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KINETICS OF THE COMBINED DRYING TECHNOLOGY OF PEAR SLICE (PYRUS)

KINETIKA KOMBINOVANE TEHNOLOGIJE SUŠENJA KRIŠKI KRUŠKE (PYRUS)

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SUMMARY

During the year 2008, a set of experiments of combined technology ,which involves the drying of a pear slice, have been conducted. The combination consisted of osmotic and convective drying. The aim of the research was measuring the influence of analysed factors of osmotic and convective drying on the change of moisture of the pear and increase of dry matter. The factors of osmotic drying were temperature and solution concentration, and factors of convective drying were temperature and air velocity in front of the layer of the material. During the osmotic drying, the most significant change concerning moisture and the increase of dry matter happened in the first 100 minutes of the process. A change in moisture is also detected later in the process, but the velocity of that change decreased. In 180 minutes the moisture decreased from the initial value of 0.82 kg/kg to 0.775 kg/kg for solution temperature of 60°C and solution concentration of 50^{o}Bx and 0.776 kg/kg for solution temperature of 40^{o}C and solution concentration of 50^{o}Bx. Maximum recorded increase of dry matter equaled 0.036 kg/kg for the solution temperature of 60°C . Within the period of 24 hours of convective drying, the biggest decrease in moisture was achieved in air temperature of 60^{o}C and air velocity of 1.5 m/s. The moisture of the material decreased from the initial value of 0.776 kg/kg to 0.453 kg/kg, and tissue temperature equaled 57.34^{o}C. Evaluation of the chosen factor levels infuences of convective drying on the speed of drying by dispersive analysis was conducted. The results of dispersive analysis pointed out the significant influence of chosen levels of air temperature and decreased influence of chosen levels of air velocity on the speed of drying.

***Key words**: pear, drying kinetics, convective drying, osmotic drying.*

REZIME

U toku 2008. godine obavljen je set eksperimenata kombinovane tehnologije sušenja ploda kruške. Kombinacija se sastojala od osmotskog i konvektivnog sušenja. Cilj istraživanja je bio merenje uticaja analiziranih faktora osmotskog i konvektivnog sušenja na promenu vlažnosti kruške i povećanja suve materije. Faktori osmotskog sušenja bili su temperature i koncentracija rastvora, a faktori konvektivnog sušenja bili su temperatura i brzina vazduha ispred sloja materijala. Tokom osmotskog sušenja najznačajnija promena vlažnosti i povećanje suve materije dogodila se u prvih 100 min procesa. Uočava se i kasnije promena vlažnosti ali brzina te promene je sve manja. Po isteku 180 min vlažnost se snizila sa početnih 0,82 kg/kg na 0,775 kg/kg za temperaturu rastvora 60^{o}C i koncentraciju rastvora 50^{o}Bx i 0,776 kg/kg za temperaturu rastvora 40^{o}C i koncentraciju rastvora 50^{o}Bx. Maksimalno zabeleženo povećanje suve materije iznosilo je 0,036 kg/kg za temperaturu rastvora 60^{o}C. Tokom 24 h konvektivnog sušena najveće sniženje vlažnosti postignuto je pri temperaturi vazduha 60^{o}C i brzini vazduha 1,5 m/s. Vlažnost materijala se snizila sa početne 0,776 na 0,453 kg/kg, a temperatura tkiva je iznosila 57,34^{o}C. Obavljena je ocena uticaja izabranih nivoa faktora konvektivnog sušenja na brzinu sušenja disperzionom analizom. Rezultati disperzione analize su ukazali na značajan uticaj izabranih nivoa temperature vazduha i smanjen uticaj izabranih nivoa brzine vazduha na brzinu sušenja.

***Ključne reči:** kruška, kinetika sušenja, konvektivno sušenje, osmotsko sušenje.*

INTRODUCTION

The pear, as type of fruit, is interesting for processing, both within the field of economy and nutrition. However, processing of a fresh pear in Serbia is limited to producing alcoholic beverages, juices, compotes, sweet courses, marmalades and jams (Annual statistics, 2007). Production of a dry pear receives little attention. Dry pear may be found only in health-food shops. Qualitative features: colour, shape, texture, aroma and scent of dried fruits are disputable. For the same reason, the costumers are distrustful. The main fault lies in the application of inadequate drying technology.

Combined technology of drying the fruit tissue consists of combining the osmotic and convective drying. Drying the fruit using combined technology gains several advantages in comparison to the classic technology of drying. The advantages reflect preserving the quality of dried fruit (natural colours, scent, aroma, taste), enabling a longer storage period with higher level of moisture, shortened time of drying until reaching the ultimate moisture and it is energetically rational (Park and associates, 2002a, 2002b, Babić, Ljiljana and associates, 2003, 2004; Babić, M and associates, 2004, 2005; 2007, 2008, Pavkov, I , 2007, Pavkov, I and associates, 2008, Radojčin, M and associates 2008).

The aim of research in this paper is the analysis of influences of chosen factor levels of osmotic and convective drying on the kinetics of drying the pear type by the name of “William”. Based on the aim of research presented in this manner, a planned experiment of drying a fresh pear in the shape of one quarter using osmotic and convective drying was conducted. During the experiments involving osmotic drying, a difference in moisture was measured (WR) as well as the increase of dry matter (SG). During the experiments of convective drying, changes in moisture (ω) were measured. A two-factor experiment involving osmotic drying with three repetitions of all factor combinations, and two-factor experiment of convective drying with three repetitions of all factor combinations was planned. It was selected that pear samples are additionally dried convectively after osmotic drying, the samples being treated with the combination of highest and lowest factor levels. Due to a great number of experimental units, it was decided that the experiment lasts for two years during the season of picking fresh pears, in the years 2008 and 2009. This paper shows the results of measuring within the first year of research (2008).

Nomenclature – Oznake

a (mm)	– fruit length / dužina ploda,
b (mm)	– fruit width / širina ploda,
c (mm)	– fruit thickness / debljina ploda,
d (mm)	– diametar of mesurment tube/prečnik merne cevi,
c_r (°Bx)	– solution concentration / koncentracija rastvora,
m (kg)	– fruit mass / masa ploda,
v (m/s)	– air velocity in front of drying layer / brzina vazduha ispred sloja,
p_d (Pa)	– dynamics air presure / dinamički pritisak vazduha,
A (m^2)	– chanal surface in front of drying layer / površina kanala sušare ispred sloja,
M (g)	– sample mass / masa uzorka,
S (g)	– dry matery mass in sample / masa suve materije u uzorku,
SG (kg/kg)	– solid gain content on wet basis / povećanje udela suve materije na vlažnu bazu,
t (°C)	– temperature / temperatura,
V (cm^3)	– fruit volume / zapremina ploda,
W (g)	– moisture mass in sample / masa vlage u uzorku,
WR (kg/kg)	– moisture content on wet basis – osmotic drying / vlažnost u odnosu na vlažnu bazu – osmotsko sušenje,
ω (kg/kg)	– moisture content on wet basis – convective drying / vlažnost u odnosu na vlažnu bazu – konvektivno sušenje,

Greek symbols – Grčka slova

Δ	– change of parameter value / promena vrednosti parametra,
σ	- standard deviation / standardna devijacija,
τ (h)	– drying time / vreme sušenja,
ρ (kg/m^3)	– air density / gustina vazduha,

Subscripts - Indeksi

0	– initial value / početna vrednost,
1, 2	– level of value / nivo vrednosti,
c	– convective drying / konvektivno sušenje,
o	– osmotic draying / osmotsko sušenje,
cp	– whol fruit / ceo plod,
k	– slice / kriška
i	– i –moment / i-tom trenutku,
r	– osmotical soulution / osmotski rastvor .

MATERIAL AND METHOD

Sample preparation

In the experimental part of the research, fresh pears (*Pyrus*) of the type named 'william' were used. The pears were acquired in the local shop, and were originally from an orchard in the Srem district, near Čerević. Until the time for processing, these fruits were stored in a cooling chamber with air temperature of 4°C and relative humidity of 75%. The stage of ripeness of the fruits was the beginning of technological ripeness and pH = 2.9. Average values of basic physical characteristics of ripe fruits measured on a random sample in 10 fruits are: moisture 82.33 % (σ = 0.71),mass of whole fruit 185.6 g (σ = 25.26), dimensions a_{cp} = 87 mm (σ = 5.21), b_{cp} = 67.6 mm (σ = 3.75) i c_{cp} =64.9 mm (σ = 3.31).

Preparation of fresh fruits consisted of washing, removing the seed capsule, slicing the fruit to a one quarter – a slice. This way of preparation enabled getting usable mass of tissue of 171.5 g (σ = 23.82), which makes 94.05% (σ = 1.1) of the initial fruit mass. The prepared slices had the following physical characteristic values (based on he measured sample of 54 slices): m_k = 42.88 g (σ = 1.84), a_k = 81.92 mm (σ = 3.70), b_k = 32.95 mm (σ = *1.19*), c_k = 31.42 mm (σ =*1.39*), V_k = 40.18 cm^3 (σ = *3.57*). Prevention of tissue darkening was achieved by dry sulfur procedure, burning 2g of technical powdered sulfur for 1kg of prepared slices. Time of exposing the slices in the chamber for sulfur processing was 8 hours. Upon completing the sulfur processing, the prepared samples were put in an osmotic dryer. Upon finishing the osmotic drying of the samples, which were dried in the solution concentration of 50°Bx and solution temperature of 40°C, were moved to a convective drying facility with wattle where they were additionally dried for another 24 hours.

In order to get the osmotic solution, saccharose in the form of consumer crystal sugar was used as the dissolved substance and distilled water as the solvent. The experiment was conducted in the osmotic dryer of the capacity of 0.032 m^3 of the semi-industrial type (Babić, M and associates, 2005). The principle of operation within the drier is based on circulation of the osmotic solution through the drying chamber with the fruit sample and heat exchanger.

The experiment of osmotic drying in the first year was conducted as a one-factor experiment. Concentration of osmotic solution was constant, 50°Bx. The temperature of the solution varied on two levels, 40°C and 60°C. Duration of the osmotic drying process was 3 hours. Mass ratio of osmotic solution and prepared pear slices was 8:1. Speed of streaming of osmotic solution in the layer of material changed insignificantly during the experiment due to the change of solution viscosity and layer porosity.

The experiment of convective drying was conducted in the experimental drying facility with wattles (Fig. 1). The principle of drier operation is based on the streaming of heated air through the drying chamber and fruit samples were laid down as a thin layer on wattles.

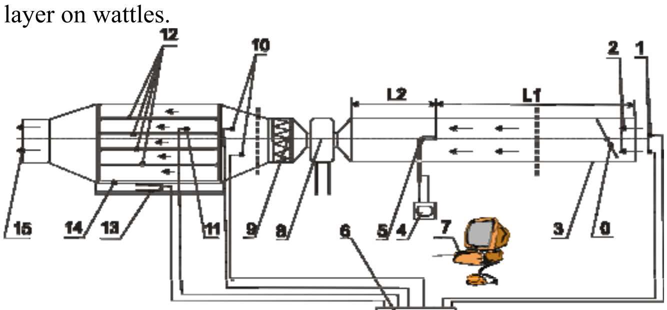


Fig. 1. Tray convective dryer with continnosly mass changes measure
(0 – gate valve, 1, 10, 11 – termometers, 2 – air flow, 3 – pipe, differential micromanometer, 5 – Pittot pipe, 6 – system acquisition, 7 – PC, 8 – fan, 9 – electrical heater, 12 – tray, 13 – mass measure, 14 – tray bearer, 15 – air autlet, L1, L2 – dimensions)
Sl. 1. Konvektivna sušara sa lesama za kontinualno merenje promene mase uzorka „IVA-2“
(0 – zasun, 1, 10, 11 - termometri, 2 – strujanje vazduha, 3 –cev, 4 – diferencijalni mikromanometar, 5 – Pittot cev, 6 – sistem akvizicija, 7 – računar, 8 – ventilator, 9 – električni grejač, 12 – lese 13 – senzor za merenje mase, 14 – nosač lesa, 15 – izlaz vazduha, L1 i L2 – dimenzije)

The experiment of convective drying within the first year of research was conducted as a two-factor experiment. The factors were air temperature and velocity of air used for drying, in front of the layer of material. Air temperature was varied on two levels, 40°C and 60°C. Air velocity varied on two levels 1 m/s and 1.5 m/s. Duration of the process of convective drying was 24 hours. Dimensions of one wattle are 440 mm x 290 mm, and distance between each of the is 45mm. 16 slices were laid down on one wattle, equally distanced within the row and between rows themselves. All four wattles are under the pressure of the same number and order of the material, as shown on picture 2.

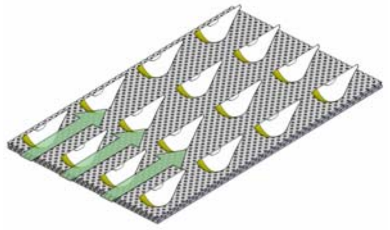


Fig. 2. Samples disposition on tray and air flow direction
Sl. 2. Raspored uzoraka na lesi i smer strjanja vazduha

Measurings

The prepared sample of quarter slices was put in the basket and then submerged in the osmotic drier. The ratio of mass and solution was 8:1. For purposes of researching the osmotic drying process special samples were formed, taken out of the whole mass prepared for osmotic treatment. These samples were specially marked, and measured for mass, dimensions and capacity before processing. 10 groups consisting of three pear slices were formed. Prepared in this manner, samples were placed in a special carrier with compartments which is also submerged in the osmotic drier. These samples were used for measuring the change of state during drying, and it was then supposed that the same changes will occur with the whole sample in benefit of the osmotic drier. Every 20 minutes, since the beginning until the end, three slices from one carrier compartment were taken out, so that they could be used for measuring moisture, dimensions and capacity.

Dimensions of the material were measured with a sliding caliper, and the capacity using the method of submerging with a scale, glass burette and a thin metal wire (Mohsenin, 1980; Babić, M and Babić Ljiljana, 2007).

Moisture (WR) and the increase of the part of dry matter (SG) were measured in the following manner: slices taken out of the carrier were washed by submerging in distilled water in order to remove the extra solution from them. They were then carefully wiped with an absorbing cloth. Using the thermogravimetric method, by drying on 80°C (WR) and (SG) were determined within the period of 24 hours. By measuring the difference in mass before and after the drying, moisture (WR) and increase of dry matter (SG) were measured. Moisture in a moment *i* is the contents of water in the sample in relation to the mass of the sample (1), and the increase of dry matter is the net increase of sample dry matter after the osmotic drying in relation to the initial sample mass (2) (Shi, 2002):

$$WR = \frac{W_i}{M_i} \tag{1}$$

$$SG = \frac{S_i - S_o}{M_0} \tag{2}$$

Besides measuring the above mentioned characteristics, measuring of other qualities of value for the kinetics of osmotic drying was conducted. Temperature of osmotic soution was measured with the mercury termometer with the measuring range of 0 – 100°C, resolution 1°C. Measuring of the pH solution was conducted with the pH meter with the measuring range of 0-14, resolution 0,1 pH, accuracy ±0,1 pH, manufactured by 'Atago', Japan model pH Teser2. Measuring of solution concentration was done with a digital refractometer with the measuring range of 0-85°Bx, resolution 0,1 °Bx, accuracy ±0,1°Bx, manufactured by 'Atago', Japan, model P-α.

After the osmotic drying, slices were moved to an experimental convective drier (Fig.. 1). Based on the knowledge of the initial sample moisture and measuring sample mass change on the wattles during the convective drying, moisture of material in a particular moment was calculated (equation 3) as well as the speed of moisture change (equation 4) (Babić, Ljiljana i Babić M, 2002).

$$\omega_i = \frac{\frac{\omega_o \cdot m_o}{100} - \Delta m_i}{m_i} \tag{3}$$

$$\frac{\Delta\omega}{\Delta\tau} = \frac{\omega - \omega_i}{\tau - \tau_i} \tag{4}$$

Measuring of sample mass change was conducted continually, without interrupting the drying process. This was enabled by a special action of wattles carrier which was placed on the sensor for measuring the mass (Fig. 1, pos, 13.) Mass measurement sensor is of a measuring range of 0-20 kilograms, resolution of 0,01 g, accuracy of ±2 g, manufactured by HBM, Germany, model PW6CC3MR. Mass measuring sensor is connected to a measuring acquisition (6), manufactured by HP, USA, model 75000 Series B, which recorded mass change during drying every 60 seconds within the period of 24 hours. In addition to mass change, within the same time interval, the acquisition recorded the temperature of dry and moist thermometer of the surrounding air using the thermocouples (pos. 1). Air temperature upon entering the layer was measured at two points with thermocouples (pos. 10). Material temperature was measured using a thermocouple placed 5mm below the upper surface of the slice (pos. 11). All thermocouples used are of J-type. Air velocity was measured in the measuring tube (pos. 3) using a Pittot-tube and differential micromanometer – Testo 506 with the measuring range of 0 – 1—hPa, resolution 1 Pa and accuracy ±1 Pa. The Pttot-tube is placed n the centre of the tube at the distance of 12d (L1) from the beginning of the measuring tube and 5d (L2) to the end of the measuring tube. Based on the measuring of dynamic pressure, air velocity at this point was calculated, and then converted to air velocity in front of the layer of material (equation 5) (Babić, M, 2005). Adjusting air velocity in front of the layer was conducted using the stator suppressing of the fan with the use of lid (0). Randomising the experiments was conducted with the use of the random numbers table.

$$v = \frac{\frac{d^2\pi}{4}\sqrt{\frac{2 \cdot p_d}{\rho_o}}}{A \cdot \rho_1} \tag{5}$$

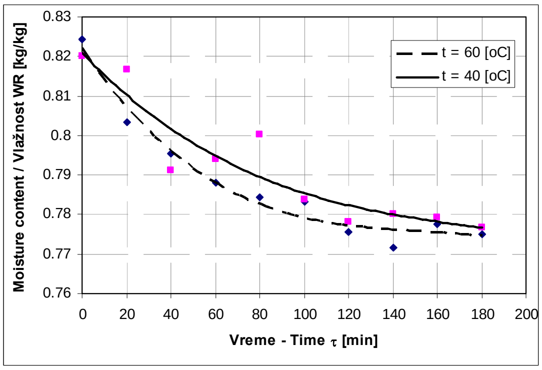
Statistic processing was done with the software programme called Statistica 8.0.

RESULTS AND DISCUSSION

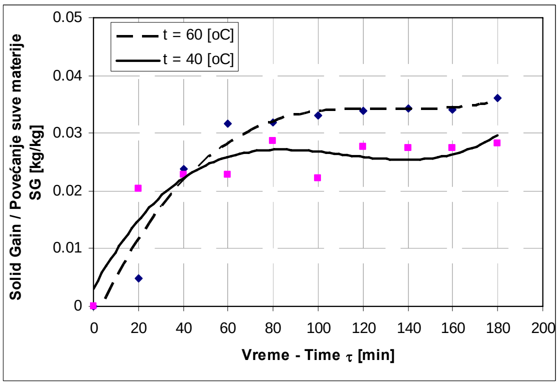
Figure 3 shows the kinetic curves of drying and changing of sample dry matter during the period of osmotic drying. The change of moisture (WR) and increase of dry matter (SG) is more prominent with higher solution temperature. The most significant change in moisture happens in the first 100 minutes of the process with the examined values of solution temperature. A change in moisture and increase of dry matter can be notices at the later time, yet the speed of the change decreases gradually.

At the end of the period of 180 minutes, moisture decreased from the initial 0.826 kg/kg to 0.775 kg/kg for t_r = 60°C and c_r = 50°Bx; and 0.776 for t_r = 40°C and c_r = 50°Bx. Maximum recorded increase of dry matter was 0.036 kg/kg with t_r = 60°C and c_r = 50°Bx; and 0.028 kg/kg with t_r = 40°C and c_r = 50°Bx.

Figure 4 shows part of the results of measuring during the convective drying of pear slices for air temperatures of 40°C (a, b) and 60°C (c, d) with air streaming velocity in front of the layer being 1.5 m/s. Also, on the same pictures a trend of air temperature curves for drying and material temperatures during the process are shown. In the air temperature of 40°C material moisture decreased to after 24 hours of drying for 0.562 kg/kg, and tissue temperature was 37.9°C. Average initial slice mass in this test was 34.76g, lenght 76.8 mm, width 31,42mm and thickness 29.18mm. In the air temperatre of 60 °C moisture fo the material decreased after 24 hours of drying for 0.453 kg/kg, the tissue temperaturebeing 57.34°C. Average initial mass of the slices was 38.94g, lenght 81.05mm, width 32.3 mm and thickness 31.1mm.



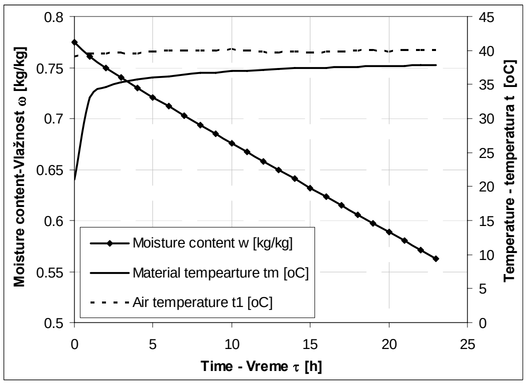
a)



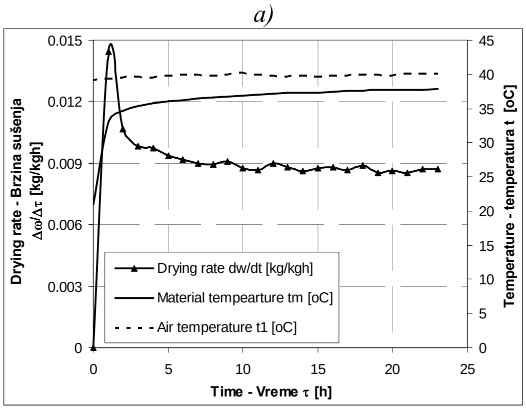
b)

Fig. 3. Moisture content (a) and solid gain content (b) during osmotic drying of pear slice on solution concentration 50°Bx
Sl. 3. Promena vlažnosti(a) i povećanje mase suve materije (b) tokom osmotskog sušenja kriški kruške pri koncentraciji rastvora 50°Bx

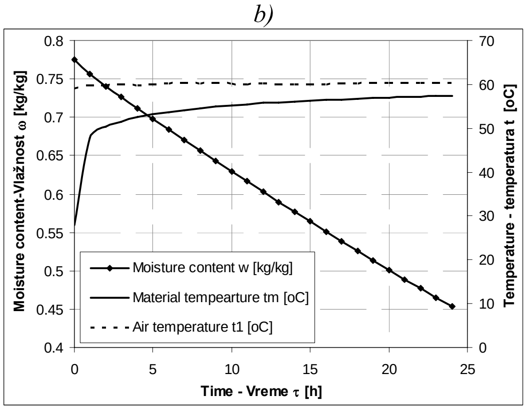
Figure 5 and 6 show the diagrams of moisture change and speed of drying for all combinations of influential factors. Curves shown reprsent average values of three repetative combinations of factors, all in all 12 experimental units. By analysing the kinetic curves of moisture change (Fig.6), the change in moisture of pear slices within the period of 24 hours of convective drying is linear. This kind of change trend concearning moisture occured primarily because of the small evaporating surface, in other words dimensions of prepared slices as wel as the stage of ripeness (pH=2.9).



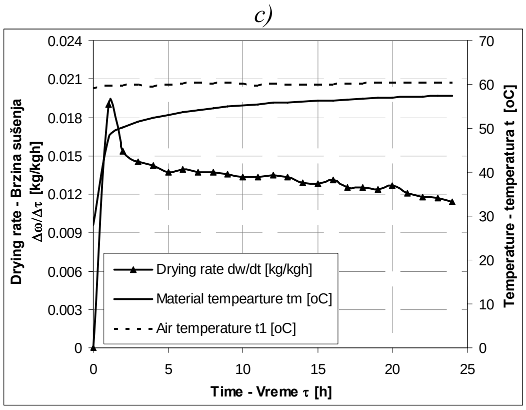
a)



b)



c)



d)

Fig. 4. Moisture content changing(a, c) and drying rate (b, d) within convective drying,
a) and b) air temperature 40°C, air velocity 1.5 m/s,
c) and d) air temperature 60°C, air velocity 1.5 m/s
Sl. 4. Promena vlažnosti (a,c) i brzina sušenja (b, d) pri konvektivnom sušenju
a) i b) temperatura vazduha 40°C, brzina strujanja vazduha 1.5 m/s,
c) i d) temperatura vazduha 60°C, brzina strujanja vazduha 1.5 m/s

The greatest decreace of moisture was recorded in air temperature of 60°C and air velocity of 1.5 m/s, what was to be expected. By analysing kinetic curves of drying rate (Fig.6) two periods of drying may be noticed. The first period is characteristic because of the increase of drying speed and reaching the maximum velocity of water molecule evaporation from the material. This period takes place during the first 60 minutes of the process. Reaching the maximum velocity of evaporation of water molecules in this period occurs as the consequence of the increased concentration of moisture bound to the surface, let there after the osmotic drying. With the evaporation of surface-bound moisture the speed of drying decreases. In the second period smaller differences may be noticed, depending on air temperature for drying and he velocity of air movement. For air temperature of 40°C and for both velocity values of air movement, the speed of drying approaches the linear trend. For air temperature of 60°C and for both values of air velocity a slight leaning of the curves is recorded as the process approaches its 25th hour. This kind of trend occurs due to the correlation of drying speed and moisture of the material at a particular moment.

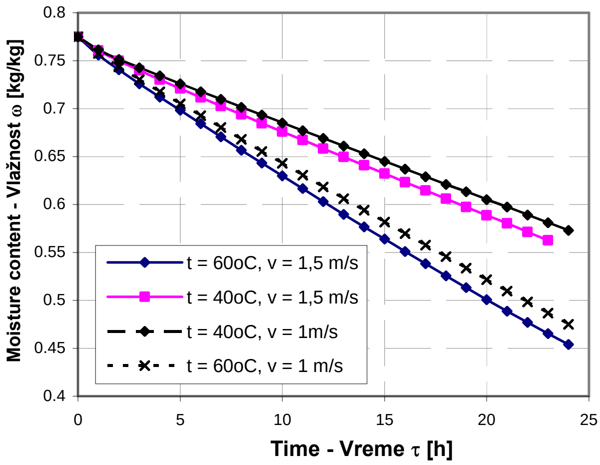


Fig. 5. Moisture content changing within convective drying
Sl. 5. Promene vlažnosti u zavisnosti od vremena tokom konvektivnog sušenja

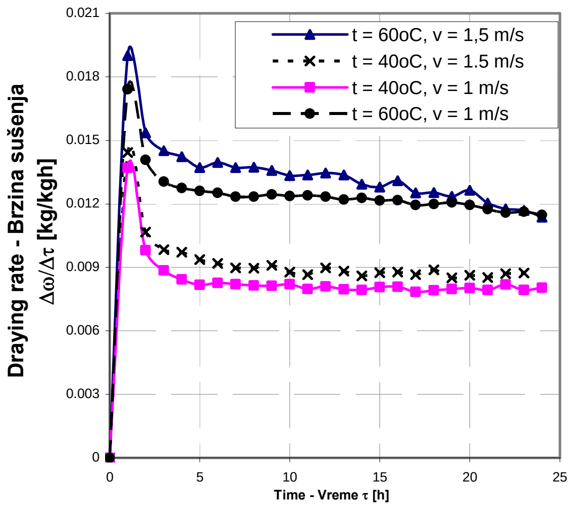


Fig. 6. Draying rate of pear slices during the convective drying for all factor combinations – air temperatures and air velocity

Sl. 6. Brzina sušenja četvrtina krušaka tokom konvektivnog sušenja za sve kombinacije faktora – temperature vazduha i brzine vazduha

Checking the influence of chosen factor levels on the speed of convective drying (Δω/Δτ) was accompliched by dispersive analysis. Table 1 shows the results of this analysis. Based on the comparison of calculated values of the Fisher criteria *(F)*, with table value *(Fcrit)* a conclusion is made about the influence of researched factor levels on the speed of drying. For the probability V=99% (*F>Fcrit*), influential factor levels on the speed of drying (*Δω/Δτ*) are air temperature and mutual interaction of air temperature and air velocity. Chosen levels of air velocity are less significant for the speed of drying, which is the consequence of a small level difference of this influential factor (1.0 i 1.5 m/s).

Table 1. Results of the dispersive analysis of the two-factor experiment with three repetitions (V=99%)
Tabela 1. Rezultati disperzione analize dvofaktornog eksperimenta sa tri ponavljanja (V = 99%)

Variation source Izvor varija-cije	Square sum / Suma kvadrata	Level of freedom Stepen slobode	Average square value Srednji kvadrat	*p-value*	*F*	*Fcrit*
Air velocity Brzina vaz-duha	1.73E-08	1	1.73E-08	0.83743	0.04235	6.931941
Air tem-perature Temperatura vazduha	0.000391	1	0.000391	4.27E-49	958.7715	6.931941
Interaction Interakcija	1.56E-05	1	1.56E-05	1.86E-08	38.3244	6.931941
Error Greška	3.59E-05	88	4.08E-07			
Overall Ukupno	0.000443	91				

CONCLUSION

Results of the experiment show that there are prominent differences concerning the kinetic change of moisture and increase of dry matter during osmotic drying, between the chosen factor levels, and that they occur within the first 100 minutes of the process. In the later period we have a decrease in speed of all changes, what is more prominent with the higher solution temperature. After 180 minutes, changes in moisture and increase of dry matter are equal for both factor combinations. The biggest change in moisture is was recorded with samples dried on solution temperature of 60°C and concentration of 50°Bx.

During the convective drying a period of material warming is evident. It is of higher intensity in higher air temperatures and air velocity. The drying rate of material can be divided into two periods. The period of constant draying rate and the period of decreasing drying rate. The period of constant draying rate is of little importance, and the period of decreasing drying rate is of a mild trend downwards, which can be approximated as a linear change. The greatest change in moisture was recorded with samples dried in the air temperature of 60°C and air velocity 1.5 m/s.

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