SORPTION BEHAVIOUR OF SCOTS PINE IN NORTHERN EUROPE

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ABSTRACT

Wood as a hygroscopic material gains or loses moisture with changes in climate of the surrounding air. The moisture content influences strength properties, hardness, durability and machinability. Therefore the hygroscopicity is a very important property, last but not least for economic factors. Below fibre saturation, a change in moisture content causes shrinkage or swelling and anisotropic behaviour can be seen in the different growth directions. For a better understanding of the sorption behaviour of Scots pine (*Pinus sylvestris* L.) the variation between different adsorption and desorption curves has been investigated. Trees from 25 different sites in Northern Europe were collected and 3651 samples (1510 heartwood- and 2141 sapwood-samples) measuring 5 (T) x 10 (R) x 30 (L) mm were obtained. The sorption isotherms for all specimens were measured at 25 °C at relative humidities of 15, 35, 55, 75 and 95 % for both desorption and adsorption. The aim of this study is to investigate the influence of raw material variability on the sorption behaviour of Scots pine. Due to the different growing conditions, densities and wooden material (heart or sapwood) variations within the sample groups have been found. Correlations between moisture and density respectively latitude were investigated.

Keywords: Geographic origin, isotherm, moisture sorption, Scots pine

INTRODUCTION

Scots pine is adapted to a wide variety of climates and growing conditions as indicated by its extremely large natural range. It grows naturally from Spain to the Pacific Ocean and from above the Arctic Circle in Scandinavia to the Mediterranean. It is the most widely distributed pine in the world and primarily used as pulpwood and saw logs (Burns et al. 1990). Due to the wide natural distribution one can find a large variation within the material. This applies to the chemical composition as well as to the wood-water relation. Wood as a hygroscopic material gains or loses moisture with changes in relative humidity of the surrounding air. The moisture content influences strength properties, hardness, durability and machinability. Therefore knowledge regarding the relationship between water and the wood structure is of great value.

The total sorption of wood is indicated by the sorption capacity of the main components. Hydroxyls are the most important groups involved in the sorption process

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accompanied by carboxylic groups. Due to the structure and available hydroxyl groups, cellulose contributes 47 %, hemicelluloses 37 % and lignin 16 % to the sorption (Kollmann 1968). According to Stamm (1964) water is mostly sorbed in the non-crystalline segments of the cellulose chains and hemicelluloses. The adsorption of vapour molecules is an accumulation to a surface, while sorption mechanisms have physical or chemical nature. The chemically bound water is compressed to a density of 1.3 g/cm³.

In a living tree moisture contents of more than 100 % can be reached in the sapwood (Fromm et al. 2001) and the water is found as bound water in the cell walls and free water in the cavities. After the tree is felled wood loses moisture until equilibrium with the surrounding climate is reached (Time 1998). The equilibrium moisture content (EMC) of wood at a given relative humidity (RH) is a function of species, location within the tree, stress, history and temperature (Skaar 1988). Below the fibre saturation point the bound water will begin to evaporate from the cell wall (desorption) while drying and accordingly, an increase of RH causes an uptake of water into the cell walls until the new EMC is reached (adsorption). In the range between oven-dry and the fibre saturation point the relationship between EMC and RH at a constant temperature is called sorption isotherm and it exhibits a sigmoid sorption curve (Rowell 2005). There is a significant difference between the sorption isotherms of de- and adsorption where the desorption curve runs above the adsorption curve (Skaar 1988). This phenomenon is called hysteresis and is the result of the linkage of free hydroxyls of the wood when there is very little moisture in wood. Hence, during the following adsorption the number of available hydroxyls is generally smaller (Tsoumis 1991).

The variations of the EMC at a given RH are caused by the different species, heart- and sapwood, the composition and proportions of cell-wall constituents and extractives (Skaar 1988). In general, the ability to transport water decreases with increased density and extractive content. Regarding Scots pine, its heartwood is known to have an extractive content twice as high as the sapwood (Sehlstedt-Persson 2001).

While Morén and Sehlstedt (1984) found no correlation between moisture content and density a significant difference in EMC for heart- and sapwood was discussed by Koponen (1985). An answer to the question if a relation can be found if one considers the available data of different sites could help to understand and classify the influencing factors on the wood-water relation for Scots pine.

MATERIAL AND METHODS

Wood material collection

The sample material used in this study was collected during autumn and winter 2009/2010 (Behr et al. 2010, Zimmer et al. 2010). Scots pine samples from 25 different sites in Estonia, Finland, Lithuania, Norway, Scotland and Sweden were collected and used to study the variation within the material. Different properties like latitude, longitude, altitude, diameter, tree height, age and site index (Norwegian site index for Scots pine: H40 = height of tree at age 40) were noted. All in all 225 logs have been collected, heart- and sapwood were separated and radial layers were produced. From these layers clear mini block samples (seven per layer) were cut. The samples were free from wood defects and had a perpendicular annual ring orientation. 3651 samples (1510 heartwood and 2141 sapwood samples) were obtained.

Sorption measurements

After cutting the samples were dried at 50 °C for two days, to assure all the samples to be on an adsorption curve during the first sorption step (15 % RH). The samples were stored in different climates at a temperature of 25 °C and relative humidities of 15, 35, 55, 75 and 95 %, until the respective EMC were reached according to EN 13183-1: 2002. For calculating the EMC the samples were dried at 103 °C in a drying-oven until constant weight was reached (Eq. 1).

$$EMC = \frac{W_u - W_0}{W_0} \times 100 \ [\%] \qquad \text{Eq. 1}$$

W_u wet weight [g]
W_0 dry-weight [g]

According to EN 13183-1: 2002, constant weight was considered to be reached when the mass change of the samples within 6 h had been less than 0.1 % (in relation to the previous measurement). The climate in the chamber was constantly controlled with an ElproEcolog TH2. The conditioning was performed with a climate chamber (Termaks KBP 6395 F). For weighing a Mettler Toledo XP 205 Delta Range (0.15 mg resolution) was used.

Data Analysis

The data collection and the first preparation were performed with Microsoft's Excel 2003. For the statistical analysis the JMP Pro 9.0.0 (2010) software from SAS Institute Inc. (Cary, North Carolina) was used. The Mahalanobis and Jackknife distance outlier analysis was performed before the analytic statistical analysis.

RESULTS AND DISCUSSION

A variation in sorption behaviour within the material was found. In average sapwood shows a higher moisture content than heartwood (Table 1).

Table 1. EMC for de- and adsorption; heartwood and sapwood.

		Heartwood		Sapwood		Difference of EMC: heart- to sapwood [%]
	RH [%]	Mean EMC [%]	Standard Deviation	Mean EMC [%]	Standard Deviation	
Adsorption	15	4,27	0,38	4,70	0,26	9,08
	35	6,72	0,33	7,25	0,24	7,28
	55	9,41	0,32	10,08	0,26	6,57
	75	13,29	0,42	14,09	0,34	5,68
	95	22,84	1,15	23,83	0,79	4,18
Desorption	75	16,00	0,49	16,66	0,34	3,98
	55	11,24	0,32	12,25	0,26	8,31
	35	8,24	0,30	8,65	0,25	4,82
	15	5,61	0,45	5,44	0,25	3,09

Additionally, a variation within a sample group of heart- and sapwood for each sorption step was found. Figure 1 shows exemplary the variation of the moisture content for heartwood at 55 % RH adsorption with a mean value and a median of 9.4 %.

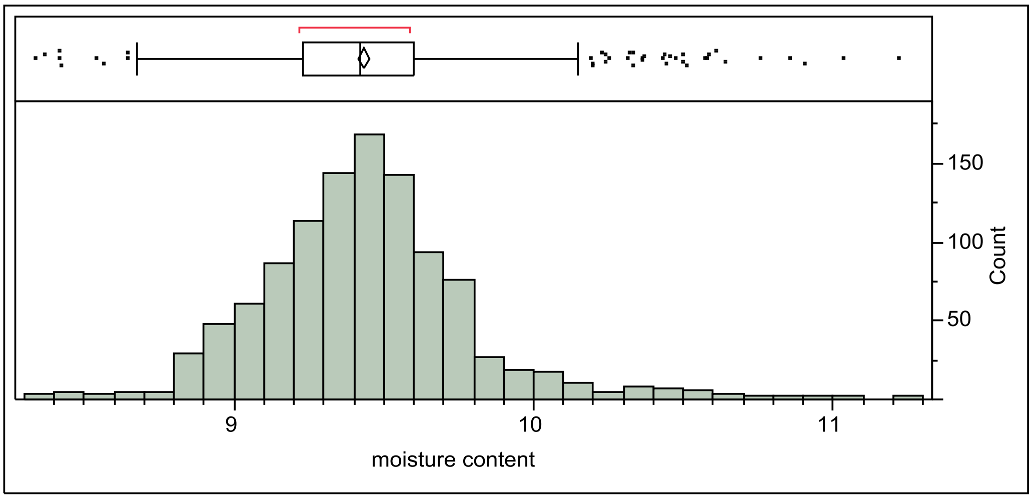

Fig. 1. Moisture content distribution for heartwood at 55 % RH adsorption.

While the bivariate analysis of moisture content [%] by density shows no correlation ($R^2 < 0.1$ for heart- and sapwood at each sorption step), the correlation of water content [g] to the density is significant (Figure 2 and 3). Heartwood shows at each sorption step a lower regression coefficient R^2. An increase of density causes a larger quantity of available functional groups. Especially hydroxyls (mainly holocellulose) are responsible for the attraction of water molecules by the wooden structure (Tsoumis 1991). The ratio of hydroxyls to attracted water molecules at a constant relative humidity is not influenced by the density, it remains constant. Due to this fact the absolute amount of water [g] has to be used for a correlation with density.

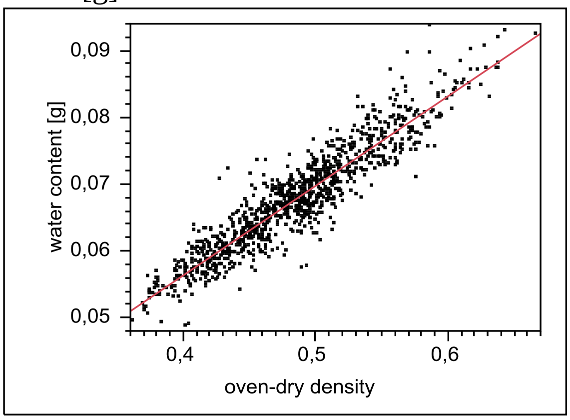

Fig. 2. Bivariate analysis of water content by density at 55 % RH adsorption (heartwood).

water content [%] = 0.0027177 + 0.1340351 * oven-dry density [g/cm³]
$R^2 = 0.87$

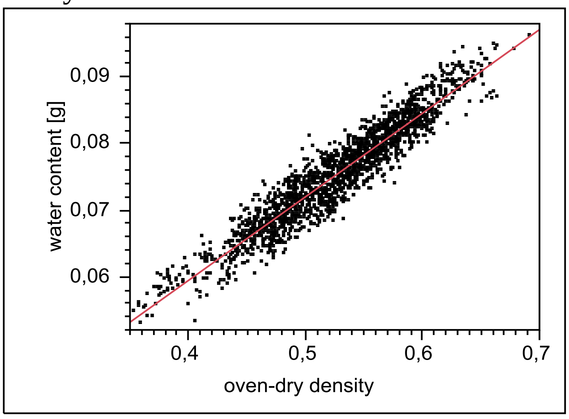

Fig. 3. Bivariate analysis of water content by density at 55 % RH adsorption (sapwood).

water content [%] = 0.00921 + 0.1255681 * oven-dry density [g/cm³]
$R^2 = 0.90$

The large sample area included different latitudes (from 55°44N in Lithuania to 66°52N in Norway). A oneway analysis of variance of water content by latitude groups shows a weak trend (Figure 4). The lower water content in higher latitudes can be seen in all sorption steps for both, heart- and sapwood.

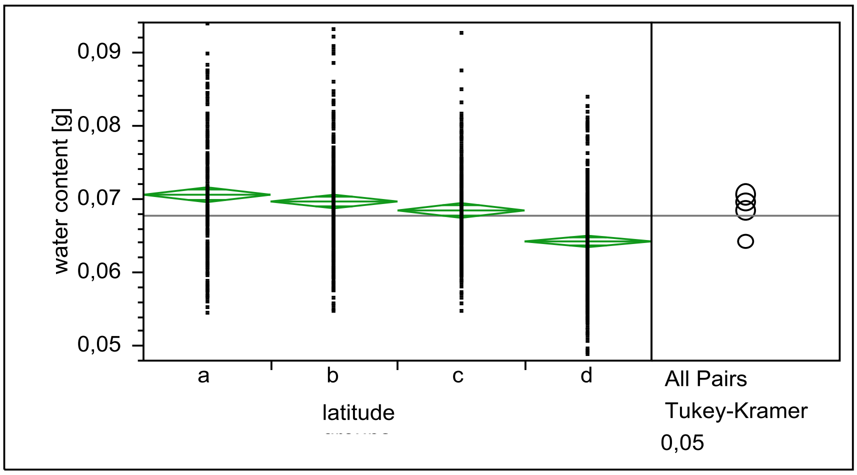

Fig. 4. Oneway analysis of variance of water content by latitude at 55 % RH adsorption (heartwood) and comparison of all pairs using Tukey-Kramer HSD (R^2 = 0,11). Each group represents stands sorted by latitude. The latitude increases from group a to group d.

Comparing the oven-dry density of the heartwood samples in relation to the latitude shows that northern stands seem to have a lower density (Figure 5). This verifies the lower water content in the same group.

The higher extractive content in the heartwood seems to lead to lower moisture contents. The specific extractive content of the samples has not been investigated yet. An increase in extractive content however causes a reduced water uptake (Sehlstedt-Persson, 2001). Due to the lower R^2 for the heartwood samples extractives seem to mask the density which has been also discussed by Posey et al. (1970). To investigate the influence of the density the absolute water content has to be considered. The low water content in the northern stands verifies the low densities in these groups. Besides the latitude the relation of water content with altitude, longitude and site index was investigated. While altitude and longitude have no influence on the water content the site index shows a weak trend: a large site index seems to lead to a higher water content.

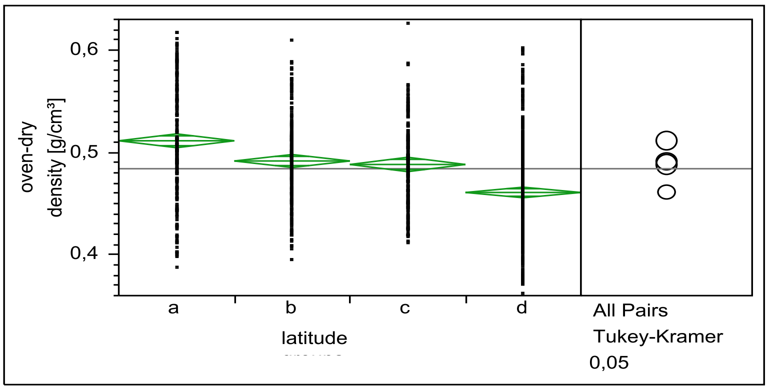

Fig. 5. Oneway analysis of oven-dry density by latitude (heartwood; R^2 = 0.13).

CONCLUSIONS

The sorption behaviour of Scots pine shows large variations between heart- and sapwood as well as within a sample group. The extractive content seems to have a strong influence. For a better understanding of the wood-water relation further investigations, especially in regards to the specific extractive content are necessary.

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