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Energy efficiency of impulse drying regimes of beetroot

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An experimental research of impulse convective drying regimes of beetroot has been done. The experiments have been grouped in two series according to the periods of heating and cooling. The first group consisted of symmetric experiments with equal periods of heating and cooling, and the second one of asymmetric experiments with a heating period that is two times longer. The temperature of the air during the heating period for both groups was 60°C. The energy consumption for each of the experiments has been determined and compared to the same consumption at the continuous regime. The influence of impulse duration on heat consumption has been analyzed. A saving of energy up to 22% was registered when compared to the continuous drying mode.

Keywords: Drying, beetroot, impulse regimes, specific energy consumption

INTRODUCTION

The drying of foodstuffs is an important and widely used method for preserving [4]. Fresh fruits and vegetables are very perishable due to their high water content of over 80% and putrefaction processes [7, 5, 11]. Drying of food is also important for reducing the weight and volume of the products and for an easier storage and transportation [6]. A relatively high drying rate and high capacity are observed in convective drying.

Beetroot contains valuable active compounds such as carotenoids, polyphenols, flavonoids, saponins and others. Dried beetroot can be consumed in the form of chips or after preparation as a component of instant food, tea, powder in bakery and food supplements [4, 1]. It also can be used in various forms as a red food colorant [4].

The quality of the final dried product is also an important criterion. Drying reflects in changing the properties of the products: discoloring, aroma loss, textural changes, nutritive value and shape. Higher drying temperature reduces the drying time but may result in poor product quality, cracking, deformation or collapse as well as leads to higher energy consumption. Improving energy efficiency in the drying process of food products will support global energy development. Lower temperatures reduce the drying rate and extend the duration of the process [3].

In recent years, new technologies have been developed, and their aim is to improve quality, to reduce the energy consumption, to reduce the harmful impact on the environment and to improve the safety of foodstuffs [8]. Intermittent drying is one of the technical solutions for this, as it reduces the effective drying time, improves the product quality [3], reduces the energy consumption and non-enzymatic browning [10]. Yang et al. have been reaching the same conclusion, using a heat pump [10]. Intermittent drying is one of the promising solutions for improving the energy efficiency and the product quality without increasing the capital cost of the drier. It is a drying method where drying conditions are variable in time. This can be achieved by the heat supply regimes, varying the airflow rate, air temperature, humidity, or operating pressure. According to Kumar et al. [3] intermittent drying can also be achieved by changing the way energy has been delivered (convection, conduction, radiation or microwave). Intensification of the moisture transfer from the center to the surface of the sample during tempering period has been achieved by the intermittent drying [3, 10]. The drying rate over a constant temperature period is faster than that during the heating period and slower than that during the cooling period. The reasons for this are the directions of the moisture and temperature gradients [10].

Kumar et al. [3] have submitted a possible classification for organizing the impulse drying. [3] A combination of convective drying with intermittent application of ultrasound, infrared heating and microwave has been considered. [3] The proposed classification by Yang et al. consists of 4 categories [10].

The improvement of the energy efficiency and the quality of food products can be achieved by a combination of convective drying and microwave pulse (using microwaves in a convection dryer)

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according to Kumar et al [2]. Experimental investigations with apple slices (from Granny Smith kind apples with a disc thickness of 10mm and a diameter of 40 mm) have been conducted. The air temperature has been 60ºC. Periods of microwave influence for 20s and convective drying for 80s have been alternated. A multiphase porous media model has been proposed, and it has been validated by comparison with the experimental results. By this model the moisture content and the temperature field after each heating and tempering period has been investigated [2].

Silva et al. [8] have conducted an experimental investigation intermittent convective drying for whole pears (the kind of Rocha). The investigation has been conducted at two temperatures (40°C and 50°C) and two air velocities (1.28 m/s and 2.66 m/s). From the conducting experiments has been established that the air temperature has higher influence on the drying kinetics, compared to that of the air velocity. Also, shorter drying periods with high relative humidity on supplied air and two temperature levels lead to longer drying period, but to improved organoleptic characteristics, productivity and energy savings [8].

Da Silva et al. [9] compared the experimental results of convective drying of whole bananas in continuous and periodic regimes for 8 hours. The impulse regimes have been symmetrical with the duration of the heating and cooling periods of 0.5h, 1h and 2h. During the heating period, the temperature was 70°C, air velocity was 0.55 m/s, and during the relaxation period, the product has been placed in a desiccator at an ambient temperature of 30°C. After comparing the regimes at the end of the process, the moisture content at a continuous regime has been 0.42, and at the periodical with period of 1h it has been 0.14. The time and the energy consumption for drying have been reduced and the quality of the final product has been increased as a result of the intermittent. Increasing the time for intermittent from 0.5 hours to 2 hours has increased the drying rate [9].

In the literature, an intermittency ratio α is defined as the ratio of the time of the relaxation period to the total time (the sum of the heating and relaxation periods). [3, 9] Yang et al. define it as the ratio of the time of the heating period to the total time [10].

Yang et al. have conducted a comparative simulation study on different intermittent heat pump dryings on Chinese cabbage seeds [10]. The experimental parameters they applied have been: initial moisture content 30% (d.b.), temperature 40°C in heating period, relative humidity 40%, airflow velocity 1m/s, drying time in a range to 1200s. At α=1/3 (for intermittent drying), the energy consumed has been 51.9% of that in the continuous drying regime, respectively the energy saving has been 48.1% [10].

Comparing with a continuous process, the energy saving increases with the increase of the intermittency ratio α. A comparison between the improving energy efficiency and the product quality in different impulse regimes also have been done [3].

Aim of the work: The aim of this study is to experimentally determine the optimum impulse regimes for convective drying of beetroot.

MATERIALS AND METHODS

Sample preparation

The process of drying in a thick layer of red beetroot (Beta vulgaris ssp. vulgaris var. vulgaris), has been studied. Beetroots of "Pablo F1" variety were cultivated in a field situated close to Plovdiv (Bulgaria). Roots have been stored at room temperature until use.

The red beetroots of similar size were washed and peeled. Roots were cut into 10 mm cubes by using of a cutter equipped with a knife moving perpendicularly to a horizontal base. The base was covered with thick rubber. The knife of the cutter is a grid with dimensions 10x10 mm.

Drying process

A convective dryer was used to dry red beetroots. It is installed in the Department of Industrial Heat Engineering, University of Food Technologies - Plovdiv.

The process of drying in a thick layer of red beetroot "Pablo F1" variety, has been studied. The red beet was cut into cubes of size 10x10x10 mm.

A dryer was designed and constructed considering the general requirements for drying resulting from pulsed provision of heat. Fig.1 is a schematic diagram of a drying stand which consists of the following basic elements: 1- centrifugal fan, 2 - air ducts, 3 - electric heater, 4 - drying chamber, 5- two-channel regulator MS8111PWM3S, 6 - two-channel microprocessor-based timer MS8203 2Ch, 7- autotransformer, 8- combined sensor "Vektor1" and W – wattmeter.

The drying chamber is in the form of a parallelepiped with dimensions 120x120x160 mm. The centrifugal fan is of the type AV50 / ATII with a power of 50 W and a volumetric flow rate

200m^3/h. The electric heater is made of 3 spiral coils with a maximum total power of 2700 W . The ducts have a square cross section with dimensions 50x50 mm. The air ducts, the drying chamber and the electric heater are insulated with aeroflex with a thickness 15mm.

The dryer is equipped with two-channel regulator MS8111PWM3S.Pt100.0, 0 – 200.0°C, 220V with two sensors ST.Pt100.A1.n60.d5.k1500Si-3W to monitor the temperatures before the drying chamber and the ambient air. For the scope of accurately controlling the heat impulse, the system is equipped with two-channel microprocessor-based timer MS8203 2Ch. The relative humidity of the outer air is monitored using a combined sensor "Vektor1", which reports periodically at an interval of 60 s.

The air is sucked in by the fan, is heated by the electric heater, and then enters the drying chamber. The exhaust air is not regenerated.

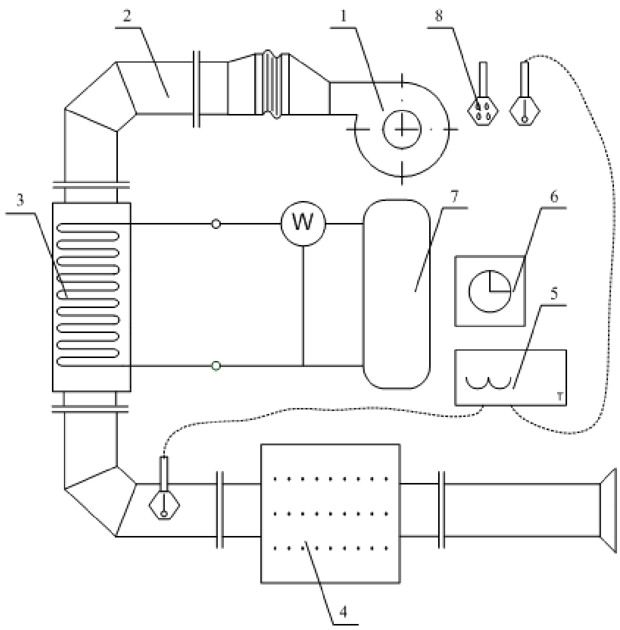

Fig.1. Scheme of the convective dryer

1- centrifugal fan, 2 - air ducts, 3 - electric heater, 4 - Drying chamber, 5 - two-channel regulator MS8111PWM3S, 6 - Two-channel microprocessor-based timer MS8203 2Ch, 7 - autotransformer, 8- combined sensor "Vektor1" and W – wattmeter.

The operating parameters in the drying chamber were: the inlet air temperature during the heating period was 60°C, relative humidity of the air φ = 50 % , air velocity was 2.2 m/s. The loading on the drying chamber was G/F = 9 kg/m^2.

The experiments were organized in the following three groups.

1st group - continuous modes;

2nd group - symmetric impulse modes: 3+3, 6+6 and 9+9 min;

3rd group - asymmetrical impulse modes are: 3+1.5; 6+3 and 9+4.5 min.

The organization of impulse symmetric and asymmetric modes was automatically made by switching on and off electric heaters by two-channel microprocessor-based timer MS8203 2Ch. The air temperature during the cooling period was 24 °C (ambient temperature).

The energy consumption for each of the experiments was compared to a continuous experiment under the same conditions (amount of evaporated water and ambient temperature).

For each experiment, a drying curve was constructed $U=f(\tau)$. The drying time ($\Delta\tau$) is determined, as it corresponds to the same initial and final humidity and the same amount of evaporated water.

The total dry matter has been determined by gravimetric method with loss of mass on drying. The sample has been dried in an atmospheric oven at 135 ± 2°C. It has been periodically weighed until reaching the constant mass. The mass of the product has been measured by an analytical balance with accuracy of 0.0001 grams.

The total amount of energy consumed for each experiment was measured by a digital multimer with a basic error ± 0.01%.

Investigation of the kinetics of the drying process

On the basis of experimental data, the drying curves have been drawn Eq.(1).

$$U=f(\tau) \tag{1}$$

From drying curves, the drying rate curves have been drawn by graphical differentiation Eq.(2).

$$\frac{dU}{d\tau} = f(U) \tag{2}$$

where:

U - moisture content,% - kg water/kg drying base;

τ - drying time, min

The drying rate in the first period is described by the Eq.(3):

$$-\frac{dU}{d\tau} = C = const. \tag{3}$$

At the approximation of the drying curve during the second drying period with a straight line (the Fisher's method), the drying rate is described by the Eq.(4):

$$-\frac{dU}{d\tau} = K_c(U - U_p) \qquad (4)$$

where: K_c - drying coefficient, %/min;
U_p - equilibrium moisture content, %. [12]

RESULTS AND DISCUSSION

Tab.1 presents the results for the final energy consumption for all experiments that were conducted. It can be seen that for all experiments in the group of symmetric regimes there is a significant decrease in the energy consumption for drying compared to that of the continuous mode. The highest energy savings (22.6%) was obtained for the mode 3+3.

Table 1. Energy consumption

Regime	Energy consumption, kWh	Energy Reduction,%
continuous	1.99	-
3+1.5	1.966	1.2
6+3	1.969	1.1
9+4.5	1.809	9.1
continuous	1.789	0
3+3	1.384	22.6
6+6	1.424	20.4
9+9	1.533	14.3

There is a slight decrease in energy consumption (about 1%) compared to the continuous mode in the 3+1.5 and 6+3 modes from the group of the asymmetrical modes. Higher energy savings (9.1%) are obtained only in the 9+4.5 mode. In general, it is seen that the application of asymmetric regimes does not lead to substantial energy savings, while increasing the drying time (up to 60 minutes). For this reason, their application to this product and under these conditions is inappropriate.

The reason for the energy savings in impulse drying is the fact that during the cooling period of the product the directions of the temperature and humidity gradient coincide. This results in the reduction of the diffusion resistance and easier movement of the moisture to the periphery of the product. The reason for the differences observed in the energy consumption, for the two groups, is the ratio of durations of the heating and cooling periods. The drying curves for the two groups of experiments are shown in Fig.2 and Fig.3.

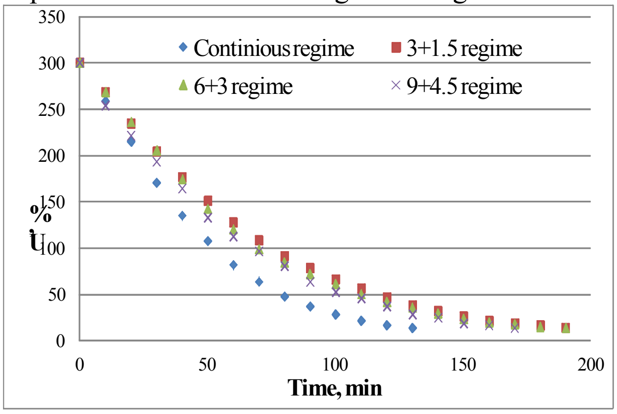

Fig.2. Drying curves for asymmetrical regimes

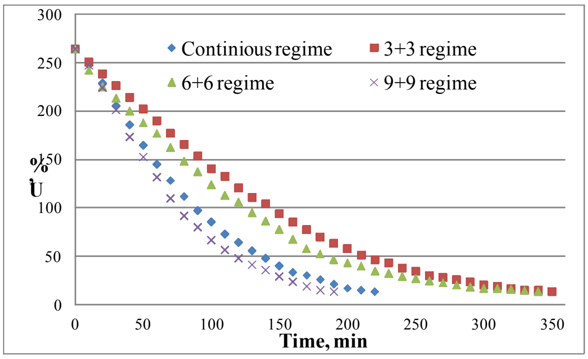

Fig.3. Drying curves for symmetrical regimes

For the group of symmetric regimes, the longest drying time is required for 3+3 mode, followed by 6+6 mode, 350 and 340 minutes, respectively. In 9+9 mode, there is a significant reduction in drying time of up to 190 minutes, which is even 30 minutes less than in continuous mode.

Fig.4 to 7 show the drying rate curves for a second period for the experiments from the group of symmetrical modes and the continuous mode with which they were compared.

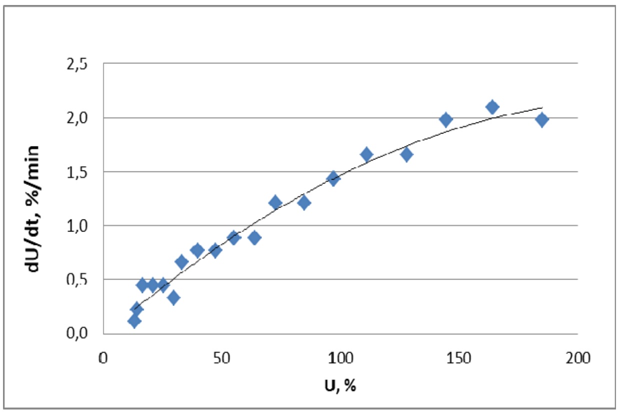

Fig.4. Drying rate curve for the second drying period for the continuous regime

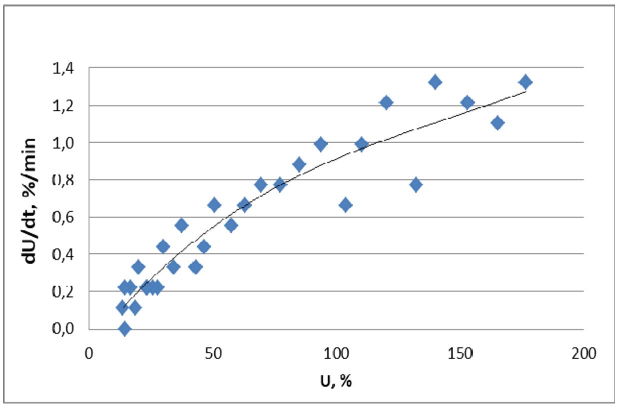

Fig.5. Drying rate curve for the second drying period for the 3+3 regime

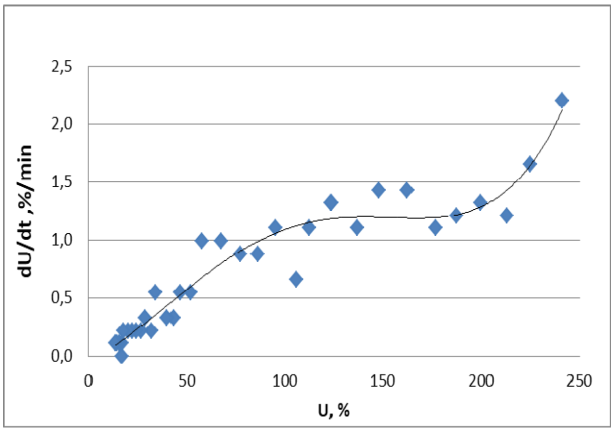

Fig.6. Drying rate curve for the second drying period for the 6+6 regime

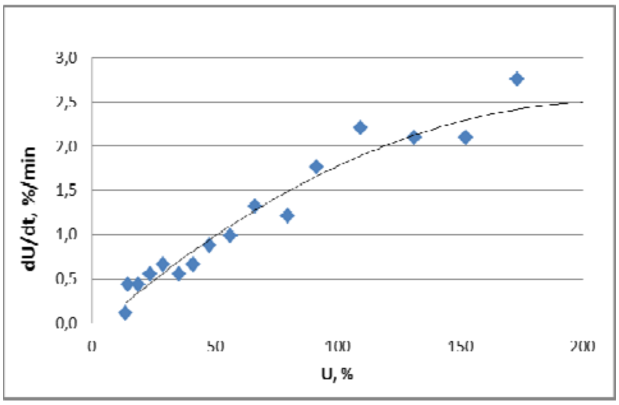

Fig.7. Drying rate curve for the second drying period for the 9+9 regime

It can be seen, from the impulse mode graphs, that there is a significant dispersion of the points due to impulse heat supply.

Tab.2 shows the values of the drying rate for the first period (C, %/min) and the drying coefficient for the second period (K, %/min), calculated on the basis of the drying curves by Fisher's method.

Table 2. The drying rate for the first period and the drying coefficient for a second period

Regime	C, %/min	K, %/min
Continuous	1.9559	0.0309
3+3	1.2241	0.0184
6+6	1.3242	0.0191
9+9	2.2241	0.038

CONCLUSIONS

There is a significant reduction in the energy consumption for drying compared to the continuous mode for all the experiments from the group of symmetrical regimes. Energy savings are in the range from 14.3 to 22.6%.

The energy savings are of lowest number for the group of asymmetric regimes. The energy consumption is comparable to that of continuous drying. This makes the applying of these regimes inappropriate, from an energy point of view.

There is a tendency to decrease the drying time by increasing the impulse duration within the range studied for the symmetrical modes.

The highest values of the of drying rate for the first period and the drying coefficient for the second period are obtained for the 9+9 symmetric mode.

NOMENCLATURE

α - intermittency ratio, -;

C - drying rate in the first period, %/min;

G/F - loading on the drying chamber, kg/m^2;

K_c - drying rate in the second period, %/min

U - moisture content, % - kg, water/kg drying base;

U_p - equilibrium moisture content, %;

φ - relative humidity, %;

τ - drying time, min.

Subscripts

d.b. - drying base.

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