KINETICS OF THE WOOD IMPREGNATION PROCESS. MODELING AND EXPERIMENT

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A physical and mathematical model of deep impregnation of wood by a fluid which allows for motion of the fluid and air in its porous structure is developed. The results of calculations of the kinetics of pressure-gradient impregnation of wood are reported. An experimental impregnation bench intended for investigations of different impregnation conditions and for measurements aimed at refinement of the impregnation parameters is described.

Introduction. Intensification of saturation of the free volume of porous bodies by a fluid under pressure is of interest in solving some scientific and engineering problems of wood processing [1], chemical technology [2], mechanical engineering, etc. The present work provides the results of an investigation of the process of deep impregnation of wood by liquid compositions (aqueous solutions, oils, melts, polymers) for the purpose of wood modification including imparting fire and bioprotection properties to it, improving its strength characteristics and resistance to the action of water, acids and alkali, changing its decorative quality, and preparation of fuel for catalytic combustion [3], sorbents, etc. from wood.

A wood sample represents an anisotropic capillary-porous body with a complicated texture. The complete description of the dynamics of impregnating fluid motion in wood due to a pressure gradient and, as a result, design of the governing parameters of the equipment and the impregnation technology encounter considerable difficulties. The latter are related, first of all, to the complicated internal structure of wood and to the choice of an adequate physicomathematical model of impregnation [4, 5].

The impregnation depth and fluid absorption by wood depend on a number of factors: pressure of an impregnating solution, the impregnation time, timber dimensions, the structural, physical, and chemical properties of the wood, the moisture content, the characteristics of the solutions used, impregnation conditions, and so on.

Proceeding from the general structure of wood as a capillary-porous structure, when investigating the process of fluid penetration into wood, the majority of investigators considered wood as a system of parallel capillaries [6, 7]. However, the results obtained and the physical models suggested were rough; they described satisfactorily only one-dimensional end-type timber impregnation of some species of hardwood having long water-conducting vessels. For softwood species such a calculation model leads to considerable discrepancies with experimental data.

In the present work we suggest a refined macroscopic physical and mathematical model of the process of wood impregnation, which phenomenologically allows for specific features of softwood structure, motion of gas and liquid phases, the presence of entrapped air, and the Zamain effect [8] on fluid absorption by wood.

Model. Softwood structure can be schematically presented as a system of tracheids connected by micropores (Fig. 1a). Correspondingly, the process of fluid motion in wood includes its flow along the tracheids and overflow through the pores connecting the neighboring tracheids.

Consider fluid motion in a system consisting of two tracheids connected with one pore (Fig. 1b). For steady flow
Fig. 1. Schematic of softwood structure: a) I is the cell walls, II is the pores; b) $x_1, x_2, x_p$ are the coordinates of the ends of tracheids and a pore, respectively.

\[ Q = \frac{(P_1 - P_2)}{R}, \]

where $Q$ is the bulk of the fluid flowing through the system per unit time; $P_1$ ($P_2$) is the fluid pressure at point 1 (2); $R$ is the hydraulic resistance of the section between points 1-2. It is obvious that the total hydraulic resistance is

\[ R = R_{1p} + R_p + R_{2p}, \]

where $R_{1p}$ ($R_{2p}$) is the resistance to fluid motion over section $x_1-x_p$ ($x_p-x_2$); $R_p$ is the hydraulic resistance of a pore. As in works [2, 6], we assume that for flow along a tracheid the Poiseuille formula is valid. Then

\[ R_{1p} = b (x_p - x_1), \quad R_{2p} = b (x_2 - x_p), \quad b = \frac{8\mu}{\pi r^4}, \]

and

\[ R = b (x_2 - x_1) + R_p = b \frac{l_1}{2} + R_p. \]

It can be assumed that if tracheids are connected by $N$ pores rather than by one pore, then formula (4) remains valid with replacement of $R_p$ by $R_p/N$:

\[ R = b \frac{l_1}{2} + R_p/N. \]

As regards the hydraulic resistance, a macroscopic wood sample with length $L_x$ and cross dimensions $L_y, L_z$ with fibers oriented along the sample can be considered as the sequence $n_x$ of successive layers consisting of $n_y n_z$ elements connected in parallel, each of which is described by formula (5). Since

\[ n_x = \frac{L_x}{l_1/2}, \quad n_y = \frac{L_y}{2r}, \quad n_z = \frac{L_z}{2r}, \]

then

\[ R_x^s = R \frac{n_x}{n_y n_z} = \left( b \frac{l_1}{2} + R_p/N \right) \frac{4r^2L_x}{L_y L_z l_1/2}. \]

In the transverse, relative to the tracheid axis, the direction of the wood resistance is attributed mainly to the resistance of pores. It is obvious that

\[ R_y^s \approx \frac{R_p}{N} \frac{n_y}{n_x n_z}, \quad R_z^s \approx \frac{R_p}{N} \frac{n_z}{n_x n_y}. \]