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MODEL OF DRYING SPRUCE (*PICEA ABIES (L.) KARST.)* CONES SUBJECTED TO PROCESS OF SEED EXTRACTION

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ABSTRACT

Process of seed extraction from the cones is long-lasting and energy-consuming. The state of spruce cone opening can be achieved in the kilns used at present after several hours of drying. Undertaking of an attempt towards improvement of the process calls for learning of the factors influencing its realization. The paper contains the results of investigations on convectional drying of spruce cones of various size, and the proposed mathematical description of the changes in their moisture content in time. It was proved that they could be well represented by a trinomial square of coefficients significantly influenced by the cone volume. However, the time essential for opening the cone dried at temperature 58°C amounted to 6–8 hours, independently of the cone size. The moisture content of open cone amounted to 3–8%.

Key words: spruce, cones, seeds, seed extraction, model of drying

INTRODUCTION

Extraction of seeds from the spruce cones, similarly to cones of other trees, calls for such opening of cone scales (Fig.1) that it is possible to separate the seeds and they can freely fall out of the cone. To open the spruce cones it is essential to decrease considerably their moisture content, down to at least 10%. Reduction of moisture content in the cone is accompanied by changes in dimensions of cells constituting the scale, while bigger changes occur at its external side than at internal one [9].

Fig.1. Spruce cone: a – closed, before drying, b – open, after drying

a **b**

Degree of cone opening is particularly influenced by changes in cell dimensions of the scale at the point of its connection to the stem. Therefore, to achieve sufficient opening of the cone it is essential to decrease the moisture content not only of the scales but also of the stem. Thus, the process of scale deflection (cone seed extraction) is long-lasting. The time needed for cone opening depends on external factors – drying medium temperature, its moisture content, but also on water diffusion conditions inside the cone elements – in the stem and scales.

The state of spruce cone opening can be achieved under natural conditions, when the increased air temperature and its low moisture content are maintained long enough, or under artificial conditions in special drying chambers with controlled temperature and air moisture content speeding up the heat and mass transfer between the cone and drying medium.

Under natural conditions and in favourable coincidence, one can expect the spruce cone opening in a week, while in artificial kilns in no more than 15 hours, depending on the initial moisture content. Considering the full process control and considerable time reduction, the artificial seed extraction from spruce cones is at present a common way of obtaining the seeds for economic purposes.

CONDITIONS FOR ARTIFICIAL SEED EXTRACTION

Determining the conditions for artificial spruce seed extraction one should consider that this operation aims at obtaining of seeds of sustained germination ability and energy. It is evident from the hitherto investigations that moisture content and temperature of drying air are the factors decisive for preservation of the above properties in the seeds [3, 7, 9]. According to Tyszkiewicz [9] the vitality of seeds shall not be deteriorated if drying air absolute humidity does not exceed 40 gm^{-3}, independently of temperature. To adhere to this value, particularly during an initial phase of drying, an intensive air exchange in the drying chamber is essential.

The lower drying medium temperature and the higher its temperature, the quicker decrease in cone moisture content during drying. Generally, the temperature in the drying chamber does not exceed 60°C, for fear that the seed vitality may be lost. Bogdanow [5] attempted to increase considerably the air temperature. His drying chamber enabled to decrease considerably the pressure (to 4 kPa). Under such pressure, an increase in drying medium temperature even up to 100°C does not result in substantial increase in cone temperature, as long as it contains water. The temperature can not exceed the water boiling point, amounted at such pressure to 30°C only. Thus, as long as the seeds adhere to the cone there is no fear of their damage. The state of cone opening under such conditions is reached after 3 hours.

ANATOMICAL CONSTITUTION OF SPRUCE CONES

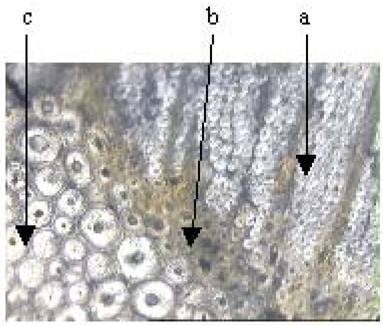
The size and shape of spruce cones depend on many factors. Thus, there occurs a high size variability – their length and thickness. The spruce cones are of cylindrical and fairly regular shape [1]. Many authors present various cone sizes. According to Tomanek [8], the cone length is contained in the range of 0.10–0.15 m, while their thickness equals from 0.035 to 0.05 m; according to Białobok [4] the length amounts to 0.15–0.20 m, the thickness from 0.035 to 0.05 m.

The cone consists of a stem constituting its axis and the bud scales and ovuliferous scales. The spruce cone bud scales are small and are on the external part of ovuliferous scale. The three varieties of ovuliferous scales are distinguished: *var. obovata, var. europea,* and *var. acuminata.*

Three kinds of ovuliferous scales are distinguished depending on their position. The small flat scales placed at the bottom part, large scales at the medium part, and medium size scales, bent towards center, of hemispherical cross section, at the upper part. They differ not only in size (length, width and thickness), but also in shape.

Considering differentiation in internal constitution of the scale one can distinguish the two characteristic parts: the first one – next-to-stem at the point of connection with the stem, and the second one – above, up to the scale top[2].

Fig. 2. Sectional view of scale at the next-to-stem part: a – small cells, b – medium size cells, c – large cells



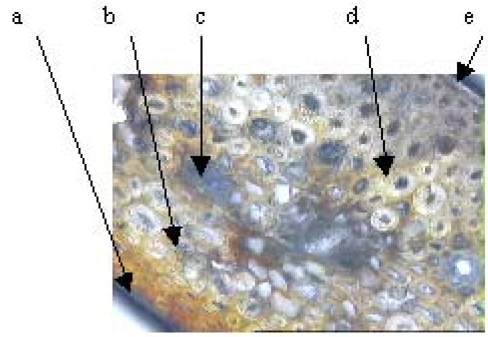
The three groups of cells of different size were distinguished in the first part (Fig.2).

On internal side of this part there are small cells (a), on external side large cells (c), and medium size cells (b) between them. The small cells are of irregular shape and have thinner walls than the large ones. The large cells are round and thick-wall, with small internal space. Both kinds of cells are colourless. The medium size cells are different from the large and small ones in shape, wall thickness, internal space and colour (yellow or dark brown). The small cells are enclosed by the medium size ones. The large cells are of average diameter 56.7 µm, the medium size cells – 32.2 µm, and small cells – 15.3 µm.

Towards the top of scale the small cells are substituted by large and medium size cells, differentiated at the second part of scale above the seed zone.

In that part of scale there are five groups of cells. The external and internal groups consist of layers of cells of irregular elongated shape, adhered to each other (a, e), and the cells in external layer (a) of open cone are rugged.

Fig. 3. Sectional view of scale above the seed zone: a – cell group of scale internal layer, b, d – cell groups of layers inside the scale, c – clusters of cells similar to bundles, e – cell group of scale external layer



Between them there are three groups consisted of numerous layers of large, thick-wall cells of different size (b, d). In the middle group the cell clusters similar to bundles are distinguished (c).

The scale thickness on its sectional view varies along its length – in next-to-stem part is the biggest and decreases towards the scale top.

Fig. 4. Sectional view of cone stem: a – cells of stem, b – cells of scale

The cone stem consists of thick-wall cells (a) with small internal space, different in size along cone length; average stem cell size amounts to 57.3 μm. One can also find the point of scale in-growing into the stem (b).

The cone scales were also investigated with respect to chemical composition [2]. Their substantial similarity to wood was found, since the following components were separated: lignin (60%), cellulose (35%) and non-structural substances (5%).

AIM AND SCOPE OF INVESTIGATIONS

Bibliography on seed extraction from spruce and pine cones does not contain any sufficient description of the process course and the control factors; e.g. there is no explanation of the effect of cone dimensions on the time needed to open cones, in spite of substantial differentiation of their dimensions.

Our investigations aimed at learning of the course of changes in moisture content of different-size spruce cones subjected to process of seed extraction, determination of their moisture content in open state as well as the time needed to achieve this state under assumed drying conditions.

The course of changes in cone moisture content will be described with a mathematical model, considering individual properties of the cone, and enabling to analyze their effect on drying rate and the time needed to achieve the state of opening.

The process of seed extraction will be carried out in a chamber allowing for constant control of moisture content and drying air temperature, ensuring vitality of the obtained seeds.

MATERIAL AND METHODS

The investigated spruce (*Picea abies (L.) Karst*.) cones were harvested in November 2001 in Forest Inspectorate Srokowo (Warmian-Mazur province) and stored in a cold room at temperature -1°C. After removing from the cold room, prior to the process of seed extraction, each cone was kept at temperature 20-22°C during 2 hours.

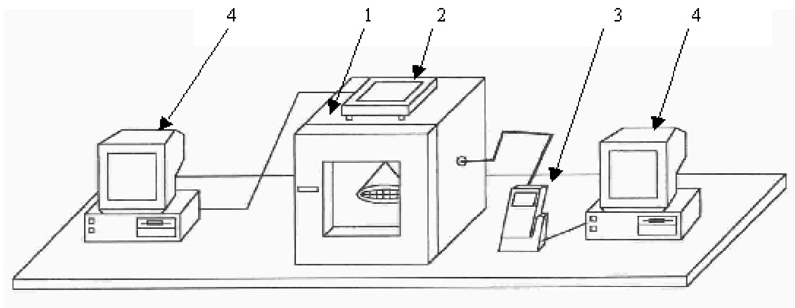
As characteristic cone parameters the following were taken: length, thickness, closed-state volume, number of scales, initial mass and dry mass. This last parameter was determined when seed extraction process was completed, and the cone was additionally dried at temperature 105°C. The cone dimensions were determined with accuracy 0.1 mm, while the mass with accuracy 0.01 g.

Table 1. Parameters of spruce cones subjected to seed extraction (Picea abies (L.) Karst.)

Cone serial number	Length h [cm]	Thickness d [cm]	Volume V [cm^3]	Number of scales	Initial mass m_0 [g]	Dry mass m_s [g]	Initial moisture content u_0
1	11.96	3.04	64.43	169	31.72	23.49	0.2787
2	9.95	2.97	51.16	202	27.30	18.98	0.3381
3	11.22	3.64	86.65	196	38.12	28.70	0.3525
4	10.50	3.35	68.69	190	40.60	27.78	0.3996
5	13.32	3.61	101.18	226	53.14	38.42	0.3007
6	11.09	2.76	49.24	160	29.97	19.18	0.4270
7	13.21	3.45	91.65	230	52.94	39.04	0.3311
8	11.60	3.23	70.54	190	37.05	28.64	0.2610
9	13.50	3.58	100.85	204	55.92	43.80	0.2478
10	11.80	2.73	51.26	156	28.91	21.54	0.2639
11	13.80	3.51	99.10	219	54.55	42.42	0.2870
12	10.83	3.19	64.24	214	30.79	23.61	0.2996
13	13.00	3.68	102.62	236	53.15	41.10	0.2876
14	11.01	3.11	62.07	207	36.18	26.97	0.3384
15	12.32	3.23	74.92	207	39.07	29.49	0.3239
16	13.00	2.65	53.21	205	35.01	27.35	0.2824
17	11.54	2.65	47.24	179	27.62	22.19	0.2466
18	12.48	2.77	55.82	174	32.24	24.55	0.3229
19	10.72	2.58	41.59	166	23.45	18.18	0.2998
20	10.96	2.65	44.86	169	22.98	16.90	0.3690
21	12.43	2.70	52.82	180	33.02	24.39	0.3665
22	10.13	2.68	42.41	170	23.25	16.93	0.3821
23	9.94	2.65	40.69	178	25.26	18.18	0.3956

Twenty three cones were subjected to seed extraction; their characteristic parameters are given in Table 1. The length of investigated cones ranged from 9.94 to 13.80 cm, thickness from 2.58 to 3.68 cm, volume from 40.69 to 102.62 cm^3, moist cone initial mass from 22.98 to 55.92 g, and dry mass from 16.70 to 43.80 g. The cones contained from 156 to 236 scales.

Fig. 5. Layout of measurement stand: 1 – dryer, 2 – scale, 3 – hygrometer, 4 – computers



Seed extraction was carried out in a convectional dryer with drying air temperature 57-58°C and its relative humidity 3–5%. The layout of measurement stand is presented in Figure 5. Apart from the dryer it contains: hygrometer (3), pan scale (2) and two computers (4) for recording the actual states of cone mass, moisture content and temperature of air, as well as temperature of wet thermometer. The values was read off every one minute with accuracy: mass – 0.01 g, temperature – 0.01°C, air humidity – 0.01%.

The cone moisture content was calculated from equation:

$$u = \frac{m - m_s}{m_s} \qquad [kg_{H_2O}/kg_{s.m}]$$

where:
m – mass of moist cone, kg
m_s – mass of dry cone, kg.

When the mass of moist and dry cones are measured with the same accuracy Δ m, the error of moisture content determination can be expressed with equation:

$$\Delta u = \pm\frac{\Delta m}{m_s}(1+\frac{m}{m_s}) = \pm\frac{\Delta m}{m_s}(2+u) \qquad [kg_{H_2O}/kg_{s.m}]$$

while relative error δu, related to amount of water contained in the cone, can be determined with equation:

$$\delta u = \pm\frac{100\cdot\Delta m}{m - m_s}(1+\frac{m}{m_s}) = \pm\frac{100\cdot\Delta m}{u\cdot m_s}(2+u) \qquad (\%)$$

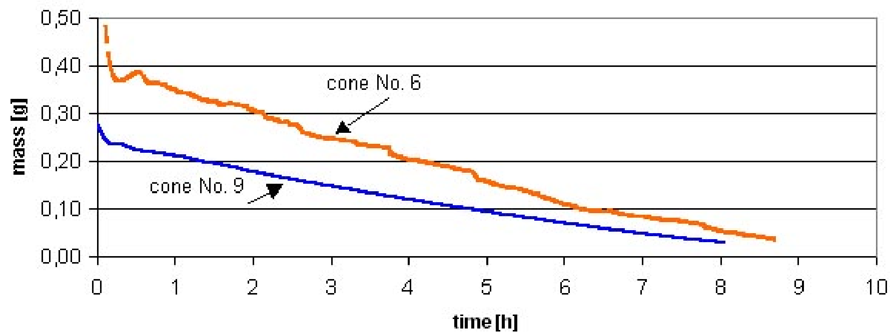
RESULTS AND DISCUSSION

Exemplary courses of changes in the mass of cones subjected to drying are presented in Figure 6, while the calculated changes in moisture content in Figure 7. It was found that a proper mathematical model describing changes in moisture content of spruce cones during seed extraction was the trinomial square:

$$u = a\cdot\tau^2 + b\cdot\tau + c \qquad [kg_{H_2O}/kg_{s.m}]$$

where τ is the time in hours.

Fig. 6. Changes in spruce cone mass (No. 6 and 9) during seed extraction in convectional dryer



Regression equation of the changes in exemplary cone moisture content is presented in Figure 7. The coefficient values a, b and c as well as correlation coefficient R for all the investigated cones are given in Table 2. It should be noted that mathematical model assumed for description of the process represents very precisely the changes in cone moisture content, since correlation coefficient ranges from 0.9716 to 0.9999, thus, is close to 1.

Fig. 7. Changes in spruce cone moisture content (No. 6 and 9 in Table 1) during seed extraction in convectional dryer

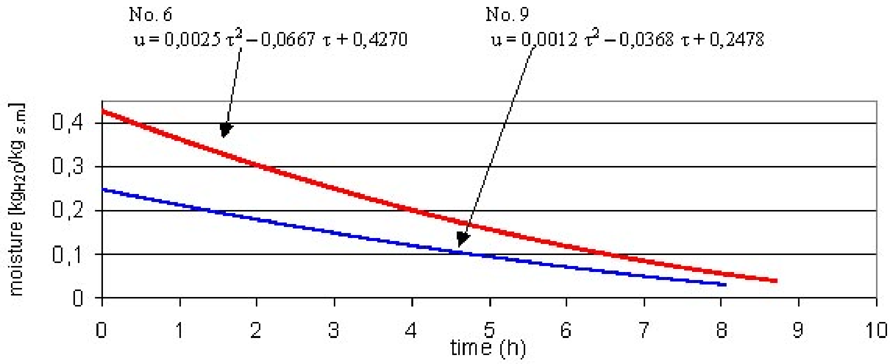
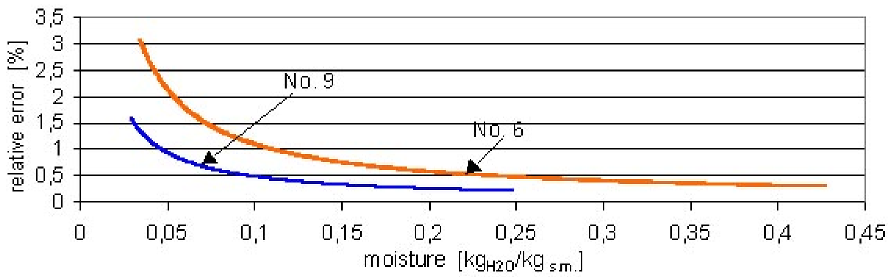


Table 2. Coefficients of equations

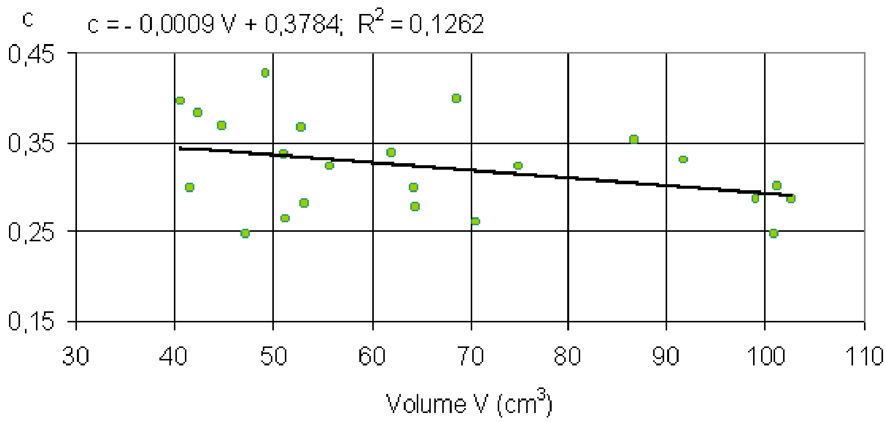
Cone serial number	Volume V (cm^3)	Coefficient of regression equations			Correlation coefficient R
		a (h^{-2})	b (h^{-1})	c	
1	64.43	0.0028	-0.0473	0.2787	0.9716
2	51.16	0.0024	-0.0572	0.3381	0.9924
3	86.65	0.0014	-0.0516	0.3525	0.9953
4	68.69	0.0016	-0.0543	0.3996	0.9976
5	101.18	0.0033	-0.0579	0.3007	0.9864
6	49.24	0.0025	-0.0667	0.4270	0.9876
7	91.65	0.0008	-0.0397	0.3311	0.9989
8	70.54	0.0028	-0.0505	0.2610	0.9979
9	100.85	0.0012	-0.0368	0.2478	0.9990
10	51.26	0.0038	-0.0589	0.2639	0.9913
11	99.10	0.0013	-0.0400	0.2870	0.9999
12	64.24	0.0038	-0.0616	0.2996	0.9996
13	102.62	0.0016	-0.0414	0.2876	0.9996
14	62.07	0.0019	-0.0478	0.3384	0.9998
15	74.92	0.0024	-0.0505	0.3239	0.9999
16	53.21	0.0023	-0.0485	0.2824	0.9999
17	47.24	0.0024	-0.0452	0.2466	0.9999
18	55.82	0.0024	-0.0558	0.3229	0.9998
19	41.59	0.0041	-0.0673	0.2998	0.9994
20	44.86	0.0034	-0.0678	0.3690	0.9995
21	52.82	0.0022	-0.0563	0.3665	0.9993
22	42.41	0.0048	-0.0773	0.3821	0.9998
23	40.69	0.0034	-0.0703	0.3956	0.9998

Fig. 8. Relative error δu of moisture content determination in cones subjected to convectional seed extraction



Relative error of cone moisture content determined in that way increases with a decrease in cone moisture content, which is presented in Figure 8. For the quoted examples it amounts to 0.2–0.3% in the initial phase of drying, and about 1.5–3.0% in the final phase.

Fig. 9. Dependence between trinomial square coefficient c and cone volume



In the assumed mathematical model of drying process the coefficient c equals the initial moisture content of cone u_0. In spite of the fact that all cones were stored under the same conditions, their initial moisture content was different. Generally, the smaller cones had higher moisture content (Fig.9). The statistical analysis performed for the investigated set of cones proved the existence of a significant linear dependence between initial moisture content and cone volume at confidence level $\alpha = 0.1$.

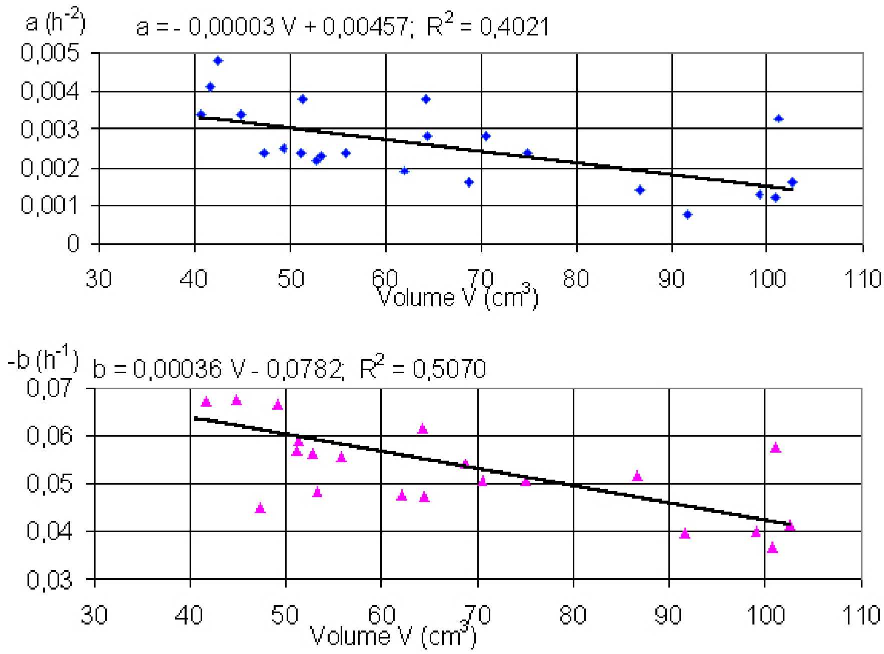
The coefficients a and b showed higher dependence on the cone size (Fig.10). A significant correlation was found for them at confidence level $\alpha = 0.01$.

The coefficient a has positive values, decreasing with an increase in cone volume (from 0.0048 to 0.0008 h^{-2}). Nevertheless, coefficient b has negative values, increasing with an increase in cone volume (from –0.0773 to – 0.0368 h^{-1}).

To recognize better the importance of coefficients a and b in the process of cone drying, there was introduced a factor of drying rate (du/dτ) determined from the equation:

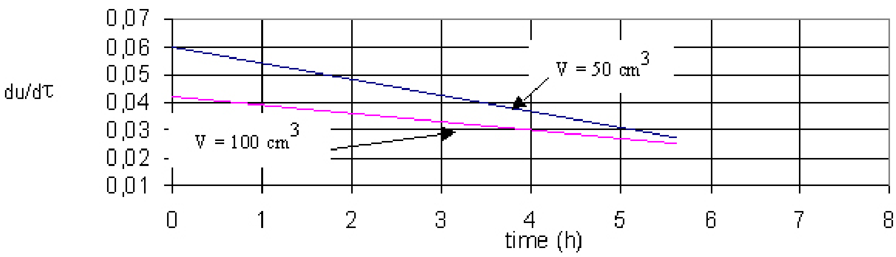
$$\frac{du}{d\tau} = 2 \cdot a \cdot \tau + b \qquad (h^{-1})$$

Fig. 10. Dependences between trinomial square coefficients a and b and cone volume



This factor for the spruce cones is linearly time-dependent. The exemplary changes in this factor values for the cones of volume 50 and 100 cm^3 are presented in Figure 11. The values for the smaller cone amount to: a = 0.0030 h^{-2} and b = -0.060 h^{-1}, while for the bigger cone a = 0.0016 h^{-2} and b = -0.042 h^{-1}.

Fig. 11. Rate of changes in moisture content of spruce cone of volume V = 50 and 100 cm^3 during seed extraction in convectional dryer of temperature 58°C



It is evident from comparison of the straight lines that the small cone (V = 50 cm^3) shows a higher rate of decreasing in moisture content than the large cone (V = 100 cm^3) only during first 6 hours of drying, while during next hours a decrease in moisture content is lower, despite a higher initial rate of the small cone by about 30% than that of the large cone. Thus, the cones of different size achieve the opening state in the similar time interval.

One should search for explanation of that phenomenon in anatomical constitution of cones and the forms of contained water. As mentioned earlier, the chemical constitution of cones is similar to wood. The water in cone, as in the wood of living trees, can be present as constitutional water (chemically combined water) in amount of 0.5–2.0%, as bound water – saturating the cell walls and filling the sub-capillary spaces in amount of 23–30%, and as free water – filling the vessels and tracheids, cell interiors and inter-cell spaces in amount of about 65% in relation to cone dry mass [6]. Considering the possible absorbability of cones, one can find their higher moisture content, since amount of free water can be increased even up to 175%.

The maximal moisture content of cone can be then estimated as about 205%. Generally, moisture content of the spruce cones subjected to drying in order to extract the seeds does not exceed 50%; free water takes about 20%, and the rest – bound water and constitutional water. During drying of a cone, at the beginning free water penetrates into the surface and evaporates, and then the bound water. Penetration of free water is relatively fast, since no changes in cell dimensions occur. However, the loss of bound water is accompanied by progressive shrinkage of the cells, the higher the bigger are dimensions of the cells. Differences in the shrinkage of scale cells making its root (by the stem) are of particular importance. As it is evident from the cross-section made in that place (Fig.2), the cells on the external side of scale are considerably bigger than that on internal side. Different shrinkage causes the fact that the loss of bound water results in the scales getting out of the stem. The state of full opening of the cone is achieved at defined moisture content.

One can suppose that the cell shrinkage is accompanied by an increased bound water diffusion resistance to the scale surface. The small cones are more sensitive to these changes, thus, the rate of drying decreases faster in the cone of volume 50 cm^3, than in the cone of volume 100 cm^3 (Fig.11). Both the small and large cones achieve the state of final opening after 6–8 hours of drying. Their moisture content amounts to 3–8%. Generally, opening of large cones occurs at higher moisture content than of smaller cones, however, it is not accompanied by a decrease in duration of the process.

Thus, separation of the spruce cones prior to seed extraction is needless, since such operation would not affect the time of their opening.

CONCLUSIONS

Mathematical model of spruce cone drying process is of trinomial square form. A high value of correlation coefficient $R = 0.9716 \div 0.9999$ proves its exact correlation with the real course.

The coefficients of trinomial square are highly dependent on the cone volume, and coefficients a and c decrease with the cone volume, while b coefficient increases. For this reason the time needed for opening the small cones is similar to that of large cones and ranges to 6–8 hours, thus, there is no need for their size separation.

REFERENCES

1. Aniszewska M.: Zmienność podstawowych parametrów szyszki świerka [Variability of basic parameters of spruce cones]. Sylwan 2001 no 6, pp. 87-93, [in Polish]
2. Aniszewska M.: Budowa anatomiczna szyszek świerka [Anatomical constitution of spruce cones]. Sylwan 2002 no 7, pp. 85-91, [in Polish].
3. Antosiewicz Z.: Doskonalenie procesów technologicznych wyłuszczania nasion sosny i świerka [Improvement of technological processes of pine and spruce seed extraction]. IBL, Warszawa 1978, p. 24, [in Polish].
4. Białobok S. i in.: Świerk pospolity [Spruce]. PWN, Warszawa 1977, p. 565, [in Polish].
5. Bogdanow B.P.: O suszkie szyszek w wakuumie [Drying of cones in vacuum]. Lesnoje Chozjajstwo, 1966, no 3, pp. 57-60, [in Russian].
6. Kubiak M., Laurow Z.,: Surowiec drzewny [Wood raw material]. Fundacja "Rozwój SGGW", Warszawa 1994, p. 493, [in Polish].
7. Rohmeder E.: Das saatqut in der Forstwirtschaft [Seeding material in forestry]. Paul Parey, Hamburg i Berlin 1972, p. 273, [in German].
8. Tomanek J.: Botanika leśna [Forest botany]. Wyd. 6. PWRiL, Warszawa 1996, p. 507, [in Polish].
9. Tyszkiewicz S.: Wyłuszczanie nasion sosny [Pine seed extraction]. PWRiL, Warszawa 1951, p. 44, [in Polish].

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