The influence of microwave drying on the permeability of fir- wood

UTJECAJ MIKROVALNOG SUŠENJA NA PERMEABILNOST JELOVINE

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Preliminary results

Summary

In this paper gas permeability of air dried fir sapwood is compared with gas permeability of microwave dried fir sapwood, and with alcohol dried fir sapwood; all wood was dried from green to under the fibre saturation point. The investigation showed that the longitudinal gas permeability of microwave dried fir sapwood is 10 times less (0.07 darcy) than the permeability of air-dried fir sapwood (0.77 darcy), while tangential gas permeability is nearly the same after air drying (0.0007 darcy) and microwave drying (0.00067 darcy). Tangential gas permeability of alcohol dried fir sapwood is 0.82 darcy. The permeability values of microwave dried fir sapwood show greater homogeneity (lesser dissipation) than the permeability values of air dried sapwood. The ratio between tangential and longitudinal permeability of microwave dried fir sapwood is significantly 10 times smaller than the same ratio for air dried fir sapwood. This indicates a reduction in anisotropy which should be investigated in more detail on a larger sample and on more species of wood. Further investigation should be followed by an examination of wood samples with an electron microscope.

Key words: fir sapwood, permeability, microwave drying.

Sažetak

U ovom radu uspoređena je permeabilnost za zrak bjeljike jelovine osušene prirodno na zraku od sirova stanja do ispod točke zasićenosti vlakanaca s permeabilnošću bjeljike jelovine osušene mikrovalovima od sirova stanja do ispod točke zasićenosti vlakanaca, te s permeabilnošću bjeljike jelovine osušene prirodno nakon zamjene vode iz sirova drva alkholom. Ispitivanja su pokazala da mikrovalno osušena bjeljika jelovine ima 10 puta manju permeabilnost u uzdužnom smjeru (0.07 darcyja) od prirodno osušene bjeljike jelovine (0.77 darcyja), dok je permeabilnost u tangentnom smjeru jednaka nakon prirodnog (0.0007 darcyja) i mikrovalnog (0.00067 darcyja) sušenja, a nakon sušenja poslije konverzije vode alkholom permeabilnost u tangentnom smjeru je 0.82 darcyja. Vrijednosti permeabilnosti mikrovalno sušene bjeljike jelovine pokazuju veću homogenost (manje rasipanje) od vrijednosti permeabilnosti prirodno sušenoga drva. Omjer tangentne i uzdužne permeabilnosti mikrovalno sušene bjeljike jelovine pokazao se signifikantno 10 puta manji od istog omjera prirodno sušene bjeljike jelovine. To upućuje na smanjenje anizotropije, što bi trebalo ispitati detaljnije na većem uzorku i na više vrsta drava. Daljnja istraživanja morala bi biti popraćena pregledavanjem drva elektronskim mikroskopom.

Ključne riječi: bjeljika jelovine, permeabilnost, sušenje mikrovalovima.

1. INTRODUCTION
1. Uvod

Permeability is a measure of the ease with which a fluid flows through a porous material under the influence of a pressure gradient (17). The permeability of wood is one of its basic physical properties, and thus dependent on the structure of wood as well as on the variation of the structure within a tree.

Intervascular pits of tracheids are the most important structural feature determining the permeability of conifers including fir-wood. Fluids pass through cell lumens fairly easy, because those are relatively large micropores. The connection between these pores are the intervascular pits on their cell walls. The membranes of those pits consist of very small micropores. In conifer wood there are several types of bordered intervascular pits. Only the pits of Pinus-type, which are formed in the wood of the *Pinaceae* family, show completely developed tori built up of microfibrils in concentric order. Interspaces between tori microfibrils are filled with pectins and ligno-complex incrustations. The torus is impermeable to water and it is positioned in the middle of the elastic pit membrane. The pit membrane consists of microfibrils or bundles of microfibrils in radial order. In other families the tori are much smaller or are not developed at all and the pit membranes are built up of microfibrils in dense radial or reticular order (11).

In green sapwood, intervascular pit membranes with tori are in the central position, which enables the relatively easy transport of liquid from one tracheid to another. During drying and during formation of heartwood, the bordered pits are aspirated because of air penetration into tracheids. This process begins with the withdrawal of the capillary water from the pit chamber and continues with the formation of a meniscus between the air and water. The meniscus, due to surface tension, pulls the pit membrane towards one of the pit domes, and the torus closes the aperture (2, 6, 13). This process is irreversible because of the hydrogen bonds which are formed between the pit domes and the tori. Subsequently, the interface is incrusted with extractives. Pit aspiration results in decreased permeability of dried softwood.

There has been a large number of investigations examining ways of increasing the permeability of softwoods (e.g. 2,6,11,13,16,17,19).

There exist various processes for improving the permeability of softwoods:

- esterification
- drying of green wood by the replacement of water with organic solvents
- steaming
- extraction with hot water or organic liquids
- treatment of wood with synthetic enzymes
- treatment of wood with micro-organisms
- drying of frozen wood in vacuum.
- The latest attempts have been aimed at the deliberate destruction of aspirated pits by repeated cycles of wood steaming under pressure and then the quick reestablishment of normal atmospheric pressure, followed by drying of wood by radio frequency (RF) in vacuum (7).

Some of these treatments are not economical because special chemicals and/or plants are required. Others cannot be performed without ponding of logs in water.

Drying of materials in an electromagnetic field is based on dielectric properties of materials. The material is heated in an alternating electrical field by heat which originates in the material itself by the conversion of electromagnetic energy into heat. Electromagnetic waves cause vibration of molecules in the dielectric material and friction between molecules leads to the heating up of the material (21). During wood drying by electromagnetic waves, the temperature gradient is usually the opposite way round to that which occurs during natural and kiln drying (4,9,10,14).

It must be emphasised that the natural permeability of green wood is much greater than the permeability of wood at the fibre saturation point, since virtually all apertures are closed due to the loss of free water. A number of authors have studied the drying of wood by means of RF heating (4,5,9,10,14), but they have omitted to record the permeability of RF dried wood. At the same time the researchers that were engaged in problems of pit aspiration, used only natural drying after specific conversion treatments (2,12,19).

However, one can postulate that microwave drying, when comapred to natural and oven-drying to moisture contents at, or below, the fibre sturation point, can yield lower reduction in permeability. This is based on the following hypothesis:

1. By increasing the temperature of water close to the boiling point in the centre of the green sapwood a cloud of water vapour will be created which will push the surrounding water towards the surface of the wood. Surface tension of the water will decrease so that during its movement through the bordered pits the water will not pull the tori and the pits will remain permeable.

2. It is expected that in this short process not enough time will be allowed for the pits to plasticize. The bordered pits will probably not aspirate or at least the number of closed pits will be reduced.

An alternative hypothesis can be put forward:

1. The surface tension of water will be reduced, but not enough to avoid pit aspiration. Hence the pits will still be aspirated due to the water movement (flow). It is known that water creates hydrogen bonds between tori and borders and, in addition, it swells the wood. Those actions are, according to Thomas and Kringstad (19) two of the three most important reasons for pit aspiration.

2. The time of drying is short but the temperature is high and plasticization of pit membrane can occur. Under those circumstances the pits could aspirate even better and easier.

2. AIM OF RESEARCH
2. Zadatak rada

The aim of the research was to examine whether drying of fir sapwood by microwaves provokes changes in permeability and to compare that with the permeability of fir sapwood dried naturally or dried by replacement of the water by alcohol.

After drying, the longitudinal and tangential gas permeability was measured according to Siau (16).

3. MATERIAL AND METHODS
3. Materijal i metode

Material and methods
Materijal i metode

For this investigation three fir trees (*Abies alba*, Mill.) were selected from the Gorski kotar area in Croatia (continental climate, 700 m above the sea level). One 40-cm- long log was cut out immediately after felling from each of those three trees. Healthy and straight trees of comparable diameter and age were selected in order to reduce the influence of variation of wood structure within the tree on the permeability of wood. The logs were taken at the same height in each tree, i.e. 4 m from the stump.

In order to further reduce the variability of samples, the specimens for different drying methods were taken from matching positions.

For tangential permeability measurements 200 μm thick sections were preapred using a conventional sliding microtome. The number of sections for each drying method per tree totalled 50.

The dimensions of samples for longitudinal permeability measurements were 50 x 20 x 20 mm in longitudinal, radial and tangential direction respectively. A total of 100 samples was taken from each tree.

All samples for natural drying were dried in room conditions (60 +- 5 R.H., 20^o+-2^oC). Microwave drying was performed for approximately 2 hours in a conventional microwave oven with 560 W or 700 W energy output, aiming to keep the temperature constant at 90^oC +- 5^oC (363 K +- 5 K). The samples were dried to a moisture content between 20 and 25%, which is below the fibre saturation point in firwood (6). The moisture content was measured during drying and after drying with a conventional electric moisture meter on randomly selected samples.

The temperature in the samples during microwave drying was kept constant between 85 and 95^oC, and was controlled by means of a thermocouple positioned in the centre of a control sample.

Measurement and calculation of permeability
Mjerenje i proračun permeabilnosti

Dry samples were conditioned for 20 days in a room climate with an average air temperature of 24^oC (297 K) and an average relative humidity of 60%, which corresponds to approximately 11% equilibrium moisture content in the wood. After conditioning, tangential or longitudinal air permeability were measured by the falling-water displacement method according to Siau (16). The aparatus shown in figure 1 works on the principle of Darcy's law which relates the volume of gas (V) which passes through the cross section of the specimen (A) to the pressure gradient along the specimen (dP/dL).

$$k = \frac{VLP}{TA\Delta PP}$$

where:
k = permeability, cm^3(air)/(cm atm sec); V = volume of air flowing through specimen, (cm^3); L = length of specimen in direction of flow, cm; P = pressure at which volume V is measured, atm; t = time of flow, sec: A = cross-sectional area of specimen perpendicular to flow direction, cm^3; ΔP = pressure difference between upstream and downstream ends of specimen, atm; P' = average pressure in specimen, atm.

4. RESULTS AND DISCUSSION
4. Rezultati i diskusija

The results of measurements of tangential permeability of fir sapwood are presented in table 1, and the longitudinal permeability results are shown in table 2. The frequency histograms of permeability are shown in figures 2 and 3. The results presented in tables and figures indicate the following:

1. The average tangential air permeaiblity of air dried

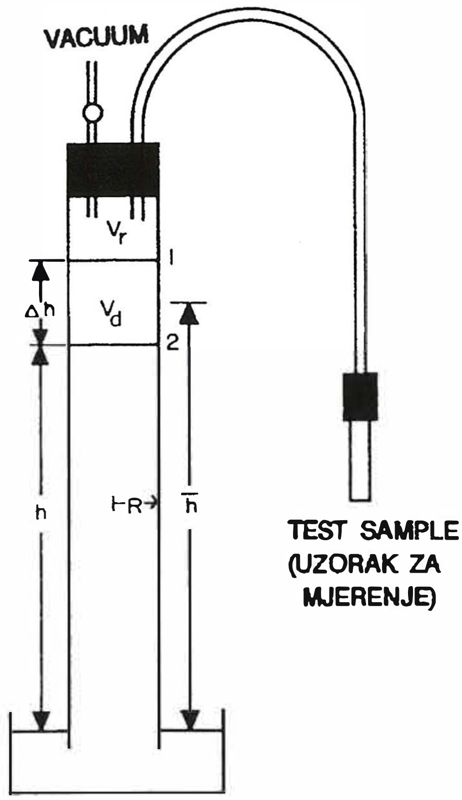

Figure 1: Diagram of the apparatus for permeability measurement.
Slika 1: Dijagram uređaja za mjerenje permeabilnosti.

fir sapwood dried from the green state to 10% moisture content is 0.0007 darcy.

2. The average tangential air permeability of microwave dried fir sapwood from the green state to 20% moisture content, and then conditioned to 10% moisture content is 0.00067 darcy.

3. The average tangtential air permeability of air dried fir sapwood after replacement of water in green wood with alcohol and then conditioned to 10% moisture content is 0.82 darcy.

4. The average longitudinal air permeability of fir sapwood dried naturally from green state to 10% moisture content is 0.77 darcy.

5. The average longitudinal air permeability of fir sapwood dried in microwave oven from green state to 20% moisture content, and then conditioned to 10% is 0.07 darcy.

6. The average tangential permeability of air dried sapwood after replacement of water with alcohol is about 1,200 times greater than the permeability of naturally and microwave dried wood.

7. The average longitudinal permeability of microwave dried sapwood is reduced 10 times when compared with longitudinal permeability of air dried sapwood.

8. The ratio between average tangential and longitudinal permeability of air dried sapwoods is 1:1100, and the same ratio for microwave dried sapwood is 1:100.

Values of tangential permeability
Vrijednosti tagentne permabilnosti

Table 1
Tablica 1

		Tangential permeability values - darcy (vrijednosti tangentne peremeabilnosti - darcy)			
drying method (način sušenja)	n	average (prosjek)	minimum	maximum	standard deviation
air (prirodno)	246	0.00070	0.00012	0.00036	0.00056
microwave (mikrovalno)	245	0.00067	0.00004	0.00387	0.00061
alcohol replacement (zamjena alkoholom)	279	0.82	0.29	2.41	0.44

Values of longitudinal permeability
Vrijednosti uzdužne permeabilnosti

Table 2
Tablica 2

		Longitudinal permeability values - darcy (vrijednosti uzdužne peremeabilnosti - darcy)			
drying method (način sušenja)	n	average (prosjek)	minimum	maximum	standard deviation
air (prirodno)	182	0.77	0.03	4.81	1.04
microwave (mikrovalno)	161	0.07	0.01	0.18	0.04

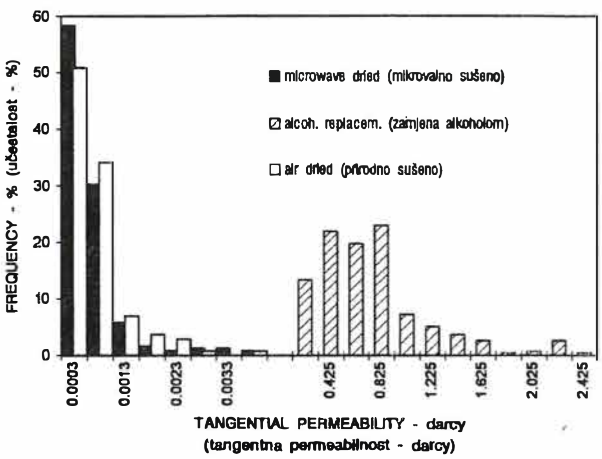

Figure 2: Frequency histograms of tangential permeability.
Slika 2: Histogrami učestalosti vrijednosti tangentne permeabilnosti.

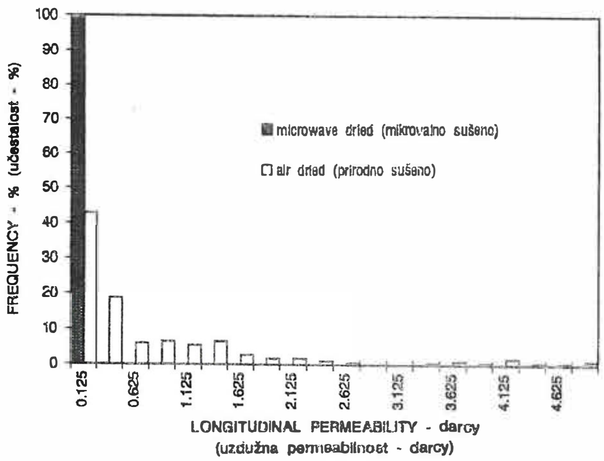

Figure 3: Frequency histograms of longitudinal permeability.
Slika 3: Histogrami učestalosti vrijednosti uzdužne permeabilnosti.

The results are in a way unexpected and we can only speculate about the possible reasons. The temperature during drying was around 90°C (363 K), and was not exceeded in the experiment because at higher temperatures checking, splitting and burning of the centre of the samples is much more likely to occur. Those negative effects were recorded even in this experiment, but only on a very small number of samples. It is probable that at this temperature the vapour cloud was not formed in the centre of the blocks for longitudinal permeability determination. Thus a liquid phase, apart from vapour, existed in blocks and caused pit aspiration.

The other reason for unexpectedly small longitudinal permeability of microwave dried wood could lie in the plasticization effect. It is already recognised that heating of wood in vacuum at a high temperature (between 93 °C and 160 °C) causes lignin flow and hemicellulose decomposition, which produces water-insoluble polymers (15). This method increases the dimensional stability but reduces the mechanical properties of wood. Šalamon (18) reports good prospects of microwave plasticization in the wood bending process. We can accordingly suppose that even at 90 °C some softening of pit membranes took place, enabling easier deformation and displacement of membranes from central position towards pit domes.

A further reason for small longitudinal permeability of microwave dried wood could be the blocking of pit membranes by dissolved and plasticized extractives, which were carried with water towards the surface. If we assume that thin wood sections used for tangential permeability measurements dry much faster than the blocks, we can explain the absence of the extractive blocking of pit membranes by a much faster rate of the process. This can account for the absence of any significant difference in tangential permeability of microwave and naturally dried sapwood.

Although the results are in a way unexpected it is most unlikely due to experimental technique. The measurement method applied on all samples was identical. The permeability values of air dried fir wood fit very well to compared data from literature (1,3,20), which contributes to impossibility of errors caused by measurement technique.

These assumption may be confirmed after an analysis with electron microscopy. Further evidence about the effects of microwave drying on wood shall be sought in the determination of mechanical properties and in the reduction in shrinkage an swelling.

5. CONCLUSIONS
5. Zaključak

Microwave drying of fir sapwood reduced longitudinal air permeability in comparison with air dried fir sapwood about 10 times, while tangential air permeability remained almost the same after microwave and air drying.

The permeability values of microwave dried fir sapwood show lower variability than the permeability values of air dried sapwood.

For wood preservation with chemicals, as well as for the glueing of wood, the latter conclusion might mean that more precise and more uniform consumption of chemicals and glues could be achieved by application of microwave drying.

The ratio between tangential and longitudinal permeability of microwave dried fir sapwood proved to be 10 times lower than the same ratio for air dried fir sapwood.

Additional evidence of the aspiration phenomena may be forthcoming from electron microscopy studies.

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