SCOTS PINE (*PINUS SYLVESTRIS* L.) STEM WOOD AND BARK MOISTURE AND DENSITY INFLUENCING FACTORS

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Abstract
Latvia uses average moisture content and density indexes obtained in Russia and European countries; though, these indexes are different, and there is no information about the most suitable one for conditions in Latvia. Research complex on Latvia's industrially important tree species - Scots pine (*Pinus sylvestris* L.) stem wood and bark moisture and density changes, depending on influencing factors, is being conducted at Forestry Faculty of Latvian University of Agriculture. The research results on Scots pine, obtained during the year 2011 in the whole territory of Latvia, are outlined in this article. Wood and bark moisture and density were analyzed in 21 sampling plots, arranged in middle-aged and cutting-aged reached forest stands, depending on tree age, cutting time and location place in the tree stem. The average moisture content of pine wood mostly depends on heartwood specific weight and age of the tree. With an increase of tree age, average wood moisture content value decreases from 111% (40 years old trees) to 77% (145 years old trees). Scots pine heartwood moisture content changes a little during the year: 30– 34% for 71 to 146 years old trees; and 34-41% for 37–70 years old trees. Sapwood moisture content changes from 113% (in the summer) to 130% (in the winter), without any reference to the age of the tree. The average density of oven dry timber obtained from 71–146 years old trees in the research is 0.501 g cm^{-3}, whereas in freshly cut condition – 0.848 g cm^{-3}.
Key words: Scots pine wood, bark, moisture, density.

Introduction

The term moisture content is expressed as the amount of water in the wood that is water percentage of wood mass. To reconcile wood moisture content of different species, absolute humidity of wood is used, which characterizes relation of water mass in wood in comparison with mass of oven dry timber (Vaņins, 1950).

Wood density depends on several factors. The most important of those is wood moisture content. Wood always contains certain amount of water. When water content in wood changes, wood density also changes (Ozoliņš, 2005).

Moisture content and density of wood and bark are interconnected and very important physical and technological indicators. These factors have influence on transportation of wood, workability, durability, drying process, calorific heat value and on other physical parameters. Wood moisture content and density mainly influences conversion coefficients, which are used for quantity assessment of round timber.

Moisture content and density are not allocated evenly neither in the longitudinal direction of the stem, nor in the direction from stem heart to bark. It differs from species, months and depends on the age of the tree, meteorological, climatic and other conditions.

Wood density dependence on the geographical growing position was clarified by several researchers in Norway, Sweden, Scotland and France. It has been observed that wood density increases more if the tree grows southwards (Hedenberg, 2003).

As a few local researches have been carried out, necessary indexes of wood moisture content and density have not been rated in Latvia for practical industrial needs, but generalization of information, obtained in other countries, is used instead. That is the reason why such research would be important for Latvia. The aim of this research is to determine wood moisture content and density ratio for the most important industrial wood species in Latvia – Scots pine (*Pinus silvestris* L), as well as to determine factors that affect these indicators.

Latvia uses average moisture content and density indexes obtained in Russia and European countries, but they are mutually different, and there is no information about the most suitable one for conditions in Latvia. Therefore, it is necessary to carry out research in Latvia, and, accordingly, the aim of the research is to find out wood moisture content and density parameters for the most industrially important tree species, as well as to find their influence factors. Pine wood and bark moisture content and density research results, acquired in the first year of investigations, are described in this article.

Materials and Methods

The research results on Scots pine were obtained during the year 2011. To assess the influence of climatic and growing conditions, sampling plots were established throughout the whole territory of Latvia. Sampling plots were placed in the most common growing site types of Scotch pine: *hylocomiosa* (7 sample plots), *myrtillosa* (6 sample plots), *vacciniosa* (1 sample plot), *myrtillosa mel.* (6 sample plots) and *myrtillosa turf. mel.* (1 sample plot).

Sampling plots are located in commercial thinning forest stands, and in the final felling forest stands, once for every month. Sampling plots are arranged in the stands where the proportion of pine is at least 60%. Plots are arranged in the harvester felling area strip most properly representing this forest stand.

Ten sample trees, with a certain step, and by regular arrangement, are chosen in the established sampling plot, for obtaining sample discs (every disc thickness equals to 5 cm). Sample trees are taken proportionally to the distribution of tree amount in diameter classes. Sample discs are taken during the harvesting, starting from the tree stem butt end and further, from every log, sawn by a tree harvester.

Subsequently diameter of sample disk in mm is measured in two mutually perpendicular directions both over and under the bark. Then each sample disk is divided in four pieces, and one sample is chosen for further processing from each piece and sawn out in 30 degree angle clockwise (Figure 1). Each sample is marked with tree numbers, for example 1-2-3, where:

- 1 – sample tree number;
- 2 – sample disk sequence in growth direction;
- 3 – piece number.

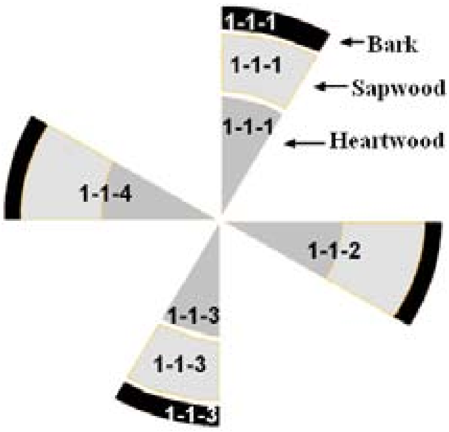

Figure 1. Segment selection.

Two samples (second and fourth in this case) are left untouched, but from other two ones the sapwood is separated from bark and heartwood (the first and the third sample), as shown in Figure 1.

Weight and volume of wood and bark samples is measured in fresh cut condition right after sawing. Weight is obtained by electronic scales, but volume is measured by immersing method. Volume equals to the amount of water, displaced by the sample. Volume of the bark samples is calculated on the basis of measuring the length, width and thickness.

Afterwards samples are placed into the drying oven at 103 °C until samples are oven dry. Weight and volume is measured again when samples are dry.

Absolute moisture indicator is used for wood and bark characterization. That is the amount of water weight in wood and bark, shown as percentage of dry wood and bark weight (Formula (1)).

$$W_a = \frac{m_1 - m_2}{m_2} \times 100, \tag{1}$$

where:
W_a – absolute moisture content of wood and bark, %;
m_1 – sample mass in humid condition, g;
m_2 – sample mass in dry condition, g.
Wood and bark density in freshly-cut and dried condition is calculated by Formula (2):

$$\rho_w = \frac{m_w}{V_w}, \tag{2}$$

where:
ρ_w – wood and bark density, g cm^{-3}, at corresponding wood moisture;
m_w – mass of the sample, g, at corresponding wood moisture;
V_w – volume of the sample, cm^3, at corresponding moisture.

To determine whether moisture content and density vary considerably depending on age, t-test with program SPSS is accomplished and p – value, at significance level $\alpha = 0.05$, is calculated. If p - value $<\alpha$, then the moisture differences are significant.

In order to determine correlation, the correlation coefficient was calculated. Correlation analysis is to determine the closeness of the relationship between the factorial and the resulting feature. If the correlation coefficient of $r \leq 0.5$ the correlation is weak; if $0.5 < r \leq 0.8$ the correlation is moderately close; if $r > 0.8$ the correlation is strong. Correlation coefficient critical values are read from the table after the iteration number.

Results and Discussion

Scots pine sapwood moisture content significantly differs from heartwood moisture content - sapwood moisture content is 3-4 times higher than of heartwood. It is shown in Table 1.

As shown in Table 1, only for sapwood $p>\alpha=0.05$, and this means that the moisture content of sapwood has no significant differences according to age, but for other parts of the tree stem cross section $p<\alpha=0.05$, which means that moisture difference is significant according to the age of the tree.

Moisture content of Scots pine heartwood varies little for a year-long period. A study conducted for Scots pine of age from 37 to 70 years reveals that moisture content varies from 34% to 41%, but for 71–146 years old trees the value of this index is between

Table 1

Moisture content of Scotch pine, depending on the age of the tree

Part of the cross-section	Wood and bark moisture content, %				p – value (α = 0.05)
	37 – 70 years	Std. Deviation	71 – 146 years	Std. Deviation	
Heartwood	37.3	4.4	32.0	2.9	0.000
Sapwood	121.3	11.9	122.4	13.1	0.606
Wood, average	108.4	11.9	90.6	10.1	0.000
Crust bark	141.2	38.5	99.4	33.8	0.000
Flaky bark	194.7	36.9	181.0	36.7	0.000
Bark average	156.0	32.3	119.4	27.4	0.000
Wood and bark	110.5	13.8	92.9	11.8	0.000

30 and 34%. Yearly fluctuations of sapwood moisture content are higher. Sapwood moisture content of 37–70 years old trees varies from 113% (in August) to 130% (in April), but for 71–146 years old trees sapwood moisture content varies from 116% (in September) to 130% (in February). The average moisture content of Scots pine wood mainly depends on proportion of heartwood and tree age.

Moisture content of Scots pine sapwood is 133%, but moisture content of heartwood is 31%, according to the study conducted in Germany. It is also shown that there is a big difference between early wood moisture (220%–226%) of sapwood and late wood moisture (58%–68%) of sapwood. In conclusion, sapwood average moisture content is affected by early wood and late wood ratio (Trendelenburg, 1939).

According to the data, obtained in St. Petersburg area from 70 to 90 years old Scots pines, sapwood moisture content is 122%; and heartwood moisture content is 33%, but average value for wood is 90% (Vaņins, 1950).

Data values, obtained in Latvia, differ more from those, which have been reported for Germany, than from the St. Petersburg region data. This could be explained by more similar climate and growing season length in Latvia and in the St. Petersburg’ region.

Tree stem wood moisture content of the same tree species depends on the tree age. Wood moisture content of young trees is slightly higher than that of old trees. Besides that, yearly moisture fluctuations (the difference between moisture maximum and minimum values) for young trees are much higher than for the old ones (Vaņins, 1950).

As it is shown in Figure 2, with an increase of tree age, average wood moisture content value decreases from 111% (40 years old trees) to 77% (145 years old trees). The correlation coefficient ($r=0.653 > r_{0.05}=0.138$) indicates to the moderately close correlation between the average wood moisture content and tree age.

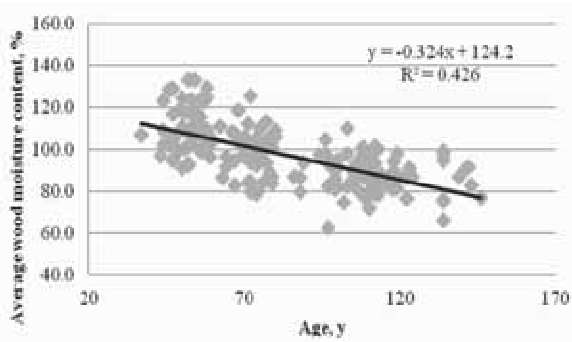

Figure 2. Average wood moisture content depending on tree age.

Average wood moisture content changes, depending on the tree age, could be explained by the heartwood part proportion.

Scots pine heartwood proportion also depends on the tree age. When a tree grows older, its heartwood proportion increases. With the tree diameter increase from 15cm to 30cm, the proportion of its heartwood increases to 67%. With the tree age increase from 60 to 129 years, its heartwood part increases from 21% to 41%; therefore, the average tree stem wood moisture content reduces. Assuming that sapwood moisture content is 131% and heartwood moisture content is 31%, the average moisture content of Scots pine wood would decrease from 110% to 90% when the tree grows older from 60 to 129 years (Gjerdrum, 2003).

As shown in Figure 3, with the tree age increase from 40 to 145 years, its heartwood part increases from 14% to 49%. Correlation coefficient value ($r=0.786 > r_{0.05}=0.138$) indicates to a moderately close correlation between heartwood proportion and the tree age.

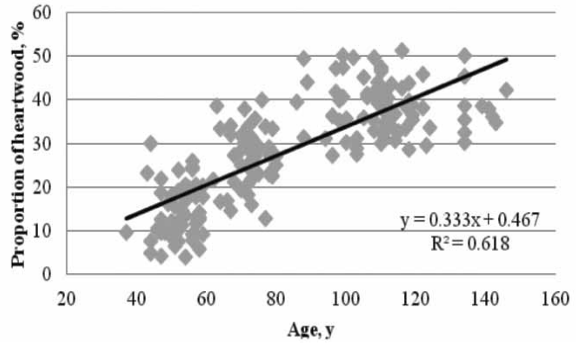

Figure 3. Tree stem heartwood proportion depending on tree age.

It has been observed that the average wood moisture content gradually decreases from butt up to the middle of the trunk for conifers, but the moisture gradually increases at the top part (Pong, 1986).

Summarizing yearly study results for the Scots pine, in the direction from the stem butt-end, average moisture content decreases to ¼ from stem length, but, with the further increasing of distance from the stem butt-end, moisture content increases, too.

Sapwood moisture content for 37–70 years old trees throughout the whole tree stem is increasing from 113% to 146%, and, to ¼ from stem length, the average wood moisture content is decreasing (from 99% down to 88%), but in the tree stem top part the average wood moisture content increases to 146%. Heartwood moisture content increases to 2/3from the stem length (from 36% up to 39%).

Sapwood moisture content of 71–146 years old trees increases throughout the stem from 111% to 137%, average wood moisture reduces to ¼ from the trunk length (from 82% up to 77%), but in the tree top part it increases to 129%. Heartwood moisture content throughout the stem is increasing from 31% to 33%.

Bark moisture content for 71–146 years old trees throughout the stem increases from 91% in the tree butt-end part to 190% in the tree top part. Bark moisture content for 37-70 years old trees throughout the stem increases from 132% in the butt part to 201% in the top part.

Correlation coefficient value r=0.714 > $r_{0.05}$=0.138 (71-146 years old trees) and r=0.593 > $r_{0.05}$=0.138 (37–70 years old trees) indicates to the moderately close correlation between the bark moisture content and location on the trunk.

Another important indicator is wood density. It describes the amount of woody tissue per volume unit, so it is closely related to the values of other wood physical and mechanical properties and their logic mutual relevance. Wood density is an important characteristic feature, related with its quality. Higher mechanical strength characteristics are expected for denser wood (Орлов, 1960).

Freshly harvested timber and bark density can also be used as a conversion factor (t m^{-3}), used for round timber quantitative estimation (Līpiņš and Liepa, 2007).

The easiest method for determining the round timber volume is mass or weighting method, which is widely used method in many countries. There is a strong correlation between round timber weight and volume (Līpiņš et al., 2011).

Wood density depends on several factors. The most important of those is wood moisture content. Wood always contains certain amount of water. Wood density varies according to water content change in wood (Ozolinš, 2005).

Wood is heavier in freshly cut condition, but it becomes lighter during drying. In order to compare density of two or more wood species, density index always has to be determined at the fixed moisture content – for wood at oven dry condition, at 12% moisture content and in freshly harvested conditions (Уголев, 2001). Density parameters by B.N. Ugolev and parameters obtained in our research are compared in Table 2.

It can be seen that results in our study differ from those, which are being reported by B.N. Ugolev. Wood density indices obtained in our research exceeds

Table 2

Wood and bark density depending on the moisture content

Data source	Wood and bark density, g cm^{-3}							
	Oven dry condition (W=0%)			Basic moisture (W=12%)		Freshly cut condition		
	Wood	Crust bark	Flaky bark	Wood	Bark	Wood	Crust bark	Flaky bark
Research	0.501	0.412	0.532	0.529	–	0.848	0.651	0.844
B.N. Ugolev (Б.Н. Уголев)	0.470	0.650		0.500	0.680	0.863	0.850	

B.N. Ugolev results by 6.2% in the case of oven dry wood density, by 5.5% in the case of wood density at basic moisture content, and only by 1.7% in the case of freshly-cut wood conditions. Bark is denser in the results of B.N. Ugolev. Only in freshly cut condition flaky bark was as dense as in the results of B.N. Ugolev.

Research on the wood density changes according to geographic disposition has been done in Norway, Sweden, Scotland and France. Correlation - wood density, wood fibre length and width increase in the direction from north to south (Hedenberg, 2003) was observed.

In some recent scientific researches the tree age rather than growing conditions has been chosen as the most important selection criterion. In these studies it was concluded that wood density and wood growth conditions do not correlate with each other (Hedenberg, 2003).

As the main reason for wood density difference, which is connected with geographical disposition, the difference in growth conditions has been referred to. The geographical longitude and latitude affect wood density because of the different soil structure in each place, the amount of thaw periods during the winter, growing season length -, all this together influence early and late wood ring width, which in turn affects the wood density (Plotnikoff et al., 2000).

The research findings difference from B.N. Ugolev data could be explained by the fact that B.N. Ugolev density parameters are obtained in Russia where the climate is continental.

Wood density depends not only on tree species, but also on the tree age. Swedish research found that the pine wood density of oven dry wood increases by increasing of tree age (Atmer and Thörnqvist, 1982).

Also, in research there is an evidence about previously detected connection that by increasing of tree age increases wood, especially heartwood, density – by 14.5%. For bark - both flaky and crust type, regarding the tree age, density remains practically unchanged (Table 3).

As shown in Table 3, for sapwood, crust bark, flaky bark and bark average $p > \alpha = 0.05$, and this means that for these parts of the tree stem cross-section, density of oven dry conditions does not have any significant differences according to the tree age, but for the heartwood, wood average, and wood and bark together $p < \alpha = 0.05$, and this means that the density differences of oven dry conditions are significant depending on tree age.

In Finland 40–60 years old Scots pine stands, oven dry wood density changes throughout the stem are significant. Scots pine wood density is decreasing in the direction from the butt-end part to the top part from 460 g cm^{-3} down to 360 g cm^{-3} (Repola, 2006).

Oven dry Scots pine wood density of 71–146 years old trees throughout the stem is decreasing from 0.550 g cm^{-3} in the butt part up to 0.447 g cm^{-3} in the top part.

Oven dry Scots pine wood density of 37-70 years old trees is decreasing from 0.519 g cm^{-3} in the butt-end part to 0.417 g cm^{-3} in the top part. Correlation coefficient values $r=0.623 > r_{0.05}=0.138$ (71–146 years old trees) and $r=0.616 > r_{0.05}=0.138$ (37-70 years old trees) indicate on moderately close correlation between absolutely dry wood density and location on the trunk.

Oven dry Scots pine bark density throughout the stem increases from 0.385 g cm^{-3} in the butt-end part to 0.575 g cm^{-3} in the top.

Bark density changes in oven dry condition throughout the stem between trees of different ages are not significant. Correlation coefficient value $r = 0.546 > r_{0.05} = 0.138$ indicates on moderately close correlation between oven dry bark density and location on the trunk.

Table 3

Pine wood and bark density in oven dry condition depending on tree age, g cm^{-3}

Part of the cross-section	Wood and bark density in oven dry condition				p – value ($\alpha = 0.05$)
	37 – 70 years	Std. Deviation	71 – 146 years	Std. Deviation	
Heartwood	0.421	0.056	0.492	0.052	0.000
Sapwood	0.490	0.033	0.504	0.042	0.024
Wood average	0.478	0.032	0.501	0.040	0.000
Crust bark	0.413	0.070	0.412	0.081	0.744
Flaky bark	0.539	0.074	0.532	0.091	0.279
Bark average	0.424	0.052	0.421	0.052	0.605
Wood and bark	0.470	0.032	0.497	0.041	0.000

Table 4

Pine wood and bark density in freshly-cut condition that depends on tree age, g cm^{-3}

Part of the cross-section	Wood and bark density in freshly-cut condition, g cm^{-3}				p – value (α = 0.05)
	37 – 70 years	Std. Deviation	71 – 146 years	Std. Deviation	
Heartwood	0.516	0.069	0.585	0.059	0.000
Sapwood	0.956	0.047	0.988	0.055	0.000
Wood average	0.881	0.064	0.848	0.062	0.001
Crust bark	0.697	0.074	0.604	0.082	0.000
Flaky bark	0.864	0.093	0.844	0.095	0.082
Bark average	0.730	0.097	0.651	0.071	0.000
Wood and bark	0.873	0.051	0.846	0.053	0.002

In the research it was found out that by an increase in tree age, wood density in freshly-cut condition is increasing – heartwood density increases by 11.8%, sapwood density increases by 3.2%, but on average wood density decreases by 3.7%. Higher average wood density for younger trees (37–70 years old) can be explained by a small proportion of heartwood. Crust bark for younger trees is by 13.3% denser and flaky bark is by 2.3 % denser (Table 4).

As shown in Table 4, only for flaky bark $p>\alpha=0.05$ and that means that density differences in oven dry condition are not significantly depending on the tree age, but for the other parts of cross section $p<\alpha=0.05$ and that means, that density differences in fresh cut condition are significantly depending on the tree age.

Scotch pine average wood density in fresh cut condition from the butt-end part gradually decreases to the middle part of the trunk, but in the top part there is a gradual increase in density.

Sapwood density of 37–70 years old trees throughout the stem decreases from 0.981 g cm^{-3} to 0.916 g cm^{-3}. The average wood density decreases till the middle part of the trunk from 0.899 g cm^{-3} up to 0.821 g cm^{-3}, but in the top it increases to 0.916 g cm^{-3}. Heartwood density throughout the stem is decreasing to 2/3 of the stem length from 0.586 g cm^{-3} to 0.479 g cm^{-3}.

Sapwood density of 71–146 years old trees throughout the stem decreases from 1.011 g cm^{-3} to 0.948 g cm^{-3}. The average wood density decreases till the middle part of the trunk from 0.889 g cm^{-3} to 0.776 g cm^{-3}, but in the top part there is an increase to 0.915 g cm^{-3}. Heartwood density throughout the stem is decreasing from 0.668 g cm^{-3} to 0.505 g cm^{-3}.

Bark density in fresh cut condition of 71–146 years old trees throughout the stem is increasing from 0.565 g cm^{-3} in the butt part and up to 0.899 g cm^{-3} in the top part, but for 37–70 years old trees throughout the stem it is increasing from 0.668 g cm^{-3} in the butt-end part and to 0.888 g cm^{-3} in the top part. Correlation coefficient values $r=0.697$ (71–146 year old trees) and $r=0.551 > r_{0.05}=0.138$ (37–70 year old trees) indicate on moderately close correlation between absolutely dry bark density and the place on the trunk.

Conclusions

1. The average moisture content of pine wood mostly depends on heartwood specific weight and age of the tree. With an increase of tree age, average wood moisture content value decreases from 111% (40 years old trees) to 77% (145 years old trees).
2. Pine heartwood moisture content changes a little during the year: 30–34% for 71 to 146 years old trees; and 34–41% for 37–70 years old trees. Sapwood moisture content changes from 113% (in the summer) to 130% (in the winter), without reference to the tree age.
3. The average density of oven dry timber obtained for 71–146 years old trees in the research is 0.501 g cm^{-3}, in freshly cut condition - 0.848 g cm^{-3}, but the average density of wood and bark in oven dry timber is 0.500 g cm^{-3}, in freshly cut condition - 0.846 g cm^{-3}. The average density of oven dry timber obtained for 71–146 years old trees is 0.478 g cm^{-3}, in freshly cut condition - 0.881 g cm^{-3}, but the average density of wood and bark in oven dry timber is 0.470 g cm^{-3}, in freshly cut condition - 0.873 g cm^{-3}.
4. The wood density of oven dry pine for 71–146 years old trees decreases from 0.550 g cm^{-3} (butt-end) down to 0.447 g cm^{-3} (top-end), but for 37-70 year old trees from 0.519 g cm^{-3} down to 0.417 g cm^{-3}.

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