1961

Calibration of electric moisture meters for Jack and Red Pine, Black Spruce, Paper Birch, Black Ash, Eastern Hemlock, and Bigtooth Aspen

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CALIBRATION OF ELECTRIC MOISTURE METERS FOR JACK AND RED PINE, BLACK SPRUCE, PAPER BIRCH, BLACK ASH, EASTERN HEMLOCK, AND BIGTOOTH ASPEN

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Summary

Direct current electrical resistance and radio frequency power absorption indexes were obtained at a temperature of 80° F. and at moisture content values from about 6 percent to near the fiber saturation point for seven native American species: jack pine (Pinus banksiana), black spruce (Picea mariana), paper birch (Betula papyrifera), black ash (Fraxinus nigra), eastern hemlock (Tsuga canadensis), bigtooth aspen (Populus grandidentata) and red pine (Pinus resinosa).

The measurements were made with commercial moisture meters--a specially calibrated resistance type and two models of the radio frequency power-loss type. Moisture-meter indications were compared with the actual moisture content of the same material as determined by the ovendrying method.

Introduction

For routine inspection of wood and wood products for moisture content, the various electric moisture meters in common use present by far the most convenient method. Several factors[2] should be considered in order to achieve maximum accuracy from a moisture meter. One of these is the species of wood, since the moisture meter requires an individual calibration for each species of wood being tested.

The species corrections for resistance-type meters are not large, rarely exceeding a deviation of plus or minus 2 percent moisture content from an average calibration. The species effect for radio frequency power-loss meters is larger than that for the resistance-type meters.

Resistance-type meters measure the electrical resistance of the wood, and the calibration of these instruments depends on the relationship between the resistance of the wood and its moisture content. Although the mechanism of conduction of electric current by wood is not clearly understood, it appears that differences between species in the resistance-moisture content relationship are due to differences in chemical deposits in the wood and to differences in structure that modify the available surface area within the wood.

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] James, W. L. "Electrical Moisture Meters for Wood," U.S. Forest Products Laboratory Report No. 1660, January 1958.

The readings of power-loss type meters depend upon the dielectric constant and the power factor of the wood, which in turn are affected by wood moisture content. Available data on the dielectric properties of wood[3] indicate that both the dielectric constant and the power factor depend largely on the density and moisture content of the wood and are relatively independent of further effects of species. The species correction for power-loss meters is, therefore, probably in effect a density correction, although it is clear from the data in this report that other effects are not insignificant.

It was the purpose of the work reported here to determine the species corrections for resistance-type and power-loss type moisture meters when used on seven American species for which such corrections were previously unavailable.

Experimental Procedure

Specimens

The specimens of each species were cut from three fresh, green logs representing three different trees cut for the purpose on the Argonne District of the Nicolet National Forest in Wisconsin. From each log, five boards were cut, 1-1/4 inches thick, 6 to 8 inches wide, and about 4 feet long. The boards were numbered in order from one side of the log to the other. Care was taken to saw the logs parallel to the grain to assure straight-grained boards. The butt end of each board was identified.

The boards were ripped to uniform 5-1/2-inch width and surfaced to about 1 inch in thickness. Five specimens, each about 5 inches long, were cut from each board. In most cases, it was possible to cut five clear 1- by 5- by 5-1/2-inch specimens from each board, but occasionally one specimen from a board had a small defect. No specimen, however, had a defect large enough to seriously affect the moisture-meter reading. Specimens were numbered in order from the butt end of the board.

The specimens were end coated with two coats of aluminum-phenolic resin varnish immediately after being cut.

Statistical Design

When cut as outlined above, each log produced five groups of five end-matched specimens, or 25 specimens from each log. Five humidity conditions were to be used, so the selection of five groups of five matched specimens permitted a statistically unbiased placement of the specimens in the various conditioning humidities according to randomly selected 5 by 5 Latin squares. The rows of the Latin squares were labeled in order from 1 to 5, corresponding to the five boards from each log, and the columns of the Latin squares were labeled in order from 1 to 5, corresponding to the five specimens from each board. The five humidities were each assigned a code number, and individual specimens from each board were assigned to the humidity whose code number fell at the intersection of the row and column for that particular board and specimen. A different Latin square was selected at random, from tables of Latin squares, for each log of a given species.

This procedure in effect was forced randomization, to reduce the chance that systematic differences between groups might modify the differences resulting from different humidity conditioning.

Apparatus

Resistance measurements were made with a standard commercial moisture meter calibrated to read moisture content directly on Douglas-fir. This instrument was, in addition, calibrated

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[3]Skaar, Christen "The Dielectric Properties of Wood at Several Radio Frequencies," New York State College of Forestry Tech. Bull. No. 69, Syracuse 10, N. Y., 1949.

as an ohmmeter, using standard resistors, to permit interpretation of the indicated moisture readings as resistance. Contact to the specimens was made with a standard four-needle electrode, the needles being 5/16 inch long and spaced at the corners of a 7/16- by 7/8-inch rectangle. The needles 7/16 inch apart were electrically connected, so the electrode consisted of two poles 7/8 inch apart, each pole being a pair of needles 5/16 inch long. An electrode with two insulated pins, 1-1/8 inches long and 1-1/16 inches apart, was also used for spot checks.

Comparative indication of radio-frequency power absorption was obtained with two models of a commercial power-loss moisture meter. The readings of these meters are empirically related to the power absorption of the specimen, but no attempt was made to deduce from these readings quantitative data on basic dielectric properties of the wood.

The three moisture meters are illustrated in figure 1.

Experimental Methods

The experiment was done in two parts. In the first part, the specimen material was distributed to the conditioning rooms as dictated by the Latin squares, and data were collected. In the second part of the experiment, complete groups of specimens in equilibrium with one condition were transferred to different conditions, and after the new equilibrium moisture values had been established, the procedure of data-collecting was repeated.

For the first part of the experiment, the power-loss model B meter was not available, and data for this meter were therefore obtained only in the second part.

In the first part of the experiment, the specimens were conditioned in rooms maintained at 80° F. and relative humidities of 30, 65, 80, 90, and 97 percent. All specimen material entered these conditioning rooms in the green condition, so equilibrium was approached in all cases in the desorption direction. End-grain drying was retarded by the end coating, so that no specimens were split or checked from drying stress.

About 4 months after placing the specimens in the conditioning rooms, a routine of weighing a few specimens of each species at about 2-week intervals was begun; this was continued until there was no significant weight change in these specimens. Every specimen was then weighed at 2-week intervals until each showed constant weight. By the end of 6 months of conditioning, no specimen showed significant weight loss in a 2-week period, and the moisture meter data were collected.

Following completion of the first part of the experiment, the material in the 65 percent humidity room was moved to the 80 percent room, the material in the 90 percent humidity room was moved to the 65 percent room, and the material in the 80 percent humidity room was moved to a room maintained at 73° F. and 50 percent humidity. The material in the 30 percent humidity room was not moved. The material in the 97 percent humidity room was ovendried and weighed, and no further measurements were made with it.

The procedure for the four remaining groups of material was exactly the same as that followed in the first part of the experiment.

When each specimen had shown constant weight for at least 2 weeks, moisture-meter readings were made on the specimens in the usual way. Readings on both sides of each specimen were made with all meters at first, but it was soon obvious that duplicating the readings of the resistance-type meter in this way was giving no additional information. Readings with only the power-loss meters were repeated on both sides of the specimen and the average recorded. The model B meter was checked periodically with the calibration standard supplied with the instrument.

Resistance readings were made with the standard four-pin electrode (see "Apparatus") driven to the full depth of about 5/16 inch, with the current flowing parallel to the grain of the wood. The reading on every fifth specimen was repeated with an electrode with two insulated pins driven about 3/8-inch deep, again oriented so the current flow was parallel to the grain. Because the specimens had a nearly uniform moisture distribution, the depth of penetration of the electrodes was not important.

Before and after each set of readings, the resistance-type meter was checked over its entire range with standard resistors to establish the constancy of calibration.

The true quantity of moisture in the specimens was defined as the loss of weight in ovendrying for 60 hours at 103° C., and the moisture content of the specimens was expressed as a percentage of the dry weight of the wood. The entire specimen was dried, as opposed to the technique of cutting a moisture sample from the specimen. From the weight of the specimen when the moisture-meter readings were made and the weight when ovendry, the moisture content of the specimen at the time of the moisture-meter readings was computed.

In order to determine if the specimen material was of approximately average specific gravity for its species, approximate values of specific gravity were calculated for each species, using the average ovendry weight and the green volume of the specimens. The volume of the specimens was estimated from the approximate dimensions to which each specimen was cut.

The values of true moisture content obtained from ovendrying determinations were averaged for each species at each humidity with values indicated by the moisture meters. The standard deviation corresponding to each such average was also calculated, to permit estimation of the significance of the average values and of the differences between groups. The averages were plotted to illustrate relationships and tabulated to make available correction factors for use of moisture meters on the species included in this study.

Values for the resistance meter that were obtained at 73° F. were corrected to 80° F., using the temperature correction chart in Forest Products Laboratory Report No. 1660,[2] by adding 0.3 percent moisture content to the averages before the data were plotted and the corrections interpolated from the curves.

Presentation of Results

The data resulting from these experiments are tabulated in tables 1 through 12 and shown graphically in figures 2 through 9.

Tables 1 through 7 show actual moisture content as determined by the ovendrying method and corresponding readings of the electric moisture meters, averaged for each species and condition. The standard deviation of the data that entered into computation of each average value is listed directly under the corresponding average.

Table 8 lists the correction terms to be added algebraically to the indicated moisture content when using a resistance-type meter calibrated for Douglas-fir on each of the seven species covered in this study. Positive corrections should be added to the indicated moisture content, and negative corrections should be subtracted from the indicated moisture content.

Table 9 lists the scale readings of the two power-loss meters, for the seven species studied, at various levels of moisture content.

The values tabulated in tables 8 and 9 were obtained from the curves plotted in figures 2 through 8 and figures 2 through 8 were obtained by plotting the data in tables 1 through 7. For values at low levels of moisture content, it was necessary to extrapolate the data, because no material was conditioned to a moisture content less than about 6 percent.

Table 10 shows the differences between readings made on the same material with the standard 4-pin electrode and the insulated 2-pin electrode. For this comparison, only specimens for which both 4- and 2-pin readings were made were considered.

Table 11 lists the approximate average specific gravity of the specimen material, and the corresponding average value of specific gravity for each species studied based on evaluation of large numbers of small, clear specimens.

Table 12 lists the actual resistance values of each species at various moisture content levels, as obtained with the standard 4-pin electrode. These data were obtained from figure 9, which is a plot of the data in table 3, using the calibration of the moisture meter as an ohmmeter.

Discussion of Results

Equilibrium Moisture Levels

Generally accepted equilibrium moisture content values for wood for the temperature and humidities used in conditioning the specimens for this study[4] are about 1-1/2 to 2 percent lower than the moisture content values at which the specimens stabilized from the green condition. There are several factors that may have contributed to this apparent discrepancy, the most important of which is that the accepted values of equilibrium moisture content were obtained from material that approached equilibrium from both higher and lower levels of moisture, while these specimens all approached equilibrium from the green condition.

The fact that the direction from which equilibrium is approached has a substantial effect on the equilibrium moisture content is illustrated in the second part of the experiment by the comparative values of moisture content of the two groups of material conditioned at 80 percent humidity. The group that approached equilibrium from the green condition stabilized at about 18 percent moisture content, and the group that approached equilibrium from about 14 percent moisture content stabilized at about 16 percent. The accepted value is about 16 percent.

In addition, different species come to slightly different levels of equilibrium moisture content under the same conditions. Also, a wood specimen may take years under constant conditions to attain a moisture content value that does not actually change with time. These and possibly other factors affect the moisture content at which the material stabilizes, or seems to stabilize, after a few months of conditioning.

Finally, the equilibrium values of moisture content depend in general upon the method used to determine the moisture content, although for practical purposes different basic methods usually give equal results. The most widely used and accepted basic method of moisture determination is weighing the specimen before and after ovendrying. This method is subject to errors due to (1) the rapid regain of moisture by dry wood from the air, tending to increase the ovendry weight unless the weighings can be done in the oven; (2) the fact that wood contains materials other than water that are evaporated from the wood during drying, tending to increase the loss of weight; (3) the fact that ovendrying may produce a small amount of actual decomposition of the wood, resulting in a loss of weight that is not due to removal of water.

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[4] Forest Products Laboratory. Relative Humidity and Equilibrium Moisture Content Graphs and Tables for Use in Kiln Drying of Lumber. Report No. 1651.

In practice, the errors resulting from these factors are rarely significant, and the oven-drying method remains the standard method of moisture determination.

Moisture-Meter Data

In general, the moisture-meter readings are similar in magnitude and variability to comparable data obtained previously on other species. The resistance data, being affected less by factors other than moisture content, show less variability than do the power-loss data. The variability of the power-loss readings probably is due principally to the effect of density on the readings, but it should be recognized that variation in density is not the only cause of variability in the readings of the power-loss meter on material at one moisture content.

This is illustrated in figures 10 and 11, in which the average reading of the two power-loss meters for each species is plotted against the specific gravity of the specimens of each species for different levels of moisture content. The trend is for the readings to increase with specific gravity, but the relationship is also strongly affected by other factors.

The fact that, for all but one of the species studied, positive corrections were required for the resistance meter at low moisture content is unfortunate, as the readings on material near 7 percent moisture content were as a result below the readable range of the meter. The very fact, however, that the readings were below readability lends crude confirmation to the species corrections derived from the extrapolated data.

Similarly, it would be desirable to confirm the conversion factors for the power-loss meters for moisture levels below 6 percent. Data for this range were not obtained for lack of material conditioned to moisture levels below 6 percent. Other studies have indicated, however, that the power-loss in wood is an approximately linear function of moisture for moisture content below 12 percent,[2] so the extrapolated values are probably correct to practical limits.

Specific Gravity of Specimen Material

The data summarized in table 11 indicate that the samples of red and jack pine used in this study may have been of lower than average specific gravity, and the sample of black ash of higher than average specific gravity. This would cause moisture indications by power-loss meters, using the conversion factors developed here, to be somewhat high on red and jack pine of average density and somewhat low on black ash of average density. However, these differences would probably be within the range of readings resulting from normal variability in specific gravity of wood of any species.

Variability of the Data

As can be seen from tables 1 through 7, the variability of the actual moisture content is very small, except for material conditioned from the green in a relative humidity of 97 percent. For all material other than that conditioned at 97 percent humidity, the standard deviation was no more than 3 percent of the mean, and in only a few cases was it more than 2 percent of the mean. Variability of the resistance meter readings was also low, but it was somewhat higher than that of the actual moisture content. In general, the standard deviation of the resistance meter readings was no greater than 5 percent of the mean, and in many cases, was no greater than 3 percent. Readings of the power-loss meters showed standard deviations that ranged from 5 to 20 percent of the mean, with a majority of the groups showing standard deviations that were about 10 percent of the mean.

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[2] Petersen, R. W. "The Dielectric Properties of Wood," Tech. Note 16, Forest Products Laboratories of Canada, Ottawa. 1960.

This larger variability of the readings of power-loss type meters has been known previously and has generally been attributed to the dependence of the readings upon the density of the specimen. In addition, it seems likely that the resistance meters may show smaller variability in their readings than do power-loss meters simply because of the more basic nature of the property of resistivity as compared to the more complex property of radio-frequency power absorption. Resistance is measurable by direct comparison with stable and accurate standard resistors. Variability from electrode contact can easily be eliminated by reasonably careful setting of the electrode needles into the wood. Calibration and adjustment of the instrument are easy because only elementary circuits are required. By contrast, not only are the readings of power-loss meters affected by the density of the specimen, but contact of the surface electrodes is quite critical. Further, the calibration and adjustment of the instrument involve several important variables that affect the range, linearity, and magnitude of the readings.

To overcome the effect of the larger variability of power-loss meter readings, a larger sample usually is required for a given level of confidence in the mean than is required for the resistance-type meter.

Conclusions

The data presented permit more accurate use of electric moisture meters on seven species for which species corrections or conversion factors were not previously available.

Limited data indicate that, when 2-pin electrodes are used with resistance-type meters, the readings are lower than corresponding readings with the standard 4-pin electrode. The difference appears to be no more than 0.5 percent moisture content for wood at moisture levels below 15 percent, increasing to nearly 1 percent for moisture levels above 15 percent.

The power-loss type meters exhibit calibration functions that are similar to the functions of total power absorption versus moisture content obtained by basic measurements, indicating that the meters themselves show a nearly linear relationship between scale reading and total power absorption.

Readings of resistance-type meters show considerably lower variability than corresponding readings of power-loss type meters.

Table 1.--Average[1] values and associated standard deviations[2] of actual moisture content and moisture meter readings on jack pine

Conditioning treatment[3]	Moisture content			
	Actual	Resistance type	Power loss, model A[4]	Power loss, model B[4]
	Percent	Percent		
80° F., 30 percent relative humidity, from green	7.2 (.20)	< 7	12.7 (.49)	....
80° F., 65 percent relative humidity, from green	14.0 (.48)	11.1 (.32)	15.7 (.90)	....
80° F., 80 percent relative humidity, from green	17.8 (.41)	15.7 (.42)	20.3 (1.45)	....
80° F., 90 percent relative humidity, from green	25.1 (.75)	20.7 (.57)	37.2 (3.53)	....
80° F., 97 percent relative humidity, from green	29.3 (.95)	27.5 (.71)	over range	....
80° F., 30 percent relative humidity, continuing at same condition	6.7 (.23)	< 7	12.1 (.46)	8.5 (.61)
73° F., 50 percent relative humidity, from equilibrium at 80° F., 80 percent relative humidity	11.0 (.30)	9.0 (.28)	14.5 (.88)	10.9 (.74)
80° F., 65 percent relative humidity, from equilibrium at 80° F., 80 percent relative humidity	13.6 (.43)	11.2 (.25)	15.1 (.78)	11.8 (.75)
80° F., 80 percent relative humidity, from equilibrium at 80° F., 65 percent relative humidity	16.1 (.54)	14.2 (.23)	17.6 (.88)	16.8 (1.42)

[1]Averaged for each species at each moisture content; each value is the average for 15 specimens.

[2]Numbers in parentheses are standard deviations of groups.

[3]Temperature and relative humidity of conditioning environment, and previous condition from which equilibrium was approached.

[4]Readings from power-loss meters do not directly indicate moisture content in percent.

Table 2.--Average[1] values and associated standard deviations[2] of actual moisture content and moisture meter readings on black spruce

Conditioning treatment[3]	Moisture content			
	Actual	Resistance type	Power loss, model A[4]	Power loss, model B[4]
	Percent	Percent		
80° F., 30 percent relative humidity, from green	7.4 (.20)	< 7	13.2 (.32)	....
80° F., 65 percent relative humidity, from green	14.4 (.15)	11.2 (.19)	16.2 (.90)	....
80° F., 80 percent relative humidity, from green	18.7 (.18)	16.1 (.39)	21.3 (1.13)	....
80° F., 90 percent relative humidity, from green	24.6 (.72)	21.8 (.95)	44.9 (2.72)	....
80° F., 97 percent relative humidity, from green	31.0 (1.28)	28.3 (1.37)	over range	....
80° F., 30 percent relative humidity, continuing at same condition	7.0 (.11)	< 7	13.0 (.85)	9.4 (.76)
73° F., 50 percent relative humidity, from equilibrium at 80° F., 80 percent relative humidity	11.6 (.22)	9.3 (.27)	15.9 (1.11)	12.1 (1.12)
80° F., 65 percent relative humidity, from equilibrium at 80° F., 80 percent relative humidity	13.9 (.19)	11.5 (.24)	16.3 (1.18)	13.4 (1.31)
80° F., 80 percent relative humidity, from equilibrium at 80° F., 65 percent relative humidity	16.6 (.15)	14.5 (.34)	18.4 (.99)	17.5 (1.46)

[1]Averaged for each species at each moisture content; each value is the average for 15 specimens.

[2]Numbers in parentheses are standard deviations of groups.

[3]Temperature and relative humidity of conditioning environment, and previous condition from which equilibrium was approached.

[4]Readings from power-loss meters do not directly indicate moisture content in percent.

Table 3.--Average[1] values and associated standard deviations[2] of actual moisture content and moisture meter readings on paper birch

Conditioning treatment[3]	Moisture content			
	Actual	Resistance type	Power loss, model A[4]	Power loss, model B[4]
	Percent	Percent		
80° F., 30 percent relative humidity, from green	6.5 (.21)	< 7	13.2 (.75)	....
80° F., 65 percent relative humidity, from green	13.3 (.19)	12.6 (.45)	17.5 (1.11)	....
80° F., 80 percent relative humidity, from green	17.7 (.18)	17.3 (.69)	25.7 (2.25)	....
80° F., 90 percent relative humidity, from green	27.3 (.30)	25.6 (1.73)	over range	....
80° F., 97 percent relative humidity, from green	40.0 (3.67)	36.4 (5.01)	over range	....
80° F., 30 percent relative humidity, continuing at same condition	6.0 (.18)	< 7	12.3 (.75)	9.2 (.80)
73° F., 50 percent relative humidity, from equilibrium at 80° F., 80 percent relative humidity	10.3 (.18)	9.2 (.29)	15.0 (.80)	11.7 (.72)
80° F., 65 percent relative humidity, from equilibrium at 80° F., 80 percent relative humidity	13.0 (.18)	11.9 (.31)	16.4 (1.15)	14.8 (1.01)
80° F., 80 percent relative humidity, from equilibrium at 80° F., 65 percent relative humidity	15.9 (.27)	15.3 (.50)	21.1 (1.84)	23.1 (2.03)

[1]Averaged for each species at each moisture content; each value is the average for 15 specimens.

[2]Numbers in parentheses are standard deviations of groups.

[3]Temperature and relative humidity of conditioning environment, and previous condition from which equilibrium was approached.

[4]Readings from power-loss meters do not directly indicate moisture content in percent.

Table 4.--Average[1] values and associated standard deviations[2] of actual moisture content and moisture meter readings on black ash

Conditioning treatment[3]	Moisture content			
	Actual	Resistance type	Power loss, model A[4]	Power loss, model B[4]
	Percent	Percent		
80° F., 30 percent relative humidity, from green	6.9 (.11)	7.1 (.14)	14.1 (.35)	....
80° F., 65 percent relative humidity, from green	14.0 (.17)	15.8 (.77)	24.8 (2.44)	....
80° F., 80 percent relative humidity, from green	18.5 (.19)	21.8 (1.05)	47.4 (3.43)	....
80° F., 90 percent relative humidity, from green	29.7 (.84)	37.1 (2.69)	over range	....
80° F., 97 percent relative humidity, from green	52.2 (7.45)	57.0 not enough data	over range	....
80° F., 30 percent relative humidity, continuing at same condition	6.3 (.11)	~ 7.0	13.6 (.39)	10.8 (.37)
73° F., 50 percent relative humidity, from equilibrium at 80° F., 80 percent relative humidity	10.9 (.14)	11.2 (.40)	18.6 (.81)	15.6 (.78)
80° F., 65 percent relative humidity, from equilibrium at 80° F., 80 percent relative humidity	13.7 (.16)	15.4 (.60)	24.5 (2.06)	23.8 (2.30)
80° F., 80 percent relative humidity, from equilibrium at 80° F., 65 percent relative humidity	16.6 (.24)	19.0 (.85)	38.3 (6.48)	37.9 (3.91)

[1]Averaged for each species at each moistire content; each value is the average for 15 specimens.

[2]Numbers in parentheses are standard deviations of groups.

[3]Temperature and relative humidity of conditioning environment, and previous condition from which equilibrium was approached.

[4]Readings from power-loss meters do not directly indicate moisture content in percent.

Table 5.--Average[1] values and associated standard deviations[2] of actual moisture content and moisture meter readings on eastern hemlock

Conditioning treatment[3]	Moisture content			
	Actual	Resistance type	Power loss, model A[4]	Power loss, model B[4]
	Percent	Percent		
80° F., 30 percent relative humidity, from green	7.3 (.15)	< 7	13.3 (.88)	....
80° F., 65 percent relative humidity, from green	14.3 (.21)	11.9 (.13)	17.4 (.69)	....
80° F., 80 percent relative humidity, from green	18.4 (.31)	17.1 (.41)	23.8 (1.19)	....
80° F., 90 percent relative humidity, from green	24.8 (.39)	23.3 (.61)	over range	....
80° F., 97 percent relative humidity, from green	60.3 (19.64)	49.8 (8.65)	over range	....
80° F., 30 percent relative humidity, continuing at same condition	6.8 (.15)	< 7	12.3 (.71)	9.0 (.78)
73° F., 50 percent relative humidity, from equilibrium at 80° F., 80 percent relative humidity	11.3 (.34)	9.3 (.27)	16.2 (.84)	12.1 (1.00)
80° F., 65 percent relative humidity, from equilibrium at 80° F., 80 percent relative humidity	13.9 (.26)	11.8 (.21)	17.4 (.61)	13.6 (1.06)
80° F., 80 percent relative humidity, from equilibrium at 80° F., 65 percent relative humidity	16.5 (.19)	14.8 (.35)	20.8 (.83)	20.1 (.96)

[1] Averaged for each species at each moisture content; each value is the average for 15 specimens.

[2] Numbers in parentheses are standard deviations of groups.

[3] Temperature and relative humidity of conditioning environment, and previous condition from which equilibrium was approached.

[4] Readings from power-loss meters do not directly indicate moisture content in percent.

Table 6.--Average[1] values and associated standard deviations[2] of actual moisture content and moisture meter readings on bigtooth aspen

Contitioning treatment[3]	Moisture content			
	Actual	Resistance type	Power loss, model A[4]	Power loss, model B[4]
	Percent	Percent		
80° F., 30 percent relative humidity, from green	6.2 (.10)	< 7	10.6 (.76)	....
80° F., 65 percent relative humidity, from green	13.1 (.16)	12.8 (.88)	16.2 (1.74)	....
80° F., 80 percent relative humidity, from green	17.3 (.18)	17.7 (1.30)	25.1 (5.40)	....
80° F., 90 percent relative humidity, from green	26.7 (.26)	26.9 (2.92)	over range	....
80° F., 97 percent relative humidity, from green	40.2 (9.10)	46.6 (11.22)	over range	....
80° F., 30 percent relative humidity, continuing at same condition	5.9 (.09)	< 7	9.7 (.73)	6.7 (.62)
73° F., 50 percent relative humidity, from equilibrium at 80° F., 80 percent relative humidity	10.2 (.22)	9.3 (.70)	13.0 (.67)	9.1 (1.07)
80° F., 65 percent relative humidity, from equilibrium at 80° F., 80 percent relative humidity	12.9 (.17)	12.4 (1.08)	15.6 (1.62)	11.6 (1.65)
80° F., 80 percent relative humidity, from equilibrium at 80° F., 65 percent relative humidity	15.5 (.14)	16.2 (1.42)	21.5 (4.91)	22.2 (4.29)

[1] Averaged for each species at each moisture content; each value is the average for 15 specimens.

[2] Numbers in parentheses are standard deviations of groups.

[3] Temperature and relative humidity of conditioning environment, and previous condition from which equilibrium was approached.

[4] Readings from power-loss meters do not directly indicate moisture content in percent.

Table 7.--Average[1] values and associated standard deviations[2] of actual moisture content and moisture meter readings on red pine

Conditioning treatment[3]	Moisture content			
	Actual	Resistance type	Power loss, model A[4]	Power loss, model B[4]
	Percent	Percent		
80° F., 30 percent relative humidity, from green	7.1 (.16)	< 7	12.6 (.62)	....
80° F., 65 percent relative humidity, from green	14.1 (.42)	11.4 (.35)	15.3 (.59)	....
80° F., 80 percent relative humidity, from green	17.7 (.34)	16.0 (.44)	20.9 (1.05)	....
80° F., 90 percent relative humidity, from green	25.9 (.86)	22.3 (.75)	47.1 (2.23)	....
80° F., 97 percent relative humidity, from green	31.7 (1.00)	32.0 (3.50)	over range	....
80° F., 30 percent relative humidity, continuing at same condition	6.7 (.17)	< 7	11.4 (.53)	7.6 (.59)
73° F., 50 percent relative humidity, from equilibrium at 80° F., 80 percent relative humidity	10.7 (.22)	8.7 (.32)	14.5 (.91)	10.4 (.52)
80° F., 65 percent relative humidity, from equilibrium at 80° F., 80 percent relative humidity	13.6 (.40)	11.3 (.35)	14.4 (.68)	11.8 (.75)
80° F., 80 percent relative humidity, from equilibrium at 80° F., 65 percent relative humidity	16.3 (.39)	14.8 (.44)	18.4 (.83)	17.4 (1.52)

[1] Averaged for each species at each moisture content; each value is the average for 15 specimens.

[2] Numbers in parentheses are standard deviations of groups.

[3] Temperature and relative humidity of conditioning environment, and previous condition from which equilibrium was approached.

[4] Readings from power-loss meters do not directly indicate moisture content in percent.

Table 8.--Species corrections for resistance-type moisture meters calibrated for Douglas-fir[1]

Moisture content indicated by meter	Jack pine		Black spruce		Paper birch		Black ash		Eastern hemlock		Bigtooth aspen		Red pine	
	Actual moisture content	Correction	Actual moisture content	Correction	Actual moisture content	Correction	Actual moisture content	Correction	Actual moisture content	Correction	Actual moisture content	Correction	Actual moisture content	Correction
Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
6	7.5	+ 1.5	7.8	+ 1.8	7.2	+ 1.2	5.9	- 0.1	8.0	+ 2.0	7.3	+ 1.3	7.9	+ 1.9
7	8.5	1.5	8.8	1.8	8.1	1.1	6.8	- .2	9.0	2.0	8.1	1.1	8.9	1.9
8	9.6	1.6	9.9	1.9	9.1	1.1	7.5	- .5	9.9	1.9	8.9	.9	9.9	1.9
9	10.7	1.7	11.0	2.0	10.0	1.0	8.3	- .7	10.9	1.9	9.8	.8	10.9	1.9
10	11.8	1.8	12.1	2.1	11.0	1.0	9.1	- .9	11.8	1.8	10.6	.6	11.9	1.9
11	12.9	1.9	13.1	2.1	12.0	1.0	9.9	- 1.1	12.8	1.8	11.5	.5	12.8	1.8
12	14.0	2.0	14.2	2.2	12.9	.9	10.7	- 1.3	13.7	1.7	12.3	.3	13.8	1.8
13	15.1	2.1	15.2	2.2	13.9	.9	11.5	- 1.5	14.6	1.6	13.1	.1	14.7	1.7
14	16.2	2.2	16.3	2.3	14.8	.8	12.2	- 1.8	15.6	1.6	13.9	- .1	15.7	1.7
15	17.2	2.2	17.4	2.4	15.8	.8	13.0	- 2.0	16.5	1.5	14.8	- .2	16.6	1.6
16	18.3	2.3	18.4	2.4	16.7	.7	13.8	- 2.2	17.5	1.5	15.6	- .4	17.6	1.6
18	20.4	2.4	20.6	2.6	18.6	.6	15.5	- 2.5	19.4	1.4	17.3	- .7	19.6	1.6
20	22.6	2.6	22.8	2.8	20.4	.4	17.0	- 3.0	21.2	1.2	18.9	- 1.1	21.6	1.6
22	24.7	2.7	24.9	2.9	22.3	.3	18.6	- 3.4	23.1	1.1	20.6	- 1.4	23.5	1.5
24	26.9	2.9	27.1	3.1	24.2	.2	20.2	- 3.8	24.9	.9	22.3	- 1.7	25.5	1.5
26	29.1	3.1	29.2	3.2	26.1	.1	21.8	- 4.2	26.8	.8	23.9	- 2.1	27.4	1.4
28	31.2	3.2	31.4	3.4	28.0	.0	23.4	- 4.6	28.7	.7	25.6	- 2.4	29.3	1.3
30	33.4	3.4	33.5	3.5	30.0	.0	24.9	- 5.1	30.5	.5	27.2	- 2.8	31.3	1.3

[1] Values below an actual moisture content of about 10 percent obtained by extrapolation--all others by interpolation.

Actual moisture content	Jack pine		Black spruce		Paper birch		Black ash		Eastern hemlock		Bigtooth aspen		Red pine	
	Meter	Model	Meter	Model	Meter	Model	Meter	Model	Meter	Model	Meter	Model	Meter	Model
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Percent														
0	9.0	5.0	10.0	5.0	9.0	6.0	8.0	5.5	8.0	4.5	5.5	3.5	9.0	3.0
1	9.5	5.5	10.0	5.5	9.5	6.5	8.5	6.5	9.0	5.0	6.0	4.0	9.5	3.5
2	10.5	6.0	10.5	6.0	10.0	7.0	9.5	7.0	9.5	6.0	7.0	4.5	10.0	4.0
3	10.5	6.5	11.0	7.0	10.5	7.5	10.5	8.0	10.0	6.5	7.5	5.0	10.5	5.0
4	11.0	7.0	11.5	7.5	11.0	8.0	11.5	9.0	10.5	7.0	8.5	5.5	11.0	5.5
5	11.5	7.5	12.0	8.0	12.0	8.5	12.5	9.5	11.5	8.0	9.0	6.0	11.0	6.0
6	12.0	8.0	12.5	8.5	12.5	9.0	13.5	10.5	12.0	8.5	10.0	7.0	11.5	7.0
7	12.5	8.5	13.0	9.0	13.0	10.0	14.0	11.5	12.5	9.0	10.5	7.5	12.0	7.5
8	13.0	9.0	13.5	10.0	13.5	10.5	15.0	12.0	13.0	10.0	11.5	8.0	12.5	8.5
9	13.5	9.5	14.0	10.5	14.5	11.0	16.0	13.0	14.0	10.5	12.0	8.5	13.0	9.0
10	14.0	10.0	14.5	11.0	15.0	11.5	17.0	14.0	14.5	11.0	13.0	9.0	13.0	10.0
12	14.5	11.0	15.5	12.0	16.0	13.0	20.5	17.5	16.0	12.5	15.0	10.0	14.0	11.0
14	15.5	12.5	16.5	13.5	18.0	16.5	25.0	25.0	17.0	13.5	17.5	15.0	15.5	13.0
16	17.5	16.0	18.0	16.0	21.0	23.0	35.0	35.0	19.5	17.0	22.0	25.0	18.0	16.0
18	20.5		20.0	24.0	26.0	(33.0)	45.0	45.0	23.0		27.0		21.5	21.5
20	24.5		24.0				>50	>50	29.0		32.0		26.0	
22	29.0		29.0										32.0	
24	34.0		35.0										38.5	
26	39.0		43.0										47.0	
28														
30														

[1] Values for moisture content below 7 percent, and values in parentheses were obtained by extrapolation, all others by interpolation, to nearest 0.5 scale reading.

Table 10.--Comparison of readings of electrical resistance moisture meters obtained with 4- and 2-pin electrodes

Equilibrium condition		Moisture content													
Temperature	Relative humidity	Jack pine		Black spruce		Paper birch		Black ash		Eastern hemlock		Bigtooth aspen		Red pine	
		4-pin	2-pin	4-pin	2-pin	4-pin	2-pin	4-pin	2-pin	4-pin	2-pin	4-pin	2-pin	4-pin	2-pin
°F.	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
73	50	8.9	8.4	9.2	9.0	9.0	8.4	10.7	10.2	9.3	8.7	9.0	8.8	8.7	8.4
80	65	11.5	11.2	11.4	10.8	12.0	11.6	15.2	14.2	11.9	11.6	12.0	11.5	11.4	11.1
80	80	14.3	14.6	14.5	13.5	15.6	14.6	18.8	17.4	14.8	14.0	17.2	16.0	15.0	13.8

Table 11.--Specific gravity[1] of specimen material compared with averages for small, clear specimens of the species[2]

Item	Specific gravity						
	Jack pine	Black spruce	Paper birch	Black ash	Eastern hemlock	Bigtooth aspen	Red pine
Specimen material	0.36	0.38	0.50	0.50	0.39	0.34	0.33
Species average	.40	.38	.48	.45	.38	.35	.41

[1]Based on volume when green and weight when ovendry.

[2]U.S. Forest Products Laboratory. Wood Handbook, U.S. Department of Agriculture Handbook No. 72. 1955.

Table 12.--Average resistance parallel to the grain, measured at 80° F. with the standard 4 pin electrode

Moisture content	Resistance parallel to grain of						
	Red pine	Bigtooth aspen	Eastern hemlock	Black ash	Paper birch	Black spruce	Jack pine
Percent	Megohms	Megohms	Megohms	Megohms	Megohms	Megohms	Megohms
6	...	...	...	120,000	...	...	...
7	700,000	300,000	...	14,000	200,000	700,000	450,000
8	100,000	24,000	120,000	2,300	24,000	90,000	52,000
9	17,000	4,000	20,000	600	5,000	16,000	9,500
10	4,300	1,100	4,300	200	1,400	4,300	2,800
11	1,300	360	1,300	85	550	1,400	1,000
12	470	150	450	40	230	580	440
13	210	60	200	20	110	250	210
14	100	30	100	10	57	120	110
15	52	16	45	6.0	30	68	60
16	28	8.6	25	3.4	17	38	35
17	16	5.0	14	2.1	10	23	21
18	10	3.1	8.8	1.3	6.0	14	13
19	6.8	2.0	5.4	.90	4.0	9.6	8.8
20	4.4	1.3	3.5	.60	2.5	6.3	5.8
21	2.8	.88	2.3	.42	1.7	4.3	3.8
22	1.9	.61	1.6	.32	1.1	3.0	2.6
23	1.2	.43	1.1	.25	.81	2.1	1.8
24	.91	.33	.78	.20	.59	1.4	1.3
25	.67	.26	.57	.17	.43	1.0	.98
26	.50	.21	.42	.14	.34	.78	.72
27	.38	.18	.33	.12	.27	.60	.56
28	.30	.15	.27	.10	.23	.46	.42
29	.25	.13	.22	.092	.20	.36	.34
30	.22	.12	.20	.082	.18	.30	.28

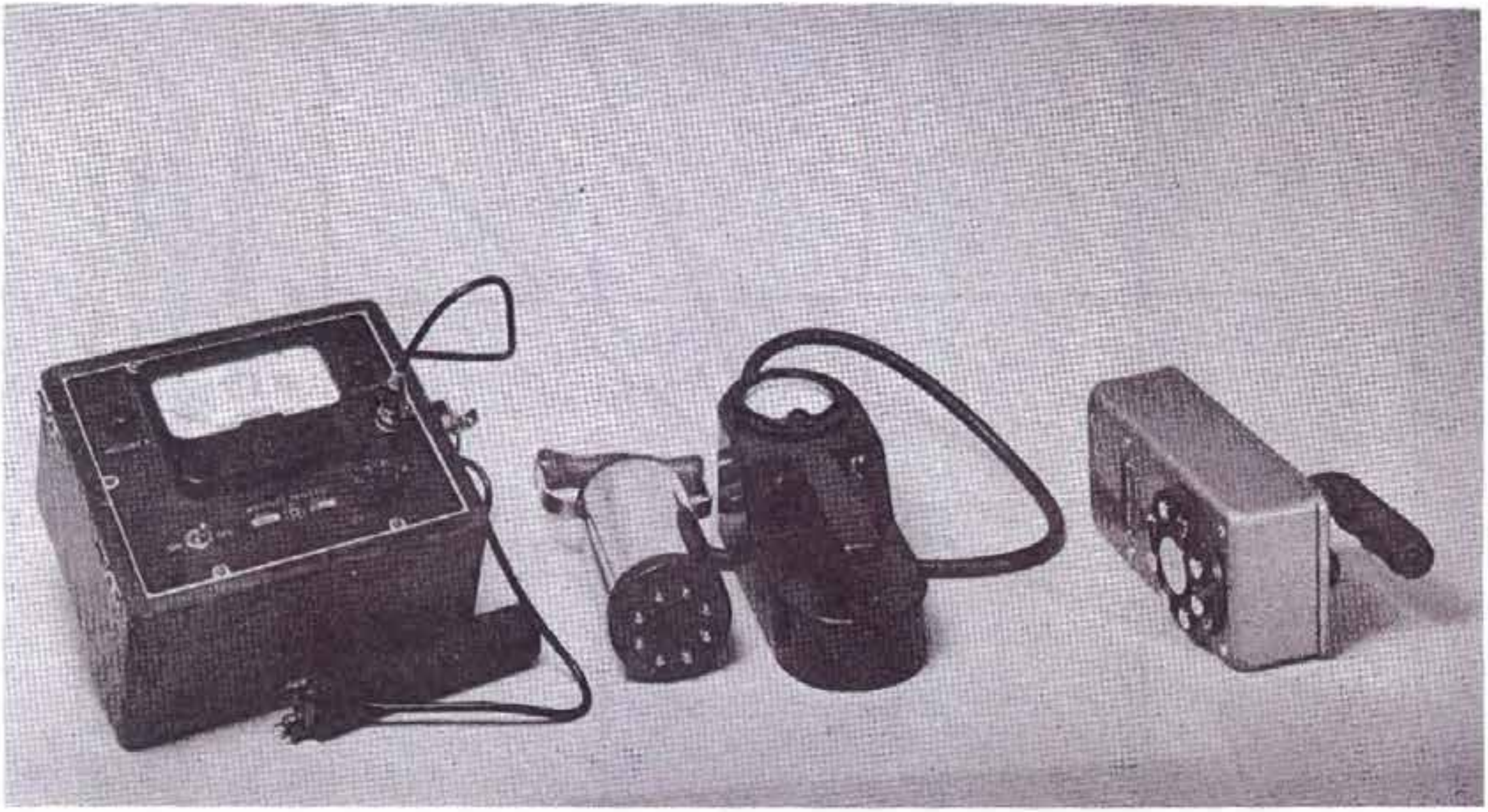

Figure 1. --Resistance-type (left), and models A and B power-loss moisture meters used to determine correction factors for seven species of wood.

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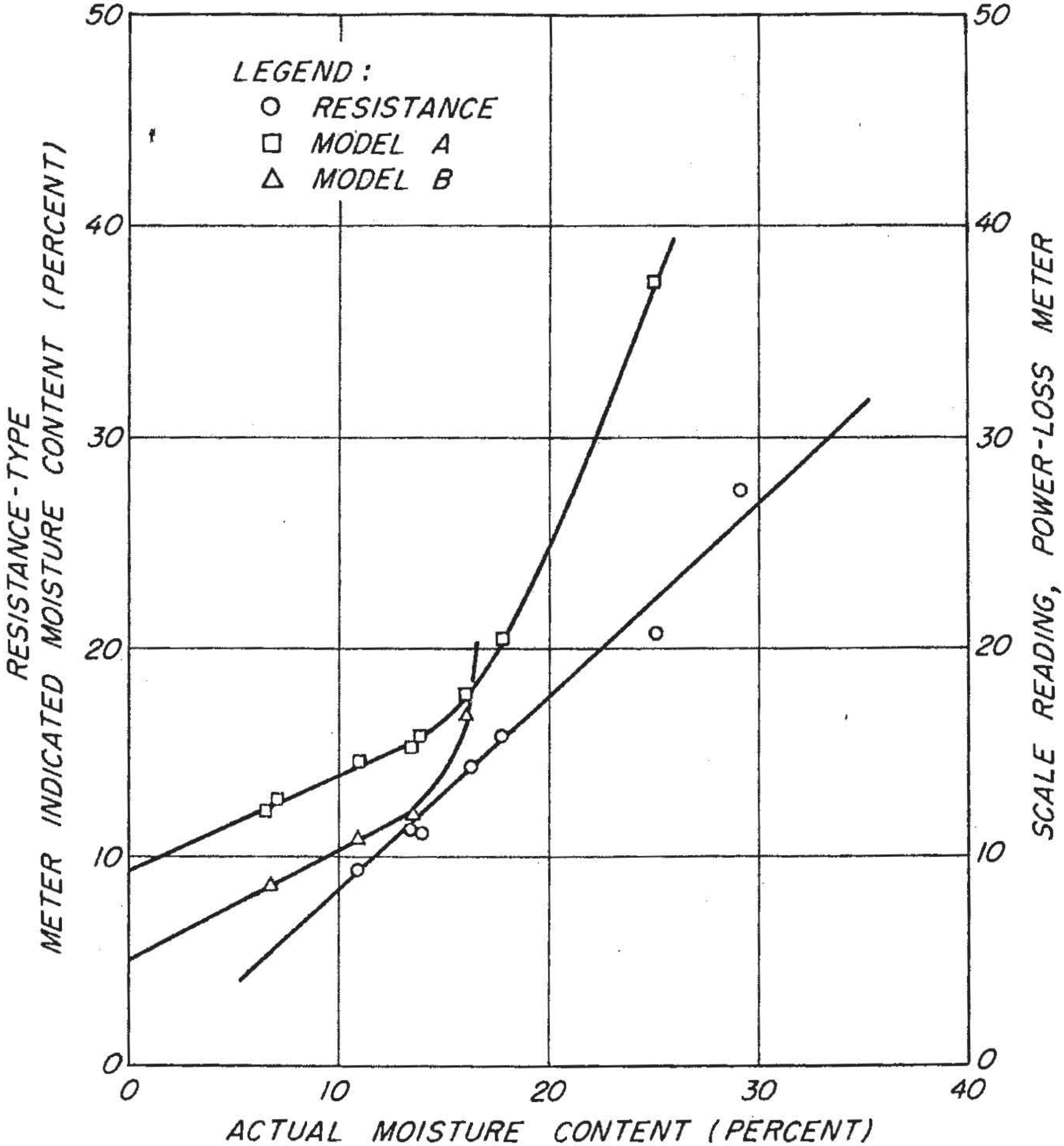

Figure 2. --Relationship between moisture meter readings and moisture content determined by oven drying for jack pine (Pinus banksiana).

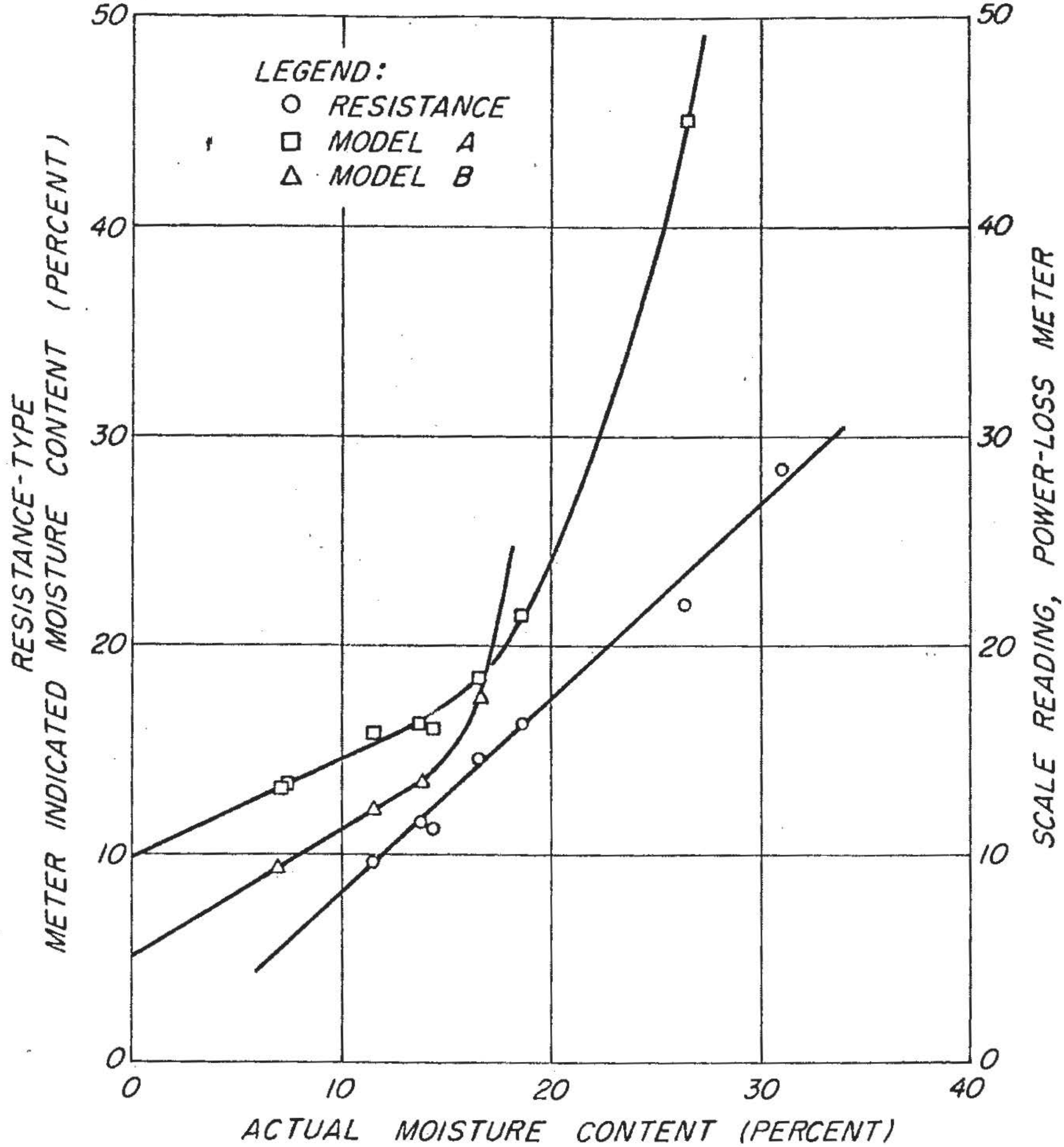

Figure 3. --Relationship between moisture meter readings and moisture content determined by oven drying for black spruce (Picea mariana).

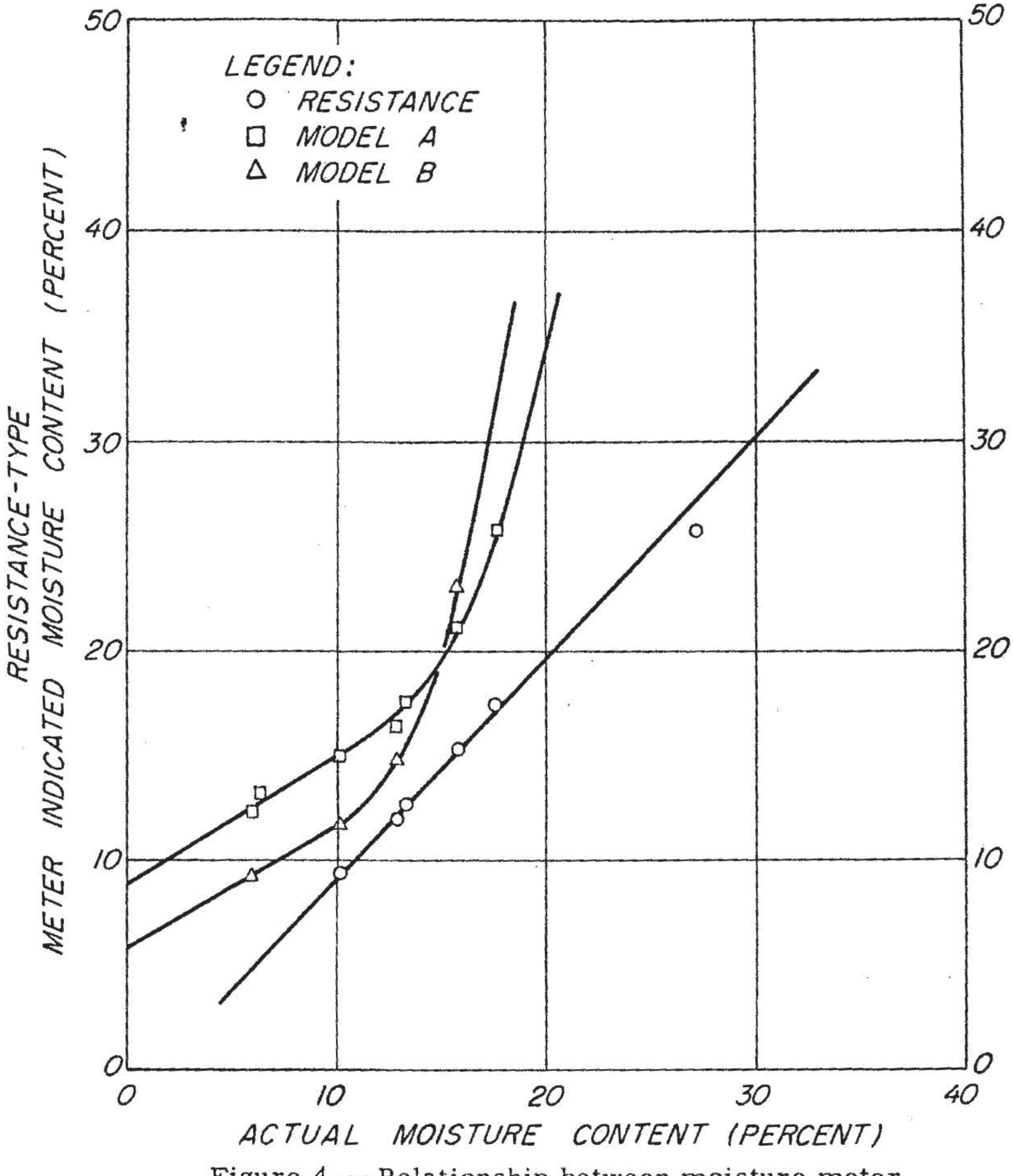

Figure 4.--Relationship between moisture meter readings and moisture content determined by oven drying for paper birch (Betula papyrifera).

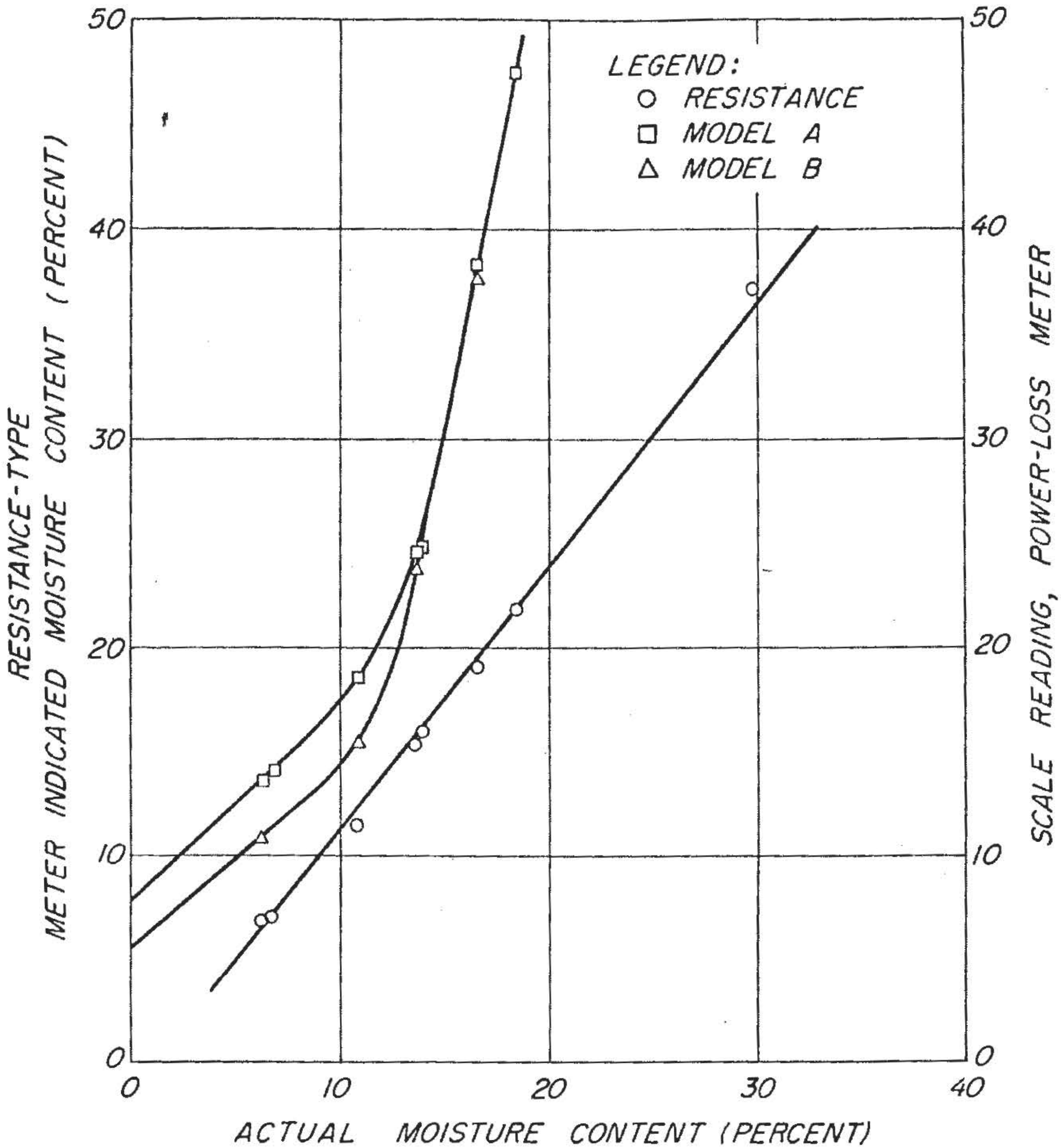

Figure 5. --Relationship between moisture meter readings and moisture content determined by oven drying for black ash (Fraxinus nigra).

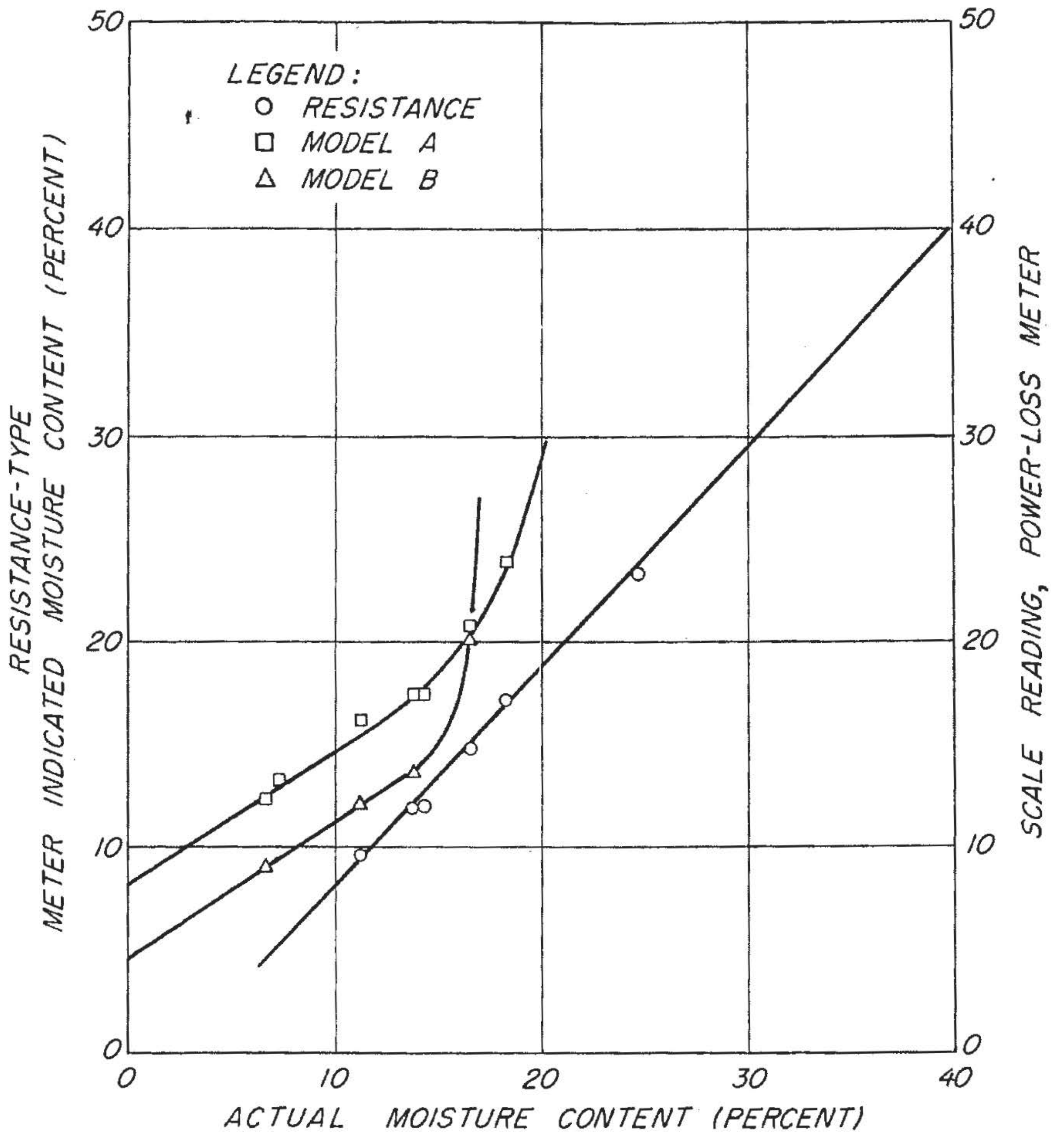

Figure 6. --Relationship between moisture meter readings and moisture content determined by oven drying for eastern hemlock (Tsuga canadensis).

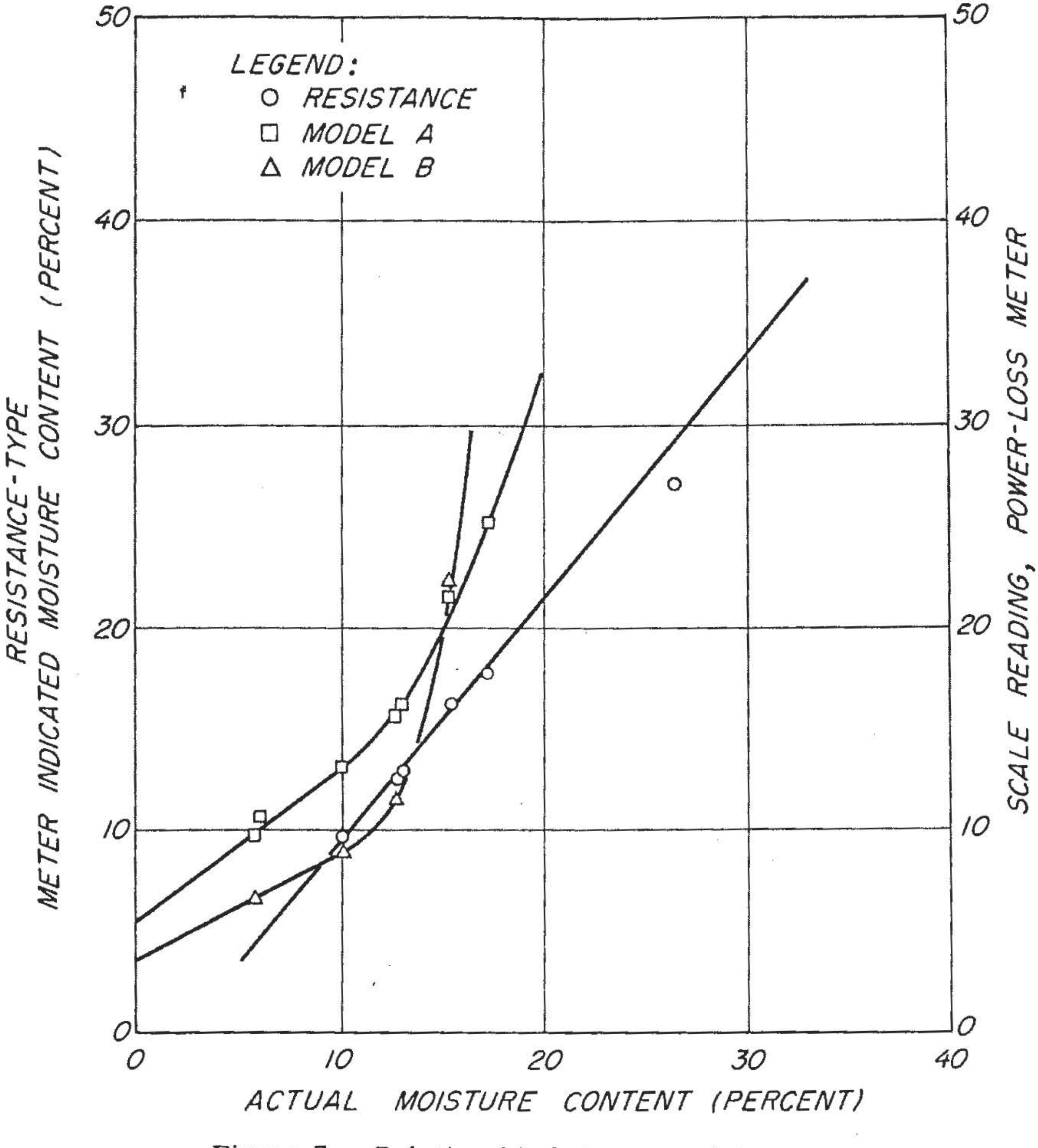

Figure 7. --Relationship between moisture meter readings and moisture content determined by oven drying for bigtooth aspen (Populus grandidentata).

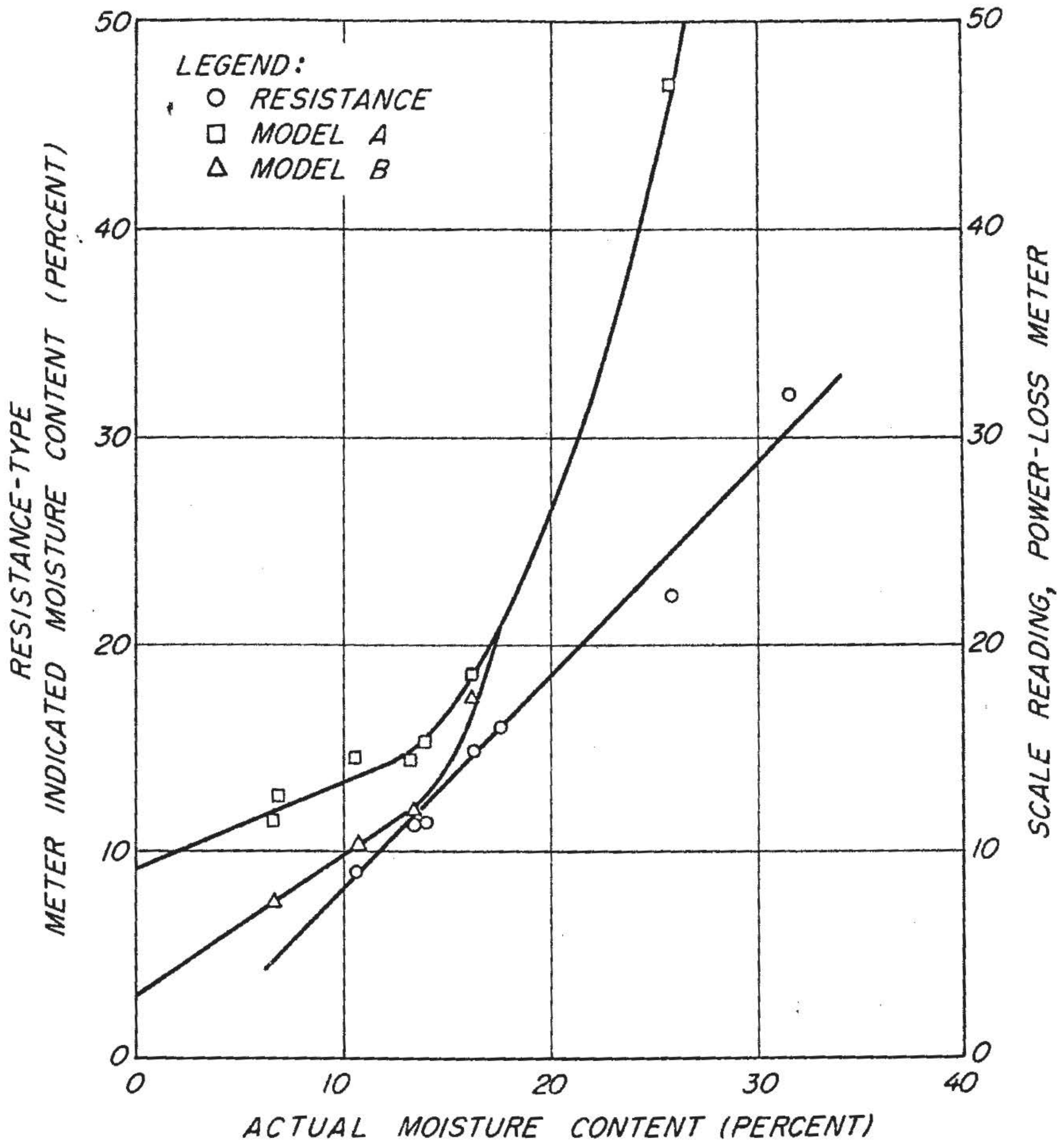

Figure 8.--Relationship between moisture meter readings and moisture content determined by oven drying for red pine (Pinus resinosa).

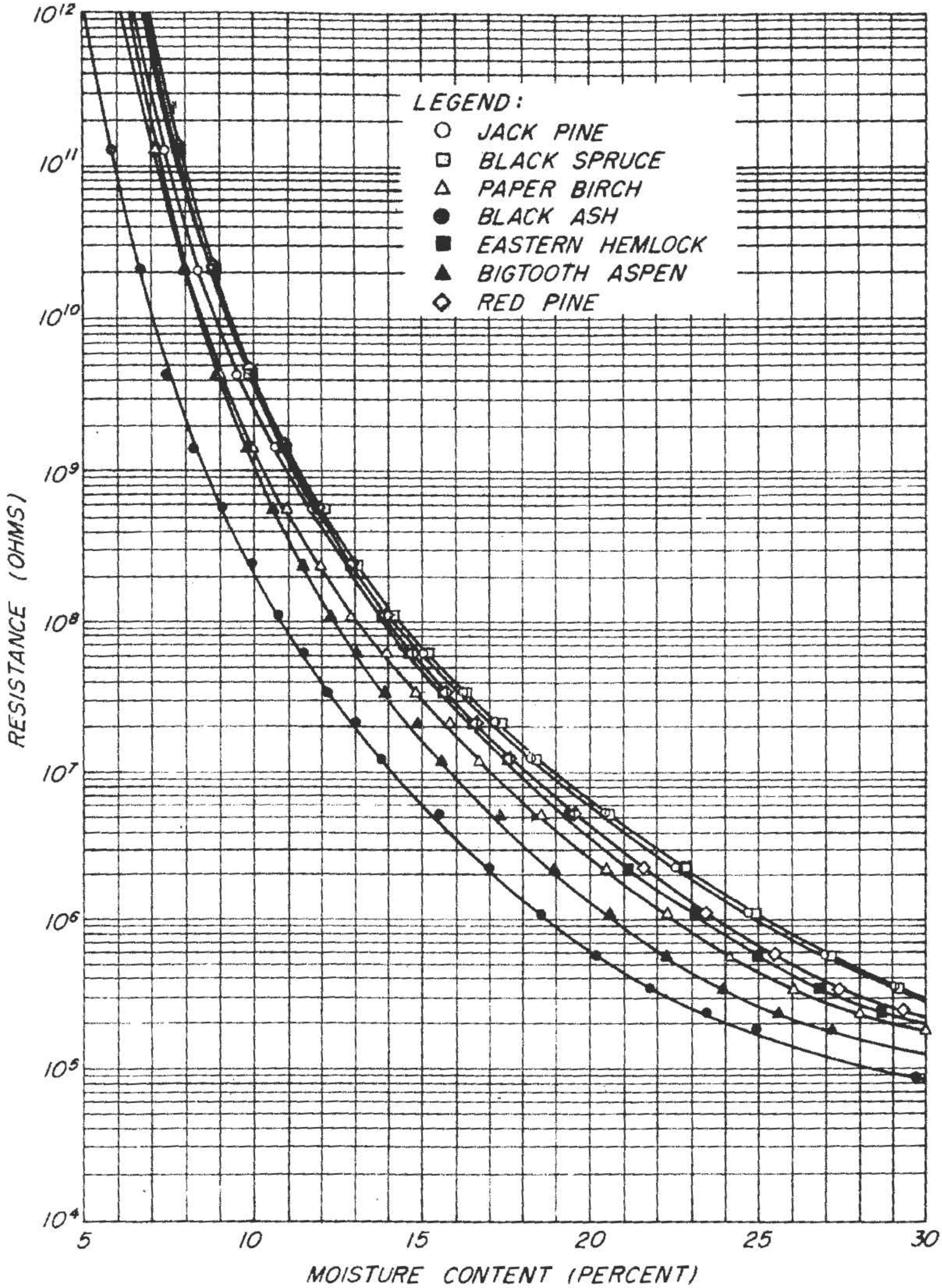

Figure 9. --Relationship between electrical resistance at 80° F., measured with a standard 4-pin electrode, and moisture content for the species studied.

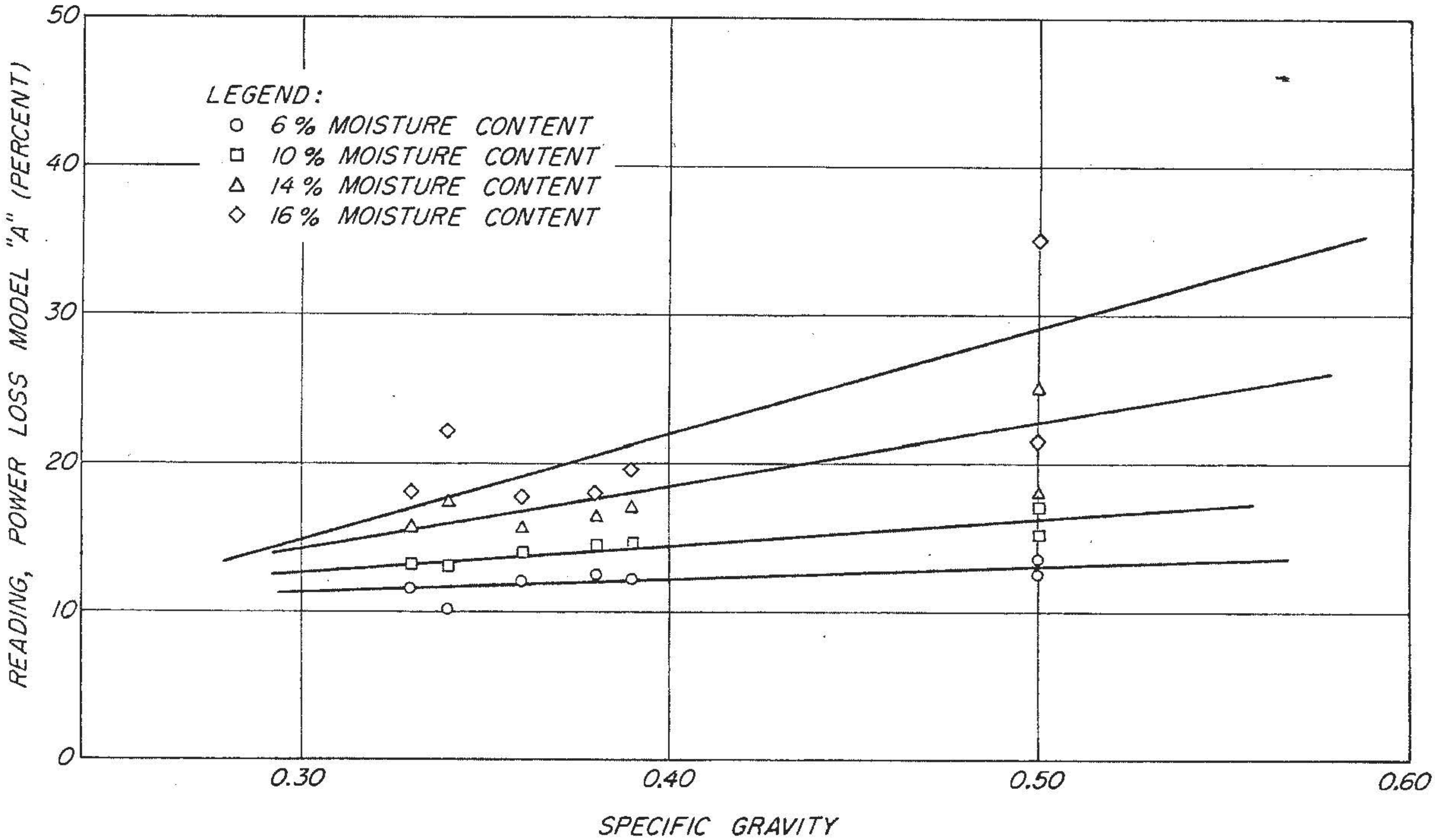

Figure 10. --Relationship between the scale reading of the model A moisture meter and the specific gravity of the specimen material, at various levels of moisture content.

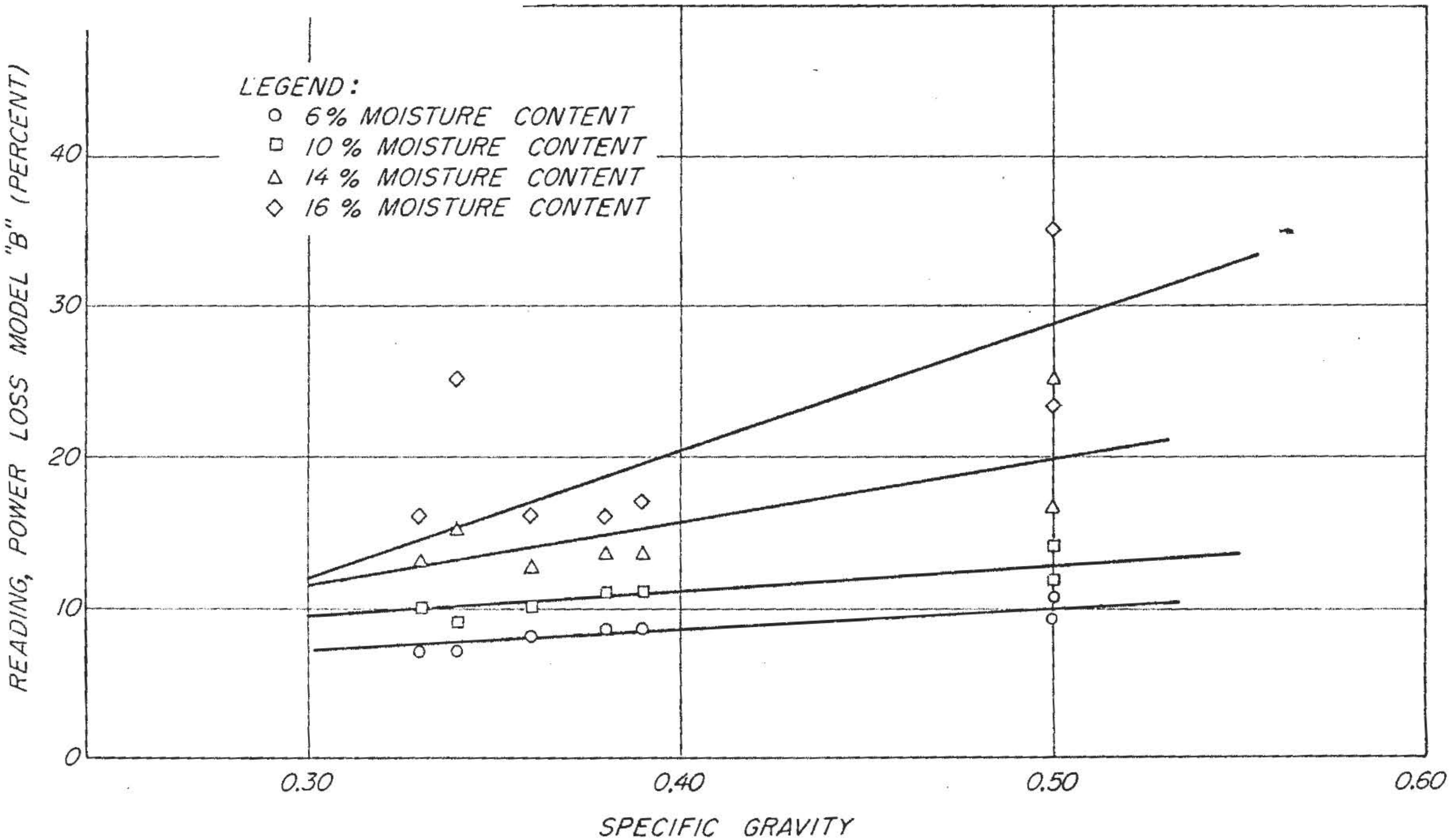

Figure 11. --Relationship between the scale reading of the model B moisture meter and the specific gravity of the specimen material, at various levels of moisture content.