

# MOISTURE CONTENT BY THE OVEN-DRY METHOD FOR INDUSTRIAL TESTING

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The oven-dry test, combined with the prong or stress test, is a very useful tool for the kiln operator to have at his or her disposal. Often the kiln operator is asked to defend the accuracy of moisture meter measurements or a customer simply does not believe moisture meter readings. In other situations, the operator may want to verify meter readings for his own piece of mind. For situations in which moisture meters will give the same information more quickly and with little effort, then they are the tools of choice. However, it is important to always remember that the oven-dry moisture content is what the meters are trying to estimate.

Various methods for measuring the moisture content of wood are described by the American Society for Testing and Materials in publication ASTM D4442. These include two oven-dry methods, a distillation, and what the standard calls other methods.

In the solid wood products industry, we most often define moisture content on a dry basis. This means that the moisture content is defined as

$$MC = \frac{\text{Weight of water}}{\text{Weight of wood}} \times 100\% \quad (1)$$

The weight of the wood does not include any water. It is the weight of the piece after it is oven-dry and all water has been removed. The weight of the water is the difference in the weight of the piece before and after drying. Therefore, when the test is done we use the following formula to calculate moisture content.

$$MC = \frac{\text{Initial weight} - \text{Oven-dry weight}}{\text{Oven-dry weight}} \times 100\% \quad (2)$$

Formulae one and two are the same, one is conceptual, two is what you put into the calculator or spreadsheet.

## Equipment Needed for the Oven-dry Test

To do the oven-dry test one needs a saw, oven, and scale. The total cost of these items can vary and the size and quality purchased should be dependent on how much they will be used. If the test is to be a regular part of quality control, good equipment will have a short payback in accuracy, time, and ease of use. The selection

of the equipment needs to be thought out carefully because the cost will be \$500 to \$2000, depending on what is purchased.

## Oven Requirements

Ovens used for the test are usually electrically heated and sit on a counter top. The outside dimensions vary in size from 1'w x 1'd x 2'h on up. At the university, our largest oven is about 6' x 4' x 4' and when we need something larger we set our laboratory kiln to the correct conditions to create an "oven" in which we can oven-dry whole boards. Companies such as VWR, Blue-M, and Fischer Scientific sell ovens. The oven needs to be able to attain and hold a temperature of 217°F (103°C). This is rather important for an accurate test. A single hole or vent in the oven provides a way for moisture to get out and fresh air to get in. The size of the hole is usually adjustable. The set-point dials on most ovens are not very accurate, so it is a good idea to have a thermometer mounted in the oven to assure that 217°F is reached and held. Some ovens have a second hole for mounting a thermometer so it can be read without opening the oven door.

## Scale Requirements

The accuracy required for the scale depends on the size of the samples to be dried and accuracy to which moisture content is to be determined. It is easiest to see this by example. Let's suppose that a piece of wood weighs 125.6 grams initially and 109.4 grams after being oven-dried. If a scale is only accurate to the nearest gram, the

$$MC = \frac{126 - 109}{109} \times 100 = 15.6\%$$

If the scale is accurate to the nearest 0.1 g, then

$$MC = \frac{125.6 - 109.4}{109.4} \times 100 = 14.8\%$$

In general, the scale should read to 1 part in 1000 for the oven-dry weight of the sample to give accuracy to the nearest 0.1% moisture content. This should be adequate for any mill measurement and, in fact, is as accurate as we ever try to get at the university. So, if the oven-dry sample weight will always be more than 1000 g (2.2 lbs), the a scale that reads to 1 gram is very adequate. In general, we have found that a scale that reads to the nearest 0.1 g is what a mill needs for small samples.

The range or weighing capacity of the scale needs to be adequate to hold the sample. This often creates a problem because scales with range large enough for big samples do not have the required accuracy to do small samples. For mills that need to weigh large (3' long) samples and small samples (1" to 4" long), it is often cheaper to buy two scales rather than to try to find a high capacity scale with high resolution. A scale will cost from \$50 for a manual triple beam balance, \$200 to \$1500 for an electronic

balance with adequate resolution. Beware of good deals. We have one scale at the lab with great specifications in the catalog, but very poor stability.

Two other points about scales. Lock them down so the drug dealers don't steal them. Be careful about overloading them, especially electronic scales when they are not plugged in.

## **Saw**

A radial arm saw is needed to cross cut the samples to an appropriate length for the oven and scale. In the short-term, a hand-held circular saw can be used. A band saw may also be needed if shell-core or prong tests are to be done.

## **Performing the Test**

It is simple to do an oven-dry test, but the devil is in the details. The test is performed by cutting the sample to be tested, weighing it, drying it to a constant weight, reweighing, and doing the calculation. Now the details.

## **Sample Selection**

The samples need to be representative of the lot of wood from which they are taken. Thus, they should come from throughout a pile or shipment, not just the top or sides. After a board is chosen, the sample should be cut at least 2 feet from the end of the board because wood picks up and loses moisture very rapidly through the end grain.

The samples should either be weighed immediately after cutting or each sample should be stored in a separate plastic bag. After the initial weight is obtained, no particular precautions for storage need to be observed and the sample can be oven-dried at your convenience.

## **Weighing**

Either a data sheet with sample numbers should be used or sometimes the weight can be written directly on the sample. Once the initial weight is taken and the sample begins to dry, there is no going back so it's important to keep a good record.

## **Drying**

The time to dry is typically about 24 hours for a one- to two-inch sample cut from dimension lumber or boards. The correct method is to dry to a constant weight, meaning that the weight change over a four-hour period is less than twice the sensitivity of the scale. This means less than about 0.2 grams for a 100 gram sample.

Do not add wet samples to the oven when other samples are almost dry. Water will evaporate from the wet samples and be picked up by the drier ones causing an error when they are weighed due to a temporary increase in moisture content.

If the oven temperature is too low, the relative humidity in the oven will not be low enough. The ambient air contains moisture and raising its temperature simply lowers its relative humidity causing a lower equilibrium moisture content. For example, if the ambient air is at 70°F and 50% relative humidity, the relative humidity in the oven will be about 1% with an equilibrium moisture content of about 0.1 to 0.2%. On a humid day the samples won't dry as much, but at 217°F the variability due to ambient conditions is minimal. An oven in a humid tropical country will give results that are within 0.3 or 0.4% moisture content of and oven in a cold dry climate as long as 217°F is used.

If the oven temperature is too high, some of the wood components can be driven off. When these are counted as moisture, the indicated moisture content is too high.

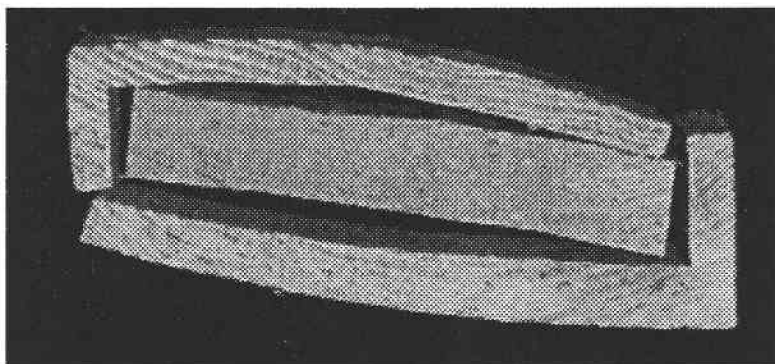
Do not overload an oven. Good air circulation around the samples is needed to reduce the risk of fire.

### Calculation

If there are a number of samples, I prefer to use a spreadsheet to calculate moisture content rather than a calculator. It is easy to go back and check for errors in data entry. After calculating a value, make sure it sense compared to what you measured. If using a spread sheet, put in some simple known values to check the calculation. For example, if you enter an initial weight of 150 grams and a final weight of 100 grams, your calculation should give a 50% moisture content.

### Other variations on the oven-dry test

The oven-dry test works well for obtaining the moisture content of a sample, but it can also be used to obtain information about the moisture distribution within a piece of wood. For example, samples can be cut every foot along the length of a board to determine how moisture content changes or a piece of wood can be sliced to determine the moisture profile through the thickness. A shell / core moisture content test is a variation on the latter. Here, the outer shell of the sample is sawn away from the inner core and the two parts are weighed and dried separately (Figure 1). This might be useful for export lumber when a customer specifies a certain moisture content at the center of a piece.



**FIGURE 1.** End grain view of wood oven-dried to measure shell and core moisture content.

## Practical Examples of the Oven-dry Test

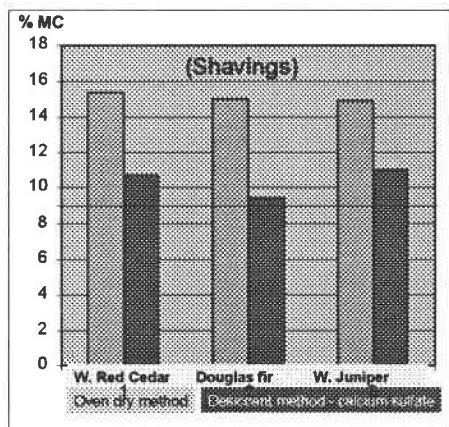
Each year the Forest Research Laboratory at Oregon State University fields thousands of questions from the general public on all aspects of wood products manufacturing. The answer to many of these comes back to moisture content. For the remainder of the presentation we would like to share some of the problems we have seen over the past year and discuss solutions.

### Comparison of MC by the Oven Dry and Desiccant Methods for Shavings

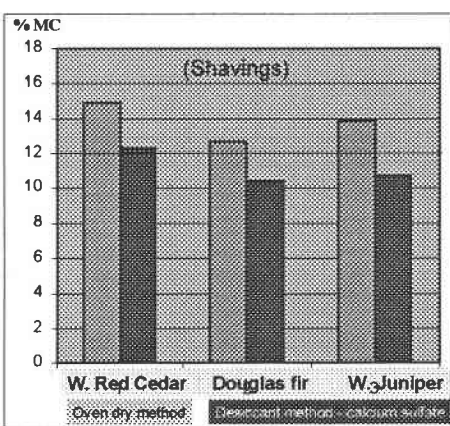
Moisture content of wood shavings was determined for three western species: Douglas-fir, western red cedar and western juniper. According to ASTM D4442, oven drying can drive volatile compounds out of some species of wood. When this occurs, the wood weighs less than if just the water had been removed. When the moisture content is calculated, the value is too high.

Usually, the more odorous the wood, the more volatile compounds are present. Extractives give wood its color. Generally speaking, the darker or richer the color of the wood, the more extractives are in the wood. Some of these extractive compounds can also be volatile and therefore driven from the wood when oven drying.

Moisture content of Douglas-fir, western red cedar, and western juniper shavings were calculated after samples were equalized at 9% and 12% equilibrium moisture content (EMC) conditions. Shaving samples were dried in an oven at  $103^{\circ}\text{C} \pm 3^{\circ}$  and shaving samples were dried over a desiccant (calcium sulfate). Results are charted in Figures 2 and 3.



**FIGURE 2.** Results of % MC calculations for three Northwest species using the OD and desiccant methods. Samples were equalized at EMC conditions of 9%.



**FIGURE 3.** Results of % MC calculations for three Northwest species using the OD and desiccant methods. Samples were equalized at EMC conditions of 12%.

For all samples the oven dry method resulted in a higher calculated moisture content. This varied from a low difference of 2.3% for Douglas-fir equalized at 12% EMC conditions to a high difference of 5.6% for Douglas-fir equalized at 9% EMC conditions.

Since there was no pattern to the data, about the only conclusion we can make is that the oven dry method may at times drive volatile compounds out of samples and therefore cause too high of a moisture content to be calculated. This is probably not as much of a problem with lumber samples since they are many times thicker than shavings.

**Importance of Understanding the Basis for MC**

A mill asked us to determine the moisture content of Douglas-fir sawmill and planer mill wood chips. We did this by weighing samples and oven drying the samples at a temperature of 103°C ± 3 degrees and calculating the moisture content using formula 2. Based on this we reported the values in the first line of Table 1.

**TABLE 1.** Values of MC reported for wood residue. Each value is an average of three measurements.

	Sawmill Chips	Planer Shavings
% Moisture content	92.7	88.6
% Bone dry	51.9	53.0

After reporting the MC results the mill manager called and said we were way off with these calculations. We told him how we calculated them and that's when we found out what they really wanted to know. They wanted us to determine the % bone dry (BD) because that is how the pulp mill pays them for their chips. It was easy to recalculate because we use the same weights as when calculating moisture content:

$$BD = \frac{\text{Oven - dry weight}}{\text{Green weight}} \cdot (100\%) \tag{3}$$

The recalculated values are shown in the second line of Table 1. A chip van can carry about 70 green tons of chips. At 50% BD, the pulp mill will pay for 35 BD tons of chips. At 40% BD the pulp mill will only pay for 28 BD tons of chips. Chips are about \$60/BD ton so the difference would be \$420 for the van load of chips.

These are reasonable values for Douglas-fir sawmill and planer mill chips. It is important to understand what people are asking. Sometimes they are not very clear on what they want or we hear something different than what they are really asking.

**Compare to moisture meter readings**

Moisture meters are, of course, calibrated to the oven-dry standard. When someone doubts their readings, we often get a few samples to oven-dry.

**Radiata pine:** A few years ago we used the oven-dry test to determine the moisture content of kiln-dried radiata pine in at a mill in New Zealand, at the port in New Zealand, at the port in the U.S., and at the secondary manufacturer in central Oregon. Because the test is so reproducible, we had high confidence that labs on both sides of the Pacific could obtain comparable results. A moisture meter could have been used, but then there are the questions of the calibration and usage by different people in different parts of the world. There was no substantial change in moisture content between New Zealand and the U.S.

In another small project with radiata pine we made the measurements shown in Table 2. The wood had been equilibrated long enough that one would not expect a moisture content difference from one side to the other. Yet, on every piece but one, the pin-type meter read higher on the bark side of the board.

**TABLE 2.** Moisture meter measurements on radiata pine.

Sample	Pin-type Meter		Received Weight	Oven-dry Weight	Oven-dry MC
	Pith side	Bark side			
	%	%	g	g	%
1	15.5	14.5	871.10	742.86	17.3
2	13.5	14.0	805.10	717.22	12.3
3	14.0	15.0	965.10	827.00	16.7
4	13.0	14.5	740.50	634.98	16.6
5	15.0	16.0	969.70	832.20	16.5
6	12.0	12.0	707.90	630.88	12.2
7	12.5	13.5	956.70	853.70	12.1
Average	13.6	14.2			14.8

**Ponderosa pine:** We often are asked to verify in-line moisture meter readings by doing an oven-dry test. The mill will pass boards across the in-line meter, cut a two-foot sample out of the board from over the meter pad. This two-foot sample gets wrapped in plastic and sent to OSU. It's very important that the piece not change weight or lose moisture from the time it crosses the pad until it is weighed. About 20 to 30 samples make a good test. After receiving the samples, we weigh, oven-dry, and reweigh them. We usually use a hand-held meter on each piece as the pieces are being weighed. In one case, the average of 30 samples was 14% for the in-line meter and 18% by the oven-dry test. A customer who receives wood at a moisture content 4% higher (or lower for that matter) than ordered can expect problems if the wood is manufactured into components such as furniture, door or window parts, and mill work. Conversely, if the meter error had been the other way, the mill is drying too much and it costs dryer time, energy, and wood degrade.

**Oregon white oak:** Oregon white oak was being dried in a small kiln near Corvallis. The kiln operators were having trouble believing that it could dry so slowly. The wood had been air dried to 20 to 25% moisture content prior to kiln drying and by day 13 of the schedule, they felt it should be dry. We suggested they use their meter on a few samples and bring them over to be oven dried. The results are shown in Table 3.

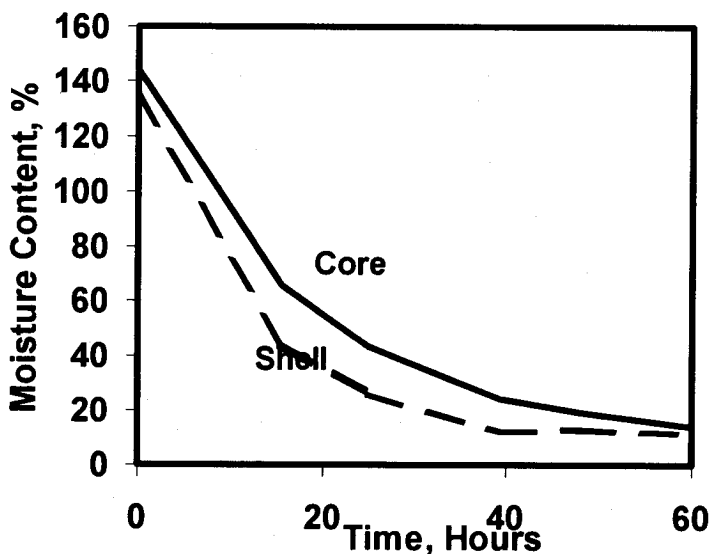
We repeated this test a week later and the meter reading were much closer to the oven-dry moisture content (in both cases meter correction factors were applied). Because their target moisture content is seven percent, they decided not to worry about the meter accuracy at higher moisture contents and recognize that the meter reading, even corrected, may be just a little high at the target moisture content.

**TABLE 3.** Moisture meter and oven-dry results for Oregon white oak.

Day 13			Day 20		
Meter	Oven-dry	Difference	Meter	Oven	Difference
11.6	13.3	1.7	6.8	6.8	0.0
11.8	13.6	1.8	9.4	9.0	0.4
11.4	12.9	1.5	7.1	6.4	0.7
10.3	11.4	1.1	9.9	9.9	0.2

### Moisture Content of Hemlock

Each year at the Oregon State Lumber Drying Workshop we dry a charge of lumber and do moisture contents by the oven-dry method. In one of our undergraduate classes we went one step further and cut shell-core moisture contents as a charge of hemlock dried. These results are shown in Figure 4.



**FIGURE 4.** Shell (broken line) and core moisture contents for 2x6 western hemlock during drying at 190°F.

Notice that the shell started at a slightly lower moisture content than the core. This is probably due to moisture losses between the time the board was sawed and the time of the test. During the early part of drying the shell lost moisture a little faster than the core, but at the end of drying the wet core caught up. During equalizing and conditioning, the core continued to lose moisture while the shell quit drying and even gained a little. Because the moisture contents at different times in Figure 4 come from different boards, there is some scatter in the data that makes this hard to see. When the same boards are weighed (instead of shell and core samples) throughout the drying process, it's easy to see that the dry boards quit losing moisture during equalizing and all boards except the wettest ones gain moisture during conditioning. This moisture gain is necessary for stress relief. If stress tests show sporadic results, it's probably the boards that were wettest at the beginning of conditioning that contain stress while the boards dried to at least three percent below the conditioning EMC are stress free. Thus, equalizing to a uniform moisture content at least three percent below the conditioning EMC is important if the conditioning process is to result in stress free-lumber.

### **Conclusions**

The oven-dry test can be a useful tool not only for verifying the readings from electronic moisture meters, but also for understanding what is happening inside of the wood as it dries. In some cases, even the oven-dry test can be in error if the wood contains a high concentration of volatile compounds other than water. The correct moisture content is important for product quality and the oven-dry test is an important QC tool.