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DESIGNING THE STRUCTURE AND DETERMINING THE OPERATING PARAMETERS OF A MICROWAVE DEHYDRATOR FOR OBTAINING PHYTO-CONCENTRATES

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This study's object is the process of obtaining phyto-concentrates using a continuous microwave dehydrator. The task addressed is associated with the concentration of food solutions in existing evaporators: product sticking to heat exchange surfaces, change in product quality, the need for additional systems for mixing, high energy consumption, inability to achieve high concentrations.

The structure of a microwave dehydrator operates under periodic and continuous modes. The dehydrator's productivity has been determined depending on microwave field power, solution type, as well as product type. Wine, apple, and grape juices; coffee and echinacea extracts, as well as extracts with acetone solvent, were investigated as solutions. For water-containing products, the productivity value varied in the range of 0.28…0.32 kg/h.

The dehydrator's operating modes have been defined, enabling the preservation of heat-sensitive components of the raw materials. The highest content of ascorbic acid was found in the concentrate of actinidia berries (375 mg) and bioflavonoids (18.5 mg). The concentrate of grape juice exceeds the control sample (directly squeezed juice) by 6.5 times.

The high quality indicators of the product and low energy consumption of the dehydrator are attributed to the selectivity of microwave heating, which has a directed effect on polar molecules of moisture and solvent, without overheating the raw materials. The dehydrator was operated under a continuous mode, which makes it possible to increase productivity, processing quality, reduce metal consumption, and simplify its structure. The energy efficiency of the dehydrator is also based on the fact that due to its use it is possible to exclude a conventional dryer from the technological chain.

A feature of the dehydrator design is the lack of need for constant operation of the vacuum pump, which ultimately reduces energy consumption.

The scope of its application includes food and processing sectors, production of phyto-concentrates, functional drinks, as well as additives. Conditions of use: small businesses and farms working with heat-sensitive raw materials

Keywords: microwave field, dehydrator, phyto-concentrate, productivity, solvent, ascorbic acid

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1. Introduction

The modern food industry requires effective technologies for processing plant raw materials. Phyto-concentrates with high biological value attract special attention. They contain vitamins, antioxidants, phytonutrients, which have a positive effect on human health. Such components are heat-sensitive and quickly decompose when heated.

The concept of functional nutrition, in which phyto-concentrates are widely used, is relevant. Previously, the main tasks of nutrition were survival, satisfaction of hunger, and support of vital functions in the body. Currently, food products are considered as a tool for health promotion and prevention of chronic diseases.

Classical methods of obtaining phyto-concentrates such as evaporation, drying, extraction cause loss of active substances and high energy consumption.

There is a need for a gentle, energy-efficient method for removing moisture from plant raw materials. Special attention is paid to new technologies, including extraction and concentration under conditions of selective energy supply from microwave sources. It is these technologies that stand out as promising and effective. Under the influence of microwaves, the water inside plant cells is heated, turning into steam, which contributes to the increase in pressure and the destruction of cell walls and the release of target components. This method combines the principles of microwave heating and the effect of "mechanodiffusion" [1]. And this provides a more efficient and careful extraction of target compounds.

Advantages of the method:

– reduced energy consumption; due to direct heating of water inside the cells or capillary, less energy is required than in conventional methods;

– reduced time; the process can last from several minutes to an hour, depending on the type of raw material, which is much faster than standard methods;

– increased yield of target components; due to the destruction of cellular structures, their complete extraction is achieved;

– preservation of the quality of the finished product; a lower heating temperature prevents thermal decomposition and loss of aromatic compounds;

– environmental friendliness; the method reduces the consumption of water and chemical solvents, which makes it more sustainable from an environmental point of view.

Therefore, research into the use of microwave technologies for food dehydration is relevant. The topic is modern and practically significant. It meets the challenges of sustainable development and functional nutrition.

2. Literature review and problem statement

In [2], the process of sucrose dehydration using a microwave vacuum evaporator was studied. The concentration of the initial sugar-alcohol solution was 70°Brix. The main task was sucrose crystallization. The experimental setup consisted of a vacuum pump connected to a chamber located inside a standard household microwave oven. The study was conducted to simulate semi-continuous crystallization of beet syrup to form a crystalline suspension. However, such an implementation is inferior in speed to fully continuously operating devices. A likely reason is difficulties associated with the organization of continuous unloading of the formed crystals.

In [3], a study of barley malt dehydration processes under microwave field conditions was conducted. For comparison, conventional convective drying (50...70°C) was implemented, the duration of which was 9...14 hours, while with microwave drying the duration was reduced by 95%. Along with the microwave energy supply, the system was vacuumed, which made it possible to significantly increase the productivity of the unit and reduce the process temperature. In fact, in units of this type it is possible to work with rheological systems (fruit purees), but this task was not set in the study. This might be due to the design features of the unit.

In work [4], the effect of microwave energy under vacuum conditions on the process of cream dehydration was studied. The process temperature did not exceed 65°C at a pressure in the range of 22...28 kPa. Homogenized cream was pre-evaporated to 43.5% of dry matter using a rotary evaporator. A microwave oven was used as a drying unit, into which samples were periodically loaded. The work did not aim to design a continuous unit that would work much more efficiently. When using a continuous unit, it would not be necessary to apply pre-treatment.

In papers [5, 6], the process of lyophilic dehydration of maltodextrin under microwave energy supply conditions was investigated. The field power varied within 120...220 W at a temperature not higher than 40°C. The experiments were carried out at a pressure of 0.1 mbar. The installation consisted of a microwave generator, a rotary table, and a vacuum pump. The aim was to investigate how the power consumption and temperature affect the drying time, energy consumption, and temperature uniformity. The installation is of a periodic type, which is possibly related to the conditions of lyophilic dehydration, namely, maintaining the required temperature and pressure.

In work [7], a control system was tested to improve microwave sublimation dehydration. Carrot slices were chosen as the object of the study. The power of microwave (MW) radiation was 100, 200, and 300 W, the process temperature varied in the range of –15...40°C. The final moisture content of the product was 6%. A study of drying kinetics was conducted. Based on the results, appropriate drying conditions were selected, optimization and process control were carried out. The goal was not to design and scale up a new installation.

Work [8] investigated issues s in the process of heating liquid and semi-liquid food media under microwave field conditions. A review of the prospects and capabilities of various energy sources in solving heat and mass transfer problems was conducted, among which microwave energy supply was also examined [9]. It was noted that the positive effect of microwave exposure is enhanced when combined with infrared (IR) exposure. However, due to the wide variation in the structure of the raw materials, the control over processing is quite complex, which encourages the use of sensor and computer technologies, neural networks, etc.

A review of the use of microwave radiation and ultrasound in the processing of food raw materials was conducted in [10]. Analysis of the research results revealed that the synergy of the heating effect of the microwave field and cavitation during ultrasound significantly increases the efficiency of processing. The study did not consider the use of vacuum in product processing.

In [11], a study was conducted on the process of grape juice evaporation under the action of a microwave field and vacuum. The values of the operating parameters varied in the following ranges: the power of the microwave field was 30...80 W, the pressure was 35...70 kPa, the duration of the process was 5...15 minutes. The final concentration of the finished product was approximately 78°Brix. The installation consisted of a microwave oven, a glass heat exchanger, a condenser, and a vacuum pump. The disadvantage of the installation is the small volume of the product being processed (100 ml) and the periodicity of the operation.

In [12], the process of microwave treatment of coconut milk was studied, the main purpose of which is to inactivate the bacteria *Bacillus coagulans*. As a result, it was noted that the sterilization of food products using microwave radiation is a promising method that preserves the quality of the product itself. Concentration tasks were not set in the study.

In works [13, 14] the advantages of microwave radiation in organizing the processes of drying, heating, baking, cooking, frying, etc. are described. It is shown that the use of a source of microwave energy makes it possible to better preserve the quality of raw materials, and also significantly saves processing time and energy consumption. But the authors pay more attention to the textural properties of the raw materials being processed, the development of new technical solutions was not on their minds.

The interactions of the microwave field with various types of solvents are also studied, the most common of which are ethanol and acetone.

In [15], microwave extraction of valuable components from avocado peel was carried out. The extractant was a solution consisting of acetone and ethanol in different proportions. Extraction was carried out at temperatures of 65...75°C. The resulting extracts had a high content of polyphenols and high antioxidant activity. Researchers pay more attention to the quality of the obtained products; the development of a new design is not considered.

Different methods are used to compare the energy efficiency of technologies involving different energy sources. The exergy approach is appropriate only within the framework of thermodynamic analysis, and economic assessments in countries with unstable economies have limited practical value [16, 17].

Theoretical energy consumption for removing 1 kg of moisture in the processes of evaporation and drying is approximately 2.3 MJ/kg. Actual energy consumption for removing 1 kg of moisture for evaporation 1.5...2.8 MJ/kg for drying 4...12 MJ/kg. Also in drying processes, the specific moisture extraction rate (SMER) is used, which is defined as the amount of moisture removed per unit of power supplied [18]. In fact, this value is the inverse of the specific energy consumption. For a convective dryer, this figure is 0.08 kg/MJ, which corresponds to 11.9 MJ/(kg of moisture removed), for a screw dryer based on an annular heat pipe 0.57 kg/MJ, which corresponds to 1.7 MJ/(kg of moisture removed). The highest figures for a freeze dryer are 45 MJ/(kg of moisture removed), the lowest for heat pump dryers are 0.4 MJ/(kg of moisture removed).

For the processes of evaporation of sugar syrup, the following energy consumptions are given in work [19]: for rotary evaporation (60°C, vacuum 250 mbar) 0.49 kW/h, for the open thermal evaporation method (46.8 min, 101.6°C) 0.83 kW/h, for microwave evaporation (13 min and 103.2°C) 0.16 kW/h.

The above review of the literature allows us to draw the following conclusions:

1. The innovative path for developing the food industry is the production of functional products, phyto-concentrates with a high content of biologically active substances, ensuring the concept of "healthy nutrition".

2. The production of functional products is associated with the need to improve conventional equipment for dehydration of phyto raw materials. Innovative equipment must meet the requirements for the quality of the finished product, energy, and environment.

The principle of volumetric energy supply, the absence of conventional heat transfer make it possible to obtain a finished product in a microwave field with a concentration higher than in conventional evaporation. This makes it possible to exclude a conventional energy-consuming dryer from the technology. Therefore, the term "microwave dehydrator" is used hereafter. The installation implements continuous feeding and unloading of the finished product with simultaneous exposure to a microwave field. The use of a new structure will allow us to increase productivity and processing quality, reduce metal consumption, and simplify the design.

Papers [2–15] prove the high quality of finished products from plant raw materials, shortening the processing, and reducing energy costs. However, most researchers do not set the goal of designing new high-performance equipment that uses the microwave field. The cited studies use ready-made solutions, such as household microwave ovens, supplementing them with the elements necessary for research (vacuum pumps, heat exchangers-condensers). The research whose results are reported in the literature was carried out on laboratory-type installations but there are no high-performance experimental installations that implement a continuous concentration process. Designing and investigating such installations could enable transition to industrial-scale structures.

3. The aim and objectives of the study

The aim of our work is to design a structure and determine the operating parameters for a microwave dehydrator to obtain phyto-concentrates.

To achieve this aim, the following objectives were accomplished:

– to devise a conceptual solution for a microwave dehydrator for obtaining phyto-concentrates;

– to determine the effect of power of the MW field on the performance of the dehydrator;

– to determine the effect of the type of solvent and product on the performance of the dehydrator.

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of our study is the process of obtaining phyto-concentrates using a continuous microwave dehydrator.

The objectives of the experiments were to confirm the hypothesis that differences in the electrophysical properties of juice components could be used for the directed supply of electromagnetic energy directly to water. In this way, it would be possible to achieve effective energy consumption only for the phase transition, which could eliminate all problems associated with heat transfer in condensed solutions.

Design assumptions:

– the structural material of the reactor is completely radiotransparent;

– the chamber has no steam or coolant leaks, and all connections are absolutely sealed;

– all internal surfaces of the resonator shaft have a 100% reflection coefficient of microwave waves.

It is assumed that the electromagnetic field inside the resonator shaft is uniform, although in practice standing waves and overheating zones are possible.

When two magnetrons operate simultaneously, it is assumed that they do not interfere with each other.

It is assumed that all the electrical energy entering the magnetron is converted into microwave radiation.

It is assumed that the entire batch of product has the same structure, although in reality local differences are possible.

4. 2. Schematic diagram of the dehydrator and test methodology

The experiments were carried out on a bench (Fig. 1), consisting of a container for the initial raw material (1), a resonator shaft with a radio-transparent reactor (2), a vacuum pump (VP), a condenser (4), a water cooler (WC), and a condensate collector (5). Data collection and processing are carried out using a measuring and computing complex (MCC).

The products chosen were plant systems promising for the Southern region and for Ukraine as a whole (Table 1).

Table 1

Classification of plant raw materials

No. of entry	Raw materials	Finished product	
		Type	Regime
1	Apple juice	Concentrate	To 50°C
2	Grape juice	Concentrate	To 50°C
3	Echinacea juice	Concentrate	To 50°C
4	Coffee extract	Concentrate	50–100°C
5	Actinidia	Dried fruit	To 50°C

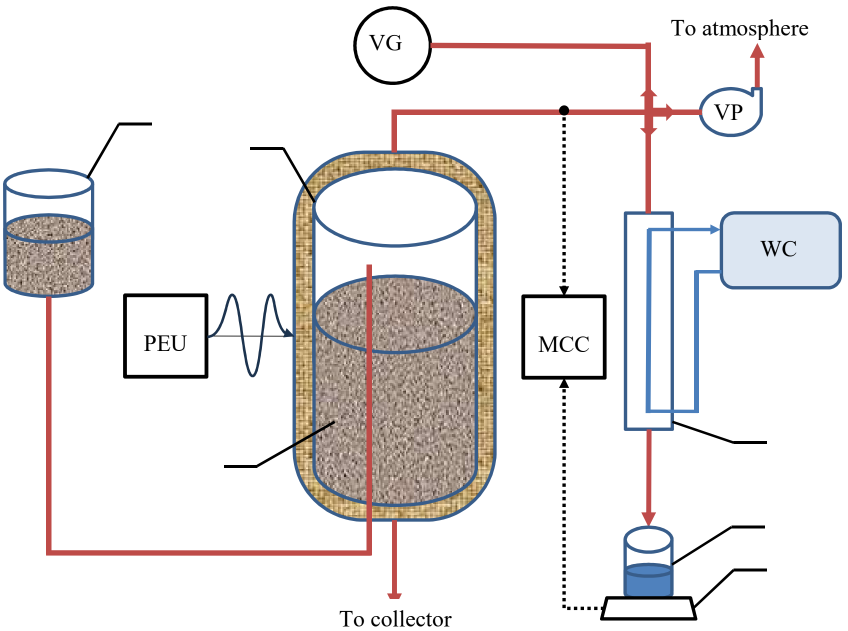


Fig. 1. Schematic diagram of the experimental dehydrator sample: 1 – initial product capacity, 2 – reaction volume, 3 – product, 4 – condenser, 5 – condensate collector, 6 – scales, VG – vacuum gauge, VP – vacuum pump, WC – water cooler, PEU – power electronics unit, MCC – measuring and computing complex, S1 – steam temperature signal, S2 – electronic scales signal

The main raw material is thermolabile. Therefore, the temperature regimes of dehydration are limited.

Before starting work, air is pumped out of the radiotransparent reactor through the outlet pipeline using a TW-1A vacuum pump (China). The raw material is continuously fed through the lower flange pipe. The finished product is discharged through the lower flange discharge pipe. The ultrahigh frequency field created by the magnetrons penetrates the reactor. The radiotransparent design of the reactor ensures the fastest possible heating of the raw material since caprolon has a low microwave absorption coefficient.

The concentration of dry substances in the products used in the study of the dehydration process was measured using a Hanna Instruments HI 96801 refractometer (Romania).

The mass of dry substances of actinidia was determined using Radwag AS 220/C analytical balances (Poland).

The processing of actinidia fruits was carried out on a rubbing machine designed at the Department of Processes, Equipment, and Energy Management, Odessa National Technological University (Ukraine). The processing was carried out in the native state (without preliminary heat treatment) on a perforated surface in a field of centrifugal forces under a continuous mode. The dispersion, depending on the requirements for the final product, is changed by re-equipping the machine (replacing the sieves). The basic version has an internal diameter of 200 mm, and the diameter of the holes is 7 mm at a circular speed of the blades of 6.28 m/s. The use of the designed rubbing machine makes it possible to simplify the technological scheme of raw material processing by removing equipment for preliminary heat treatment.

The dehydrator is connected to the condenser by a wire. The vacuum in the system is controlled using a sample vacuum gauge. The pressure in the system was maintained at 0.01 MPa. The power electronics unit, based on signals from the control unit, which includes a power regulator and a timer, organizes the supply of electromagnetic energy to the product. The water cooling system includes a compressor refrigeration machine, a tank with cooling water, a water temperature regulator, and a circulation pump, which provides cold water to the condenser (4). The current values of the outlet steam temperature sensor (S1) and electronic scales (6) are sent to the MCC processor via the interface for further processing. The reactor load is 5 kg for each experiment. The following measuring instruments were used: electronic scales TVE-0.21-0.01 (Ukraine) and Dallas DS 18b20 temperature sensor (USA). Information was collected using a CHUWI CW1506 tablet (China). The data recording and processing program was implemented on the basis of the SCADA system. The developed program provided for the display of thermograms, kinetics of moisture reduction in the reactor, and instantaneous values of the moisture removal rate on the display screen. The condensate weight was recorded using scales, due to which accurate values of steam output were obtained.

Actinidia fruits have pulp consisting of parenchymal cells 50–150 μm in size; shells rich in cellulose and pectin; vacuole with dissolved organic acids (ascorbic, malic); chloroplasts, leucoplasts, starch granules. The particle size of actinidia puree was experimentally determined. The bulk of the particles has a size of 20...800 microns. The particle sizes are much smaller than the wavelength (≈ 12.2 cm).

Samples of concentrates from the dehydrator were analyzed at the educational and scientific laboratory "Fat Nutrition" (Odesa, Ukraine).

A spectrophotometric method was used to determine ascorbic acid and vitamin P (bioflavonoids).

Control samples; apple juice, grape juice, dry actinidia berries.

The laboratory (spectrophotometric) method for determining the content of ascorbic acid and vitamin P was compared with the method regulated by the DSTU ISO 6557-2:2005 and DSTU 2117-93 standards, respectively. According to the results of the comparative analysis, it was found that the indicators obtained by the laboratory method do not differ statistically significantly from the results obtained according to the standard.

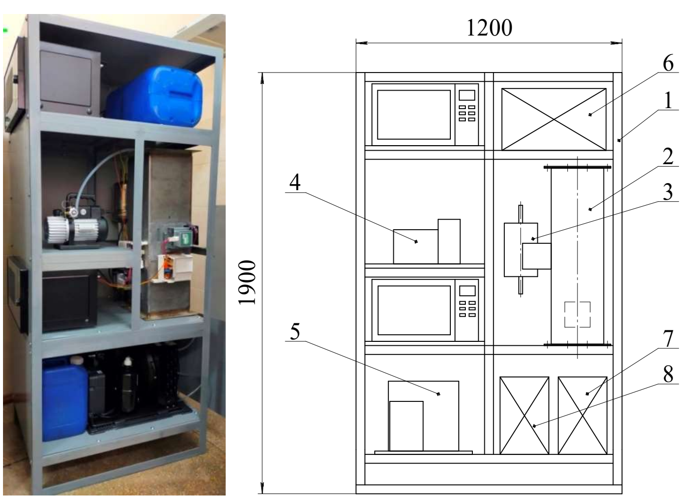
5. Results of designing an experimental microwave dehydrator

5. 1. Conceptual solution of a microwave dehydrator

The designed structure refers to food industry devices for concentrating liquid food products by evaporating them in a vacuum. The dehydrator can be used at small enterprises and farms, in canning lines, food concentrate plants. The dehydrator has prospects for implementation at restaurant service enterprises, health care enterprises, such as canteens at medical and preventive institutions, as well as healthy food enterprises. In all the examples given, it is important to implement the principles of uniform thermal impact on the product, ensuring low energy costs and compactness of the equipment.

The general view of the microwave dehydrator is shown in Fig. 2.

Inside slipway 1, rectangular resonator shaft 2 is vertically located (Fig. 3).



a *b*

Fig. 2. General view of the microwave dehydrator:
a – photograph; *b* – drawing:
1 – slipway; 2 – resonator shaft; 3 – condenser;
4 – vacuum pump; 5 – refrigeration unit;
6 – container for raw materials; 7 – container for the resulting product; 8 – container for condensate

The resonator shaft with a cross section of 0.24 × 0.24 m is made of stainless steel, 1.5 mm thick, 1 m high. Inside the resonator shaft there is a reactor made of radio-transparent material (Fig. 3). The working volume of the reactor is divided into formation and separation zones. The diameter of the reactor is 0.2 m, and the height is 0.7 m. The reactor is filled with raw material by 75%.

a *b*

Fig. 3. Resonator shaft: *a* – with built-in magnetrons;
b – with a radio-transparent reactor

Two magnetrons are mounted on the side walls of the shaft in such a way that their safe operation and the ability of the microwave field to penetrate the liquid volume are taken into account. Inside the shaft on the flanges (Fig. 4) a radio-transparent reactor is fixed.

Fig. 4. Dehydrator flange

The microwave dehydrator structure is mounted on a slipway.

The dehydrator flanges are made of copper, which allows it to work with "aggressive" environments.

5. 2. Results of research on the influence of microwave field power on dehydrator performance

The performance of the dehydrator was determined from the power of magnetrons. The experiments were conducted on water. The results are given in Table 2.

During the experiments, the dehydrator performance values were obtained at different capacities (Fig. 5).

As the magnetron power increases, the dehydrator's performance increases directly proportionally.

Table 2

Dehydrator test results at different magnetron powers

No.	Parameter	Measurement unit	Value					
1	Magnetron power	kW	0.3	0.9	1.32	1.8	2.4	3
2	Productivity	kg/h	0.31	0.93	1.37	1.86	2.48	3.11
3	Operating time	min	90	90	90	90	90	90
4	Energy consumption	MJ	1.9	6.56	9.48	13.08	16.4	19.25
5	Specific energy	MJ/kg	4.08	4.7	4.61	4.69	4.41	4.13

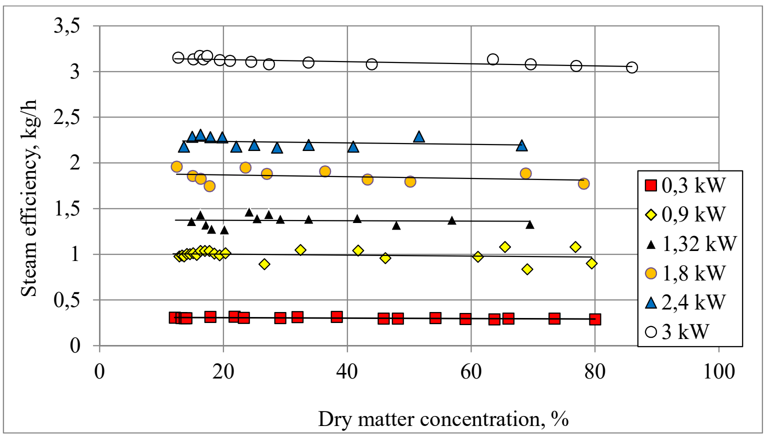


Fig. 5. Dependence of productivity on dry matter concentration for different power values

5. 3. Results of studies on the influence of the type of solvent and product on the performance of the dehydrator

At the second stage, the performance of the dehydrator was determined depending on the type of solution. The results are given in Table 3.

Based on our data (Table 3), graphical dependences of the dehydrator performance on the type of solvent were constructed (Fig. 6).

The productivity of the dehydrator directly depends on the type of solution, namely on the heat of formation. When the heat of phase transition of the solution decreases, the productivity increases, and vice versa.

The next step was to study the dehydrator on different raw materials. The results are given in Table 4.

By analogy, key graphical relationships were derived, reflecting the performance of the dehydrator for various products (Fig. 7).

Productivity has a linear dependence on the concentration of dry matter of the products under study. For different products, productivity is practically the same.

The content of ascorbic acid and vitamin P in dry actinidia berries, a preparation – concentrate of actinidia berries, preparations – concentrates of apple and grape juices was determined.

The highest content of ascorbic acid is found in the preparation – concentrate from actinidia berries (375 mg). The preparation – concentrate from grape juice – exceeds the control sample (directly squeezed juice) by 6.5 times.

Table 3

Dehydrator test results on different types of solutions

No.	Parameter	Measurement unit	Value				
1	Solvent	–	Water	Wine	Vodka	Ethanol	Acetone
2	Product	–	Apple juice	–	Miscanthus root extract	Coffee oil extract	Grape seed oil extract
3	Productivity	kg/h	0.31	0.33	0.34	0.69	1.43
4	Operating time	min	60	60	60	60	60
5	Magnetron power	kW	0.3	0.3	0.3	0.3	0.3
6	Energy consumption	MJ	1.26	1.26	1.26	1.26	1.26
7	Specific energy	MJ/kg	4.07	3.82	3.71	1.83	0.88

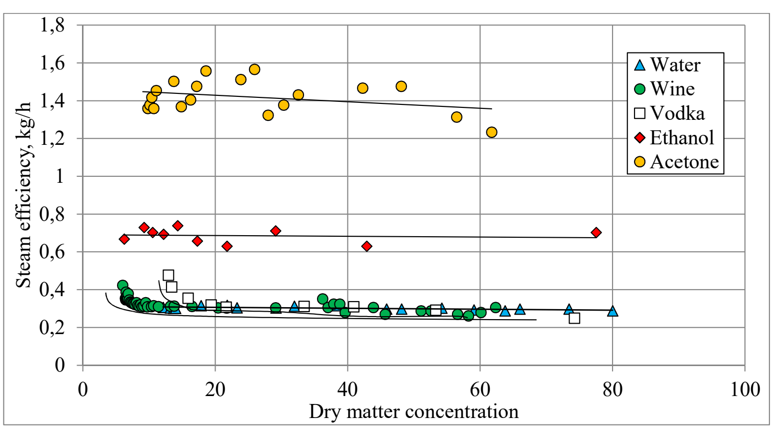


Fig. 6. Dependence of productivity on the concentration of solids for different types of solvent

Table 4

Dehydrator test results on different types of raw materials

No.	Parameter	Measurement unit	Value				
1	Product	–	Apple juice	Grape juice	Echinacea juice	Coffee extract	Actinidia
2	Productivity	kg/h	0.34	0.34	0.28	0.31	0.32
3	Operating time	min	60	60	60	60	60
4	Magnetron power	kW	0.3	0.3	0.3	0.3	0.3
5	Energy consumption	MJ	1.26	1.26	1.26	1.26	1.26
6	Specific energy	MJ/kg	3.71	3.71	4.5	4.07	3.94

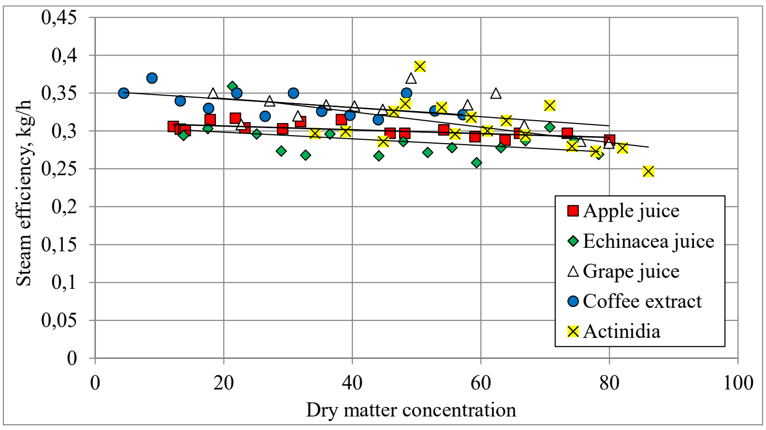


Fig. 7. Dependence of productivity on dry matter concentration for different raw materials

Table 5

Results of research on the qualitative characteristics of phyto-concentrate samples

No.	Sample	Ascorbic acid content, mg%	Bioflavonoid content, mg%
1	Dried actinidia berries	364	6.85
2	Concentrated preparation of actinidia berries	375	18.5
3	Apple juice	1.2	0.64
4	Concentrated preparation of apple juice	243	0.84
5	Grape juice	50	0.84
6	Concentrated preparation of grape juice	325	2.23

The highest content of bioflavonoids is found in the preparation – concentrate from actinidia berries (18.5 mg). The preparation – concentrate from apple juice – exceeds the control sample (directly squeezed juice) by 1.3 times, and grape juice by 3 times.

6. Discussion of results based on the study of the experimental microwave dehydrator

The productivity of the installation (Fig. 5) does not change significantly (0.35...0.25 kg/h) with a fairly significant change in concentrations (10...85%). This is attributed to the fact that under a continuous mode, only the power of the magnetrons actually has an effect on productivity.

With a complex solvent (water-alcohol mixture in wine, vodka), productivity gradually decreases as alcohol vapor exits (Fig. 6). As the heat of vaporization of alcohol at a pressure of 0.01 MPa is 916 kJ/kg, and water is 2393 kJ/kg, therefore, with the same specific power of the MW field, the productivity of the dehydrator will be different (higher when removing alcohol). Accordingly, when the solution boils, alcohol is removed first since its boiling point is lower than that of water, the productivity has high values. However, when alcohol is completely removed from the solution, water removal begins. This results in a decrease in the dehydrator's performance.

Over the entire concentration range up to 80°brix, the productivity does not depend on the type of raw material (Fig. 7). Firstly, this is explained by the fact that the products under study are water-containing and have similar thermophysical properties. Secondly, due to the volumetric supply of energy directly to the moisture in the raw material, there is no classical heat transfer, respectively, the boundary layer is not formed. The process takes place with active boiling and mixing of the liquid, which ensures uniform distribution of thermal energy throughout the entire volume of the product regardless of the depth of penetration of the MW field.

The content of vitamin C, which is the most heat-sensitive vitamin contained in fruits, was determined. The content of vitamins in the obtained phyto-concentrates (Table 5) is many times higher than that in control samples. This is explained by the fact that the concentration process takes place under vacuum. Also, there is no overheating of the product due to the volumetric supply of microwave energy.

The application of the designed structure is limited to the power of magnetrons of 0.9–3 kW, the working volume of the radio-transparent reactor – 10 l.

The disadvantage is the difficult scaling of installations for large-capacity enterprises. That requires powerful magnetrons and power sources.

The prospects of our research is to optimize the operating modes of the designed structure. To minimize the specific energy consumption of the dehydrator, it is necessary to find the optimal ratio of magnetron power and product consumption.

7. Conclusions

1. A conceptual solution of a microwave dehydrator for obtaining phyto-concentrates has been devised. The microwave dehydrator is of continuous operation, it has a larger volume of the chamber for product processing and lower energy consumption than in known designs, while the pressure in the system remains constant during operation. The low energy consumption of the dehydrator is explained by the selectivity of microwave heating, which directly affects polar molecules of moisture and solvent, without overheating

the raw material. The energy efficiency of the dehydrator is also determined by the fact that due to its use it is possible to exclude a conventional dryer from the technological chain.

2. The dehydrator performance was determined depending on the microwave field power. The current-action dehydrator provides high performance (0.31…3.11 kg/h) at moderate energy consumption (4.08…4.13 MJ/kg). It does not require constant operation of the vacuum pump. The pressure in the system is provided by matching the magnetron energy with the parameters of the condenser cooling system. With an increase in the magnetron power, the dehydrator performance increases directly proportionally. With an increase in the magnetron power by 8 times, the performance increases by 7.6 times.

3. The effect of the type of solvent on the dehydrator performance has been determined. With a complex solvent (water-alcohol mixture in wine, vodka), the performance decreases when alcohol vapor is released (for wine, vodka, from 0.5 to 0.3 kg/h). The main parameter of influence is the heat of phase transformations. The effect of the type of product on the dehydrator performance has been determined. The tests were conducted with both liquid and solid phases. Wine, apple, and grape juices, coffee extracts, echinacea, extracts with acetone solvent were investigated as solutions. The productivity changes slightly if the solvents removed from the raw materials have similar heats of formation. Food raw materials belong to the class of water-containing products; therefore, the productivity value varies in the range of 0.28…0.32 kg/h.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

The data will be provided upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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