DRY KILN CONTROL BY ELECTRICAL RESISTANCE MOISTURE METER

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DRY KILN CONTROL BY ELECTRICAL

RESISTANCE MOISTURE METER

By

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Philip H. Wang

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I. INTRODUCTION

Hardwoods are generally dried according to one of the moisture content schedules provided by the Forest Products Laboratory (1).

A moisture content schedule prescribes the kiln condition as a function of the moisture content of the kiln charge. It is designed to dry the lumber in the shortest possible time with a minimum of degrade. This is accomplished by using mild conditions during the first part of the drying schedule when the moisture content of the lumber is high, and increasingly severe conditions as the moisture content approaches the final value. The control of kiln drying by the moisture content schedule makes it necessary to determine the moisture content of the kiln charge as a function of the drying time. The conventional method for determining the moisture content of the kiln charge as a function of drying time involves the use of kiln samples which are taken at uniform time intervals from various locations in the kiln charge. The number of kiln samples used depends on the characteristics of the stock to be dried, on the amount of lumber in the kiln and other factors. The average moisture content of all the kiln samples is generally assumed to represent the average moisture content of the kiln charge.

The kiln sample method does not provide a continuous record of the moisture content of the kiln charge. It is a tedious procedure subject to errors on the part of the operator. Kiln samples must be accessible and cannot be placed in the interior of the lumber pile. The operator must enter the kiln every time a sample is taken. The kiln sample method is a destructive method causing a certain amount of loss. To improve the determination of moisture content during the drying operation, some commercial instruments have been developed and are available which are based on the correlation between moisture content and electrical resistance of wood. These instruments provide a continuous record of the moisture content of the kiln charge. The electrodes may be applied anywhere in the lumber pile. They provide a quick method for determining the moisture content just by turning on the Moisture Detector without entering the kiln. By using electrode needles of various lengths, it is possible to get some differentiation between the moisture content in the shell and the moisture content in the core of the board. Therefore, compared with the kiln sample method, electrical resistance type moisture meters provide a time and labor, as well as material saving method for the determination of moisture content. However, the moisture content range, for which the moisture content-resistance relationship is usable as a basis for these instruments, is limited. Also, the electrical resistance of wood is not only a function of its moisture content. It is affected by temperature, species, grain directions, etc. Any moisture content gradient might also affect the reading, depending on the electrode arrangement.

The following is a study of the performance of a commercial instrument under actual drying conditions. The conclusions are limited to the drying of 4/4 beech.

II. DETERMINATION OF MOISTURE CONTENT OF WOOD WITH ELECTRICAL RESISTANCE METER

The Electrical Resistance of Wood

Wood, when dry, is a very good insulator. Its resistance is about 25,000 Megohms (Douglas fir board thickness 3/8", pin electrodes driven perpendicularly to the surface, 1" apart).

However, when the moisture content of wood increases, the electrical resistance decreases very rapidly. The significance of this great dependence of resistance upon moisture content has been investigated by C. G. Suits, and M. E. Dunlap (2) on 3/8 inch Douglas fir, pin electrodes spaced one inch apart, as shown on Table 1.

It may be seen that between these limits:

1. The ratio of resistance is of the order of 10^5:1.
2. The maximum resistance is of the order of 10^{10} ohms.
3. An approximate determination of resistance is a relatively accurate determination of moisture content because of the extreme variation of resistance with moisture content. If the Log 10 resistance is plotted as a function of moisture content in percent, the curve in Figure 1 will be obtained.

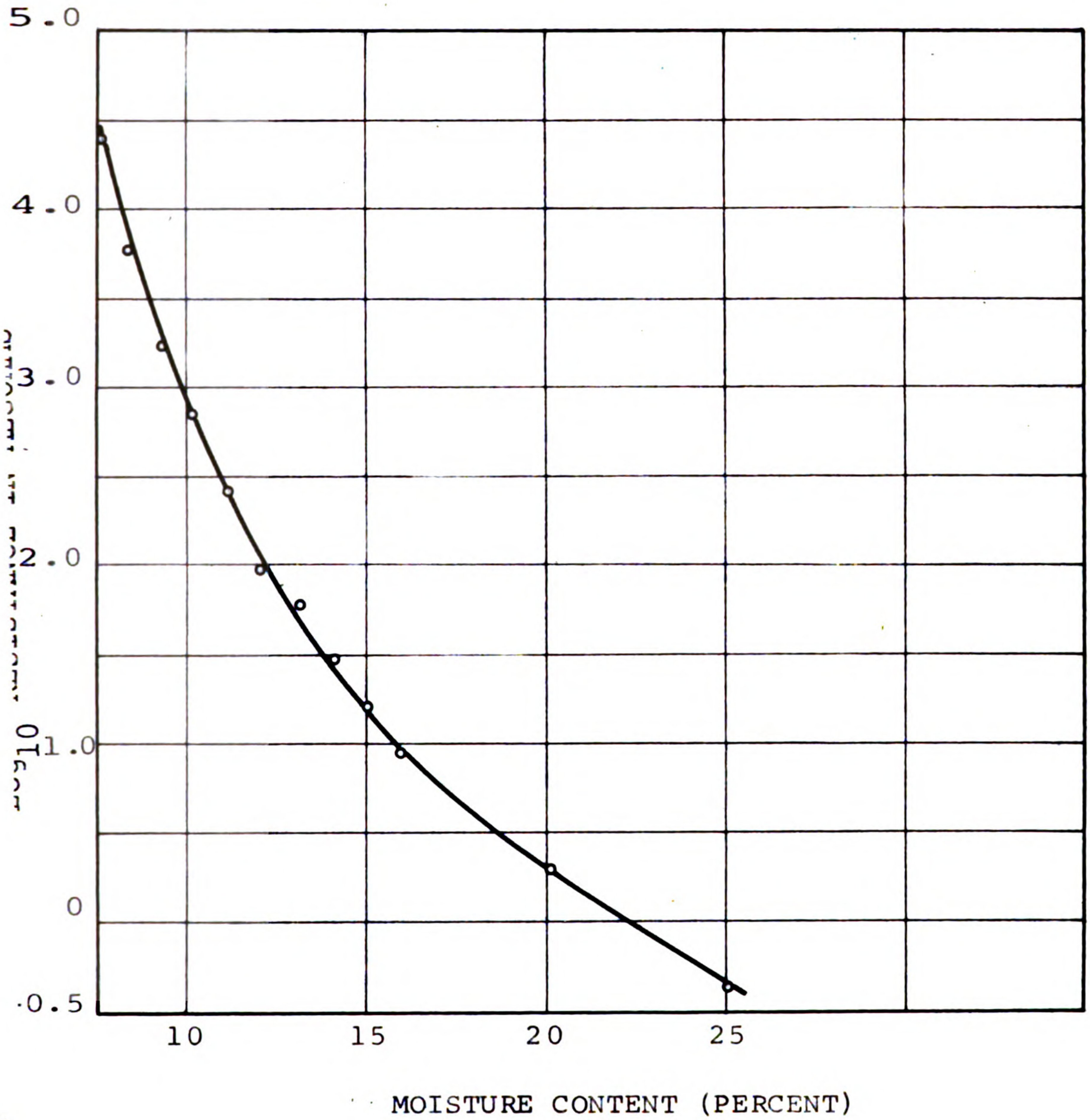
Table 1.* Relationship between moisture content and electrical resistance of wood.

Moisture content (per cent)	Resistance (Megohms)
7	25000
8	5750
9	1720
10	630
11	257
12	120
13	58.2
14	33.0
15	19.0
16	11.6
17	7.37
18	4.50
19	3.1
20	2.18
21	1.58
22	1.15
23	0.85
24	0.63
25	0.473
26	0.35

*C. G. Suits and M. E. Dunlap, "Determination of the Moisture Content of Wood by Electrical Means," General Electric Review, December, 1931.

Figure 1.* Relation between moisture content and log of resistance for Douglas fir.

*C. G. Suits and Dunlap, M. E. Determination of the moisture content of wood by Electrical Means. General Electric Review, Dec., 1931.

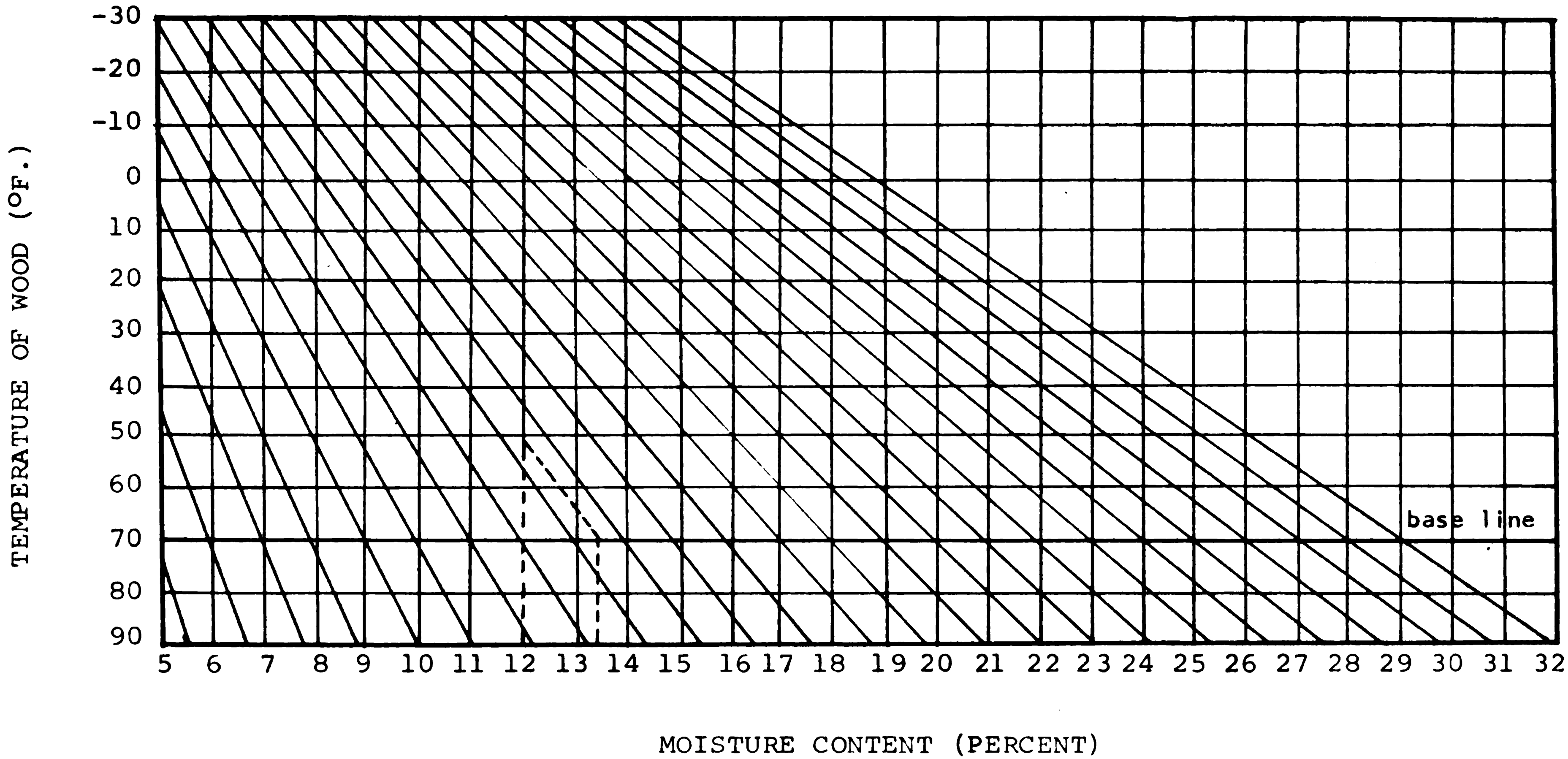


5.0
4.0
3.0
2.0
1.0
0
-0.5
10
15
20
25
MOISTURE CONTENT (PERCENT)

Besides moisture content, such factors as temperature, the presence of electrolytes, high relative humidity, species of wood, direction of current flow relative to the grain, and moisture gradient also affect the resistance of wood. But compared with the moisture content, the above factors are of secondary importance. The effects of these factors may be described as follows:

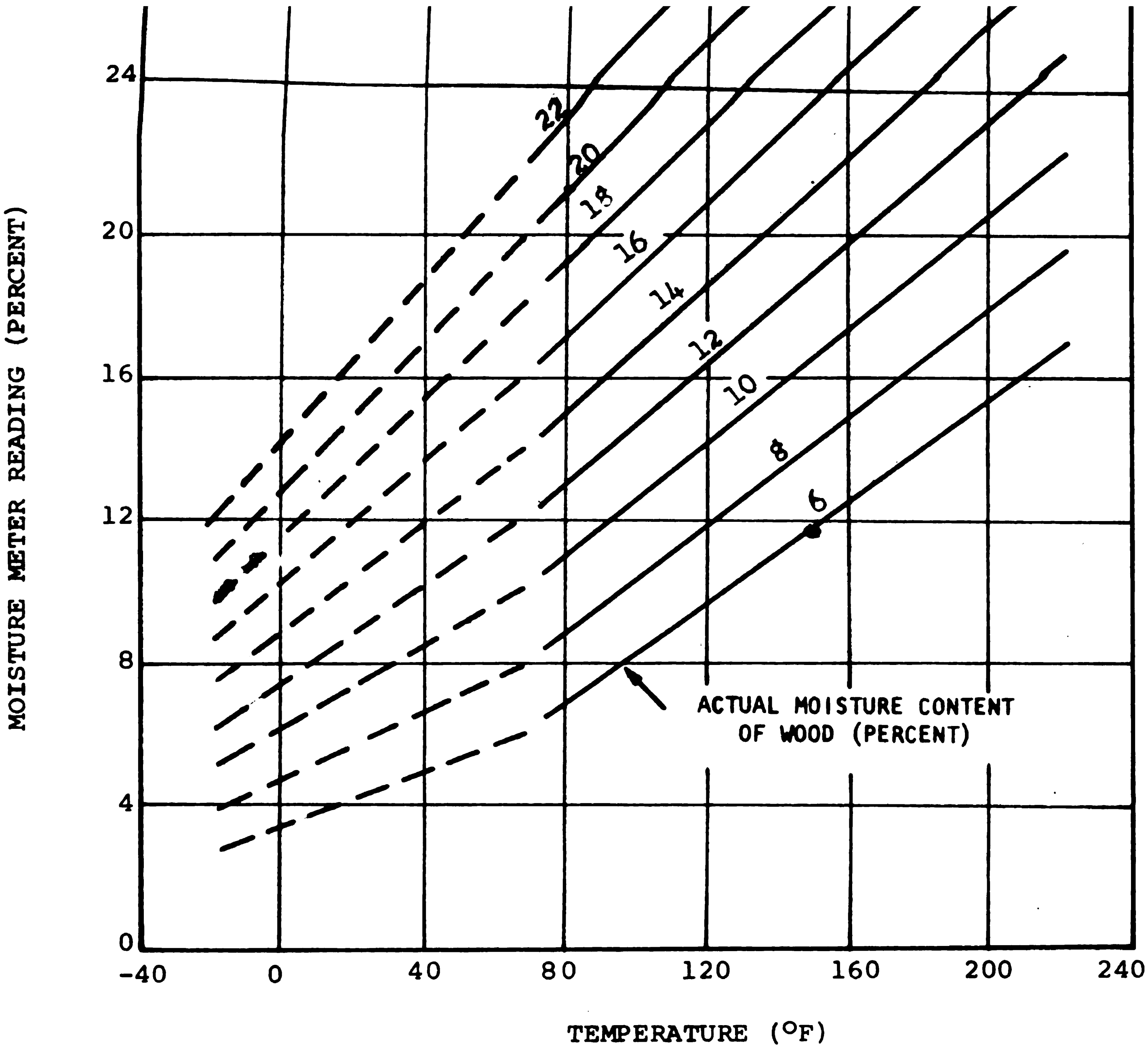
1. Temperature--As the temperature of wood increases, the electrical resistance decreases and vice versa (3). The rate of change of resistance with temperature is higher at higher moisture contents. Because of this phenomenon, the readings of resistance-type moisture meters should be corrected if the temperature of the wood is different from the temperature at which the meter was calibrated. This correction can most easily be obtained graphically from a chart, such as shown on Figures 2 and 3. Figure 2 is drawn for temperatures below 90^{o}F. Figure 3 extends to temperatures above 90^{o}F (3).
2. Electrolytes--When wood is treated with salts for preservative or fire-retarding purposes, the wood becomes more conductive and consequently an electrical-resistance moisture meter may indicate a moisture

Figure 2. Temperature corrections applicable to moisture content determined with resistance type electric moisture meters. Find the moisture content indicated by the moisture meter on the lower margin of the diagram, follow this line vertically to the horizontal temperature line approximating the temperature of the wood being tested, then follow the sloping lines to the 70°F. base line and read the corrected moisture content vertically below. Example: measured moisture content, 12 percent, temperature of wood, 50°F., corrected moisture content, 13.5 percent. If the meter was calibrated at a temperature different from 70°F., the base line should be at the actual calibration temperature, not 70°F.



TEMPERATURE OF WOOD (°F.)
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
base line
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
MOISTURE CONTENT (PERCENT)

Figure 3. Temperature correction chart for resistance-type moisture meters for wood.


MOISTURE METER READING (PERCENT)
24
20
16
12
8
4
0
-40
0
40
80
120
160
200
240
TEMPERATURE (°F)
ACTUAL MOISTURE CONTENT OF WOOD (PERCENT)
22
20
18
16
14
12
10
8
6

content greater than the correct value. This is also true of some glue lines and measurements of moisture content of plywood specimens may, therefore, indicate higher values than the actual moisture content.

3. High relative humidity--When resistance-type meters are used in wet weather, their surfaces may become damp and provide leakage paths with low resistance, and thus preclude measurements at low moisture content (3).
4. Species of wood--At any moisture content the electrical resistance of wood depends on the species. The apparent variation between species may be due partly to differences in the electrolyte content of various species.
5. Direction of current with respect to grain--The resistance of several cubes 5 x 5 x 5 cm^3 were determined, by A. J. Stamm (4), in each of the three structural directions of the wood. Namely, the longitudinal, the tangential and the radial direction. The results are shown in Table 2.

The resistance in the tangential direction is only slightly greater than in the radial direction but about twice as great as in the longitudinal direction. Similar variations were found by Hiruma (5).

Table 2.* Variations in the electrical resistance of wood in its different structural directions.

Species	Density	Moisture Content (%)	Electrical resistance (in Megohms) Longitudinal	Radial	Tangential
Western red cedar	0.336	14.0	9	22	24
Sitka spruce	0.417	15.7	10	18	20
Alaska cedar	0.547	15.6	18	27	27
Douglas fir	0.584	15.3	11	21	23

*A. J. Stamm, "The Electrical Resistance of Wood as a Measure of Its Moisture Content," Industrial and Engineering Chemistry, Sept., 1927.

The practical equality of radial and tangential resistance is of interest because it eliminates the "grain" factor in two directions as a variable in making resistance-moisture determinations.

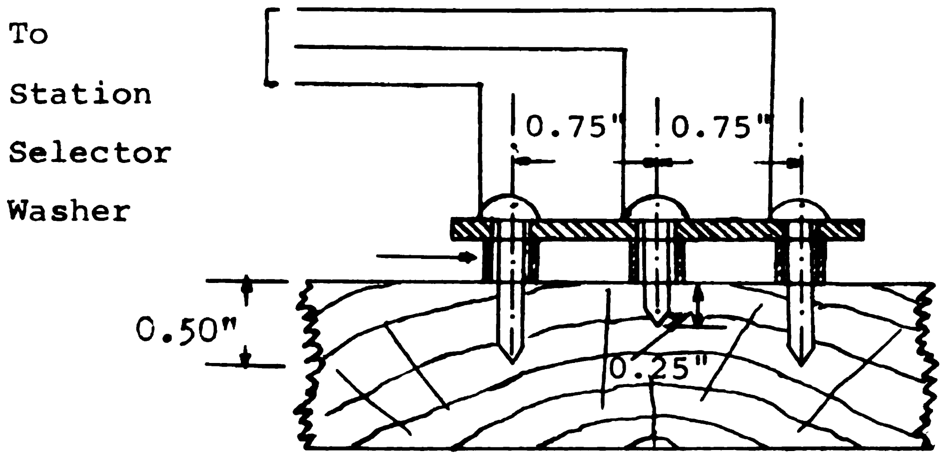
6. Moisture gradient--Measurements were made by A. J. Stamm (4) to determine the effect of variations in the moisture distribution through a section. Four pieces of veneer 0.2 cm thick at moisture contents of 15.0, 27.7, 6.4 and 6.2 per cent, respectively, and averaging 13.8 per cent, were clamped together between the electrodes, with the first and second

veneers located at the outside. The resistance was 450 Megohms; with the first and second veneers at the inside it was 560 Megohms. These results show that the surface layers affect the moisture content determination considerably. When the surface layers are drier than the core, a lower moisture content will be obtained, and vice versa. In the present study the electrodes were driven to a depth of 1/4 inch and 1/2 inch respectively. This arrangement will allow some differentiation between core and shell moisture content. Generally, the core will always have a higher moisture content than the shell.

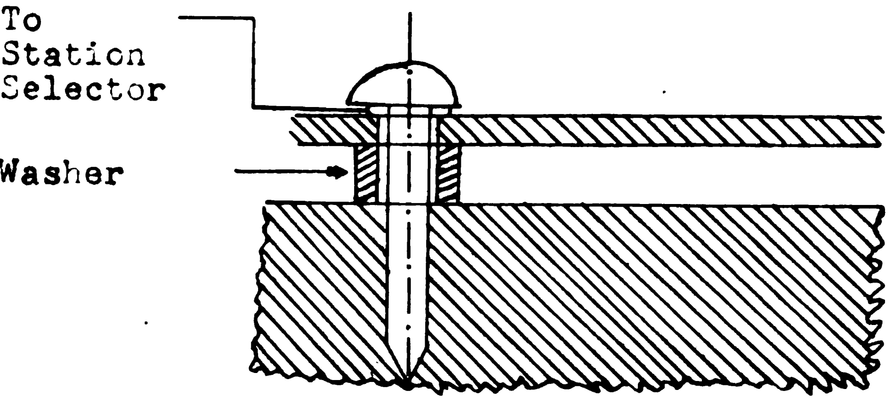
The Kil-Mo-Trol Moisture Meter

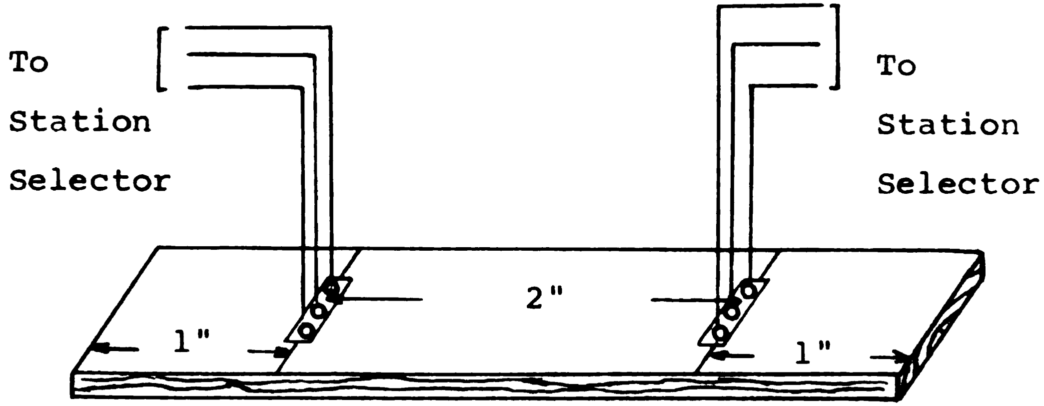
The Kil-Mo-Trol is an electrical system designed to measure the moisture content of lumber in different parts of the kiln charge at any time while the kiln is in operation. With this instrument it is not necessary for the operator to enter the kiln. Sample boards are not used but tests are made directly on the lumber without degrading the quality. Moisture content in either the shell or the core can be measured when desired in any part of the kiln where a station has been set up by driving an electrode assembly into the board (Fig. 4). Any station can be selected by a station

Figure 4. Electrode assembly and its location on sample board.



ELECTRODE ASSEMBLY





THE LOCATION OF ELECTRODE ASSEMBLY

ON BOARD

selector and the moisture content can be read on a strip chart recorder, which is connected to the switch selector box. The Station Selector and Moisture Meter are located near the kiln control instruments (Fig. 5). The reading obtained from the strip-chart recorder is not the actual moisture content. The actual moisture content of wood is obtained by converting the chart readings to moisture content according to the conversion table shown in Table 3. This conversion table is provided by the manufacturer of Kil-Mo-Trol.

A station is the point at which contact is made with the board (Fig. 4). It consists of two long insulated, stainless steel contact pins (available in three different lengths depending upon the lumber thickness being dried) driven to the center of the board, and a short, uninsulated, stainless steel pin driven to a depth of 1/4 inch for determining core and shell moisture content respectively. The stations may be located anywhere in the load and if a sufficient number is set up when the charge is built up, the entire drying process can be studied.

The range of Kil-Mo-Trol is advertised as being between 7 and 65 per cent moisture content. But an accuracy of $\pm$ 1 per cent is limited to a range from 7 to 30 per cent moisture content. It is not expected that readings of moisture content above 30 per cent will be as accurate as those in the lower range.

1. Heating Coil
2. Automatic control valve
3. Automatic Controller-Recorder
4. Moisture Detector
5. Station Selector
6. Strip-Chart Recorder
7. Fuse Box
8. Automatic Time Switch
9. Main Fuse Box
10. Fan

Figure 5. The control equipment for Kiln drying operation.

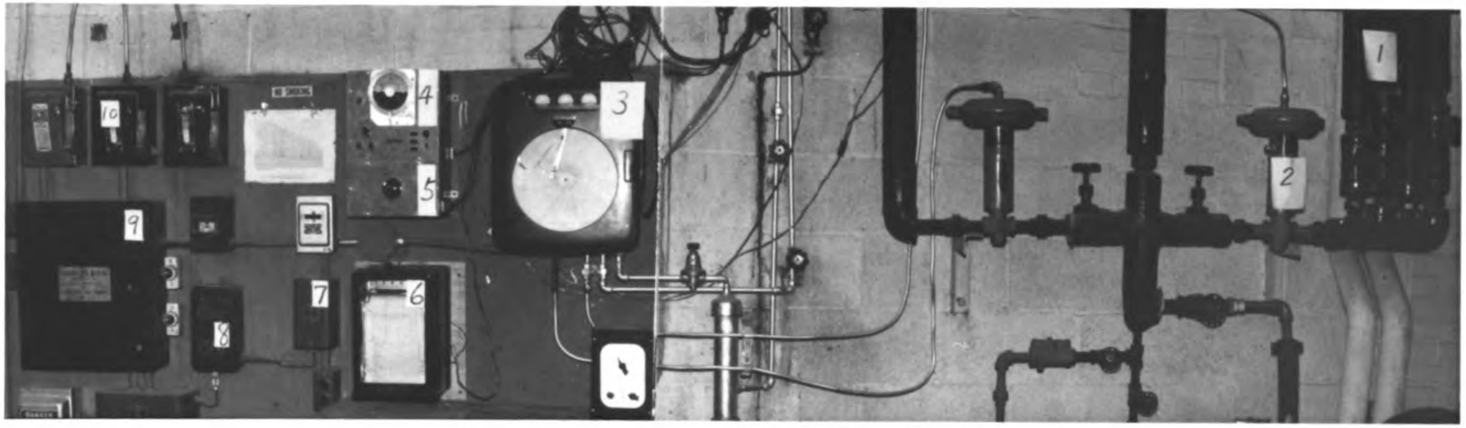

1
2
3
4
5
6
7
8
9
10

Table 3. Conversion table for strip chart recorder Esterline-Argus Model AW.

A		B		C	
Chart Reading	Moisture Content(%)	Chart Reading	Moisture Content(%)	Chart Reading	Moisture Content(%)
10	22	6	12	4	7
12	23	11	13	16	8
15	24	21	14	26	9
19	25	30	15	54	10
22	26	40	16	74	11
27	27	51	17	88	12
31	28	64	18		
34	29	70	19		
39	30	78	20		
45	32	83	21		
50	34	88	22		
55	36				
59	38				
63	40				
71	45				
76	50				
79	55				
80	60				
82	65				

III. EXPERIMENTAL PROCEDURE

Material Selection and Preparation for Kiln Operation

The material used in this study was green, flat sawn, 4/4 inch beech (Fagus grandifolia), each board having nominal dimensions of 1" x 6" x 4'. All test samples were free from apparent defects such as decay, shakes and knots.

Two kiln runs were conducted in a 36 cubic feet drying chamber (Figure 6) which was set up inside the internal-fan cross-circulation kiln in the Forest Products Department, Michigan State University. For each kiln run 8 boards with the above-mentioned nominal dimensions were used; three of them were used as kiln samples, and the other five served as station boards connected with the Kil-Mo-Trol system. During the kiln operation, such equipment as automatic recorder-controller, a hygrometer with both dry bulb and wet bulb thermometer, and the Kil-Mo-Trol systems were used. The moisture content schedule used was T8-C2 (Table 4) provided by the U.S. government Forest Products Laboratory.

Figure 6. Drying chamber.

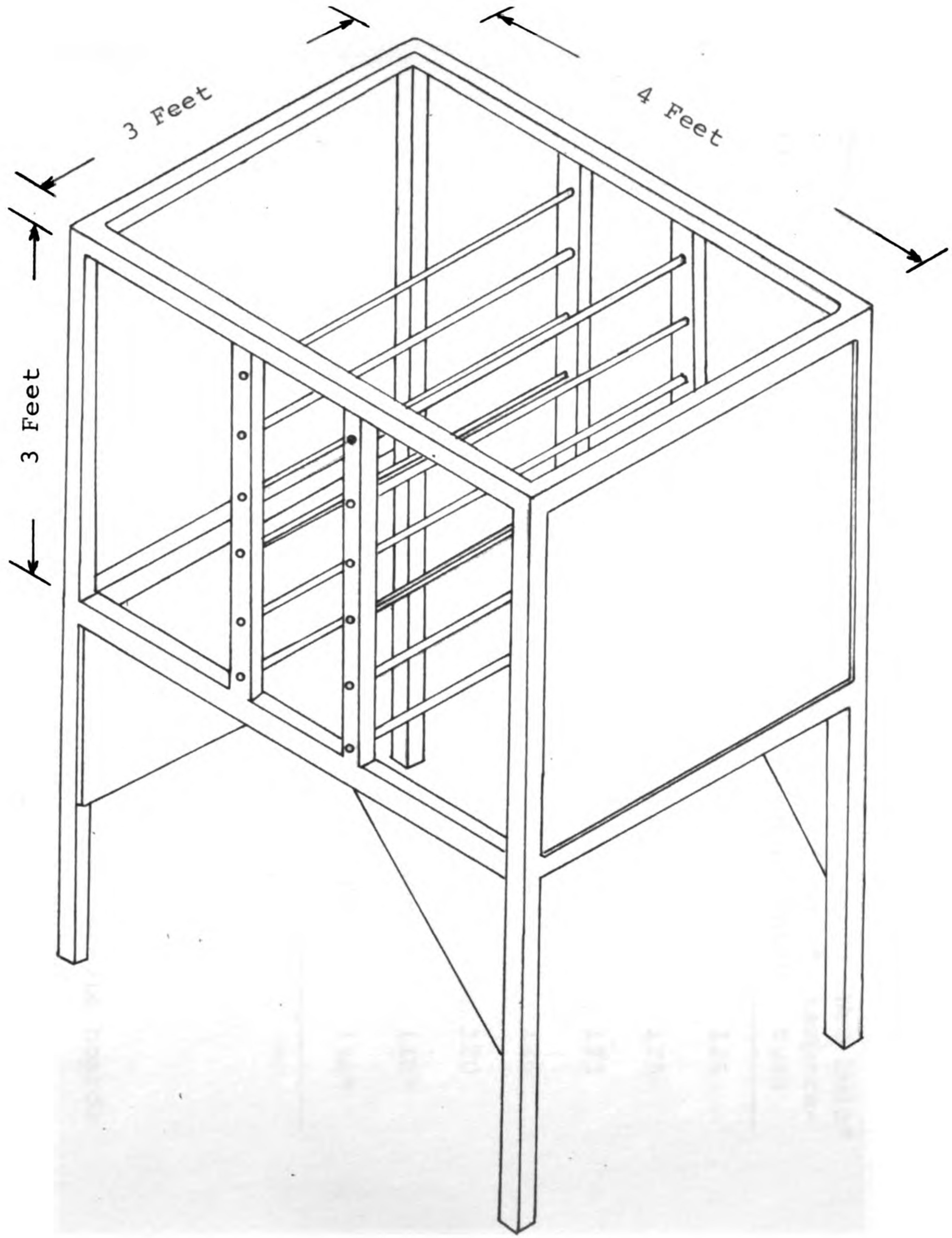

3 Feet
4 Feet
3 Feet

Table 4. T8-C2 Moisture content schedule.

Temperature step No.	Wet bulb depression No.	Moisture content at start(%)	Dry bulb* temperature	Wet bulb* depression	Wet bulb* temperature
1	1	> 40	130	4	126
1	2	40	130	5	125
1	3	35	130	8	123
2	4	30	140	14	126
3	5	25	150	30	120
4	6	20	160	50*	110*
5	6	15	180	50*	130*

*Temperature used in this table is ^{o}F.

Experimental Procedure

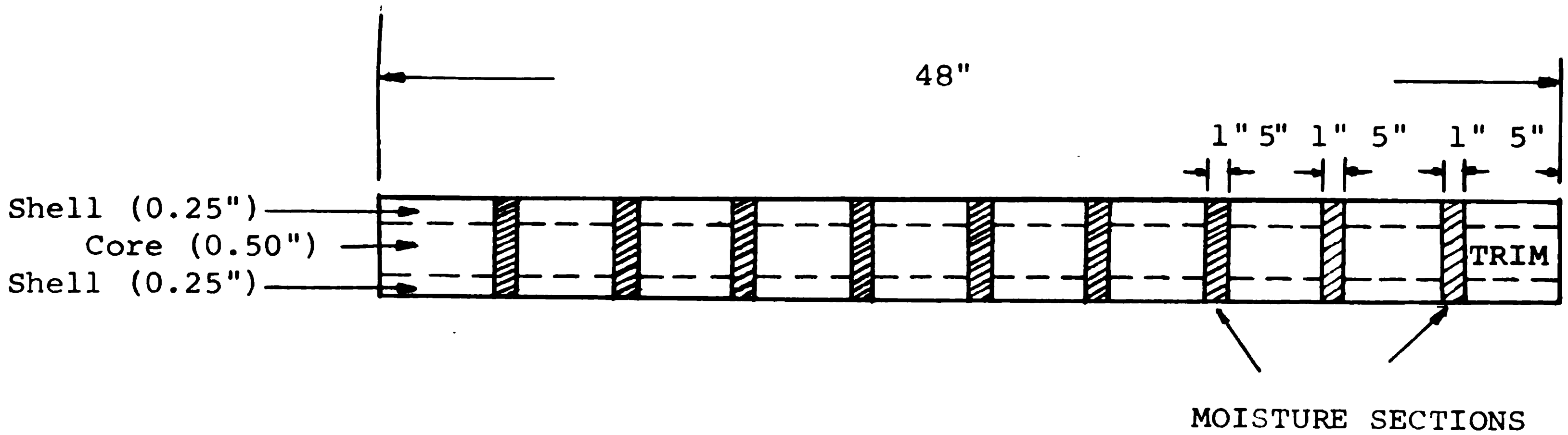
During each of the two kiln runs, eight sample boards were used as mentioned previously. They were put in the 36 cubic feet drying chamber. The installation of the Kil-Mo-Trol was according to the "operating Instructions for Kil-Mo-Trol" published by the manufacturer--Delmhorst Instrument Co., Boonton, New Jersey. Two stations were set up on each of the five station boards. Each station consisted of two long-insulated, stainless steel contact pins driven to the center of the board for core moisture determination, and one short, uninsulated, stainless steel pin driven to a depth of 1/4 inch

for shell moisture determination.

Two stations were located at one foot distance from each end of the board. The data were recorded automatically four times a day, namely at 7 a.m., 12 a.m., 5 p.m., and 12 p.m. (these readings will be designated as K.M.T. moisture content later). However, one can take readings at any time and on any station for both the shell and the core as desired by throwing the toggle switch to the "on" position and turning the station selector dial clockwise to "test" position. After chart readings had been taken, conversion was made according to Table 3.

The moisture content of the kiln samples was determined twice a day (at 8:30 a.m. and 2:00 p.m., these results will be designated as actual moisture content later). Moisture content determinations were conducted by both weighing one of the kiln samples as a whole and by cutting moisture content sections from one of the other two kiln sample boards. The latter was done in this way: each time five inches along the length of the board were trimmed off from the end, a one-inch section was cut (Fig. 7) and then each section was cut across its length into three layers with the exterior layers being 1/4 inch thick (representing the shell) and the center layer being 1/2 inch thick (representing

Figure 7. Method of cutting moisture section from the kiln sample.


48"
1" 5" 1" 5" 1" 5"
Shell (0.25")
Core (0.50")
Shell (0.25")
TRIM
MOISTURE SECTIONS

the core). These layers were put into the oven, and the shell and core moisture content was obtained according to oven-dry method. After both ends had been re-coated, the board was put back to its original position in the drying chamber. The moisture content obtained in such a way can be taken as a guidance for the kiln operation.

When the moisture content of the driest kiln sample board reached a value 2% below the desired final moisture content (7% in this case), an equalization treatment was provided. The equalization process continued until all boards in the drying chamber reached 7% moisture content. After the equalization period, a conditioning treatment followed. The purpose of this treatment was to relieve all the stresses within the board. Therefore, a stress test was made at the start of the conditioning treatment. Severe case hardening was found. The conditioning temperature was the same as the dry bulb temperature at the end of the drying period. The wet-bulb was set at such a temperature that the conditioning equilibrium moisture content was 4% above the desired final moisture content (in this case 180°F dry bulb and 165°F wet bulb temperature). The conditioning treatment covered 24 hours. At the end of this treatment, a stress test was made again, and at this time all stresses were relieved.

IV. RESULTS

The results of the two experimental kiln runs are shown in Figures 8 and 9 for the first and the second kiln run respectively. It seems that there is a considerable discrepancy between the moisture contents obtained by Kil-Mo-Trol and those determined by oven-drying method.

The following symbols are used in the graphs:

Shell (K.M.T.) = shell moisture content determined by Kil-Mo-Trol.

Core (K.M.T.) = Core moisture content determined by Kil-Mo-Trol.

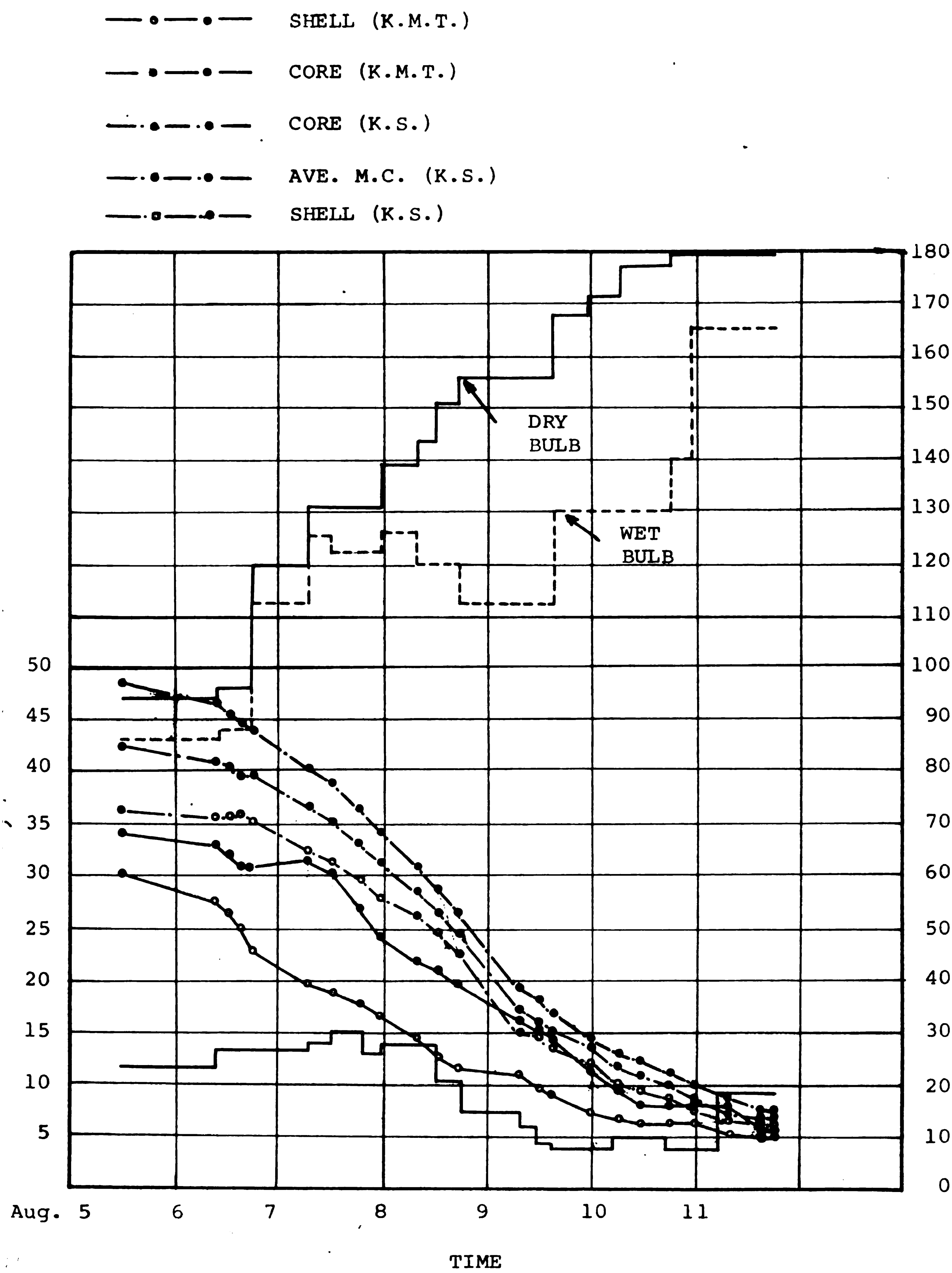
Ave. M.C. (K.S.) = Average moisture content of the kiln sample determined by oven-dry method.

Core (K.S.) = Core moisture content of the kiln sample determined by oven-dry method.

Shell (K.S.) = Shell moisture content of the kiln sample determined by oven-dry method.

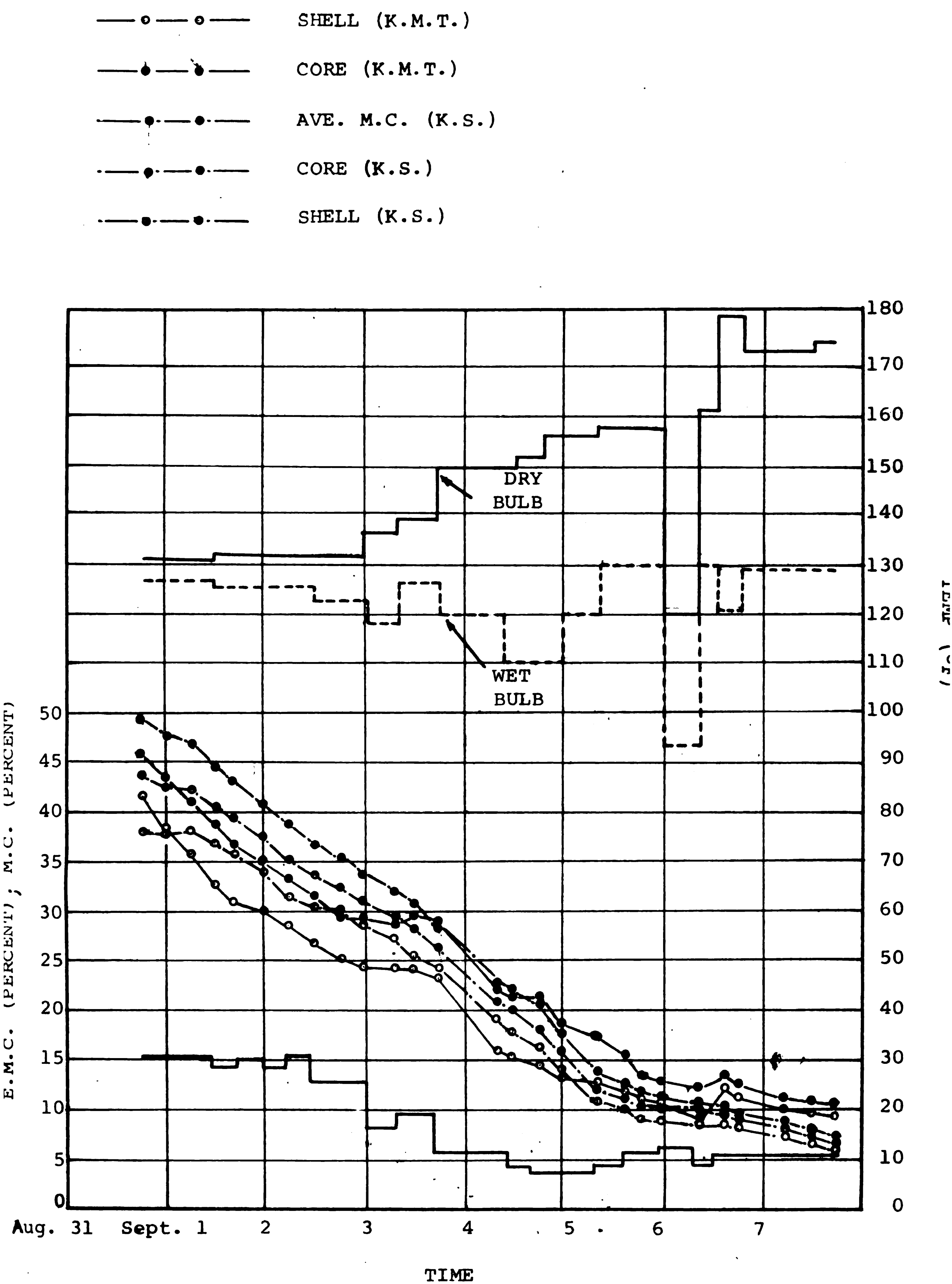
THESIS

Figure 8. Results of first kiln run.



SHELL (K.M.T.)
CORE (K.M.T.)
CORE (K.S.)
AVE. M.C. (K.S.)
SHELL (K.S.)
DRY BULB
WET BULB
50
45
40
35
30
25
20
15
10
5
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Aug. 5
6
7
8
9
10
11
TIME

Figure 9. Results of second kiln run.


SHELL (K.M.T.)
CORE (K.M.T.)
AVE. M.C. (K.S.)
CORE (K.S.)
SHELL (K.S.)
DRY BULB
WET BULB
E.M.C. (PERCENT); M.C. (PERCENT)
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Aug. 31
Sept. 1
2
3
4
5
6
7
TIME

V. ANALYSIS OF RESULTS

As has been mentioned previously, due to the effects of temperature, high moisture content, and moisture content gradient, etc., the moisture content determined by Kil-Mo-Trol does not represent the true average moisture content of the wood. In order to include and consider the effects of these factors, a multiple correlation analysis was conducted according to K. A. Brownlee's "Industrial Experimentation" (6). The analysis was done in the following three steps:

1. Correlation Between Two Variables

A correlation problem considers the joint variation of two measurements, neither of which is restricted by the experimenter. In the present case there are the following variables:

y_s = Moisture content of shell determined by Kil-Mo-Trol.

y_c = Moisture content of core determined by Kil-Mo-Trol.

$(x_1)_s$ = Moisture content of shell determined by kiln sample (oven-dry method).

$(x_1)_c$ = Moisture content of core determined by kiln sample (oven-dry method).

x_3 = Average moisture content determined by kiln sample (oven-dry method).

x_2 = Kiln temperature ^{o}F.

For the shell moisture content

$y_s = 4.1027 + 0.6812\ (X_1)_S$ (Figure 10)

$y_s = 54.9076 - 0.2706\ X_2$ (Figure 11)

$y_s = 2.8603 + 0.5729\ X_3$ (Figure 12)

For the core moisture content

$y_c = 2.4427 + 0.6593\ (X_1)_c$ (Figure 13)

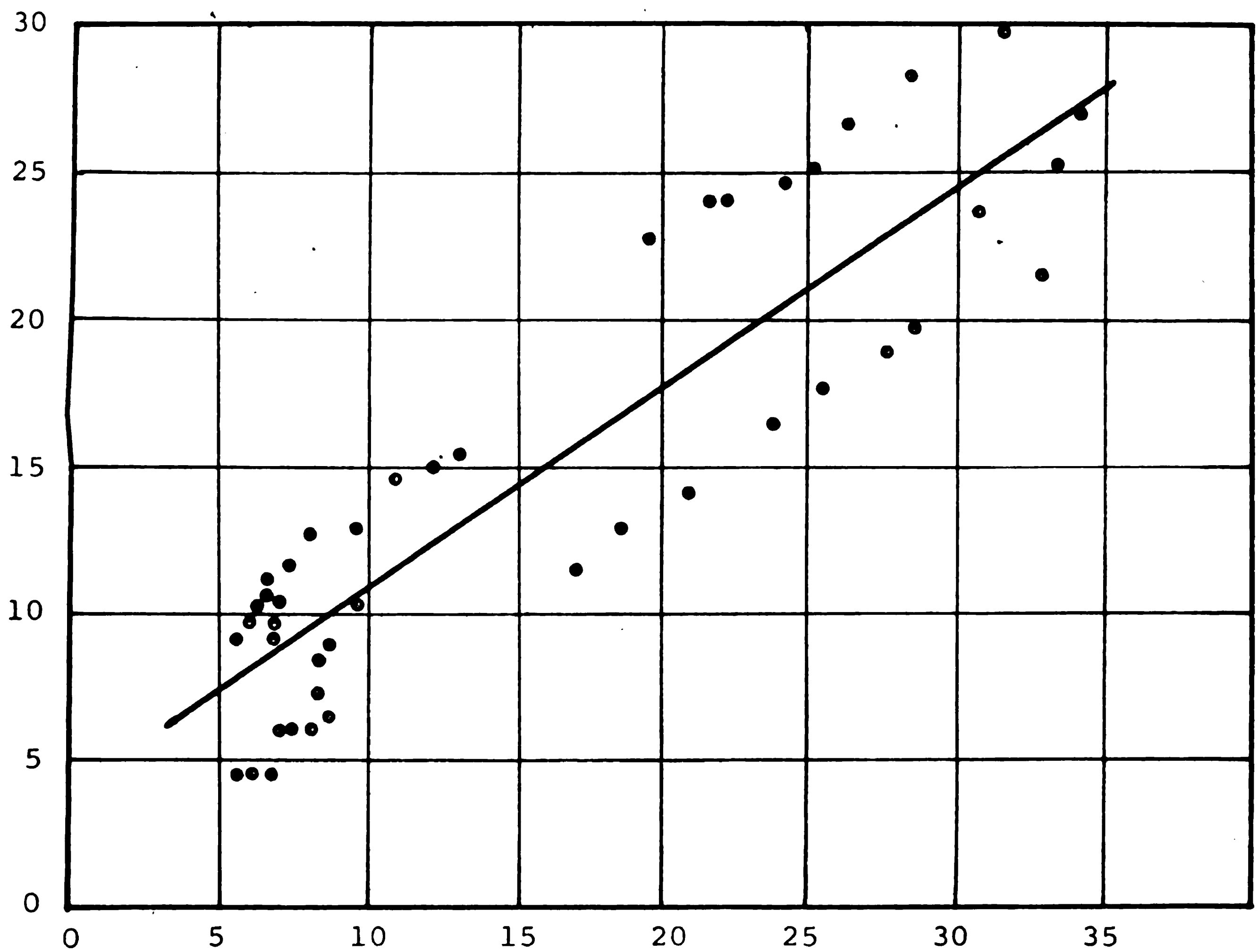
$y_c = 78.0769 - 0.3946\ X_2$ (Figure 14)

$y_c = 3.0164 + 0.8113\ X_3$ (Figure 15)

These equations have been derived from the combined data obtained from both kiln runs. The equations are limited to a moisture content range below 30% M.C. All other values were eliminated because the linear relationship between the electrical resistance of the wood and moisture content only exists when the wood moisture content is below 30% (see Figures 10, 11, 12, 13, 14, and 15).

Figure 10. Correlation between electrical resistance moisture content and actual moisture content for shell.

$$Y_s = 4.1027 + 0.6812\,(X_1)_s$$



$(X_1)_s$ (ACTUAL MOISTURE CONTENT) IN PERCENT

Figure 11. Correlation between electrical resistance moisture content and temperature for shell.

$$Y_s = 54.9076 - 0.2706\ X_2$$

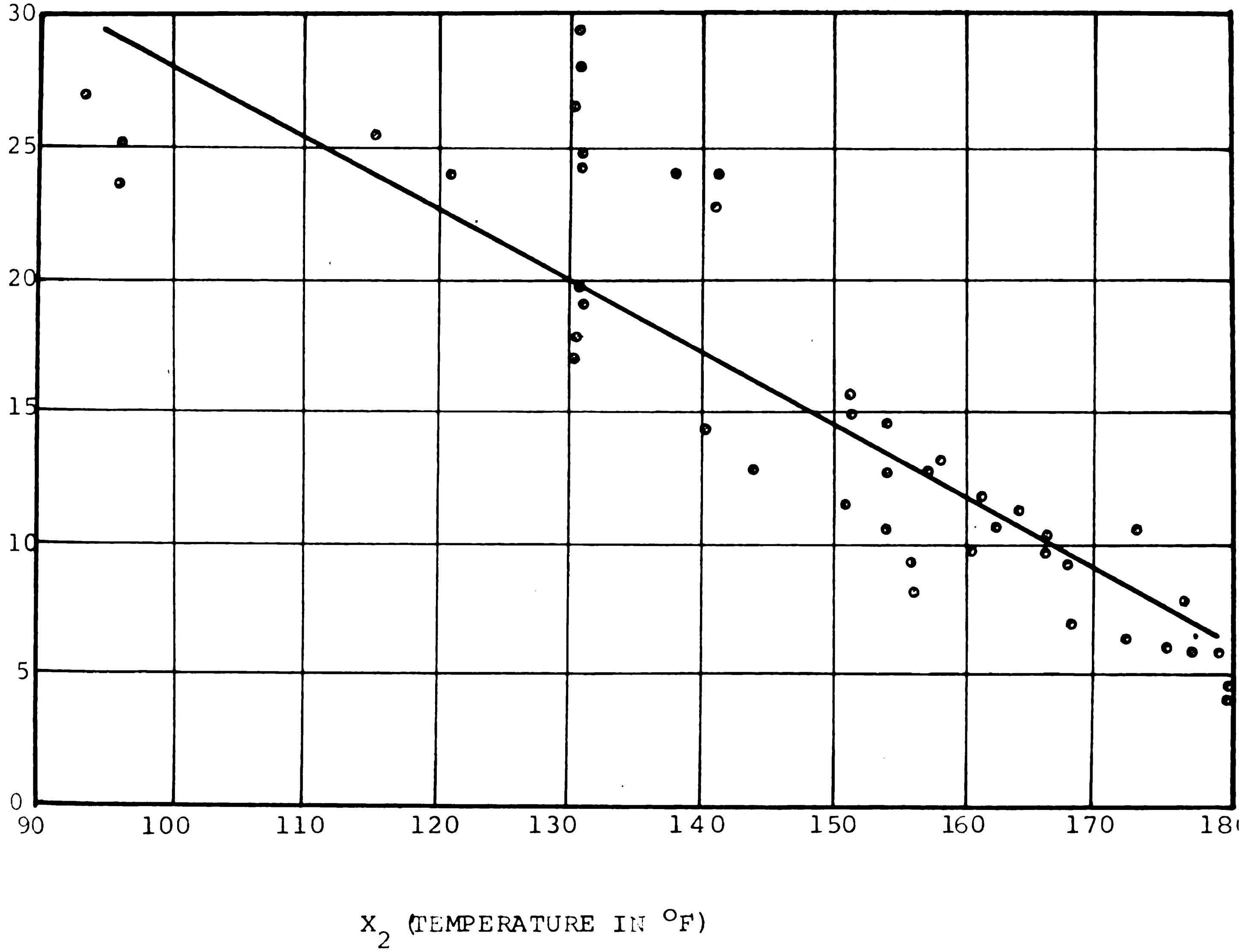


Figure 12. Correlation between electrical resistance moisture content and actual average moisture.

$$Y_s = 2.8603 + 0.5729\ X_3$$

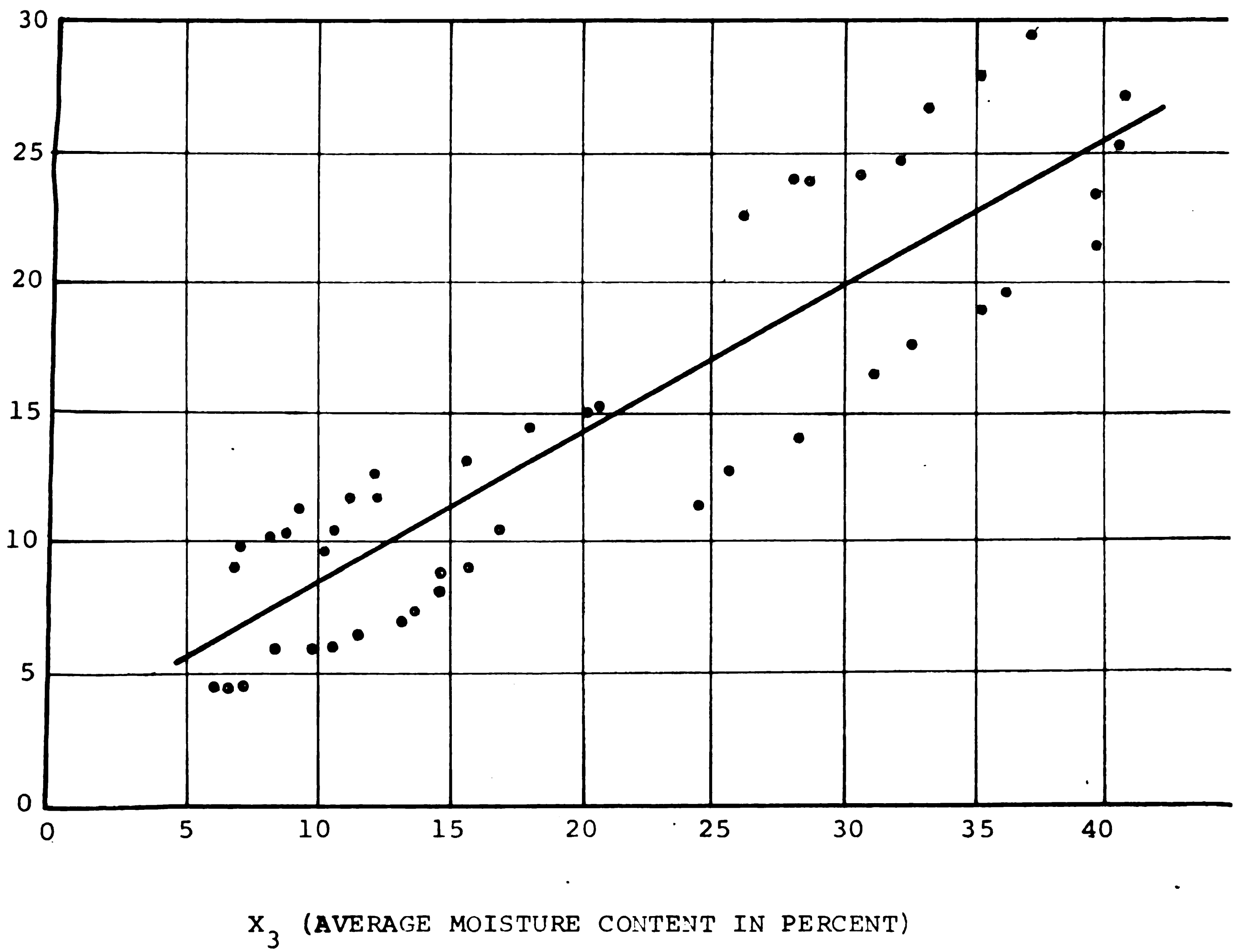


Figure 13. Correlation between electrical resistance moisture content and actual moisture content for core.

$Y_c \;=\; 2.4427 + 0.6593\,(X_1)_c$

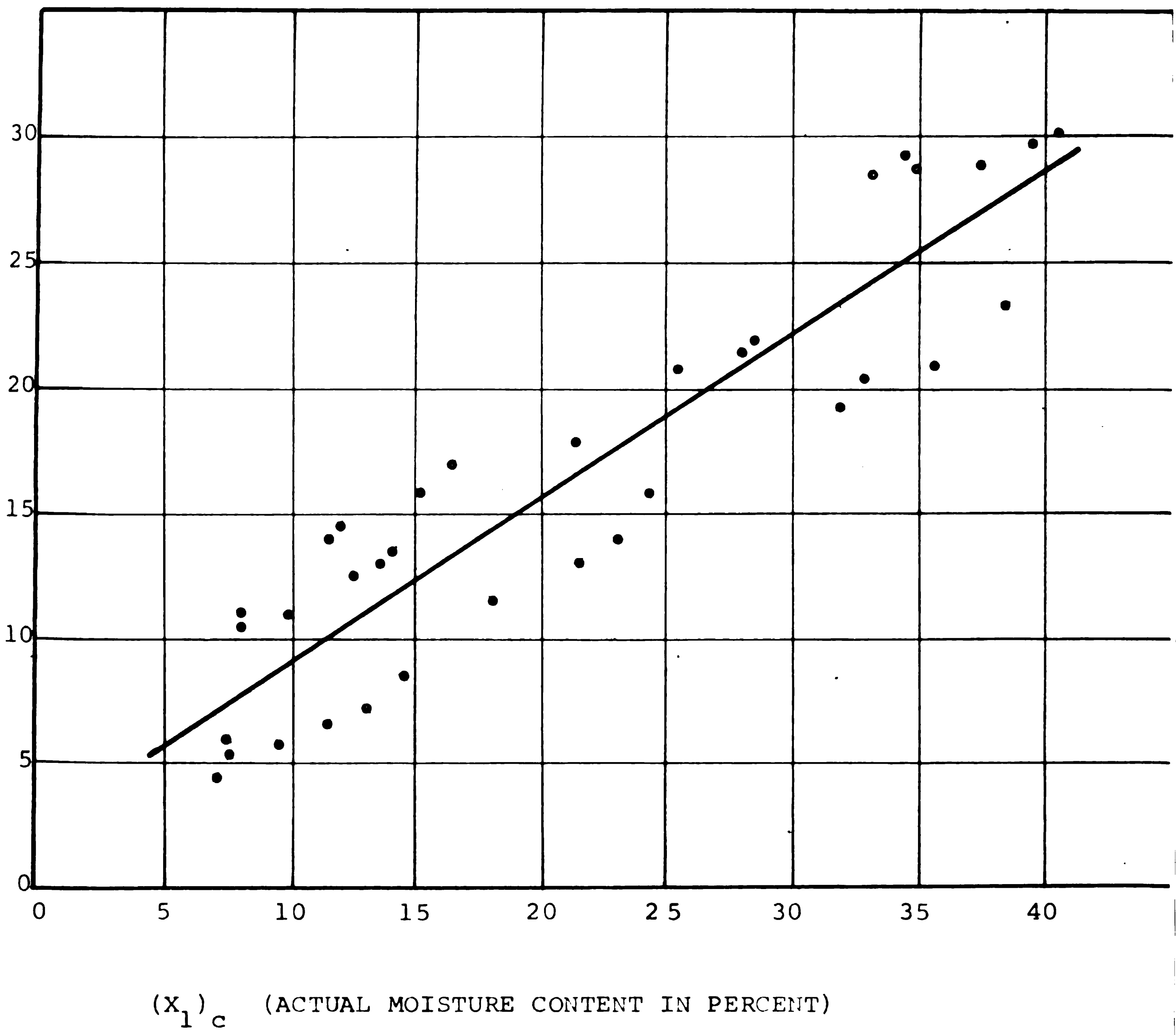


Figure 14. Correlation between electrical resistance moisture content and temperature for core.

$$Y_c = 78.0169 - 0.3946\, X_2$$

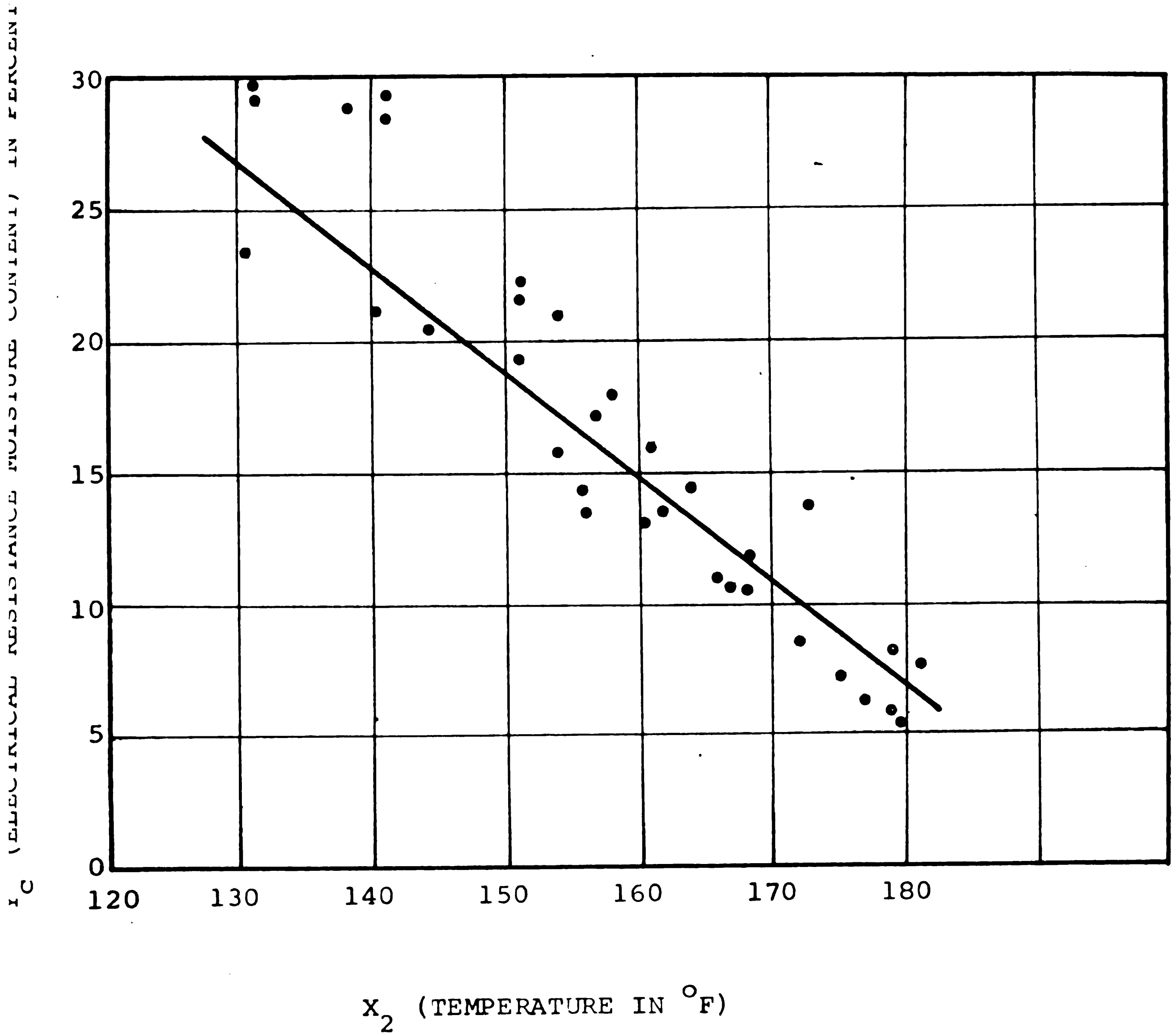
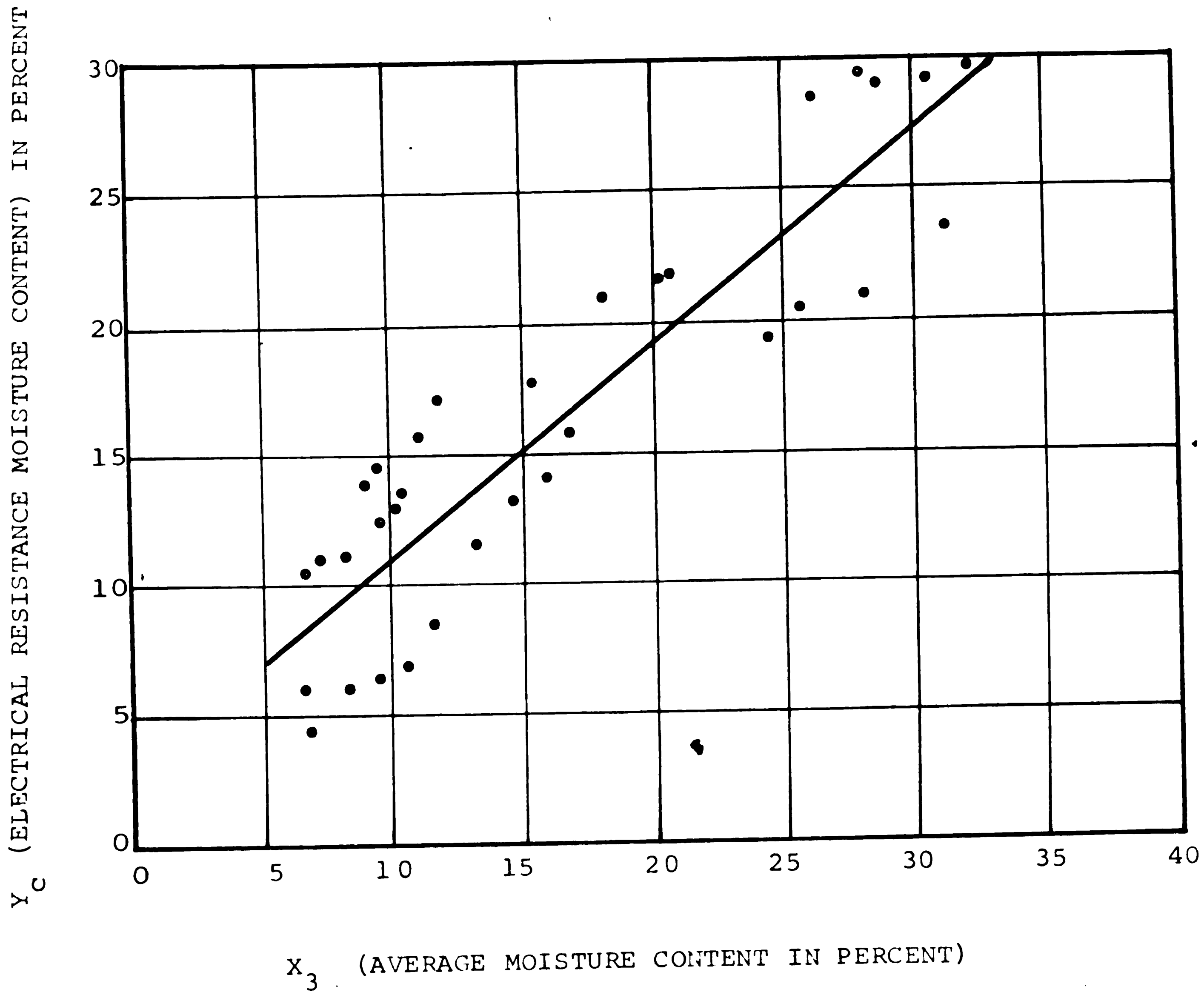


Figure 15. Correlation between electrical resistance moisture content and actual average moisture content for core.

$$Y_c = 3.0164 + 0.8113 X_3$$



2. Multiple Correlation Analysis

Following Brownlee's Industrial Experimentation, the following three multiple correlation equations were obtained:

$Y_s = 2.9038 (X_1)_S + 0.3518 \ X_2 + 3.866 \ X_3 - 72.724$ (Equation 4) for the shell moisture content.

$Y_c = 0.3933 (X_1)_c - 0.1341 \ X_2 + 1.0525 \ X_3 + 28.2985$ (Equation 5) for the core moisture content.

$X_3 = 0.2988 \ Y_s + 0.6553 \ Y_c + 0.0085 \ X_2 + 2.42$ (Equation 6, Figure 16) . X_3 in terms of Y_s, Y_c, and X_2.

The above multiple correlation equations were derived in the same way as the above-mentioned correlation equations. The only difference is more variables are involved here.

When we apply Equation 6 to Figures17 and 18, a close agreement was found between the average kiln sample moisture content and the average moisture content calculated as a function of Y_s, Y_c, and X_2 even above 30% moisture content. The greatest deviation is only 3% moisture content.

Figure 16. Nomography of the multiple correlation equation.

$$X_3 = 0.2988\ Y_s + 0.6553\ Y_c + 0.0085\ X_2 + 2.42$$

INDEX LINE 1 AND 2 $\quad X_3 = 0.2988\ (40) + 0.6553\ (35) + 0.0085\ (135) + 2.42 = 37.86$

INDEX LINE 1' AND 2' $\quad X_3 = 0.2988\ (35) + 0.6553\ (30) + 0.0085\ (140) + 2.42 = 33.53$

INDEX LINE 1" AND 2" $\quad X_3 = 0.2988\ (25) + 0.6553\ (25) + 0.0085\ (150) + 2.42 = 26.95$

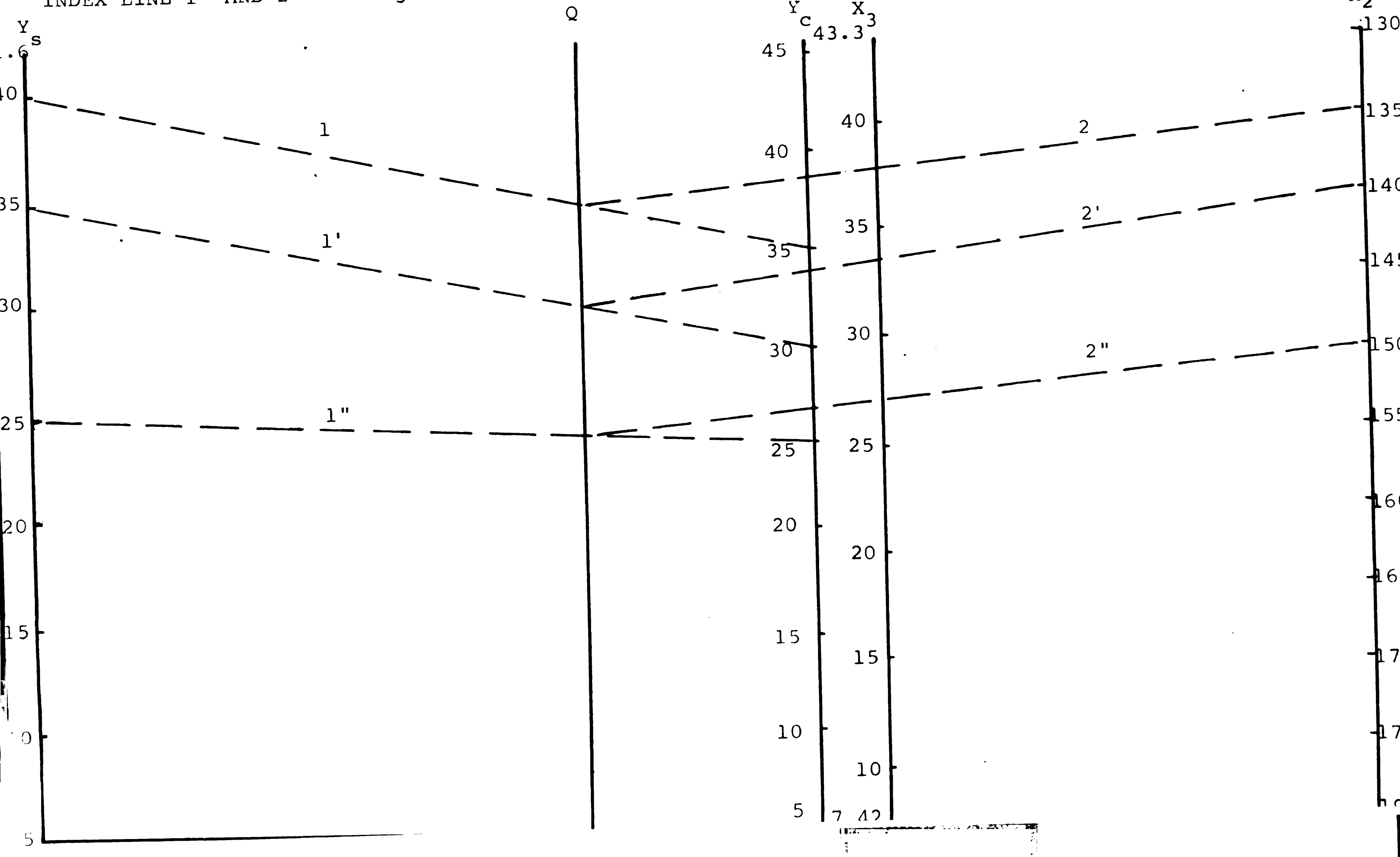
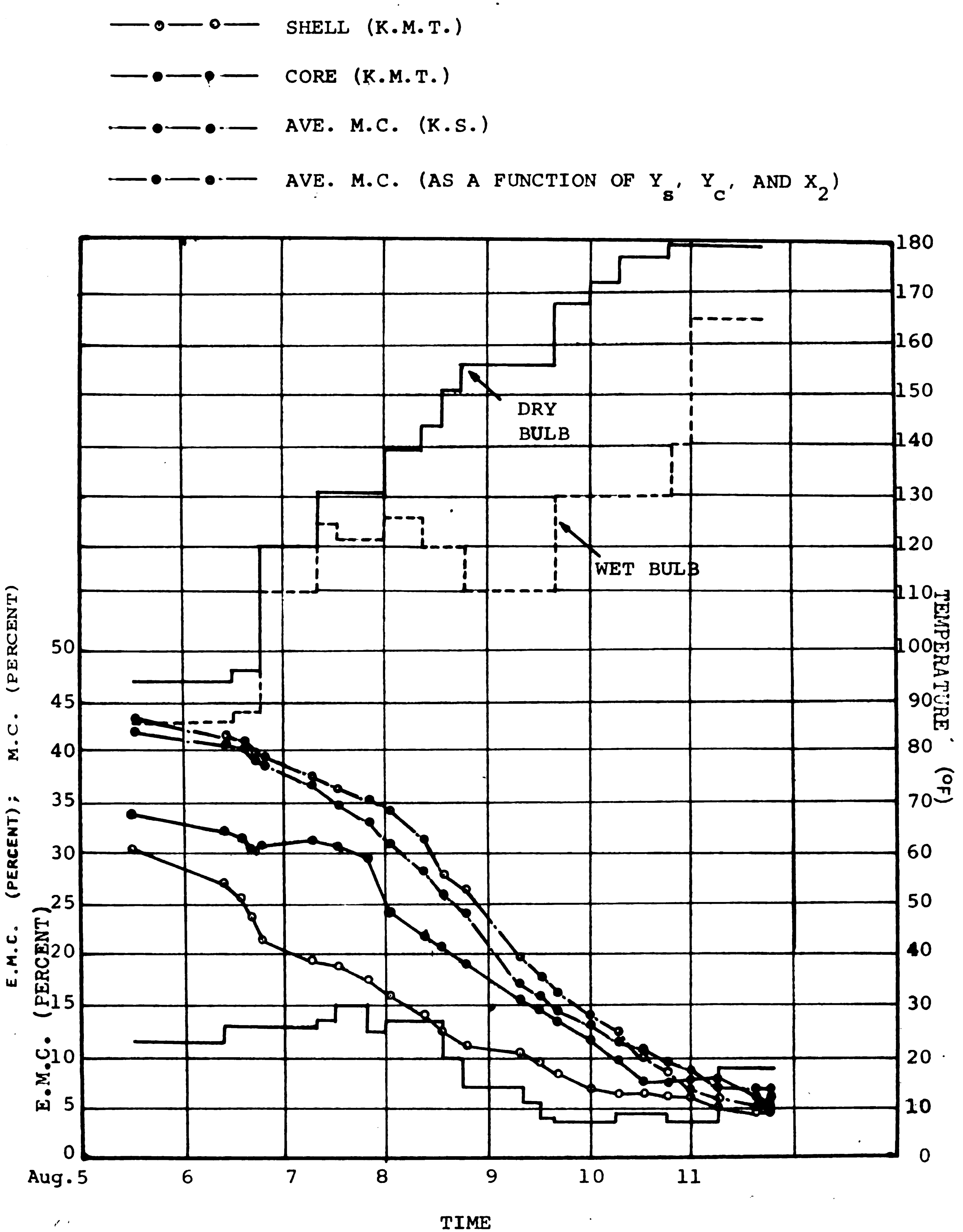
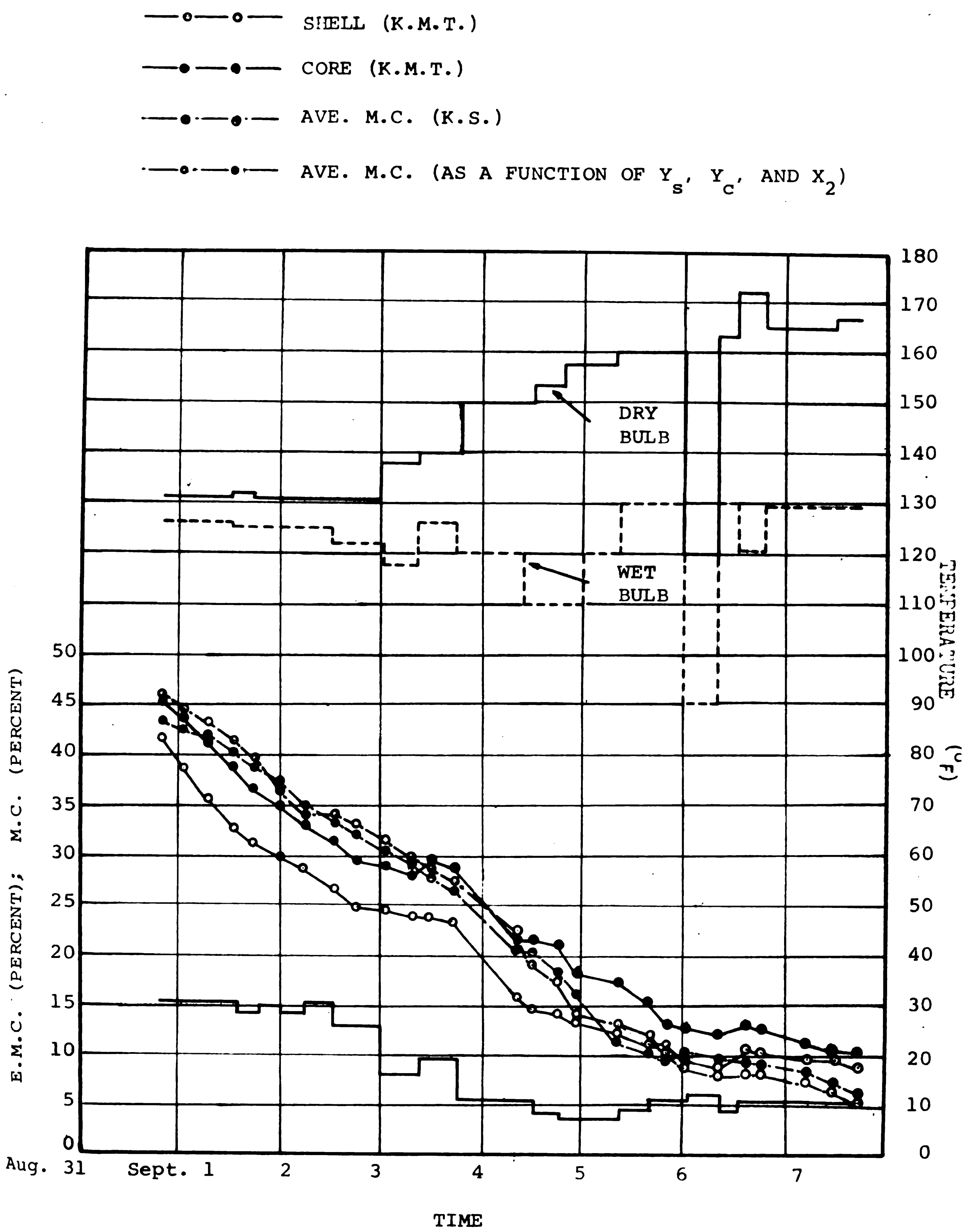


Figure 17. Comparison between actual average moisture content and average mositure content (as a function of Y_s, Y_c, and X_2) for first kiln run.



SHELL (K.M.T.)
CORE (K.M.T.)
AVE. M.C. (K.S.)
AVE. M.C. (AS A FUNCTION OF Y_s, Y_c, AND X_2)
DRY BULB
WET BULB
E.M.C. (PERCENT); M.C. (PERCENT)
E.M.C. (PERCENT)
TEMPERATURE (°F)
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Aug.5
6
7
8
9
10
11
TIME

Figure **18.** Comparison between actual average moisture content and average moisture content (as a function of Y_s, Y_c, and X_2) for second kiln run.


SHELL (K.M.T.)
CORE (K.M.T.)
AVE. M.C. (K.S.)
AVE. M.C. (AS A FUNCTION OF Y_s, Y_c, AND X_2)
DRY BULB
WET BULB
E.M.C. (PERCENT); M.C. (PERCENT)
TEMPERATURE (°F)
Aug. 31
Sept. 1
2
3
4
5
6
7
TIME

3. Nomograph

The Equation 6 is represented in the form of a nomograph as shown in Figure 16. If values are given for Y_s, Y_c, and X_2, the corresponding value of X_3 is found as follows:

Set index line 1 to values of Y_s and Y_c, marking the resulting value of Q on the Q-line; set index line 2 on this mark for Q and also on the given value of X_2 and read the corresponding value of X_3 on the X_3-scale. Several checks for the accuracy of this nomograph were made on Figure 16, and accurate answers were obtained as shown on said figure.

VI. CONCLUSIONS

The use of an electrical resistance moisture meter like the Kil-Mo-Trol as a means for controlling the kiln drying of lumber makes it necessary to apply certain corrections to the readings in order to compensate the error due to high M.C., temperature, and other factors. The present study is an example of how such corrections are obtained for a particular drying situation. The presented equations and the nomograph cannot be considered to be of value in different conditions. They are limited to two kiln runs drying 4/4 beech.

The multiple correlation analysis seems to yield satisfactory results.

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