

Curves for the estimation of the moisture content of ten hardwoods by means of electrical resistance measurements

J. Fernandez-Golfin^{1*}, M. Conde Garcia², M. Conde Garcia¹, J. J. Fernandez-Golfin³,
R. Calvo Haro¹, M. V. Baonza Merino¹ and P. de Palacios³

¹ *Departamento de Productos Forestales, CIFOR-INIA, Apartado 8111, 28080 Madrid*

² *Universidad de Córdoba, Escuela Técnica Superior de Ingenieros Agrónomos y Montes, Edificio Leonardo Da Vinci, Campus de Rabanales, Carretera Nacional IV km 396, 14071 Córdoba*

³ *Universidad Politécnica de Madrid, Escuela Técnica Superior de Ingenieros de Montes, Departamento de Ingeniería Forestal, Ciudad Universitaria, 28040 Madrid*

Abstract

Accuracy in moisture content measurement is of great importance in the assurance of wood product quality and is necessary to meet administrative and normative requirements. Improving the accuracy of resistance-type moisture meters, and meeting the normative demands of their annual calibration, requires the use of optimised curves relating electrical resistance to moisture content for the most commercially important wood types. The Samuelsson model, adjusted by linear regression techniques, was used to describe the relationship between the electrical resistance and moisture content of seven boreal and three tropical hardwoods available on the Spanish market. The curves produced can be used to predict the moisture contents of these hardwoods via the measurement of their electrical resistance with an error of just $\pm 1.0\%$. These curves should also prove of great use in the calibration of wood resistance-type moisture meters.

Key words: moisture meter; xyl hygrometer calibration; calibration curves; Samuelsson model.

Resumen

Determinación de curvas para la estimación del contenido de humedad de diez maderas de frondosas mediante medidas de resistencia eléctrica

La precisión en la medida del contenido de humedad juega un papel fundamental no solo en el aseguramiento de la calidad de los productos de la madera sino, también, en el cumplimiento de las exigencias normativas y administrativas que gravitan sobre los productos. Para ser capaces de mejorar la precisión de la medida tomada por los xilohigrómetros de resistencia y cumplir con las exigencias normativas de calibración anual de los equipos, es necesario obtener curvas optimizadas que relacionen la resistencia eléctrica con la humedad en las maderas de mayor importancia comercial.

El modelo de Samuelsson, $\text{Log}[\text{Log}(R) + 1] = a \cdot h + b$, ajustado mediante técnicas de regresión lineal, fue usado para describir la relación existente entre la resistencia eléctrica de la madera (R) y el contenido de humedad (h) de siete maderas de frondosas boreales y tres de frondosas tropicales comercialmente disponibles en el mercado español. Las curvas obtenidas pueden ser usadas para la predicción del contenido de humedad de dichas maderas, con un error máximo de $\pm 1.0\%$, mediante la medición de su resistencia eléctrica. Estas curvas serían también de interés para la calibración de medidores de humedad de madera por resistencia eléctrica.

Palabras clave: medidor de humedad; calibración de xilohigrómetros; curvas de calibración; modelo de Samuelsson.

Introduction

The moisture content of wood has an important influence on its physical and mechanical properties, and therefore ultimately on its performance. Indeed, many

of the challenges of using wood as an engineering material arise through changes in its moisture content (Glass and Zelinka, 2010). The effective use of wood and wood-based materials therefore requires efficient and reliable ways of measuring and adjusting it.

* Corresponding author: golfin@inia.es
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The oven-drying method is the most reliable means of determining wood moisture content, but it involves weighing samples before and after drying to a constant weight at $103 \pm 2^\circ\text{C}$. Although it is the method of choice when accuracy is of the utmost importance, e.g., in the resolution of disputes or the calibration of research instruments, it is both destructive to the timber and requires a considerable amount of time (Blakemore, 2003). It is therefore of little use as a routine method for the wood industry. Rather, fast, cheap, reliable and non-destructive methods are needed that can be used to assess the moisture content of wood at every step in its use. The wood transformation sector in particular can suffer economic losses due to inaccuracies in the measurement of wood moisture, and both non-detected moisture excess and ‘false rejects’ can be a problem. Being able to accurately determine this variable is therefore of great everyday importance to this industry.

Hand-held moisture meters provide a rapid method for obtaining the moisture content of wood and wood products during processing and when in service. These instruments measure electrical properties that correlate with the amount of water in the wood (Gillis *et al.*, 2001). Two types of moisture meters are currently available: resistance-type and dielectric-type moisture meters (which measure the dielectric constant and/or power loss factor). The resistance-type method is widely used in the monitoring of kiln drying, forming an integrated part of the control and regulation equipment of wood driers, and for assessing the conformity of the final moisture content of sawn timber and other kinds of wood products. Dielectric-type moisture meters are mainly used in production lines to provide on-line and non-contact measurements; they are typically used in the plywood and glulam production industries.

The basic principles of both methods are well known, but both suffer from drawbacks, particularly with respect to their accuracy. One of the most important sources of error when estimating the moisture content with resistance-type moisture meters is the use of inadequate corrections of the internal calibration curve for different species. For example, Vermaas (1982) reported that the moisture meters calibrated for a European pine species did not give the required accuracy when used on Monterrey (*Pinus radiata*) and maritime pines (*P. pinaster*) grown in South Africa.

In agreement with the Construction Products Directive 89/106/EC, and with the harmonised standard EN 14081-1, the CE marking of wood products for con-

struction requires factory production control. Indeed, the declaration of the moisture content when grading structural timber is mandatory, standard EN 14081-1 requires all timber producers’ moisture meters be calibrated annually. For the calibration of resistance-type moisture meters, the use of high resistance decade boxes is the cheapest, fastest and most reliable method. Unfortunately, however, the calibration curve describing the relationship between electrical resistance and moisture content must be known for each species of wood concerned.

Although Hiruma, in 1915, and Hasselblatt, in 1926, were the first to study the variation of electrical resistance of wood with moisture, Stamm (1927) was the first to show a linear relationship to exist between the logarithm of the electrical resistivity and the moisture content of wood (with resistivity decreasing as moisture increases) below the fibre saturation point. Many authors (Brown *et al.*, 1963; Clark and Williams, 1933; Forsén and Tarvainen, 2000; Keylwerth and Noack, 1956; Langwig and Skaar, 1975; Lin, 1965; Nusser, 1938; Okoh, 1976; Samuelsson, 1990; Suits and Dunlap, 1931; Vermaas, 1982) have confirmed the possibility of using logarithmic models to explain the dependence of wood’s electrical resistance (as well as resistivity or conductivity) on its moisture content.

The logarithmic model used in the present study was that proposed by Samuelsson (1990), which relates the electrical resistance (R , in $\text{M}\Omega$) to moisture content (h , in %) according to the following expression:

$$\text{Log}[\text{Log}(R) + 1] = a \cdot h + b \quad [1]$$

where:

R is the electrical resistance of the wood (in $\text{M}\Omega$),
 a and b are model coefficients,
 h is the wood moisture content (in %).

The interest in using this expression is based on its good fit with experimental data and on the fact that it was used in an extensive study performed by Forsén and Tarvainen (2000), who determined the above cited coefficients ‘ a ’ and ‘ b ’ for different types of European wood species (Scots pine, maritime pine, spruce, European oak, birch, beech, alder and larch). This allows for comparisons of the present results for European oak and beech with those obtained by the above authors, and improves the database of calibration curves obtained with similar methodologies.

Vermaas (1975) indicated the variables to be considered when measuring with resistance-type moisture meters:

1) Internal variables (material properties): species, wood density, wood temperature, measuring direction, chemical components (mainly preservatives), internal moisture gradients, and the effects of heartwood and sapwood.

2) External variables (measurement variables): geometric characteristics of the electrodes, distance between electrodes, measurement depth, contact pressure of the electrodes, shape and size of the wood elements inspected, electrolytic effects, measuring voltage, and the measuring delay.

Most of the aforementioned variables (nearly all the external variables, plus the measuring direction, moisture gradients and chemical treatment) can be controlled through the use of the measurement methodology included in European Standard EN 13183-2:2002, whereas others, such as species, have to be considered in the sampling process. As far as the variation of density within a given species of wood is concerned, several studies (Keylwerth and Noack, 1956; Vermaas, 1982; Forsén and Tarvainen, 2000) have reported its influence on the electrical resistance to be statistically insignificant. It was therefore not taken into account in the present study.

The aim of the present work was to obtain improved resistance-moisture content curves for the most important hardwood species available on the Spanish market. Curves should improve the reliability of the hand-held resistance-type wood moisture meters used in Spain.

Materials and Methods

Test material

Flat sawn 50 mm-thick lumber boards of American chestnut (*Castanea dentata*), American white oak (*Quercus alba*), red oak (*Quercus rubra*), cherry (*Prunus serotina*), ash (*Fraxinus sp.*), beech (*Fagus sylvatica*), European white oak (*Quercus robur*), iroko (*Chlorophora excelsa*), limba (*Terminalia superba*) and samba (*Triplochiton scleroxylon*) (n = 12 per species) were collected from three different Spanish companies (four from each supplier for each species). This collection procedure was followed to ensure as much variation as possible with regard to provenance, thus providing a representative sample of the material present on the market.

The lumber boards were cut into test samples approximately 50 mm long, 50 mm wide and 20 mm

thick. At least 50 cm were discarded from each end of the boards before the test specimens were cut. Thirty six test samples for each species (twelve per supplier) free of visible defects, such as knots, decay, resin pockets, gum and high grain angles, were randomly selected.

After initial weighing, the test material was subjected to four sets of environmental conditions in climate chambers: a temperature of $20 \pm 0.5^\circ\text{C}$ and a relative humidity of either $40 \pm 5\%$, $65 \pm 5\%$, $80 \pm 5\%$ or $90 \pm 5\%$. Nine test pieces (three per supplier) for each species were randomly selected for introduction into each chamber. However, due to a problem of surface staining, only 27 American cherry and 19 Samba wood samples were available (see Table 1). The masses of the test materials were monitored weekly, recording the gains or losses of each. To avoid the effect of internal moisture gradients on the electrical resistance measurements, the test materials were kept in the chambers until a constant mass was reached. The moisture content was deemed to be in equilibrium when the weekly mass variation was $\leq 0.1\%$ (after about four months in the chamber). All masses were determined using a METTLER TOLEDO (Delta Range PB 303) balance with a resolution of 1 mg. Both the chambers and the balance were subjected to the periodic calibration and maintenance procedures contemplated in the ISO 17025 Manual of Quality adopted by our laboratory (ENAC accredited).

Measurement of electrical resistance and moisture content

At the end of the conditioning period the electrical resistance of each sample was measured using an AGILENT 4339B high resistance meter (range $10^3 - 10^{15} \Omega$, accuracy 0.5%, display resolution 5 digits). The measuring specifications were as follows:

- Measuring voltage: 10 V
- Measuring temperature (material and laboratory): 20°C
- Measuring time delay: 5 s

These measuring specifications were the same as those used by Forsén and Tarvainen (2000). Stainless steel pin-type electrodes 10 mm long, 2.6 mm in diameter and 28.5 mm spacing were used, the pins driven tangentially (i.e., with respect to the rings) into the samples. Wood electrical resistance was

Table 1. Regression coefficients (Samuelsson model)

Species	N° samples	Parallel to the grain (Rp)			Perpendicular to the grain (Rt)		
		a	b	R ²	a	b	R ²
Beech <i>Fagus sylvatica</i>	36	-0.046722 ± 0.000579	1.12606 ± 0.008708	0.994	-0.0442859 ± 0.000340	1.1073 ± 0.005106	0.998
European white oak <i>Quercus robur</i>	36	-0.046368 ± 0.000597	1.07042 ± 0.007946	0.994	-0.0450918 ± 0.000598	1.06539 ± 0.007934	0.994
American red oak <i>Quercus rubra</i>	36	-0.045562 ± 0.000508	1.11785 ± 0.006794	0.995	-0.04319794 ± 0.000536	1.10047 ± 0.007164	0.994
American white oak <i>Quercus alba</i>	36	-0.0514145 ± 0.000899	1.16365 ± 0.011588	0.989	-0.0486017 ± 0.000526	1.14459 ± 0.006864	0.996
American ash <i>Fraxinus sp.</i>	36	-0.051567 ± 0.000621	1.13545 ± 0.009242	0.995	-0.0512429 ± 0.000448	1.14442 ± 0.006667	0.997
American chestnut <i>Castanea dentata</i>	36	-0.0393465 ± 0.000775	1.0294 ± 0.011427	0.987	-0.0388596 ± 0.000690	1.04045 ± 0.010177	0.989
Iroko/African teak <i>Chlorophora excelsa</i>	36	-0.07511565 ± 0.001854	1.33626 ± 0.022151	0.979	-0.0703272 ± 0.001389	1.29684 ± 0.016605	0.986
American cherry <i>Prunus serotina</i>	27	-0.0467145 ± 0.001164	1.13123 ± 0.013117	0.983	-0.0459089 ± 0.000912	1.13424 ± 0.010274	0.989
Limba/White afara <i>Terminalia superba</i>	35	-0.0480084 ± 0.000790	1.10629 ± 0.011088	0.991	-0.04570594 ± 0.000856	1.09253 ± 0.012006	0.988
Samba/Obeche <i>Triplochiton scleroxylon</i>	19	-0.0539734 ± 0.000976	1.16087 ± 0.012704	0.994	-0.055207 ± 0.000873	1.1822 ± 0.011361	0.995

measured parallel to the grain (Rp) (as required by standard EN 13183-2:2002) and perpendicular (transversally) to the grain (Rt).

All resistance measurements were taken after verifying the readings provided by the high resistance meter using a TINSLEY 4721 decade box (in possession of an external ISO 17025 calibration certificate).

To prevent any moisture content or temperature changes during the measurement process, all electrical readings were taken with samples still in their climate chambers. After the electrical readings were completed, the specimens were removed from the chambers and weighed (wet weight [w_h]) with a delay of no more than 1 min. All specimens were then oven-dried to a constant mass at $103 \pm 2^\circ\text{C}$ and the dry weight (w_d) recorded. The moisture content (h) of each specimen was then calculated (as a percentage of the dry weight) according to the following expression:

$$h = [(w_h - w_d)/w_d] \cdot 100 \quad [2]$$

where:

w_h is the wet weight, and w_d is the dry weight.

Samuelsson model fitting for the data was performed by linear regression using Statgraphics Centurion XV software.

Results and Discussion

Table 1 shows the regression coefficients for the Samuelsson model (1990) using $\text{Log}[\text{Log}(R) + 1]$ as a function of the moisture content (h). For all regression curves, the coefficient of determination R^2 was very high (> 0.95). The variable ‘species’ had a clear effect on the coefficients ‘a’ and ‘b’. Table 1 also shows the values of these coefficients that should be used when making Rp and Rt measurements for each species. Figure 1 graphically shows the effect of the measuring direction, revealing that, in practical terms, this variable had almost negligible influence (error of estimation $< \pm 0.5\%$) on moisture content estimates (HRP when using parallel models HRT when using transverse models) when the latter was $< 13\%$. This agrees with that indicated in standard AS/NZS 1080.1 (1988 version) and with that reported by James (1988), who notes that, in practical terms, the effect of the measuring direction on meter readings is negligible below a moisture content of about 15%. It also partly agrees with that indicated by Samuelsson (1990) and Forsén and Tarvainen (2000), who found it to have no significant influence over the entire moisture content range. Figure 1 also shows that above a moisture content of 13% the difference in the estimates between parallel

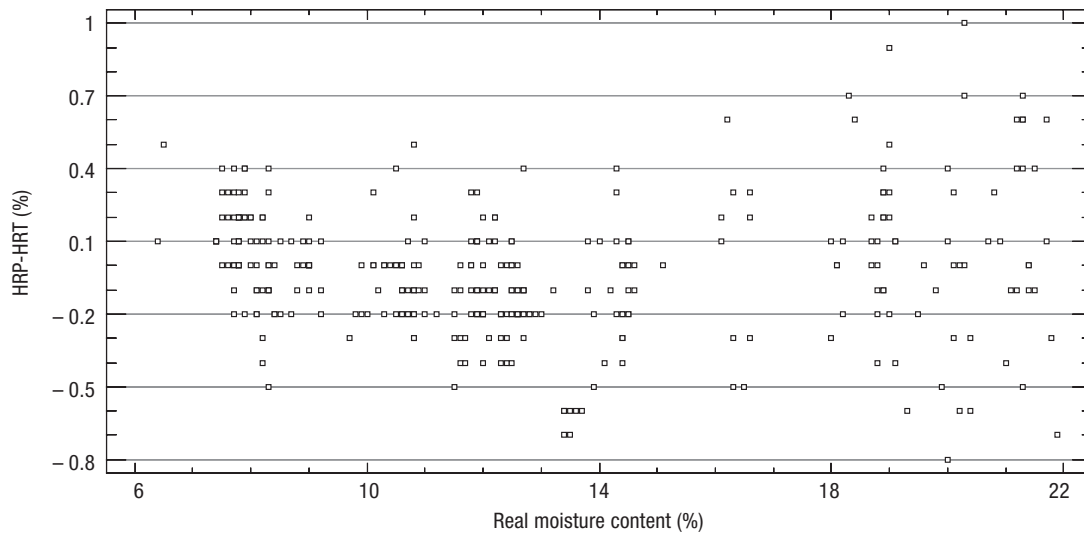


Figure 1. Differences between moisture content estimates (HRP-HRT) measured in the parallel (R_p) and transverse (R_t) directions.

and transverse measurements (HRP-HRT) increases by up to 1.0%. However, this is of little industrial importance either since UNE-EN 13183-2 requires that all moisture content estimates made with hand-held resistance meters be expressed to the nearest whole percentage point.

Comparison of the resistance-moisture content curves for European white oak and beech obtained in the present work with those reported by Forsén and Tarvainen (2000) shows there to be no significant differences (in practical terms) between the estimated moisture content values based on R_p measurements

(see Table 2). This agreement validates the present results and their usefulness in the calibration/verification of hand held resistance-type moisture meters for the estimation of wood moisture content below the fibre saturation point.

Figure 2 shows the distribution of the errors for the estimates of moisture content determined via the measurement of R_p and the use of the models in Table 1. The error of the bulk of the data is clearly within $\pm 1.0\%$. This is in line with that reported by Forsén and Tarvainen (2000) for European oak ($\pm 1.0\%$) and beech ($\pm 1.3\%$). The calculated error of estimation can only

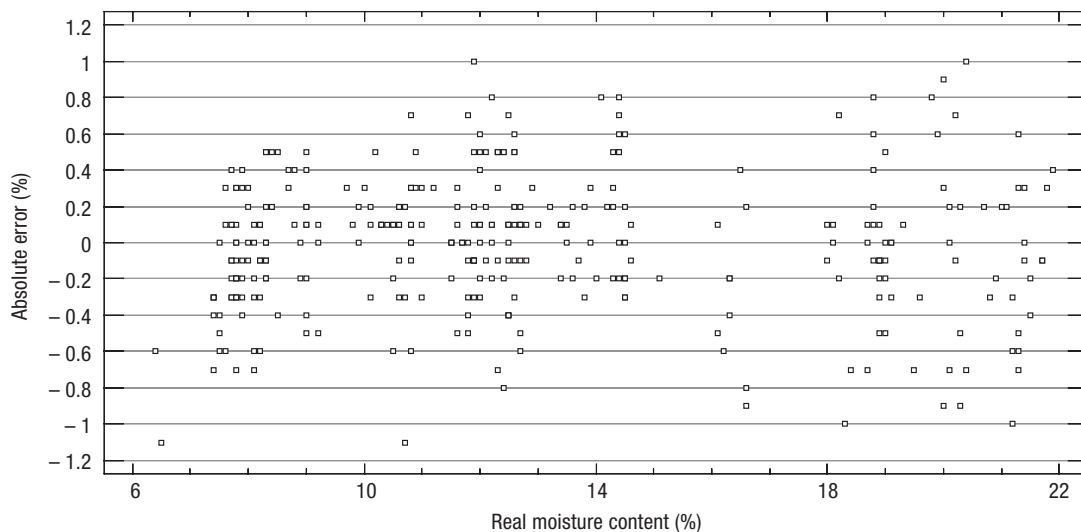


Figure 2. Distribution of absolute error of estimation (R_p direction).

Table 2. Comparison of the estimated values for European oak and beech produced by the Forsén and Tarvainen and present study models

R (MΩ)	Oak		Beech	
	Forsén and Tarvainen	Oak	Forsén and Tarvainen	Beech
10	16.6	16.6	17.8	17.7
100	12.8	12.8	14.0	13.9
1,000	10.1	10.1	11.2	11.2
10,000	8.1	8.0	9.1	9.1

be used when the wood to be inspected is environmentally well conditioned (without significant moisture gradients), its temperature is accurately known, and the resistance curve used to calculate moisture content from the measured R_p is taken from Table 1.

Conclusions

The Samuelsson model, $\text{Log}[\text{Log}(R) + 1] = a \cdot h + b$, was used to accurately predict ($\pm 1.0\%$) the moisture content of 10 hardwoods available on the Spanish market. It should be emphasised that the above expected error is applicable only when the piece of wood under inspection is environmentally fully conditioned and its temperature is accurately known and its effect compensated for.

The proposed curves in Table 1 allow the calibration of the hand-held resistance-type moisture meters commonly used in industry. They could help avoid the marketing of defective wood, reducing complaints regarding inadequate moisture contents. They should also be useful in the calibration of hand held resistance-type moisture meters, the use of which is mandatory according to EN 14081-1 and for the CE marking of wood products for construction.

The proposed curves are valid only for a temperature of 20°C; adjustments must be contemplated when measurements are made at other temperatures, for example using the species independent expression suggested by Forsén and Tarvainen (2000), the graphical correction suggested by James (1988), or that included in standard AS/NZS 1080.1:1997.

Attention should be paid to the difference between R_p and R_t moisture content readings when the moisture content is $> 14\%$. Although in the present work the differences were negligible this may not always be the case. In such cases, attention should be paid to the

instructions provide by the meter manufacturers and the appropriate curve chosen.

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