

LUMBER MOISTURE CONTENT AND TEMPERATURE AS A BASES FOR CONTROL OF KILN CONDITIONS

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INTRODUCTION

Lumber drying is an enormous industry in this country. Last year about 50 BILLION board feet of lumber were produced. Of that about 25 BILLION were kiln dried.

I know that most of you are already doing a good job drying lumber. But I imagine many of you would like to do better. You'd probably like to increase the quality and quantity of lumber coming out of your kilns.

What I'm going to talk about is how you might be able to do just that. I'm going to describe how you can monitor drying and control your kilns better by having direct knowledge of the lumbers' moisture content (MC) and temperature.

Why use lumber MC and temperature for kiln control? Because control of drying is ideally based on adjusting kiln conditions to the MC of part or all of the lumber. The methods I'll describe do just that.

Some of what I say won't be news to all of you. Some of you already use kiln controllers that monitor and control kiln conditions based on lumbers' MC and temperature. I'm going to talk about the principles on which those machines work, when they're effective, and when not.

GOAL AND OBJECTIVES

My goal is to explain how you can use lumbers' MC and temperature to control kiln conditions.

My objectives are to:

1. Explain how water is contained in wood and how it tends to move out during drying,
2. Describe how lumber's MC can be determined by its electrical resistance,
3. Discuss how lumbers' MC and temperature are related to kiln conditions,
4. Discuss the results of tests we did to measure those relationships, and
5. Conclude with some thoughts about how you might use lumbers' MC and temperature to control drying of most softwoods.

WATER IN WOOD

I'll briefly describe how water exists in and moves out of wood so you'll understand why MC and temperature gradients develop. I'll do this because those gradients can greatly affect the timing and type of control possible with the controllers I'll be talking about.

Water exists in wood primarily as a liquid or vapor in the cell cavities, which is called "free water". It also exists as molecules bound to the woody material in the cell walls, which are called "bound water". During drying, when the pits or holes in the cell walls allow it, the free water tends to move first and fastest out of the wood.

The condition that exists when an individual cell's walls are saturated with bound water but there is no free water in the cavity, is called the fiber's saturation point (FSP). Since drying tends to take place faster on the surface of a piece of wood you would expect the cells in that part of the wood to reach the FSP faster than those in the center of the piece, which is exactly what tends to happen. For that reason, even though

we talk about a piece of wood being at the FSP what we really mean is that the average of all the cells in the piece is at that state called the FSP.

That's an important phenomenon to be aware of when measuring wood MC electrically.

Different woods have different MCs. Sapwood MC usually differs from heartwood MC. Lumber from trees cut in the spring usually have different MC from trees cut in the winter. And so on. All these factors can affect not only the MC of the lumber going into the kilns but also the way the water moves out of the logs.

Something else that exists in wood are chemicals that give wood it's characteristic colors, odors and feel. What's important about those chemicals is that some of them also act as electrolytes, which can conduct electricity very well.

I won't deal with that anymore than to say that how and where electrolytes and water are contained in lumber, and how fast that water moves out of lumber in response to kiln conditions, can all affect the way MC is detected.

MEASURING MOISTURE CONTENT ELECTRICALLY IN LUMBER

The following are some important considerations when trying to monitor and control kiln conditions based on what's happening in the kiln.

There are many ways to measure lumber's MC. We used electrical resistance because we were interested in how and how well the commercial kiln controllers using that principle worked.

Most of you probably are familiar with the electrical resistance or pin-type MC meters. These meters function by trying to pass a current from one electrode or pin stuck in the wood to another stuck in the wood a little way away. The meters measure the resistance.

The woody material, water and electrolytes conduct different amounts of electricity. Wood alone is an excellent insulator and conducts little electricity and therefore is said to show a high resistance. Water is just the opposite and electrolytes are better conductors yet. Water and electrolytes show a low resistance.

The way electric MC meters function depends on a large number of factors like extractives type and content, wood temperature, grain direction, and specific gravity. Some modern meters correct for some of these factors automatically.

Now for the key point! Published research has shown that the electrical resistance of wood is so low above the FSP, or about 28% MC, that it can't be detected reliably. This is because the free water and electrolytes in the wood above the FSP create a relatively open pathway for electrical current so the resistance is very low. Therefore, any MC detected above about 28% is suspect.

Conversely, electrical resistance of wood below about 7% MC can't be detected reliably. In this case there is so little water that too little electrical current is passed to be detected reliably. Therefore, any MC detected below about 7% is suspect.

You should keep this range of 28% to 7% in mind during my talk and even moreso if you decide to use this type of equipment in your operations.

HOW LUMBER'S MC AND TEMPERATURE ARE RELATED TO KILN CONDITIONS

Lumber's Moisture Content

Air Temperature

Air temperature is related to lumber MC in the following way. Moisture tends to move within and out of lumber at a greater rate at higher temperatures. By increasing air temperature the moisture in lumber will tend to move out of the lumber at a greater rate. As the MC gets lower it takes higher temperatures to keep the remaining moisture moving into the air stream. In the same way, if the air temperature goes down you would expect the rate of moisture movement to slow down.

Air Humidity

Moisture tends to move within and out of lumber at a greater rate at lower humidities. By decreasing air humidity, usually indicated as a lowered wet-bulb temperature, the moisture in lumber will tend to move out of the lumber at a greater rate. As the MC gets lower it takes lower humidities yet to keep the remaining moisture moving. In the same way, if the air humidity goes up you would expect the rate of moisture movement to slow down.

Air Circulation

The velocity, volume and turbulence of the air stream can all affect the rate at which surface moisture evaporates from the lumber. In general, increases in all three will increase the rate of moisture movement given the moisture is at the surface and able to escape into the air stream.

Lumber's Temperature

Were the cooling effects of evaporation not a factor, higher air temperatures would heat the lumber and cooler air would cool the lumber. However, as moisture evaporates from the surface of the lumber it takes with it some heat, which cools the lumber as a result. This same phenomenon takes place from the surface into the center of the piece so the entire piece is cooled by evaporation from the surface. Therefore, the effects of air temperature, humidity and circulation characteristics all affect lumber temperature in as much as they alter the rate of evaporation and evaporative cooling.

Thus, air hotter than the surface of the lumber will tend to heat the lumber. But as water evaporates the lumber will cool. The cooling effects penetrate into the lumber.

At the start of drying when free water exists at the lumber's surface, the lumber's surface temperature will be about the same as the wet-bulb temperature since the same evaporative-cooling phenomenon is at work. This condition will persist until no free water exists on the surface. Where there's free water inside the lumber, however, this same cooling phenomenon will continue to exist and the temperature of the interior of the lumber will tend to the wet-bulb temperature.

When no free water exists the surface temperature will increase. As the free-water line moves into the piece the higher-than-wet-bulb temperature line will migrate into the lumber.

In this way the temperature of the piece will be indicative of the MC of the piece at the point where the temperature was measured. In the same way, the rate and timing of the change in temperature will be indicative of the rate and timing of the change in MC of the piece.

That's the KEY phenomenon to consider that monitoring and controlling lumber drying based on lumber's temperature.

TESTS IN A COMMERCIAL KILN

Kiln Conditions

We measured dry- and wet-bulb temperatures during the first test by attaching 24-gauge thermocouples to the bulbs on the side of the kiln where we measured lumber conditions.

Because the bulb temperatures didn't give us the kind of data we wanted, for the second and third tests, we switched and measured temperatures entering and leaving the lumber load with 24-gauge thermocouples inserted in the sticker slots, on both sides of the charge, immediately above where the sensors were installed in the lumber.

Wood Conditions

Our meter's electrodes were small, stainless steel ball bearings to which tiny, 40-gauge wires had been welded (Figure 1).

We drilled holes 1 1/4" apart and 2" into the edges of lumber on the edge of the load. This was about how and where sensors would have been placed in a commercial, high-production softwood mill.

We installed sets of sensors in holes drilled immediately below the surface and at three other equally-spaced depths through the thickness of each piece, that is, at 1/6, 1/3 and 1/2 the thickness of the pieces. I'll call the MC just under the surface the "surface MC" and the one in the center the "core MC".

Temperature

We measured lumber temperature with the same sensors we used to measure MC.

The Tests

We gathered data from three kiln runs. The runs took place in December. For several reasons the kilns didn't have all the steam they needed to maintain the set-point conditions.

In each of the three figures that follow I'll describe the findings from a single test. In each of these figures the bottom lines represent kiln conditions, the middle lines represent lumber temperature and the top lines represent lumber MC.

The vertical lines are there to help make comparisons easier.

Test #1

Kiln conditions

Because of an electrical malfunction, Test 1 yielded data for only the last 27 hours (Figure 2). However, those data indicate good control of both temperature and humidity during that period.

Lumber Temperature

Lumber temperatures are shown from the surface (top line) to the center of the piece (lowest line). Only near the surface did changes in lumber temperature reflect changes in air temperature. The core temperature was 9-14° F below dry-bulb temperature and 16-21° F above wet-bulb temperature. The core temperature rose only about 1.5° F. This indicates that drying was still taking place through the thickness of the piece.

Lumber Moisture Content

Surface MC declined from 7% to 6%, values lower than those considered reliably detectable.

Average internal MCs declined from 15.5% to 9.75%. There was a small but measurable difference between measurements at the other depths.

Implications for Control

Under these conditions kiln control based on internal wood temperature probably would be only slightly more precise than control based on air temperature, because internal wood temperature was slightly less variable. However, since air temperature and humidity reflect drying among many of the boards in the kiln, an operator would choose that means.

On the other hand, kiln control based on lumber's internal MC probably would be a better means because MC showed a greater and steadier decrease.

Test #2

Kiln Conditions

These data show there was insufficient steam to bring the kiln up to the setpoint temperatures until near the end of drying (Figure 3).

The entering-air temperature was higher and tended to oscillate up and down a great deal whereas the leaving-air temperature did not probably because the evaporative-cooling and moderating effects of the lumber load.

Lumber Temperature

For the most part, wood temperature followed air temperature. But there were some important exceptions.

The first exceptions were related to fan reversals. During hours 0 through 24, when the air passed over the sample board before entering the load, wood temperature followed air temperatures closely and positively. Immediately after the fan reversal at hour 24, however, wood temperature decreased as air temperature continued to increase. This was as expected because now air passing over the sample board first had to pass through 9 feet of sticker slot from the other side of the load, picking up moisture and losing heat. That moist, cooler air moistened and cooled the sample board.

The second fan reversal, at 72 hours, had the opposite effect; relatively hot, dry air again passed over the sample board before entering the load. Board temperature then rose rapidly and followed air temperature for the rest of the test. As in Test 1, air temperature affected surface temperature more than it affected internal temperature.

Lumber Moisture Content

Surface MC, the lowermost line, rose sharply at the outset probably indicating a temperature-based response of the sensor. This could also indicate a rapid movement of free water from the interior to the surface. Keep in mind, however, that these data are suspect because they're out of the accuracy range of the MC meter. MC fell steadily to below 28% after about 10 hours.

At hour 24, when the fans were reversed, surface MC rose rapidly, probably because moisture-laden air now passed over the sample board preventing evaporation of moisture migrating from the interior and perhaps even causing some moisture to be reabsorbed from the air. After that initial rise, surface MC changed little until about hour 48, when air temperature began a gradual upward trend.

From hour 48 until hour 72 there was an increasingly rapid drop in surface MC in inverse response to air temperature. At hour 72, when the fans were again reversed, surface MC dropped rapidly to about 5%, the equilibrium MC of the circulating air. Because MC measurements below 7% are suspect, we consider the 5% measurement as only a general indication that the wood surface was no longer drying. Internal MCs showed trends, e.g., MC increased before decreasing, which, though expected, cannot be explained because of limitations in the data. What is significant is that the sensor nearest the surface registered unreliable MCs until hour 45, and the other two sensors showed unreliable MC readings until hour 60. Those times represent about 1/2 and 2/3 of the total drying time.

The MC of the dry, cooled board, measured with a hand-held meter, was 12.5%, about that indicated by the sensor at the 1/3 depth. That's a good indication that the in-kiln sensor was accurate at that MC.

Implications for Control

Kiln control based on the temperature of either air or lumber would be difficult under the conditions of Test 2. It's not clear which internal temperature would be best nor how to cope with fan reversals.

Control based on lumber MC might be effective and reliable, assuming the sample board was chosen correctly, in the range of 28% to 7% MC. There are, however, two problems that are made very clear by these data.

First, while the surface MC dropped into the reliably-measurable range early in the drying run, making those data usable for drying control, that MC reading was rendered "questionable" after the fan reversal. Then, towards the end of drying the

surface MC dropped below the reliably-measurable level making it unsuitable for reliable control.

Second, during from 1/2 to 2/3 of the entire drying period the internal MCs were outside the 28% range making them unreliable for control. Therefore, control of kiln conditions for the first 1/2 to 2/3 of the schedule would have to be based on some other measurement.

Test #3

Kiln Conditions

These data show the kilns inability to achieve the desired setpoints (Figure 4). Control, however, was better.

Lumber Temperature

The two lumber temperature lines correspond to the average surface (upper) and core temperatures of three different pieces. Lumber temperatures changed positively with air temperature although the change was not great until the fans were slowed at hour 66 and again when they were reversed at hour 72.

The owners had recently installed a variable-frequency fan motor controller. At hour 66 they slowed the fans, which dropped the air velocity from 450 to 360 feet per minute. The effect was that lumber temperature dropped. The effect probably would not have been so noticeable had the fans been slowed after fan reversal so that air would not have passed through the stack before passing over the sample board.

When the fans were reversed again at hour 72, and the air striking the sample lumber now was coming right off the heating coils, lumber temperature rose rapidly and continued to rise for the rest of the drying period.

Lumber Moisture Content

The three lines correspond to the MCs of three different boards in which sensors were placed at 1/3 of board thickness. The two upper lines represent "slow-growth" boards while the lower line represents a "fast-growth" board. Two significant phenomena appeared in all three cases:

- 1) an initial sharp rise and then fall in MC, and
- 2) a later, relatively rapid increase in drying rate after the second fan reversal at hour 72.

The MC of the fast-growth board, the lower line, fell below 28% at about hour 15. The MCs of the slow-growth boards did not reach this level until about hours 74 or 84, equal to 2/3 and 3/4 of the entire drying period.

The more obvious trends appear related to the kiln conditions and lumber temperatures as described in Test #2.

Implications for Control

Implications for control are the same as those for Test #2.

CONCLUSIONS

Kiln Conditions

Lumber drying is controlled by manipulating the temperature, humidity, and character of air circulating in the kiln. Control requires that sufficient heat, humidity and air circulation be available to achieve and maintain the desired conditions. Without that there can be only poor control at best.

If only dry- and wet-bulb conditions are measured, then what are controlled directly are dry- and wet-bulb conditions. Only indirectly is lumber drying manipulated.

Lumber Temperature

Internal temperature may be a useful indirect indicator of MC and of the rate at which drying is taking place in the sampled boards. However, surface temperature may be so like air temperature that its measurement would give little or no added benefit.

Internal temperature could be used to indicate MC indirectly. Once the lumber is heated up, a big difference between internal temperature and air temperature would indicate high internal MC; a small difference would indicate low MC and slow drying rate.

Determining the drying endpoint from internal temperature probably would be possible only with species that exhibit a fast drying rate and higher MC all the way to the end of the drying period. In other species, the difference between lumber and air temperature might be too small to be reliably measurable and therefore of significant benefit.

Lumber Moisture Content

Electrical-resistance measurement of lumber MC appears useful for kiln control within the range of about 7% to 28%. If you're drying lumber that has a high average green MC then you might be faced with the situation of having to control kiln conditions based on some other measure for a significant part of the total drying period.

On the other hand if your lumber has a lower average green MC, or is air dried, the conditions you're faced with may be entirely different. The commercial controllers that function on these principles are today controlling thousands of kilns in other countries around the world primarily in hardwood operations.

As with lumber temperature, control is based on what is happening in the single or few pieces being measured.

The effectiveness of this measure may be reduced or eliminated by fan reversals, which can result in surface wetting.

Therefore, given the limits of a very small sample size and MC range, internal lumber MC appears to be an effective direct measure for kiln-control purposes. If sensors are placed correctly in lumber whose drying character is understood, the actual MC, and the rate and timing of its changes, can be accurately and precisely known.

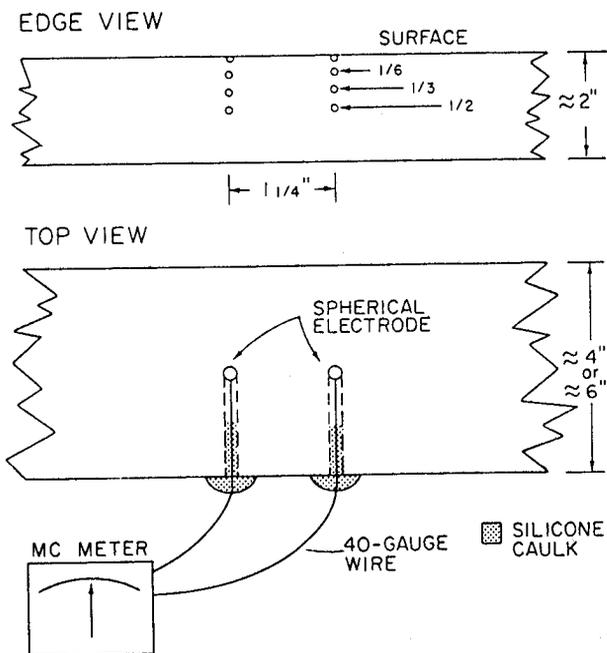


Figure 1. Illustration of sensor locations for measuring lumber temperature and MC.

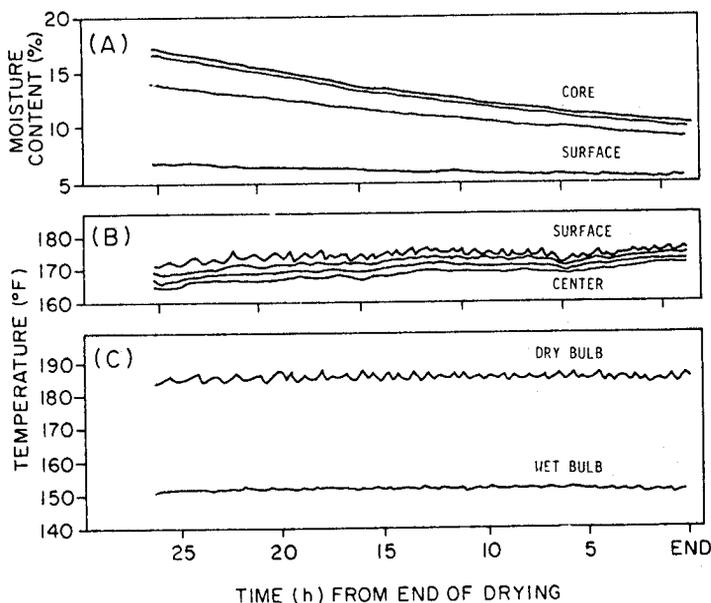


Figure 2. Graphs of (A) lumber MC, (B) lumber temperature, and (C) dry- and wet-bulb temperatures for the last 27 hours of Test 1.

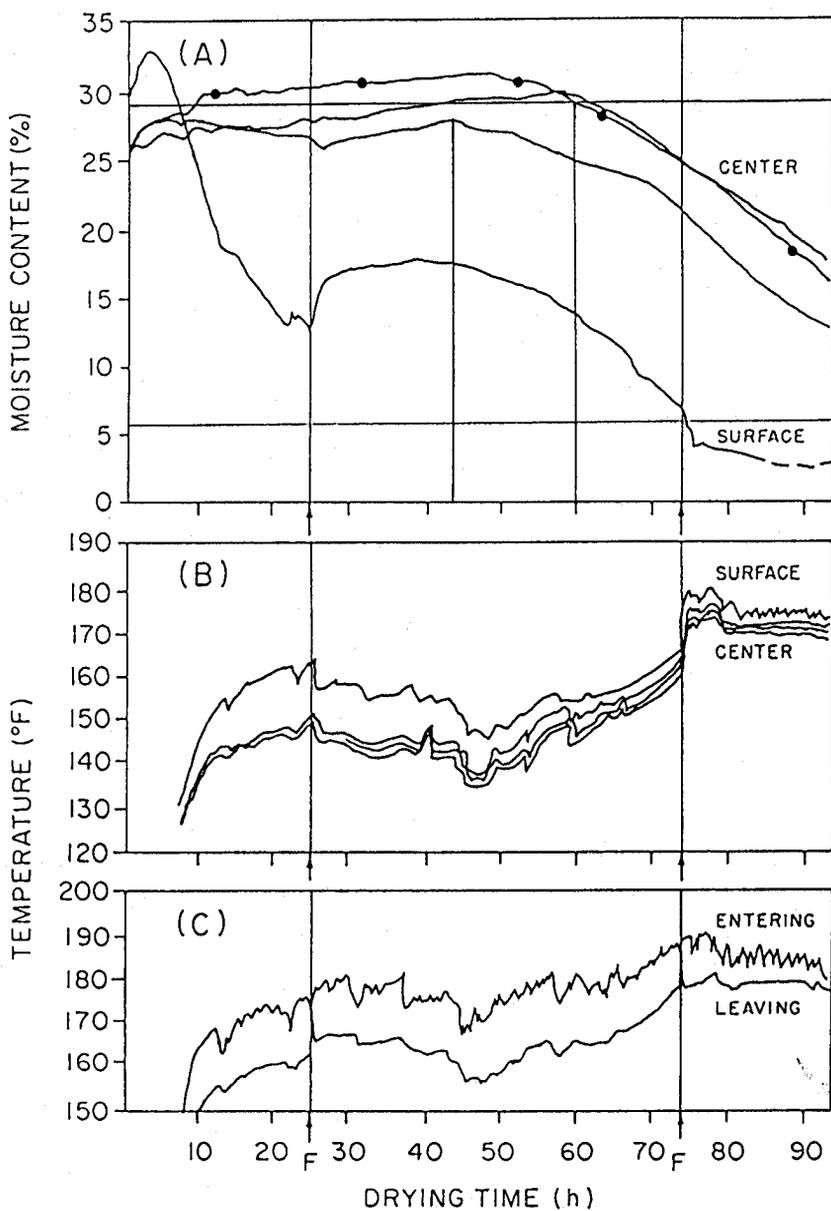


Figure 3. Graphs of (A) lumber MC, (B) lumber temperature, and (C) air temperature both entering and leaving the lumber pile for Test 2. F indicates fan reversals at 24 and 72 hours.

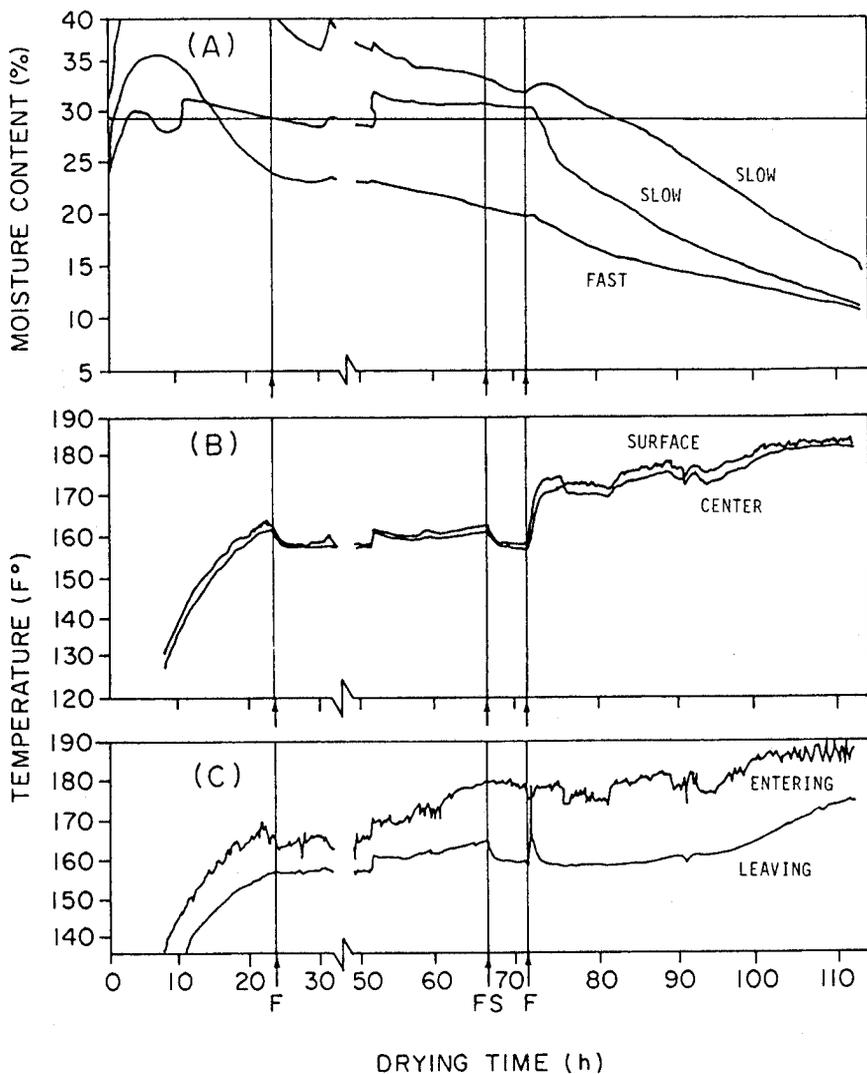


Figure 4. Graphs of (A) lumber MC (all center), (B) lumber temperature, and (C) air temperature both entering and leaving the lumber pile for Test 3. F indicates fan reversals at 24 and 72 hours; FS indicates fan slowing at about 66 hours. Note: Data for hours 31 to 50 are missing.