

Energy-Efficient Technologies of Plant Raw Material Extraction

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Abstract. The aim of this work is to create the scientific foundations of microwave extractors implementing the effect of mechanodiffusion discovered by the authors, as well as visual, kinetic, and energy substantiation of the fundamentals of mechanodiffusion, and optimization of the operating parameters of this process. To achieve this aim, a concept of innovative extractors has been formulated — sequential reduction of the extractant layer on the surface of the solid phase. Comprehensive experimental studies have been conducted, and the time of rational energy use has been determined. A model is presented that makes it possible to determine the operating mode of the extractor depending on the specific power of the generators. A methodology for the calculation and optimization of microwave extractors with the objective function of minimum energy consumption is presented. An example of estimating energy overconsumption is given. A scientific and technical hypothesis for the creation of innovative extractors that would solve traditional problems is formulated. The most significant result of the work is that the foundations for the design and optimization of energy-efficient continuous microwave extractors have been created, making it possible to obtain polyextracts in a single apparatus. The significance of the work lies in the development of mechanodiffusion theoretical foundations and the proposal of engineering methods for optimization of microwave extractors. The result is an electrodynamic extractor that could be of commercial interest in the cognac industry.

Keywords: thermophysics, heat and mass transfer, extraction, mechanodiffusion, microwave field, electrodynamic systems, experimental and mathematical modeling.

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Tehnologii energoeficiente pentru extracția materiilor prime vegetale

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Rezumat. Scopul lucrării este de a crea bazele științifice ale extractoarelor cu microunde care implementează efectul mecanodifuziei descoperit de autori, precum și fundamentarea vizuală, cinetică și energetică a principiilor fundamentale ale mecanodifuziei și optimizarea parametrilor de funcționare ai acestui proces. Pentru a atinge acest scop, a fost formulat un concept de extractoare inovatoare - reducerea secvențială a stratului de extractant la suprafața fazei solide. Au fost efectuate studii experimentale cuprinzătoare și a fost determinat timpul de utilizare rațională a energiei. Este prezentat un model care permite determinarea modului de funcționare al extractorului în funcție de puterea specifică a generatoarelor. O metodologie pentru calculul și optimizarea extractoarelor cu microunde cu funcția obiectiv de consum minim de energie este prezentată. Un exemplu de estimare a supraconsumului de energie este dat. Este formulată o ipoteză științifică și tehnică pentru crearea de extractoare inovatoare care ar rezolva problemele tradiționale. Cel mai semnificativ rezultat al lucrării este crearea bazelor pentru proiectarea și optimizarea extractoarelor continue cu microunde eficiente din punct de vedere energetic, făcând posibilă obținerea de poliextracte într-un singur aparat. Importanța lucrării constă în dezvoltarea fundamentelor teoretice ale mecanodifuziei și propunerea unor metode ingineresti pentru optimizarea extractoarelor cu microunde. Astfel, a fost creat un extractor electrodinamic care poate prezenta interes comercial în contextul producției de coniac.

Cuvinte-cheie: termofizică, transfer de căldură și masă, extracție, mecanodifuzie, câmp de microunde, sisteme electrodinamice, modelare experimentală și matematică.

Энергоэффективные технологии экстрагирования из растительного сырья
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Аннотация. Проведен анализ процессов экстрагирования в пищевых и фармацевтических технологиях. Определены ключевые проблемы экстрагирования: низкая интенсивность процессов тепломассообмена, продолжительность, сложность получения полиэкстрактов. Анализируется мировой опыт исследований технологий экстрагирования на базе генераторов энергии микроволнового диапазона. Показано, что научный интерес к микроволновым экстракторам динамично растет. Однако, в доступной литературе не обнаружены примеры испытаний микроволновых экстракторов в условиях производства. Отсутствуют методы их инженерного расчета и оптимизации. Целью работы является создание научных основ микроволновых экстракторов, реализующих открытый авторами эффект механодиффузии, визуальные, кинетические и энергетические обоснования основ механодиффузии, оптимизация режимных параметров этого процесса. Для достижения поставленной цели сформулирована концепция инновационных экстракторов — последовательное уменьшение слоя экстрагента на поверхности твердой фазы. Проведены комплексные экспериментальные исследования и установлено время целесообразного использования энергии. Целевой функцией принято минимум энергетических затрат. Приведена модель, которая позволяет определить режим работы экстрактора в зависимости от приведенной мощности генераторов. Дана методика расчета и оптимизации микроволновых экстракторов с целевой функцией минимум энергетических затрат. Приведен пример оценки перерасхода энергии. Сформулирована научно-техническая гипотеза создания инновационных экстракторов, которые решали бы традиционные проблемы. Приведена эволюция разработанных микроволновых экстракторов: объемного, пленочного и циркуляционного типов. Наиболее существенным результатом работы является то, что созданы основы проектирования и оптимизации энергоэффективных микроволновых экстракторов непрерывного действия, позволяющий в одном аппарате получать полиэкстракты. Значимость работы заключается в том, что получили развитие теоретические основы механодиффузии, предложены инженерные методы оптимизации микроволновых экстракторов. В результате создан электродинамический экстрактор, который может представлять коммерческий интерес в условиях коньячного производства.

Ключевые слова: теплофизика, тепломассообмен, экстрагирование, механодиффузия, микроволновое поле, электродинамические системы, экспериментальное и математическое моделирование.

INTRODUCTION

Extraction is an important process in food technologies and in pharmaceutical production. This process determines the quality of the extract and phytopreparation, the duration of operation, and energy consumption. Recently, interest in polyextracts has been dynamically increasing. To obtain them, two-stage schemes and technologies with mixtures of extractants are used [1, 2]. Satisfactory solutions to the problem are lacking.

The authors of the article have discovered a new effect, termed mechanodiffusion. Practical application of this effect makes it possible to obtain high-quality polyextracts with significant intensification of the process. Testing of the mechanodiffusion effect under cognac production conditions has shown that process intensification is achieved by orders of magnitude.

Analysis of the Problem and Formulation of the Scientific and Technical Hypothesis

In 2025, scientists from the Institute of Agricultural Biology and Biotechnology and the University of Pisa (Italy) conducted a comparative analysis of microwave (MW), ultrasonic (US), and ultrasonic-microwave extraction methods from hemp seeds and wheat

bran [3]. MW extraction was carried out using a 50% ethanol solution for 2, 5, and 24 minutes at supplied power levels of 550 W and 1000 W and temperatures of 30°C and 70°C. The obtained results indicate that the microwave method proved to be the most effective, especially for wheat bran - the resulting extracts exhibited superior antioxidant and antimicrobial properties. In the same year, at the Polytechnic University and the University of Agronomic Sciences and Veterinary Medicine (Romania), methods for optimizing MW extraction of polyphenols from hawthorn leaves and flowers were investigated [4]. The results showed that, compared with conventional extraction, the MW method provides higher concentrations.

In [5], a study of the extraction of phenolic acids from wheat using MW radiation was carried out. Water and an aqueous ethanol solution (80%) were used as extractants. The process duration varied within 2—15 minutes. The treatment temperature reached 180°C. As a result, it was found that pure water extracts phenolic substances better without their apparent degradation.

At the same time, at the Federal University of Goiás (Brazil) and the University of Saskatchewan (Canada), the process of protein extraction from pigeon pea was studied [6]. As a

result, it was found that short-term but high-power MW treatment (120 s, 900 W) significantly increased the protein yield up to 61.92%.

In 2024, scientists at Istanbul University (Turkey) investigated the process of extracting antioxidants from hazelnut by-products [7]. Along with MW extraction, ultrasonic and pressurized liquid methods were also used. The maximum allowable MW radiation power did not exceed 1500 W. Analysis of the obtained results showed that MW treatment is a more environmentally friendly extraction method.

In 2025, through joint efforts of scientists from Chiang Mai University, Prince of Songkla University (Thailand), National Chung Hsing University, and Yuan Ze University (Taiwan), studies were conducted on the extraction of algal protein using a deep eutectic solvent under MW field conditions [8]. The exposure time to electromagnetic radiation ranged from 2 to 15 minutes at variable power in the range of 80–320 W. During the experiments, all parameters remained constant except one, which was varied in a series of tests to determine its effect on protein yield. Significant protein yields of 30.48% (*Spirulina*) and 15.53% (*Chlorella*) were achieved at a microwave power level of 160 W.

In the same year, at the Indian Institute of Technology [9], as well as at Universiti Sains Malaysia and Universiti Teknologi MARA (Malaysia) [10], the process of extracting bioactive compounds from *Centella asiatica* leaves (tiger grass) using microwave and ultrasonic pretreatments was studied. In [9], the leaves were subjected to MW blanching for 30, 45, and 60 s. Blanching for 45 seconds followed by drying at 50°C effectively preserved bioactive compounds, making it the optimal condition for extraction. In [10], extraction was carried out directly in the MW field. Analyses of the bioactivity of the extract confirmed its strong antioxidant properties.

In 2024, similar studies were conducted on the extraction of bioactive compounds from blueberry by-products [11]. For the entire series of experiments, the microwave radiation power was set at 800 W. The process temperature varied within 60-70°C, and the duration was 15-30 minutes. Compared to conventional extraction, the polyphenol yield was increased by 45%.

In the same year, at the University of Eastern Piedmont (Italy), the University of Minho (Portugal), and the University of Vigo (Spain), studies on MW extraction of phenolic compounds from raspberry pomace were conducted [12].

Experiments were carried out at a maximum power of 850 W and temperatures of 100-200°C over a period from 1 to 40 minutes. The application of the MW field under optimized conditions (200°C for 10 minutes with 50% ethanol) demonstrates a significant improvement in the extraction of phenolic compounds and flavonoids compared to conventional extraction methods.

In 2023, scientists from the University of Zagreb and the Teaching Institute of Public Health (Croatia) attempted to isolate proteins from the epidermis of coffee bean husks using MW extraction [13]. The MW radiation power varied within 100-200 W, and the processing time was 6-9 minutes. The highest value of total protein concentration (0.77 ± 0.07 mg/L) was found in the sample treated for 9 minutes at a power level of 200 W.

In the same year, through joint efforts of Izmir and Ege Universities (Turkey), the neurotherapeutic potential of red cabbage extract obtained in an MW field was investigated [14]. The radiation power varied in the range of 400-800 W with a duration of 4–12 minutes. Water, as well as ethanol at 50% and 100% concentrations, was used as the extractant. The process temperature was 25°C. Microwave extraction outperformed conventional solvent extracts (hexane, dichloromethane, 2-methyltetrahydrofuran, ethanol, and water) in activity and content.

In the 2025 study [15], the results of MW extraction of phenolic compounds from caimito fruits are presented. The results showed that MW extraction yielded about 23 compounds, in contrast to conventional maceration (15–17 compounds). In addition, the antioxidant activity was higher in extracts obtained using the MW field.

In the same year, at the Ho Chi Minh City University of Technology (China) and the Vietnam–Australia International School (Vietnam), studies were conducted on the extraction of anthocyanins and phenolic compounds from *Clitoria ternatea* flowers [16]. Experimental samples were subjected to microwave pretreatment at a power of 385 W for 45 s, which proved to be an effective strategy for maximizing the yield of anthocyanins and polyphenols.

In order to increase the commercial attractiveness of black carrot pomace, experiments were carried out on pectin extraction using MW extraction [17]. The electromagnetic

field power varied in the range of 50–90 W, and the treatment duration was 2-10 minutes. As a result, the optimal conditions for maximum yield (26.29% in terms of dry matter) were as follows: microwave power 79 W, extraction time 6.5 minutes. The pectin extracted under these conditions was compared with pectin obtained by conventional methods. The MW method demonstrated a higher yield and lower ash content, indicating higher purity.

In 2024, at Bursa Uludağ University, the Atatürk Central Horticultural Research Institute, and the Central Research Institute for Food and Feed Control (Turkey), experiments were conducted on obtaining extract from chestnut shell under MW energy input [18]. At a radiation power of 800 W for 12 minutes, an extract with high bioactive potential as well as strong brown coloration properties was obtained.

In the same year, scientists from the University of Cartagena (Colombia) studied the effect of MW energy input during the extraction of phenolic compounds from mango peel [19]. The obtained extract exhibited enhanced antioxidant activity and a high content of phenolic compounds.

In [20], the authors present results of MW extraction of tannins and saponins from spinach leaves. The independent variables of the study were microwave power (from 100 to 300 W), processing time (from 5 to 15 minutes), and solid-to-solvent ratio (from 0.025 to 0.05 g/mL).

The study of MW extraction of crocins from saffron stigmas is considered in [21]. The key parameters were varied within the following ranges: MW treatment time — 2–14 min, MW field power — 100–700 W, solid-to-solvent ratio — 4–10 mg/40 mL. The maximum crocin content with the highest antioxidant activity and coloring capacity was achieved under optimal conditions: 9.23 min, a solid-to-solvent ratio of 7.41 mg/40 mL, and 400 W of supplied microwave energy. Under these optimal conditions, HPLC analysis revealed nine dominant esters of crocetin, picrocrocetin, and safranal in the saffron extract. In addition, two flavonol-O-glycosides were identified.

A review of achievements in the field of microwave extraction of flavonoids was carried out by scientists at Qingdao University (China) [22]. The study emphasizes that the MW method offers advantages compared to traditional methods, including reduced extraction time and higher yields. However, the authors note that MW technology is still at the research stage of

industrialization, and large-scale production of flavonoids remains a challenging task.

The conducted analytical review of the literature allows the following conclusions to be drawn:

1. The kinetics of the extraction process under microwave field conditions is actively studied.
2. The studies are carried out on laboratory-scale setups.
3. No examples of industrial implementation of microwave extractors have been found.

The calculation of mass transfer kinetics is carried out using Fick's equation, which accounts for diffusive transport and hydraulic flow with velocity w . In conventional technologies, such a flow is practically absent and is neglected in calculations.

$$\frac{dc}{d\tau} = D \cdot \frac{d^2c}{dz^2} + \frac{dc}{dz} \cdot w_z \quad (1)$$

The present work addresses the problem of activating this flow. The following scientific and technical hypothesis is formulated: "Under microwave field conditions, at a certain combination of specific input energy density and exposure time, excess pressure can be created inside the capillaries of the solid phase and ejections of their contents can be initiated." This represents a powerful hydraulic flow.

$$\Delta P = \frac{\rho w^2}{2} \left[\frac{\lambda l}{d} + \Sigma \zeta \right] + \rho g l + \frac{\sigma}{d} \quad (2)$$

where: l is the channel length, d is their diameter, λ is the friction coefficient, ζ is the sum of local hydraulic resistances, σ is the surface tension coefficient.

Its efficiency can exceed conventional diffusive transport by orders of magnitude.

Evolution of Extractors with Microwave-Range Electromagnetic Energy Supply Sources

At present, the authors have developed three types of such extractors: volumetric, film, and circulation. The volumetric extractor is designed as a vessel filled with plant raw material and extractant (Fig. 1). The apparatus operates under sub-atmospheric pressure: $P_A < P_O$. This makes it possible to carry out the extraction process at low

temperatures, which ensures high extract quality. To intensify the mass transfer process, boiling within the volume is induced at low temperatures. As a result, the problem of heat transfer and thermal resistance of the boundary layer is solved. Flow turbulence significantly reduces process time and energy consumption. A characteristic feature of the process has been identified —

traditional extractants (hexane, naphtha) prove to be less effective than environmentally safe ethanol. The microwave electromagnetic field actively affects solutions containing polar molecules (water, ethanol, acetone). Therefore, under microwave field conditions, aqueous and alcoholic extracts are economically and environmentally more preferable.

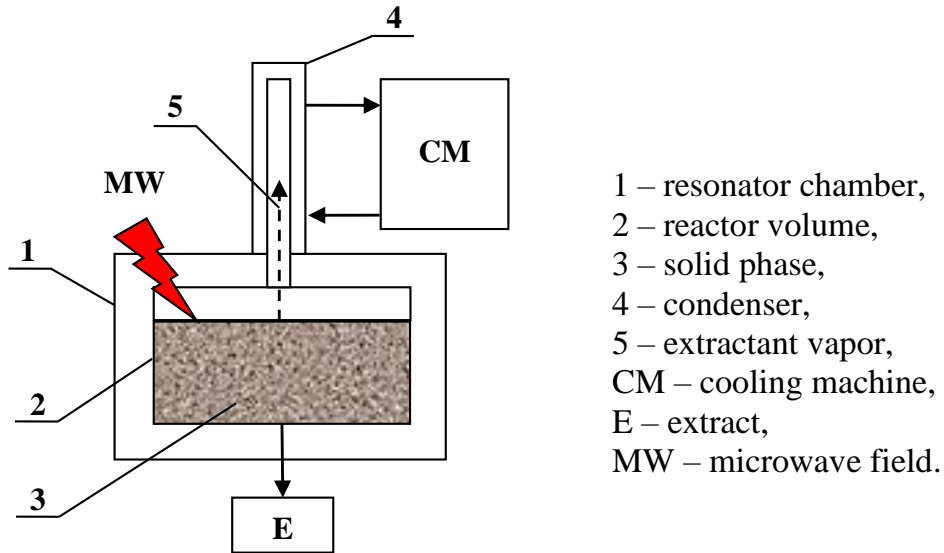


Fig. 1. Physical model of volume extractor.

The advantages of the volumetric extractor include the possibility of operation under vacuum in the reaction volume, as well as a high intensity of energy input in the boiling regime when using an environmentally safe extractant. However, a significant liquid layer above the solid phase acts

as a barrier to the realization of the mechanodiffusion effect.

The idea of the film extractor (Fig. 2) was that the solution flows over the solid phase in the form of a thin film.

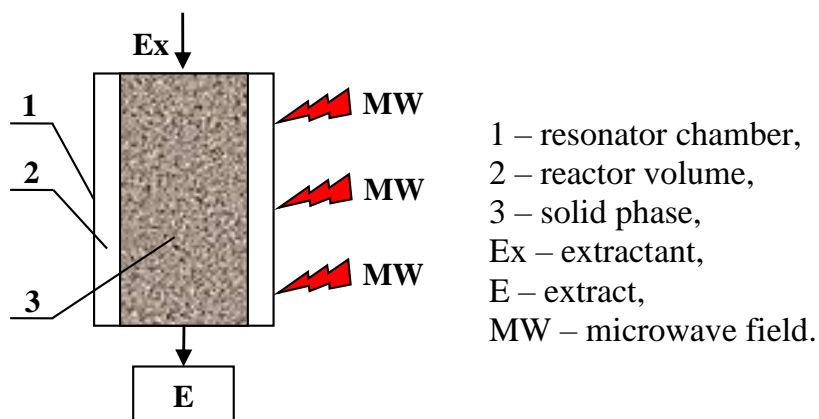
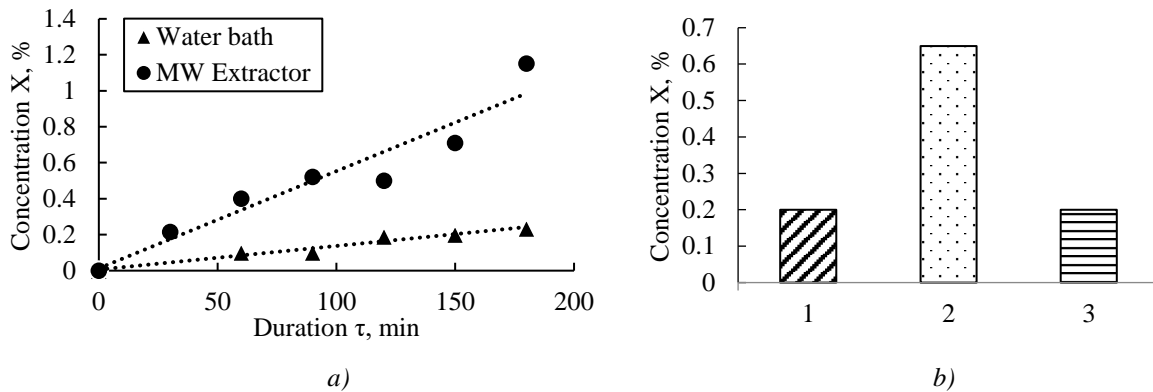


Fig. 2. Physical model of film extractor.

Bench-scale studies of the film extractor were carried out. In the first experiment, rosehip fruits were poured with distilled water (hydromodule 1:3) at a temperature of 70°C and kept for 1 minute in a stationary layer in a

thermostat. In the second experiment, the fruits were poured with distilled water (hydromodule 1:3) at a temperature of 15°C. The water was then drained, and the fruits were treated with an MW field for 1 minute. The third

experiment differed from the second in that the treatment was carried out for only 15 s (Fig. 3).



1. Fixed bed without MW (Water bath).
2. MW treatment ($\tau_{MW} = 60 \text{ sec}$, $E = 62 \text{ kJ}$, $j = 1,2 \text{ MJ}/(\text{kg of seeds})$, MW Extractor, $t = 70^\circ\text{C}$).
3. MW ($\tau_{MW} = 15 \text{ sec}$, $E = 15 \text{ kJ}$, $j = 0,3 \text{ MJ}/(\text{kg of seeds})$, MW Extractor, $t = 20^\circ\text{C}$).

Fig. 3. Extraction kinetics of film extractor.

It was established (Fig. 3b) that for the same extraction time, the concentration of the solution in both the conventional technology and the MW extractor was identical. However, the experiments in the thermostat were carried out at a temperature of 70°C (Fig. 3b, 1), while the temperature level in the MW extractor was 25°C (Fig. 3b, 3). During extraction in the MW field at a temperature level of 70°C (Fig. 3b, 2), the yield of target components increased by 3.5 times. In this case, energy consumption was $E = 62 \text{ kJ}$, with a

specific energy of $J = 1.2 \text{ MJ}/\text{kg}$. The conducted studies indicate the prospects of film extractors. The next stage of research aimed to eliminate the influence of the liquid film, which remained a barrier to the development of mechanodiffusion.

The idea of the circulation extractor was that microwave energy was supplied after the extractant had been drained from the reaction volume (Fig. 4).

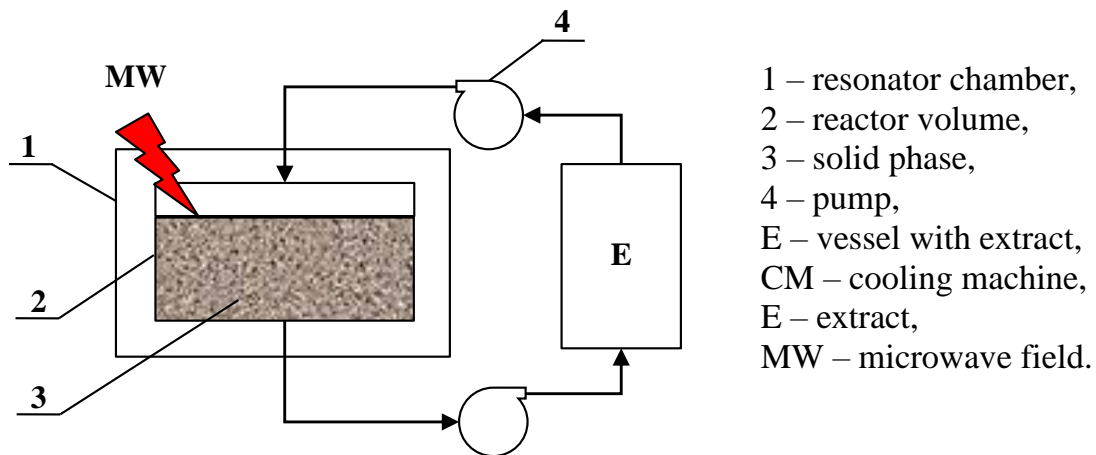


Fig. 4. Physical model of circulation extractor.

The operation of the extractor includes the following stages. The first is filling the reaction volume with the extractant. The second is wetting the solid phase with the extractant. The third is draining the extractant. The fourth is switching on the MW field.

Under gradient-free wave delivery of electromagnetic energy to polar molecules of the solution, a phenomenon was identified and named the “mechanodiffusion effect.” As a result of electromagnetic energy input, vapor bubbles are generated deep inside the capillary. Due to the

phase transition of the liquid into the vapor phase, its volume increases and pressure rises. This creates a driving force for the flow of extract from the capillary. This is a powerful, purely hydraulic flow that carries away the extract from the

boundary layer, as well as weakly soluble and insoluble components.

Let us represent the structure of the flow from the capillary based on the principles of electrodiffusion modeling (Fig. 5).

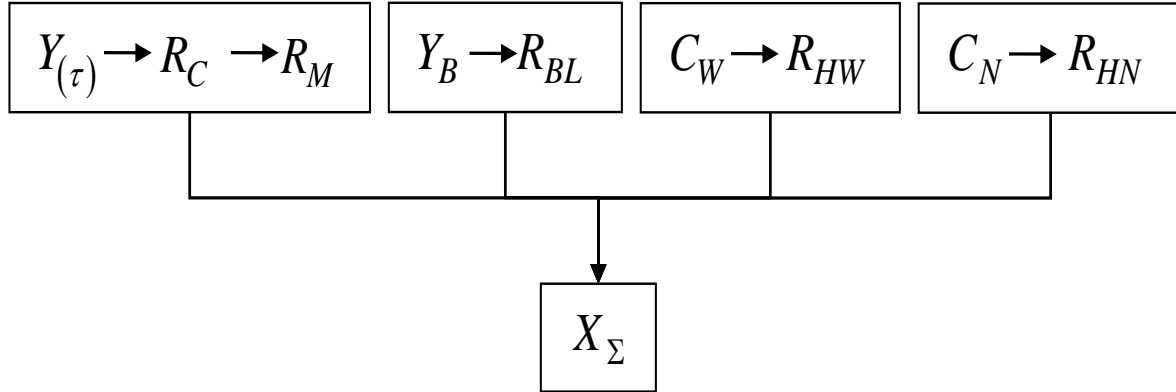


Fig. 5. Electrodiffusion model of associated hydrodiffusion flows from capillary channel.

In the figure, the following concentration designations are used: Y_{τ} — current concentration in the solid phase; Y_B — concentration in the solid phase at the interface with the extractant; C_W and C_N — concentrations in the solid phase of components that are weakly soluble and insoluble

in the extractant, respectively; X_{Σ} — total value of all components transferred into the extract, which is composed of the contributions of diffusive and hydraulic flows.

The total component flux is calculated by (3):

$$\sum M_I = (M_{P1} + M_{P1} + M_C + M_N) \cdot F^{-1} = \frac{Y - X_{RD}}{R_D} + \rho \cdot \left[\frac{P_K - P_0}{R_{BL}} + \frac{P_K - P_0}{R_{HW}} + \frac{P_K - P_0}{R_{HN}} \right] \quad (3)$$

It can be seen (Fig. 5) that the classical, purely diffusive flow sequentially overcomes a chain of diffusion resistances: capillary resistance (R_C) and mass transfer resistance (R_M). The remaining components overcome classical hydraulic resistances. Soluble components from the boundary layer are (R_{BL}), weakly soluble components are (R_{HW}), and insoluble components are (R_{HN}).

The hydraulic flow, driven by a pressure difference, can increase the intensity of mass transfer during extraction by orders of magnitude.

Optimization of Operating Modes of the Circulation Extractor

Based on the mechanodiffusion effect, microwave extractors are capable of intensifying the mass transfer process by an order of magnitude. Thus, mechanodiffusion is a key

factor in the operating mode of a microwave extractor. A set of experimental studies shows that energy must be expended to initiate the mechanodiffusion process. First, heating of the solution in the capillaries occurs, then an expulsion of the solution from the capillaries is formed. The peak of expulsion is characterized by the lowest energy consumption. This is followed by a phase of decrease in the mass of the expulsion and the practical cessation of the mechanodiffusion effect. The duration of its action depends on the microwave field power. The task of optimizing the operating mode of the MW extractor is relevant. The objective function should be the minimization of energy consumption.

Based on the results of comprehensive studies of mechanodiffusion processes, individual phases of the organization of this process have been identified (Table 1).

Table 1.

Key Phases of Mechanodiffusion Process

Dimensionless specific power, n	Phases	Solution heating, sec	Ejection formatting, sec	Decreasing wave, sec
		$\tau_0 \dots \tau_1$	$\tau_1 \dots \tau_2$	$\tau_2 \dots \tau_3$
43,2		0...15	15...50	50...80
42,4		0...15	15...65	65...80
34,5		0...20	20...70	70...80
33,9		0...25	25...50	50...80
28,8		0...25	25...45	45...80
28,3		0...30	30...95	95...135
24,7		0...25	25...80	80...115
24,2		0...35	35...85	85...145
21,6		0...35	35...95	95...115
21,2		0...40	40...75	75...180
20,8		0...35	35...100	100...120
19,2		0...45	45...105	105...145
18,8		0...30	30...105	105...180
17,2		0...40	40...85	85...175
16,9		0...50	50...100	100...180
12,7		0...85	85...140	140...220
10		0...75	75...180	180...300
5,6		0...185	185...310	310...380

At time τ_2 , the peak in the mass of ejections is reached, while energy consumption is minimal. At times greater than τ_3 , energy input becomes ineffective. Thus, for the objective function of

minimum energy at maximum mass, it is necessary to determine the dependence of τ_3 on power.

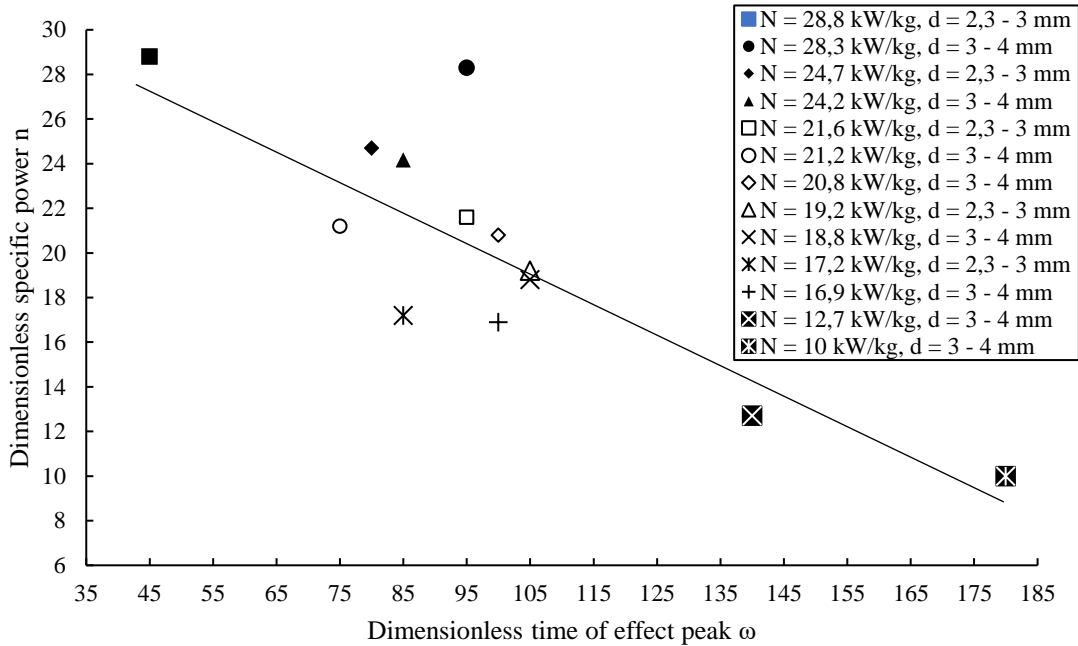


Fig. 6. Rate of specific energy supply to the solution in capillaries in time.

A corresponding dependence has been constructed (Fig. 6), in which the data of the peak-

effect time and the amount of energy reduced to the liquid have been converted into a

dimensionless form, and a generalized curve describing the decrease in the efficiency of the effect with decreasing magnetron power has been plotted.

For generalization, the following points on the mean line were selected: $\tau_1 = 45$ s, $N_1 = 28.8$ kW/kg, $\tau_2 = 100$ s, $N_2 = 16.9$ kW/kg. The indicated values were converted into a dimensionless form by dividing them by one in the corresponding unit of measurement.

$$\omega_1 = \frac{\tau_1}{\tau_0} = \frac{45}{1} = 45 \quad (4)$$

$$n_1 = \frac{N_1}{N_0} = \frac{28,8}{1} = 28,8 \quad (5)$$

Where: ω_1 is dimensionless time; n_1 is dimensionless amount of reduced energy; τ_0 is

the base time; $\tau_0 = 1$ s, N_0 is the base amount of reduced energy; $N_0 = 1$ kW/kg .

It is necessary to determine the dependence of time on the amount of reduced energy:

$$\omega = A \cdot n^k \quad (6)$$

A system of logarithmic equations is formulated, and a model for generalizing the experimental data is obtained:

$$\omega = 8000 \cdot n^{-1.5} \quad (7)$$

A comparison of the calculation results according to (7) with the experimental data is shown in Fig. 7.

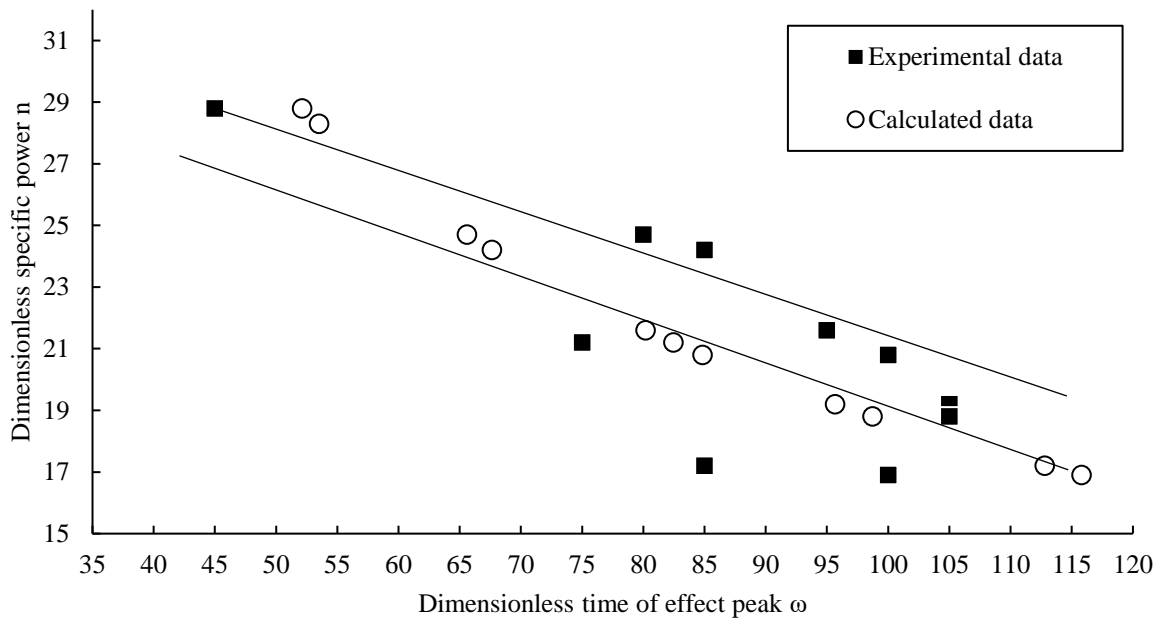


Fig. 7. Comparative graph of experimental and calculated data.

The error of model (4) is approximately $\pm 7\%$ relative to the experimental values.

The innovative microwave extractor of the circulation type acts on the raw material with an electromagnetic field at a specified periodicity, generating in the material a mechanodiffusion effect characterized by its peaks and declines. It has been experimentally determined that, for the formation of this effect, time is required to heat the raw material, after which a peak of ejections of extractive substances from the capillaries begins; at this moment, the energy efficiency of

the process is highest. Energy consumption at this stage is minimal while the amount of extracted substances is maximal; thereafter, the effect declines, the ejections decrease significantly, and the energy efficiency drops.

The amount of energy that can be saved by timely termination of the process can be determined using model (4).

Figure 8 shows the lines of energy consumption, in which useful energy and excessively expended energy are separated.

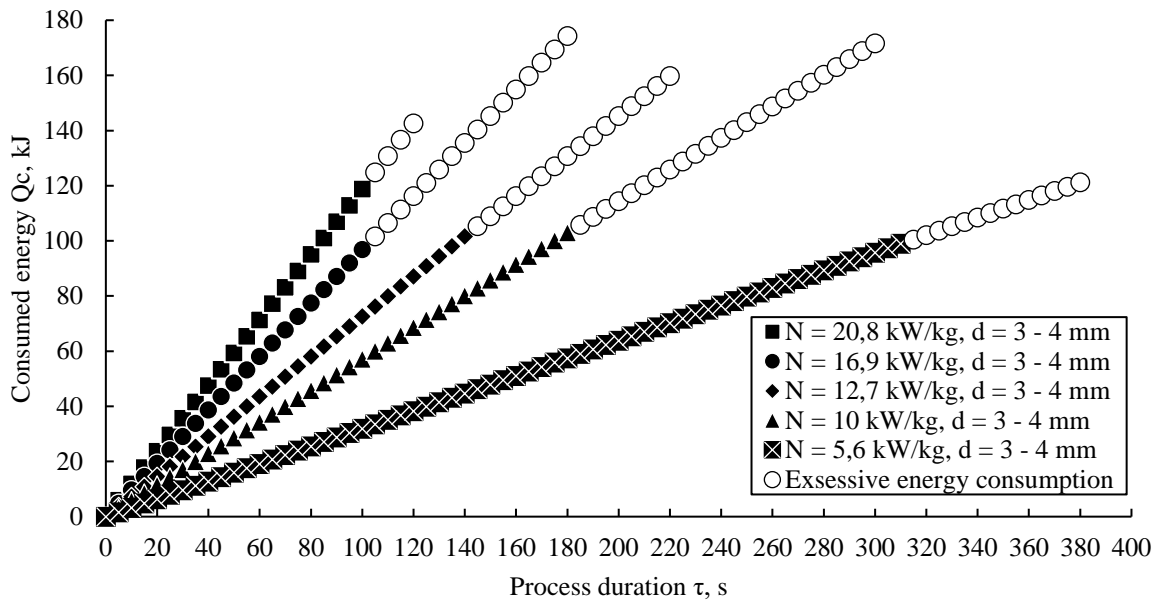


Fig. 8. Energy consumption during plant raw material treatment.

The amount of useful energy expended for the process of moisture extraction from the capillaries is $Q_U = 121-174$ kJ, while the amount of excess energy expended is proportional to time in Fig. 8, $Q_C = 22.3-77.5$ kJ. The mass of liquid extracted before the completion of the mechanodiffusion effect is $M_M = 41-44.4$ g; the mass of liquid

extracted after its completion is practically absent, while energy continues to be supplied.

A unique technology has been developed that ensures industrial principles of cognac spirit production. The technology is based on the mechanodiffusion effect discovered by the authors (Fig. 9).

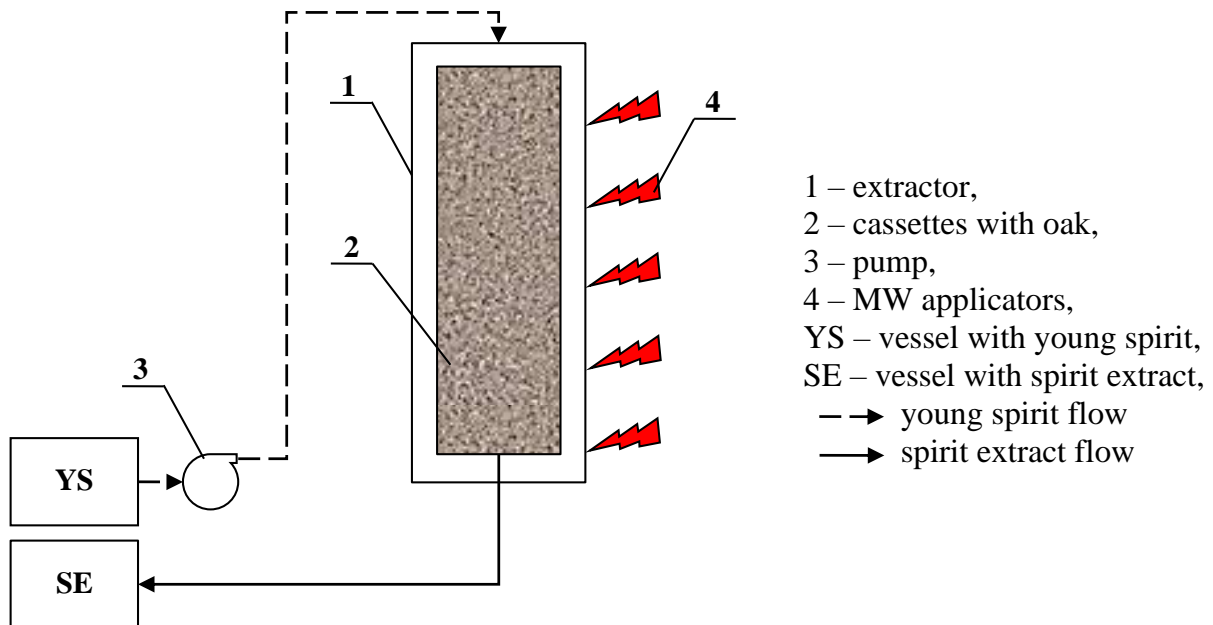


Fig. 8. Scheme of plant for obtaining of cognac spirit in flow.

The technology makes it possible to saturate spirits with components of oak wood in a flow and to control the extract concentration. The production time of high-quality cognac spirits is

reduced by thousands of times. Spirits have been obtained that correspond, in terms of dry matter concentration, to spirits aged for a hundred years.

They are characterized by relevant consumer properties: the products are environmentally safe and maximally preserve the biologically active substances of the raw material. Nanotechnological innovations provide a powerful flow of extractive components from oak wood due to the initiation of additional driving forces. Such forces arise as a result of targeted delivery of energy to the polar molecules of the solution. The possibility of controlling the bouquet of cognac spirit has been achieved. A pilot prototype of a cognac extractor has been manufactured (Fig. 10), which has been tested under production conditions [23].



Fig. 10. Microwave extractor.

The capacity of the unit is 70 L/h when saturating the spirit with target components to a level equivalent to 7-year aging by standard technology.

CONCLUSIONS

The paper analyzes the designs of volumetric, film, and circulation extractors. The modes for effective implementation of mechanodiffusion have been established. Experimental data have been generalized, resulting in a criterion dependence of raw material processing time on the electromagnetic energy flux density. The time of effective energy utilization and energy losses as a function of flux density have been determined. Under cognac production conditions, an electrodynamic extractor with a capacity of 70 L of spirit per hour has been tested. For the first time, samples of a high-quality finished product corresponding to 7-year aging have been obtained in a flow.

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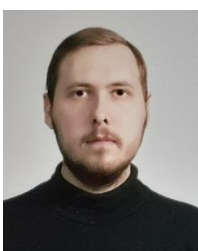
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