6} inches per inch despite the fact that pine has a listed density of 0.4 and copper 8.9--over twenty-two times as great!

I would like to know whether the thermal expansion of wood is due to increased amplitude of vibration of atoms or whether other mechanisms are involved, and what the effects of these variables are on structural integrity or degrade.

I would also like to know how the thermal expansion and shrinkage of the low density early wood and the high density late wood affect the bonding of the interface between the two growth types.

Air Velocity as an Independent Variable: There is lack of agreement concerning whether air velocity per se affects the rate of drying, all other factors remaining constant. There are those who maintain that high air velocity provides a "scrubbing" action which in turn increases the coefficient of heat transfer between the air and the wood and that higher speed drying takes place because of the greater ease with which heat energy enters the wood.

I intuitively hold that air velocity and temperature drop across the load are positively linked. That is, for a given size of slot the lower the air velocity (that is, the less quantity of air that is passing through the slot in unit time) the greater the

temperature drop across the load must be for a given amount of moisture removal. Also the greater the wet bulb temperature depression must be in order to permit the required temperature drop across the load.

Stated in another way air moving at a given rate through a slot of a given width will result in the same rate of drying as air moving at half the speed through a slot of double the width with the same temperature drop across the load.

I believe that the answers to these questions have significance both in the establishment of drying schedules and also for vendors in the design of air moving systems.

Air Flow: It may not be of earth-shattering importance from a practical drying standpoint, but I would like to know how the air flow through a charge of lumber varies during the course of drying. Near the end of the drying schedule the temperature is elevated and the density is decreased--that is, a mole of gas occupies a larger volume as the temperature increases at constant pressure. Does this mean that fewer pounds of material (actually fewer molecular weights of gas) are being passed through a slot in unit time as the temperature increases?

It is a very simple matter to calculate the volumetric specific heat of different mixtures of air and moisture at different temperatures and if the quantity of gas flowing is known the temperature drop across the load is an accurate measure of the rate of heat transfer from the air to the wood. However, if the quantity of air flowing differs from the quantity estimated by measuring the air velocity on the leaving air side at ambient conditions these calculations will be in substantial error.

The questions can be asked in a different way. What does a fan do? Does it move volume? Does it establish a given static pressure difference? Does the speed of the fan remain constant as temperature and gas density change during drying? I had opportunity at one time to get data relative to some of these questions but failed to do so. Undoubtedly many people know the answers--I don't.

Air Velocity Over Wet Bulb Sock: This is one for which I can only blame myself because I once had experimental facilities available for making the measurements. However at that time I didn't feel the necessity because on the experimental kiln I was using. I controlled the wet bulb temperature by sampling the kiln air and passing it through a fan and tube to the wet bulb and back into the kiln. Air velocity over the wick was of the order of 1200 feet per minute.

This annoying question should be answered. It is obvious that the air does not move over the wet bulb sock the indicated wet bulb temperature will be the same as the dry bulb temperature. As the air velocity increases the indicated wet bulb temperature decreases and approaches the true value, but the literature is not consistent in specifying just how fast the air should move over the wick to guarantee a correct reading. However, velocities of the order of 600-1000 feet per minute are frequently given. Such velocities are not attained in most dry kilns. Air moving through the plenum and over the wick is moving much more slowly than the air that moves through the slots because the plenum cross-section is generally much greater than the total cross-section of the slots. Therefore, in most kilns, the wet bulb wick is being

washed with less than optimum velocity air and the indicated wet bulb temperature is therefore higher than the true value. It follows then that the actual humidity in most kilns is lower than the intended value. But how much lower? This is what I would like to know, and somebody could find out by very simple tests.

Air-to-Wood Temperature Gradient: One of the more important variables relating to the rate of drying is the temperature difference between the air (source) and the wood surface (sink). The amount of heat energy transferred in unit time is dependent upon this quantity. The greater the temperature difference, the greater the rate of heat transfer, all other factors remaining constant. I would very much like to know what factors determine the magnitude of the air-to-wood temperature gradient in a kiln when the wood surface moisture is no longer at the wet bulb temperature. If kiln temperatures are such that the wood and its contained water are at or slightly above the normal boiling point of water, the wood, of course, is maintained at the boiling point, and the temperature between the air and the wood decreases as the air progresses across the charge. This is the case during much of high temperature drying. But I am concerned about the variables that dictate the temperature gradient at lower temperatures.

Heat Transfer Coefficient and Surface Moisture Content: Every kiln operator knows that high moisture content green lumber loses moisture during drying at a faster rate than low moisture content green lumber. This is shown by the fact that kiln dry moisture contents of individual boards are generally reasonably close together even though the original green moisture contents were extremely different. For example, if a board with a green moisture content of 30% were dried to 15%, it might be expected that a neighboring board with a green moisture content of 115% would lose the same amount of moisture and end up at 100%. This is not true. The wetter board might end up at 20% or perhaps a bit higher, but it would certainly not be 100%. In other words, the wetter board absorbed heat and vaporized moisture faster than the dryer board. In fact, it is not uncommon to observe that the initially wetter board ends up with the lower kiln dry moisture content.

I would like to have more data relative to the relationship between the coefficient of heat transfer and the moisture content of the lumber. Also I would like to know whether the coefficient changes as drying proceeds. This is of particular interest because in CRT drying, the drying rate which is established at the start of the run tends to be maintained. This suggests that the rate of heat transfer remains constant even down to levels far below the fiber saturation point. Since data indicate that the temperature difference between the air and the wood remains substantially constant the heat transfer coefficient must remain substantially constant. I wish that I had independent corroborative data.

Equalization Before and During the Drying Cycle: Many kiln operators make a practice of presteaming the lumber before the drying cycle is initiated. The rationale is that by so doing the surfaces are made wetter by condensation, and the core-to-shell moisture content gradient is reduced so that when drying does start the rate is increased because of the wetter surfaces and the onset of surface stresses is postponed. I do not have positive knowledge concerning the effectiveness of such processing.

It is difficult to do a true presteaming job in most kilns because the spray steam which is admitted to the kiln is under pressure-- often as much as up to 150 psi. When steam under pressure is allowed to expand to atmospheric pressure, the "superheat" in the steam results in a significant wet bulb temperature depression. Consequently, in many kilns, the lowest wet bulb temperature depression that can be achieved with spray steam alone is 10° or more, and if the vents are not completely closed, the dilution air which leaks in will further increase the depression. This substantial drying generally takes place during the period when equalization is the goal.

Many years ago when the Weyerhaeuser drying study was just beginning, my associates and I became very much intrigued with a procedure which we called cyclical drying. This was accomplished by alternately drying and humidifying by either turning off the heat while the vents were tightly closed, by allowing the wet bulb temperature to rise as high as it could with spray steam, or by turning off the air and allowing the load to "steep" in a moist atmosphere. I am still intrigued and would like to get back to those studies.

Mechanism of Constant Rate: A very key question in my mind relates to the substantially constant rate of moisture removal which is a major characteristic of CRT drying. It is known that when doing conventional drying, the rate of moisture removal is proportional to the moisture content at any time. Therefore, the drying rate decreases as the moisture content decreases. However, it is characteristic of CRT drying that the rate is proportional to the green content--that is, the rate of drying which is established in a given board at the beginning of drying is the rate which tends to be maintained throughout the drying cycle, other factors remaining constant. This one bothers me a great deal. Logically it cannot be true--yet it is. It is my very fond hope that I may ultimately become as comfortable with this phenomenon as I am with some of the things which I think I know about heat transfer and moisture migration mechanisms.

Booster Coil Control: As air passes over a charge of lumber in a dry kiln, the air cools and picks up moisture from the wood. However, because of the energy which was transferred to the wood was not used to vaporize water, the wet bulb temperature decreases slightly. In a double track kiln, the spent air from the first charge is reheated before it enters the second charge without humidity adjustment. During the reheating step, the wet bulb temperature is increased significantly. Therefore, even if the air entering the second load is reheated to the same dry bulb temperature as the entering air for the first load, the wet bulb temperature depression will be somewhat less. This fact suggests that the dry bulb temperature of the air entering the second charge should be controlled at a higher level than that of the plenum ahead of the first load, in order that the drying conditions in the two charges may be comparable.

Unfortunately, the temperature of the booster air is not even controlled in many kilns. The result is that much emphasis is placed on achieving and maintaining a predetermined set of dry bulb and wet bulb temperature conditions for drying the lumber on the entering air track, but the conditions for the charge on the leaving air track are not even known.

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<u>Dimensional Change</u>: I wish that I had a clearer picture of
what takes place during swelling and shrinking. I know that when
a water molecule decides to enter a cell wall, it has to make room
for itself. The volume of that cell wall is increased by almost
exactly the same amount as the volume of a water molecule in the
liquid state.

Now as the cell walls and the entire wood specimen swell from
the oven dry state to the maximum volume at fiber saturation, what
is happening to the bonds between adjacent cellulose chains? What
is happening to the bonds between adjacent cell walls? What is
happening to the bonds between tracheids and ray cells? What is
happening to the bonds between spring wood and late wood, since the
late wood is much more dense than the early wood and therefore
swells more? Are the bonds merely stretched, or are they broken
and reformed? Or are they broken and not reformed? Or are they
broken and only partly reformed? For that matter, what are the
bonds that keep the various elements of wood structure together?
Are they primary valence bonds such as those that hold atoms to-
gether in a molecule? Are they covalent bonds? Are they resonance
bonds such as hydrogen bonds? Are they gravitational bonds?

Now consider shrinkage--when a molecule of water leaves the
cell wall, the cell wall collapses in volume by an amount almost
exactly equal to the volume occupied by a molecule of water in the
liquid state. What is the mechanism here?

The volume changes which take place during seasoning deter-
mine the major portion of degrade during drying, and degrade is
the determining factor of seasoning economics--and economics is the
name of the game we play.

These large changes in overall dimensions cannot take place
without major effect upon the bonds which provide the continuity
between the elements of the wood structure. It appears obvious
that the bonds must be distorted and ultimately broken and reformed.

I do not have a clear mental picture of what the bonding sys-
tem is. There are primary valence bonds which unit the atoms to
one another in the basic molecules. The elementary molecules are
linked together in chains probably by primary valences or by
electron sharing covalence. These chains are linked together in
parallel strands probably by resonance bonding such as hydrogen
bonding, which involves only a part of the points of potential
bonding, thereby forming so-called crystalline regions. Those
potential bonding sites which are not inter-locked between strands
are the so-called amorphous regions and allow for a certain amount
of flexibility in the overall structure. It is supposedly these
potential bonds in the amorphous region which become the sites upon
which the sorbed water is attached.

Thus far, the assumption has been made that wood is composed
entirely of cellulose. Such is obviously not the case. A substan-
tial portion of the carbohydrate material in wood is made up of
non-cellulosic material called hemicellulose. This material is
distributed throughout the structure. It is certainly hygroscopic
and must play a role in moisture take-up and loss. Then wood also
contains approximately 40% of a material called lignin, which is a
highly complex chemical substance and which also has hygroscopic
properties.

Regardless of where the bound water is situated, any change in
the amount of water results in a change in volume of the cell wall,

which in turn results in a change in linear dimensions. This must result in stressing of structural bonds. There are four alternative effects. First, the bonds may simply stay in the stressed or stretched condition. Second, the stretched bonds may be elastic and strong enough to cause the shape of the whole structure to change as by warping, twisting, cupping or bowing. Third, the bonds may break and produce a rupture in the structure to produce internal or surface checks. The fourth alternative is for the bonds to be broken but reformed as the structural elements move past one another to produce a continuous structure without stress.

The fourth alternative, of course, is the desired one. A board that is full of residual stresses is not desirable because it will react unfavorably at any time the internal or external restraints are changed, as would take place during remanufacture. Boards that are deformed in shape are not acceptable. Neither are boards that have experienced structural damage.

Thus it may be assumed that any board which experiences any change in bound moisture content will become internally stressed and produce either shape or structural degrade until or unless the stresses are relieved.

The process of stress relieval, fortunately, does take place, presumably by means of various structural elements of the cell wall sliding along each other and by breaking and reforming bonds as they move so that structural integrity and shape are maintained. This process is called "creep."

The process of "creeping" or stress relief obviously requires that there are opposing forces operating. Some of these forces exist within the board itself. Others are applied by restraint forces outside the boards as is shown by the fact that boards near the top of the charge in the kiln are much more prone to warping than are the boards near the bottom of the stack.

The key problem in successful drying lumber to produce maximum quantity and quality of product is, therefore, to balance the rate of moisture removal from the various cell walls within the rate of creep which takes place or can be made to take place in order to minimize the stresses which are set up. This concept is, of course, not new. It was inferred by the classic work of John McMillen at the Forest Products Laboratory, and stated more specifically by Bello in his doctoral dissertation at the University of Wisconsin.

I am convinced that if more knowledge existed (or if probably existing knowledge were applied more effectively) concerning the mechanism of stress relief at boundaries between various components such as molecular chains, micelles, high density late wood and low density early wood, tracheids and rays, cellulose and hemicellulose, cellulose and lignen and others, more effective drying of lumber with less loss of value would result. I am not comfortable with the present state of the adequacy of my knowledge.

General: A final question I cannot answer is why we do not operate our kilns as well as we know how? Why do we tolerate sloppy stacking, stickering and other load preparations? Why do we not use our charts to better advantage to show what the drying conditions actually are? And why is kiln maintenance so often neglected. I am not speaking to any one of you, but the man sitting next to you is probably guilty of this type of operation.