Algorithm of electrokinetic dehydration and final drying of valuable tree

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Abstract. The paper considers the issues of wood drying followed by huge energy consumption rates. It analyzes current traditional technologies of wood drying in order to identify the main disadvantages. The key idea of the study is the phenomenon of electric osmosis that makes it possible to extract liquid from the massif of wood. The technology shall significantly increase energy efficiency of wood drying due to energy saving thus reducing the costs of wood drying.

1. Introduction

Today wood is an important component of the consumer market and a unique construction and structural material. Wood drying is used everywhere these days. At the same time, this process is quite complex and the quality of drying is defined by the final moisture content and the nature of the process as such. A wide range of indicators may impact the process, including:

- timber species;
- initial wood moisture;
- drying time;
- quality requirements to a final product;
- drying efficiency;
- energy consumption.

Besides, it is critical to avoid the formation of microcracks and deformation in the final product [1, 8].

Review of traditional technologies. The current technology is based on long-term maintenance of fixed temperature and moisture in a drying chamber. As soon as the moisture of wood technologically falls to a certain level (transitional), the air parameters are changed. In this case, the psychrometric difference of characteristics and air temperature are substantially increased and maintained by constant parameters for a long time. There are from two to five changes of drying depending on the utilized mode.

A certain equilibrium moisture of wood, which is always below the current moisture, corresponds to specified air parameters. This causes the drying of the wood surface, which leads to reduction of its moisture. Such technology implies that moisture reduction of timber surface below the saturation threshold of wood fiber (which corresponds to 30%) leads to wastage of timber surface and thus triggers tension stresses.
If to continue drying, the surface tension stresses described above increase, which may lead to excessive strength limit and formation of surface cracks. Definitely it is critical to avoid cracks since it will be regarded as a drying defect.

Heat and moisture treatment (HMT) of wood is regularly conducted to avoid the above. It involves the creation of high air moisture in a drying chamber thus moistening the timber surface.

HMT duration is defined by a drying operator or is implied by a drying program. Drying chambers have a moistening unit: a water sprinkler or a pipe for moisturizing steam inlet. Such damping unit increases the cost of construction and maintenance of a drying chamber.

The above makes it possible to highlight some disadvantages of the current process:
- surface heating of wood leading to internal stresses in the structure thus causing cracks;
- considerable energy resources.

Electroosmotic phenomenon. Electric osmosis makes mobile counter-ions move towards the relevant source of a current pole together with liquid due to nonequivalence of phase charges [3]. Electroosmotic transfer of liquid through a pore space of a capillary and porous body is defined by electokinetic potential and the structure of a double electric layer of phase boundary.

The effort for substance fragmentation for bond rupture between molecules is accumulated in the form of potential energy of unsaturated bonds on phase boundary. In case of enormous surface area this excessive surface energy reaches big values. Thus, the substance in a colloidal state has bigger energy and activity than unfragmented substance having the same composition [4].

At the same time the double electric layer (DEL) is considered the main reason for electokinetic energy and mass transfer. In electrically conductive dispersion medium ions mainly of one sign are absorbed around a dispersed particle of dielectric material on unloaded surfaces due to disperse forces caused by fluctuation of electron shells of atoms.

The above-mentioned forces (specific adsorption forces) depend on polarization, in other words, on the impact of this ion on atoms being on a surface, and its ability to deform their electron shells. It shall be noted that the polarizing force of an ion depends on the stress of its electric field [5].

Thus established equilibrium distribution forms a “cloud” of electric charges with decreasing density near the interface, similar to distribution of gas density in the atmosphere. The counter-ions of DEL diffusion layer in the electric field and energetically loosely coupled with a surface of a solid phase (membrane) will move to the corresponding electrode and due to molecular friction will to entrain a dispersion medium (water solution of electrolytes).

Thus, the dependence of electric field strength and thickness of a diffusion layer is formed from charge carriers. The more their quantity, the faster the movement of liquid in a porous body of wood in a conductive dispersion medium [7].

It is supposed that the mass transfer via electroosmosis excludes heating of wood and drying structures, which shall improve efficiency and reduce energy consumption for wood preparation in relation to traditional methods of drying.

2. Results

It was decided to develop a phenomenological model in order to form the corresponding method.

\[ w = f(B_0, \tau, c, E) \]  

where \( B_0 \) – initial wood moisture, %; \( \tau \) – power pulse duration, h; \( E \) – electric field strength, \( V/m \); \( c \) – relative pulse duration.

The range of control factors is chosen within the following limits:

\( B_0 = 11 \ldots 35\% \); \( \tau = 1 \ldots 5 \) hours; \( E = 20 \ldots 500 \) V/m; \( c = 4 \ldots 6 \)

The following factors are chosen as uncontrollable:

\( B_i \) – air humidity, %;
\( \rho_w \) – wood density, kg/m\textsuperscript{3};
\( T_{\text{air}} \) – air temperature, °C.
The choice of design data was caused by the variation requirement of experimental parameters, such as:

- initial and current moisture;
- electric field strength;
- relative duration of electric impulses;
- etc.

The main methods used to register initial parameters for the analysis are as follows:

- measurement of electric field;
- measurement of initial moisture of wood;
- definition of relative duration of electric impulses.

Standard methods of analysis allow studying the impact of each factor on optimization criterion separately, at the same time one of the factors is varied, while the others shall remain invariable.

The research procedure implies the measurement of specific energy consumption for water release from wood via electroosmosis by fixing energy consumption and moisture liberation on a unit consisting of power supply, electrodes connected to a wood pile on dielectric boards. Electrodes represent lattices, in the nodes of which and perpendicular to them there are contact needles implanted in wood. Besides, the experimental unit is equipped with devices to measure power consumption. For the purposes of experiments it is supposed to mount a unit for electroosmotic dehydration of timber.

Throughout treatment the moisture of external layers of wood will be shifted beyond the threshold of fiber saturation point and they will begin to dry out, and in internal layers, which moisture is 30% higher, the shrinkage will not happen yet, then the external layers will be in a condition of undershrinkage and will be stretched, while the internal layers – compressed. This means that there are stresses in wood. Drying of wood happens so that in zones adjacent to assortment surfaces the humidity is much lower than in internal zones. This is the main reason for internal stresses. Internal stresses are formed without external loads only as a result of heterogeneous changes of volume and are counterbalanced within a given body. It is convenient to consider full internal stresses in wood as a combination of two components – moisture and residual stress. The moisture stress is caused by non-uniform shrinkage of a material. This component of full stresses is caused by the restraint of free shrinkage and disappears at moisture levelling when each site of assortment has an opportunity to accept the volume corresponding to its moisture.

Residual stress is caused by inhomogeneous permanent deformation of wood. Unlike moisture deformation it does not disappear at moisture levelling and is observed both during drying and after its full completion. Signs of moisture and residual stress are opposite and the resultant full stress represents the algebraic sum. During the first cycle of drying the moisture stresses are more than residual, and full stresses having a sign of a bigger component appear as stretching assortment near the surface and as squeezing – inside it. During the second cycle the residual stresses exceeds moisture stresses and the resulting stresses change the sign.

If the stretching stresses reach the threshold of wood yield strength across fibers, cracks are formed. Thus, surface cracks are formed at the beginning of drying and internal cracks (knot holes) – at the end of drying.

Internal stresses remaining in dried material (residual stresses) may cause changes of the set form of parts during wood machining. Quantitative characteristic of internal stresses can be found by the following method: two sections with the thickness (by fiber) of approximately 15 mm from a board covering the entire section are cut at a distance of 0.3 m from an end face. After conditioning within 1-2 days for moisture levelling one of the sections is split parallel to length into layers 4 mm thick. Change of their sizes is defined by measuring the length of these layers before and after cutting and the size of relative deformation of each layer is found. The second section is sawn into layers 8-10 mm thick; the received bars with direction of fibers perpendicular to their length are used to define the elasticity.
modulus (at static bending with loading in two points). Based on received values of relative deformation \( \varepsilon \) and the elasticity modulus E stresses are calculated for each layer according to the formula.

The stress distribution curve (diagram) by board thickness is build following the obtained data. The residual stress after chamber drying is much higher than after atmospheric. With some complications the described method can also be applied to measure internal stresses in wood during atmospheric drying and by the end of chamber drying.

Usual drying using chamber drying technology includes the following operations:
1) Initial heating
2) Drying following a particular mode
3) Intermediate moisture and heat treatment
4) Final moisture and heat treatment
5) Conditioning
6) Cooling

The conducted analysis and experimental works on electroosmotic drying showed that the number of operations similar to the cost of such treatment is significantly reduced.

3. Conclusion
The current wood drying systems are not perfect. They imply huge energy and water consumption. Besides, in case an operator makes a mistake, this may lead to cracks in finished goods thus causing direct financial losses. The drying unit of a new generation on the basis of electric osmosis is intended to minimize or to nullify the above difficulties and at the same time to reduce energy consumption. The technology described above can be applied to modify the existing wood drying units at enterprises.

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