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ANALYSIS OF DRYING POTATO KINETICS IN LABORATORY CONDITIONS

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Abstract: Chemistry is in its nature a fundamental science, but nowadays its results are increasingly used in practice. In such a way, many syntheses of important nutrition and industrial compounds (chemical technology), or destruction of harmful substances (chemical ecology) have been developed. The analytic part of chemistry (analytical chemistry) has found a significant usage even in optimisation of technological processes of food tehnology.

One of the oldest ways of food preservation is drying (dehydration). The basis of this process of preservation is to vaporise water, to dry enough the product, in order to stop the activity of enzymes and possibility of microorganisms' development.

Water in agricultural products is not free but bound to dry matter. Therefore, for its vaporising it is necessary to bring enough heat. The part of the brought heat is used for vaporising water, but one part of it becomes the energy for activation of several chemical reactions that decrease the nutritive values and the quality of future food. Therefore, the important engineering problem emerges: determination of optimal conditions for drying. For optimisation of technological process of drying, it is necessary to do mathematical modelling of dependence of water vaporising speed from environmental conditions beforehand.

The aim of this paper is to determine potato pieces drying kinetics in laboratory dryer, in order to determine the optimal conditions for its industrial dehydration.

It was established that in the first quarter of the time of drying evaporated 28.3% of total evaporation of water, and then in order by quarters: 53%, 14.1% and 4.6%, respectively. The greatest speed of drying was realized at moisture of potatoes about 50%.

Key words: drying kinetics, potato, dehydrator.

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Introduction

No matter how it emerged, the life on this planet has been adapted to conditions which provide large presence of water. Although water appears as a reactant in only few reactions, it provides conditions that serve to the activity of enzymes, that is, biochemical reactions developing (Rajković et al., 2004). On the other hand, regardless of all the differences, life can and must be observed as a natural process of mass and energy changing in biologically closed systems called cells or their organised structures - organisms. All those reactions are controlled and regulated by enzymes, as biological catalysts.

Having all this in mind, it is obvious that water is necessary for metabolism of all living organisms on the Earth, even the simplest one-cell microorganisms.

Although a cell (organism) represents a closed system in biological sense, thermodynamically, it is a completely open system. Namely, mass and energy changing has been developing between a cell and its environment. That process is called feeding. So, intake of different substances (nutritiens, food) necessary for preserving all balances in metabolism is important, because only a stable metabolism provides a healthy organism.

As food man intakes different agricultural products which by themselves are products of somebody's life. Because of that, all of them possess large quantities of water. As such, they are adequate for micro-organisms' lives, which also try to preserve their metabolisms and have to take water nutrients from our food. Of course, that brings about classical natural fight for survival. From our point of view, micro-organisms with their lives induce spoiling of food intended for our nutrition (Zlatković, 2003).

To stop food spoiling, different kinds of preservations are used nowadays (Flaumenbaum et al., 1986). One of the oldest ways is decreasing water level in food (Vereš, 2004).

In connection with this, it should be reminded that molecules of water are bounded with different energies (forces) with dry matter from food. Some are tightly bounded: chemically (by covalent bounds – hydro water), physical-chemical (absorbed water) or mechanical (micro-capillary water). The other molecules of water are connected with less energy (free water): micro-capillary, colloidal and osmotic (Kandić, 2002).

Because of different accessibility of reactants in chemical reactions, the term „activity" is introduced. So it is spoken about the activity of water (A_w). Actually, it is measurement for energy, which bounds water with solid basis of some material:

$$E = - RT \ln A_w$$

So, the higher the energy of water bound, the less its activity, that is, the less its accessibility to cell enzymes or microorganisms, so the spoiling is decelerated or stopped. In that sense, for preserving it is not important how much water will remain (in total amount), but how much of the remain water is chemically „active” (Smiljanić, 1998; Zlatković et al., 1998). Unfortunately, for water vaporising a large amount of heat should be supplied, but its exploitation is small. In other words, a large amount of supplied heat becomes energy of activation, so the processes of changing in physiologically very important substances (vitamins and other nutrients) accelerate.

To determine the optimal conditions that should be fulfilled for decreasing the risk of microbiological spoilage and heat damage of future product, it is important to study well dehydration kinetics processes of each product as well as kinetics of degradation changes in drying raw material.

Kinetics of drying means determination and monitoring of the water vaporising speed (v) (Niketić et al., 1998):

$$v = du/dt$$

where u - water content [%], and t - time of drying [h].

The aim of this paper was to study drying kinetics of potato pieces in a laboratory drier.

Material and Methods

Potato was selected for the analysis of drying kinetics (Rajković et al., 2002). The quality of the product was not of utmost importance, so the preparation was simple: potatoes were only mechanically peeled by a household blender, sliced into sticks, and then sliced into cubes by kitchen knife. Thus, a unique geometry of the material in the shape of a cube of 0.8 cm x 0.8 cm x 0.8 cm was obtained.

Taking water from potato was done by bio-drier „Stockli”, Switzerland, as shown in Fig 1.

Fig. 1. – Out viewer of dehydrator „Stockli”

This drier contains three drying trays. Each drying tray has perforated bottom, and is built from solid plastic in order to be heat resistant (Fig. 2.). The material for drying is put on a drying tray. Air is heated with a heater till given temperature and then through special directors it is repressed from below upwards by ventilators, so that it passes through drying trays. After taking water from potato, air goes out through the top of a drier.

Drier is equipped with a thermostat that regulates and keeps the air temperature in beforehand given values.

Drying kinetics is analysed for the temperature of 70°C.

Fig. 2. – A view of drying trays

Drying speed (kinetics) is analysed according to water content in potato during dehydration. For that reason, before starting the drying and at every half an hour of drying, the samples of potato are taken to determine the level of moisture by gravimetric method.

Gravimetric method for water content determination (Rajković, 2004). This method is based on water vaporising from a material to be analysed, and then the moisture is calculated on the basis of vaporised water mass loss. As water in this method, it is meant only the water that can evaporate at the temperature of 105°C. Water that is bounded with high energy, in a way that at such temperature doesn't evaporate, is not considered as water. On the other hand, all the substances that evaporate of the above mentioned temperature are taken for water.

First, the weighing bottle is washed and dried and thereafter its mass is measured (m_1). Then in a measured dish about 10 g of sample is put, and then the mass of dish together with the sample in it is measured (m_2). Dish with a sample is put in a drier where the drying is done for about two to three hours at 105°C. During that time the dish is open, so the water can evaporate from the product. When the drying time is over, vegeglas is closed with a lid and taken from a drier to cool in exicator with some hygroscopic substance that would stop further moisturising. After cooling, the mass of dry debris is measured (m_3).

Measuring of the mass is done by analytic scale that gives three reliable decimals. Drying is repeated until, after two dryings that last for half an hour, the constant mass is obtained, that is, the mass that doesn't change at the third decimal.

According to the results of these measurements, by calculating it can be obtained:

– s – part of dry matter (%)

$$s = \frac{m_3 - m_1}{m_2 - m_1} \cdot 100$$

– d – part of water expressed on dry basis (g water/g dry basis)

$$d = \frac{m_2 - m_3}{m_3 - m_1}$$

– u – part of water expressed on moisture basis (in %)

$$u = \frac{m_2 - m_3}{m_2 - m_1} \cdot 100$$

However, by calculating one way of expressing the water content, other ways can be calculated as given in Table 1.

Tab. 1. - Calculation of different ways of expressing water contents in matter

	u	d	s
u	-	$\frac{100 \cdot d}{d+1}$	100 - s
d	$\frac{u}{100-u}$	-	$\frac{100}{s-1}$
s	100 - u	$\frac{100}{1+d}$	-

Drying kinetics curve. According to gravimetric determination of water in potato during drying, the graph of dependence u : t is drawn. Of course, due to experimental mistakes and differences in the amount of certain cubes and, first of all, because taking samples for measurement cannot be a statistic representive of the total, this obtained spots are very „scattered". In order to make the curve of drying more acceptable and close to reality, the approximation of received results was done. So a theoretical (approximate) curve of drying has been received from the broken (experimental) line.

From that theoretical curve of drying, the „possible" potato moistures during the time have been read by interpolation. According to them, the speed of drying (v) is calculated as the du/dt ratio.

Although all the processes in Nature are developing over time, time cannot serve as potential for any of them. Therefore, it is not enough (correct) to observe changing of water evaporation speed in the function of time. Namely, the potential of food drying is the difference among relative moisture of material and surrounding air, so for the studying of drying kinetics it is necessary to observe dependency of water vaporising speed from its material content.

Results and Discussion

The results of gravimetrical determination of water content in potato during drying (u_e) are shown in Table 2.

Tab. 2. - Values of the results received by drying: experimental (u_e) and values received by approximation (u_t)

t [h]	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5,0	5.5	6.0	6.5
u_e [%]	79.2	78.5	76.7	74.0	56.0	50.8	45.0	44.3	33.0	28.5	17.3	12.7	11.9	8.3
u_t [%]	79.2	78.3	77.1	73.5	65.0	55.2	45.0	36.5	28.9	23.0	17.1	13.0	11.3	9.1

According to them the graph of dependence (Fig. 3.) was drawn as well as approximate theoretical curve of drying. Theoretically present potato moisture (u_t) during the drying was determined from that graph by interpolation (Table 2.).

From Fig. 3. it can be observed that sample moisture changes according to some curve that is slightly curved at the beginning and at the end. That is why it is important to follow the speed changing du/dt during drying, which is shown in Table 3. and Fig. 4. and 5.

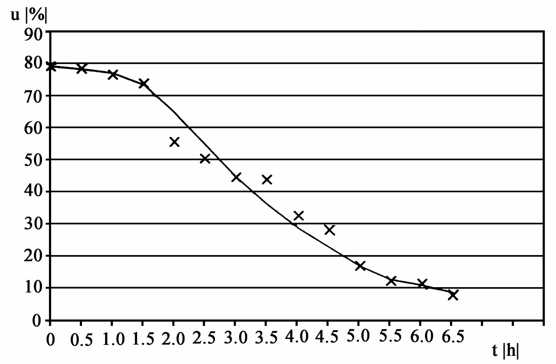

Fig. 3. – Samples' moisture according to the time of drying, where x represents pairs of measured values, and full line is approximate (theoretical) curve of drying

Tab. 3. - Approximate values and drying speed

t [h]	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
u_t [%]	79.2	78.3	77.1	73.5	65.0	55.25	45.0	36.5	28.9	23.0	17.1	13	11.3	9.1
du/dt	-	1.8	2.4	7.2	17.0	19.5	20.5	17.0	15.2	11.8	11.0	8.2	3.4	3.0

Change of drying speed over time is shown in Fig. 4.

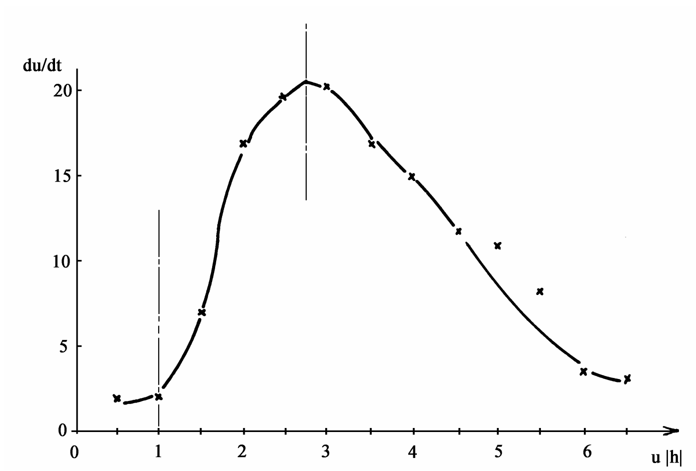

Fig. 4. - Drying speed during time

Fig. 4. shows that there actually exist three phases of drying with two critical spots. The first one is after the first hour, and the second after the second hour of drying.

In the first period, conditions were developed for later equalised (balanced) drying. Supplied heat was spent mainly on the heating of potato, and only the small quantities for water evaporating. Namely, heat first warms the surface of a sample and then, gradually, during the first hour, it spreads on the whole mass of the material. During that period only the free surface water evaporates.

In the period between the two critical spots, very fast drying is done because the interior is heated as well as the surface. Because of that weakly bound water from the interior comes to the surface of the material and evaporates from it. The water evaporation speed is always followed by sufficient diffusion of liquid water from the inside layers.

In the third period of drying, after the second critical spot, the amount of water that evaporates in the unit of time gradually decreases although the same quantities of heat are supplied. Namely, now the strongly bounded water evaporates, that is, the supplied heat is used for deceleration of bounds between water and dry matter. Because of that, the kinetic energy of molecules increases, that is, potato cubes are heated and their temperature almost equals the temperature of air. When these two temperatures become equal, drying practically stops. So, gradually it comes to physical deforming of sample and to creating of conditions for developing chemical reactions between the molecules of dry matter (before all sugar and amino acids), after which cubes change colour and receive unpleasant smell and taste.

It has already been said that better conclusions can be obtained by the analysis of the graph of evaporation speed dependency and present moisture in the material (Fig. 5.).

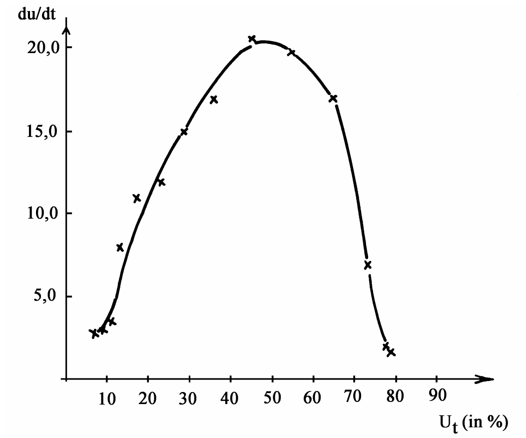

Fig. 5. - Evaporation speed dependency and present moisture in material

Again, in principle, from the stand point of water decreasing speed, three periods of drying can be distinguished. In the first and the third period speed is less than 10% per hour, while in the second period drying speed is substantially higher. This second period can be divided into two phases: the phase of increasing speed and the phase of decreasing drying speed. From the results of measurements as suggested in tables, it can be accepted with much approximation but also with certainty that mentioned periods (phases) last 1.5 hour each.

To define the process of dehydration closely (more precisely), it is easier if the potato moisture is expressed as water content per unit of dry mass (d) as shown in Table 4.

Tab. 4. - Potato moisture during drying expressed on moisture (u) and dry (d) basis

t [h]	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
u [%]	79.2	78.3	77.1	73.5	65.0	55.2	45.0	36.5	28.9	23.0	17.1	13.0	11.3	9.1
d [g/g]	3.81	3.61	3.37	2.77	1.86	1.23	0.82	0.57	0.44	0.30	0.21	0.15	0.13	0.10

From Table 4. it can be noticed that at the beginning of drying 100 g of dry matter of potato is bounded with 381 g water and after 6 hours of drying the same amount of dry matter (it doesn't change during drying) bounds only 13 g of water. So, the potato amount with 100 g of dry matter, evaporates 368 g of water during drying.

Loss of water during drying, calculated for drying periods of 1.5 hours and for 100 g of dry matter is shown in Table 5.

Tab. 5. - Loss of water during drying (in %) for separate phases

Time [h]	Content of water [g /100 g]	Loss of water [g]	Loss of water [in %]
0.0	381	-	-
1.5	277	104	28.3
3.0	82	195	53.0
4.5	30	52	14.1
6.0	13	17	4.6

From Table 5. it can be concluded that in the first period of drying when the speed is relatively small because the part of heating is spent on heating the material about 28% of water evaporates. In the next 1.5 hour the drying speed substantially increases and about half of the totally evaporated water evaporates. In the next 1.5 hours the drying speed slowly decreases and only 14% of water evaporates. In the last phase (the same time of duration and the same temperature of drying) only about 5% of water evaporates.

Conclusion

According to the results obtained by measurement of potato cubes moisture during drying at 70°C in a laboratory drier, the following can be concluded:

1. Curve of drying has two clearly defined critical spots or three periods of drying.
2. In the first period heat is spent on the heating of the material, but also on water evaporation. In 1.5 hour duration of this period, only 28.3% of water evaporated, and the drying speed is below 10% per hour.
3. In the second period drying speed is substantially higher and ranges from 10% per hour to 20% per hour. The highest speed was when the water content was 45.0%. Then it was 20.5% per hour. This period lasts for 3 hours and can be divided into the period of constant increasing of speed and the phase of decreasing of evaporating water speed. Both phases last 1.5 hour each.
4. In the first phase of the second period the largest quantity of water evaporated (half of the total amount of evaporated water during complete drying). After that, the drying speed slowly decreases and in the second phase (during the same time and under the same air characteristics) only 14% of water evaporated.

5. In the last phase of drying (third period) only strongly bounded water lags behind, so the drying speed is extremely small and the rest of 5% of water evaporated. Of course, the material has no way for cooling because small quantities of water evaporate. So, it comes to the heating of potato cubes, which becomes the factor of risk for the quality of the finished product.

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ISPITIVANJE KINETIKE SUŠENJA KROMPIRA U LABORATORIJSKIM USLOVIMA

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R e z i m e

Hemija jeste, po svojoj prirodi, fundamentalna nauka, ali su danas njena saznanja sve više primenjena u praksi. Tako su razvijene mnoge sinteze važnih prehrambenih i industrijskih jedinjenja (hemijska tehnologija), ili razgradnja štetnih supstanci (hemijska ekologija). Analitički deo hemije (analitička hemija) našla je značajnu primenu čak i u optimizaciji tehnoloških postupaka tehnologije hrane.

Jedan od najstarijih načina konzervisanja namirnica je sušenje (dehidracija). Osnova ovog postupka konzervisanja je da se voda ispari, da se proizvod dovoljno isuši, kako bi se sprečila aktivnost enzima i mogućnost razvoja mikroorganizama.

Voda u poljoprivrednim proizvodima nije slobodna već je vezana za suvu materiju. Zato je za njeno isparavanje potrebno dovesti dovoljno toplote. Deo dovedene toplote se koristi za isparavanje vode, ali jedan njen deo postaje energija aktivacije za niz hemijskih reakcija koje umanjuju nutritivnu vrednost i kvalitet buduće hrane. Stoga se postavlja važan inženjerski problem: odrediti optimalne uslove sušenja. Za optimizaciju tehnološkog postupka sušenja neophodno je prethodno izvršiti matematičko modeliranje zavisnosti brzine isparavanja vode od uslova sredine.

Cilj ovog rada je da utvrdi kinetiku sušenja komada krompira u laboratorijskoj sušari, kako bi se zatim utvrdili optimalni uslovi za njegovu industrijsku dehidraciju.

Utvrđeno je da u prvoj četvrtini vremena sušenja ispari 28,3% ukupno isparene vode, a zatim redom po četvrtinama: 53%, 14,1% i 4,6%. Najveća brzina sušenja ostvarena je pri vlažnosti krompira od oko 50%.

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