CHANGES IN SWELLING PROPERTIES AND MOISTURE UPTAKE RATE OF OIL-HEAT-TREATED POPLAR (*POPULUS* × *EURAMERICANA* CV. PANNÓNIA) WOOD

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In this work, the effect of oil heat treatment (OHT) on the swelling properties and changes in the rate of moisture uptake of poplar wood (*Populus* × *euramericana* cv. Pannónia) were investigated. Eighteen different treatments (combinations of three vegetable oils, two temperatures, and three durations) were studied. The results showed that OHT decreases the equilibrium moisture content (EMC) and the swelling of poplar wood. The degree of swelling and the EMC are influenced by both the duration and temperature of treatment. With an increase in duration and temperature, the EMC decreased. Consequently, the anti-swelling efficiency (ASE) increased. OHT wood adsorbs less moisture than natural wood, but it reaches a maximum – EMC at the momentary climate – at the same time under all the investigated treatments. The moisture uptake is fastest in the beginning and thereafter it slows significantly. Decreasing the moisture uptake by OHT wood is due to the decreasing of its water storage capacity.

Keywords: Wood modification; Poplar wood; ASE; Equilibrium moisture content, OHT, Moisture uptake rate

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INTRODUCTION

The aim of this research was to improve the dimension stability (ASE) of a Hungarian plantation timber species, namely Pannonia Poplar (*Populus* × *euramericana* cv. Pannonia) using a hot vegetable oil treatment (OHT). Pannonia Poplar has favourable material properties (air-dry density 406 kg/m^3, MOR 72 MPa, and MOE 7590 MPa), and has a high growth rate among cultivated poplars in Europe (Molnár and Bariska 2002; Komán and Fehér 2010). The thermal treatment of wood was a research topic long ago, and the processes were permanently optimized in different countries. The first trials by Tiemann (1920) have already showed that high temperature drying increases the dimensional stability, but targeted investigations only began later (Stamm and Hansen 1937; Burmester 1973, 1975; Giebeler 1983). Since that time, four different processes have been widely used in Europe. They are: ThermoWood – Finland, Plato wood – The Netherlands, Retification – France, and OHT (Menz Holz) Germany (Hill 2006). The most recent developments, new technologies, and production volumes were summarised by Hill (2011).

The characteristics of heat-treated woods' sorption behaviour usually include slower reaction to relative humidity changes than natural wood; therefore, the moisture uptake becomes lower and slower (Pfriem *et al.* 2007). Changes in sorption behaviour due to heat treatment are also strongly influenced, however, by the wood species. Despite the obvious differences between softwoods and hardwoods, the alteration of material properties between them can be similar (Kollmann and Fengel 1965; Kamdem *et al.* 2002). The phenomenon of modification is even more complicated, as all of the treatment parameters influence the sorption behaviour. Primarily, the alteration mechanism is dependent on the treatment medium, *e.g.* air, nitrogen, steam, or oil (Borrega and Karenlampi 2010; Edvardsen and Sandland 1999; Schneider and Rusche 1973). The moisture uptake rate can therefore be different after various treatments. The sorption hysteresis can also be observed in heat-treated wood. The difference between the adsorption and desorption curves does not change (Militz 2002).

A decrease in EMC results in an improvement in the dimensional stabilisation of wood. It is also affected by the process parameter. ASE increases as treatment time and temperature increase (Yun *et al.* 1999; Sailer *et al.* 2000), with temperature being the governing factor (Rezayati Charani *et al.* 2007; Akyildiz *et al.* 2009). Changes in EMC and ASE due to heat treatment are dependent on the wood species (Keith and Chang 1978; Militz 2002). Improvement in dimensional stability is different in the anatomical directions. The reduction in the tangential direction is more remarkable than in the radial direction (Militz 2002; Esteves *et al.* 2007, 2008). The results in literature also reveal that in spite of the remarkable reduction of swelling in the tangential direction, the swelling anisotropy does not disappear (Popper *et al.* 2005).

The main goal of this investigation, other than improving the dimension stability (ASE) of poplar wood, was to determine the influence of OHT on the moisture uptake rate of poplar wood. This is relevant because it not only allows for a decrease in EMC – which also results in improvement of dimensional stability – but is also important during the utilization. Further investigations showed that EMC of OHT wood decreases significantly depending on the used treatment type for all climates tested (Tjeerdsma *et al.* 1998; Kamdem *et al.* 2002; Epmeier *et al.* 2001; Bustos Avila *et al.* 2012). During the service life of a product, the surrounding climate is regularly changing, thus the EMC, and therefore the dimensions, are changing too. Short time exposure to extreme climates (either high or low relative humidity) will not result in pronounced dimensional changes if the moisture uptake is damped. The OHT is a promising method to reduce both the EMC and the moisture uptake rate and therefore investigations are necessary to prove the effect of the treatment on the water-related properties of poplar wood.

EXPERIMENTAL

Oil Heat Treatment (OHT)

Poplar (*Populus* × *euramericana* cv. Pannónia) wood was heat-treated in various vegetable oils. The dimensions of the treated samples were limited by the size of the experimental device to 18 × 40 × 220 mm^3 (TxRxL). Three different vegetable oils were used: sunflower, linseed, and rapeseed oil. The oil bath ensured the deficiency of oxygen during the treatment as the samples were immersed in the oil. The treatments were performed at two different temperatures, 160 °C and 200 °C, and three different time durations, 2h, 4h, and 6h, totalling 18 different treatment studies (oil, temperature, and duration combinations). Four samples (laths) with an initial moisture content of 12% were used for each schedule. The samples were placed directly in the hot oil bath without preheating. At the end of the OHT process, the samples were removed from the oil bath and were stored under standard conditions (T = 20°C, φ = 65%). Untreated and air-dried laths having the same dimensions served as the control.

Anti-Swelling Efficiency (ASE)

To determine swelling and ASE, 40×18×15 mm^3 (radial × tangential × longitudinal) samples were cut from the heat-treated laths; there were 20 pieces from all of the 18 treatment types investigated. Twenty pieces of untreated samples served as the control. The samples were dried at 105 °C until a constant mass, and then the dimensions were measured in the radial and tangential directions. Thereafter, the samples were stored under standard conditions (T = 20°C, φ = 65%) until obtaining a constant mass, and finally the dimensions were measured again in the radial and tangential directions.

Swelling was determined according to Eq. (1),

$$S_{r,t} = \frac{l_u - l_0}{l_0} \cdot 100 \ (\%) \tag{1}$$

where $S_{r,t}$ is the swelling, radial, or tangential (%), l_u is the dimension at EMC under standard conditions (mm), and l_0 is the dimension in the dry state (mm).

ASE was determined according to Eq. (2),

$$ASE_{r,t} = \frac{S_{0,r,t} - S_{OHT,r,t}}{S_{0,r,t}} \cdot 100 \ (\%) \tag{2}$$

where $ASE_{r,t}$ is the anti-swelling efficiency, radial, or tangential (%), $S_{0,r,t}$ is the swelling of untreated samples, radial or tangential (%), and $S_{OHT,r,t}$ is the swelling of OHT samples, radial or tangential (%).

Moisture Uptake Rate

To determine the moisture uptake rate, 40×18×15 mm^3 (radial × tangential × longitudinal) samples were cut from the oil heat-treated laths. There were 20 pieces from all of the 18 treatment types investigated. Twenty pieces of the untreated samples served as the control. The samples were dried at 105 °C until constant mass and then weighed. Thereafter, the samples were stored under standard conditions (T = 20 °C, φ = 65%) until reaching constant mass. To determine the moisture uptake rate the samples were weighed at assigned moments; namely, at 4, 8, 24, 48, 72, and 172 hours after placement in the climate chamber.

The moisture uptake rate was determined according to Eq. (3),

$$V_m = \frac{MC}{T} \quad \left(\frac{\%}{h}\right) \tag{3}$$

where V_m is the moisture uptake rate (% / h), *MC* is the moisture content (%), and *T* is the time (h).

RESULTS AND DISCUSSION

Anti-Swelling Efficiency (ASE)

No significant differences could be found to prove an effect of the vegetable oil's type on the investigated properties; therefore, only the results for the OHT in linseed oil are shown.

The dimensional stability of heat-treated poplar wood improved significantly (Fig. 1.) A reduction in swelling was already noticeable under the mildest treatment (160 °C/2h), decreasing 21% in the radial direction and 29% in the tangential direction. The longest treatment (6h) at 160 °C resulted in a 32% and 41% decrease in swelling in the radial and tangential directions, respectively.

Treatments at 200 °C had an even greater favourable effect on swelling properties. In this case, 2 hours of treatment decreased swelling by 29% and 39% in the radial and tangential directions, respectively.

The best dimensional stabilisation was obtained at 200 °C with 6 hours of treatment, as expected. This treatment resulted in a 39% decrease in the radial direction and a 46% decrease in the tangential direction.

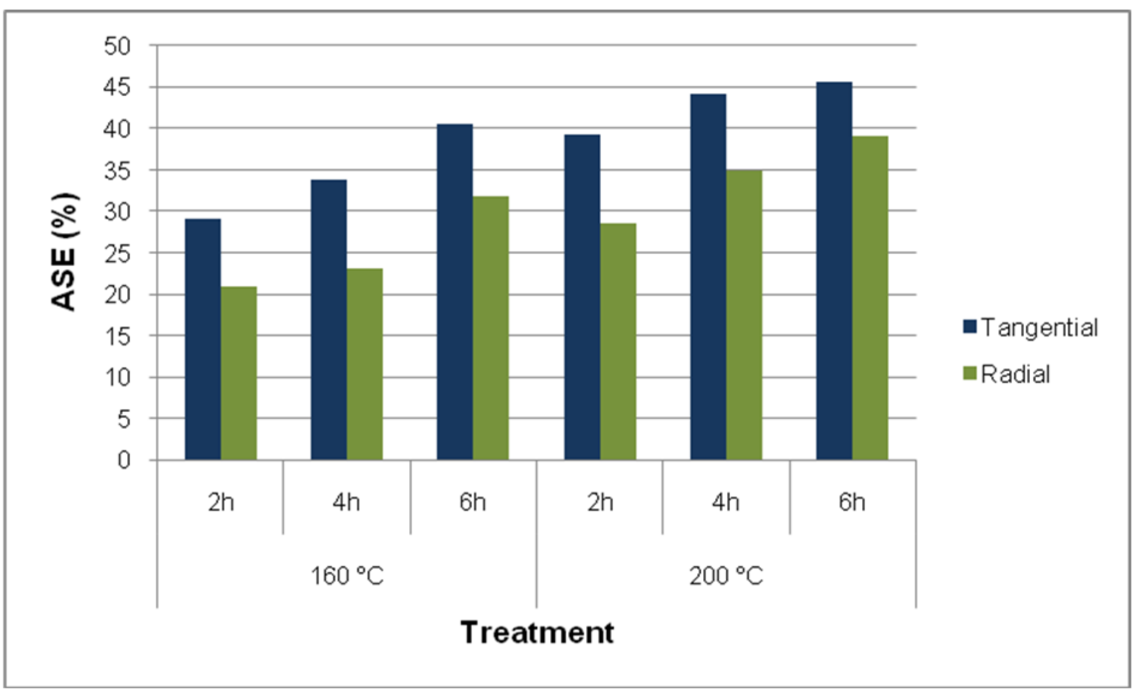

Fig. 1. ASE values after OHT in linseed oil (T= 20°C, φ= 65%)

Treatment at 160 °C and 6 hours resulted in better ASE values than treatment at 200 °C and 2 hours. This result shows that it is possible to reach the same results at a lower temperature, demonstrating that it is only necessary to select the correct treatment time. However, temperature is more important factor than treatment time. Rezayati Charani *et al.* (2007) and Akyildiz *et al.* (2009) reported similar results by other wood species and treatment methods.

According to earlier studies (Militz 2002; Esteves *et al.* 2007, 2008), the anti-swelling efficiency in the tangential direction was higher for all treatments. The difference between ASE values in the radial and tangential directions was observed between 7 and 11%, irrespective of the treatment time and temperature. This result shows that although the swelling anisotropy decreases, it will not disappear, supporting the earlier observation of Popper *et al.* (2005). The result that the difference between ASE values in the radial and tangential directions is constant by the several schedules shows, that the effect of treatment time is independent from the treatment temperature.

Equilibrium moisture content (EMC) of heat-treated poplar wood decreased significantly, which is strongly correlated with the improvement in dimensional stability. As also resulted in the anti-swelling efficiency, the treatment at 160 °C and 6 hours resulted in better EMC values than the treatment at 200 °C and 2 hours (Table 1).

Table 1. Equilibrium moisture content (EMC) values after OHT in linseed oil [%] (T = 20°C, φ = 65%)

Control	160 °C/2h	160 °C/4h	160 °C/6h	200 °C/2h	200 °C/4h	200 °C/6h
9.67	6.58	6.31	6.06	6.27	5.29	4.95

Moisture Uptake Rate

The moisture content of heat-treated specimens was lower at all of the investigated time intervals compared to the untreated wood. The lowest values were observed for treatments at 200 °C. The change in moisture content of oil heat-treated wood was similar to that of the untreated wood, as after 48 hours, the moisture content increased only slightly, and all specimens were close to the EMC (Fig. 2). Similar to the observation of Pfriem *et al.* (2007) by another heat treatment method it can be stated that OHT treatment reduces the moisture uptake rate because heat-treated samples adsorb less moisture during the same amount of time than untreated samples. But in spite of the mentioned authors, the saturation of the OHT and untreated wood specimens occurs in the same duration.

The moisture uptake rate values from the investigated periods of moisture uptake are shown in Fig. 3. The moisture uptake rate was the highest during the first 4 hours. In this period, the moisture content of the untreated wood increased 0.8 % per hour and that of the OHT samples increased between 0.43 and 0.65 % per hour.

During this time, the different effects of the treatment temperatures can still be separated well. The moisture uptake rate had already significantly decreased in the second 4-hour interval. The change in moisture content of the untreated wood was 0.5% per hour and between 0.21 and 0.30 % per hour for the OHT wood.

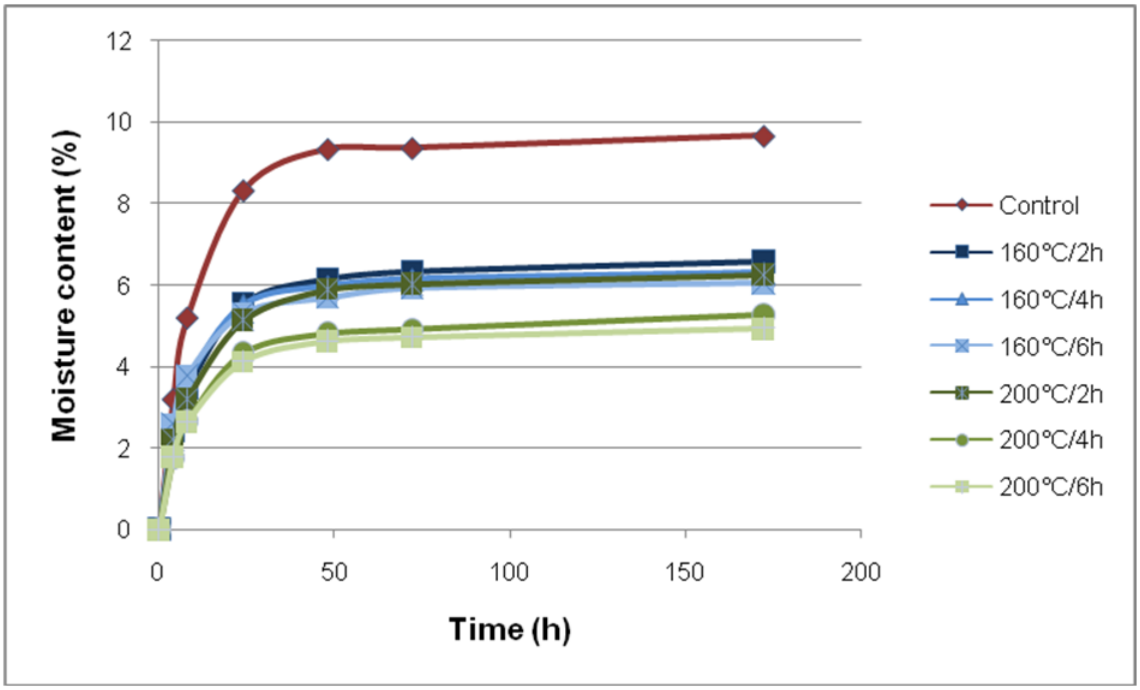

Fig. 2. Changes in moisture content of oil heat-treated and untreated poplar wood at normal climate (T = 20°C, φ = 65%) as a function of time (Treatment medium: linseed oil)

The difference between OHT and untreated wood increased in this interval. This is explained by the lower water storage capacity of heat-treated wood. This lower capacity runs out earlier in treated wood than in natural wood. The difference between the samples treated at different temperatures decreased, but the treatment at the higher temperature still resulted in a lower moisture uptake rate. At the end of the next 16-hour period, the moisture uptake rate was only half of that at the start of the interval. The moisture content of natural wood and OHT wood increased by 0.19 % per hour and between 0.9 and 0.13% per hour, respectively. The effect of treatment on the moisture uptake slowly diminishes as time passes. Over the next 24-hour interval, the moisture uptake of untreated wood was still higher (0.04% per hour), but the difference compared to OHT wood was small (0.02 to 0.03 % per hour). In the last period (near the EMC), moisture uptake was minimal, as there were not significant differences between untreated and OHT woods.

These results of investigating the first short period showed that the intensity of OHT wood's moisture uptake falls far behind that of the untreated wood; however, it is well known that the amount of sites which are able to adsorb bound water (-OH groups) decreases due to chemical changes during heat treatment (Hakkou *et al*. 2005; Repellin and Guyonnet 2005; Tjeerdsma and Militz 2005; Wikberg and Maunu 2004). The water storage capacity of the wood therefore decreases. Considering that saturation occurs during the same time by natural and heat-treated wood, it is revealed that a decrease in the moisture uptake rate in OHT wood is due to the decrease in water storage capacity.

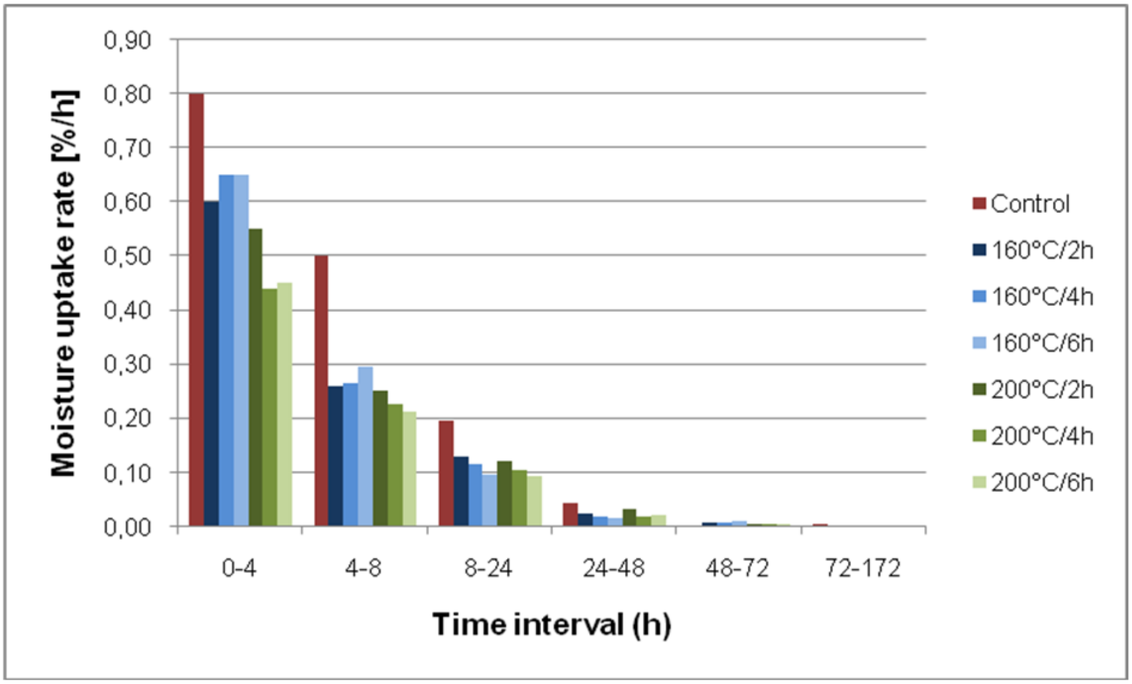

Fig. 3. Moisture uptake rates at normal climate (T = 20°C, φ = 65%) for the several investigated periods (Treatment medium: linseed oil)

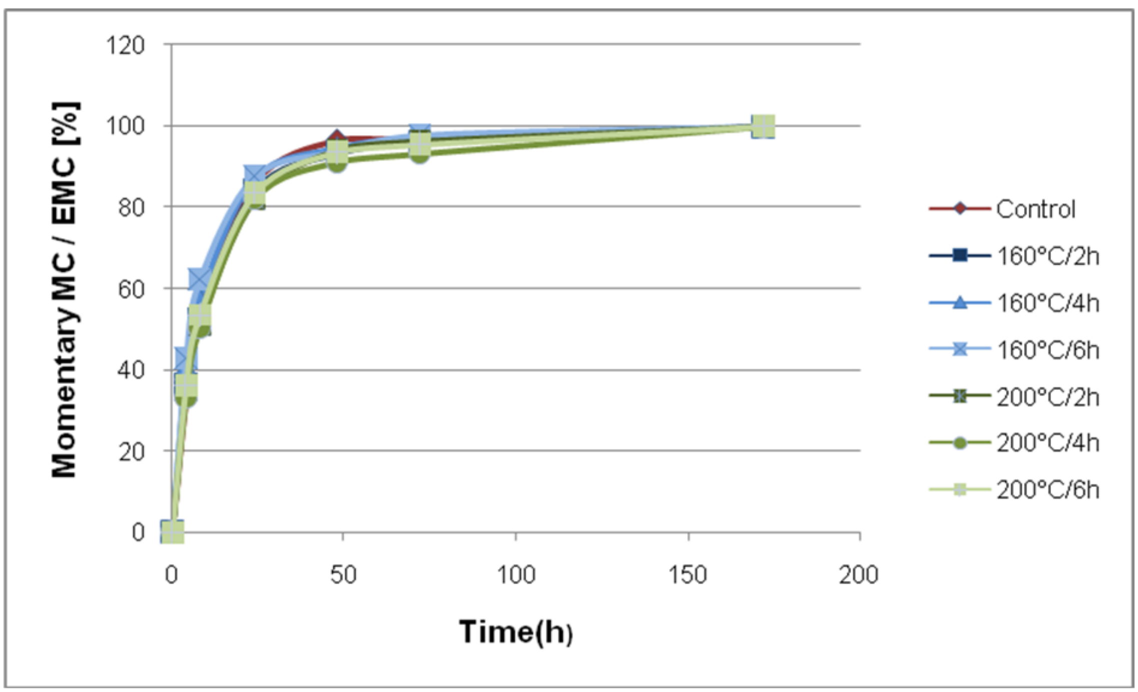

Fig. 4. Ratio of momentary moisture content and equilibrium moisture content at normal climate (T = 20°C, φ = 65%) as a function of time (Treatment medium: linseed oil)

However, a decrease in moisture uptake rate is only apparent. By dividing the reduced equilibrium moisture contents (due to OHT treatment) by the momentary moisture contents, no significant differences can be found between untreated and OHT samples at the investigated moments (Fig. 4). This result shows also that due to chemical changes during heat treatment, moisture uptake into the cell wall and the bonding of water molecules is not blocked, because all samples reached EMC nearly at the same time. The apparent decrease in moisture uptake rate is therefore due to the reduction in the amount of sites, which are able to bound water molecules. Namely, the water bonding capacity decreases, not the water binding capability.

Apart from that, under changing climatic conditions, the use of heat-treated wood is preferable. Also, due to this apparent decrease in moisture uptake rate, swelling/shrinking will be smaller in heat-treated wood compared to natural wood for the same time interval.

CONCLUSIONS

1. The equilibrium moisture content of OHT wood is lower than that of untreated wood. Moisture content is lower in OHT wood than in untreated wood throughout the moisture uptake process. The moisture uptake rate is therefore lower as well. The intensity of moisture uptake is greatest in the first period and decreases permanently, but in the process as a whole, it is smaller than that of heat-treated wood.
2. A decrease in moisture uptake rate was only apparent. Momentary moisture contents divided by the equilibrium moisture contents did not show significant differences between untreated and OHT samples at the investigated moments. The equilibrium moisture content was reached by all samples in the same amount of time; therefore the decreasing moisture uptake rate in OHT wood is due to the decrease in water storage capacity.
3. Heat treatment in vegetable oils improved the dimensional stability of poplar wood (*Populus* × *euramericana* cv. Pannonia) significantly. Heat treatment at 200°C was more effective, but it is possible to reach the same results at lower temperatures. It is only necessary to specify the correct treatment time. The effect of treatment time on ASE is independent from the treatment temperature.
4. The anti-swelling efficiency of the treatment was different in the tangential and radial directions. Swelling in the tangential direction decreased more than in the radial direction, but swelling anisotropy did not disappear.

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