

THE POSSIBILITY OF CONTINUOUS MOISTURE CONTENT
DETERMINATION DURING KILN-DRYING OF DOUGLAS FIR,
USING ELECTRIC RESISTANCE TECHNIQUE

By M. Salamon

Summary

A correction chart has been developed for electric moisture meters to allow their use for continuous metering of Douglas fir lumber during kiln-drying at temperatures up to 200°F.

The chart was constructed from resistance readings made with two spring-loaded resin-coated needles inserted 1.25 inches apart in test specimens at eight known levels of moisture and four of temperature. It was tested during the drying of three kiln charges of 2 by 8-inch Douglas fir in an experimental kiln by checking the corrected readings against moisture contents determined by the oven-drying method.

By using the chart and spring-loaded electrodes with an electric moisture meter, the moisture content after the first 24 hours of drying can be followed continuously throughout the drying period. Thus the time at which the moisture content of 2-inch Douglas fir passes the fibre saturation point and the time at which the lumber reaches the desired internal moisture content can be determined.

FIGURE 14. 1-1/2" DOUGLAS-FIR DIMENSION SCHEDULES

Schedule No. 1 - 2 x 6

Hrs.	Dry Bulb (°F)	Wet Bulb (°F)
0-12	190	175
12-24	190	170
24-36	190	164
36-48	190	160
48-60	190	166
60-66	190	172
66-72	condition	

Schedule No. 2 - 2 x 8

0-24	180	172
24-36	180	167
36-48	180	163
48-72	180	159
72-78	180	174

Schedule No. 3 - 2 x 10

0-24	160	152
24-36	160	148
36-48	160	144
48-72	160	140
72-84	165	150

Schedule No. 4 - All Widths

0-12	140	130
12-24	145	130
24-60	155	130
60-78	145	130

Introduction

The resistance type electric moisture meters are widely used in industry at ambient temperatures and their correction factors for many important species have been published (7). Under closely controlled physical conditions, the relationship between equilibrium moisture content and wood temperature up to 200°F. has also been determined and published (1, 3, 7, 8, 11). However, the few references in the literature (4, 5, 8) to the application of electrical moisture content readings to kiln-drying report only partial success.

The sources of error in measuring moisture content during drying are numerous and as a result the moisture meters give only an indication of the moisture content. Some of these factors are: poor contact with wood, between and within species variation, changes in moisture gradient and temperature variation--the latter resulting in leakage conductance.

The objective of this study was to develop a correction chart for an electric moisture meter under conditions used in a kiln and to devise techniques to maintain a good contact with the needles so that the method could be used for commercial drying schedules of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) or to develop new schedules based on the moisture content measured in lumber as it dries.

The experiment was divided into two parts. First, the actual moisture contents at predetermined temperatures were determined and the corrections for the readings worked out in chart form. Secondly, after establishing the correction chart a few charges were dried to test the readings against the oven-dry determinations.

Part I

The experimental kiln described earlier (6) was slightly modified to determine moisture contents of Douglas fir specimens. A rack was built on top of the kiln to hold an optical balance and a well insulated tube was inserted in the ceiling (Fig. 1).

Test pieces, 2 x 8 x 3-1/2 inches, cut from a 2 x 8-inch Douglas fir plank, were used for the moisture content determinations. An electrode assembly was mounted on this piece with needle electrodes spaced 1.25 inches apart in the direction of the grain. This test piece was then suspended in the kiln on a pair of well insulated wires from the electrode through the tube to the bottom of an optical balance on the top of the kiln. The conductor wires served both as leads to the resistance and electric moisture meters for resistance measurements and as connection to the balance for weight measurement. Temperatures were measured by thermocouples placed at the surface and in the centre of a second test piece suspended from the ceiling of the kiln at the same height as the first.

The experimental work was based on test samples with equalized moisture distribution at specific moisture contents. By doing this the contact resistance remained constant for each curve. The curves of resistance versus temperature at different moisture contents then were only functions of the wood moisture content since the resistance characteristics of the electrode assembly remained constant. The variation in wood texture within the species could not be eliminated.

The needle assembly was devised for the purpose of ensuring good contact during the drying process and therefore a force of approximately five pounds was applied on each needle to eliminate significant changes in contact resistance between the needle and wood as drying progressed (9). The assembly appeared satisfactory and throughout the experiment no sudden variations in resistance indicative of poor contact were observed.

The needle assemblies were mounted as follows (Fig. 2):

1. Holes were drilled into the specimen at the proper locations. These were made slightly oversize to give a very small clearance between the specimen and the enamel of the needles. Friction forces on the sides of the needles were thus eliminated.
2. A rubber diaphragm was fastened to the surface of the specimen over each hole. This provided a barrier preventing condensation or evaporation in the hole during decreasing relative humidity conditions.
3. The contact needles were then driven into the holes through the diaphragm.
4. The clamp was then firmly fastened to the specimen in such a way that an inverted spring-loaded needle was centered over each contact needle and applied to the latter at a constant downward thrust of approximately five pounds.

Dry and wet-bulb temperatures were maintained by a Taylor recorder controller. With even the most careful attention to adjustment, however, the dry-bulb temperature oscillated between $\pm 6^{\circ}\text{F.}$ and the wet bulb between $\pm 3^{\circ}\text{F.}$ of the requirements in the first experimental series. To correct these variations a powerstat was installed and the variations were reduced to $\pm 2^{\circ}\text{F.}$ for both the dry and the wet-bulb temperatures in the second experimental series.

Dry and wet-bulb temperatures and surface and core temperatures of the specimens were measured with an accuracy of 0.1°F. with a potentiometer using copper-constantan thermocouples. The optical balance used was accurate to 0.01 grams.

The megohm meter was suitable for measurements in the range of 100 kilo ohms to 100 megohms, which correspond to moisture contents above approximately 11 per cent at 140°F. and an electrometer having a range extending to 10^{14} ohms was used for measurements at a moisture content less than 11 per cent. A standard resistance type moisture meter was calibrated for higher moisture content range with standard resistors and by comparing its readings made on wood samples with those made with the electrometer. Throughout the study readings were taken with all three instruments to obtain comparable data.

Determination of the Correction Table

On the basis used by other investigators (2, 1, 3, 8, 11) it was accepted that the plot of the logarithm of resistance versus the reciprocal of absolute temperature yields a straight line with the resistance decreasing as the temperature increases. Each point to be converted into this straight line relation was determined in the following manner.

1. The kiln was carefully set as closely as possible to the required wet and dry-bulb temperatures.
2. The two test specimens were then placed in the kiln for several days.
3. Each day the following procedure was carried out:
 - (a) At one minute intervals for a period of twenty minutes dry and wet bulb temperatures were measured to 0.1°F.
 - (b) Similarly the surface and internal temperatures of the test specimen were measured.
 - (c) Twice a day measurements were made of: (1) the weight of the specimen, (2) the resistance with the electric moisture meter and (3) the resistance with the appropriate resistance meter.
4. By the sixth day equilibrium had been established between specimen and its environment. The readings made on this day were used for the graph.
5. The kiln was then brought to the next selected wet and dry-bulb temperature (but with the same equilibrium moisture content) and after a period of 24 to 64 hours a new series of measurements were made.

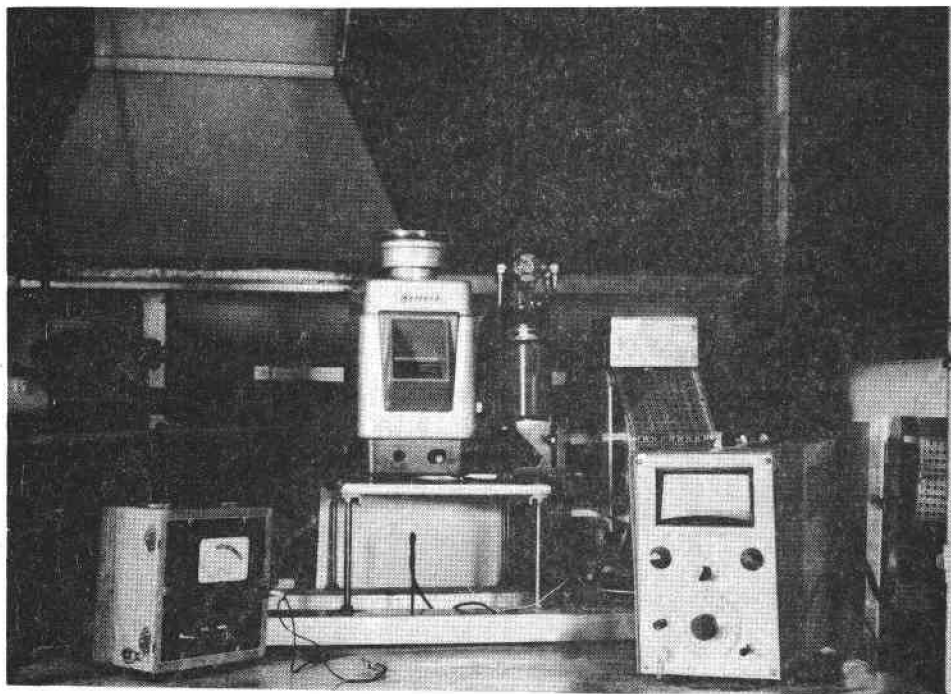
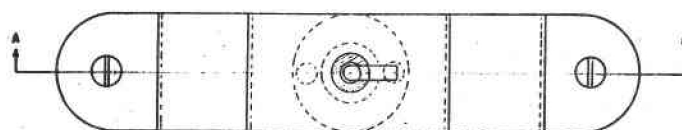
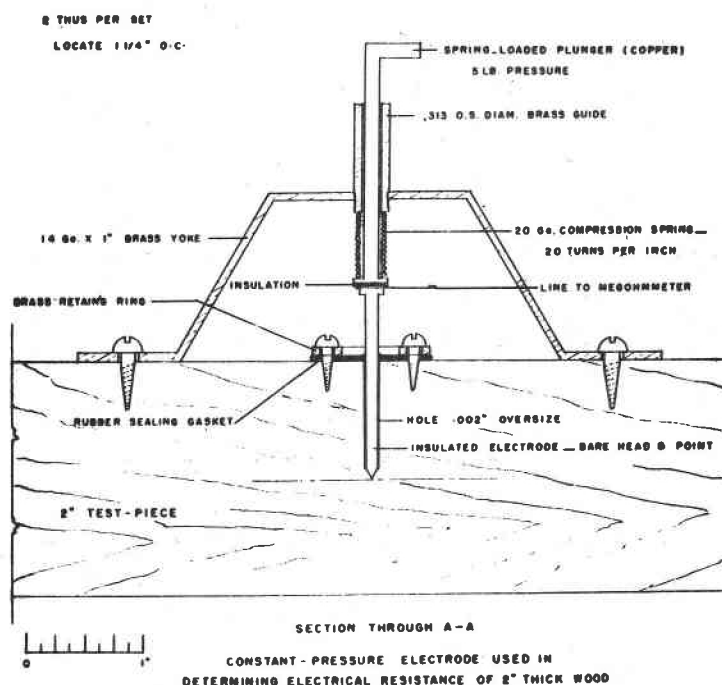


Fig. 1. Showing arrangement of balance and resistance meters on the top of the kiln.

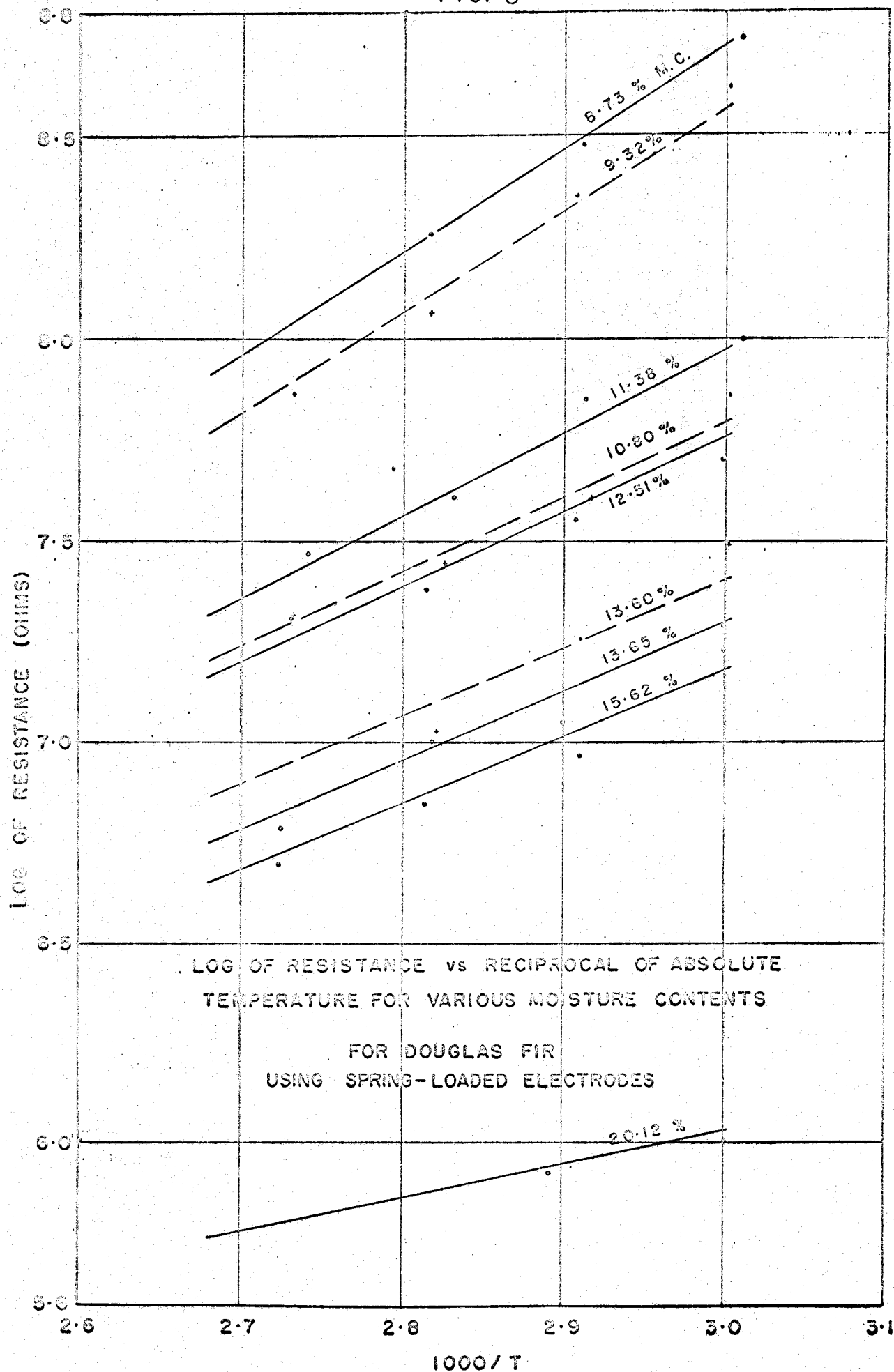
FIG 2



PLAN



1000/T



These procedures were repeated at four different temperatures at eight different equilibrium moisture contents.

Determination of final moisture content by the oven method gave results differing by 1.2 per cent from the direct weighings made during the operation of the kiln.

Results

The straight line relationships between the logarithm of resistance and reciprocal of absolute temperatures for each of the moisture content levels tested are shown in Figure 3.

This information was re-plotted in Figure 4 with the resistances in megohms on the left ordinate and the corresponding moisture content as read on an electric moisture meter on the right ordinate. The curves represent changes in resistance at the same moisture contents at different temperatures.

Figure 5, which was developed from Figure 4, is a temperature correction chart for use with resistance-type moisture meters using spring-loaded enamel coated needles 1.25 inches apart in Douglas fir.

When a moisture meter reading is obtained at a known temperature (say 20 per cent is at 160°F.) the chart is used by following a horizontal line from the 20 per cent on the left ordinate to the intersection with a vertical line from the 160° on the abscissa. This point is then followed to the right ordinate parallel to the sloping lines and the actual moisture content of 18.2 per cent read.

Discussion

The study was based on the theory that electrical conductivity in wood is an ionic process rather than an electronic one as in metals (2) which explains the linear relationship between logarithm of resistance and reciprocal of absolute temperature.

It has been shown (10) that the magnitude of the voltage applied influences the resistance measurements of cellulose materials. This fact was apparent in this study when instruments which operated at different voltages were used. Differences in resistance of up to 20 per cent between the electrometer and megohm meter readings were found when the same wood samples were measured. But the apparent resistances fall within the ± 1 per cent accuracy range of any moisture meter reading. The discrepancies in the resistance measurements are influenced by voltage, polarization and errors of the instruments which are all included in the readings.

Spring-loaded electrodes to keep the contact resistance constant were an improvement over the knock-in type resin-coated electrodes as the wood may dry away from them. It is felt that within the range of moisture measured the surface and leakage conductances were kept at a minimum by the design of the needle set. The resin coated nails extended 3/8-inch above the surface and the rubber sealing gasket was used to avoid leakage conductance.

To check the values of the basic five moisture content lines, a second series of experiments was carried out and three more lines were plotted (Fig. 3 dotted lines). It is apparent that a within species variation occurs in the electrical resistance of Douglas fir (see the lines of 10.8 and 11.38 per cent moisture content), but the variation found was within the range of 1.5 percentage points at 200°F.

Part 2

To assess the feasibility of using the correction chart, three charges of 2-inch Douglas fir lumber fitted with the spring-loaded resin coated needles, were dried. In these runs while the wood

was drying the moisture contents of different boards were measured with an electric moisture meter, then the boards were removed and the moisture content of small sections around the needles determined by the oven-drying method.

The three charges with average green moisture contents of 40, 46 and 38 per cent were prepared from two shipments of lumber. The first kiln charge was cut from 2 by 8 inch rough lumber, the second and third from 2 by 8 inch S4S lumber. The three-foot pieces used were end-coated after cross-sections were taken from their ends to determine their moisture contents. Each of the eighteen pieces of a charge were fitted with two sets of needles inserted 1.25 inches apart in direction of the grain; one set to measure the shell moisture contents and the other set to check the core moisture content. The lumber was dried in two tiers, 9 courses high and 3/4 inch stickers were used.

The same type of needle set as in Part 1 was used except that the spring was modified to fit between two lumber courses. Figure 6 shows the needle sets with insulated wires leading through the rubber stopper to the outside of the kiln. The lead wires were numbered to identify the board to which they were attached.

A constant air-circulation rate of 600 fpm was used in all kiln runs.

Run 1 was dried starting at 140°F. with 7°F. wet bulb depression and ending at 174°F. with 20°F. depression in 163 hours. Run 2 was started at 140°F. with 10°F. depression and ended in 148 hours at 174°F. with 20°F. depression; finally Run 3 was started at 160°F. with 8°F. depression and completed at 185°F. with 30°F. depression in 146 hours.

A resistance type electric moisture meter and a potentiometer were used for moisture content and temperature measurements.

After the first 24 hours drying time, the following readings were made twice each day:

- (1) Dry and wet-bulb temperatures were read with the potentiometer.
 - (2) The internal temperatures of three boards were read from thermocouples inserted in the cores.
 - (3) The apparent moisture contents of all boards were read with the electric moisture meter.
- After 48 hours drying time, twice a day and at the same time as the above readings were made, the following steps were taken:
- (4) The kiln was opened and one piece was taken out, its needle set removed and a cross-section cut out of the plank at this point. The cross-section was halved and the moisture distribution determined in the half which had contained the shell needle set and in the other half which had contained the core needle set. To determine the moisture distribution each piece was split into three sections, two shells each 1/4 of the thickness and a core of 1/2 of the thickness. The sections then were weighed in weighing bottles, dried and their individual moisture contents determined.
 - (5) A cross-section, 3/4 inch long, was also taken 2 inches from the freshly cut surface of each plank for overall moisture determination.

The kiln was gradually emptied by this procedure. Figure 7 shows four pieces of lumber left.

Results

To show the accuracy of the corrected readings against their oven-dry values, the three runs were presented in graph form. The first run also gives examples of readings at high humidity and the second includes readings of cooled lumber.

The three graphs on Figure 8 show:

FIG. 4

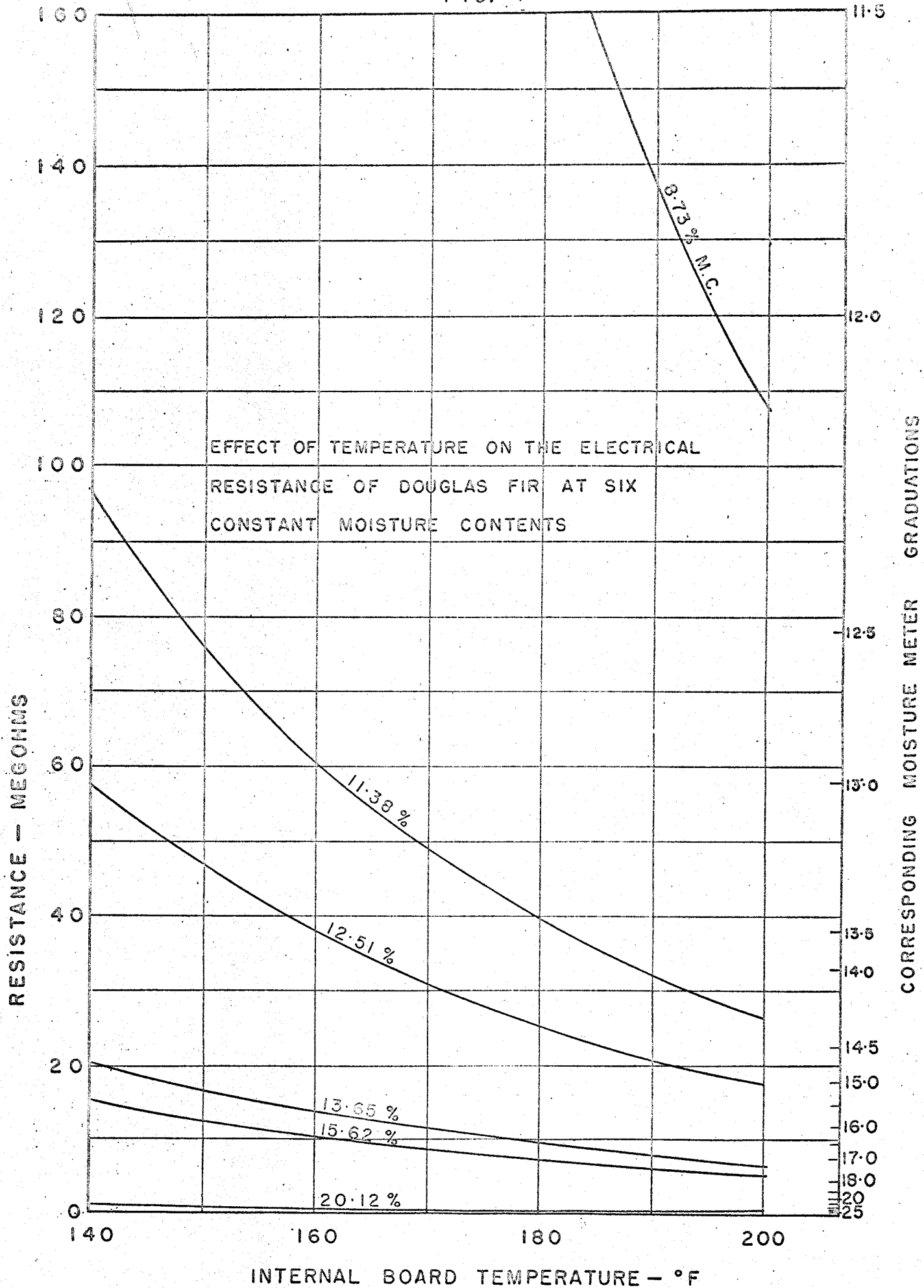
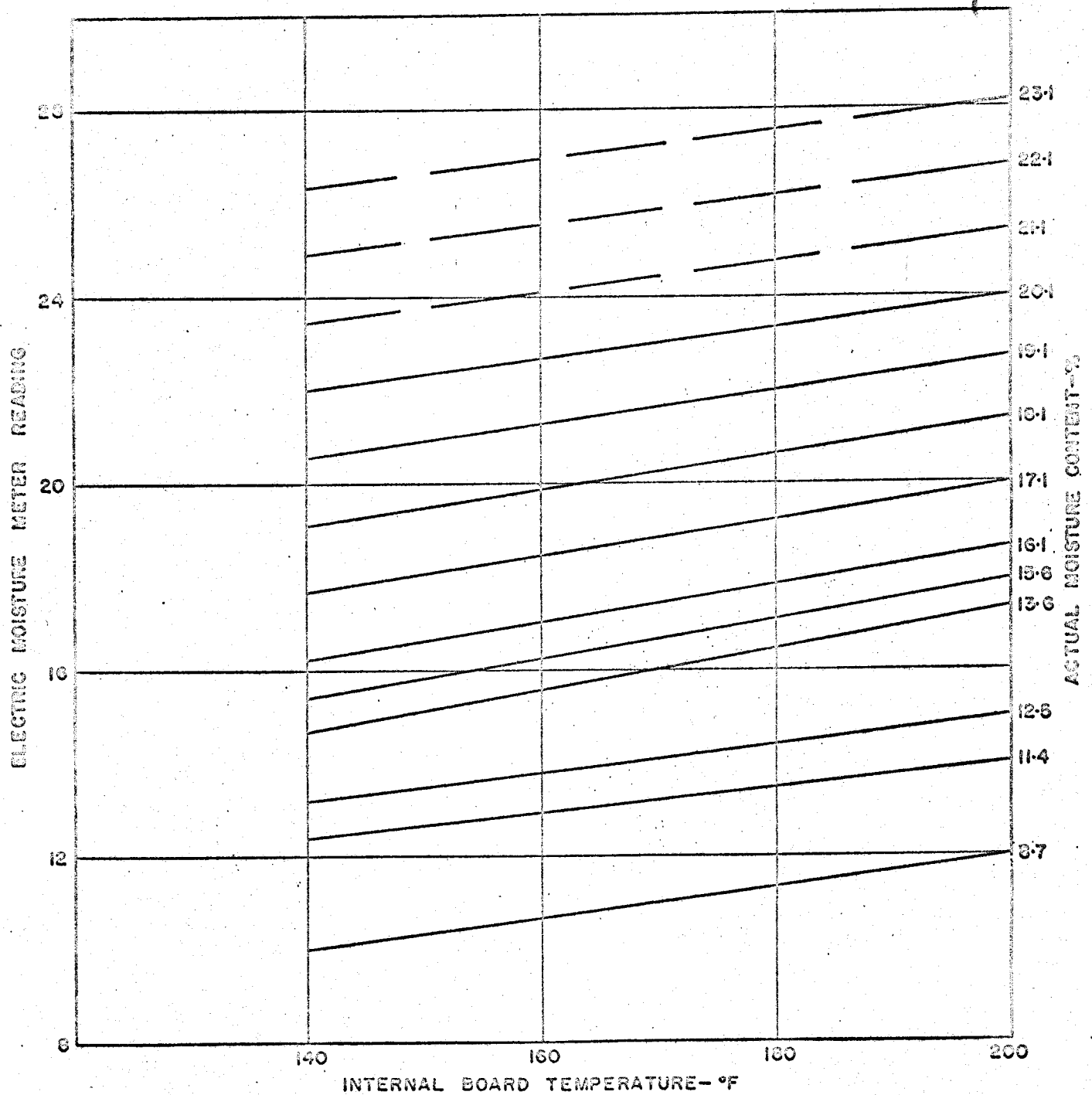


Figure 5

TEMPERATURE CORRECTION CHART
FOR RESISTANCE-TYPE MOISTURE METERS
USING SPRING-LOADED NEEDLES
FOR DOUGLAS FIR



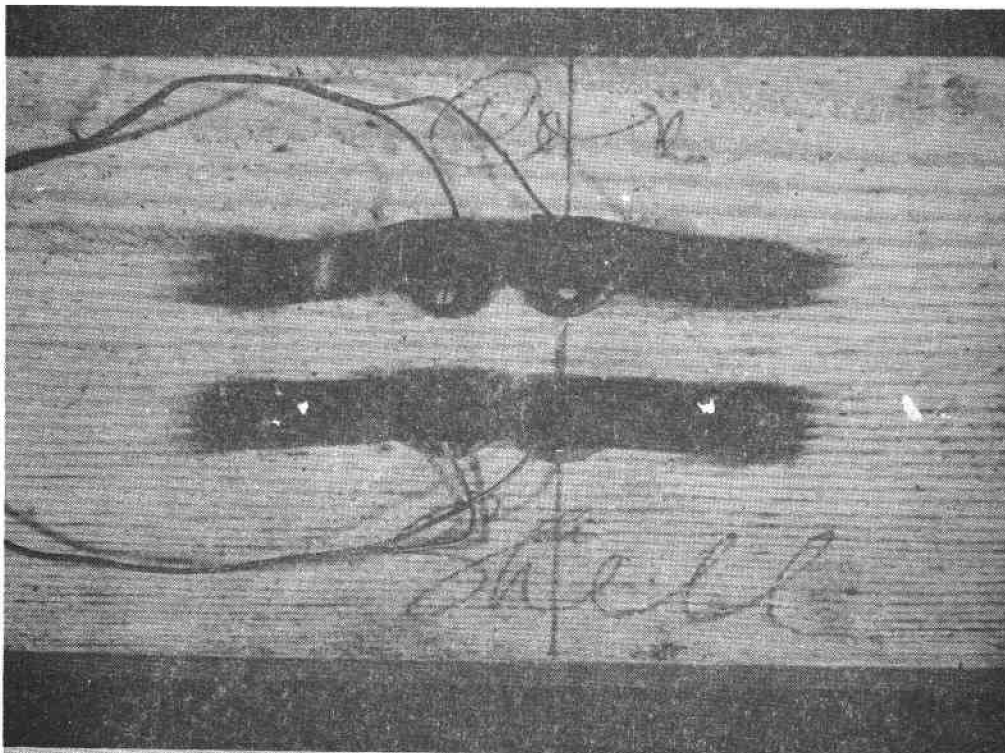


Fig. 6. Showing spring-loaded needle-sets in place.

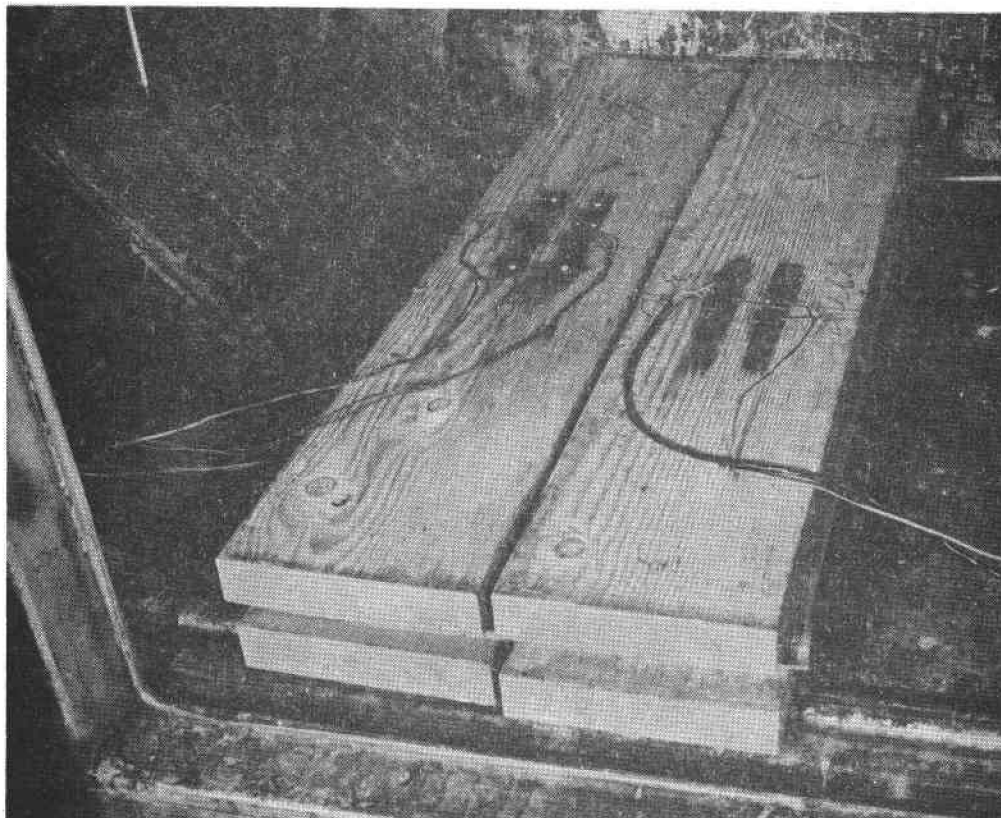


Fig. 7. Showing the last four pieces of 2 by 8-inch Douglas fir in the kiln.

1. *Chlorophyll a* (Chl *a*)

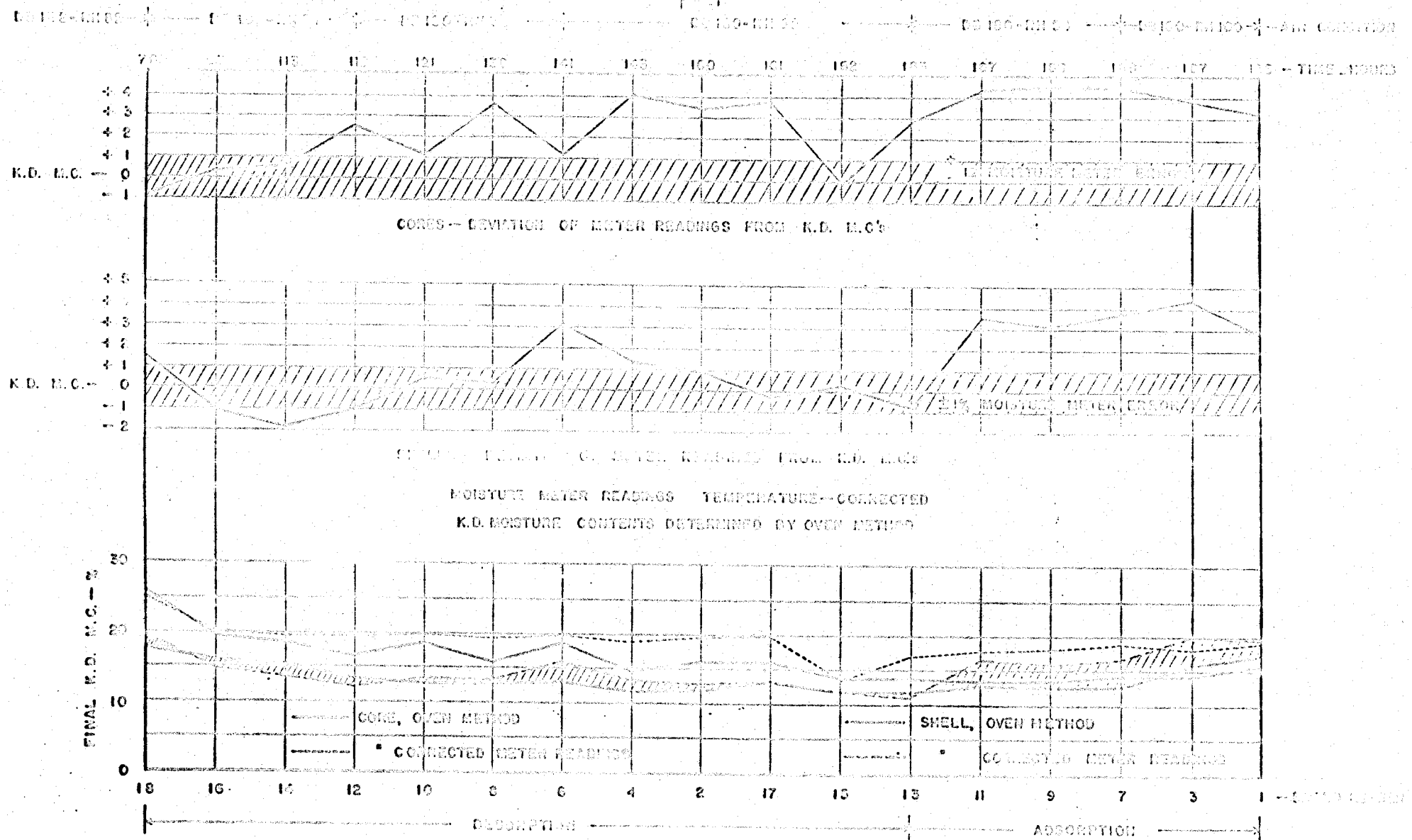


Figure 9

Run 2

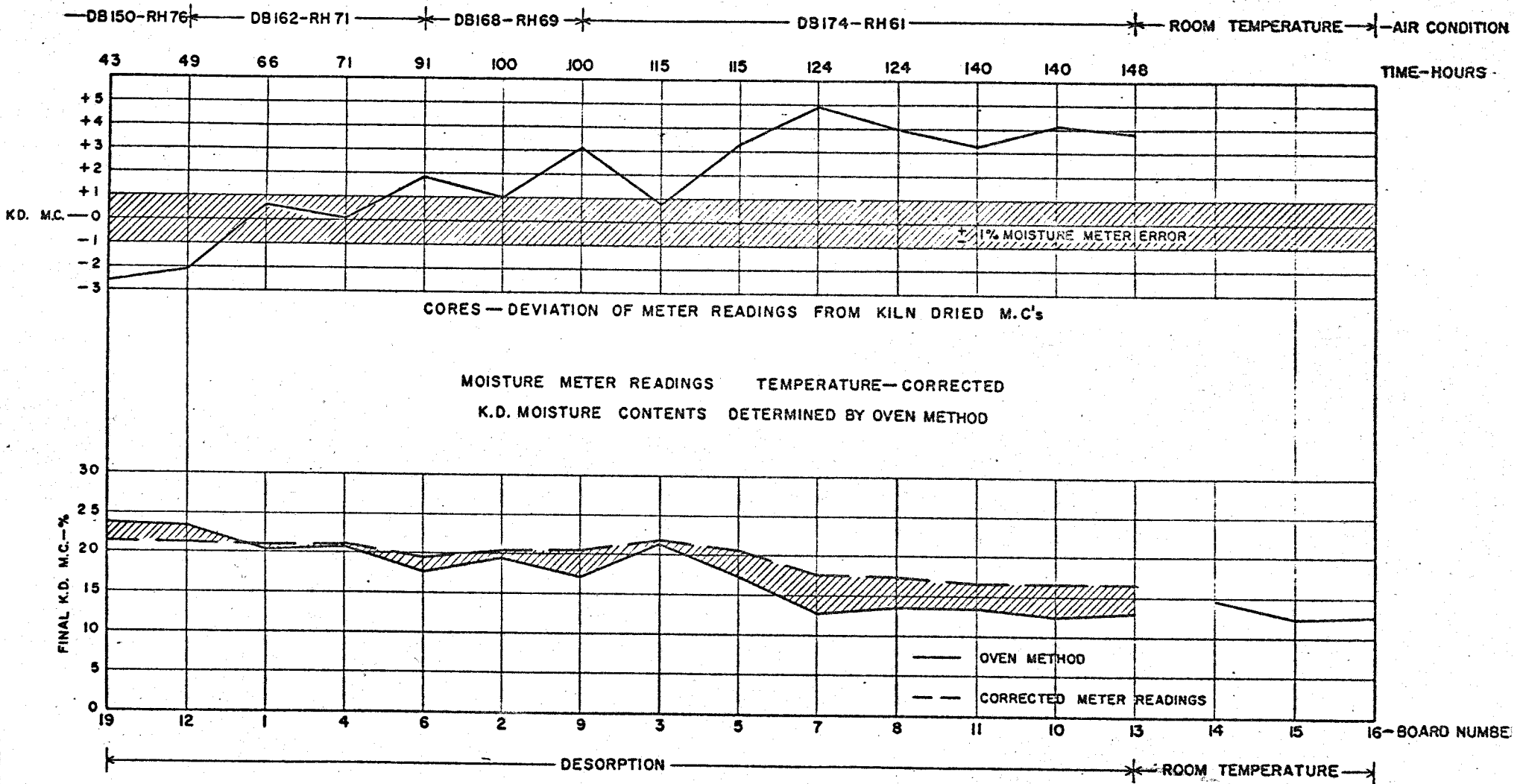
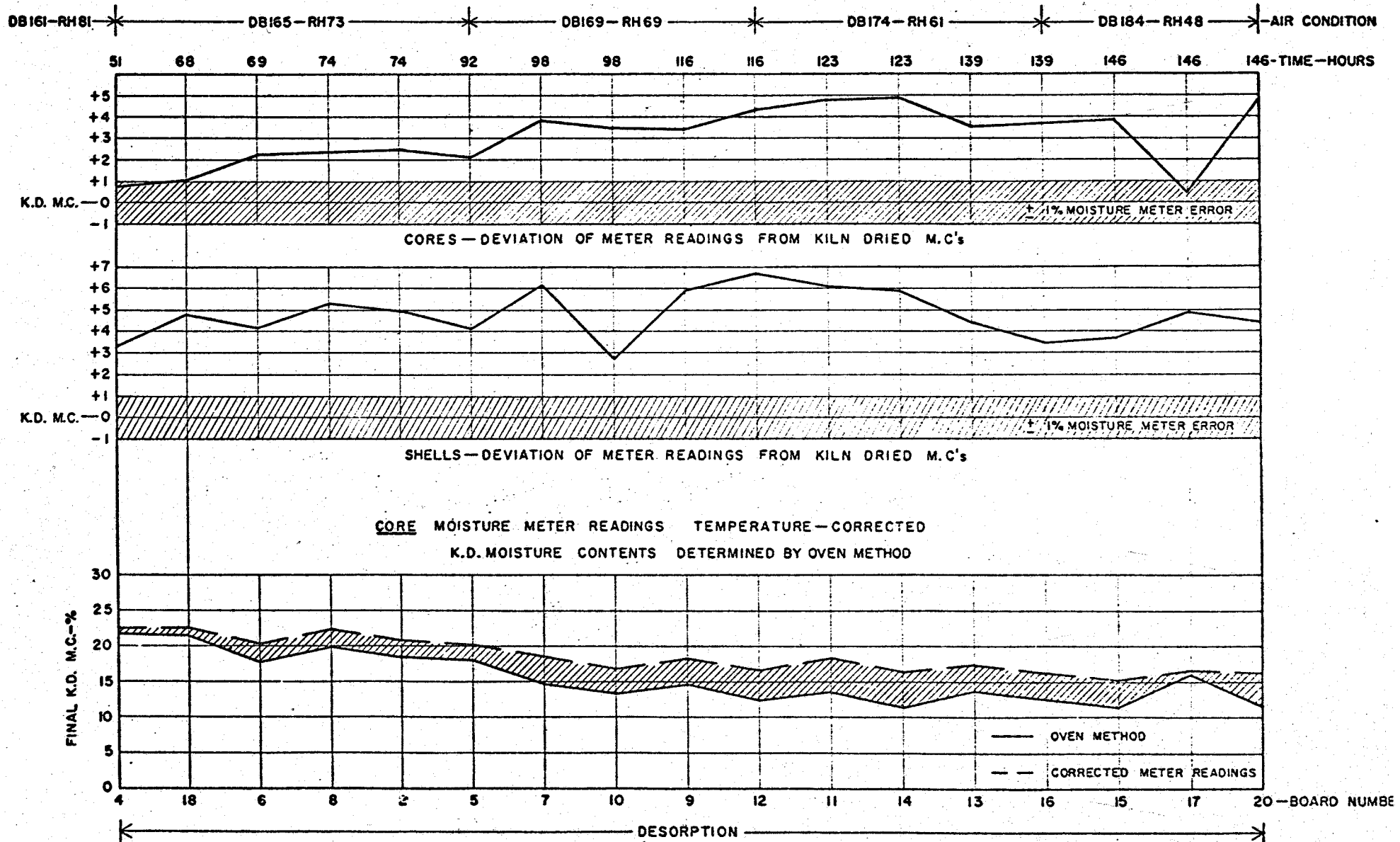


Figure 10
Run 3



- (1) The deviations of corrected core moisture content readings against the corresponding gravimetric moisture contents for all the boards in the time sequence of their sampling.
- (2) Similar deviations for the shell.
- (3) The corrected moisture meter readings and the actual moisture contents for both the core and the shell.

At the top graph the dry-bulb settings and the relative humidities are shown. The numbers at the top of each vertical line refer to the drying time which had elapsed before the board, numbered at the bottom of the same vertical line, was taken out of the kiln.

Figure 9 presents a graph similar to Figure 8 for Run 2. Here the deviations of corrected meter readings of the core only are shown. The graph on the bottom of this figure shows the corrected meter readings and oven-dry moisture contents of sampled boards as drying progressed.

At the end of this second graph the moisture content of three boards are shown after they had cooled down on completion of kiln-drying. The oven-dry moisture contents conform with those determined at the end of drying.

Figure 10 shows 3 similar graphs for Run 3, one for core moisture, one for shell moisture and the last comparing the corrected meter readings with the moisture contents determined by oven-drying.

These data indicate that as the temperature and wet-bulb depression were increased, the actual moisture contents became lower than the corrected meter values indicated. At a wet-bulb depression of 12° to 13°F. the corrected meter readings were 2.2 per cent too high, at a depression of 15°F. by 3.2 per cent and at 20°F. depression by 2.5-3.5 per cent.

Discussion

The moisture content readings from the electrodes and thermocouples positioned in each piece showed that the moisture content decreased steadily. The rubber gaskets applied to the needles prevented leakage conductance while the humidities were decreasing and were helpful in insulating the needles from the temperature of the surrounding air. The readings were within reasonable limits even at moisture contents as high as 30 per cent.

The temperature of the core section of the drying wood was within 3°F. of dry bulb temperature even at 184°F. with 30 degrees wet-bulb depression.

Leakage conductance developed when the humidity was increased by steaming at the end of drying. Consequently the electric moisture meter cannot be used at the end of drying, when the humidity is raised to equalize the shell moisture content to that of the core. But this is not important because after equalization the charge is removed from the kiln and measurements can be made on cooled lumber.

The shell readings of the rough Douglas fir were satisfactory but those of surfaced lumber were too high. The difficulty of inserting the needles to close tolerances and the steep moisture gradient near the surface might explain this variation.

Because of the moisture gradient in the lumber during drying the highest moisture content is found at the centre of a board and it decreases to the surface. At low humidities toward the end of the run this is quite pronounced so the moisture meter reading at the centre will always be larger than the average moisture of the core piece. This is an explanation of the differences between the corrected moisture meter readings and those determined by gravimetric methods.

Conclusions

1. A temperature correction chart for Douglas fir for resistance type electric moisture meters using spring-loaded electrodes was developed for use during kiln-drying.
2. Corrected moisture meter readings of core moisture contents were closer to actual values than anything reported previously.
3. Shell moisture measurements were not always reliable.
4. By applying the correction chart to moisture meter readings during kiln-drying, the following information can be obtained:
 - (a) After the first 24 hours of kiln schedule, the change in moisture content of the core can be followed and the readings even at this early stage are indicative of changes in moisture content.
 - (b) The time at which 2-inch Douglas fir lumber dries through the fibre saturation point can be determined.
 - (c) The time at which the lumber reaches a desired internal moisture content can be measured.

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