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ANALYSIS OF POWER AND ENERGY PARAMETERS OF THE CONVEYOR INFRARED DRYER OF OIL-CONTAINING RAW MATERIALS

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Abstract. *Infrared drying of bulk agricultural products is becoming increasingly widespread in processing and food industries due to energy efficiency, compactness of technological equipment, and ease of operation. The purpose of the presented research is to determine the influence of the technological parameters of the process of infrared drying of the moving layer of oil-containing raw materials. An experimental model of a vibro-conveyor dryer and a set of measuring equipment were developed to solve the problems. The scientific novelty of the work is the confirmation that in the conditions of a vibro-liquefied layer of products, unique conditions are created for the constant renewal of heat exchange surfaces and, accordingly, the leveling of the negative thermal radiation effect on the products, the possibility of advancing the product layer along the working zone, reducing the forces of internal friction in the technological mass, which leads to a decrease in energy consumption on the process Laws have been established regarding the effect of the number of thermoradiation blocks, the load on the flexible belt of the wave conveyor, the speed of product advancement on the belt on the dynamics of infrared drying of soybeans and rapeseed. The practical value of the work was the substantiation of the operating modes of thermoradiation drying with the help of a vibrating wave conveyor installation based on the energy saving of the technological impact, high intensification of the process and minimization of the negative effect on the properties of the processed products.*

Keywords: thermoradiation drying, infrared conveyor dryer, oil-containing raw materials, vibrofluidized bed, energy and power parameters, low-frequency oscillations

ANALIZA MOCY I PARAMETRÓW ENERGETYCZNYCH PRZENOŚNIKOWEJ, DZIAŁAJĄCEJ NA PODCZERWIEŃ SUSZARNI SUROWCÓW ZAWIERAJĄCYCH OLEJ

Streszczenie. *Suszenie podczerwienią produktów rolnych luzem staje się coraz bardziej powszechne w przemyśle przetwórczym i spożywczym ze względu na energooszczędność, kompaktowość urządzeń technologicznych i łatwość obsługi. Celem prezentowanych badań jest określenie wpływu parametrów technologicznych procesu suszenia podczerwienią ruchomej warstwy surowców zawierających olej. W celu rozwiązania problemów opracowano eksperymentalny model suszarki z przenośnikiem wibracyjnym oraz zestaw urządzeń pomiarowych. Naukową nowością pracy jest potwierdzenie, że w warunkach skraplania wibracyjnego warstwy produktów powstają unikalne warunki do ciągłego odnawiania powierzchni wymiany ciepła, a tym samym niwelowania negatywnego wpływu promieniowania cieplnego na produkty, możliwość przesuwania warstwy produktu wzdłuż strefy roboczej, Zmniejszenie sił tarcia wewnętrznego w masie technologicznej, co prowadzi do zmniejszenia zużycia energii w procesie. Zdefiniowano prawa dotyczące wpływu liczby bloków termoradiacyjnych, obciążenia elastycznej taśmy przenośnika falowego, prędkości przesuwania produktu na taśmie na dynamikę suszenia soi i rzepaku w podczerwieni. Praktyczną wartością pracy było uzasadnienie trybów pracy suszenia termoradiacyjnego za pomocą instalacji przenośnika wibracyjno-falowego w oparciu o oszczędność energii oddziaływania technologicznego, wysoką intensyfikację procesu i minimalizację negatywnego wpływu na właściwości przetwarzanych produktów.*

Słowa kluczowe: suszenie termiczne, suszarka przenośnikowa na podczerwień, surowce zawierające olej, złoże wibrofluidyzowane, parametry energii i mocy, oscylacje o niskiej częstotliwości

Introduction

The drying process is one of the most complex mass transfer processes, which is a complex complex of interconnected elements that includes heat transfer during the transfer of heat to products through the boundary layer; evaporation during phase transformation; heat and mass transfer during the transfer of moisture and heat inside the material; heat and mass transfer during the transfer of moisture and heat from the surface of the material to the environment through the boundary layer by diffusion or molecular transfer; filtration or molar transfer under convection conditions; thermodiffusion, that is, the transfer of moisture under the influence of a temperature gradient, for which the direction of the thermodiffusion density of the substance mass flow corresponds to the direction of the heat flow density. When justifying the structural and technological scheme of the equipment for the implementation of the presented stages of heat and mass transfer, it is necessary to conduct an analysis of energy costs to ensure their implementation, to assess the technical and economic feasibility of the process and its impact on the change in the physical and chemical properties of the processed raw materials. It is the power and energy characteristics of the process that ensure the dynamics of the development of these factors [5, 9, 12, 19, 25].

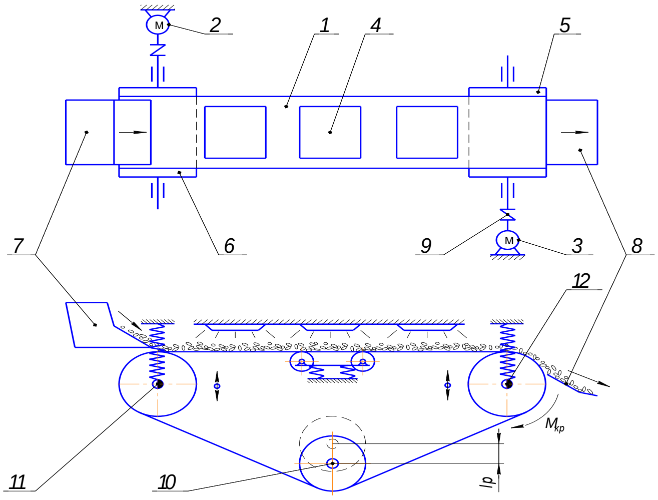
Among the main factors of intensification of the drying process of bulk material, it is possible to note the transfer of heat of the product from the source of radiant energy and the creation of a fluidized layer of products to increase the heat and mass exchange surface. In the process of heat exchange, the radiant flow partially penetrates into the capillary-porous bodies to a depth of 0.1...2 mm and is almost completely absorbed due to a series of reflections from the walls [1, 10, 12, 21, 25, 27]. At the same time, the heat exchange coefficient has a significant value and the duration of the drying process is reduced by 30...100 times compared to the convective or conductive method [1, 8, 21, 22]. The vibration of the executive bodies of the dryer ensures the movement of the particles of the loose medium at a constant speed or at a slowly changing speed. This leads to drift – displacement of the equilibrium positions of such particles and to the appearance of one or more discrete positions of their quasi-equilibrium; as a result of which there is an almost 10-fold decrease in the effective coefficient of friction in the product mass, which increases the coefficient of thermal contact with the product to 100%, significantly reduces the time of technological action and indirectly leads to a 3-5-fold decrease in energy consumption for the process [8, 23, 11, 17, 26, 18].

To carry out the investigated process in modern technologies, vibrating transport and technological machines are used. The main disadvantages of vibro-conveyor systems with an undeformed conveying body remain high metal consumption and energy consumption, structural imbalance and, accordingly, high dynamic loads on support nodes [8, 4, 20, 24, 16]. The presence of a transport device in the form of a flexible conveyor in dryers allows to eliminate the indicated shortcomings and to create energy-saving product processing schemes with prospects for the implementation of automated modes [2, 3, 7, 28, 6]. However, it is the presence of a flexible transport element that greatly complicates the design of the machine, makes it difficult, and in some cases, eliminates the possibility of adjusting the operating modes of the vibrating installation.

Thus, the power and energy characteristics of the researched process determine both the possibilities and the efficiency of its implementation, the degree of influence on the surface of the loose product and the corresponding provision of the required properties, which determines the relevance of these studies in the design of infrared technological equipment.

1. Object of investigation

The developed drying unit contains a flexible load-bearing body 1 (Fig. 1), on which a running or standing wave is created during the operation of mechanical vibrators 2, 3 [13–15]. Such a wave spreads along the belt 1, occurs as the transportation of products coming from the feeder 7, with a speed that is regulated by the amplitude-frequency characteristics of the vibrators, which leads to the emergence of a fluidized state of the processing material and its intensive mixing. translational movement. This ensures constant renewal of the surface of products with a thermal energy carrier and accordingly reduces the heat intensity on the surface layer while maintaining a sufficiently high flow rate. Oscillation of rollers 5, 6 ensures the advancement of loose material at a speed necessary to maintain the kinetics of the process under study.



a)

b)

Fig. 1. Schematic diagram of the conveyor vibrating wave infrared dryer (a) and its experimental and industrial model (b): 1 – belt; 2, 3 – motors of vibration exciters; 4 – infrared emitters; 5,6 – rollers; 7 – feeder; 8 – receiving hopper; 9 – flexible coupling; 10 – tension roller; 11, 12 – unbalanced vibrators

The aggregated mechanical vibration exciter in the support rollers 5, 6 of the dryer compactly and organically fits into the scheme of the wave conveyor, allows to reduce the oscillating mass of the drive and provides for the leveling of parasitic vibrations with the help of elastic elements 9. Such a scheme of the drive body, together with the presence of a wave conveyor with a deformable transport element, allows significantly improve the balancing system of the dryer. In addition, it is possible, together with the reduction of the metal and energy consumption of the device compared to existing designs of vibro-infrared dryers of the type "Uragan", "USK", UTZ-4 "M-500", "SVIK" [13], to provide conditions for regulated intensification of the removal process free and physically bound moisture from the processing material. The last factor is implemented by changing the power and energy characteristics of the "vibration field" due to the selection of the corresponding amplitude and frequency of oscillations of the support rollers 5 and 6.

2. Evaluation of the parameters of the investigated infrared drying process

In order to evaluate the desired parameters of the process of infrared irradiation of oily material (Fig. 2), the selection of equipment was carried out according to the following factors: ensuring the necessary level of activity of substances and humidity; implementation of constructive solutions for the organization of infrared irradiation to ensure the necessary energy and technological efficiency of the process; the choice of the method of mechanical action to ensure the transportation and mixing of the material [7, 8, 17, 22].

The process of infrared drying of oil-containing products was carried out in two stages: first, processing of the product at the maximum temperature of the source of infrared radiation until the formation of a browning crust on the surface of the product; then bringing the product to full readiness at a reduced constant temperature of the generators. The temperature decrease in the second stage occurred with the help of reducing the electric power or increasing the distance of the product to the source of infrared radiation. Design solutions for the layout of the infrared lamp block and the generators themselves ensured the achievement of uniform irradiation according to the requirements of this treatment for the corresponding oil-containing material [2, 3], including the content of anti-nutrients [28].

When conducting experimental studies, a certain amount of whole grain of rapeseed or soybeans was received on the tape, obtaining values of specific loading equal to 2.5, respectively; 3.5; 5 kg/m^2. After that, they ensured the promotion of products on tape 2 (Fig. 2) at a speed of 0.13; 0.33 or 0.54 cm/s. At the same time, under the influence of infrared emitters 4, which were turned on individually and together, the product perceives radiation with a power of 100, 200, 300 W. The power of the emitters was adjusted by changing the current strength with the help of current clamps.

Fig. 2. Scheme of the experimental conveyor installation for infrared drying: 1 – drive roller; 2 – ribbon; 3 – tension roller; 4 – infrared irradiated; 5 – production

The temperature of the product layer was determined using a pyrometer through the windows in the casing of the installation, which are located after each of the emitters along the movement of the products on the belt.

3. Determination of the investigated parameters of infrared drying for the moving layer of products

On the basis of the conducted experiments, we obtained numerical data of the desired characteristics of infrared drying of rapeseed and soybeans in a moving layer of products, and built the dependencies presented in Figures 3, 4, 5.

When the speed of the conveyor belt increases from 0.0015 to 0.0285 m/s, the intensity of humidity changes for a fixed processing time decreases by 3 times (Fig. 3). With a 5-fold increase in the power of irradiation, the intensity of humidity changes increases by 8 times (Fig. 4a). When the load of products in the working area changes from 0.2 to 0.5 kg/m^2, the intensity of humidity changes increases by 3.5 times (Fig. 4b).

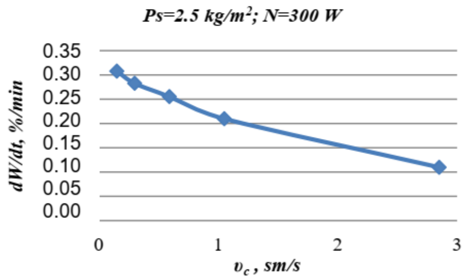
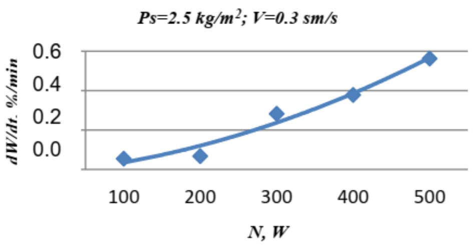
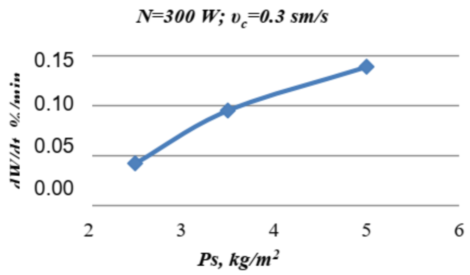


Fig. 3. Dependences of humidity reduction for rapeseed when changing the speed of the belt



a)



b)

Fig. 4. Dependencies of humidity reduction for rapeseed grain when changing power (a) and when changing specific load (b)

The dynamics of changes in the speed of infrared drying of rapeseed and soybeans depending on the number of radiating modules, with a change in the radiation power N_{op}, loading in the working area P_s, and the speed of the conveyor belt υ_{st} are presented, respectively, in figures 5, 6.

According to the results of the experiments, the most optimal values of the speed of transportation of products were determined in the range from 0.15 to 0.3 cm/s, under the conditions of the power of infrared emitters of 400 – 500 W. It turned out that a specific loading of more than 3.5 kg/m^2 is impractical to use due to the fact that a large layer of products does not allow infrared rays to carry out uniform processing of grains, especially at sufficiently high speeds of the belt movement. It was determined that it is more expedient to carry out the drying process with three successively located infrared emitters, to increase the amount of moisture removed, it is effective to reduce the power of the emitters from 500 to 300 W.

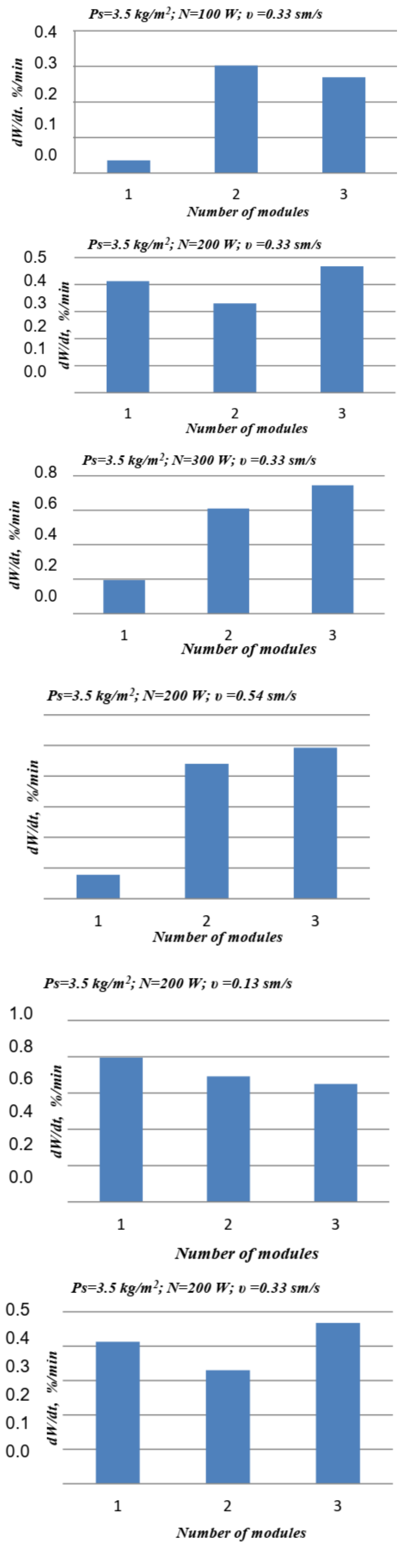


Fig. 5. Change in the speed of infrared drying of soybeans dW/dt (in %/min) in the moving layer of products when the conditions of technological processing vary

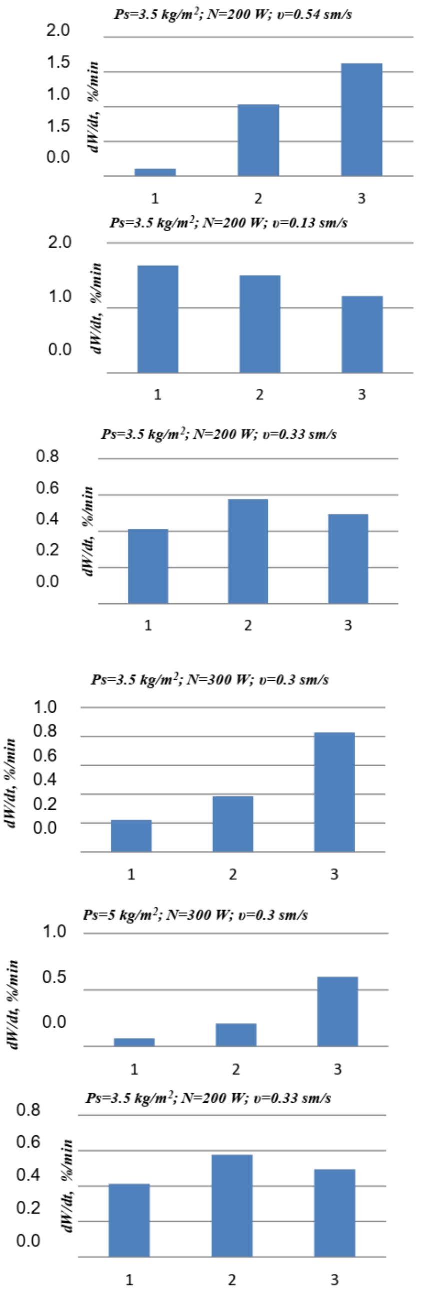


Fig. 6. Change in the rate of infrared drying of rapeseed dW/dt (in %/min) in the moving layer of products when the conditions of technological processing vary

4. Conclusions

1) Experimental studies of the technological parameters of thermoradiation drying for a moving layer of raw materials made it possible to obtain graphs of the drying speed depending on different irradiation modes, different loading of the working area and the speed of the conveyor belt for rapeseed and soybean, which made it possible to obtain the necessary experimental database for substantiating the working parameters infrared vibro-conveyor dryer under the conditions of minimizing energy consumption and thermal damage of oil-containing products, namely, rapeseed and soybeans.
2) The intensity of humidity change for a fixed processing time decreases 3 times when the speed of the conveyor belt increases from 0.0015 to 0.0285 m/s, 8 times – when the irradiation power increases by 5 times; 3.5 times – when the load of products in the working area changes from 0.2 to 0.5 kg/m^2.
3) With the simultaneous operation of two vibration exciters, stable transportation of products by a wave conveyor while ensuring the necessary productivity and quality of processing is observed under the following operating modes of processing: speed of transportation of products in the range from 0.15 to 0.3 cm/s; power of infrared emitters in the range of 400 – 500 W; the specific loading of the load-bearing body should not exceed 3.5 kg/m^2.
4) Carrying out the drying process with three successively located infrared emitters while reducing the power of the emitters from 500 to 300 W made it possible to increase the amount of moisture removed per unit of time.

References

[1] Abbaspour-Gilandeh Y. et al.: Evaluation of the Changes in Thermal, Qualitative and Antioxidant Properties of Terebinth (Pistacia atlantica) Fruit under Different Drying Methods. Agronomy 10, 2020, 20–24.

[2] Bandura V. et al.: Investigation of properties of sunflower and rapeseed oils obtained by the soxhlet and microwave extraction methods. Agraarteadus 33(1), 2022, 48–58.

[3] Bandura V. et al.: Case study: Dynamics of sunflower seed movement in the vibrating tray of the infrared dryer and its influence on the drying process. Agraarteadus 32(2), 2021, 204–213.

[4] Basok B. I. et al.: Radiative-Convective Heat Exchange of a Building with the Environment on Exposure to Solar Radiation. Journal of Engineering Physics and Thermophysics 93(1), 2020, 45–53.

[5] Bahlul N. et al.: Coupling of Microwave Radiations to Convective Drying for Improving Fruit Quality. IDS'2018: 21st International Drying Symposium, 2018, 699.

[6] Bezbah, I. et al.: Designing the structure and determining the mode characteristics of the grain dryer based on thermosiphons – Eastern-European Journal of Enterprise Technologies 2(8-116), 2022, 54–61.

[7] Burdo O. G. et al.: Energetics and Kinetics of Plant Raw Material Dehydration Processes – Energetică și cinetică a proceselor de dezhidratare a proceselor de dezhidratare a materiei prime vegetale. Problems of the Regional Energetics 2, 2022, 111–129.

[8] Burdo O. et al.: Studying the operation of innovative equipment for thermomechanical treatment and dehydration of food raw materials. Eastern-European Journal of Enterprise Technologies 5(11-101), 2019, 24–32.

[9] De Faria R. Q., dos Santos A. R. P., Gariepy Y., da Silva E. A. A., Sartori M. M. P., Raghavan V.: Optimization of the Process of Drying of Corn Seeds with the Use of Microwaves – Drying Technology 38(5-6)/2019, 676–684.

[10] Horuz E. et al.: Effects of Hybrid (Microwave-Convectional) and Convectional Drying on Drying Kinetics, Total Phenolics, Antioxidant Capacity, Vitamin C, Color and Rehydration Capacity of Sour Cherries. Food Chemistry 230, 2017, 295–305.

[11] Kuznietsova I. et al.: Application of the differential scanning calorimetry method in the study of the tomato fruits drying process. Agraarteadus 31(2), 2020, 173–180.

[12] Liu H. et al.: Microwave Drying Characteristics and Drying Quality Analysis of Corn in China. Processes 9(9), 2021.

[13] Palamarchuk I. et al.: The intensification of dehydration process of pectin-containing raw materials. Potravinarstvo Slovak Journal of Food Sciences 16, 2022, 15–26.

[14] Palamarchuk I. et al.: Analysis of main process characteristics of infrared drying in the moving layer of grain produce. Modern Development Paths of Agricultural Production: Trends and Innovations. Part 1 – Springer International Publishing 1, 2019, 317–322

[15] Palamarchuk I. et al.: Optimization of the Parameters 2 for the Process of Grain Cooling. Modern Development Paths of Agricultural Production: Trends and Innovations. Part 2. Springer International Publishing 2, 2019, 981– 988

[16] Paziuk V. et al.: Special aspects of soybean drying with high seedling vigor. UPB Scientific Bulletin, Series D. Mechanical Engineering 83(2), 2021, 327–336.

[17] Petrova Z. A., Slobodyanyuk E. S.: Energy-Efficient Modes of Drying of Colloidal Capillary-Porous Materials. Journal of Engineering Physics and Thermophysics 92(5), 2019, 1231–1238.

[18] Polishchuk L., Bilyy O., Kharchenko Y.: Prediction of the propagation of crack-like defects in profile elements of the boom of stack discharge conveyor. Eastern-European Journal of Enterprise Technologies 6(1), 2016, 44–52

[19] Qu F. et al.: Effect of Different Drying Methods on the Sensory Quality and Chemical Components of Black Tea. Lebensmittel-Wissenschaft + Technologie 99, 2019, 112–118.

[20] Semko T., Palamarchuk, V., Sukhenko, V. Application of ultra-high-temperature processing of raw milk to improve cheese quality. Potravinarstvo Slovak Journal of Food Sciences 13(1), 2019, 840–845.

[21] Snezhkin Y. F., Shapar R. A., Gusarova E. V.: Theoretical and Experimental Studies of Convective Dehydration of Spicy-Aromatic Raw Materials. Journal of Engineering Physics and Thermophysics 95(6), 2022, 1366–1373.

[22] Snezhkin Y. F. et al.: Determination of the energy efficient modes for barley seeds drying. INMATEH – Agricultural Engineering 61(2), 2020, 183–192.

[23] Sorokova N., Didur V., Variny M.: Mathematical Modeling of Heat and Mass Transfer during Moisture–Heat Treatment of Castor Beans to Improve the Quality of Vegetable Oil. Agriculture 12(9), 2022, 1356.

[24] Sorokova N. N. et al.: Mathematical Simulation and Optimization of the Continuous Drying of Thermolabile Materials. Journal of Engineering Physics and Thermophysics 92(5), 2019, 1180–1190.

[25] Wei Q. et al.: Effects of Different Combined Drying Methods on Drying Uniformity and Quality of Dried Taro Slices – Drying Technology 37(3), 2019, 322–330.

[26] Yaropud V. et al.: Experimental studies of design-and-technological parameters of heat exchanger. Badania eksperymentalne parametrów konstrukcyjno-technologicznych wymiennika ciepła. Przeglad Elektrotechniczny 98(10), 2022, 57–60.

[27] Yildiz G., Izli G.: Influence of Microwave and Microwave-Convective Drying on the Drying Kinetics and Quality Characteristics of Pomelo – Journal of Food Processing and Preservation 6(3), 2019 [http://doi.org/10.1111/jfpp.13812].

[28] Zavialov V. et al.: Development of mathematical models of external mass exchange under conditions of vibroextraction from vegetable raw materials. Chemistry & Chemical Technology 3(9), 2015, 367–374.

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