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THE EFFECT OF DEHYDRATION ON LENGTHWISE SHRINKAGE OF SCOTS PINE NEEDLES (*PINUS SILVESTRIS* L.)

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Axial desorption shrinkage of needles dehydrated at 25°C to different equilibrium moisture content was studied. The relation between equilibrium moisture content and degree of lengthwise shrinkage of needles is curvilinear. The degree of desorption shrinkage of pine needles is considerably higher than the corresponding one for mature wood but it is comparable to the degree of lengthwise shrinkage of juvenile wood.

INTRODUCTION

The potential possibility of using foliage of forest trees, particulary needles, as a source of fibrous raw material has been exploited only on small scale [2, 3, 10 - 12, 21, 24]. This is to a certain degree due to insufficient knowledge about structure and properties of foliage. The data on physical and mechanical properties of forest tree foliage are scarce both concerning coniferous [8, 10] and deciduous trees [13]. Therefore it is worth-while carying out further studies on properties of needles having relatively long fibrous elements [10, 13]. Sorption properties of needles seem to be of interest at first. Hence experiments were carried out to determine the effect of dehydration conditions for pine needles on their lengthwise desorption shrinkage.

EXPERIMENTS

The needles for experiments were collected in September from pine (*Pinus silvestris* L.) trees (5 years old) belonging in the artifical stand to the faster growing trees. The forest belonged to Forest Experimental Stations (FES) of the Poznań Agricultural University (Huta Pusta and FES-Murowana Goślina). Two years old green needles were collected from lateral near top shoots of three experimental trees. Immediately after collection the needles were put into foil bags and refrigerated at about 5°C.

Total length of the needles at green state was determined on 50 needle cluster samples from each tree. The measurements were made on one needle from each clusters with accuracy to 1 mm. Moisture con-

Table 1 - Tabela 1

Properties of *P. silvestris* needles in green state
Właściwości igieł sosny zwyczajnej w stanie świeżym

Properties of needles Właściwości igieł		Number of tree Numer drzewa		
		1	2	3
Total length*) Długość całkowita	L (mm)	67	62	51
Moisture**) Wilgotność	M (%)	144	128	124
Density**) Gęstość	ρ (kg/m^3)	394	416	443

*) mean from 50 measurements
**) mean from 3 measurements

tent of green needles, i.e. directly after collection, was determined on 20 needle samples. The needles were dried at 103 ± 2°C for 24 hrs. The moisture content of the needles was related to their mass in ovendry state. In density determinations bunches of 20 needles were used. Density was determined as, so called, basic density being a quotient of needle mass in ovendry state and their volume in green state. The needle volume in green state was determined with the method of hydrostatic weighting.

The green needle parameters are given in Table 1. The total length of the experimental needles is within the limit of mean length of pine needles from Poland [16]. Variability of the length of the studied needles is slight since the coefficient of variation for each tree is from 6% to 9%. The green needle moisture content is also close to that from ordinary and other pine species [9, 10, 15] taking into account the needle moisture content variability depending on the season and time of a day [1]. The mean basic density of the studied needles is comparable to that found for this species from other studies [8].

The degree of desorption shrinkage of needles along the main axis was determined on 20 mm samples cut from the middle part of the needles. Dehydration of the needles was carried out in the air of very high relative humidity (RH$\cong$85%), in the air of relative humidity close to normal (RH$\cong$65%), in the air of very low humidity (RH$\cong$30%) and in the completely dry air (RH$\cong$0%). To do this saturated water solutions of potasium chloride (KCl), sodium nitrite ($NaNO_2$) and calcium chloride

($CaCl_2$) were prepared which secured appropriate relative humidity of air over their surfaces. Needles drying to completely dry state were placed over anhydrous phosphorous pentoxide (P_2O_5). Desiccators with needle samples were stored in incubator at 25°C. Kinetics of dehydration of needles in these conditions is illustrated at Fig. 1. Generally the

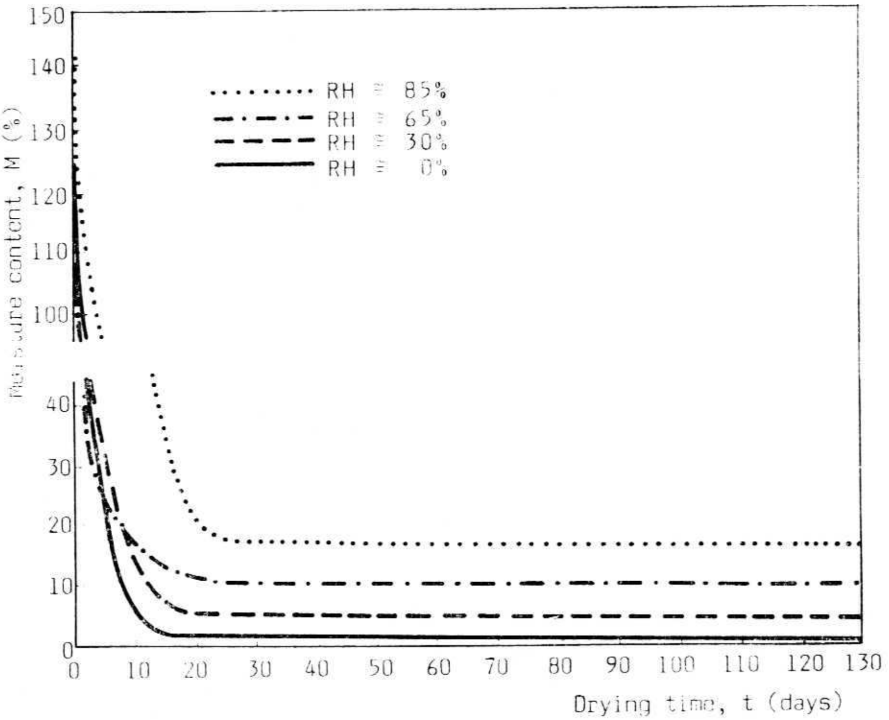

Fig. 1. Course of dehydration of pine needle samples in the conditions of various relative air humidity at 25°C

Rys. 1. Przebieg dehydratacji igieł sosny zwyczajnej w warunkach różnej względnej wilgotności powietrza w temperaturze 25°C

needle samples reach equilibrium moisture content the sooner the lower is relative air humidity. In the proper experiments the time 60 days was assumed after which the equilibrium moisture content is perfectly stable. The equilibrium moisture contents of needles are given in Table 2. They are slightly lower than the moisture contents of wood in the same conditions of air humidity and temperature (e.g. [5]).

The length of needle samples in green state and after they reached the assumed equilibrium moisture content was measured with a measuring microscope with the accuracy of 0.01 mm. The degree of lengthwise desorption shrinkage of needles was calculated from the relation

$\beta=(\Delta l/l)100$ (%), where Δl is desorptive shortening of a sample along the main axis at drying from green state to assumed equilibrium moisture content, and l is an initial sample length in green state.

RESULTS AND DISCUSSION

The degree of lengthwise desorption shrinkage of the pine needle samples at dehydration to various equilibrium moisture contents is given in Table 3. The histograms of frequency distribution are presented

Table 2 - Tabela 2

Equilibrium moisture content of *P. silvestris* needles dehydrated in different conditions at 25°C

Wilgotność równoważna igieł sosny zwyczajnej poddanych dehydratacji w różnych warunkach w temperaturze 25°C

Salts controlling RH in containers / Sole klimatyzujące	Relative air humidity / Względna wilgotność powietrza RH %	Equilibrium moisture content of needle samples / Wilgotność równoważna próbek igieł EMC %
KCl	~85	17.3 (16.8 ... 17.8)
$NaNO_2$	~65	10.3 (10.0 ... 10.5)
$CaCl_2$	~30	5.8 (5.5 ... 6.1)
P_2O_5	~ 0	0.9 (0.89 ... 0.94)

Table 3 - Tabela 3

Degree of desorption shrinkage of *P. silvestris* needles at dehydration to different equilibrium moisture content at 25°C

Stopień desorpcyjnego kurczenia się igieł sosny zwyczajnej przy dehydratacji do różnej wilgotności równoważnej w temperaturze 25°C

Equilibrium moisture content / Wilgotność równoważna %	Number of a tree / Numer drzewa	Statistical values / Wielkości statystyczne: n (number)	$\bar{x}$ (%)	x_{min} (%)	x_{max} (%)	$\pm\sigma$ (%)	$\pm m$ (%)
17.0 (16.8 ... 17.8)	1	24	0.25	0.05	0.92	0.13	0.03
	2	25	0.23	0.05	0.64	0.16	0.03
	3	25	0.22	0.05	0.58	0.13	0.03
10.1 (10.0 ... 10.5)	1	25	0.37	0.14	0.96	0.18	0.04
	2	25	0.31	0.10	0.58	0.13	0.03
	3	25	0.30	0.10	0.97	0.18	0.04
6.0 (5.5 ... 6.1)	1	25	0.57	0.10	1.40	0.29	0.06
	2	24	0.49	0.20	0.81	0.15	0.03
	3	25	0.53	0.29	0.77	0.12	0.02
1.0 (0.89 ... 0.94)	1	25	0.98	0.30	1.66	0.35	0.07
	2	24	1.00	0.48	1.62	0.28	0.06
	3	25	0.89	0.29	1.27	0.21	0.04

n — replicate measurements, $\bar{x}$ — mean value, x_{min} — minimum value, x_{max} — maximum value, $\pm\sigma$ — standard deviation, $\pm m$ — standard error of the mean in Fig. 2. Differentiation of the values for mean degrees of lengthwise shrinkage for given conditions of dehydration of needles from different trees is very slight. However, it is worth-while noticing high coefficient of variation of the degree of shrinkage of needles from the same sample. It amounts to $V=20\%$ at the equilibrium moisture content of EMC$=1\%$, $V=35\%$ at EMC$=6\%$, $V=50\%$ at EMC$=10\%$ and $V=60\%$ at EMC$=17\%$.

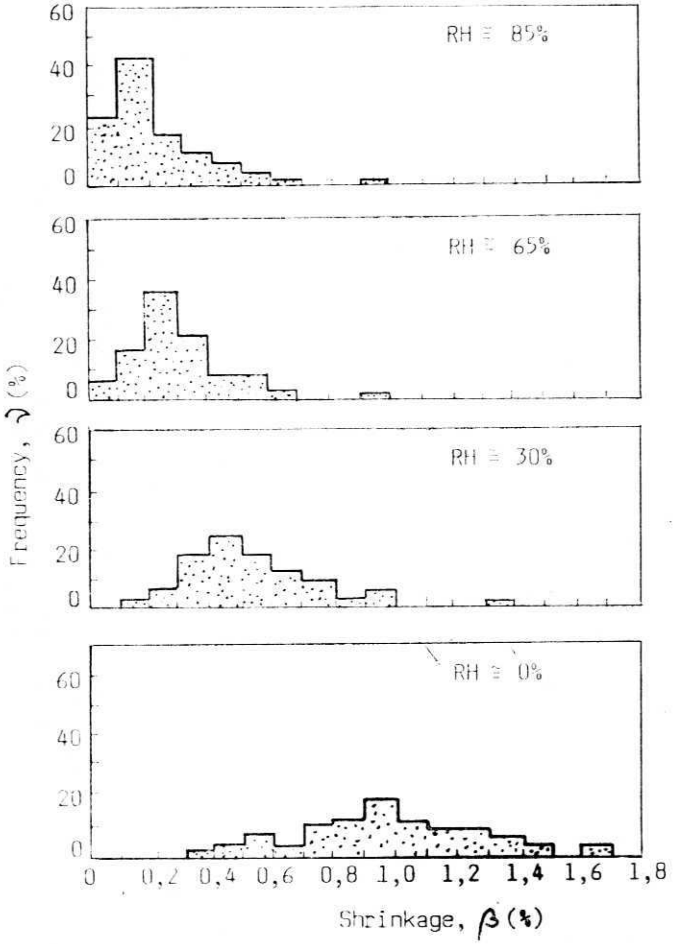

Fig. 2. Histogram of the lengthwise shrinkage of pine needles dehydrated with various relative air humidity at 25°C

Rys. 2. Histogramy rozkładu częstości stopnia desorpcyjnego kurczenia się igieł sosny zwyczajnej w warunkach różnej względnej wilgotności powietrza w temperaturze 25°C

The maximum degree of lengthwise shrinkage of the pine needles at drying from green to completely dry state is on average about 1%. The maximum desorption shrinkage for needles of other pine species is from

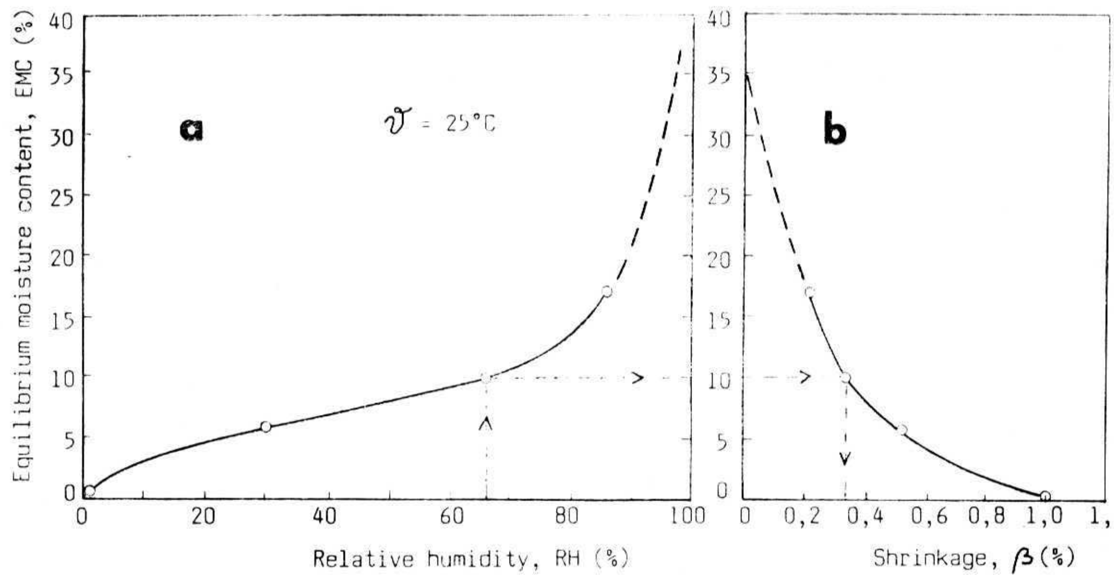

Fig. 3. Composite graph showing relationship of relative air humidity (RH) to equilibrium moisture content (EMC) and moisture content to lengthwise shrinkage of scots pine needles (β)

Rys. 3. Kompleksowa zależność między względną wilgotnością powietrza (RH) i wilgotnością równoważną (EMC) oraz stopniem desorpcyjnego kurczenia się (β) igieł sosny zwyczajnej

0.6% for *P. ponderosa* and *P. nigra* to 2.7% for *P. strobus* and *P. cembra* [9, 10]. With respect to the degree of the maximum shrinkage the *P. silvestris* needles are in the group of species with low lengthwise shrinkage[9].

During drying the needles to higher equilibrium moisture content their degree of lengthwise shrinkage is appropriately lower. A complex relation between relative air humidity (RH), equilibrium moisture content of needles (EMC) and their degree of lengthwise shrinkage (β) is given in Fig. 3. The relation between the equilibrium moisture content of needles and the degree of their lengthwise shrinkage (Fig. 3b) is clearly curvilinear. From this relation results that lengthwise desorption shrinkage of needles drying to the equilibrium moisture content of about 10% is relatively slight and only below this value it increases considerably. This is confirmed by the values of, so called, shrinkage coefficient calculated for each moisture content intervals from the relation

$$K=\frac{\Delta\beta}{\Delta \mathrm{EMC}}.$$

In the moisture content range from 17% to 10% this coefficient is only 0.01, in the interval from 10% to 6% it increases to 0.05 and in the interval from 6% to 1% it reaches 0.09.

The degree of lengthwise desorption shrinkage in plant tissues depends on their chemical composition and on the structure and ultrastructure of anatomical elements. The structural elements deciding about moisture deformations of needle samples are the elements of conductive tissue. The needle conductive tissue creates fibrous core (axial cyllinder) located centrally along the main axis which in scots pine consists of two vascular bundles containing phloem and xylem separated with cambial tissue [7, 10]. The percentage of the axial cyllinder in the area of cross-section of *P. silvestris* needle is about 30% [8]. The desorption shrinkage of the needles is probably a resultant of shrinkage of wood and phloem in the phloem-xylem bundles. Besides the axial cyllinder also the sclerenchymatic cells of hypoderm, fibrous sheath of resin canals and epidermal cells can participate in forming of desorption deformations.

The maximum lengthwise desorption shrinkage of pine needles is much greater than the longitudinal shrinkage of mature wood which is usually from 0.1% to 0.3% (e.g. [14]). It is comparable to longitudinal shrinkage of juvenile wood (core wood) which is from 0.4% to 2.5% [4, 6]. Increased lengthwise shrinkage in the juvenile wood is related to great fibril angle in the S_2 layer of the secondary cell wall. In the proper mature wood this angle is small. However, in the juvenile or compression wood the fibril angle increases to 45 and more degrees.

Since higroscopic changes in dimensions take place at the right angle to the fibril axis then the resultant of shrinkage along the cell axis (along the grain) increases with increase in the fibril angle [22, 23]. The fibril angle in the walls of tracheid cells and of phloem fibres of needle axial cyllinder should be relatively higher than that mature wood. However, this is only a hypothesis based on the results of lengthwise desorption shrinkage of needles. This hypothesis seems to be confirmed by the studies into the structure of fibrous elements of secondary phloem [17 - 20]. But it is only an indirect confirmation since there are no, to the author's knowledge, data on ultrastructure of wood and phloem cell wall in vascular bundles of needles.

CONCLUSIONS

1. The sample of *P. silvestris* needles dehydrated in air at 25°C and different air humidity of 85%, 65%, 30% and ca. 0% reach the equilibrium moisture content of 17%, 10%, 6% and 1%, respectively.

2. The degree of lengthwise desorption shrinkage attributed to each equilibrium moisture contents is 0.2%, 0.3%, 0.5% and 1.0%, respectively.

3. The relation between the equilibrium moisture content and the degree of lengthwise shrinkage of needles is curvilinear. In the interval of the equilibrium moisture content from 17% to 10% the shrinkage coefficient for needles is only 0.01, in the interval from 10% to 6% this coefficient rises to 0.05 and in the interval from 6% to 1% it reaches 0.09.

4. The maximum lengthwise desorption shrinkagee of *P. silvestris* needles is much greater than the corresponding degree of shrinkage of mature wood. However, it is comparable to lengthwise shrinkage of juvenile wood.

5. The magnitude of lengthwise desorption shrinkage of needles seems to indicate that the fibril angle in the secondary wall the elements of xylem and phloem in vascular bundles of needles should be relatively high.

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WPŁYW DEHYDRATACJI NA PODŁUŻNE KURCZENIE SIĘ IGIEŁ SOSNY (*PINUS SILVESTRIS* L.)

Streszczenie

Oznaczano podłużne kurczenie się igieł sosny sezonowanych w temperaturze 25°C do wilgotności równoważnych wynoszących: 17%, 10%, 6% i 1%. Odpowiadający tym wilgotnościom stopień desorpcyjnego kurczenia się wynosi: 0,2%, 0,3%, 0,5% i 1,0%. Zależność między wilgotnością równoważną a stopniem podłużnego kurczenia się igieł jest krzywoliniowa. Podłużne kurczenie się igieł jest znacznie większe od odpowiedniego kurczenia się prawidłowego drewna dojrzałego, ale jest porównywalne z podłużnym kurczeniem się drewna młodocianego.

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