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KINETICS OF DRYING SELECTED VEGETABLES IN FOUNTAIN BED

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ABSTRACT

The results of drying kinetics are usually correlated with the linear flow of evaporated water depending on its content in the dried material. Investigation into the kinetics of drying vegetables such as: carrot, parsley, radish, celery and red beet, was the main aim of the present work in the bed fountain at temperatures close to ambient temperatures. Another aim of these investigations was to study the influence on the process of its three basic parameters: time, temperature, and moisture.

Keywords: vegetables, fountain bed, drying

INTRODUCTION

Drying by removing moisture from raw material by means of heat is a good way of food preservation. It is a very effective and economical method. Products obtained in the process are characterized by excellent stability. It is notable that not all materials can be dried by the same method. The development of various drying facilities allowed to develop many methods and ways of drying, which enables the application of the optimum conditions for a particular material and minimization of the loss of key ingredients from foods.

The drying process minimizes enzymatic and non-enzymatic conversion. Protection against microbial and mould growth is usually achieved by lowering the water content in the product to about 15%. However, to inhibit enzymatic and non-enzymatic conversion it was required to reduce water content in the product to quantities below 5%.

Drying should take place at temperatures from 60°C to 80°C. It must be remembered that excess temperatures cause denaturation of proteins of which the strength is lower in more humid environments.

A product dried at too high temperatures shows an ability to absorb water. Application of temperatures above 100°C leads to the decomposition and caramelization of sugar and, therefore, to the loss of dry matter and obtaining a dark brown colour of the dried product. The rate of evaporation of water is highly influenced by fragmentation of raw vegetables. If drying proceeds too rapidly, a very rapid evaporation of moisture follows from the surface layers of the product, with the result produced on the outside shell, which impedes the evaporation of water from deeper layers. Raw materials may be burned in certain places and not fully dried in other ones [1].

Application in the drying process of fluid fountain, which is the case of the fluidized bed [5, 6], enables the process to be conducted most efficiently.

The results of drying kinetics are usually correlated with the linear flow of evaporated water depending on its content in the dried material. The obtained values of the kinetic coefficient of the drying process depend on the particle size and hygroscopic properties, velocity, temperature and relative humidity [2, 7].

Investigation into the kinetics of drying vegetables such as: carrot, parsley, radish, celery and red beet, was the main aim of the present work in the bed fountain at temperatures close to ambient temperatures.

Another aim of these investigations was to study the influence on the process of its three basic parameters: time, temperature, and moisture.

METHODS

The vegetables used in the study were: carrot, parsley, radish, celery and beetroot. The vegetables were initially dehydrated in a juice extractor. After obtaining a vegetable press the corresponding five saponification-charges were prepared. Two samples, each weighing 50 g, were placed in a drying chamber for a period of seven days at 50°C to determine the weight of dry matter. However, three attempts at 200 g each were used for drying in a fluid fountain in three different times: 15, 30, 45 minutes. Before proceeding to drying at elevated temperatures a fan heater was started and then the drier fountain was filled with 200 g of the vegetable press. To prevent stripping away of the smallest dried particles of material a lid with a grid of mesh size 0.05 mm was used.

The successive trials in the drying fountain lasted 15, 30 or 45 minutes. The time and temperature of the process were strictly controlled. After the time had lapsed, the water mass loss was measured by weighing the sample by means of an electronic scale with an accuracy to 0.001 g. Immediately after the process, the sample was placed in a drying chamber for a period of seven days at 50°C.

The test was conducted in the air stream collected from the surroundings heated to temperatures in the range 30÷40°C, and not heated at temperatures in the range 8÷16°C. The same vegetables were used in both cases, which enabled determination of the effect of temperature on the drying kinetics.

The study of the drying kinetics in the air stream in a fluid fountain was conducted in the camera; the pattern shown is in Figure 1.

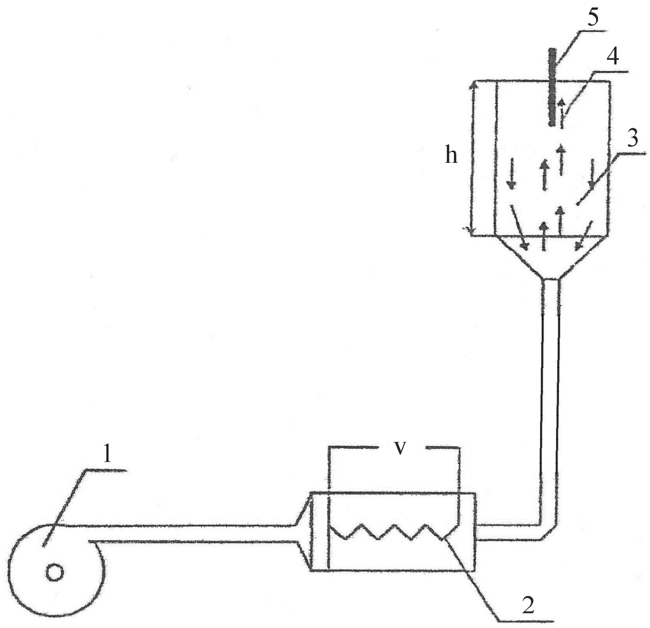

Fig. 1. Diagram of drying apparatus: 1 – blowing fan, 2 – air heater, 3 – chamber, 4 – dried material in fountain bed, 5 – thermometer.

Drying was held in a conical chamber of which the height was about 320 mm, inlet diameter 50 mm and outlet diameter 180 mm. The flow rate of the stream of air carried out by the deposit was 20 $dm^3 \cdot s^{-1}$. Temperature was measured in the interior deposit of the fountain bed at 5 min time intervals. The results of the measurements: temperature t, sample mass before drying M_0, sample mass after drying in the fountain deposit M_1, mass after drying in the chamber dryer M_{S1}, content of dry matter after drying in the chamber dryer m_s in a sample of the mass m_0 were given in Table 1.

RESULTS AND DISCUSSION

Due to the possibility of material loss during the sample on drying, dry mass M_S was calculated on the basis of the dry matter content in a 1 g sample (m_S/m_0):

$$M_S = \frac{m_S}{m_0} M_0 \tag{1}$$

where:

M_S – dry matter contained in sample M_0, [g],
m_S – dry matter received from sample of mass m_0, [g],
M_0 – the mass used to drying in fountain bed, [g].

From the above, the content of water $M_{W0} = M_0 - M_S$ in the sample M_0.

Based on the moisture content in the sample after drying ($M_1 - M_{S1}$) in a fluid fountain M_{W1} the mass of water in the sample to dry M_S was calculated:

$$M_{W1} = \frac{M_1 - M_{S1}}{M_{S1}} M_S \tag{2}$$

where:

M_{W1} – the mass of water contained in the sample after drying in fountain bed, [g].

Equation of the speed of drying:

$$-\frac{dM_W}{d\tau} = kP_W M_W \tag{3}$$

where:

P_W – saturated vapour pressure [kPa].

After transformation of Equation (3) the mass of water M_W was determined in a dried analytical sample in drying time:

$$M_W = M_{W0} \exp(-kP_W \tau) \tag{4}$$

or

$$y = \frac{M_W}{M_{W0}} = a_0 \exp(-kx) \tag{5}$$

where:

τ – time of drying in fountain bed, [h],
P_W – saturated vapour pressure at drying temperature, [kPa],
x = ($P_W \cdot \tau$) [kPa · h],
a_0 = 1.

Table 1. Drying in heater air (round 1).

Raw material	Sample no.	Mass before drying in chamber drier	Mass after drying in chamber drier	Mass before drying in fountain bed	Mass after drying in fountain bed	Mass after drying in chamber drier (period 7 days)	Process temperature	Drying time
		m_0 [g]	m_s [g]	M_0 [g]	M_1 [g]	M_{s1} [g]	t [°C]	τ [h]
Carrot	I	50	7.1	200	111.2	26.3	35.5	0.25
	II			200	59.9	25.5	38	0.5
	III			200	27.9	23.7	39.5	0.75
Parsley	I	50	10.6	200	70	39	34	0.25
	II			200	45.4	39.6	34	0.5
	III			200	30.3	26.5	37	0.75
Radish	I	50	4.95	200	68.9	20	34.5	0.25
	II			200	37.3	19.9	36	0.5
	III			200	24.6	18.8	38.5	0.75
Celery	I	50	6.8	200	88.7	25.1	30	0.25
	II			200	37.6	27.1	30	0.5
	III			200	26.9	22.6	31.5	0.75
Red beet	I	50	8.65	200	130.6	33.8	31	0.25
	II			200	64.3	32.4	32.5	0.5
	III			200	31.8	27.7	37.5	0.75

Table 2. Drying in cool air (round 2).

Raw material	Sample no.	Mass before drying in chamber drier	Mass after drying in chamber drier	Mass before drying in fountain bed	Mass after drying in fountain bed	Mass after drying in chamber drier (period 7 days)	Process temperature	Drying time
		m_0 [g]	m_s [g]	M_0 [g]	M_1 [g]	M_{s1} [g]	t [°C]	τ [h]
Carrot	I	50	8.2	200	131.5	32.3	15	0.25
	II			200	121.5	30.8	16	0.5
	III			200	105.9	28.8	15.5	0.75
Parsley	I	50	13.7	200	175.4	58.1	8.5	0.25
	II			200	144.9	56.9	9	0.5
	III			200	117.5	51.3	9	0.75
Radish	I	50	4.7	200	164.4	19.8	9	0.25
	II			200	148.2	20	8.5	0.5
	III			200	108.3	18.6	9	0.75
Celery	I	50	7.75	200	159.1	31.1	15	0.25
	II			200	119.4	30.6	14.5	0.5
	III			200	83.0	29.9	14	0.75
Red beet	I	50	8.5	200	149.3	35.9	9.5	0.25
	II			200	118.7	37.1	8	0.5
	III			200	87.7	33.8	9.5	0.75

Table 3. Drying in heater air (round 1).

Raw material	Sample no.	Dry matter content	Water content in sample before drying in fountain bed	Water content in sample after drying in fountain bed	Saturate vapour pressure at fountain bed temperature	Coefficient k
		M_s [g]	M_{w0} [g]	M_{w1} [g]	P_W [kPa]	k [h · kPa]$^{-1}$
Carrot	I	28.4	171.6	91.67	5.6227	0.4460
	II			38.31	6.6229	0.4526
	III			5.03	6.9915	0.6731
Parsley	I	42.4	157.6	33.7	5.3192	1.16
	II			6.21	5.3192	1.2159
	III			6.08	6.2749	0.6916
Radish	I	19.8	180.2	48.4	5.3192	0.9885
	II			17.3	5.9411	0.7888
	III			6.1	6.6249	0.6814
Celery	I	27.2	172.8	68.9	4.2427	0.8669
	II			10.5	4.2427	1.3202
	III			5.2	4.4922	1.0399
Red beet	I	34.6	165.4	99.0	4.4922	0.4570
	II			34.0	4.7545	0.6655
	III			5.12	6.2749	0.7384

Table 4. Drying in cool air (round 2).

Raw material	Sample no.	Dry matter content	Water content in sample before drying in fountain bed	Water content in sample after drying in fountain bed	Saturate vapour pressure at fountain bed temperature	Coefficient k
		M_s [g]	M_{w0} [g]	M_{w1} [g]	P_W [kPa]	k [h · kPa]$^{-1}$
Carrot	I	32.8	167.2	100.8	1.7048	1.1874
	II			96.5	1.8176	0.6048
	III			87.8	1.7048	0.5038
Parsley	I	54.8	145.2	110.6	1.116	0.9756
	II			84.7	1.1847	0.9099
	III			70.7	1.1847	0.8099
Radish	I	18.8	181.2	137.2	1.1847	0.9391
	II			120.5	1.116	0.7311
	III			90.7	1.1847	0.7789
Celery	I	31.2	168.8	128.4	1.7048	0.6419
	II			90.5	1.5981	0.7801
	III			55.4	1.5981	0.9295
Red beet	I	34	166	107.4	1.1847	1.4702
	II			73.9	1.116	1.4503
	III			54.21	1.1847	1.2595

CONCLUSIONS

– The kinetic coefficient, *k*, of drying in fountain bed for five vegetables and three drying periods was determined:
  – during drying in a stream of ambient air the kinetic coefficient ranges from 0.5 – 1.5 [h · kPa]. The lowest value was obtained for the carrot, and the highest for the beet root,
  – when drying in a stream of air heated to about 25°C, the kinetic coefficient ranges from 0.4 to 1.3 [h · kPa]. The lowest value was obtained for the coefficient of carrots, and the highest for celery.

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