Calculation of Roundwood Volume through Its Density

JÜRI JÄNES
Department of Forest Management,
Estonian Agricultural University, Kreutzwaldi 5, Tartu 51014, Estonia

Jänes J. 2001. Calculation of Roundwood Volume through Its Density. *Baltic Forestry,* 7 (2): 57–62.

The goal of the research work was to analyse the applicability of roundwood volume estimation method. The method is based on measurements of dry density and moisture content in a timber-load. Results of the trials showed the applicability of the method on the assumption of accurate moisture content measurements. The measurement of moisture content of timber was made with the electronic tool that uses the timber electric conductivity principle and was specially developed for water content measurement of timber above its fibre saturation point. The tool did not succeed in giving needed accuracy for the measurement method. When moisture content assessment is made by ordinary kiln-drying method, the volume estimation method remains remarkably slower and more labour- consuming as compared to other roundwood volume measurement methods in use. The most important result discovered is high correlation between weighed average moisture content of cross-section of roundwood and its moisture content in outermost layer 0-1.5 cm under bark. Coefficients of determination- (R^2) were 0.80 to 0.97 according to test results.

Key words: volume of roundwood, dry density, density of a timber-load, absolute moisture content.

Introduction

The research work was carried out in 1995 in order to investigate a timber measurement method (Jänes 1997). The need to search for better and easier roundwood measurement method came from growing roundwood trade in Estonia at the beginning of the nineties.

Different assortments of roundwood are measured by different ways. Sawlogs are mainly measured piece by piece, and their volume achieved by using formulas or volume tables. Pulplogs are measured in piles and pile volumes are estimated. There are different methods for measurement of pulpwood piles:

1. The gross volume of a pile is calculated according to its dimensions. Using solid volume coefficient that is subjectively estimated to the pile by measurer-person, volume of timber is calculated. The method needs minimum expenditure to measurement equipment but requires highly skilled measurer-persons. High skill is needed for timber coefficient assessment in stacked pulpwood measurement. The measurement method is cheap and consumes time approximately 5-15 minutes for a truck- load, but the subjectivity in the measurement process reduces its reliability. After Heiskanen (1973), the coefficient of solid volume with bark in pulpwood piles varies normally in borders 0,54 to 0,69 in case of 3,0 m long coniferous pulpwood and in borders 0,45 to 0,61 in case of 3,0 m long pulpwood of broadleaves.

The subjectivity factor is often eliminated in ordinary pulpwood measurement practice by using the same average constant of solid volume coefficient for every load of pulpwood. This simplification involves reduced accuracy of measurement (using the coefficients from Heiskanen (1973), error of estimation is ±12 % in the case of coniferous pulpwood and ±15 % for broadleaves pulpwood.

2. Pulpwood piles are weighed on a vehicle and their volume is calculated through average density of timber. The average density is achieved by weighing and measuring pulplogs in samples. This method needs expensive weighing equipment for vehicles and is also labour- and time consuming because each sample log must be measured manually. Timber volume is determined at the accuracy ± 4 % by the method. Measurement of one load of truck or tractor approximately takes 12 minutes in the case of pulpwood and 7 minutes for sawlogs (Sikanen 1993).

3. Volume of pulpwood piles on a vehicle is estimated using pictures of laser-beam reflections from outermost pulplogs in stacks. Through the picture analysis gross-volume of a stack and coefficient for calculating timber volume in the stack are estimated. Estimation error of the timber volume by the method is ± 4 %. The method enables quick measurement of timber loads (one truck load is measured in 20 seconds) to be made but presumes expensive equipment that pays off when pulpwood flow is as big as in pulpmill (Sairanen 1993).

None of the listed pulpwood measurement methods are quick, cheap and reliable at the same time. That conclusion led to the idea of investigating totally new roundwood measurement method.

The investigated volume determination method of roundwood is based on determination of timber load average moisture content, its average dry density and weight.

Data of previous research works that describe the variation in dry density of timber (Kasesalu 1963, Veermets 1960, 1963) and variation in the moisture content of tree species (Kokk, Paalberg 1979, Vait 1982) showed probable applicability of the method and also the need for further research of the timber properties.

Main objectives of the research work were the following:

- To collect detailed data of moisture content from roundwood,
- To determine the needed number of measurements of the moisture content and dry density for calculating roundwood volume at the accuracy of 5% at various probability levels,
- To give estimation to studied roundwood volume determination method's usability in comparison with other measurement methods in use,
- To control the apparatus for moisture content measurement and work out adjustment parameters for the measurement of indigenous tree species.

Materials and methods

The principle of the method is based on the determination of timber samples green density. The green density is calculated on the basis of absolute moisture content and absolute dry density in timber.

gd=dd+(dd*amc), where

gd - green density of timber. It is the ratio of the weight of a timber sample that contains water, to its volume,

dd - dry density of timber. Dry density is calculated as timber weight in absolute dry state divided by its green volume,

amc - absolute moisture content in timber (expressed in percentage).

Timber loads are weighed and their volumes are calculated dividing their weight by their green density.

V = m/gd,

where
V - volume of the load of roundwood
m - mass of the load of roundwood

The principles of the measurement method are the following:

1. A load of roundwood is weighed,
2. Few samples of timber are taken from load for approximate determination of dry density of the timber-load. Variation coefficient of timber dry density is 5 - 12 % (Kasesalu 1963). Relatively small variation enables us to determine dry density with needed accuracy on the basis of a small number of measurement results,
3. A comparatively large number of humidity measurements are taken from the whole load of roundwood. In order to achieve a reliable result in the moisture content determination, a considerable number of measurements is needed. The above mentioned apparatus for timber moisture content measurements has characteristics for numerous quick measurements and therefore a large amount of measurements needed is not a problem,
4. The volume of the load in solid cubic meters is calculated on the bases of the achieved results.

The apparatus for measurement of moisture content

The biggest problem that had prevented the application of the method is insufficient accuracy in absolute moisture content measurement above timber fibre saturation point by the electrical conductivity principle. Timber will attain its fibre saturation point when it contains approximately 30% of water of its absolute dry weight. Up to fibre saturation point water is absorbed into cell walls. When the water content is over 30%, water starts to fill timber cell cavities (Saarman 1998).

A new special apparatus for the timber water content measurement was developed in Germany in 1995. The apparatus is produced in the company BES Bollmann Electronic Systeme GmbH. This device uses some totally new working principles compared to its predecessors. The most valuable characteristic of the tool for the research work was the ability to measure timber water content far above its saturation point.

In addition to the improved accuracy, the new apparatus has a portable memory block with the module of statistics that enables us to gather the quantities of measurement results more easily and faster. Some accurate adjustments for better results can also be made and saved into the memory block for measurement of different tree species.

Here are some technical data from the manual of the apparatus:

Model name: "Combo 200", version V 2,3
Measuring range of absolute moisture content: 4 – 120 %
Accuracy of measurement: 0,1 %

Temperature range of measured material:- 10° C until + 110° C

Capacity of the memory: for 256 measurements

Number of adjustment-parameter groups for tree-species that can be saved: 9

Functions of keyboard: 26

Sampling procedure of timber

Test samples were taken from felled growing trees and from stored and therefore partially dried pulpwood logs. Samples from partially dried logs were necessary to create the range of moisture content from low to high for testing the apparatus.

Test samples were split from sample-disks (Chart 1). The sample-disks were approximately 6 -cm thick cross-sections sawn from sample-logs or -stems.

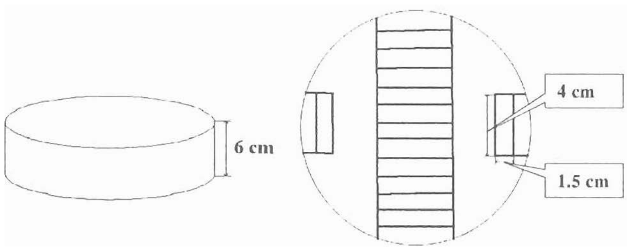

Chart 1. Sample disk and its splitting scheme

Sample-disks were split into test samples in radial direction counting from outside to inside and in calculations the test samples were considered to represent ring-shape timber layers with thickness of 1.5 cm. Test samples were split from four directions of sample-disks in two outermost 1.5 cm thick layers. The sample taking from four directions was needed to level the differences in timber characteristics in different sides of roundwood. In deeper layers test samples were split from two directions.

Test samples were used for determination of the moisture content in both ways: by apparatus and by the kiln-drying method. The same samples were also used for determination of dry density. The size of test samples wase approximately 6*4*1.5 cm (Chart 2).

The sample's volumes were measured at the accuracy of 1cm^3 in water in a special measurement container and masses were measured at the accuracy of 0.01 gram on electronic scales. To avoid mistakes from moisture content measurement by apparatus, six measurements were made in each test sample (as seen on the Chart 2) and the average of measurements was calculated to each test sample.

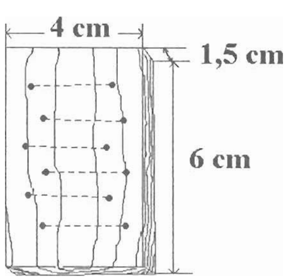

Chart 2. Test sample with small holes left from probe needles of moisture content measurement apparatus. Dashed lines are drawn between needle hole pairs to show measurement direction

The splitting method for gaining sample-pieces was better alternative than sawing because splitting method was quick and enabled us to weigh samples right after splitting, without letting them dry in open-air.

Absolute moisture content of timber

Different research works about timber moisture content confirm that basic factors influencing the moisture content in growing tree are its species, the season of a year, age of a tree and its growing site type (Avery, Burkhart 1994). The most significant influence exerted on the moisture content of a tree-stem is determined by the season of a year in temperate-zone forests (Kokk, Paalberg 1979).

Dry density of timber

Dry density of a timber sample depends on the species of a tree, its age and growing site type. Dry density of a timber sample is also largely dependent on its location in the stem in the radial direction and in lengthwise (Jalava 1957; Kasesalu 1963; Veermets 1960, 1963). There is also significant variation between dry density of individual trees having similar growth speed (Malinauskas 1999).

The conclusion from above-mentioned research results is that the factors influencing the moisture content in roundwood and its dry density are not sufficiently definable in a pile of roundwood. The latest conclusion leads to derivation that both, dry density and the moisture content of timber must be determined in every timber-load measured by the current method. It is therefore necessary to know the variations of both dry density and absolute moisture content to take statistically sufficient number of measurements.

Results

Absolute dry density of timber of investigated tree species varies in a relatively small range. According to the current research the variation coefficient is roughly in a range of 10% in case of the Norway Spruce (*Picea abies*), the Scotch Pine (*Pinus sylvestris*) and Silver and Downy Birch (*Betula pendula, Betula pubescens*) as shown in Table 1.

The absolute dry density is calculated according to the next formula:

dd=v1/m1,

where
v1 - volume of timber in its green state,
m1 - mass of timber in the absolutely dried state (kiln-dried).

Table 1. Results and statistics concerning the absolute dry density of the tree stem cross-sections

Tree-species	Number of cross-sections	Minimum and maximum values of dry density (g/ cm³)	Arithmetical mean of dry density (g/ cm³)	Standard deviation	Variation coefficient	Necessary number of timber samples from tree stem cross-sections for dry density determination that are needed for the measurement method to gain accuracy of 5% of volume estimation of timber loads at the following probability levels: 95 %	97 %
		0.593					
Spruce	59	0.350-0.519	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Pine	49	0.326-0.562	0.448	0.056	12.448	[illegible]	[illegible]

The absolute moisture content of roundwood varies much more than its dry density, the variation coefficient in growing trees is approximately 20% (Table 2). The variation is even more significant in the load of roundwood that contains both freshly cut and stored round timber.

The absolute moisture content is calculated according to the next formula:

amc = wm/dd,

where
wm - mass of the water inside timber,
dd - absolute dry density.

In Table 2 there are only weighed average absolute moisture contents of sample disks that were sawn from felled growing trees. All together weighed average absolute moisture contents were calculated to 117 birch, 59 spruce and 49 pine sample disks. Most of the sample-disks were sawn from pulpwood logs that had lost some of the water from log ends over the storing period. Therefore, the variation in the absolute moisture content is more significant yin partly dried pulpwood logs than in freshly cut pulpwood logs. This table is an example of the variation of weighed average absolute moisture content in freshly cut round timber cross-sections.

Table 2. Absolute moisture content in growing trees in summer

Tree-species	Number of measured cross-sections (sample-disks)	Minimum and maximum values of absolute moisture content (%)	Arithmetical mean of absolute moisture content (%)	Standard deviation of absolute moisture content (%)	Variation coefficient of absolute moisture content (%)	Necessary number of measurements of absolute moisture content from tree stem cross-sections needed for the measurement method to gain the accuracy of 5% of volume estimation of timber loads at the following probability levels: 95 %	97 %
Birch	10	58…91	70	11.23	16.12	10	29
Spruce	15	46…113	80	19.23	24.09	23	64
Pine	8	81…152	110	21.02	19.12	15	41

The accuracy of the moisture content measurement apparatus must be relatively good to get the moisture content data with requisite accuracy through the reasonable amount of work. The more significant the dispersion between the real absolute moisture content and the absolute moisture content gained by the apparatus, the larger the number of measurements is needed to get a reliable result.

When the correlation between measured and actual absolute moisture content becomes too weak, the needed number of measurements necessary for the calculation of the real absolute moisture content with the requisite accuracy grows too large to use this method in practice. The coefficient of determination (R^2) according to linear regression between real and measured absolute moisture contents is expressed in Table 3 and illustrated with Chart 3. The mentioned real absolute moisture contents were achieved by weighing timber samples before and after kiln-drying and measuring their volumes before kiln-drying as it is described in the Chapter "Materials and methods".

If the purpose of the research had been only the determination of the absolute moisture content of tree-species, the coefficient of determination (R^2) between real and measured absolute moisture content around 0.5 would have probably been convenient. By the current timber volume determination method the ab-

Table 3. Results of linear regression between real and measured absolute moisture contents

Tree- species	Number of observations	The coefficient of determination (R^2)	Standard error
Birch	378	0.17794	11.91
Spruce	119	0.53046	10.41
Pine	155	0.52209	10.43

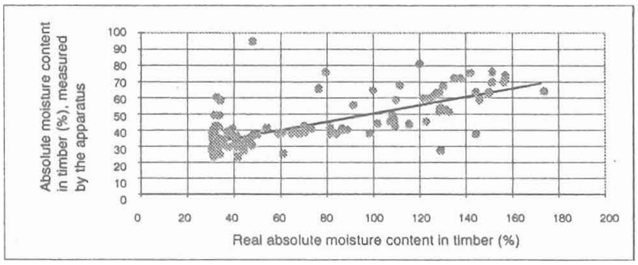

Chart 3. Relation between real and measured absolute moisture content in spruce timber

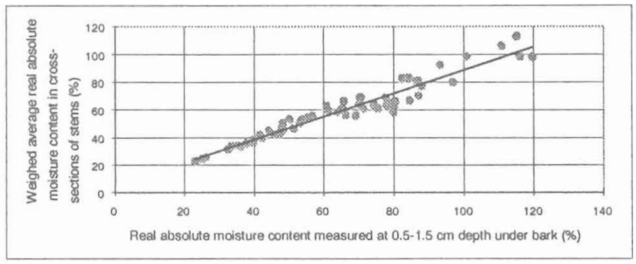

Chart 4. Relation between the weighed average real absolute moisture content in the cross-sections of spruce stems and real absolute moisture content measured at the depth of 0.5-1.5 cm under bark

solute moisture content is only one of the preliminary components in the volume calculation and it gives its error that affects the accuracy of the final result. The current method of the timber volume calculation needs a higher R^2 between the real and measured absolute moisture content to be used in everyday practice.

In order to compensate the scattering of the absolute moisture content results achieved by the apparatus compared to real values of absolute moisture content a vast amount of measurements by the apparatus is necessary. The numbers of measurements needed to get the accuracy of 5% at the real absolute moisture content level being 70% are the following: for Spruce 516, Pine 674 and Birch 2145. Such numbers of needed measurements exclude the use of the above apparatus in roundwood volume determination.

The second alternative to get absolute moisture content of timber samples is the kiln-drying method. When the kiln-drying method is used for the purpose of roundwood loads volume calculation, the timber volume determination process takes much more time and labour compared to the rest of measurement methods in practice. Measurement of one truckload of roundwood would take several hours by kiln drying of timber samples.

The results of the research work show that tested volume determination method cannot be used in practice before a more accurate and fast method for measuring of timber absolute moisture content above its fiber saturation point is developed. However, several findings resulted from the research enable us to make the following research with smaller efforts by using data already gained in the current research.

It appeared that the real absolute moisture content determined by the kiln-drying method at the depth of 0.5-1.5 cm under the tree bark of the roundwood gives practically the same result as weighed average real absolute moisture content of the tree stem cross-section determined by the kiln-drying method. The coefficients of determination (R^2) between the named two absolute moisture contents according to the trials are the following: Birch 0.968, Spruce 0.809, Pine 0.984 (Chart 4).

An important factor must be recognized in this result: in order to analyse a tree stem cross-section in the radial direction it was imaginary divided into hoops with the thickness of 1.5 cm. It is clear that the most outward imaginary hoop has the largest area and therefore gives the biggest weight to the real absolute moisture content of the weighed average cross-sections. Although absolute moisture content remarkably differs in inner and outer areas of the cross-sections of tree stems, the finding has a significant value.

The research work gave correction parameters for the particular moisture measurement apparatus. These correction parameters allow us to use the apparatus by some less demanding procedures, for example in monitoring timber moisture content in industrial kiln-dryers.

Conclusions

Newly developed measurement method must be easier, faster or cheaper to be taken into usage. The studied method is not easy enough to use it in general practice because of the need for too numerous moisture content measurements to obtain reliable results.

The reason for preferring ordinary roundwood measurement methods is the need for timber quality assessment. It cannot be done automatically. That leads to the conclusion that assessment of roundwood volume remains continually sophisticated work of measurer-persons in timber terminals.

The studied method can be used when much more accurate moisture measurement method or device is developed.

References

Avery T. E., Burkhart H. E. 1994. Forest measurements. Service foresters handbook. USDA Forest Service Southern Region in co-operation with Southern State Foresters. pp. 53-81.

Heiskanen V. 1973. Kiintomitan määrittäminen pinosta. [Determination of timber solid volume in pile]. Eripainos Paperi ja Puu lehdestä n:o 11, (1973) 13 pp. (in Finnish).

Jalava M. 1957. Puun käytöön vaikuttavat ominaisuudet. [Timber characteristics that influence its use]. Metsäkäsikirja 2. osa. Helsinki, pp. 306-320 (in Finnish).

Jänes J. 1997. Ümarpuidu mahu määramise võimalustest [Possibilities for estimation of roundwood volume]. Master's thesis. Tartu, (unpubl.). 43 pp. (in Estonian).

Kasesalu A. 1963. Aru- ja sookase puidu tehniliste omaduste võrdlevaid andmeid [Comparison of timber technical characteristics between two species of birch (*Betula verrucosa* Ehrh. and *Betula pubescens* Ehrh.)]. EPA Teaduslike tööde kogumik 29. Tartu, pp. 149-157 (in Estonian).

Kokk A., Paalberg R. 1979. Puiduniiskuse uurimine kasvavatel mändidel ja kuuskedel [Research of moisture content in growing spruce (*Pinus sylvestris* L.) and pine (*Picea abies* Karst.) timber]. Bachelor's thesis. (unpubl.). Tartu, 80 pp. (in Estonian).

Malinauskas A. 1999. The influence of the initial density and site conditions on Scots Pine growth and wood quality. Baltic Forestry, 5 (2): 8-19.

Saarman E. 1998. Puiduteadus [Timber Science] Tartu, 248 pp. (in Estonian).

Sairanen P. 1993. Kehuskuvajärjestelmä kuitupuun mittaukseen tehtaalla. [Picture-based system for pulpwood measurement in factory]. Pori, 13 pp. (in Finnish).

Sikanen L. 1993. Metsätraktorin kuormainvaakan perustuva mittaus. [Measurement based on forestry tractor weighing device]. Presentation paper for timber measurement seminar, 6 pp. (in Finnish).

Vait U. 1982. Puiduniiskuse uurimine kasvavatel mändidel ja kuuskedel Saaremaa Metsamajandis. [Research of moisture content in growing spruce (*Pinus sylvestris* L.) and pine (*Picea abies* Karst.) timber in Saaremaa Forestry Region]. Bachelor's thesis. (unpubl.). Tartu, 42 pp. (in Estonian).

Veermets K. 1960. Seaduspärasusi männipuidu tehnilistest omadustest. [Principles of changes in technical characteristics of pine (*Pinus sylvestris* L.) timber]. EPA Teaduslike tööde kogumik 17. Tartu, pp. 77-87 (in Estonian).

Veermets K. 1963. Kuusepuidu mahukaalust (EPA Õppe- ja Katsemetsamajandi andmeil). [Density of spruce (*Picea abies* Karst.) timber]. EPA Teaduslike tööde kogumik 29. Tartu, pp. 112-119 (in Estonian).

ПОДСЧЕТ ОБЪЕМА КРУГЛОГО ДЕРЕВА ЧЕРЕЗ ЕГО ПЛОТНОСТЬ

Ю. Янес

Резюме

Целью исследовательской работы был анализ возможностей использования метода оценки объема круглой древесины. Метод основан на измерении сухой плотности и содержания воды в партии круглой древесины. Результаты опытов показали, что метод можно использовать при условии точного измерения содержания воды. Измерение содержания воды в древесине свыше 30% электронным инструментом, использующим электрическую проводимость древесины, не обеспечило необходимой точности. При проведении оценки содержания воды обычным методом сушки в печи метод оценки объема становится заметно более медленным и трудоемким по сравнению с другими используемыми методами измерения объема круглой древесины. Наиболее важным результатом является высокая корреляция между взвешиваемым средним содержанием воды в разрезе круглого дерева и содержанием воды во внешнем слое 0-1,5 см под корой. Коэффициенты определения (R^2) по результатам экспериментов составляли от 0,80 до 0,97.

Ключевые слова: объем круглого дерева, сухая плотность, плотность партии круглой древесины, абсолютное содержание воды.