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OPTIMIZATION OF THE DRYING FACTORS

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ABSTRACT
In order to improve Kollmann's analytical formula for calculating the duration of the process of convective drying done experimental research thermodynamic factors of the drying process under real conditions. Based on the experiment is defined by a mathematical model of the influence of temperature, humidity and velocity of air in the dryer on the drying of beech planks 32 mm thick, and the method of linear programming optimal proportions of the same.
Keywords: experiment, model parameters, optimization, temperature, humidity, air velocity.

1. INTRODUCTION

Wood is hygroscopic, anisotropic and orthotropic material that makes it special in operation, compared with other conventional materials. Drying of wood as an isotropic material difficult by the fact that the coefficients which determine the thermo-physical properties of wood are not constant in size, but depend on the direction of extension of grain. Variability drying conditions (temperature, relative humidity and air velocity) and their dependence on the characteristics, condition, dimensions and the final exploitation of wood prevents finding an adequate mathematical model of impact velocity and duration of drying for all cases and all types of wood. Although the theory of heat and mass transfer in drying wood, as well as physical processes have long known, with the emergence of numerical analysis and development of computer techniques open the possibility of finding not just a one-dimensional, but two-dimensional problem of heat transfer.

According to data that can be found in the literature, the general regime of drying connect the relative humidity and temperature of drying a certain type and thickness of the wood. However, the influence of relative humidity on the drying rate is not sufficiently explored. The importance of air velocity, as an influential parameter has not been completely established.

This paper modeled the drying process parameters: temperature, relative humidity and air velocity of air in the chamber where the dried beech lumber thickness 32 mm, average humidity over 40%, the final transport humidity. Based on the obtained mathematical model of the same optimization was performed to determine the optimum drying time for the given conditions.

2. DEFINING THE ISSUES AND CASE STUDIES

Based on theoretical calculation of drying time by Kollmann:

$$z = \frac{1}{\alpha}(\ln u_p - \ln u_k)\left(\frac{d}{25}\right)^{1,25}\left(\frac{65}{t}\right) \quad (1)$$

where:

$\left(\frac{d}{25}\right)^{1,25}$ - effect of thickness on the duration of drying,

$\left(\frac{65}{t}\right)$ - effect of air temperature on the duration of drying,

α - constant drying,

u_p - initial moisture content of wood,

u_k - final moisture content of wood.

The coefficient α is a constant which depends on the conditions of the drying chamber, which are not adequately tested and determined. It is a constant for constant thickness and bulk density of wood, and the constant drying conditions. So far, α by a computer equation (2.1), when other sizes are known. This information as such is still used in the theory and practice, for a specific type of wood and other conditions of drying. In Kollmann's formula (2.1) there is no humidity, no air flow velocity in the dryer. Account only the mean temperature, although the temperature increases from start to finish drying. It is therefore this formula is applicable only for the approximate calculation that meets in practice.
The aim of the research is to model the drying of wood with the aim of optimizing the process parameters, their impact in the chamber of which depends on the constant α in Kollmann's formula for calculating the time of drying. The variables of the drying process are temperature, relative humidity and velocity of air in the dryer. Define the optimal drying process would be improved Kollmann formula for the duration of the drying process.

3. PLANNING EXPERIMENT

The aim of experimental research to investigate the influence of drying parameters: temperature, relative humidity and air velocity during artificial drying of beech lumber thickness 32 mm, and the analysis of experimental data from the standpoint of the potential of achieving high-speed drying, and shorter duration of the drying process, while at the without compromising the quality of dried materials and reduce overall production costs. The purpose of the experiment plan is to generate mathematical models and equations (polynomial of second degree), which describes the process. If studied parameters in the experiment actually the ones who influence the process and the data obtained by experiment acceptable accuracy and precision, it is possible to develop a model that describes the process credible.
Beech lumber is dried in a conventional dryer assembly capacity of 20 m^3, which is equipped with an automatic device for keeping the drying process, supported by computer. Drying is equipped with functional elements for the maintenance and measurement of study parameters drying temperature (T), the equilibrium humidity (u_r) and currently wood moisture (u_m), which were duly recorded and stored in the memory device. To measure the comparative analysis of the actual size of the tested parameters in the dryer was used to mini data logger with 4 external channels Hobo H8-ext, which with the help of a temperature sensor TMC-20HD, hygro adapter PCE-HA-702 adapter and anemometer PCE-AM-402 was measured temperature, relative humidity and velocity of air in the chamber. The device is equipped with software Boxcar 4.3 for parameterization logger, reading the data, graphing, and the possibility of comparing several parameters in one graphic. Measurements were performed every hour during the drying process. Sensors were placed in the chamber, and through flexible cables connected to the data logger outside the dryer.
The following parameters were investigated drying on five levels:

- Temperature T = 32°, 35°; 40°; 45° and 48 °C
- Relative humidity φ = 42, 45, 50, 55 and 58%
- Air velocity w = 1.1, 1.3, 1.6, 1.9 and 2.1 [m/s]

The total number of trials in this experiment was determined with three independently variable size. Physical and coded values of the parameters of the process of convective drying of wood varied in five levels. The total number of tests:

$$N = 2^k + n_\alpha + n_0 = 2^k + 2k + n_0 = 2^3 + 2 \cdot 3 + 6 = 20 \text{ tests} \qquad (2)$$

where:

$k = 3$ – variable number of variables,

$n_\alpha = 2k$ – number of points placed symmetrically around the center of the plan,

$n_0 = 6$ – number of repetitions in the central point plan.

Experimental results show the following diagram:

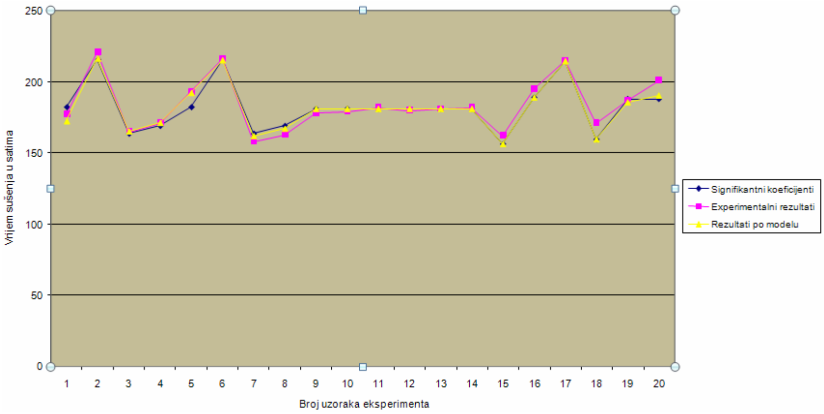

Figure 1. Experimental results

4. MATHEMATICAL MODELING

In this paper we applied stochastic modeling, with application of active experimental research on a real object, the convective dryer with intelligent control of drying wood. Pre-plan the experiment was performed, i.e., varying input parameters of the experiment in the appropriate limits of variation. Used the regression analysis that determined the functional relationship between the dependent variable in size y (drying time) and independent variables x_i (temperature, relative humidity and air velocity dryers). This connection can be presented as a function of regression:

$$y = f(x_i) \qquad (3)$$

Table 1. Analysis of the adequacy of the mathematical model

Varijansa	Stepen slobode f_i	Zbir kvadrata S_i	Procjena varijance $s_0^2 = \frac{S_0}{f_0}$	Izračunati odnos $F_a = \frac{S_a^2}{S_0^2}$	Tablična vrijednost $F_t(f_a, f_0)$
Rezidualni broj	$f_R = N - \frac{0,5(k+1)(k+2)}{2}$ $f_R = 10$	$S_R = \sum_{i=1}^{N}(y_i^E - y_i^R$ $S_R = 630,80$	-	-	-
Greška pokusa	$f_0 = n_0 - 1$ $f_0 = 5$	$S_0 = \sum_{i=1}^{n_0}(y_{0i} - \bar{y}_0$ $S_0 = 13,33$	$S_0^2 = 2,67$	-	-
Adekvatnost modela	$f_a = N - 0,5(k+1)(k+2) - f_0 = 5$ ili $f_a = N - k' - f_0 = 20 - 7 - 5 = 8$	$S_a = S_R - S_0$ $S_a = 617,47$	$S_a^2 = 123,49$ ili $S_a^2 = 77,18$	$F_a = 9,26$ ili $F_a = 5,79$	$F_t(5,5) = 11,0$ ili $F_t(8,5) = 10,30$
Koeficijent višestruke regresije		0,949			
Koeficijent determinacije		0,901			

Modeling the drying process of wood made a mathematical model-tick higher order because of the previous theoretical analysis known that the drying time can represent a linear function. Was used to model the second order, and modeling was performed using rotatable plan that is often applied in the processes with multiple variables. After calculating the regression coefficients and their test of significance was obtained by a mathematical model examined the influence of drying parameters on the duration of the process formalized in the form:

$$z = z_{(t,\varphi w)=} (-203{,}37-0{,}28t\varphi)-t(0{,}12t-25{,}53)+\varphi(0{,}08\varphi-0{,}53)+w(27{,}39w-87{,}68) \quad (4)$$

5. OPTIMIZATION PROCESS

The optimization procedure is expressed mathematically as requiring minimum or maximum objective function. Generally, the objective function is a scalar function F with one or more parameters x_i, depending on how many variables are considered during the process of optimizing the model. In optimization mode processing starts from a mathematical model that describes the process. Set the appropriate criteria for the optimization and requires a combination of processing elements in the field of possible solutions to the corresponding objective function given the extreme value (minimum or maximum).

The paper used the method of nonlinear programming with constraints, direct search, given that the objective function is not linear but quadratic with iterations between variables. The objective function (four) set a condition:

$$F_{cilja} = y(x_1, x_2, x_3) = z_3(t, \varphi, w) \quad (5)$$

and the following limitations:

$$32{,}0 \le t \le 48{,}0\,;\ 42{,}0 \le \varphi \le 58{,}0\,;\ 1{,}10 \le w \le 2{,}10$$

The programming language C + + program was developed to search the minimum objective function with the step:

for t: $t = t+0{,}1$; for φ: $\varphi = \varphi+0{,}1$; for w: $w = w+0{,}01$.

Limitations are provide in the final points of the interval of modeling parameters: t, φ w, and the results of several ten thousand combinations of these three parameters were obtained minimum value of objective function and the parameters t, φ in w in the minimum point of objective function:

$$F_{cilja} = z(t, \varphi, w) = 134{,}282 = F_{\min}$$

respectively:

$$t = 47{,}9998\ {}^0C\,;\ \ \varphi = 57{,}9998\ \%\,;\ \ w = 1{,}60\ m/s$$

6. CONCLUSION

Application of the results obtained in the process of convective drying of wood, and Kollmann improved formula of the form:

$$z = z_{opt} \cdot (\ln u_p - \ln u_k) \cdot \left(\frac{d}{25}\right)^{1{,}25}$$

gives the possibility of more accurate calculation of drying time of beech wood. Justification of enhanced Kollmann formula in the calculation of the duration of drying of beech compared to analytical calculations of drying time is as follows:

- An improved model is essentially real as defined in realistic conditions of drying.
- Coefficient of multiple regression R = 0.949 shows a good enough interdependence factors drying mathematical model, which means that the mathematical model is sufficiently accurate and reliable is described during the drying process.
- The value of the coefficient of determination R2 = 0.901 means that 90.1% of variability attributed to action variables (Xi) on the duration of drying wood.

7. REFERENCES

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