Structural diagram of mass transfer in larch wood during convective drying

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Abstract. The article provides a substantiation of the structural diagram of the moisture removal mechanism, which is similar to baromembrane process, from larch sawnwood during convective drying. The concept proposed is based on such provisions as the presence of a semipermeable membranes system in larch wood and the chemical activity of larch wood, which leads to the formation of a gas-vapor mixture in volumes many times exceeding the volume of the sample itself. As a result, mass transfer of an aqueous solution of extractives from the center of the board to the surface is observed. The passage of an aqueous solution of extractives through a system of semi-permeable membranes leads to the separation of the solution into concentrate and permeate. The change in the physical state of permeate leads to the formation of the layer that greatly reduces the intensity of the moisture removal from the wood. Then the entire duration of drying should be considered as the sum of two clearly marked periods - intensive and slow. The aim of the work is to substantiate the structural diagram of mass transfer in larch wood during convective drying.

Introduction.
The modern theory of the convective drying of larch lumber is based on such provisions as the presence of permanent micro channels in larch wood, in which there is a redistribution of moisture [8], which eliminates the possibility of overpressure formation in the wood in the low-temperature process. Then, by using certain thermodynamic relations the micro mechanism of moisture transfer in the wood during drying was developed [5] and advanced in many other works. It is assumed that the flux density of moisture is proportional to the gradient of moisture content and coefficient of hydraulic conductivity [5].

It is possible to agree with this approach only partly, because the Board sawn from larch logs is some substance of plant origin. Larch wood contains a significant amount of extractives, which are able to dissolve in different types of solvents, including water. The influence of extractives on the drying process in the modern theory is not taken into consideration. The presence of the system of semi-permeable membranes, which provides vital activity of the tree also influences the water transfer in wood [6], [9], which is not adequately reflected in the modern theory of wood drying.

Chemical activity of larch wood, which manifests itself with increasing temperature [1], promotes the formation of overpressure in the center of the Board. The above material indicates the need in revision of the structural diagram of moisture removal from larch wood during drying. Then the aim of the paper is to justify a structural diagram of a mass transfer in larch wood during convective drying.
Experiments.
To reproduce dynamics of the process of the overpressure action in the centre of larch sawngoods a number of experiments were carried out in a specially designed drying installation. The results of the experiments showed (figure 1, 2) that the whole process of larch sawn goods drying should be considered as the sum of two clearly marked periods - intensive and slow. The intensive period is characterized by relatively low values of overpressure \( p_{\text{excess}} \leq 20 \text{ kPa}, \) figure 1) and high specific drying speed \( G = 0.065 \text{ kg/(m}^2\text{h}) \). Similar results were obtained in the study of the permeability of the membrane system of pine wood.

![Figure 1. Overpressure \( p_c \) in the center of the Board at the temperature of drying agent in the initial period of drying \( t_c = 55^0\text{C}; 1 \)– temperature of drying agent; 2 – pressure in the center of the Board.](image1)

The slow period is characterized by increased pressure in the center of the Board \( p_{\text{excess}} \gg 20\text{kPa}, \) figure 1) with a relatively low index of specific drying rate \( G = 0.011 \text{ kg/(m}^2\text{h}) \).

A similar pattern is observed for other components of an aqueous solution.

![Figure 2. Kinetics of drying of larch lumber with 25x100 mm section: 1 – temperature; 2 – moisture content of wood; 3 – specific rate of drying.](image2)
Discussion.
At all variety of processes that occur in the larch wood during the drying process, the mass transfer of substances through non-porous membranes at the baromembrane process is of particular interest. The overpressure, which is pressurized into the cavity of the cell, equally creates the conditions of substances transfer both through cell walls and a membrane system of intercellular pores.

To analyze the conditions of transfer, the linear Darcy's law is used [7] as a product of power transfer in a particular area and the environmental resistance to the passage of the solution:

$$G = \frac{Ap \cdot \kappa}{x \cdot \mu}, \tag{1}$$

where $G$ - volume flow rate; $\kappa$ - permeability of environment; $\mu$ - dynamic viscosity of liquid or gas; $Ap$ - pressure drop across the length of the $x$ environment.

The equation (1) shows that the shorter the path of this solution, the higher the volumetric flow. For a given parameter the membrane, which is located in an intercellular bordered pore, is preferred.

The main steps of the transfer of the aqueous solution of arabinogalactan in the larch wood during convective drying can be represented in a structural diagram of membrane separation (figure 3). To ascertain the type of separation is not possible, since the degree of blockage of the extracellular pores by extractive substances varies widely. The molecular weight of arabinogalactan also varies widely (3000 ... 94000 [2], [3]). So, one can equally speak of ultra-filtration and microfiltration [7].

Direct transfer of the molecules of elements in the water solution through the membrane can be represented as the result of successive periodic jumping of the diffusing molecules from one equilibrium position to another [4]. The possibility of this approach to the movement of molecules in non-porous medium is justified by the heat motion of the molecules in the polymer at temperatures above its glass transition temperature when micro cavities are continuously appearing and disappearing. Then the diffusion of elements in the aqueous solution is due to the movement of molecules from one cavity to another in the presence of a concentration gradient.

![Figure 3. Structural diagram of mass transfer in larch wood during convective drying of sawngoods: 1 – pressure pump (overpressure); 2 – membrane apparatus (larch wood); 3 – semi-permeable (intercellular) membrane; 4 – throttle (wood temperature)](image)

Consequently, the formation of microcavities of a certain size is set by the temperature level, and their filling (substitution) depends on the shearing force generated by overpressure. Then, such property of the membrane as selectivity depends on the temperature of wood, which relates to one of the core components of an aqueous solution of extractives - arabinogalactan. As a result, larger molecules of arabinogalactan remain in the wood to form a concentrate, and smaller macromolecules...
with moisture and vapor-gas mixture are carried through the system of intercellular membranes (figure 5, step 3) onto the Board's surface, forming the permeate.

After a certain period of time on the surface of larch Board a layer of water-soluble substances is formed. The intensity of the formation will be larger, the higher the temperature level is in the drying chamber [1]. Therefore, on the surface of larch boards regardless of the temperature of drying the layer of water-soluble extractives is formed, and it sets the intensity of moisture removal from larch wood during drying.

The second period of drying is characterized by degradation of intercellular membranes with regard to moisture up to 8 ... 10 times regardless of the Board thickness, and temperature level as well. This effect is explained by the formation of permeate on the external side of the system of membranes. The presence of permeate on the surface of the Board is well observed visually in the form of spots (figure 4).

![Figure 4. Presence of extractives spots on the face of dried larch Board](image)

**Conclusions.**

1. In the larch wood during drying a baromembrane process is being formed, i.e. there is a transfer of the aqueous solution elements from the center of the Board onto the surface.

2. The passage of an aqueous solution of extractives through a system of semi-permeable membranes leads to separation of molecules of arabinogalactan into the major fractions - large and small. A large fraction (concentrate) remains in the center of the Board, and a small one is moved onto the Board's surface, forming the permeate.

3. On the surface of the Board there is a division of the solution into fractions. Then, the gas-vapor mixture and water are removed, and extractives will accumulate (permeate).

4. The layer of permeate formed in the initial period of drying greatly hinders the removal of moisture from the drying lumber. The effect of restraining removal is manifested until the end of the drying process.

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