Laboratory convective dryer combined with microwaves

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Abstract. A laboratory equipment for combinations of convective and microwave drying is presented. It was applied for drying of parsnips. Lower energy consumption at microwave heating of the product at intermitted drying is confirmed in comparison to continuous convective drying with hot air. In addition, the influence of the drying process on the phenols and flavonoids contents in at continuous convective drying were investigated. The results give useful information for the organisation and the operating of the drying modes of vegetables.

1 Introduction

Drying of food products is an important and widely used method of its preservation. There are different methods for food products' drying, and the choice of the most appropriate method depends on various criteria: energy consumption, technological process, quality of the obtained product, etc.

The energy efficiency of the process of removing moisture from the product is mainly assessed by the specific energy consumption for its implementation.

The energy for drying (dehydration) during the process can be supplied to the product in different ways – convective, conductive, microwave or electromagnetic waves.

The energy in the convective drying process is used to heat the dryer and the wet product, to transport the drying agent and the product, to maintain a temperature and humidity gradient, to transport moisture from the interior to the surface of the product, to provide a process of mass exchange between the product and the drying agent, as well as to cover the energy loss in the environment. The energy balance of the given drying system determines the share of each component in the total energy consumption [1 - 6]. The quality of the obtained dried product is an important criterion. The drying process leads to different changes in the properties of the products: discoloration; loss of flavors; changes in texture, nutritional value and shape [19]. A higher drying temperature reduces the drying time, but may lead to poorer product quality, cracking, distortion or disintegration, as well as higher energy consumption. Improving the energy efficiency of the food drying process would aid efforts to limit global warming. Low-temperature drying processes reduce the drying rate and extend the duration of the process [21].

In recent years, new technologies for drying products have been developed, which lead to: improving food safety; increase product quality; reduction of energy consumption and the harmful impact of processes on the environment [7, 9, 11, 12, 13, 14, 20, 22, 23].

The batch drying process is one of the possible technical solutions for: reducing the effective drying time; improvement of product quality [8, 9, 10, 15, 17, 18, 24]; reducing energy consumption and non-enzymatic browning [19].

The combined impulse drying mode has been one of the promising decisions to improve the process energy efficiency and the product quality. The regime's parameters change over time in this drying method. This could be achieved by changing the heat supply mode and the velocity, temperature, relative humidity or operating pressure of the drying agent. According to [10] batch drying process could also be realized by changing the way of energy supply (convection, conduction, radiation or by microwaves) [16, 19, 20, 21, 22]. In the process of intermittent drying, the movement of moisture from the center to the surface of the sample is accelerated during the cooling period [10]. The drying rate in the constant temperature period is higher than that in the heating period and lower than that in the cooling period. The reason is the coincident direction of the moisture and temperature gradients [22].

Based on the general requirements for drying installations and the specific requirements resulting from pulsed energy supply, a laboratory convective dryer combined with microwaves for drying vegetable food products (mainly root crops) was designed and built.

2 Laboratory dryer - construction and operating principle

A laboratory convective dryer combined with a microwave power supply was constructed. It allows the implementation of various drying regimes. Fig. 1 shows the proposed laboratory dryer with combined operation modes.

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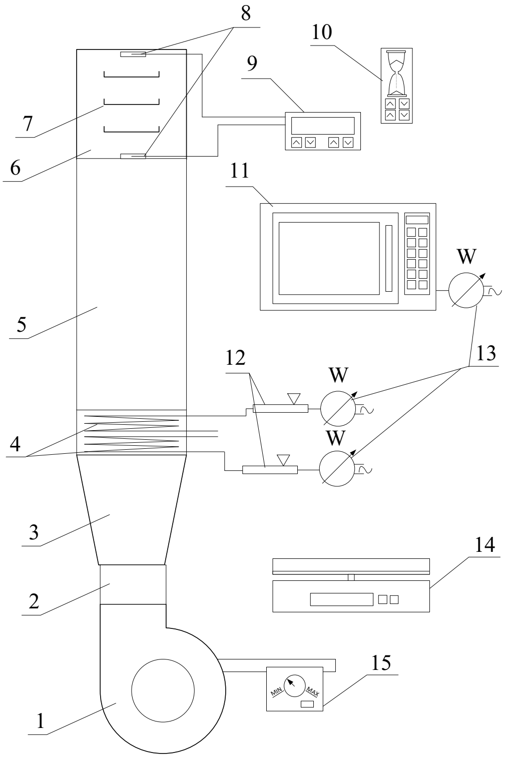

Fig. 1. Laboratory dryer with combined operation modes.

1 - centrifugal fan; 2 – leather sleeve; 3 - transition air duct; 4 – heaters; 5 – air duct; 6 – drying chamber; 7 – tray with product; 8 – thermistor temperature sensors; 9 – controller for temperature monitoring; 10 – controller for time monitoring; 11 – microwave chamber; 12 – autotransformers; 13 – digital watt meters; 14 – electronic scale; 15 - regulator for velocity control.

The weight of wet and dried product was measured during drying process by technical electronic scale - model B6P (14) with a maximum load and minimum load of 6 kg and 4 g respectively, accuracy of 0.2 g, and dimensions of the measuring plate 250x300 mm.

The temperature of product during the drying process was measured with an infrared thermometer - type Pyrometer BP 20, with measuring range from -35 ºC to 800°C, accuracy ±1% of measured value, emission factor of 0.1-1.0, optical resolution 12:1, target display laser class 2, response time of 0.3 s.

The drying chamber (6) has the shape of a parallelepiped with dimensions of 305×203×300 mm. The fan (1) is a channel type centrifugal, industrial, type Bahchivanmotors BVN G2S-250, with a nominal power consumption of 156 W, volume flow up to 1000 m³/h, speed 2380 rpm, total pressure 600 Pa, sound power level of 63 dB. The regulation of the volume flow rate of drying agent was carried out by velocity control regulator (15) with the possibility of step less control. The electric heater (4) is made of two spirally wound Cantal wires with a maximum power of 2000 W each (total available power is 4000 W). The power of the heaters is regulated step less by two autotransformers (12). Each heater is equipped with a separate digital watt meter (13) for measuring the energy consumption. The cross-section of the air duct (5) is rectangular with dimensions of 325×260 mm, with a length of 1 m and was made from insulating material (polyurethane foam sheets with aluminium foil).

The air velocity is measured with a thermo-anemometer with a hotwire probe type VT50.

The dryer was equipped with a two-channel controller MS8111_1M.2.22.T0.PA.I0.AA.BA.CA.D type (9), with two inputs for Pt100 sensors with temperature range of 0.0-200.0°C and supply voltage of 220V. The thermistor temperature sensors ST.R. A1_B5.D1.P4.NX.S3.k1 RTD-Pt100 type (8) with range from -50°C to 200°C. They are mounted for temperature monitoring before and after the drying chamber (6). For precisely control of the heat intermittent regimes, the dryer was equipped with a two-channel timer MS8226_R1.PA.AF.BB.CA.GA type (10).

The power of microwave magnetron (11) is adjustable with a maximum value of 1000 W and is measured by independent digital watt meter (13). The dimensions of the chamber are 331×331×197 mm, with a volume of 26 l.

The dryer works as follows: The sucked air from fan (1) enter in the heater (4) and proceed in the drying chamber (6). The product is placed on trays (7). The chamber has the capability to dry the product up to four trays with longitudinal flow or cross blowing of the layer. The laboratory dryer with combined operation modes works with one pass use of drying agent.

3 Dryer's application

The laboratory dryer with combined operation modes offers the following capabilities for organizing different drying processes:

- convective drying - continuous regime with longitudinal flow or cross blowing of the layer;
- convective drying using intermittent regimes of heating and cooling (symmetrical and asymmetrical);
- combined drying - convective and microwave heating with longitudinal flow or cross blowing of the layer;
- combined drying - using intermittent regimes of heating and cooling (symmetrical and asymmetrical).

When drying agent flows longitudinally of the layer, the drying chamber (6) is installed horizontally.

In convective drying, the product is heated by the drying agent - by the heater (4). In combined drying, the product is heated by a microwave chamber (11), and the drying agent - by the heater (4).

The type of intermittent modes depends on the duration of the heating and cooling product periods. Duration the heating and cooling periods are equal in symmetric regimes and different for asymmetric modes.

4 The drying product

Initial experiments were conducted to test the dryer with a parsnip. The product is a 2021 vintage and it was cut into 4 mm thickness discs (those with larger diameters were cut into two or four pieces additionally).

The drying process was carried out by blowing the layer from bottom to top with a drying agent in the following modes:

- continuous convective drying;

- combined symmetrical (5+5) regime with microwave heating of the product;

- combined asymmetric (1+3) regime with microwave heating of the product.

The drying agent was at ambient temperature in the combined modes. The first number indicates the duration of microwave heating in minutes, and the second - the duration of cooling when blowing the layer. The average load of the drying chamber was 8 kg/m².

The conditions for conducting the experiments in some regimes are presented in Table 1.

Table 1. Conditions for conducting the experiments

Parameter	Continuous regime	Symmetrical (5+5) regime	Asymmetric (1+3) regime
Initial moisture content of the product, %	83	83	83
Final moisture content of the product, %	5	5	5
Amount of evaporated water, kg	0.852	0.852	0.852
Drying time, min	250	320	230
Total energy consumption, kWh	13.3	1.309	1.339
Specific energy consumption kJ/kg w.e.	56197	5531	5658
Temperature of the drying agent, °C	45	20	20
Average temp. of the product, °C	-	70	50
Drying agent rate, m/s	3 - 6	3 - 6	3 - 6
Microwave power, W	-	500	1000

The experimental results show a significant reduction in total energy consumption for drying with combined microwave heating of the product compared to that with convective heating. On the one hand, this is due to the fact that the energy required for drying is only applied to the product without heating the air. On the other hand, the reason for the energy saving in intermittent drying is the fact that during the cooling period of the product, the directions of the temperature and humidity gradient coincide. This leads to a reduction in diffusion resistance and easier movement of moisture to the periphery of the product.

It can be seen from the experimental results that there is a significant difference in drying time between intermittent modes. The reason is in the ratio of the length's duration of the heating and cooling periods of the product. The shorter heating period in regime 1+3 results in a significant reduction in drying time with almost the same total energy consumption compared to the 5+5 mode. Also, in this mode, a lower average temperature of the product is observed due to its more frequent cooling, although the supplied power is greater, compared to the 5+5 regime. This helps to protect the product from overheating, which leads to browning, especially in the extreme, thinner parts of the slices.

The product before and after drying is shown in Fig. 2. Initial inspection shows very good color retention with no signs of scorching or non-enzymatic browning.

a

b

Fig. 2. Drying product - parsnip
a – before drying; b - after drying

The influence of the drying process on the total phenols and flavonoids in one of the modes (continuous convective drying) was also investigated. The amount of total phenols in the obtained extracts was determined by the Folin-Ciocalteu's method. Total flavonoid content (TFC) in quercetin equivalents (mgQE/g dw) of the extracts obtained was determined spectrophotometrically (UV-VIS Helios Omega, USA). The Samples have been subjected to TF analysis. The results are presented in Table 2.

Table 2. Content of flavonoids and phenols in fresh and dried parsnips

Fresh product			
Parsnips core moisture content 82.96%		Parsnip waste moisture content 82.76%	
flavonoids	phenols	flavonoids	phenols
2.18 ± 0.056	5.865 ± 1.378	2.385 ± 0.063	9.045 ± 0.346
Dried product			
Parsnips core moisture content 5.04%		Parsnip waste moisture content 6,36%	
flavonoids	phenols	flavonoids	phenols
0.672 ± 0.108	2.632 ± 0.371	0.442 ± 0.005	3.685 ± 0.035

It can be seen from the obtained results, that product exposure to heat during the convective drying process leads to an expected decrease in the content of phenols and flavonoids in the dried product. An increase in their content can be expected when using combined drying regimes and intermittent regimes.

5 Conclusion

A laboratory convective dryer combined with a microwave power supply was designed and built. It can work at different drying modes: convective drying; intermittent convective drying; combined drying; combined drying using intermittent modes.

Initial experiments conducted with parsnips drying in laboratory dryer show that the dried product has good quality indicators. The dried product has a well-preserved color without burning or non-enzymatic browning. Studies on the influence of combined drying regimes on the content of some active substances - phenols and flavonoids are planned to be conducted.

Conducted experiments show a significant reduction in energy consumption in modes using microwave energy. The combination with periodic regimes proved to be particularly promising.

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