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INVESTIGATION OF CONVECTIVE DRYING CHARACTERISTICS AND SPECIFIC ENERGY CONSUMPTION OF APRICOT AND APPLE TREE DISCS

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Abstract: *The aim of this work was to investigate the drying characteristics and specific energy consumption during convective drying of apricot and apple tree. The measurements were performed in an experimental dryer with disk-shaped wood samples of 20 mm thickness at the temperatures of 40, 50, 60 and 70 °C. The velocity of the air during all experiments was set to be 2 m/s. Overall 8 experiments were performed – 4 with each tree type. Drying time and equilibrium moisture content were determined for each experiment. Analysis of drying curves showed that the increase in drying temperature decreases drying time. Based on the results of drying time, air temperature and velocity the specific energy consumption for drying of apricot and apple samples was determined and analysed. Short abstract (Style Abstract: 9 pt, italic, pt, justified, 0.75 pt left and right indentation).*

Key words: *apricot tree, apple tree, thin discs, drying kinetics, specific energy consumption, equilibrium moisture content*

1. INTRODUCTION

In modern technological processes the emphasis is on the energy efficiency and rational use of energy in all industry sectors. One of the industrial sectors with highest energy consumption is certainly drying sector. Drying is one of the energy most demanding processes overall, especially in wood processing industry where the majority of energy is consumed for drying. Therefore, the energy consumption of wood drying is a paramount when assessing the economic value of the dried wood products. Drying is a critical step in wood processing, since a high energy is required to evaporate water [1]. In conventional kiln dryers the energy consumption for wood drying ranges from 600 (2160) to 1000 (3600) kWh/m^3 depending on wood type and thickness. This energy accounts for 50-70% of the total needed energy for wood processing, which is agreement with other reports on energy consumption for wood drying [The CIPEC survey]. According to [The CIPEC survey] on average, softwood lumber production consumes 1514 Megajoules of energy per cubic meter of lumber produced (MJ/m^3). Of this total, drying consumes 1000 MJ/m^3 which is round 2/3 of total energy consumption. For solar drying consumption is a little bit lower round 915 MJ/m^3 [2]. In [3] the specific consumption ranged from 1.15 – 4 kWh/kg 4.14-14.4 MJ/kg, i.e. 2600-8600 MJ/m^3. 4.5 to 5.6 MJ/kg [4] i.e. 2700 – 3360 MJ/m^3 if we assume the density of the wood to be 600 m^3/kg. Thus, optimization of energy consumption, together with drying time and quality of dried wood are the main priorities in wood industry.

Common types of wood in Serbia are analyzed – apple and apricot tree. The goal of this investigation was to evaluate the specific energy consumption of wooden discs of apricot and apple tree based on drying time measurements. Furthermore, the drying kinetics of apricot and apple tree discs was determined and compared to each other. This study aims to investigate the energy consumption of thin wooden samples under different drying temperatures.

2. MATERIAL AND METHODS

The material was acquired from local tree plantation in Serbia. The apricot and apple tree branches were first cut from the tree, then brought to the laboratory and chopped into thin wooden discs of the 20 mm thickness and approximately 100 mm in diameter (Fig.1). Two identical samples were cut at the beginning of the measurements process, one of which was placed in the oven at 105ºC for moisture content investigation, while the other was placed in the laboratory dryer at predefined drying regime.

Fig.1. Samples of apricot and apple wood discs

Initial moisture content was determined as follows (Eq.1):

$$M_0 = \frac{m_w(\tau_0)}{m_{dm}} \left[\frac{kg_w}{kg_{dm}}\right] \quad (1)$$

For both apricot and apple samples, drying regimes were as follows: air velocity was kept at 2 m/s while the air temperature ranged from 40 to 70 ºC with 10 ºC step. The drying was stopped when the sample reached the equilibrium moisture content at particular drying regime, i.e. when the mass of the sample was not changing anymore. Equilibrium moisture content is defined by the ratio between initial mass of the samples and mass of the samples at the end of the drying process (Eq.2).

$$M_e = \frac{m_e}{m_{dm}} - 1 \left[\frac{kg_w}{kg_{dm}}\right] \quad (2)$$

2.1. Evaluation of drying time and equilibrium moisture content of the samples

Drying time was measured from placing the samples into the drying chamber until the samples reached equilibrium moisture content. Equilibrium moisture content was calculated with Eq. 2 for all regimes.

2.2. Evaluation of specific energy consumption for drying

The specific energy consumption for drying was calculated based on the dryer specifications, which are investigated in [5]. The specific energy consumption depends on the drying regime, i.e. drying temperature and it was evaluated with Equation 3:

$$Q_V = a \cdot \tau + b \quad (3)$$

Where τ represents drying time and the coefficients a and b are given in Table 1 as function of drying temperature.

Table 1. Coefficients for determining the dryer energy consumption

Temperature [ºC]	30	40	50	60	70
a	15.12	28.08	43.56	57.60	74.88
b	230.4	167.04	782.64	1008	991.44

Based on the drying temperature and time, the total energy consumption was calculated for each experiment.

The specific energy consumption is then evaluated by dividing the total energy consumption with the mass of moisture evaporated during drying, i.e. Equation 4

$$q_V = \frac{Q_V}{m_w} \left[\frac{kJ}{kg_w}\right] \quad (4)$$

2.3. Evaluation of drying kinetics of the samples

For determination of drying characteristics, the mass of the samples was continuously measured during the experiments using specialized equipment and software with KERN precision balance with accuracy of 0.01 g and measuring range up to 3600 g. From the mass measurements, knowing initial and equilibrium moisture content values (Eq.1 and Eq. 2), the dimensionless moisture ratio (MR) is then calculated (Eq. 5) and plotted against the experiment time.

$$MR = \frac{M - M_e}{M_0 - M_e} \; [-]$$	(5)

Also the Drying rate (DR) was calculated as the ratio between the moisture loss and time span between two consecutive measurements - Equation 6.

$$DR = \frac{M(\tau_{n+1}) - M(\tau_n)}{\tau_{n+1} - \tau_n} \left[\frac{kg_w}{kg_{dm}\, s}\right]$$	(6)

3. RESULTS AND DISCUSSION

3.1. Evaluation of drying time and equilibrium moisture content of the samples

Drying time was measured from placing the samples into the drying chamber until the samples reached equilibrium moisture content and the results were given in Table 2.

Table 2. Drying time in minutes

Temperature	Apricot tree discs	Apple tree discs
40	3292	3091
50		
60		
70	689	650

As it could be seen from the measurements of drying time, the longest drying times are recorded for drying temperature of 40 °C and the shortest drying times are recorded for temperatures of 70 °C.

Equilibrium moisture content was calculated with Eq. 2 for all regimes and it is presented in the Table 3.

Table 3. Equilibrium moisture content [-]

Temperature	Apricot tree discs	Apple tree discs
40	0.30	0.32
50	0.20	0.22
60	0.14	0.15
70	0.04	0.05

3.2. Evaluation of specific energy consumption for drying

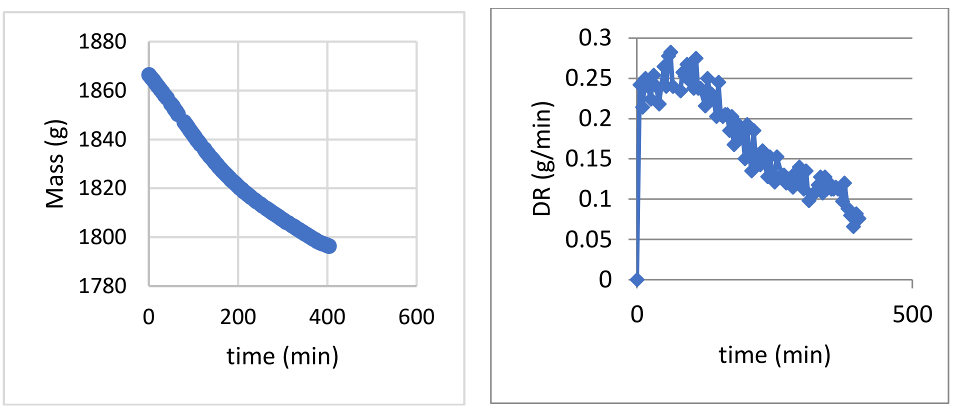
The specific energy consumption for drying was calculated using Eq. 3. The specific energy consumption for each experiment is given in Table 4.

Table 4. Specific energy consumption [kJ/kg_w]

Temperature	Apricot tree discs	Apple tree discs
40	91654	86962
50		
60		
d70	79567	77158

3.3. Evaluation of drying kinetics of the samples

For determination of drying characteristics, the MR was plotted against experiment time for all experiments for apricot and apple tree discs and shown in Fig. 2a and In Fig. 2b the DR was plotted against time.



(a) (b)

Fig. 2. (a) Mass vs time (b) Dr vs time

As it could be seen from Fig. 1. the drying takes place first in short constant rate period and then in falling rate period, which is characteristic for wood drying. This also means that both internal and external resistances to moisture transfer play important role for wood discs drying (Ivan Susenje). The maximal values of DR are observed with drying temperatures of 70 °C and minimal with milder drying regimes at temperatures of 40 °C.

4. CONCLUSIONS

In modern technological processes the emphasis is on the energy efficiency and rational use of energy in all industry sectors. One of the industrial sectors with highest energy consumption is certainly drying sector. Drying is one of the energy most demanding processes overall, especially in wood processing industry where the majority of energy is consumed for drying. Therefore, the energy consumption of wood drying is a paramount when assessing the economic value of the dried wood products.

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REFERENCES

[1] B. Lamrani, F. Kuznik, A. Ajbar, M. Boumaza, *Energy*. **2021**, 228. https://doi.org/10.1016/j.energy.2021.120598.

[2] X. Chi, S. Tang, X. Song, S. Rahimi, Z. Ren, G. Han, S. Q. Shi, W. Cheng, S. Avramidis, *Energy*. **2023**, 283 (July), 128718. https://doi.org/10.1016/j.energy.2023.128718.

[3] P. Perré, R. Rémond, J. Colin, E. Mougel, G. Almeida, *Dry. Technol.* **2012**, 30 (11–12), 1136–1146. https://doi.org/10.1080/07373937.2012.705205.

[4] A. Konopka, J. Barański, K. A. Orłowski, D. Mikielewicz, L. Dzurenda, *Wood Sci. Technol.* **2021**, 55 (3), 741–755. https://doi.org/10.1007/s00226-021-01276-8.

[5] M. P. Milanović, Thermomechanical Aspects of the Drying Process of Juice Indrustry Residues, University Of Belgrade, Faculty Of Mechanical Engineering **2021**.