Address Energy Delivery Technologies Based on The Hybrid Electrodynamic Processes

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Abstract. An effective tool has been identified for transferring technologies for processing food raw materials onto the rails of the nano-eco-industry — these are hybrid processes in electrodynamic devices. The aim of the work is a comprehensive study of hybrid processes in microwave electrodynamic systems. To achieve the goal, an experimental stand was created, which made it possible to visually confirm the effects of mechanical diffusion and establish the influence of key parameters on the kinetics and energy of hybrid processes. The working section — a model of a capillary-porous structure — was a bundle of calibrated glass tubes. When processing experimental data, the dependences of the influence of field power, channel diameter, temperature, and beam orientation on the kinetics and energy of the hybrid process were obtained. The most significant result of the work is the use of certain modes of organizing hybrid processes to control the extraction process in electrodynamic devices of three types: volumetric, film and circulation. Tests of these structures confirmed the formulated hypotheses of the formation of a hybrid process. The importance of the work lies in the fact that it is shown that the effect of mechanical diffusion is most powerfully manifested in electrodynamic extractors of the circulation type and energy consumption in electrodynamic extractors of the volumetric type is 1.4 times lower, film extractors are 1.5 times lower, and circulation type ones are 1.9 times lower, than in devices of traditional design.
***Keywords*:** electrodynamic apparatuses, energy technologies, hybrid processes, extraction, evaporation, drying, mathematical and experimental modeling.

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Tehnologii pentru livrarea țintită a energiei bazate pe procese electrodinamice hibride

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***Rezumat*.** A fost identificat un instrument eficient pentru transferul tehnologiilor de procesare a materiilor prime alimentare pe șinele eco-nano-industriei acestea sunt procese hibride în dispozitive electrodinamice. Scopul lucrării este un studiu cuprinzător al proceselor hibride în sisteme electrodinamice cu microunde. Pentru a atinge scopul, a fost creat un stand experimental, care a făcut posibilă confirmarea vizuală a efectelor difuziei mecanice și stabilirea influenței parametrilor cheie asupra cineticii și energiei proceselor hibride. Secțiunea de lucru - un model al unei structuri poroase capilare - era un mănunchi de tuburi de sticlă calibrate. La prelucrarea datelor experimentale, s-au obținut dependențele influenței puterii câmpului, diametrului canalului, temperaturii și orientării fasciculului asupra cineticii și energiei procesului hibrid. Cel mai importantv rezultat al lucrării este utilizarea anumitor moduri de organizare a proceselor hibride pentru controlul procesului de extracție în dispozitive electrodinamice de trei tipuri: volumetrice, film și circulație. Testele acestor structuri au confirmat ipotezele formulate de formare a unui proces hibrid. Importanța lucrării constă în faptul că se arată că efectul difuziei mecanice se manifestă cel mai puternic la extractoarele electrodinamice de tip circulație iar consumul de energie la extractoarele electrodinamice de tip volumetric este de 1,4 ori mai mic, extractoarele cu peliculă sunt de 1,5 ori mai mici, iar cele de tip circulație sunt de 1,9 ori mai mici decât la dispozitivele cu design tradițional.
***Cuvinte-cheie*:** aparate electrodinamice, tehnologii energetice, procese hibride, extracție, evaporare, uscare, modelare matematică și experimentală.

Технологии адресной доставки энергии на основе гибридных электродинамических процессов

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Аннотация. Определен эффективный инструмент перевода технологий переработки пищевого сырья на рельсы нано-экоиндустрии — это гибридные процессы в аппаратах электродинамического вида. Проведен анализ литературных источников, который показал, что электродинамическими системами, микроволновыми технологиями в мире активно занимаются. Однако сведения о теоретических основах таких технологий, о практической апробации аппаратов в условиях производства в доступной литературе не обнаружены. В работе поставлена цель комплексного исследования гибридных процессов в микроволновых электродинамических системах. Для достижения поставленной цели создан экспериментальный стенд, который позволил визуально подтвердить эффекты механодиффузии, установить влияние ключевых параметров на кинетику и энергетику гибридных процессов. Рабочим участком — моделью капиллярно—пористой структуры — был пучок откалиброванных стеклянных трубок. При обработке экспериментальных данных получены зависимости влияния мощности поля, диаметра канала, температуры, ориентации пучка на кинетику и энергетику гибридного процесса. С помощью видеозаписи были зафиксированы картины формирования гибридного процесса, этапы роста и спада интенсивности выбросов смеси раствора и пара, режимы их перемещения. Эти результаты представляют научную новизну работы. Наиболее существенным результатом работы является использование определенных режимов организации гибридных процессов для управления процессом экстрагирования в электродинамических аппаратах трех типов: объемного, пленочного и циркуляционного. Испытания этих конструкций подтвердили сформулированные гипотезы формирования гибридного процесса. Значимость работы заключается в том, что показано, что эффект механодиффузии наиболее мощно проявляется в электродинамических экстракторах циркуляционного типа и затраты энергии в электродинамических экстракторах объемного типа в 1,4 раза, пленочного в 1,5 раза, а циркуляционного в 1,9 раза ниже, чем в аппаратах традиционной конструкции.

Ключевые слова: электродинамические аппараты, энерготехнологии, гибридные процессы, экстрагирование, выпарка, сушка, математическое и экспериментальное моделирование.

INTRODUCTION

Profligate consumption of raw materials and energy resources, unbridled pollution of the atmosphere, hydrosphere, and lithosphere have led humanity into a severe global crisis. Such a crisis was forecasted in various models of human development. For example, a predictive model known as "Kondratiev waves" [1] was proposed a century ago. The cycle includes periods of growth and decline. Decline periods are characterized by prolonged depression, crises accompanied by revolutions, wars, and major social upheavals. However, crises have always spurred innovative development based on new technologies. A period of growth begins, marked by powerful scientific and technological progress that stabilizes and balances economic and social processes.

Currently, humanity is at a stage where the way out of the crisis involves the convergence of nano—, bio—, and information technologies. Similar conclusions can be drawn from a well-known model of the industrial development of humanity. Fundamental achievements in science and technology occur approximately twice a century.

It is important to identify the sectors of the economy that should be prioritized. To do this, let's turn to the well-known global predictive model of the "Club of Rome" [2]. It is forecasted that in 2030, humanity will face an acute energy crisis, by 2060 — an ecological crisis, and by 2090 — a food crisis. All these problems are most pronounced in the agro—industrial sector [3]. Therefore, the agro—industrial complex (AIC) economy will be a priority in overcoming the current crisis, with a focus on bio— and nanotechnologies. In [3], the mechanism of interaction between nanoscale elements of food raw materials and the electromagnetic field (EMF) is justified. The following is an analysis of the global experience of using EMF in food raw material processing technologies.

RESEARCH ON THE PROCESSING OF FOOD RAW MATERIALS IN AN ELECTROMAGNETIC FIELD

Various examples of the use of hybrid electromagnetic processes are provided in article [3]. A significant number of studies are known that explore the application of electromagnetic technologies and their combinations for processing food raw materials. The combination of convection drying with sublimation drying and microwave (MW) drying with sublimation drying allowed obtaining dried material with less shrinkage compared to conventional or microwave drying [4]. Trials of microwave drying of corn are presented in study [5]. Energy consumption in microwave drying is more than three times lower than that in traditional electrothermal drying. Microwave drying is often considered as an alternative to traditional drying methods. For example, in [6], it is shown that microwave drying is effective for drying slices of hawthorn. It is characterized by high product quality and biological activity, as well as low operating costs. The influence of microwave and traditional drying on the drying kinetics and quality of ilmenite—coke composite pellets is presented in [7]. The drying time in microwave drying was significantly reduced (90 s) compared to conventional drying (10 min). Moreover, granules dried in a microwave field showed the same strength in the dry state, and the efficiency of recovery of granules dried by microwave radiation was better due to the formation of microcracks. The efficiency and energy consumption of vacuum—MW drying of oil camellia seeds were studied in [8]. The results showed that internal water diffusion and surface water evaporation dominate during vacuum—MW drying. As the microwave radiation power increased, vacuum level increased, and the amount of load decreased, the drying time and energy consumption decreased. It was found that the optimal conditions for vacuum—microwave drying are a loading volume of 150 g, microwave power of 350 W, and a vacuum of 0.09 MPa. In [9], microwave and vacuum—microwave drying of barley malt was studied. Evaluation of hydration, germination, and drying was conducted. Traditional convective drying (50—70°C) took 540—840 minutes, while microwave drying reduced processing time by approximately 95%. Vacuum increased the drying rate and reduced the product temperature. The impact of microwave and sublimation drying methods on the chemical composition, sensory, textural, and antioxidant properties of kiwano seeds was investigated in [10], as well as the potential of microwave drying as an alternative to sublimation drying. Kiwano seeds were dried using sublimation and microwave dryers. Kiwano seeds dried at 180 W and lyophilized seeds received the highest expert ratings. Microwave drying increased the total phenolic content in kiwano seeds to 35.54 mg/g. The research results indicated that microwave drying could be a promising innovative alternative for the rapid production of freeze—dried fruit material while maintaining product quality. Microwave drying of bee pollen grains was explored in [11]. Images of fresh and microwave—dried bee pollen obtained using scanning electron microscopy were evaluated by experts for their organoleptic properties. The values of the effective moisture diffusion coefficient ranged from 0.04×10^{-8} to 1.14×10^{-8} m²/s, and the activation energy was 71.68 W/g. Drying time was reduced by 94% when the microwave radiation power level was increased from 180 to 900 W. In [12], it is demonstrated that compared to beans dehydrated by convective and sublimation drying, microwave products have higher moisture content, but the distribution of microscopic pores leads to good rehydration characteristics. Dehydration time can be further reduced to 6 hours compared to convective drying, and moisture content can be reduced to 11% by lowering the pressure during microwave drying. During rehydration, the period is successfully reduced to 30 minutes by raising the water temperature to 70°C. The results show that microwave drying does not affect the value of raw protein, and rehydrated products are comparable to fresh beans. In study [13], microwave extraction of anthocyanins from red cabbage is considered. Three independent variables were extraction time (4—6 hours), extraction temperature (40—70°C), and solvent type (water and ethanol/water, 1:1). The highest anthocyanin content, reaching 241.20 mg cyanidin/L, was obtained with a 4—hour extraction at 40°C using a mixture of ethanol and water. The optimal conditions for extraction with an ethanol—water solvent were a 5—minute extraction at a solid-to-solvent ratio of 1:20 and a microwave power of 200 W. For water—only extraction, the optimal conditions were a 10—minute extraction at a solid-to-solvent ratio of 1:20 and a microwave power of 442 W. The extraction process conditions were optimized using response surface methodology. Eight types of anthocyanins were identified in red cabbage extracts. In [14], oil was extracted from tiger nut flour by subcritical extraction with n—butane after prior microwave treatment. The results showed that microwave treatment (560 W, 6 min) significantly increased the efficiency of subcritical extraction. Subcritical extraction of tiger nut oil with a liquid—solid ratio of 3.62 kg/kg at a temperature of 52°C for 32 minutes after three extraction cycles yielded the highest amount of oil and maximum oil yield (24.74%)

from tiger nuts. The ratio of unsaturated to saturated fatty acids, low acid value, low peroxide value, and the predominance of oleic acid indicate the high quality of tiger nut oil. In [15], microwave extraction was conducted as an effective method for extracting anthocyanins, phenolic, and flavonoid compounds from eggplant peels. The possibility of extracting these valuable components from waste could improve the economics of the canning industry and minimize potential pollution from these byproducts. In [16], microwave (MW) extraction was applied to extract polyphenols from pomelo (Citrus maxima Merr.). The results showed that the highest polyphenol content (2.46 g GAE/L) and antioxidant activity (1325.85 µmol TE/L) were observed at an ethanol concentration of 60%, microwave radiation power of 300 W, microwave exposure time of 2 minutes, and material-to-solvent ratio of 1:30. The aim of the study in [17] was to extract bioactive compounds from cornel using microwave extraction (ME) and ohmic—heating—assisted microwave extraction (OH—ME) as alternatives to maceration (M). The application of ohmic heating before extraction increased the yield of phenolic compounds by 1.1 and 5.4 times compared to ME and M, respectively. Furthermore, the extraction time was reduced by approximately 42% and 95% for ME and M, respectively. Experimental data show that the combined use of ohmic heating and microwave extraction is a potential alternative method for the complete extraction of phenolic compounds from cornel, increasing yield, and reducing extraction time. In [18], an analysis of the efficiency of MW extraction for separating pectin from cocoa bean husks using a cheaper and milder acidifying agent — oxalic acid — was performed. Higher tartaric acid concentration and prolonged irradiation time increased the yield but decreased the degree of esterification, affecting the gelling ability of pectin. This method also significantly reduced the extraction time compared to the traditional method. In [19], the potential of saffron flowers as a source of polyphenols, especially anthocyanins, for the extraction of bioactive compounds and obtaining cyan dye was analyzed. It was found that adding pre-microwave treatment to the traditional process reduced the extraction time by 12 times and improved the characteristics of the final product when using a microwave energy density of only 0.16—0.54 kJ/mL. Pre-microwave treatment, when the material is heated to 65°C with a solvent ratio of 0.30 g/mL, was selected as optimal to maximize process efficiency and product quality. In [20], the ability of convective—microwave (CMW) and thermo—hydro (TH) treatments to alter the techno—functional properties and viscoelasticity of rice flour gel was studied. Samples of flour with moisture content of 30%, 20%, 15%, 13%, 8%, and 3% were subjected to microwave treatment for 480 s at 18 W/g. After treatment, the swelling force increased in all samples, while water solubility increased only in samples with 8% and 30% TH. The treatment contributed to gel stability and increased viscoelastic moduli, especially in samples with 8% and 20% TH. Microwave treatment allowed modulation of the techno—functional properties of rice flour, as well as the rheological and thermal characteristics of its gels. In [21], the study considered how the pre-treatment of macadamia nuts in an oven or microwave followed by oil extraction with a mechanical press affects the yield and chemical characteristics of macadamia oil. Oils extracted using a hydraulic press in combination with a microwave had the highest yield, better oxidative stability, and the lowest peroxide value. The results indicate that the combination of microwaves and a hydraulic press extracts oils with quality superior to other studied extraction methods. In [22], research on intermittent convective—microwave drying is presented, indicating that intermittent microwave—convective drying (IMCD) is an advanced drying technology that eliminates the drawbacks of microwave, convective, and microwave—convective drying methods. In [23], it is stated that microwave (MW) heating is a unique approach that, unlike conductivity and convection—based heating, can provide volumetric heating. Complex microstructural changes in food materials occur due to simultaneous heat and mass transfer during drying, significantly impacting the structure and quality of food products. The properties of food products, drying methods, and other drying parameters influence the microstructure of food product samples, which, in turn, affects drying kinetics and the quality of food products. The study presents new research on microstructural changes in food products during MW drying, with a focus on the formation of nanomicro-pores on cell walls and their impact on moisture transfer kinetics. Hot air was maintained at a temperature of 70°C, while microwave drying used power levels of 100 W, 200 W, 300 W, and 400 W. The research results show that the development of nanomicro-pores occurs only during intermittent MW drying, while the cell walls of food product samples tend to burn or disintegrate during continuous microwave drying due to the released high heat. Additionally, nanomicro-pores were not observed in the cell walls during convective drying. During MW processing with power ranging from 100 W to 400 W, a range of pore sizes from 0.1 µm to 8.5 µm was observed. Due to the formation of nanomicro-pores and collapses, MW drying takes about 10—20 times less time than convective drying to remove the same amount of moisture.

As a result of a critical analysis of scientific and technical literature, the following conclusions have been drawn:

1. Research on microwave processing of various raw materials is widely conducted worldwide. There is an evident positive trend and diversity in the objects of study.

2. The feasibility of using microwave technologies to intensify transfer processes and improve the qualitative characteristics of the final product is noted.

3. Studies on the structure of raw materials, the formation of nanomicro-pores after microwave treatment have emerged. However, theoretical foundations for the interaction of electromagnetic fields with raw materials are lacking. There are no recommendations for managing the parameters of electromagnetic systems. Existing research is limited to laboratory setups.

Therefore, the authors set the following objectives:

— Develop the hybrid process model proposed in [3];
— Formulate a scientific and technical hypothesis for initiating hybrid processes;
— Obtain visual representations of their formation and investigate the kinetics and energetics of hybrid processes.

RESULTS OF VISUAL, KINETIC, AND ENERGETIC STUDIES OF HYBRID PROCESSES

The following scientific and technical hypothesis is formulated: "When electromagnetic fields interact with capillary—porous materials, conditions for the emergence of a hybrid process are possible, initiating the hydrodynamic transport of target components from the depth of the volume to the dispersion phase." Understanding such conditions will allow for the control of the location, kinetics, and energetics of hybrid processes by electromagnetic field parameters. This will result in the development of a tool for managing electromagnetic devices, optimizing them for performance, energy consumption, and the qualitative characteristics of the final product.

An experimental stand has been developed to solve these problems (Fig. 1).

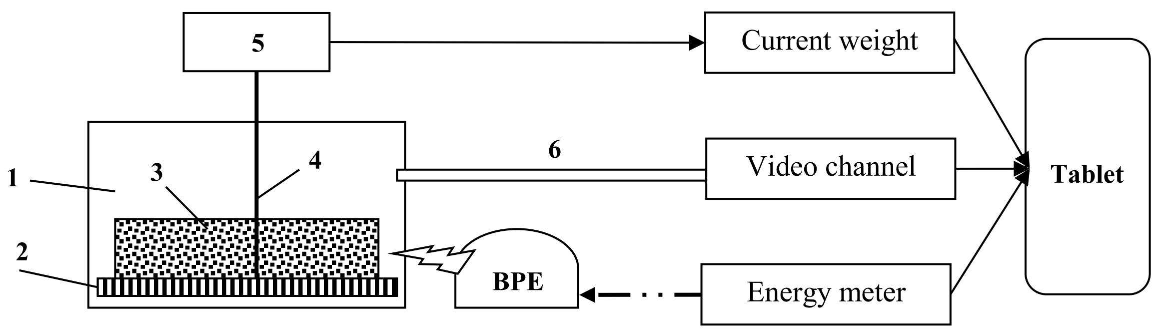

Fig. 1. Scheme of the experimental plant.

In resonant chamber 1, on shelf 2, the working area 3 is located, which is a block of glass tubes filled with colored water. The shelf, suspended by string 4, is connected to digital scales 5, Radwag PS 750/C/1 model. The block of power consumption (BPC) is measured by the Feron TM55 energy meter. The current weight of the working area, power consumption, and video footage of emissions from the block are recorded using a CHUWI tablet.

Procedure for preparing the working area: The tubes were carefully calibrated, numbered, weighed, filled with colored water, re-weighed, and assembled into a block (Fig. 2a).

a) *b)*

a) before treatment; b) after treatment

Fig. 2. Photos of work area.

The working area (Fig. 2a) was positioned in the resonant chamber and suspended from the digital scales. The kinetics of moisture loss was recorded as a result (Fig. 3).

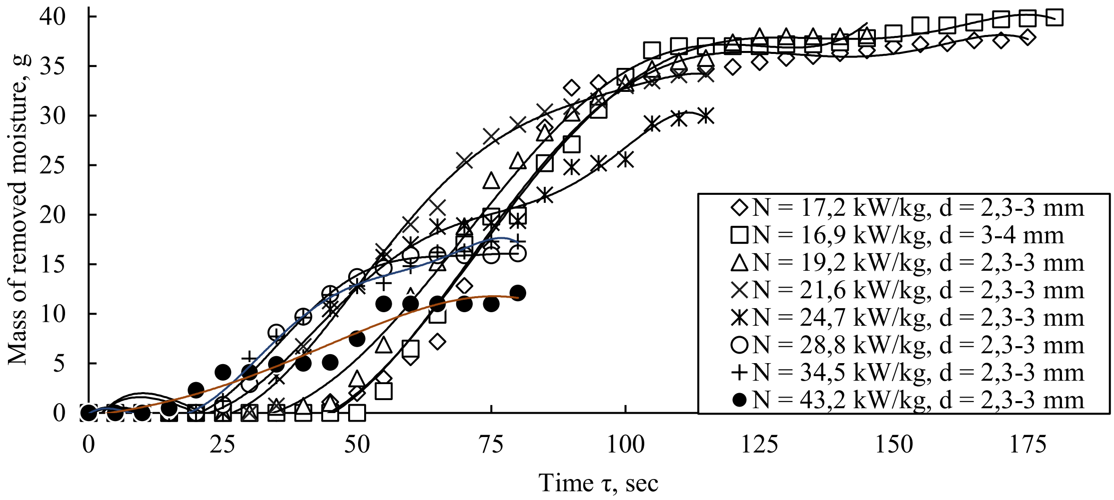

Fig. 3. Total moisture removal in the hybrid processes.

Data processing (Fig. 3) determined the variation in the moisture output rate from the working area over time
(Fig. 4).

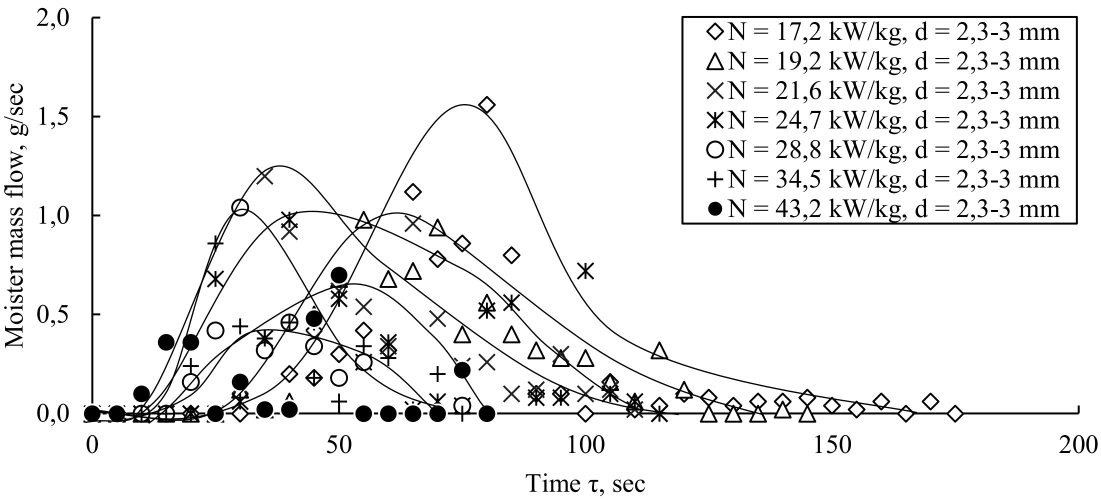

Fig. 4. Point moisture removal in the hybrid processes.

In the experiments, the electricity consumption was recorded (Fig. 5).

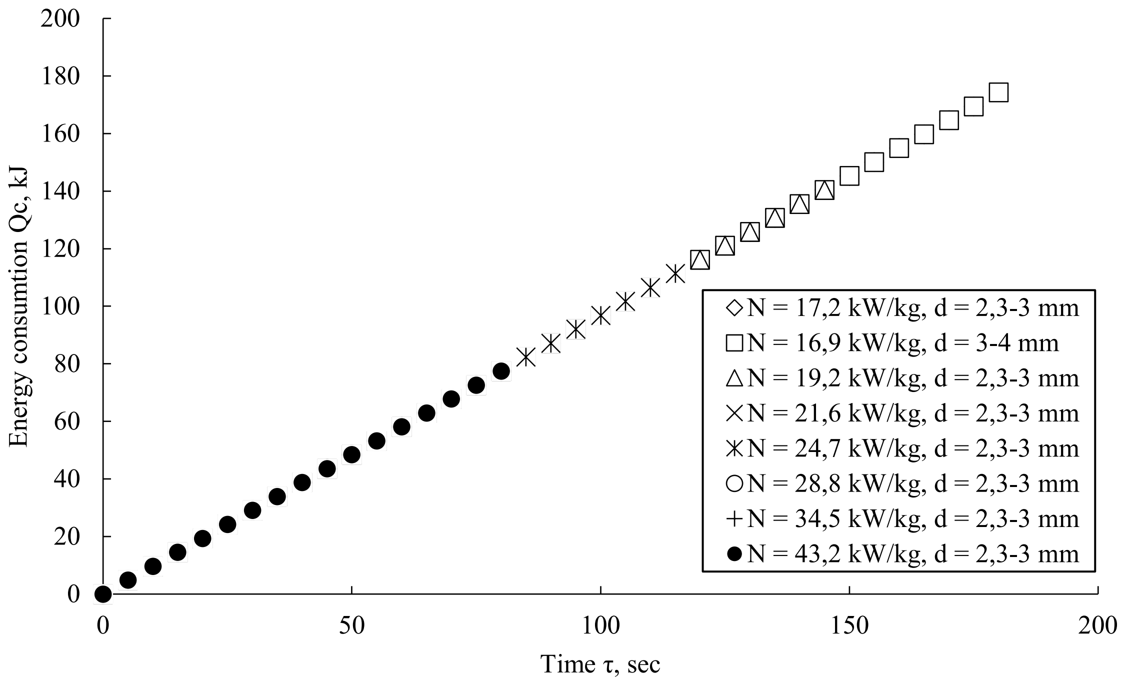

Fig. 5. Energy consumption.

Data processing (Fig. 4) and energy consumption established the specific energy costs for removing 1 kg of moisture from the working area (Fig. 6).

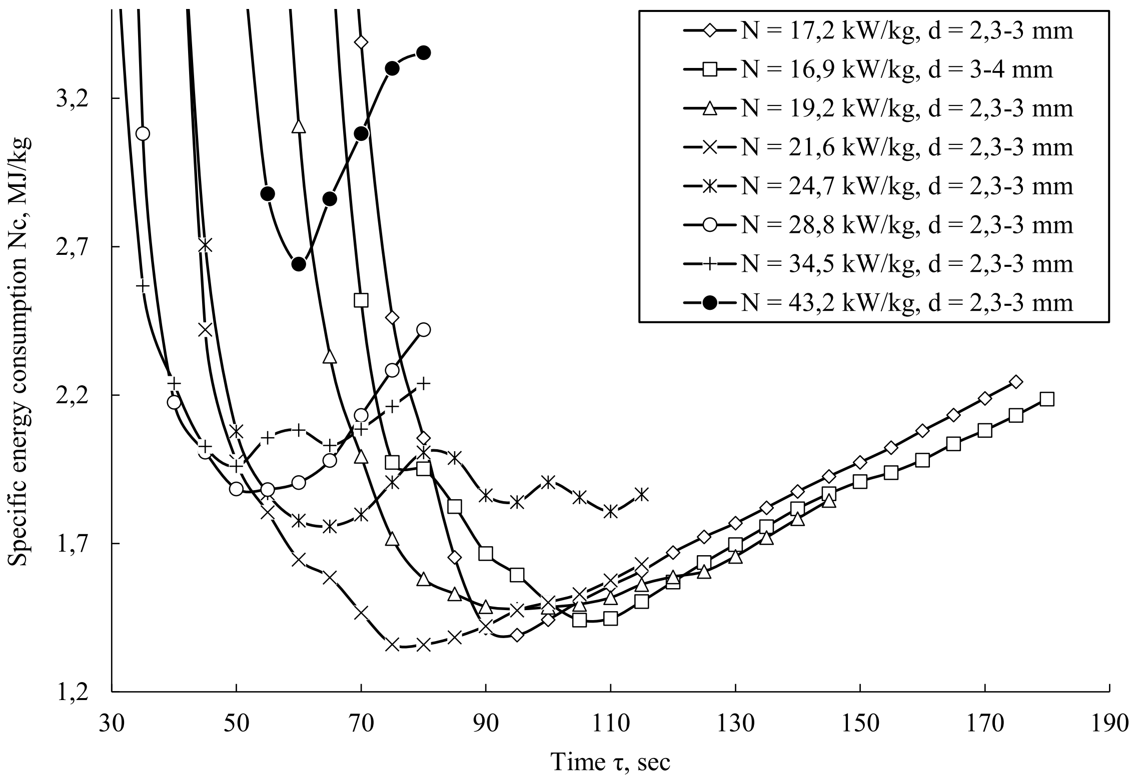

Fig. 6. Specific energy consumption.

Experimental conditions with different tube bundles, kinetic, and energy characteristics are presented in Table 1.

Table 1.

Experimental modeling results.

Bunch parameters	Supplied energy, kW/kg	Effect start time, sec	Effect peak time, sec	Effect decay time, sec	Specific energy consumption at peak, MJ/kg	Emissions at peak, g
d = 3—4 mm	42,4	20	55	80	2,1	3,2
d = 3—4 mm	33,9	25	50	75	1,7	3,3
d = 3—4 mm	28,3	30	75	135	2,2	1,2
d = 3—4 mm	24,2	25	50	145	1,7	2,6
d = 3—4 mm	21,2	35	85	180	1,5	5,6
d = 3—4 mm	20,8	35	90	120	1,35	3,7
d = 3—4 mm	18,8	35	115	180	1,5	2,2
d = 3—4 mm	16,9	50	105	180	1,4	2,7
d = 3—4 mm	16,8	55	110	180	1,4	2,7
d = 3—4 mm	12,7	30	150	220	1,5	2,5
d = 3—4 mm	10	55	185	300	1,6	1,5
d = 3—4 mm	5,6	165	340	380	1,3	1,7

The analysis of experimental results and video recordings shows that the hybrid process consists of several stages: initiation, intensity growth, reaching a peak, and attenuation. In this case:

- The initiation time correlates with specific power, and the minima of specific energy consumption correspond to lower power levels;
- At the peaks of emissions, specific energy consumption is minimal and amounts to 1.3—1.4 MJ/kg;
- The maximum volume emissions and their frequency are observed at the peak of the effect;
- In capillaries with a larger diameter (even with the same liquid volume), the process of forming a hydrodynamic flow increased by 5—15 sec;
- At an initial temperature of 15°C, the intensity of the hybrid process was twice as low as at a temperature of 40°C. Energy consumption for processes at initial temperatures of 15 and 40°C, with an experiment time of 50 s, was 2.36 and 1.7 MJ/kg, respectively.

Based on the conducted research, a schematic diagram of a circulation extractor is proposed (Fig. 7).

1 stage. Switching on the magnetron and processing the solid phase.	$\tau_0 < \tau < \tau_1$

2 stage. Filling the reactor with extractant $(N = 0)$	$\tau_1 < \tau < \tau_2$

3 stage. Delay $(N = 0)$	$\tau_2 < \tau < \tau_3$

4 stage. Extract pumping $(N = 0)$	$\tau_0 < \tau < \tau_1$

Fig. 7. Work stages of circulation extractor.

Next, the processes are repeated. Let's consider the model of the most complex stage, stages (1)—(3).

For the length $0 \le Z \le Z_1$, radii $0 \le r \le r_1$: initial conditions $(\tau = 0)$: $t_1 = t_i$, $V_1 = V_i$.

Mass transfer equation:

$$\frac{dM}{dF \cdot d\tau} = K \Delta C_\tau^1 \tag{1}$$

Navier—Stokes equation:

$$\rho_\tau^1 \cdot w_e^1 \cdot \frac{dw_e^1}{dz} = \frac{dP_\tau^1}{dz} \tag{2}$$

Diffusion equation:

$$\frac{dC_\tau^1}{d\tau} = D \cdot \left(\frac{d^2 C_\tau^1}{dr^2} + \frac{d^2 C_\tau^1}{dz^2} \right) \tag{3}$$

The system of equations (1)—(3) is supplemented by Fick's law:

$$\frac{dC_\tau^1}{d\tau} = D \cdot \frac{d^2 C_\tau^1}{dr^2} + \frac{dC_\tau^1}{dz} \cdot w_Z \tag{4}$$

The non—stationary temperature field, taking into account the action of the electromagnetic field (EMF), is determined as:

$$\frac{\partial t_1}{\partial \tau} = a_1 \left(\frac{\partial^2 t_1}{\partial r^2} + \frac{1}{r}\frac{\partial t_1}{\partial r} + \frac{\partial^2 t_1}{\partial z^2} \right) + \frac{N\eta}{V_1 c_{1V} \rho_1}, \tag{5}$$

In equations (1—5): c — is the specific heat capacity; λ — is the coefficient of thermal conductivity; a — is the coefficient of temperature conductivity; N — is the power of the electromagnetic generator; η — is the magnetron efficiency; τ — is the operating time; z, r, φ — is the coordinates.

The influence of the EMF is expressed in (5) as the action of an internal energy source with power N and efficiency η.

During comparative experiments between the traditional extraction method (experiments in a water bath) and the innovative method conducted on three electromagnetically dynamic extractors of different designs, the following data were obtained.

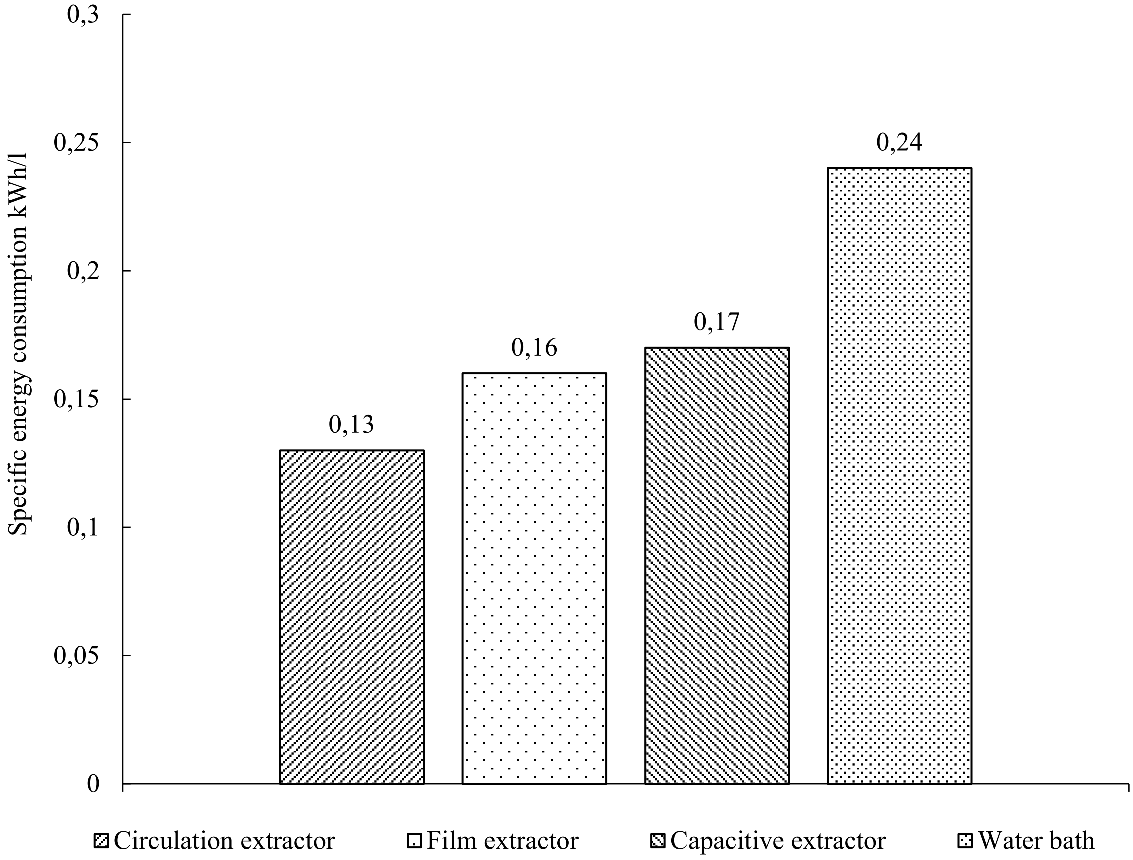

Fig. 8. Specific energy consumption at the innovative extractors of different constructions.

The efficiency of the extractors used in the comparative experiments (Burdo O.G. et al, *Problemele energeticii regionale*, 2023), was as follows:

— Circulation extractor: 61%;
— Film extractor: 51.2%;
— Volumetric vacuum extractor: 48.1%;
— Traditional extractor: 33.8%.

It was determined that the specific energy consumption for extracting 1 kg of target components is as follows: for the circulation extractor — 0.13 kWh; for the film extractor — 0.16 kWh; for the volumetric extractor — 0.17 kWh; for the traditional extractor — 0.24 kWh.

It was found that in the innovative circulation extractor, the energy costs for extracting one mass of dry matter are half compared to the traditional extractor.

CONCLUSIONS

In recent years, there has been a steady increase in interest in electromagnetic devices for various processing of raw materials. Positive results have been obtained in drying, extraction, and evaporation processes. In the development of these studies, the authors of the article have demonstrated that electromagnetically driven processes can be a convenient tool for organizing hybrid transport processes. Visualizing the hybrid process on a model of a capillary—porous body resulted in videos showing the formation, initiation, peak, and decay of the process of ejecting the contents from the volume. Analyzing the values of point emission rates, specific energy consumption for the output of the steam—water flow from the volume of raw material was determined. It was observed that specific energy consumption is at the level of 1.3 MJ per 1 kg of water, which is 2 times less than the specific heat of vaporization of water. Control of the hybrid process is achieved by changing the power of the electromagnetic field applied to the moisture in the processed product. Minimization of energy consumption is determined by the coordination of the structural characteristics of the solid phase and the parameters of the electromagnetic field. An analytical model of the hybrid process is presented by a system of non-stationary differential equations of the Navier—Stokes equations, continuity, energy, and the first law of thermodynamics. It is precisely based on the first law of thermodynamics that it is shown that in the volume of raw material, electromagnetic energy in the hybrid process performs work to move moisture from the volume of raw material into the surrounding space. As a result, in addition to diffusion, a hydrodynamic flow is formed, the power of which is orders of magnitude higher than the first one. An analysis of the energy reserves of innovative electromagnetic extractors showed that the efficiency of circulatory and film—type installations is 1.9 and 1.5 times higher than the efficiency of a traditional extractor, respectively.

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