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The activation energy of swelling sap of pine wood (*Pinus sylvestris* L.) in water

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Abstract: *The activation energy of swelling sap of pine wood (Pinus sylvestris L.) in water.* This paper shows the results of the activation energy of swelling sapwood of pine wood in water. The results showed that activation energy value range from 4.8 to 10.7 kJ/mol. It is also noted that its depend on the density.

Keywords: activation energy, swelling, sapwood, pine wood

INTRODUCTION

Understanding the interaction of wood with water is important to use properly this valuable material. Wood properties strongly depend on their moisture content and its changes. In particular, the great difficulties gives its wood deformation (Mantanis et al. 1994a and b, Berry and Roderick 2005). Wood deformation under changing moister contents are limited in hygroscopic range, the range in which the water molecules bind to the wood substance with physico-chemical forces. The binding of water molecules on the inner surface of the wood is conditioned by the quantity and availability of functional groups, especially hydroxyl groups. The water molecules are attached to the OH groups through hydrogen bonding. At the same time, almost in proportion to the amount of bound water, cell walls are swelling – microfibrils moves away from each other. This leads to a partial breakage of hydrogen bonds between them, and consequently, the creation of the new places able to adsorb more H_2O molecules. Wood swelling process continues until the attractive forces balance the water molecules with the cohesion forces between the chemical components. Rowell and Ellis (1984) observed that the swelling of wood in some organic compounds at higher temperature is drastically large in spite of that at room temperature wood almost didn`t swell. In turn West (1988) stated that the wood swells in quinoline in the same way as in the water, provided that the temperature is higher than room temperature. In another work Banks and West (1989) have shown that kinetics of wood swelling strongly depends on temperature, and this relationship is subordinated classical Arrhenius equation. The calculated activation energy of the process of pine wood swelling in pyridine, acetone, quinoline and pentanol was: 46; 48; 86 and 145 kJ/mol. Mantanis et al. (1994a), determined the activation energy of the wood swelling of spruce and sugar maple in water which was respectively 32.2 and 47.6 kJ/mol. In other work (Mantanis et al. 1994b) this value was determined for 40 other organic liquids. Results show that the swelling of wood in the tangential direction is strongly correlated with the molar volume and the molecular weight of the solvent. Energy of wood swelling increases with its density and compounds extraction.

As far as the authors know, there is no information on the activation energy of pine sapwood swelling in water. This paper presents results of marking the activation energy of swelling sapwood of pine (*Pinus sylvestris* L.) in water in correlation with the wood density.

MATERIALS

The experimental material used in this study was a unedged timber with a 60 mm thickness. It was seasoned by two years under the roof. Five planks were selected for the study. It`s sapwood characterized by differential ring width and contribution of latewood. Straight grain, defects-free planks were handling to 50 cm length. From sapwood part of those planks 50 x 50 mm samples were cut off. Then, samples were conditioned in the laboratory for two weeks. After this time period, the elements were cut to final dimensions using a planer – 25 x 25 mm. In this way, tangential and radial directions of wood were parallel to the edges. In next step, planks were cut in length. Samples were obtained to 25 (R) x 25 (T) x 10 (L) mm. Samples were properly described to permit their origin identification (from timber and planks). A scheme of preparation of the samples is shown in Figure 1.

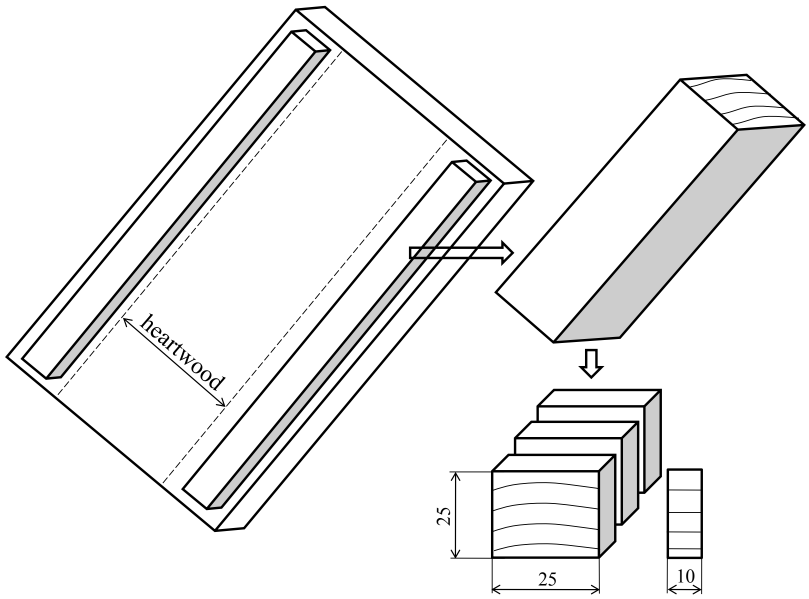

Figure 1. A scheme of preparation of the samples from the pine sapwood timber

The samples were then laboratory kiln dried at 103±2°C to completely dry condition. After the seasoning to room temperature, their linear dimensions (±0.001 mm) and their mass (±0.001 g) were measured. Density of each sample were calculated. For samples obtained from individual planks the macro-structural parameters of wood were also measured.

The method of determination kinetics of the wood swelling in water was similar to that used in the Mantanis'a et al. (1994a) work. This value was determine for the tangential direction. Samples were moistened in water with varying temperature: 20, 40, 60 and 80°C. KEST ELECTRONICS displacement meter with special software were used to measure kinetics of swelling. It allows for automatic registration of displacement inductive sensor in time with an accuracy of 0.001 mm. Moistening in water has been done on the triple water bath LWR RS-485. It allows maintaining the water temperature at the desired level during the experiment with accuracy of 0.5°C. The registration process of wood swelling continued until complete end of this process. 48 samples were measured.

RESULTS

Tested wood, which comes from different pieces of timber characterized by a diversity of macro-structural parameters (Table 1). Those parameters, and more precisely, contribution of latewood gives that density ranged from 420 to 515 kg/m^3. It should be noted that density for each plank were very similar, so the table shows average values.

Kinetics of the wood swelling in water with varying temperature is shown in Figure 2. Its shows only average initial swelling of wood in the tangential direction, calculated for the three samples in each case with a similar wood density of 515 kg/m^3. It shows that the kinetics of wood swelling, in the initial phase of the process to about 2 minutes (without induction period, first 0.5 minutes) is linear irrespective of the temperature of the process. Probably very high initial swelling kinetics of pine sapwood in the water is the results of the no information about the activation energy of wood swelling in the water. The initial value of the swelling rate of the tested samples are shown in Table 2. Their extreme value as a function of temperature of these process is illustrated in Figure 3.

Table 1. Macro-structural parameters and density of wood samples selected for study

Plank	Ring width [mm]			Average latewood percentage [%]	Density, ρ_0 [kg/m^3]
	minimum	average	maximum		
I	0.45	1.07	1.59	38.2	515
II	0.53	1.16	1.99	29.0	460
III	2.68	4.40	5.61	19.7	420
IV	0.63	1.40	2.22	30.8	510

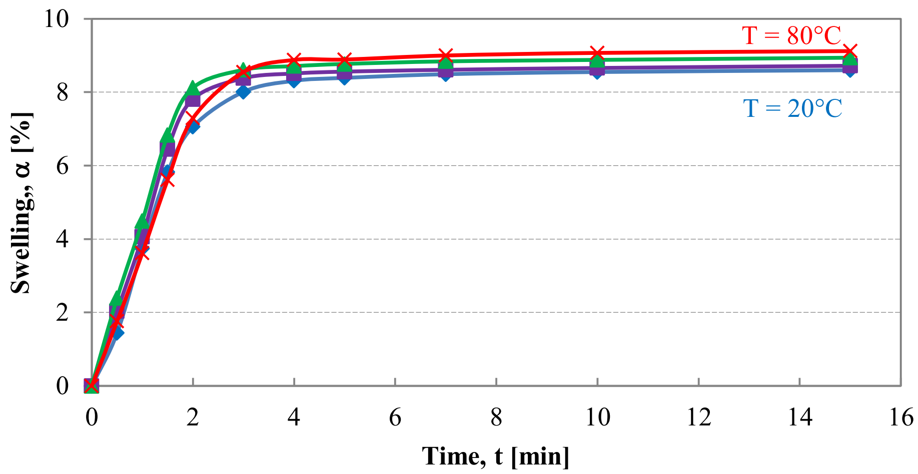

Figure 2. Initial period of wood swelling in the tangential direction for the pine samples with density of 515 kg/m^3

Table 2. The initial value of the swelling rate of the pine sapwood with varying temperature

Temperature, T [°C]	Initial value of the swelling rate [%/min]			
	I (515)*	II (460)*	III (420)*	IV (510)*
20	3.084	3.977	3.248	2.336
40	3.660	5.061	3.584	3.191
60	4.226	5.895	3.991	4.082
80	4.886	5.930	4.530	4.778

* plank number (density, ρ_0 [kg/m^3])

Table 2 data shows that the swelling rate in water of wood in the initial, linear range is not directly correlated with the wood density. Probably varied ultrastructure of cell walls in samples of different density can explain these. We have similar situation in the case of a maximum degree of swelling of the tested timber that value as a function of temperature (Figure 4). However, regardless of the density, the maximum value of the swelling in tangential direction increase linear with increasing temperature. The linear dependence of the natural logarithm of the initial swelling rate (ln k) as a function of the inverse absolute temperature (1/T) (shown in figure 5), allowed the calculation of the activation energy of wood swelling test samples:

$$k = Ae^{\frac{-E_A}{RT}}$$

where:
k – constant reaction rate,
A – coefficient,
E_A – activation energy [J/mol],
R – gas constant = 8.314 [J/(mol*K)],
T – temperature [K].

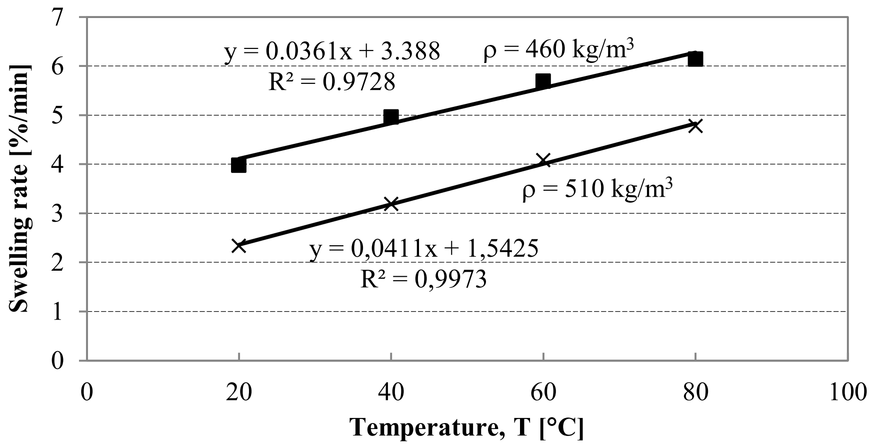

Figure 3. An example of the temperature influence on the initial swelling rate of the pine wood

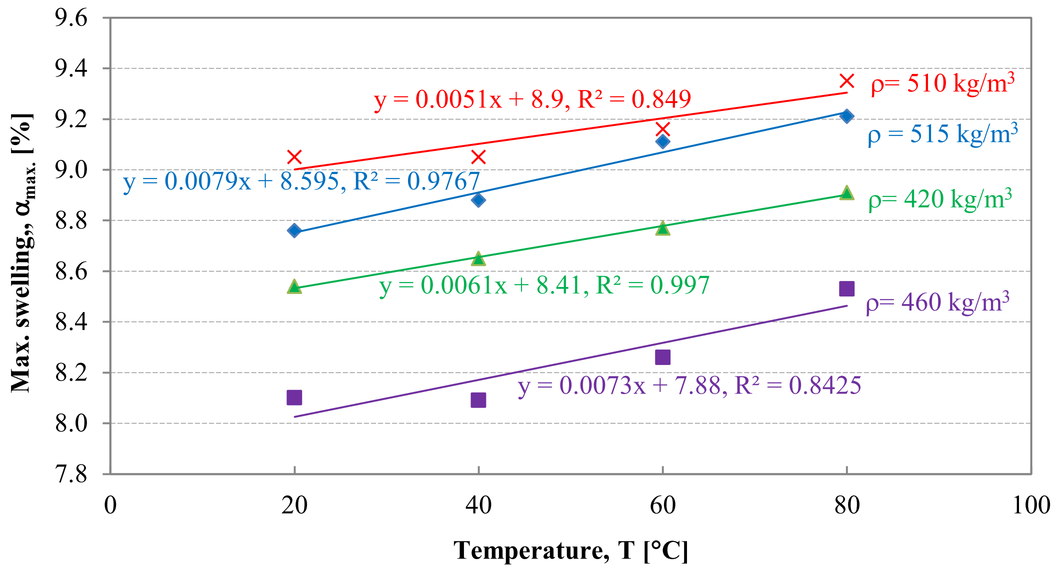

Figure 4. Maximum degree of pine sapwood swelling as a function of temperature

The calculated activation energy of the swelling sapwood of pine ranged from 4.82 to 10.74 kJ/mol. Its analysis showed that activation energy increase with increasing density. However, this correlation is characterized by a relatively low coefficient of determination (R^2 < 0.3).

This correlation, however, was characterized by a relatively low coefficient R^2 (< 0.3), which seems to be because a speed effect on the ultrastructure of swelling of the cell wall. This is probably again influence of the cell wall ultrastructure. It has been long known, that wood deformation under changing moister contents depends, among others, from the microfibril angle (MFA) in cell wall's S2 layer (Cave 1972; Anagnost et al. 2002; Lundgren 2004; Jordan et al. 2007; Fabisiak et al. 2008; Fabisiak and Moliński 2009; Rafsanjani et al. 2014). The results of this study suggest that more research are needed, especially with material with clearly differentiated ultrastructure (according normal, juvenile and compression wood).

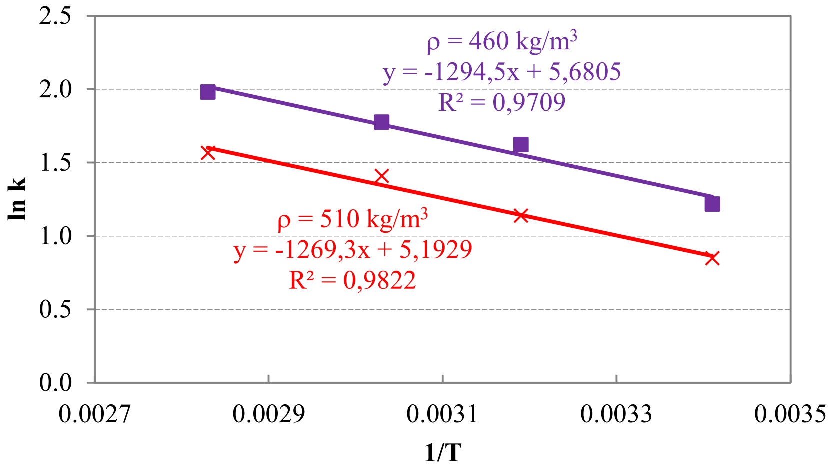

Figure 5. Dependence of the natural logarithm of the initial swelling rate of the pine sapwood (ln k) as a function of the inverse absolute temperature (1/T)

The activation energy of swelling sapwood of pine wood in water are much lower than those indicated by Mantanisa et al. (1994a) for Sitka spruce (32.2) and sugar maple (47.6 kJ/mol). Perhaps the lower values are the result of the lower. Its presence increases activation energy (Mantanis et al. 1994a and 1994b, Sahin 2007 and 2010). So it seems expedient to do a similar study in terms of content in the wood of the white pine compounds extraction.

CONCLUSIONS

On the grounds of the results, it can be concluded that:

1. During the increasing temperature of swelling pine sapwood in water, in the initial phase of process, swelling rate increases strongly but the maximum value of the swelling in tangential direction increases slightly.
2. The linear dependence of the natural logarithm of the initial swelling rate as a function of the temperature, allowed to calculate activation energy.
3. The activation energy of swelling sapwood of pine wood in water range from 4,8 to 10.7 kJ/mol.

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Streszczenie: *Energia aktywacji pęcznienia bielastego drewna sosny (Pinus sylvestris L.) w wodzie.* W pracy przedstawiono wyniki oznaczeń energii aktywacji procesu pęcznienia bielu drewna sosny zwyczajnej w wodzie. Uzyskane rezultaty wykazały, że wartość tej energii mieści się w przedziale od 4,8 do 10,7 kJ/mol i jest słabo zależna od gęstości drewna.

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