Mathematical modeling of the extraction process of oil-containing raw materials with pulsed intensification of heat of mass transfer

Kolyanovska, Lyudmila , Palamarchuk, Igor , Sukhenko, Yuri , Mushtruk, Mykhailo , Sukhenko, Vladislav , et al.

Lyudmila M. Kolyanovska, Igor P. Palamarchuk, Yuri G. Sukhenko, Mykhailo M. Mushtruk, Vladislav Y. Sukhenko, Volodymyr P. Vasuliev, Tetyana V. Semko, Liudmyla M. Tyshchenko, Piotr Popiel, Assel Mussabekova, Baituma Bissarinov, "Mathematical modeling of the extraction process of oil-containing raw materials with pulsed intensification of heat of mass transfer," Proc. SPIE 11045, Optical Fibers and Their Applications 2018, 110450X (15 March 2019); doi: 10.1117/12.2522354

Event: 18th Conference on Optical Fibers and Their Applications, 2018, Naleczow, Poland

Mathematical modeling of the extraction process of oil-containing raw materials with pulsed intensification of heat of mass transfer

Lyudmila M. Kolyanovska*[a], Igor P. Palamarchuk[b], Yuri G. Sukhenko[b], Mykhailo M. Mushtruk[b], Vladislav Y. Sukhenko[b], Volodymyr P. Vasuliev[b], Tetyana V. Semko[a], Liudmyla M. Tyshchenko[b], Piotr Popiel[c], Assel Mussabekova[d]; Baituma Bissarinov[e]
[a]Vinnytsia Institute of Trade and Economics of Kyiv National University of Trade and Economics 87 Soborna Str., Vinnytsia, Ukraine; [b]National University Life and Environmental Sciences of Ukraine 34 Academichna Str., Vinnytsia, Ukraine; [c]Lublin University of Technology, Institute of Electronics and Information Technology, Nadbystrzycka 38D, 20-618 Lublin, Poland; [d]Kazakh Academy of Transport & Communication, Rayimbek Ave 165, Almaty, Kazachstan; [e]Al-Farabi Kazakh National University, Almaty, Kazakhstan

ABSTRACT

Extraction method is still the most waste-free in oil recovery technologies, and in the case of low-soybean seeds, the most convenient. Therefore, with the impulse intensification of this process, it is possible not only to increase its efficiency, but also to achieve compactness of equipment, to reduce energy costs and to improve the quality of extraction oils. The methods of intensification of the extraction process from plant raw materials, which can be divided into mechanical, thermal, biochemical and electrophysical, are analyzed, generalized and classified. The hypothesis is confirmed according to which the intensification of the extraction process of oil with an increased content of tocopherols occurs due to the use of a pressure diffusion flux from the capillary-porous structure of plant raw materials under the action of a microwave field. It is proved that the proposed number of energy effects successfully correlates the effect of the pulsed microwave field on the mass-transfer rate when extracting oil from rapeseed and soybean seeds. Using the developed mathematical model of the extraction process with pulse intensification, it is possible to deduce the dependences of the mass transfer coefficient on the number of energy effects, the dependence of the mass transfer coefficient on the microwave power and other dependences of the dimensionless criterial complexes characterizing the investigated process with means of its intensification. A determining effect on the mass transfer coefficient microwave power is defined. Burdo (Bu) vaporization number, showing the ratio of the microwave power and power needed to convert the liquid into vapor, corrects and coordinates the experimental data with an error of 8-16.5%.

Keywords: extraction, oil-containing impulse intensification, similarity criteria, theory of "dimensions"

1. INTRODUCTION

Process technologies in the microwave field are used for liquid and gas phases, both under normal and supercritical conditions. Some examples of the use of processes in the microwave field in the liquid phase are: extraction of valuable oils, flavoring substances from plant raw materials, biphenyls from animal tissues, polycyclic aromatic hydrocarbons from polyurethane foams, which are used in monitoring air and various solids – soil, sediments, etc. The second field of application of processes in the microwave field is the extraction of dissolved organic substances from water[1].

In the UK, the use of microwave irradiation to prepare samples compared to the traditional Soxhlet method reduced the process time by 8 to 16 hours to 30 minutes, energy consumption by about 90%, while the yield and purity of the obtained extract are increased. These properties not only reduce production costs, but are also considered more environmentally friendly. The method allows to determine more than 100 pollutants from various sources (soil, water, animal tissues, etc.)[1] . In France, the amount of fat in meat and dairy products is determined with the help of microwave technologies.

*vibroprocessing@gmail.com

Optical Fibers and Their Applications 2018, edited by Ryszard S. Romaniuk,
Waldemar Wójcik, Andrzej Smolarz, Proc. of SPIE Vol. 11045, 110450X
· doi: 10.1117/12.2522354

Along with the traditional methods of intensifying the extraction process (grinding, mixing, heating), new methods, such as the imposition of a field of oscillations of mechanical (low-frequency), acoustic and ultrasonic, high-voltage discharges of liquid have recently begun to be used[2,3]. The application of these effects can significantly improve the efficiency of the process even at room temperature, reduce mass-exchange characteristics of equipment, significantly reduce the amount of electricity consumption.

When mechanical low-frequency (infrasonic) vibrations[3] are applied in the solid-liquid system, leaching from the destroyed cells of intracellular contents and its dissolution takes place. With the generalized list, the author[4] distinguishes the following types of mass transfer, depending on the method of transfer of mechanical vibrations to the medium:

- fluctuations in the liquid flow in the medium of suspended solids of raw materials;
- vibrational motion of solid particles in a stationary liquid or moved liquid at a given speed;
- oscillations between a layer of solid particles and a pulsating flow of liquid.

There are data on the processing of fruit mash by ultrasound[5]. Ultrasound has a destructive, crushing effect on plant cells. Raw material is processed by ultrasound with the use of magnetostricters, which work is based on the creation of vibration due to changes in the linear dimensions of some materials (nickel and its alloys) under the influence of a magnetic field[6]. Negative aspects of this impact are relatively high energy consumption. Also, according to[1], it is recommended to add glycerin and surfactants to extractant that delay the formation of cavitation, that is, eliminate possible destructive changes and don't always agree with the production technology. When extracting, it is necessary to take into account the temperature increase of the extractant due to the absorption of ultrasound energy and to ensure that the temperature of the extract does not exceed the permissible values[7].

2. LITERATURE REVIEW AND PROBLEM STATEMENT

The authors of the scientific school of Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies Lviv, headed by Doctor of Technical Sciences, Prof. Yu. Bilonog, is proposed to intensify the process of extraction of thermolabile substances in devices with a fluidized bed with surfactants[8]. The change in the hydrodynamic parameters of the system and the reduction of the diffusion resistance make it possible to minimize the average thickness of the near-surface laminar layer and to increase the yield of the extract.

Significant intensification of mass transfer in the solid-liquid system can be achieved by applying impulse treatment of plant material. Along with mechanical and hydraulic methods, there are electric pulse[9], magnetic pulse[10] and laser (optic pulse)[11] methods of intensification of extraction from plant materials that have their advantages. However, the main drawback of these methods is large energy expenditure[4].

During the mechanical method of superimposing vibrational force fields on the medium, the acceleration of the diffusion transport mechanism is well manifested in the low-frequency range of 3-50 Hz for small particle sizes. In the case of the electric pulse path of the intensification of mass transfer, an electrohydraulic effect arises, resulting in pulsed electromagnetic radiation, high pulsed pressure, ultrasonic radiation and, as a consequence, an increase in the flow rate of the particles of the solid phase by the extractant and a decrease in the external diffusion resistance[4]. The paper[10] is devoted to the theoretical and experimental investigation of magnetic liquid oscillations and magnetic liquids for operation in oil extraction industry[4].

The content of soluble substances in the extract is significantly increase if the plant raw material is treated with alternating current[12], which results in partial maceration of tissues, denaturation of protein substances of cell protoplasm, increase in the permeability of cell membranes, facilitating diffusion of their contents into the environment. Likewise, processing with ionizing radiation, which is carried out in special apparatus-irradiators, acts on vegetable raw materials[13].

Recently, vacuum-impulse technologies for processing of plant raw materials have been increasingly used, which make it possible to obtain sufficiently concentrated extracts in a short period of time with the least expenditure of raw materials and energy[14]. The principle of vacuum-pulse extraction[15,16] is based on the preliminary degassing of the raw material under vacuum, its leakage by the extractant at atmospheric pressure, periodic heating followed by pulsating evacuation to a residual pressure equal to the vapor pressure of the solvent at a given temperature, and the connection with atmospheric pressure[1]. As a result of pulsed evacuation, the solvent effervesces in the pores of the material, and the resulting vapor pushes the extractant, saturated with the target component, into the miscella volume. Then, when combined with the atmosphere, fresh portions of the solvent enter the pores of the material. The sequence of operations described above is repeated the required number of times[1].

The works of Ya. Gumnitskaya and co-authors[17,18] are devoted to the problems of intensification of mass-exchange processes under conditions of evacuation. In this case, a three-phase solid-liquid-gas system is formed, which is characterized by a high mass-transfer coefficient. During the extraction of the target component from the solid particles under evacuation conditions, the vapor bubbles that form on the surface of the solid particle, breaking off, destroy the boundary diffuse layer. A feature of this method is creation of a vacuum in the system, leading to a boiling of the liquid at relatively low temperatures[4].

Mass transfer in the extraction of soluble substances from particles of plant material in a vacuum is studied in the works of O. Stratienko[19]. According to the authors, this method significantly intensifies the process[4]. Physical dissolution in vacuum conditions is investigated in[11]. It is shown that extraction in vacuum conditions allows to increase the process speed by 6-8 times in comparison with mechanical mixing[4]. At the same time, it should be noted that the vacuuming method has certain drawbacks (energy consumption, the need for special equipment, etc.). However, further improvement of this method will allow to come to industrial scale[4].

The scale of modern food production based on extracts and the existing problem of the most complete extraction of target components from plant raw materials is promising in this respect to consider extraction using vibration that provides intensive hydrodynamic conditions of the process, bringing the active surface of the interacting phases to 100%. Vibroextraction is a relatively new technological process and today has a certain development in the Department of Processes and Apparatuses of Food Production of the National University of Food Technologies. Professors V. Zavyalov and V. Bodrov acquired deep ideas about hydrodynamics and mass transfer of continuous and periodic vibroextraction[20,21,22]. Also, this process of extraction intensification is actively studied and introduced by the chair of food production equipment of the Donetsk National University of Economics and Trade named after Mikhail Tugan-Baranovsky headed by Doctor of Technical Sciences, Prof. A. Poperechnyi[23,38]. The complex of heat exchangers with vibrating and wave intensifiers of both technological action and transport movement in the processing area is developed under the guidance of Prof. I. Palamarchuk[24-26].

Such variety of technological and constructive approaches to the impulse intensification of extraction processes determines their relevance and prospects for development. However, with the technological use of oscillatory or pulsed processing modes, there is no systematic approach and the targeted transfer of energy to the processing raw materials. Much attention is paid to this issue in the works of the professor, Doctor of Technical Sciences O. Burdo and Doctor of Technical Sciences V. Terziev, who analyzed the data of the last 10 ... 20 years on the use of microwave technologies, substantiated the theory of the emergence of "baric effect" in the pulse transfer of energy to the microcapillary structure and introduced a number of promising technologies and designs into production. The development of these studies became the materials of the scientific article[36,37,39].

3. THE AIM AND OBJECTIVES OF RESEARCH

Considering the positive aspects of the application of microwave energy: the selective ability of withdrawals, a significant intensification of processes, the absence of the need for preliminary drying of the material, the lack of the need for serious capital investments, etc. and formulated the tasks set in the scientific work.

The aim of the scientific work is intensification of the process of oil extraction, to reduce energy consumption with an increase in its yield under the influence of a pulsed microwave action due to the development of a mathematical model of the investigated process and a graphical analysis of the obtained criterial dependencies.

To achieve this aim, the following tasks are set:

- to analyze methods of extraction intensification of target components in the extraction process;
- to develop a mathematical model of the extraction process in the microwave field using the similarity criteria;
- to justify the principle diagram of the device with a microwave intensifier;
- to check the adequacy of the developed mathematical model.

4. MATERIALS AND METHODS OF RESEARCH

For theoretical studies, the classical theory of similarity, methods of thermophysical modeling, methods for analyzing the structure of solutions are used. In experimental studies, instrumentation for the evaluation of heat and mass transfer parameters, modern techniques and devices for determining the characteristics of impulse technological action, among which the TC-80 M2thermostat, an experimental microwave stand, a semi-industrial model of an extractor with a microwave intensifier are used. To process the obtained results, software packages are used: MathCAD, Excel, Compass 3-D V17.

5. RESEARCH RESULTS

For realization of the investigated technological process of extraction with the use of pulsed electromagnetic energy for its intensification, several conceptual diagrams of the apparatus shown in Fig. 1 are developed.

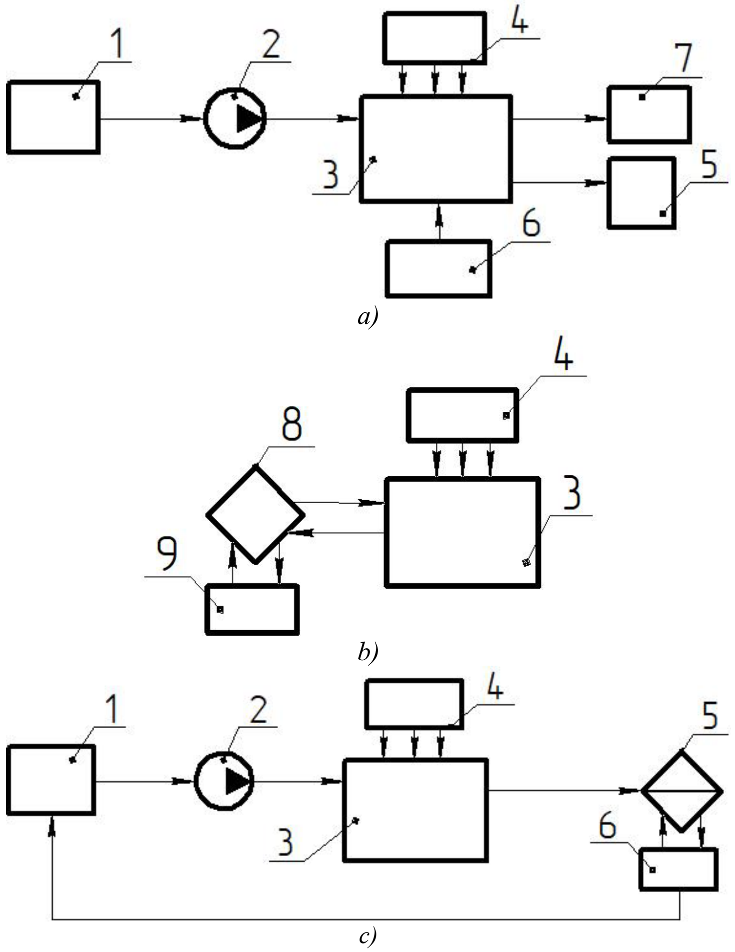


Fig. 1. Schematic diagrams of extractors with impulse intensification of the process: a) - flowing; b) - chamber; c) - circulation; 1 - container with a solvent, 2 - pump; 3 - extraction chamber, 4 - magnetron; 5 - container with extract; 6 - capacity with raw material, 7 - reservoir for slurry, 8 - cooler; 9 - autonomous refrigeration unit.

In substantiating the circuit diagram of the apparatus for extracting the oils of the investigated cultures, a simplified chamber-type diagram is selected (Fig. 1 (c)), because the unknowns leave a number of characteristics that allow planning more complex, flowing and circulation extraction diagrams. The influence degree of temperature regimes on the intensity of heat and mass transfer characteristics is undefined, so it is difficult to predict. A given diagram realizes a combination of the specific power of a pulsed microwave field and then the temperature conditions in the extraction chamber, the design of the chamber elements, the characteristics of the crushed test seeds in the complex determine the efficiency of the extractor[34,35].

Under classical extraction conditions, a stream emanating from the solid phase meets the resistance of the limiting diffusion layer, which is a perceptible obstacle, which affects the duration and amount of removal of the target component.

According to the classical extraction conditions, the stream emanating from the solid phase meets the resistance of the limiting diffusion layer, which is a perceptible obstacle, which affects the duration and amount of removal of the target component. When an impulse field with an oscillating regime is applied, along with three mass flows, another flow of motion of the extracted substance M_4 arises. Pressure diffusion, which is caused by increased pressure, produces cavitation bubbles that intensify the process and remove the hard-to-reach component into the total flow from the narrow diameter of the capillary (Fig. 2). Since the thickness of the boundary layer depends on the hydrodynamics of the process, then under the action of the microwave field its barrier is almost imperceptible, because the intensive movement of the fluid reduces its thickness.

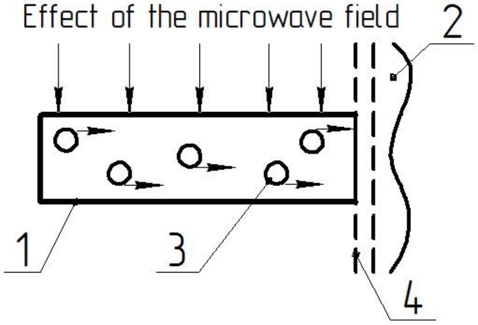


Fig. 2. Scheme of the pressure diffusion mechanism in the middle of the capillary: 1- capillary of soybean, rape; 2 - solvent; 3 - vapor bubbles; 4 - boundary diffuse layer.

The main factor is the difference in pressure between the capillary P_c and the extractant stream P_e, as well as the mass-transfer coefficient β_m, for the amount of seized substance:

$$M_4 = \beta_m (P_c - P_e). \tag{1}$$

The action of the microwave impulse energy supply during extraction is transferring the process of diffusion from the external medium to the internal one, since in the process it is not convective diffusion that dominates with the influence of external intensifying factors, but internal pressure diffusion. The extraction rate is limited depending on the porous material of the soybean and rapeseed particles. Therefore, the amount of the total flow mass will be:

$$\sum M = M_1 + M_4 . \tag{2}$$

Since the limiting diffusion layer, when intensified by the microwave field, is an order of magnitude smaller than in convective diffusion, the main obstacle to such process is the overcoming of the diffusion resistance of the solid phase. In this case, some of the liquid passes into vapor. In order for the pressure diffusion flux to overcome the diffuse resistance of the solid phase, it is necessary to determine the thermodynamic parameters of the mixture of a pair of hexane and alcohol solvents at the initial pressure P_e and the pressure P_c, which ensures pressure barodiffusion.

$$P_{BD} = P_e + P_c . \tag{3}$$

Hence the hydraulic resistance in a separate channel is:

$$P_c = \frac{\rho w^2}{2}\left[\frac{\lambda \cdot l}{d} + \sum \xi\right] + \rho \cdot g \cdot l + \frac{\sigma}{d}, \tag{4}$$

where ρ - density of the liquid; w - velocity of the liquid in the capillary; λ – coefficient of hydraulic friction; l – length of the capillary; d – diameter of the channel; ξ – local resistance; g – acceleration of gravity; σ - surface tension forces.

A mathematical description of the extraction process is obtained by an empirical method. To obtain the structure of the criterial equation for calculating the intensive mass transfer that occurs when the fluid moves and causes pressure losses and corresponding mass transfer coefficients, let's use the dimensional analysis method[27-30].

The intensity of the extraction process is determined by the mass transfer coefficient β, which dimension is m/s[31]. The value of the mass transfer coefficient β and the course of the process is influenced by particle sizes d, mass density ρ, viscosity β, diffusion coefficient D, product costs and solvent costs. Under the investigated conditions, pressure diffusion is related to the effect of the microwave field by the difference in pressures, the magnitude of which is proportional to the energy of radiation and the energy required for evaporation, that is, to the specific heat of vaporization r and the power of the field N. The contribution of natural convection is established by the difference in the concentrations of ΔC and the gravitational field with the gravitational constant g.

So, the initial functional dependence of the general form will be as follows:

$$\beta = f\,(M_{pr}, D, \Delta C, d, \rho, \mu, M_{cal}, r, N, g). \tag{5}$$

All these parameters contain only three basic dimensions: length (L), mass (M) and time (T). Using the analysis of dimensions, let's replace this unknown function of the relationship between the similarity criteria. In this case, the number of variables is $a = 11$, the number of units is $b = 3$. Then, according to the π - theorem, the number of dimensionless complexes describing the process should be equal to $a - b = 8$.

The output functional dependence of the mass-transfer coefficient on the parameters (5) according to the dimensional analysis is presented in the form of a power series:

$$\beta = A{M_{pr}}^{\alpha} D^{\gamma} \Delta C^{\delta} d^{\varepsilon} \rho^{\eta} \mu^{\theta} {M_{cal}}^{\iota} r^{\kappa} N^{\lambda} g^{\nu}$$

Using the three basic dimensions of the selected parameters, let's compose a matrix of dimensions on the basis of which obtain a system of algebraic equations (6):

$$\begin{array}{c||l} L & 1 = 2\gamma - 3\delta + \varepsilon - 3\eta - \theta + 2\kappa + 2\lambda + \nu \\ M & 0 = \alpha + \delta + \eta + \theta + \iota + \lambda \\ T & -1 = -\alpha - \gamma - \theta - \iota - 2\kappa - 3\lambda - 2\nu \end{array} \tag{6}$$

After certain mathematical transformations, equation (5) takes the form:

$$\begin{aligned} \beta &= A{M_{pr}}^{\alpha} D^{\gamma} \Delta C^{\delta} d^{-1-d+2\kappa+\lambda+3\nu-\iota} \cdot \\ &\cdot \rho^{-\delta-1+\gamma+2k+2\lambda+2\nu} \mu^{1-\alpha-\gamma-\iota-2\kappa-3\lambda-2\nu} \cdot \\ &\cdot {M_{cal}}^{\iota} r^{\kappa} N^{\lambda} g^{\nu} \end{aligned} \tag{7}$$

After the corresponding grouping, equation (7) can be represented in the form

$$\begin{aligned} \frac{\beta d\rho}{\mu} &= \left(\frac{M_{pr}}{d\mu}\right)^{\alpha} \cdot \left(\frac{\mu}{D\rho}\right)^{-\gamma} \cdot \left(\frac{\Delta C}{\rho}\right)^{\delta} \cdot \left(\frac{M_{cal}}{d\mu}\right)^{\iota} \cdot \\ &\cdot \left(\frac{d^2\rho^2 r}{\mu^2}\right)^{\kappa} \left(\frac{d\rho^2 N}{\mu^3}\right)^{\lambda} \left(\frac{d^3\rho^2 g}{\mu^2}\right)^{\nu} \end{aligned} \tag{8}$$

The complexes obtained in equation (8) give combinations that form the structure of the equation in generalized replaceable ones:

The complex $\left(\frac{M_{pr}}{d\mu}\right)^{\alpha} \cdot \left(\frac{d\mu}{M_{cal}}\right)^{-\varepsilon} = \left(\frac{M_{pr}}{M_{cal}}\right) = \zeta$ is dimensionless and takes into account the ratio of the solid and liquid phases.

The groups $\frac{\beta d\rho}{\mu}$ and $\frac{\mu}{D\rho}$ give the ratio of the coefficient of convective mass transfer with the diffusion coefficient is the Sherwood number;

$$\frac{\beta d\rho}{\mu} \cdot \frac{\mu}{D\rho} = \frac{\beta d}{D} = Sh.$$

The ratio $\frac{\mu}{D\rho} = \frac{v}{D} = \mathrm{Sc}$ is the Schmidt number; $\frac{\Delta C}{\rho} \cdot \frac{gd^3\rho^2}{\mu^2} = \frac{gd^3\Delta C\rho}{\mu^2} = \mathrm{Gr}$ - the Grashof number of similarity. But in these studies, the influence of the microwave field is also dominant and in the inertial flow regime the contribution of natural convection is insignificant. Therefore, the influence of Gr can be neglected. As a result, we get the Burdo number as a characteristic of the energy effect, which establishes the relationship between the energy of radiation and the energy that is required to vaporize the entire solution passing through the extractor

$$\left(\frac{\mu^2}{d^2\rho^2 r}\right)^{-\kappa} \cdot \left(\frac{Nd\rho^2}{\mu^3}\right)^{\lambda} \cdot \left(\frac{M_{cal}}{d\mu}\right)^{-1} = \frac{N}{V\rho r} = \mathrm{Bu} \tag{9}$$

The maximum approximation of Bu similarity criterion to 1 gives the formation of steam passing through the extractor, an increase in the pressure gradient, which entails intensive emissions of the saturated extractant from the middle of the capillaries will increase the turbulence of the boundary layer[2].

Consequently, the structure of the criterial equation in terms of similarity numbers will be as follows:

$$\mathrm{Sh} = A \cdot \mathrm{Sc}^{\sigma} \cdot \zeta^{\phi} \cdot \mathrm{Bu}^{\chi} \tag{10}$$

The constants A, σ, φ, χ are determined experimentally.

The constant σ for the Sc number is taken equal to 0.33, as usual, the influence of the Sc number in traditional mass transfer problems is established[31-33]. For a dimensionless complex, the ratio of the solid and liquid phases to the constant φ is determined from the graphical dependences (Fig. 3, 4, 5, 6) of the hydromodule from the Z (11) complex for the conditions "rape-alcohol", "rape-hexane", "soybean- alcohol "," soybean-hexane".

$$Z = Sh/Sc^{0,33} \tag{11}$$

The next stage in the generalization of the base of experimental values is the search for the exponent χ for the number of energy effects of Bu – the similarity number. Based on the experimental data obtained as a result of the investigation of the effect of the microwave power on the removal of the target component, the complex of numbers C (12) is constructed as a function of the number of evaporation. The constant χ is determined by the graphical dependence of the Bu number on the complex C (Fig. 7, 8).

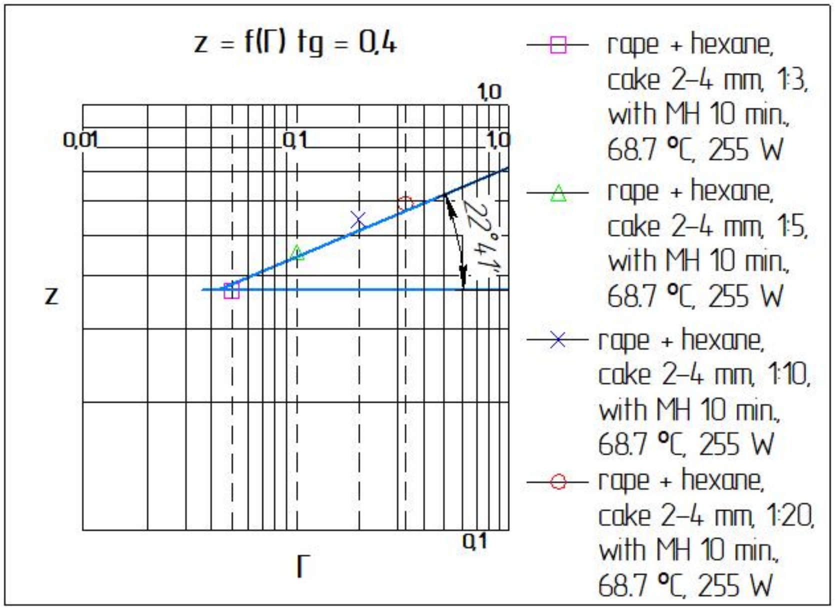


Fig. 3. Dependence of the dimensionless complex on the ratio of solid and liquid phases to the Z complex for the conditions "rape-hexane".

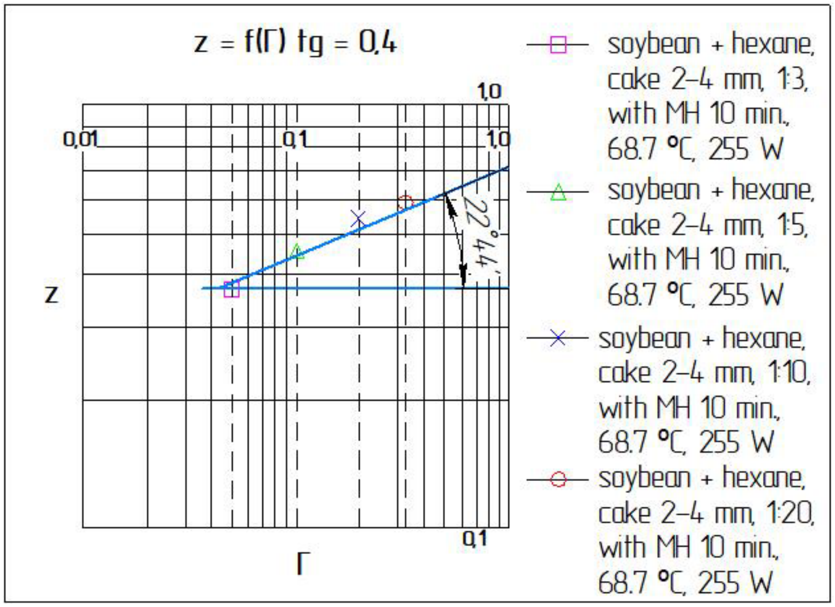


Fig. 4. Dependence of the dimensionless complex of the ratio of solid and liquid phases to Z complex for the conditions "soybean-hexane".

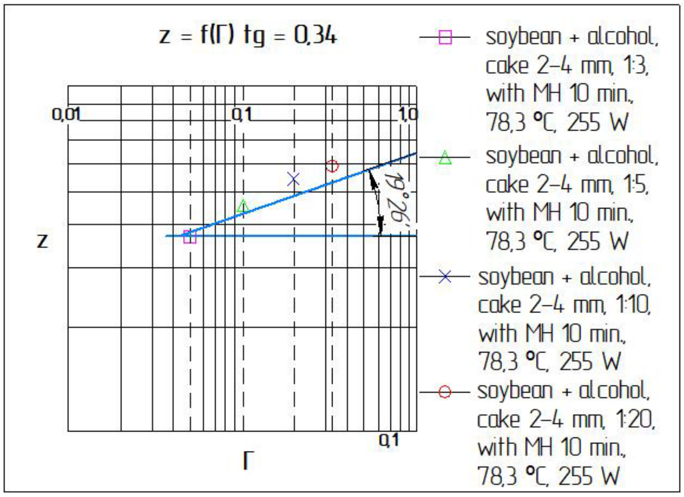


Fig. 5. Dependence of the dimensionless complex of the ratio of solid and liquid phases to Z complex for the conditions "soybean-alcohol".

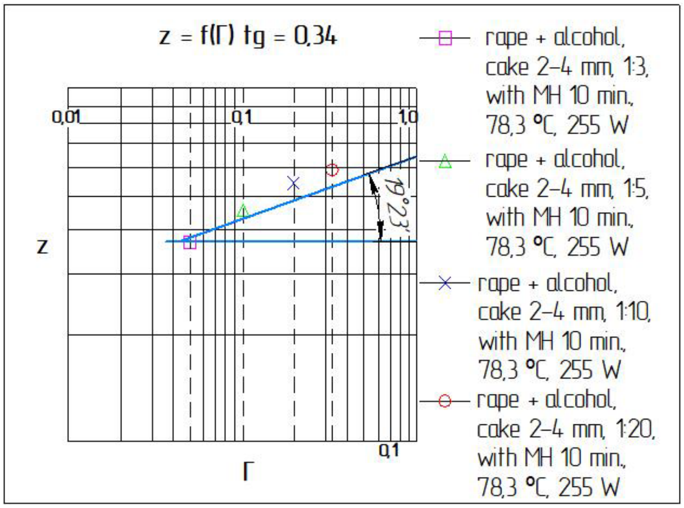


Fig. 6. Dependence of the dimensionless complex of the ratio of solid and liquid phases to the Z complex for the conditions "rape-alcohol".

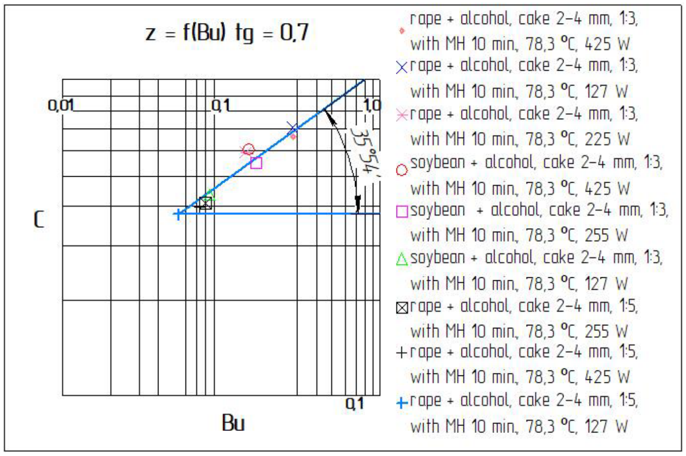


Fig. 7. Dependence of the number of energetic effects of Bu on complex C for the conditions "soybean-alcohol", "rape-alcohol".

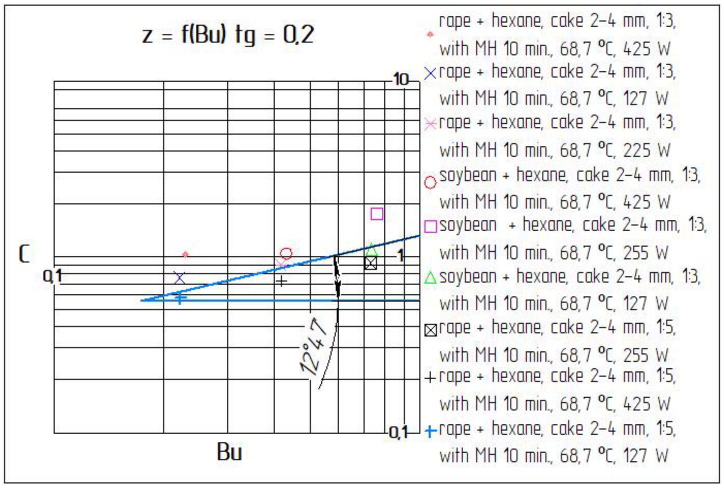


Fig. 8. Dependence of the Bu number of energy effects on complex C for the conditions "soybean-hexane" and "rape-hexane".

A positive alignment of all research data is achieved using a correcting Bu number. Intensifying the effect of this dimensionless complex on the removal of the target component in the extraction process in the microwave field, as shown in Fig. 9, 10, 11, 12.

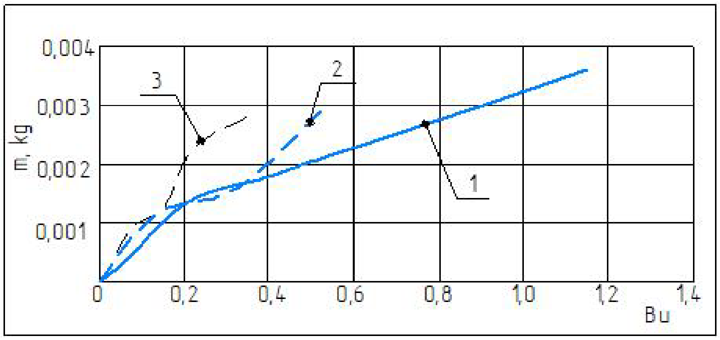


Fig. 9. Dependence of the oil mass on the number of energy effects when extracting the rape seed meal with ethyl alcohol in a microwave field: 1 – rape + alcohol, meal 2-4 mm, 1: 3, with MH, 10 min., 78.3 °C, 425 W; 2 – rape + alcohol, meal 2-4 mm, 1: 3, with MH, 10 min., 78.3 °C, 127 W; 3 – rape + alcohol, meal 2-4 mm, 1: 3, with MX, 10 min., 78.3 °C, 255 W.

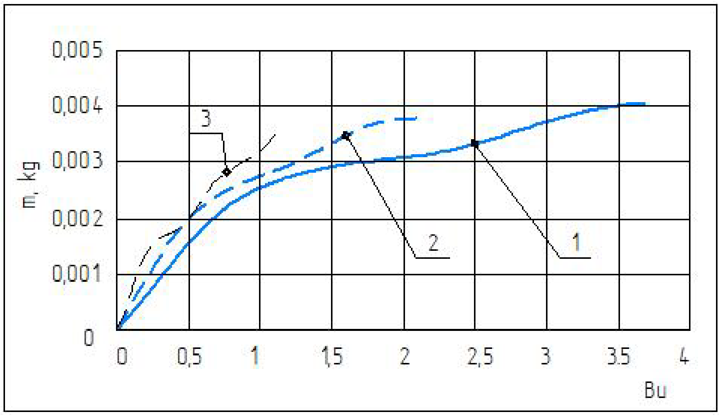


Fig. 10. Dependence of the oil mass on the number of energy effects when extracting the rape seed meal with hexane in a microwave field: 1 – rape + hexane, meal 2-4 mm, 1: 3, with MH, 10 min., 68,7 °C, 425 W; 2 – rape + hexane, meal 2-4 mm, 1: 3, with MH, 10 min., 68,7 °C, 127 W; 3 – rape + hexane, meal 2-4 mm, 1: 3, with MX, 10 min., 68,7 °C, 255 W.

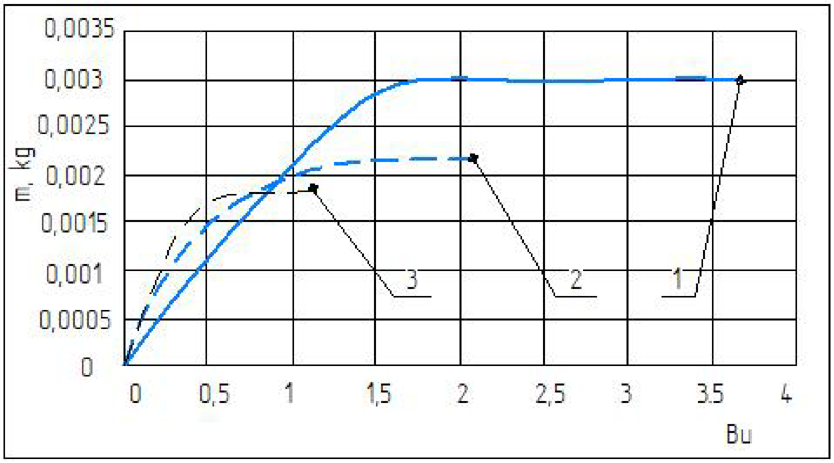


Fig. 11. Dependence of the oil mass on the number of energy effects when extracting the soybean meal with hexane in a microwave field: 1 – soybean + hexane, meal 2-4 mm, 1: 3, with MH, 10 min., 68,7 °C, 425 W; 2 – soybean + hexane, meal 2-4 mm, 1: 3, with MH, 10 min., 68,7 °C, 127 W; 3 – soybean + hexane, meal 2-4 mm, 1: 3, with MX, 10 min., 68,7 °C, 255 W.

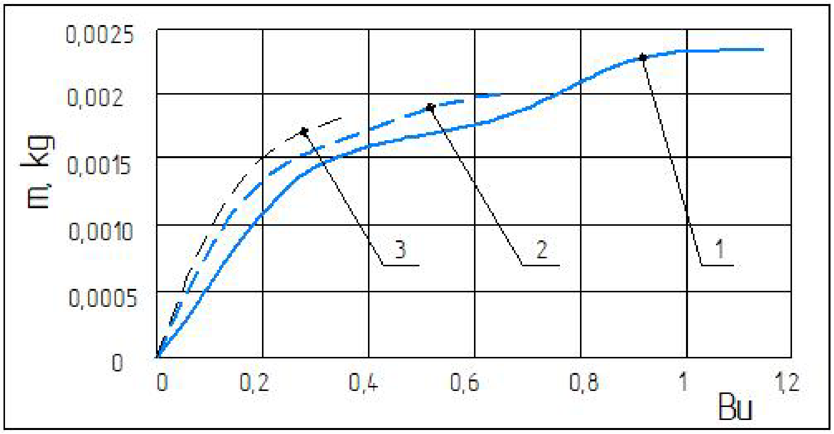


Fig.12. Dependence of the oil mass on the number of energy effects when extracting the soybean meal with ethyl alcohol in a microwave field: 1 – soybean + alcohol, meal 2-4 mm, 1: 3, with MH, 10 min., 78,3 °C, 425 W; 2 – soybean + alcohol, meal 2-4 mm, 1: 3, with MH, 10 min., 78,3 °C, 127 W; 3 – soybean + alcohol, meal 2-4 mm, 1: 3, with MX, 10 min., 78,3 °C, 255 W.

Consequently, with increasing power, the number of energy impacts increases, which leads to an increase in the mass of the removed oil.

The dependence (13) is determined from the criterion dependence of the constant A.

$$A=C/Bu^{\chi} \qquad (13)$$

Processing of the array of experimental data allows to recommend the following expressions for the calculation of the mass transfer intensity when extracting oil from rapeseed and soybean seeds with hexanes and alcohol solvents under the action of a microwave field:

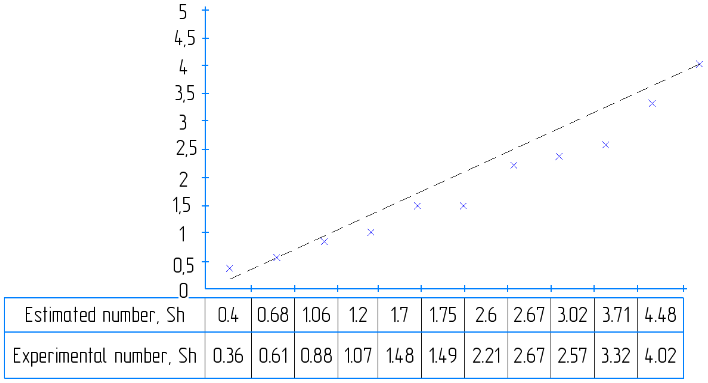
$$Sh = 1{,}7 \cdot Sc^{0,33} \cdot \varsigma^{0,34} \cdot Bu^{0,7} \text{ – for rapeseed-alcohol;} \qquad (14)$$

$$Sh = 0{,}9 \cdot Sc^{0,33} \cdot \varsigma^{0,4} \cdot Bu^{0,2} \text{ – for rapeseed-hexane;} \qquad (15)$$

$$Sh = 1{,}8 \cdot Sc^{0,33} \cdot \varsigma^{0,34} \cdot Bu^{0,7} \text{ – for soybean-alcohol;} \qquad (16)$$

$$Sh = 0{,}7 \cdot Sc^{0,33} \cdot \varsigma^{0,4} \cdot Bu^{0,2} \text{ – for soybean- hexane;} \qquad (17)$$

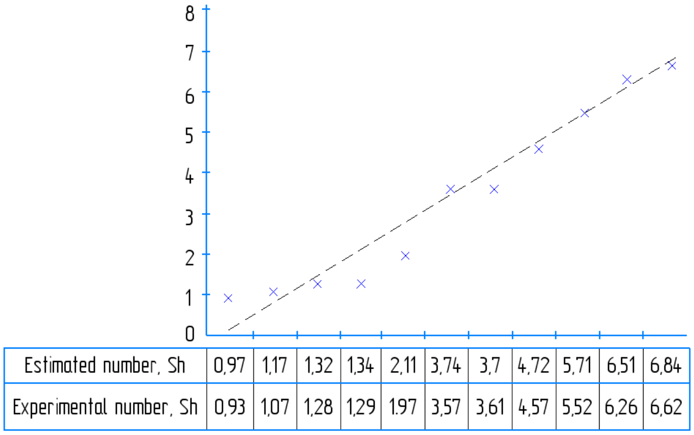
As the comparative analysis of theoretical and experimental studies has shown, the total error of the calculation using expressions 14-17 in the range of 16.5% (Fig. 13, 14, 15).



Estimated number, Sh	0.4	0.68	1.06	1.2	1.7	1.75	2.6	2.67	3.02	3.71	4.48
Experimental number, Sh	0.36	0.61	0.88	1.07	1.48	1.49	2.21	2.67	2.57	3.32	4.02

Rape – Alcohol

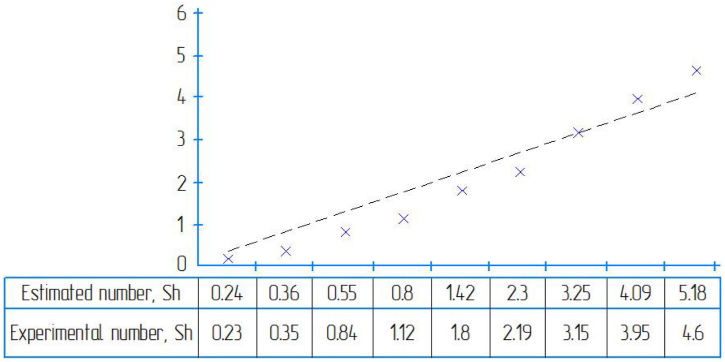
Fig.13. Comparison of the calculated and experimental data of the Sh similarity numbers for the conditions "rape-alcohol".



Estimated number, Sh	0,97	1,17	1,32	1,34	2,11	3,74	3,7	4,72	5,71	6,51	6,84
Experimental number, Sh	0,93	1,07	1,28	1,29	1,97	3,57	3,61	4,57	5,52	6,26	6,62

Rape – Hexane

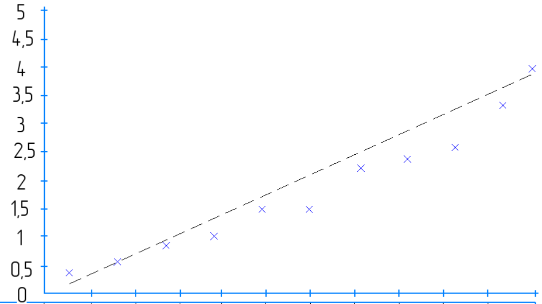
Fig. 14. Comparison of the calculated and experimental data of the Sh similarity numbers for the conditions "rape-hexane".



Estimated number, Sh	0.24	0.36	0.55	0.8	1.42	2.3	3.25	4.09	5.18
Experimental number, Sh	0.23	0.35	0.84	1.12	1.8	2.19	3.15	3.95	4.6

Soybean – Hexane

Fig. 15. Comparison of the calculated and experimental data of the Sh similarity numbers for the conditions "soybean-hexane".



Estimated number, Sh	0.43	0.55	1.16	1.24	1.76	1.75	2.69	2.79	3.86	3.96	4.6
Experimental number, Sh	0.4	0.51	0.96	0.97	1.53	1.53	2.29	2.5	3.46	3.32	4.12

Soybean – Alcohol

Fig. 16. Comparison of the calculated and experimental data of the Sh similarity numbers for the conditions "soybean-alcohol".

For the conditions for extracting soybean and rapeseed with solvent hexane is within 8.6% and for extraction conditions with ethyl alcohol - 16.5%.

6. CONCLUSIONS

1. Existing technologies and schematic diagrams of extractors with a microwave intensifier are considered and a choice of a chamber scheme for extracting oil-containing industrial crops of soybean and rape to determine the heat and mass exchange characteristics on which the design features of the extractor with an electromagnetic intensifier depend.
2. Using the theory of "dimensions" and the second similarity theorem, a criterial equation is developed for describing the processes of heat of mass transfer during extraction with pulse intensification. For the case of extraction in a microwave field during the motion of a solution through a porous layer, the Sherwood number is determined by the Schmidt number, the ratio of solid and liquid phases, and the number of evaporation that establishes the ratio of the field power and the energy needed to transfer the solution to the vapor phase.
3. The determining influence on the value of the mass-transfer coefficient of the microwave power is established. The Burdo vaporization number (Bu), showing the ratio of the microwave power and power needed to convert the liquid into vapor, corrects and coordinates the experimental data with an error of 8-16.5%.

REFERENCES

[1] Burdo, O.G. and Ryashko, G.M., [Extraction in the "coffee-water" system], Odessa (2007).
[2] Molchanov, G.I., [Intensive treatment of medicinal raw materials], Meditsina, Moscow (1981).
[3] Stabnikov, V.P. and Loboda, P.P., [Intensification of mass transfer from solids in the field of oscillations. Heat and mass transfer], Science and Technology, Minsk (1968).
[4] Moroz, V.I., "Mechanism and kinetics of extraction of target components from seeds of amaranth," Author's abstract. dis for obtaining sciences. Degree Candidate tech Sciences, Lviv (2008).
[5] Orlov, I.V., "Infusions obtained with aqueous and ultrasound extraction from herbs of oregano, motherwort, peppermint," Storage and processing of agricultural raw materials 12, 26-27 (2002).
[6] Maremitsu, I. and Yoshimi, S., "Method and device for extracting effective ingredients from dried plant materials," Pat. No 5358725 США, МРК^5 A 23 F 3/00, 5/00 (1994).
[7] Chaplinskaya, M.G. and Galun, A.V., [On the use of the laser in the production of certain drugs], Modern problems of pharmaceutical science and practice, Kharkiv (1972).
[8] Matvienko, A.B., "Intensification of the process of extraction of soluble substances by electroprocessing of plant material and aqueous media," Abstract. dis. for academic competition. Degree of Candidate tech. Sciences Kharkiv (1996).
[9] Molchanov, G.I. and Lube, V.M., "Preparation of medicinal forms by ultrasound in pharmacy conditions," Materials of the third All-Russia. congress of pharmacists, Sverdlovsk 136-137 (1975).

[10] Papchenko, A.Y., "Investigation electric pulse treatment process of vegetable raw materials in order to intensify its sokootdachi," Abstract. dis. for academic competition. Degree of Candidate tech. Sciences, Odessa (1979).

[11] Rybalchenko, A.S., Golitsyn, V.P. and Komarova, L.F., "Study of liquorice root extraction," Chemistry of plant raw materials 4, 55-59 (2002).

[12] Wenger, L.O., "Intensification of the extraction of the target components from the solid phase by vacuuming the system," Abstract. dis. for academic competition. Degree of Candidate tech. Sciences, Lviv (2005).

[13] Bilonoga, Yu.L. and Drachuk, U.R., "Intensification of the extraction of rhinosides with the use of surfactants," Integrated technologies and energy saving 3, 111-116 (2010).

[14] Hyiotic, G.F., "Development and research of magnetoridine seals for the equipment of extraction production of vegetable oil," Author's abstract. dis for obtaining sciences, Degree Candidate tech Sciences, (2002).

[15] Sensoy, I. and Sastry S.K., "Extraction using moderate electric fields," Journal of Food Science 1 (69), 7–13 (2004).

[16] Gumnitsky, Ya. M., Yuri, M.F. and Sen'kiv, V.M., "Method of extraction from a solid," Pat. 6651 Ukraine, B01 D11 / 00 No. 20041008630 (2005).

[17] Gumnitsky, Ya.M., Wenger, L.O. and Yurim, M.F., "Kinetics of the extraction of the target component from a single capillary under vacuum system conditions," Chemistry, technology of substances and their applications: Visn. nats Lviv Polytechnic University 488, 220-222 (2003).

[18] Abramov, Ya.K., Golitsyn, V.P., Molokeev, V.A., Sidorov, S.I., Malyutin, V.E., Borisov, S.I., Belous, V.K., "Method of extraction of materials," Pat. 2163827 Russian Federation, No. 98113349/12, (2001).

[19] Stratienko, O.V., "Investigation of mass transfer with intensification of sugar extraction from sugar beet shavings," The author's abstract dis. for academic competition. Degree of Candidate tech. Sciences, 1-20 (1971).

[20] Zavialov, V.L., Popova, N.V. and Lobok, O.P., "Investigation of the kinetics of the extraction process from leaf tea raw materials in periodic apparatus with different vibration mixing systems," Visn. Kharkiv nats. Tech. un-th., 102-112 (2007).

[21] Zavialov, V.L, and Popova, N.V., Pat. 25090 Ukraine, IPC 01/01/11, Extractor, No U 200703028, Bull 11 (2007).

[22] Zavialov, V. L and Popova, N.V., Stalemate 25088 Ukraine, IPC 01/01/11, Extractor, U 2007 03024, Bull 11 (2007).

[23] Transverse, A.M. and Borovkov, S.O., "Development of design and method of calculation of vibration extractor," Visn. DonNUET Series: Engineering 1 (41), 15-23 (2009).

[24] Palamarchuk, I., Bandura, V. and Palamarchuk, V., "Justification of the design and technological scheme of conveyor vibrating dryer," Vibration in technology and technologies 2 (66), 116-125 (2012).

[25] Palamarchuk, I., Bandura, V. and Palamarchuk, V., "Analysis of dynamics of vibroconveyor technological system with kinematic combined vibroexcitation," MOTROL Commission of Motorization and Energetics in Agriculture, 15 (4), 314-323 (2013).

[26] Palamarchuk, I., Turcan, O. and Palamarchuk, V., "Justification of the design and technological scheme of infra-red vibrating conveyor dryer for post-harvest processing of loose agricultural products, " Collection of scientific works of Vinnytsia National Agrarian University. Series: Engineering 1 (89), 117-123 (2015).

[27] Isaev, S.I., Kozhinov, I.A. and Kozhinov, V.I., [Theory of heat and mass transfer under the editorship of A.I. Leontev], Moscow 1979.

[28] Grigorieva, V.A. and Zorina, V.M., [Heat and mass transfer. Thermotechnical experiment], Atomisdat, Moscow (1982).

[29] Piasecka-Belkhayat, A. and Korczak, A., "Modelowanie przepływu ciepła w dwuwymiarowym ciele krystalicznym za pomocą interwałowej metody siatek boltzmanna," Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska 4 (1), 69-71 (2014).

[30] Ivanyi, A. and Jancskar, I., "Full multigrid solver for 2D steady-state diffusion," Przeglad Elektrotechniczny 06, 37-41 (2005).

[31] Axelrud, G.A. and Lysyansky, V. M., [Extraction. The solid-liquid system], Chemistry, Leningrad (1974).

[32] Romankov, P.G. and Kurochkina, M.I., [Extraction from solid materials], Chemistry, Leningrad (1983).

[33] Gukhman, A.A., [Application of the theory of similarity to the study of heat and mass transfer processes], Izd. Vysshaya Shkola, Moscow (1974).

[34] Osadchuk, V.S. and Osadchuk, A.V., "Radiomeasuring Microelectronic Transducers of Physical Quantities," Proceedings of the 2015 International Siberian Conference on Control and Communications (SIBCON), 1-8 (2015).

[35] Osadchuk, A.V. and Osadchuk, I.A., "Frequency transducer of the pressure on the basis of reactive properties of transistor structure with negative resistance," Proceedings of the 2015 International Siberian Conference on Control and Communications (SIBCON), 1-3 (2015).

[36] Osadchuk, A., Osadchuk, I., Smolarz, A. and Kussambayeva, N., "Pressure transducer of the on the basis of reactive properties of transistor structure with negative resistance," Proc. SPIE 98161C, 1-7 (2015).

[37] Azarov, O.D., Murashchenko, O.G., Chernyak, O.I., Smolarz, A. and Kashaganova, G., "Method of glitch reduction in DAC with weight redundancy," Proc. SPIE 98161T, 1-8 (2015).

[38] Azarov, O.D., Dudnyk, O.D., Duk, M. and Porubov, D., "Static and dynamic characteristics of the self-calibrating multibit ADC analog components, "Proc. SPIE 8698, 1-8 (2013).

[39] Azarov, A.D., Chernyak, A.I. and Chernyak, P.A., "Class of numerical systems for pipeline bit sequential development of multiple optoelectronic data streams," Proc. SPIE 4425, 1-5 (2001).