Växjö University
School of Technology and Design, TD

Water Uptake of Hardwoods

Vattenupptagning hos lövträ

Växjö 2006-08-28
Thesis work no: TD083/2006
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Dokumenttyp/Type of document Examensarbete/ Diplomawork	**Handledare/tutor** Åsa Blom, Jimmy Johansson

Titel och undertitel/Title and subtitle

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Sammanfattning (på svenska)

Nyckelord

Abstract (in English)

This study investigate water uptake in six different species of hardwood in tangential and radial section. Alder (Alnus glutinosa) and beech (Fagus sylvatika) represent semi-diffuse-porous hardwoods. Aspen (Popolus tremula) and birch (Betula pubescens) represent diffuse-porous group; oak (Quercus robur) and ash (Fraxinus excelsior) the ring-porous hardwoods. Spruce (Picea abies) was used as a reference sample.

Significantly higher water uptake was observed in the diffuse-porous and the semi-diffuse-porous group. Water uptake varied among the species, nevertheless tangential section was more permeable in general. Any impact of density or annual rings width on water uptake was observed. Correlation between ratio of earlywood and latewood and water uptake in dependence on hardwood group was found out. Ring-porous species had low rate of earlywood and low water uptake, whereas diffuse-porous and semi-diffuse-porous hardwoods had high rate of earlywood and high water uptake. Relation between water uptake and microstructure of wood was observed.

Key Words
annual ring orientation, floating test, permeability

Utgivningsår/Year of issue	**Språk/Language**	**Antal sidor/Number of pages**
2006	English	13

Internet/WWW http://www.vxu.se/td

Acknowledgement

We would like to thank Göran Petersson that he brought us to this project.
Furthermore we thank especially Jimmy Johansson and Åsa Blom for the opportunity to do this work, for their supervising and open help at any time.
Also, we thank Dick Sandberg for explaining the work with microtome and for his help with the equipment needed during the experiments.
Special thanks go to our families and friends.

Abstract

This study investigate water uptake in six different species of hardwood in tangential and radial section. Alder (*Alnus glutinosa*) and beech (*Fagus sylvatika*) represent semi-diffuse-porous hardwoods. Aspen (*Popolus tremula*) and birch (*Betula pubescens*) represent diffuse-porous group; oak (*Quercus robur*) and ash (*Fraxinus excelsior*) the ring-porous hardwoods. Spruce (*Picea abies*) was used as a reference sample. Wood boards without knots and other defects, were sawn to size 150x70x20 ($\pm$ 2) mm.

Twenty samples from each species were used for investigations (half for tangential, and half for radial direction). Then the samples were coated except the investigated section, which was left untreated, conditioned for two weeks in the climate chamber and let flow on de-ionized water surface. Weight measurements were carried out after 1, 2, 4, 8, 24, 48 and 72 hours in order to measure the water uptake. Annual rings width, ratio of earlywood and latewood and density was also calculated.

Significantly higher water uptake was observed in the diffuse-porous and the semi-diffuse-porous group. Water uptake varied among the species, nevertheless tangential section was more permeable in general. Any impact of density or annual rings width on water uptake was observed. Correlation between ratio of earlywood and latewood and water uptake in dependence on hardwood group was found out. Ring-porous species had low rate of earlywood and low water uptake, whereas diffuse-porous and semi-diffuse-porous hardwoods had high rate of earlywood and high water uptake. Relation between water uptake and microstructure of wood was observed.

Contents

Introduction

Moisture content is closely related with durability and further utilizing of wood. Increase of water or moisture content in wood causes dimensional changes which may result in cracking and checking of the coating film [1]. High moisture also sharply decline resistance to microbial degradation. Permeability, the way of ingress of water into wood mass, is one of the most variable properties of timber and it further influences nearly all the physical properties of wood [2,3]. Differences in permeability occur not only between species but also between the principal directions within timber [2]. Knowledge about permeability and holding ability of different liquids is needed in further treating of wood. Mainly coating and gluing.

Broad-leaved trees constitute 16 % of whole standing stock of Swedish forests and the biggest volume is located in the southern part of Sweden, in regions Svealand and Götaland. The most common species is birch (10.5 %); followed by aspen (1.4 %), alder (1.2 %), oak (0.9 %) and beech (0.6 %) (Swedish National Forest Inventory, 2003) [4]. These species are also the most commercially used hardwood species in Sweden [5].

The aim of this study is to obtain further knowledge about water uptake of hardwoods concerning diffuse-porous hardwoods: aspen *(Populus tremula)* and birch *(Betula pubescens)*; semi-diffuse porous hardwoods: alder *(Alnus glutinosa)* and beech *(Fagus sylvatica)*, and ring-porous hardwoods: oak *(Quercus robur)* and ash *(Fraxinus excelsior)*. Spruce *(Picea abies)* was used as a reference sample.

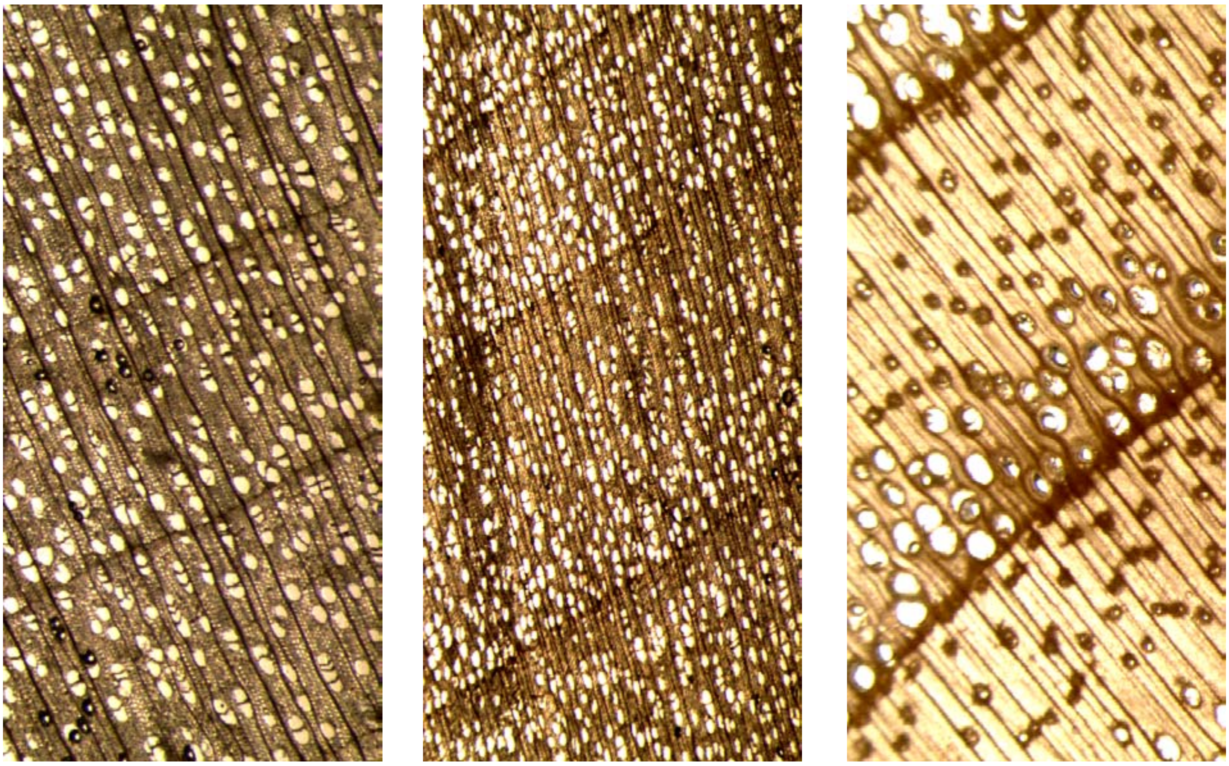
The objective is to investigate the influence of density, annual rings width and the ratio of earlywood and latewood on the water permeability in different hardwoods. Furthermore, investigate water uptake in the radial and tangential direction.

Theory Chapter

1.1 Microstructure of hardwood

Microstructure of hardwood is much more varied than for softwoods. Thus also permeability and capillary behavior is much more variable [2].

The following tissues occur in hardwood: vessels (20-60% for diffuse-porous wood, 5-25% for ring-porous), fibers and tracheids (20-70%) and longitudinal parenchyma (1-18%) going vertically through trunk; and wood rays (5-33%) lying horizontally [3]. Vessels are thin-walled with either partly or completely dissolved end-walls between following elements and provide conductive function. Vessels of diffuse-porous hardwoods occupy larger volume fraction (20-60%) and the diameters of the vessels are relatively uniform. The sizes vary from 20 μm to 100 μm. Ring-porous wood has earlywood vessels of considerably larger diameter (50-400 μm) than latewood vessels (20-50 μm). Also the volumetric percentage is much lower (5-25%), than in the diffuse-porous group [3].



Diffuse porous (Birch　　**Semi-diffuse-porous (Alder)**　　**Ring-porous (Ash)**

Figure 1: Groups of hardwood

Fibers consist of thick-walled cells and have supporting function. Parenchyma cells are mainly located in the form of rays in the horizontal direction and are responsible for the storage of food material [2].

The communication between vessels and fibers or tracheids is through bordered pits. Simple or half-bordered pits lead to parenchyma cells.

In contrast, just two cell types can be observed in softwoods; tracheids and parenchyma cells. Tracheids (93%) are oriented in longitudinal direction and interconnected by pits. The earlywood tracheids are thin-walled and have mainly conductive function, whereas latewood are thick-walled with support function. The number of pit pairs per tracheids varies from 50 to 300 in earlywood and fewer in latewood. Nearly all of the pits are concentrated on the radial surfaces. Resin canals (1%) are intercellular spaces presented in longitudinal and horizontal direction. Parenchyma cells mainly occur in the form of wood rays (6%) [2, 3].

1.2 Moisture content

Moisture content influences nearly all the physical properties of wood [3]. In timber, there occur three types of moisture: bound water within the cell walls (below the fiber saturation point), free liquid water in the cell cavities (above the fiber saturation point) and water vapor [2].

Since wood is a hygroscopic material, an equilibrium is established between wood moisture content and the relative humidity of the surrounding environment. When placed at 98% RH the moisture content is about 25-30 % which is equal to the fiber saturation point. In that time, the cell wall is fully saturated while the voids are empty [2]. Relative humidity 65 %, 20°C is equal to moisture content 12 %.

1.3 Flow in timber

There are two principal modes for the transport of fluids through wood: bulk flow and diffusion. Bulk flow occurs through the interconnected voids of the wood structure under the influence of a static or capillary pressure gradient, whereas transport of water vapor, or bound-water is run by diffusion. The magnitude of the bulk flow is determined by permeability of wood. Permeability is a measure of the ease with which fluids move through a porous solid under the influence of a pressure gradient. Thus follow that there exist a correlation between permeability and porosity of the material – a solid must be porous to be permeable [3].

1.4 Ways of flow

Longitudinal flow in hardwoods is carried out mainly through vessels. Liquids flow from vessels to fibers, vasicentric tracheids, vertical parenchyma, and rays through pits [3].

Ring-porous hardwoods have vessels of large diameter in earlywood and if they are not sealed by tyloses, ring-porous hardwoods have higher permeability [2]. Multiseriate rays are low permeable and also bring down the permeability [3]. Heartwood is always less permeable because of more pit aspiration, extractives, encrustations, and tyloses in the vessels [3].

A very good correlation exists between tangential and radial permeability [2]. Contribution of rays to radial hardwood permeability is approximately equal to that of the interfiber pits on the radial surfaces to the tangential permeability [3].

1.5 Measurements

Absorption of liquid water into wood is set by measuring the change in the overall moisture content in various time intervals [6]. Coating is an important factor blocking the moisture transport. Non material is ideal thus microscopic pores of different sizes still exist, nevertheless, coating strongly reduce the rate of liquid water entering the wood surface [7].

Material and Method

Wood boards without knots and other defects, were sawn to size 150x70x20 (±2) mm according to the Figure 2. Half of the samples were sawn with vertical annual rings and half with horizontal annual rings according to Figure 2.

The number of samples for each wood species is listed in Table 1. The annual ring width was measured on each sample. The mean ratio of earlywood and latewood was also determined by microscope investigation.

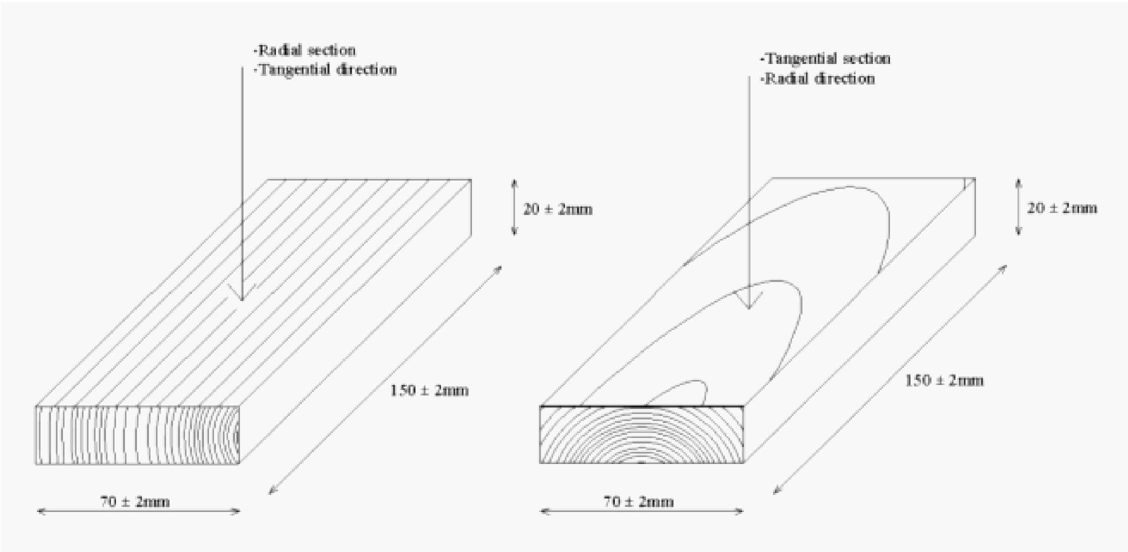


Figure 2: Description of the samples.

After sawing, the samples were coated. The top and the sides were coated with two layers of paint (Reafen Prime, TE801-8001 Becker-Acroma; Reafen Top, TH1851-5505, Becker-Acroma; and hardener TV300 Becker-Acroma). The cross cut sections were coated once (Primer 144650, Acre) and then sealed with silicon (Bostic). The investigated section was left untreated. Samples were divided into two groups according to annual ring directions and placed in a climate chamber (20°C, 65% RH) for two weeks. Thereafter, the samples were let float in de-ionized water for 72 hours. Weighing was carried out after 1, 2, 4, 8, 24, 48 and 72 hours. Water uptake was calculated in grams per square meter. The testing followed a modified EN 927-5 method [8].

Density test was carried out on small reference samples. The samples were placed under water for 24 hours and then weighed. The *volume* was calculated by dividing the received weight (m_1) with the density of water $V_{Wood} = \frac{m_1}{\rho_{H_2O}}$. Afterwards, the samples were dried and weighed again (m_2). The basic density was calculated according to the equation $\rho_{Wood} = \frac{m_2}{V_{Wood}}$.

Figure 3: Floating of the samples

Results

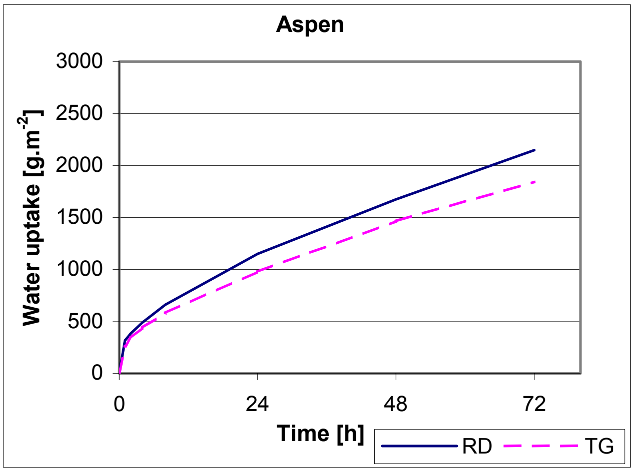
Diffuse-porous and semi-diffuse-porous hardwoods had significantly higher water uptake than ring-porous woods. The average difference was 49.5 % for radial direction and 41.2 % for tangential direction.

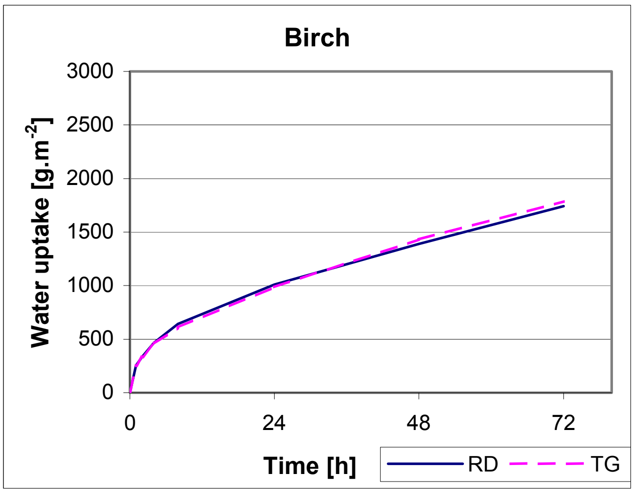
In the line with findings of Chen et al. (1998) [9], annual ring width had no effect on permeability. Also density was found to be insignificant. Ratio of earlywood and latewood in annual rings was measured. In the diffuse-porous and the semi-diffuse-porous species it was difficult to see the border; nevertheless in general the amount of latewood was very low. Spruce had comparable ratio of earlywood with the diffuse-porous species, whereas the ring-porous group had higher amount of latewood.

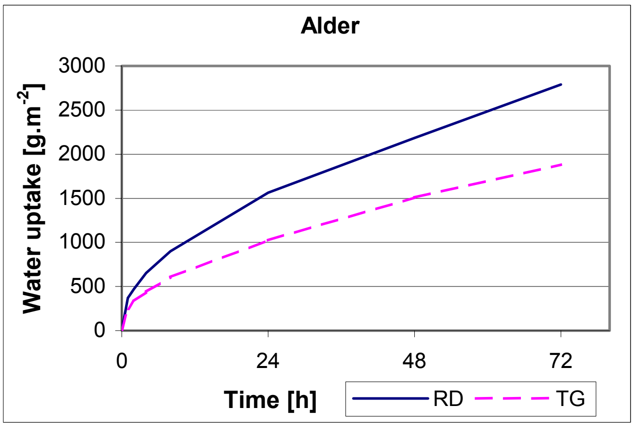
Table 1: Table of investigated attributes (RD=radial direction, TG=tangential direction)

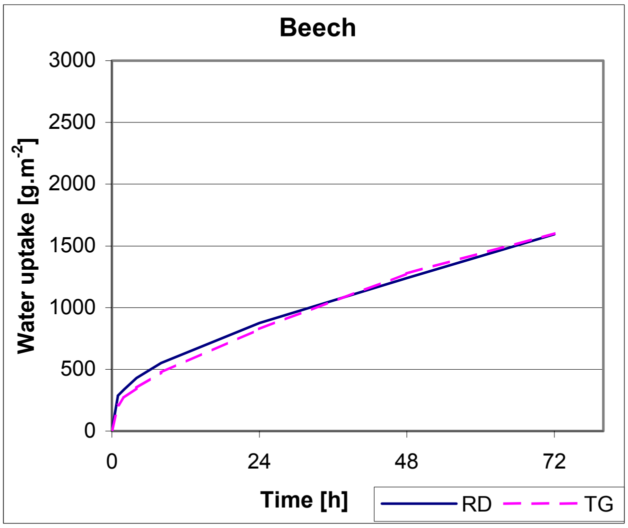
Porosity	Species	Number of samples		Basic density [kg.m^{-3}]	Annual ring width [mm]		Earlywood percentage [%]		Average water uptake after 72h of swelling [g.m^{-2}]	
		RD	TG		RD	TG	RD	TG	RD	TG
Diffuse	Aspen	10	10	389	3.90	3.49	-	-	2149	1842
	Birch	8	10	572	1.04	1.79	-	-	1741	1787
Semi-diffuse	Alder	10	10	430	1.62	1.65	-	-	2789	1884
	Beech	10	10	550	3.18	3.35	-	-	1594	1603
Ring	Ash	7	8	529	3.49	2.95	32	32	1111	1217
	Oak	10	10	618	3.51	2.61	30	34	979	877
	Spruce	10	10	353	2.28	3.43	74	87	1039	1234

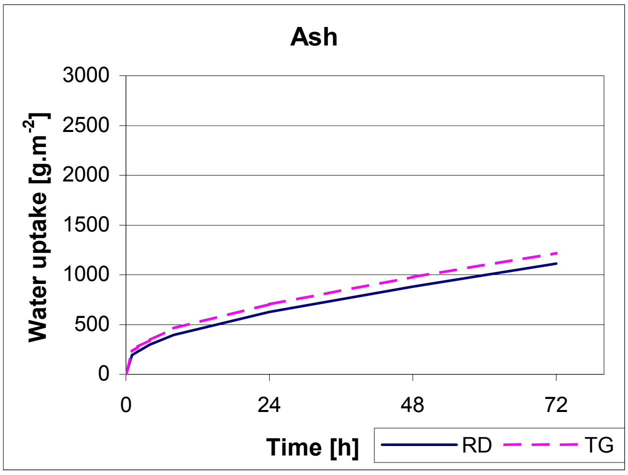
The graphs in Figure 3 show differences in water uptake between tangential and radial direction. In general, higher water uptake was observed in radial direction but it widely differed among species. The biggest difference was observed in alder, where the permeability of radial direction was significantly higher (32.5 %), followed by aspen (14.3 %). Birch and beech had nearly the same permeability in both directions. The difference in water uptake between two directions in ring-porous woods was in the range of 10%. Oak had higher radial water uptake, ash the tangential as well as spruce.

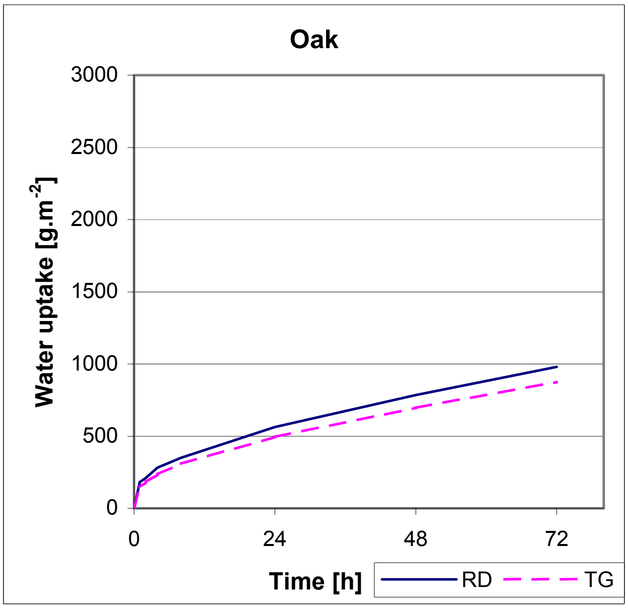

Aspen
Water uptake [g.m-2]
Time [h]
RD
TG


Birch
Water uptake [g.m-2]
Time [h]
RD
TG


Alder
Water uptake [g.m-2]
Time [h]
RD
TG


Beech
Water uptake [g.m-2]
Time [h]
RD
TG


Ash
Water uptake [g.m-2]
Time [h]
RD
TG


Oak
Water uptake [g.m-2]
Time [h]
RD
TG

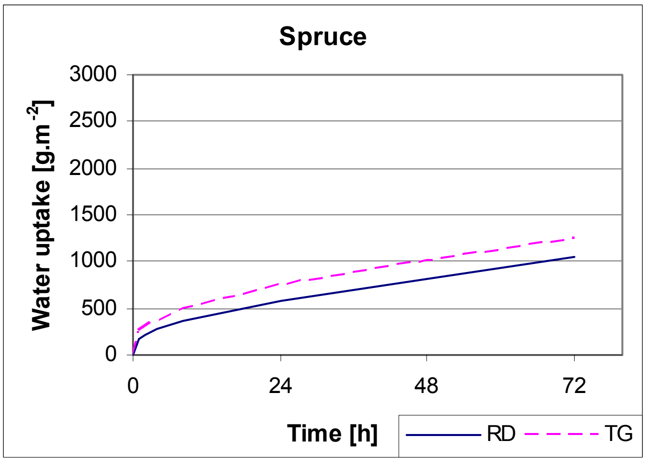
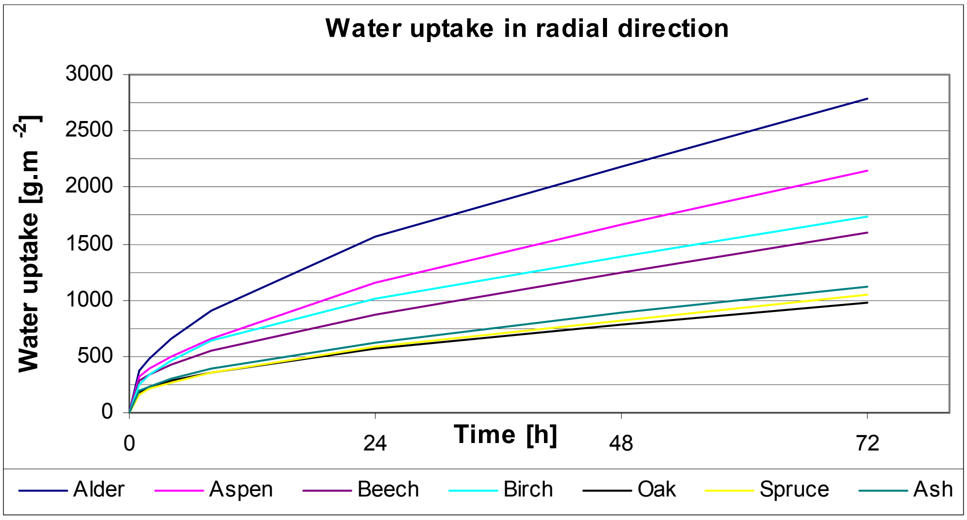


Figure3: Graphs of water uptake in radial (RD) and tangential (TG) direction

Graphs in Figure 4 show comparison of water uptake among investigated species. Significantly higher water uptake was observed in the diffuse-porous and the semi-diffuse-porous group. Investigated hardwood species followed the same order in the amount of water uptake in both directions. The highest water uptake was observed in alder, followed by aspen, birch, and beech. Significantly lower permeability was found out in ash and oak. Spruce had water uptake very close to the ring-porous species. Tangential permeability of spruce slightly overtopped ash, whereas the amount of water uptake in radial direction was between oak and ash.



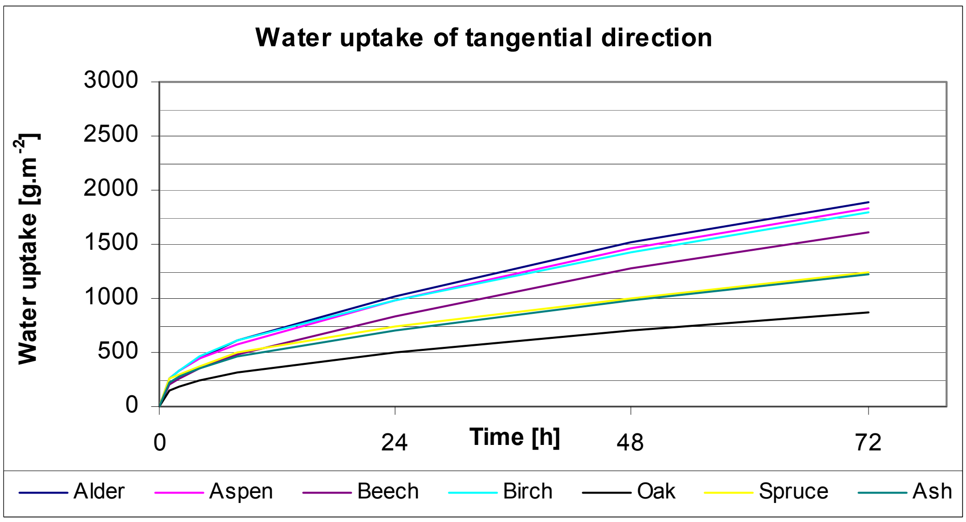


Figure 4: Graphs of tangential and radial water uptake

Discussion

Water uptake particularly relied on microstructure of hardwood and neither density nor annual rings width had any essential impact in this study.

In general the diffuse-porous and the semi-diffuse-porous hardwoods were observed to be more easily permeable than the ring-porous species. Behaviour of these two groups was observed to be very similar. This might be caused by higher uniformity of the structure. Also the investigated ring-porous species develop tyloses that seal earlywood vessels and significantly bring down the permeability.

Since the heartwood permeability of softwoods is much lower than that of sapwood [10] the water uptake of spruce was close to the ring-porous hardwoods. The tangential permeability was observed higher. This can be explained by the microstructure of softwoods. The greater number of pits is presented on the radial surface of tracheids and the contribution of wood rays and resin canals to the flow can be neglected, hence water uptake in the tangential direction was observed higher [3].

Influence of the ratio of earlywood and latewood in annual rings to water uptake depending on hardwood group was observed. The ring-porous hardwoods had earlywood vessels of large diameter but they were often sealed by tyloses. With the contribution of high amount of latewood (ca 70 %) this significantly brought down the ability of water absorption. It was not possible to measure the exact amount of latewood in the diffuse-porous and the semi-diffuse-porous group because the border was not clear; nevertheless in general this amount was low (ca up to 30 %). This means that the majority of the wood mass consisted of earlywood vessels hence the structure was for the most part very uniform.

The variability of hardwood structure causes wide differences in water absorption ability not only among species but also among investigated sections. The biggest difference between investigated sections was found out in alder, followed by aspen. Tangential and radial water absorption of beech and birch was very similar. This shows upon fairly big differences in the water uptake behavior within the diffuse-porous and the semi-diffuse-porous group. Oak develop large multiseriate rays that bring down the tangential permeability [3] hence ash had higher water uptake in this direction and the radial was lower.

Water uptake behavior is widely affected by the microstructure of wood e.g. number of vessels that are not sealed by tyloses and their distribution within the mass, diameter of the vessel lumens, type of perforation between vessel elements and type of pitting [3,9]. Furthermore presence of extractives and encrustations [2] in cell walls might have some influence.

For better understanding of the results it would be helpful to carry out a detailed study of the microscopic structure of the investigated samples. Further, it would be interesting to compare permeability of heartwood and sapwood and earlywood and latewood under consideration of the types of hardwoods.

Samples will be later used for testing in a Mycologg. This is a new accelerating test method investigating durability of wood placed into environment with variable relative humidity. Extreme conditions are simulated and periodically repeated in the Mycologg. The frequency of the exposure to moisture can be altered in many ways. This provides good conditions for growth of discolouring fungi. It is also a good method for monitoring moisture fluctuations [11].

This work should not be seen as the end of the project, but rather as a start up for continuing studies within the field of permeability of hardwood.

References

1 Ekstedt J., Ostberg G.: *Liquid permeability of exterior wood coatings-testing according to a proposed European standard method.* Journal of Coatings Technology, Mar 2001; 73, 914

2. Dinwoodie J. M., OBE: *Timber: Its nature and behavior.* E & FN Spon [2000]

3. Siau J. F.: *Wood: Influence of moisture on physical properties.* [1995]

4. Swedish National Forest Inventory: Homepage of the Swedish National Forest Inventory. http://www-nfi.slu.se, 2003-06-18 [2003]

5. Johansson J.: *Product differentiation in the Swedish hardwood industry.* Växjö University, School of Technology and Design, Växjö [2005]

6. Meijer M., Militz H.: *Moisture transport in coated wood. Part 1: Analysis of sorption rates and moisture content profiles in spruce during liquid water uptake.* Holz als Roh-und Werkstoff 58: 355-363 [2000]

7. Stamn A. J.: *Bound water diffusion into wood across the fibre directions.* Forest Prod J 10: 524-528 [1960]

8. CEN: EN 927-5 *Paints and varnishes - Coating materials and coating systems for exterior wood - Part 5: Assessment of the liquid water permeability*. European committee for Standardisation [2000]

9. Chen P. Y. S., Zhang G., Van Sambeek J. W.: *Relationships among growth rate, vessel lumen area, and wood permeability for three central hardwood species.* Forest Product J 48(3): 87-90 [1998]

10. Bergström M., Rydell Å., Thörnqvist T.: *Durability and moisture dynamics of Norway spruce (Picea abies) heartwood and sapwood.* Proceedings of the Woodframe Housing Durability and Disaster Issues Conference, Forest Products Society, USA, October 4-6 2004

11. Blom Å, Bergström M. Mycologg-A new accelerated test Metod for wood durability above ground. Wood science and technology 39(8)663-673 [2005]

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