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Microwave Electro-technological Installation for Processing Vegetable-origin Organic Materials and Agricultural Crops

Midhat Tukhvatullin[1]* and Eduard Khasanov[2]

[1]Department of Electric Power Supply and Technological Process Automation, Federal State Budgetary Educational Institution of Higher Education, Bashkir State Agrarian University, Ufa, Russia
[2]Department of Mechatronics Systems and Agricultural Machinery, Federal State Budgetary Educational Institution of Higher Education, Bashkir State Agrarian University, Ufa, Russia

ABSTRACT

The research aims to conduct experimental studies of the drying schedule for processing vegetable-origin organic materials using a microwave electro-technological installation. The design and development of a microwave electro-technological installation for processing vegetable-origin organic materials and agricultural crops are based on the solution of an agreed boundary value problem of electrodynamics and heat and mass transfer. The experiments on the microwave processing of vegetable-origin organic materials using a microwave electro-technological installation allowed us to identify the preferred process conditions, which involve the work of 7 magnetrons and a rotation mechanism of vegetable-origin organic materials along their axis. The processing time is less than 15 hours; the final humidity does not exceed 7%. The temperature change is uniform. The temperature at a depth of 1/4 of the thickness of the samples differs from the temperature on the surface of the samples by 0.5–1.0°C. The differences in the calculated and experimental data on the humidity of organic materials of plant origin do not exceed 3.8%, and on temperature, it is 4.3%. The creation of a microwave installation for the simultaneous microwave processing of vegetable organic materials and agricultural crops will significantly increase the energy and economic efficiency of the installation by reducing the processing time and increasing the quality of dried material quality. Moreover, unlike the existing ones, the proposed electro-technological installation contributes to the sale of more than two products with improved qualities, thus increasing the profits at the same energy costs.

Keywords: Agricultural crop, electro-technological installation, organic material

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E-mail addresses:
midhat_tukhvatullin@rambler.ru (Midhat Tukhvatullin)
edkhasanov43@rambler.ru (Eduard Khasanov)
* Corresponding author

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INTRODUCTION

Microwave energy is used for drying, heating, defrosting, and disinfection of different products, including agricultural crops such as barley, wheat, and soy. This technology has become popular with agricultural and processing enterprises since it has many positive features. The most attractive feature of microwave technology is the short processing time and the preservation of nutrients in the product after processing. Khasanov (2015) in his work states that the pre-sowing treatment of seeds with microwave current ensures high processing uniformity, at least 98%, with a productivity of 10 t / hour in the etching mode and 4 t / hour in the inlay mode.

Excess humidity reduction is one of the urgent tasks for cereal breeding centers producing elite and super elite seeds in western and eastern Canada (Saskatchewan, Alberta, Manitoba, Ontario, Quebec), as well as in China (the Songliao Plain) and the Ural and Volga Federal Districts of Russia. Excessive humidity shortens the product's best-before date, decreases its use efficiency, leads to deterioration in the product's commercial qualities after drying, and the rapid development of disease-producing agents that make grain useless (the average loss of grain without drying is 25%–28%) (Khasanov, 2015; Nirmaan et al., 2020).

Therefore, issue number one for enterprises that process vegetable-origin organic materials is to ensure their high-quality and uniform drying. The existing methods of drying vegetable-origin organic materials are atmospheric, convective, chamber, contact drying, flue gas drying, drying with infrared rays, high-frequency currents drying, induction and vacuum drying. Among the disadvantages of the above methods are high energy consumption and equipment cost, complex drying process control, low quality of the dried material, and the use of equipment polluting the environment (Arkhangelsky et al., 2018; Khasanov, 2015; Sivyakov & Grigorieva, 2019).

Using microwave energy eliminates the disadvantages of drying machines and reduces the seeds' moisture content. In their work, Tuhvatullin and Aipov (2019) state that the processing time is reduced to 9–12 hours due to the rotation of lumber along its axis in the microwave electromagnetic field; high uniformity of processing is ensured (95%–98%). Moreover, two-stage processing allows for a large increase (10%–20%) in yield compared to control due to the microwave field's various effects on seeds (Khasanov, 2015).

The authors propose a new technology for processing agricultural crops and vegetable-derived organic materials, which will allow obtaining better-quality products at low energy costs. Using the new technology will contribute to the transition to high-yielding and environmentally friendly agriculture for the selection and processing of plant products.

All of the above proves the research's relevance and great scientific and practical significance for the agro-industrial complexes of Europe, America, and the Russian Federation.

LITERATURE REVIEW

World literature covers the use of electromagnetic microwave energy for the thermal processing of materials. Some papers present information on agricultural use of microwave drying, such as farm products drying (Sivyakov & Grigorieva, 2019), assessment of corn germination by microwave priming (Lazim, 2023), microwave processing of materials at agricultural facilities (Aipov et al., 2019), and corn microwave drying (Zhou et al., 2019). Some of them give an analysis of microwave drying methods of rice varieties (Nirmaan et al., 2020), the effect of microwave treatment on disinfection and stimulation of seed germination followed by inlay (Khasanov, 2015). Papers devoted to the use of microwave drying in the food industry describe microwave mixture processing (Shishkina et al., 2019), sterilization of packaged food products (Patel et al., 2019) and polymer packaging for food products (Zhou et al., 2019).

They give an analysis of microwave disinfection of food products (Stepanenko & Kazhevnikov, 2017), the effect of microwave heat treatment on nutritional indicators (Waseem et al., 2022), synergistic effects of ultrasound and microwave treatment on the physicochemical properties and phytochemicals of watermelon (Navida et al., 2022), investigation of the effect of ultrasonic pasteurization on the physico-chemical profile and stability during storage of pumpkin (Nadeem, Tehreem et al., 2022), the effect of ultrasound treatment on the functional properties of various citrus juices (Nadeem, Ranjha et al., 2022); microwave processing of lemon cordial (Malik et al., 2022), convection combined microwave drying of essential oils (Monton et al., 2019), microwave processing of lime flavored drink (Patel & Bhise, 2023).

Some literature sources study the use of microwave drying in the woodworking industry: microwave electro-technological installation for drying rotating sawn timber (Tukhvatullin & Aipov, 2019), microwave bamboo vacuum drying (Lv et al., 2018), the effect of microwave radiation on the humidity of different wood species (Aniszewska et al., 2021), microwave timber processing (Tuhvatullin et al., 2019), drying of wood chips (Rezaei et al., 2017). There are papers presenting information on the use of microwave drying in the construction industry. They review the effects of microwave radiation on the geopolymers' properties (Sun et al., 2021), describe microwave processing of carbon-covered polymer composites (Galos, 2021), give an interpretation of the structure and properties of biological polyhydroxyalkanoates with different monomeric compositions (Ishak et al., 2021), present information on the electrification of microwave processing of materials (Amini et al., 2021), including microwave processing of bitumen (Abdrabou et al., 2023).

For example, in the work by Nirmaan et al. (2020), the microwave processing of rice for 7 minutes in a microwave installation with a power of 500 watts gives better results compared to traditional processing methods. The moisture content of rice decreases by

12%–20%, which is similar to the research results presented by Sivyakov and Grigorieva (2019) and Khasanov (2015).

The work by Navida et al. (2022) studies the effect of ultrasound and microwave energy treatment on the physico-chemical parameters of watermelon juice stored for 120 days. Microwave treatment increases acidity (0.15%), turbidity (3.00), vitamin C content (202.67 mg/100 ml), TP (852.57 mg/100 ml), TF (1970.9 mcg CE /100 ml) and TAC (8650.3 mcg ascorbic acid equivalent/ml juice) and the antioxidant content, which is similar to the research results presented in Nadeem, Ranjha et al. (2022) and Malik et al. (2022).

Aniszewska et al. (2021) studied the effect of microwave radiation on various types of wood. They found that the decrease in humidity for various fractions is 8–16 mm (14.60% and 17.66%) and 16–31.5 mm (14.68% and 16.77%), which indicates the effectiveness of continuous processing and is similar to the research results presented in the papers (Tuhvatullin & Aipov, 2019).

The work by Sun et al. (2021) proves the increase in the strength of geopolymers and changes in their microstructure under the effect of microwave radiation, similar to the research results presented in the work (Galos, 2021).

At the same time, microwave processing of different materials has some disadvantages. The effect of microwave energy on different materials is heterogeneous. Therefore, intensive controlled processing methods are needed to achieve the desired effect.

For example, Montenegro et al. (2021) studied the effect of microwave processing on the physical, physico-chemical and rheological properties of wheat grain. It is difficult to control the processing of the materials under study at high power values (from 100 W to 3000 W).

Qu et al. (2021) investigate the effect of microwave stabilization on the properties of whole-grain flour and prove that it significantly increases the product's storage time. However, the stabilization process is long and complicated.

Waseem et al. (2022) studied the effect of microwave processing on potatoes' nutritional parameters and properties. Microwave processing positively affects the material under study, making this method appropriate for processing food products.

As mentioned above, there are many studies on the effects of microwaves on different materials (vegetable-origin organic materials, seeds, and crop materials). Materials exposed to microwave processing are different. Some scientists study the properties of materials exposed to microwave energy; some investigate the process of microwave treatment (Aipov et al., 2019; Montenegro et al., 2021; Navida et al., 2022; Tuhvatullin et al., 2019; Waseem et al., 2022). The choice of materials for this study is justified by the fact that microwave processing allows obtaining better quality products, which contributes to the transition to high-yielding and environmentally friendly agriculture for selecting and processing plant products. Since most studies are aimed at investigating the properties of vegetable-origin organic materials and agricultural crops (cereals) exposed to microwave energy, the study of microwave processing of vegetable-origin organic materials and agricultural crops is of particular interest both from the scientific and practical points of view (Khasanov, 2015; Monton et al., 2019; Nirmaan et al., 2020; Qu et al., 2021; Zhou et al., 2019).

The main problem of the intensive processing of vegetable-origin organic materials and agricultural crops is a decrease in the quality of the processed material. The long-term effects of microwave energy on agricultural crops, such as wheat, lead to the destruction of cellular structures and the deterioration of nutrients. As for vegetable-origin organic materials, the long-term microwave effect changes the internal and external structure of the material (deformation, torsion, charring) (Khasanov, 2015; Tukhvatullin & Aipov, 2019).

Thus, new solutions are necessary to preserve the quality of vegetable-origin organic materials and agricultural crops during microwave processing and reduce the processing energy intensity.

It is possible to combine two technological blocks (a block of thermal microwave modification of vegetable-origin organic materials and a block of non-thermal microwave modification of agricultural crops) into one working chamber of a microwave electro-technological installation to reduce the energy intensity of microwave processing of vegetable-origin organic materials and crops.

Thus, the combination of microwave and ultraviolet treatment inside one installation reduces the number of microorganisms or completely inhibits the pathogenic microflora on the material surface and increases raw materials' microbiological safety and stability (Kolokolova et al., 2020).

The main line of research in the world and scientific competitors: The development of the presented energy-saving technology, which allows obtaining agricultural products with improved quality, has been proposed for the first time.

The technology implies simultaneous thermal and non-thermal energy-saving processing of vegetable-origin organic materials and agricultural crops.

For the first time, the technology developed for simultaneous thermal and non-thermal processing of vegetable-origin organic material and agricultural crops has been presented.

The research aims to conduct experimental studies of the drying schedule for processing vegetable-origin organic materials using a microwave electro-technological installation with the following objectives:

1. Development of an automated control system for a microwave electro-technological installation.
2. Development of a simulation model of a microwave electro-technological installation.
3. Conducting experimental studies to determine the preferred schedule for processing vegetable-origin organic materials.

METHODS AND MATERIALS

Installation Model

The microwave electro-technological installation proposed by the authors for microwave processing of vegetable-origin organic materials and agricultural crops consists of two technological blocks-a block of thermal microwave processing of vegetable-origin organic materials and a block of non-thermal microwave processing of agricultural crops. A working chamber and a transmission line are the technological units of thermal microwave processing. The type of transmission line is a rectangular waveguide. A working chamber and a transmission line are the technological blocks of non-thermal microwave processing. The transmission line is a rectangular waveguide. Convenient placement and operation of the installation determine the length of the transmission line and the possible presence of a waveguide rotation.

The working chamber for non-thermal microwave processing of agricultural crops provides them with preferred technological properties. A waveguide should have the same cross-section as the transmission line, supplying it with microwave energy from a microwave energy source to reduce the reflection of the microwave electromagnetic wave from the entrance to the working chamber (Arkhangelsky & Grishina, 2007; Dobrodum & Arkhangelsky, 2017).

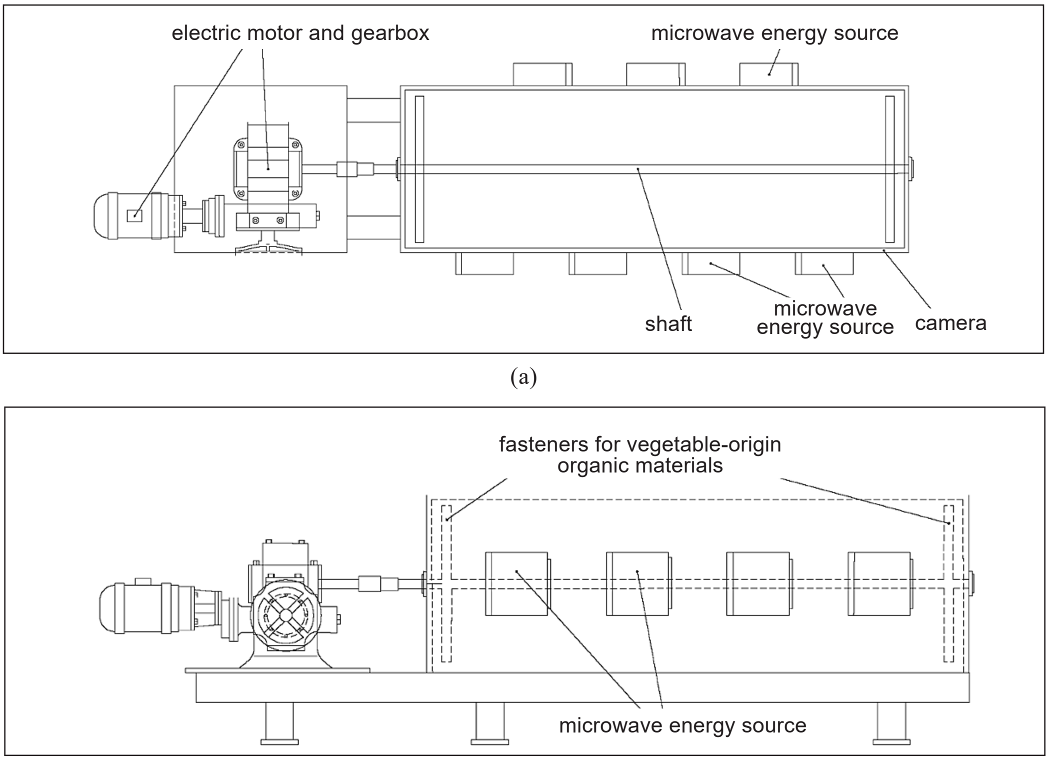
Figure 1 shows a diagram of a microwave electrotechnological installation for the microwave processing of plant material. Chamber 1 has shaft 3 with fasteners for vegetable-origin organic materials. Gearmotor 5 provides a rotation of vegetable-origin organic materials. The geometrical and technical characteristics of the installation model are presented in Table 1.

The microwave electro-technological installation has technological blocks for the non-thermal microwave processing of agricultural crops.

The microwave installation uses seven sources of microwave energy, making seven working chambers of non-thermal microwave processing possible. Each chamber can be assembled on a segment of a rectangular homogeneous waveguide with flanges and a round hole in the middle of wide walls. Agricultural crops (seed and plant material) are processed in those holes in a pipe made of organic glass.

It is important to note that each technological block of non-thermal microwave processing can produce the same or different agricultural products. Therefore, a microwave electro-technological installation can produce up to seven different materials.

If the water vapors from vegetable-derived organic materials are undesirable for agricultural crops, the technological block for non-thermal treatment can be protected from water vapor by a moisture-proof thin dielectric radio-transparent partition separating the zones where crops are located from the zones where vegetable-derived organic material rotates (Arkhangelsky et al., 2018; Dobrodum & Arkhangelsky, 2017).



(a)

(b)

Figure 1. Diagram of a microwave electro-technological installation for microwave processing of plant material: (a) Top view; and (b) side view

The absence of horn radiators matching the working chamber with a microwave generator creates a problem for a microwave electro-technological installation assembled according to the diagram shown in Figure 2. The microwave energy reflected from the entrance to the working chamber creates a partially standing wave mode in the working chamber of non-thermal microwave processing. As a result, $\mathring{A}(z)$ there is a dependence between a slit length and the crop processing quality. Thus, if a slit length is bigger than the wavelength in the waveguide, the processing quality decreases. A quarter-wave matching transformer should be used in the installation to avoid this. Therefore, using horn radiators and quarter-wave matching transformers increases the installation's economic efficiency and guarantees high production quality.

Table 1
Geometrical and technical parameters of the installation model

Parameter	Value
Installation dimensions, m	2.42 × 0.6 × 0.6
Number of magnetrons, pcs.	7
Power consumption of one magnetron, W	1,200
Output power of one magnetron, W	850
Radiation frequency, MHz	2,450
Dimensions of the waveguide energy output, mm	70 × 30

Installation Simulating Model

To simulate complicated processes, a simulation model of a microwave electro-technological installation for the microwave processing of vegetable-origin organic materials should be created in the MATLAB/Simulink software environment. The model is shown in Figure 2.

The simulation model consists of the following main blocks: a technological block for microwave processing of vegetable-origin organic materials (Subsystem), seven microwave energy sources (Rad1–Rad7), a device for determining the materials' temperature (T, degrees C), a device for determining the materials' moisture (W,%), an indicator (Score) for displaying graphical dependences of changes in temperature and moisture of vegetable origin organic materials during microwave processing, a power source (Step), a block (Constant1) for setting the initial values of temperature and moisture of vegetable origin organic materials and the final processing moisture, a key ((Rotate Switch) for rotating vegetable origin organic materials around their axis in the technological block, a key (Magn Switch) for switching on the selected mode of vegetable origin organic materials' processing.

The presented studies consider four modes of the simulation model operation: Mode 1: Switching on seven sources of microwave energy and vegetable-origin organic materials' rotation; Mode 2: Switching on four sources of microwave energy and vegetable-origin organic materials' rotation; Mode 3: Switching on seven sources of microwave energy and vegetable origin organic materials' rotation, and Mode 4: Switching on four sources of microwave energy without the rotation of vegetable origin organic materials.

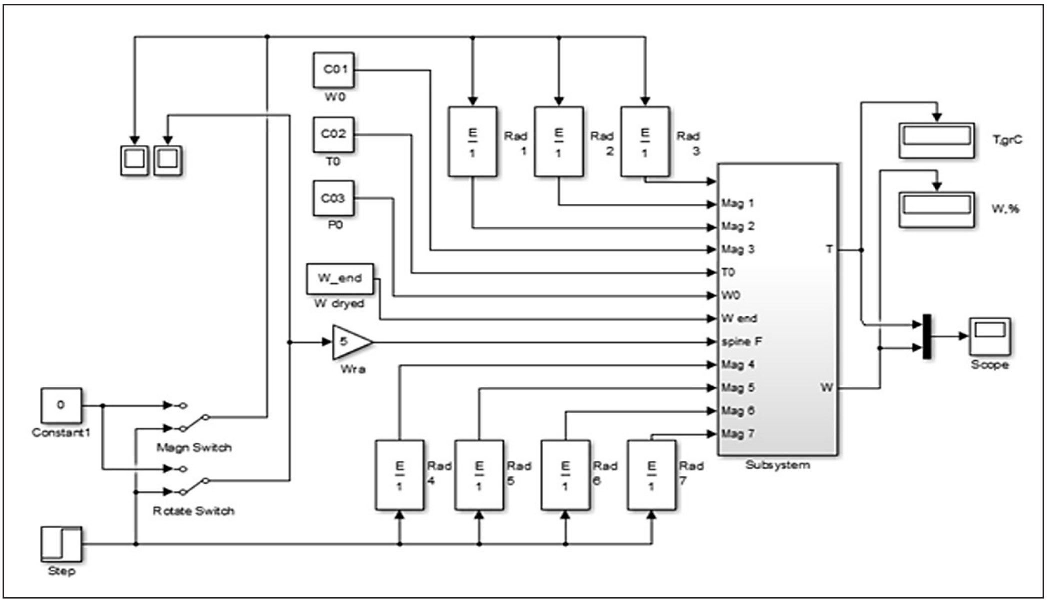
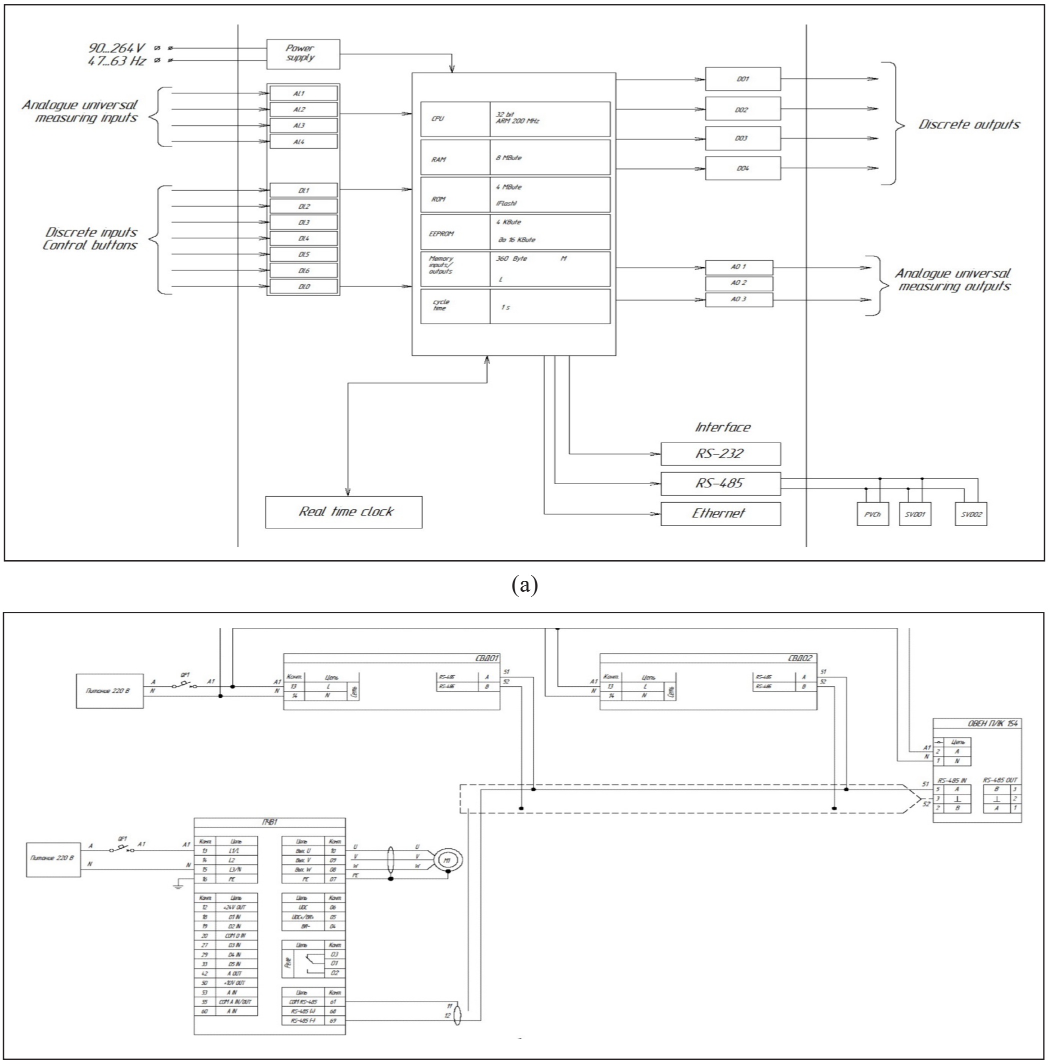


Figure 2. Simulation model of a microwave electro-technological installation for microwave processing of vegetable-origin organic materials

Methods Used to Measure the Processing Parameters

An automated control system has been developed to control the microwave processing organic materials of vegetable origin. Figure 3 shows the functional and circuit diagrams of the control system.

The automated control system for microwave processing organic materials of vegetable origin consists of four temperature sensors, four moisture sensors, a controller, two temperature and moisture measuring devices and a frequency transducer.



(a)

(b)

Figure 3. Diagram of an automated control system for microwave processing of vegetable-origin organic materials: (a) circuit diagram and (b) functional diagram

Note. OVEN PLC154—controller (PLC-programmable logic controller); SVD01, SVD02—temperature and moisture measuring device (SVD—wood moisture meter); PVCh1, PVCh—high-frequency transducer)

The humidity and temperature measuring device of the SVD series is designed for remote determination of humidity in drying chambers using four conductometric sensors. The device has one or two thermometers, depending on the model. The results of temperature measurements are transmitted via the RS-485 port according to the Modbus ASCII protocol. The length of the communication line is up to 1,000 meters; about 31 humidity meters can be connected to the line.

The technical characteristics of the OVEN PLK 154 controller are given in Table 2. The technical characteristics of the ARIES PCHV1 frequency converter are given in Table 3.

Table 2
Technical characteristics of the ARIES PLC 154 controller

Parameter	Value
Case protection level	IP20
Power supply voltage PLK154-220	90–264 V AC (rated voltage, 220 V), frequency of 47–63 Hz
Power consumption	6 Watts
Front panel display	1 Power indicator 6 digital input status indicators 4 output status indicators 1 indicator of connection with CODESYS 1 user program operation indicator
Interfaces	Ethernet 100 Base-T RS-232 RS-485
Exchange rate over RS interfaces	from 4800 to 115200 bps
Protocols	OVEN Modbus-RTU, Modbus-ASCII DCON Modbus-TCP GateWay (protocol CODESYS)

Table 3
Technical characteristics of the ARIES PCHV1 frequency converter

Parameter	Value
Power supply network	3 phases, 380–480 V (5.5–22 kW)
Output voltage (U, V, W), %	0–100
Output frequency, Hz	0–200 Hz(VC), 0–400 (U/F)
RS-485 protocol	Modbus RTU
Enclosure protection class	IP20

Testing Procedure

The purpose of the experimental studies is to determine the appropriate drying mode, which ensures fast processing and the preservation of nutrients in organic materials of vegetable origin.

Four modes of technological installation operation were studied. The first mode involves switching on seven magnetrons and materials' rotation. The second mode consists of actuating four magnetrons and materials' rotation. The third mode implies turning on seven magnetrons without the materials' rotation. The fourth mode involves actuating four magnetrons without materials' rotation.

Test characteristics are given in Table 4.

Table 4
Test characteristics

Parameter	Value
The first processing mode (7 magnetrons and the rotation mechanism of organic materials of plant origin along its axis are working)	
Initial humidity, %	85–92
Initial temperature, ˚C	21–23
Final humidity, %	6–10
Final temperature, ˚C	77–85
Processing time, hour	15
The second processing mode (4 magnetrons are working; the mechanism of rotation of organic materials of plant origin along its axis is disabled)	
Initial humidity, %	78–87
Initial temperature, ˚C	20–23
Final humidity, %	8–30
Final temperature, ˚C	78–93
Processing time, hour	39

Vegetable-derived organic materials are fastened horizontally to two frames of the working chamber of the microwave electro-technological installation. After the materials are laid, the lid is closed.

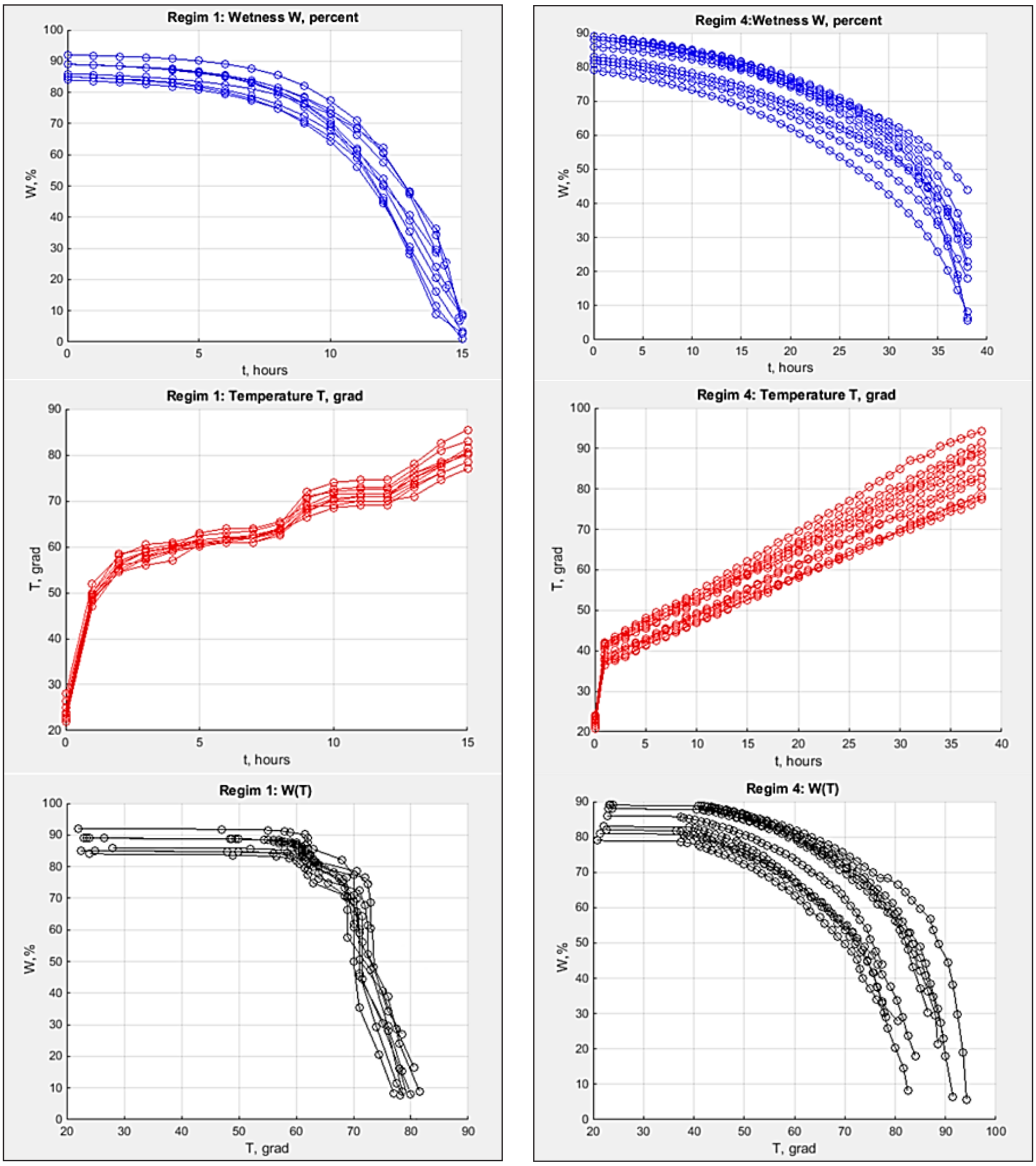
The moisture and temperature of vegetable-origin organic materials were measured every 60 minutes during microwave processing.

The experiments involved an infrared pyrometer, a surface thermometer, and a moisture-measuring device.

RESULTS

The paper presents the experimental results of the first and fourth processing modes. Figure 4 shows the modes of processing vegetable-origin organic materials in a microwave electro-thermal installation. Each mode gives the dependencies between moisture and time, temperature and time, and moisture and temperature.

- The drying time for the first mode was 15 hours; the final moisture was 7%.
- The drying time for the fourth mode was 39 hours; the final moisture was 12%.
- The first mode lasted 15 hours, and the fourth lasted 38 hours.

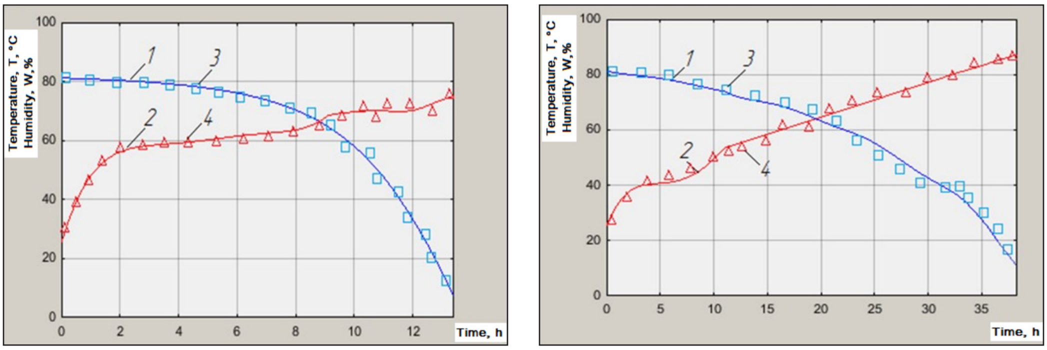


(a) (b)

Figure 4. Modes of processing of vegetable-origin organic materials in a microwave electro-thermal installation: (a) the first mode; (b) the fourth mode

Figure 5 contrasts the simulation modeling results with the experimental studies of the microwave processing of vegetable-origin organic materials in the first and fourth modes.

The analysis of the results shows that the first mode is characterized by the absence of wrapping, charring, curving and twisting of the samples of vegetable-origin organic materials during their processing in the microwave electro-technological installation.



(a) (b)

Figure 5. Comparison of the simulation modeling results and experimental studies of the microwave processing of vegetable-origin organic materials for the first and fourth modes: (a) the first mode, (b) the fourth mode

Note. 1, 2—simulation modeling results; 3, 4—experimental results

The fourth mode is characterized by wrapping and cracking the material, but there is no twisting, curving or charring.

Experimental studies and simulation modeling of the first and fourth modes of the microwave processing of vegetable-origin organic materials revealed the following:

- The drying time for the first mode was 15 hours; the final moisture was 7%.
- The drying time for the fourth mode was 39 hours; the final moisture was 12%.

The first mode provides a uniform temperature change of organic materials of vegetable origin. The surface temperature of the samples is almost the same as the temperature at half their thickness.

The fourth mode does not provide a uniform temperature change. The surface temperature of the samples differs by 8–13 °C from the temperature at half the depth of their thickness.

The simulation modeling of four modes of the technological installation operation provides a thorough and reliable analysis of changes in the temperature and moisture of vegetable-origin organic materials. The discrepancy between experimental data and simulation modeling does not exceed 4%.

Thus, the results of simulation modeling almost agree with the experimental results. The relative error does not exceed 3.5%.

DISCUSSION

Table 5 presents a comparative analysis of the results obtained and those of other authors.

The rotation of vegetable-origin organic material in the technological block of a thermal microwave installation has a positive effect, reducing the processing time and ensuring the required quality of the dried material, which is similar to the results of the studies

Table 5
Comparison of the results obtained with the results of other authors

Parameter	Results of experimental studies	Khasanov (2015)	Waseem et al. (2022)	Navida et al. (2022)	Malik et al. (2022)	Martins (2021)
Radiation frequency, MHz	2,450	2,450	2,450	2,450	2,450	2,450
Power, W	1,200	1,200	1,100	1,000	1,000	100–3,000
Uniformity processing, %	95–98	98	88.3	85	95	90
Productivity, t/hour	5–6	4	2.8–3.2	-	-	1.8–2.5
Positive effect	Reduction of processing time, improvement of properties	Increasing yields, improving seed quality	Improving the potato powder nutritional properties	Improving the watermelon juice's nutritional properties	Preservation of nutritional properties in a lemon drink	Improving the physical properties of grain

presented in the work (Aipov et al., 2019). The work states that the lumber pile rotation along its axis also reduces the processing time and provides a high-quality dried material.

Using two technological blocks (a block of thermal microwave processing of vegetable-origin organic materials and a block of non-thermal microwave processing of agricultural crops) in an electro-technological installation gives a positive economic effect since the processing of materials occurs simultaneously. The same findings are presented in Dobrodum and Arkhangelsky (2017). They justify using a microwave electro-technological installation with a hybrid working chamber for processing dielectric and polymer materials and prove its commercial importance.

Non-thermal microwave processing of agricultural crops in an electro-technological installation does not worsen the nutritional value and organoleptic characteristics of the material. On the contrary, this method improves crops' properties (e.g., increases their nutritional value). The same findings are presented in Qu et al. (2021) and Waseem et al. (2022), which prove the increased nutritional value of a baked product made with the addition of less than 7.5% of potato powder. The product was processed in a microwave oven. Microwave processing did not damage potato starch.

Non-thermal microwave processing of agricultural crops, including grain, in an electrotechnological installation increases storage time and provides a high-quality product. Qu et al. (2021) present similar findings, describing the process of lipase destruction in whole-grain flour by microwave heating, thus significantly increasing flour storage time and quality.

Combining two technological blocks in one electro-technological installation (a block of thermal microwave processing of vegetable-origin organic materials and a block of non-thermal microwave processing of agricultural crops) is a complex engineering problem under development. However, using this method will increase important economic and energy production indicators. The same findings are presented in Arkhangelsky and Grishina (2007) and Nadeem, Tehreem et al. (2022), which prove the economic and practical efficiency of combining two methods of processing different materials.

The creation of a microwave electro-technological installation for the microwave processing of vegetable-origin organic materials and agricultural crops implies combining two technological processes. Khasanov (2015) and Tukhvatullin and Aipov (2019) studied these processes, but their findings differ from those presented in this paper since they describe the microwave processing of various materials as one technological process. However, this method reduces the processing time and ensures the high quality of the processed materials.

Thus, the proposed prototype model for microwave processing of vegetable-origin organic materials and agricultural crops significantly increases the energy and economic efficiency of the installation by reducing the processing time and ensuring the required quality of the materials being dried, unlike existing electro-technological installations, which process only one material.

Moreover, unlike the existing ones, the proposed electro-technological installation increases the possibility of selling more than two products, thus significantly reducing costs and increasing the formation of positive financial results. In other words, the proposed installation contributes to profit growth at the same energy costs.

CONCLUSION

One of the options for designing a microwave electro-technological installation for microwave processing of vegetable-origin organic materials and agricultural crops is combining two technological blocks for non-thermal and thermal processing. Traveling wave chambers with a homogeneous rectangular waveguide are recommended to be used as blocks. A mechanism of rotation around their axis is used to ensure uniform processing of samples of vegetable-origin organic materials in a microwave electro-technological installation. As a result, the processing time decreases, and the quality of the processed material improves.

Experiments show that simulating the first and fourth modes of microwave processing of vegetable-origin organic materials decreases the drying time and the moisture rate. Thus, the drying time of the fourth mode is reduced from 39 to 15 hours, and the moisture rate is 12%. During the first mode, the moisture rate is 7%.

The first mode is characterized by a uniform temperature change (the temperature at the depth of half the thickness of the samples differs from the samples' surface temperature by no more than 0.5–1.0°C). The fourth mode is characterized by an uneven temperature change (the temperature at a depth of half the thickness of the samples differs from the samples' surface temperature by 5–7°C).

Therefore, the first mode of microwave processing of organic materials of vegetable origin is preferable since it provides high-quality dried material in a short processing time.

Together with the heat treatment of vegetable-origin organic materials, the presented microwave electro-technological installation implements seven other technological processes of non-thermal microwave processing of agricultural products. In this case, after each of the seven sources of microwave energy (magnetron), a technological unit for non-thermal microwave modification of the corresponding material should be placed.

PRACTICAL APPLICATION OF THE FINDINGS

The creation of a microwave electro-technological installation for processing vegetable-origin organic materials and agricultural crops will solve the fundamentally new problem of coordinating technological blocks of thermal and non-thermal processing. This will contribute to the development of agriculture and allow the production of better-quality agricultural products.

Moreover, unlike the existing ones, the proposed electro-technological installation increases the possibility of selling more than two products with improved qualities, thus increasing profits at the same energy costs.

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