Extractors with vibratory mixing devices And prospects of their use in the food industry

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Abstract. *The low efficiency of the existing technologies for the extraction of desired components from vegetable raw materials with a high degree of milling is due to the imperfection of extraction equipment. Though the designs of modern periodic and continuous extractors are fairly diversified, there exist common disadvantages caused by the insignificant porosity of fine-fraction vegetable raw materials or the mass prepared from them for counterflow continuous extraction, their poor transportability, densification, and, as a result, the low permeability for the extractant. It has been established that vibratory extractors are most promising in this respect. In the present work, we present results of investigations of the intensifying action of low-frequency mechanical vibrations on the extraction process of desired components from vegetable raw materials under conditions of continuous vibration extraction.*

For industry, we propose a new design of a periodical and a continuous apparatus with vibratory mixing devices.

Key Words: vibratory extraction, mathematical modeling, intensification, mass transfer, vegetable raw material, hydrodynamic flow

I. Introduction

At present, the most important line of investigations on extraction in the solid body–liquid system is the search of methods of the intensification of extraction process and the development of the engineering methods for the computation of apparatuses. The existing extraction equipment, which is extensively used in the food industry with screw, belt, rack, and bucket transporters for continuous processes or with mixing devices of different kind of rotational character for periodic technologies, is inefficient or low-capacity in extraction of desired components from vegetable raw materials with a high degree of milling [1]. For instance, vegetable raw materials or mass prepared from them do not have a sufficient porosity for efficient counterflow extraction and are not densified under the action of transporters in the apparatus, which leads to the screening of the largest part of their active surface and disruption of the counterflow of phases.

In this connection, the use of low-frequency mechanical vibrations in periodic and continuous apparatuses can be a promising method of the intensification of the extraction process [2].

The practice of investigations in this direction brought to the forefront the necessity of studying the action of vibrations on the internal and external mass exchange, structure, velocities of flows in the working medium, time of processes, degree of extraction of desired components, and scaling of apparatuses with regard for technological requirements.

II. Materials and methods

In the present work, kapron crumbs, beet chips and hop were used as raw materials.

Methods of investigations include analytic modeling, multifactor experiments, and typical procedures for the determination of qualitative indices of extracts of vegetable raw materials.

The output of a continuous vibratory extractor was determined by the weight method using an AJ-220CE balance. The frequency of vibrations of vibratory mixing devices was set with an Eurotron CT 50 electronic tachometer, which uses stroboscopy. The amount of soluble extractive substances of vegetable raw materials was determined by the refractometric method with the use of an RPL refractometer. The intensity of vibrations of the vibratory transporting system was established in accord from the distance of propagation of pulsing turbulent jets, which do not cause the critical level of longitudinal mixing in the working zone of the apparatus, in the closed medium of pulsing turbulent jets. The distance of propagation of turbulent pulsing jets generated by the elements of vibrating mixing devices was determined with the help of Prandtl–Pitot tubes from the indications of differential manometers.

Processing of experimental data and computations were performed by using the modern integrated systems such as MathCAD 15, KOMPAS – 3D V13, AutoCAD 2012, CorelDRAW X5, etc.

III. Results and discussion

The indicated problems were solved as a result of the development of new extraction continuous and periodic equipment at the Department of Processes and Apparatuses for Food Production of the Kiev National University of Food Technologies (Ukraine) [3, 4, 5].

In apparatuses intended for performing continuous processes, a new principle of counterflow transportation (separation) of phases with the help of vibrating partitions of special design [3,4] was used. These vibrating partitions rule out the possibility of pressing of raw materials and provide their porosity independently of the particle size (Fig. 1).

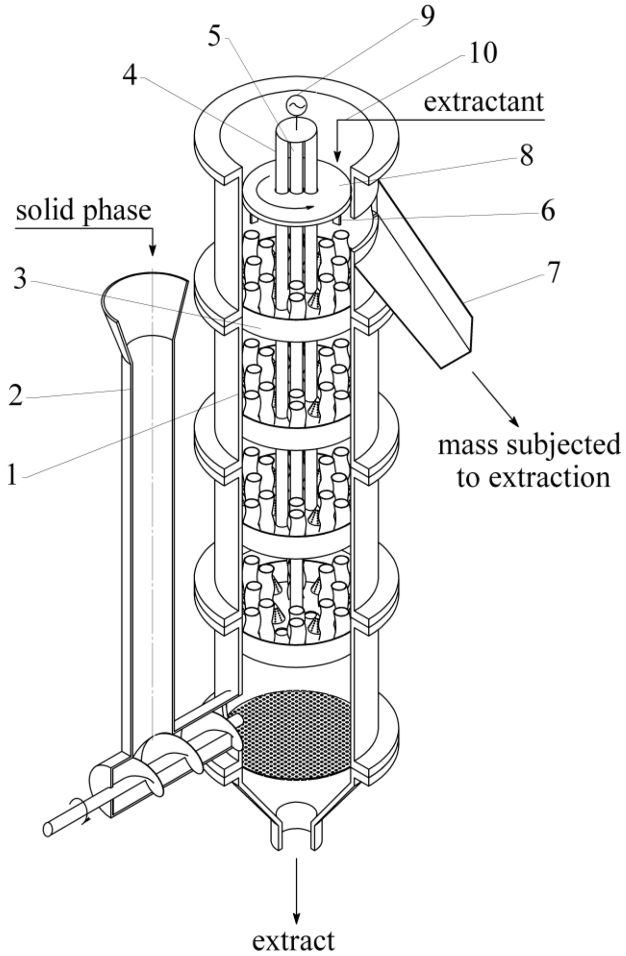

Figure 1. *Scheme of a continuous extractor: (1) apparatus body; (2) charging device; (3) vibratory transporting plate; (4,5) rods; (6) scraper; (7) tray; (8) discharging mechanism; (9) vibratory drive; (10) sprinkler*

The apparatus consists of a cylindrical column (1) with an U-shaped charging device (2), vibratory transporter with transverse partitions (plates) (3) that are fixed in turn on vertical rods (4) and (5) and execute harmonic vibrations shifted by a one-half period. A vibratory drive (9) with a crank mechanism provides constant amplitude and a constant frequency of motion of rods. A scraper (6) and a tray (7) serve for discharging extracted raw materials from the apparatus. A sprinkler (10) located above the upper plate serves for feeding the extractant into the apparatus.

In continuous vibratory extraction of desired components from vegetable raw materials, the activation of the interface is accompanied by the counterflow separation of phases. The mechanism of this separation (filtering or sedimentation mechanism) consists in the displacement and accumulation of the solid phase on one side of a vibratory transporting partition in the direction of its transportation. The transporting capacity of the vibratory extractor was studied at different intensities of vibrations of plates. The amplitude of vibrations was varied within the range (5–20)$\cdot 10^{-3}$ m, and the frequency was changed in the range 1–4 Hz. The results of investigations were generalized by graphic dependences in Fig. 2 for different types of vegetable raw materials.

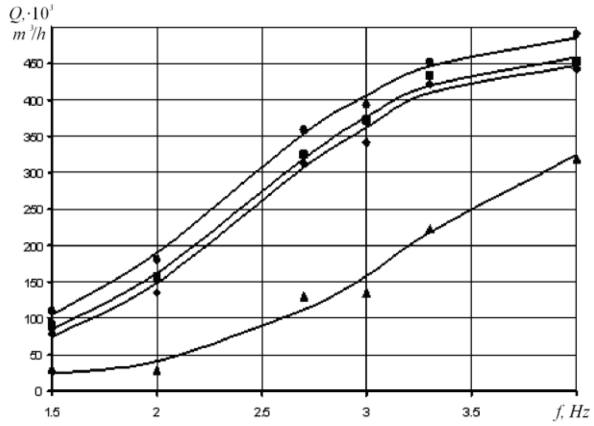

Figure 2. *Dependence of the output of the vibratory extractor on the frequency of vibrations of the vibratory transporting system: (●) hop; (◆) kapron crumbs; (■) beet chips;(▲) hop*

As a result of the mathematical modeling of the transporting capacity of the apparatus, the following formula for computing the solid-phase output was obtained:

$$V = \left. \frac{m_{tr} F_{tr} \left(\rho_{s_2} \omega_{tr_2} - \rho_{s_1} \omega_{s.tr_1} \right)}{\rho_{c_1}} + \frac{\rho_f \omega_f F_f \left(\omega_{f_2} - \omega_{f_1} \right)}{\rho_{s_1}} \right] T \qquad (1)$$

where m_{tr} and m_f are, respectively, the number of transporting elements and the number of filtering elements; F_{tr} and F_f are, respectively, the cross-sectional areas of the transporting and filtering elements, m^2; ρ_{s_1} and ρ_{s_2} are, respectively, the density of the suspension that passes through a transporting element in motion of the plate upward and downward and the density of the suspension that passes through the transporting element and the filtering element, kg/m^3; ω_{f_1}, ω_{f_2}, ω_{tr_2}, and $\omega_{s.tr_1}$ are, respectively, the velocities of media through individual transporting and filtering elements, m/sec, and T is the period of vibrations of the plate, s.

The results of investigation of the mass-exchange characteristics of the vibratory extractor are generalized in the coordinates Sh/Sc$^{0.5}$ = f(Re) in Fig. 3 for sugar beet, where Sh = $\beta d_e/D$ is the Sherwood number, Sc = ν_f/D is the Schmidt number, Re = $\omega_L d_e/\nu_f$ is the Reynolds number, d_e is the equivalent particle diameter, m, ν_f is the kinematic viscosity of the boundary film on the particle surface, m^2/s; D is the diffusion coefficient of the matter solution, m^2/s, and β is the mass-transfer coefficient, m/s.

It can be seen from the graph that the substantial activation of the interface occurs at Re ≈ 2300, and the mass-exchange characteristics of the apparatus can be represented by the following criterion dependences:

$$\mathrm{Sh} = 0.85\ 10^{-3}\mathrm{Re}^{1.0}\mathrm{Sc}^{0.5} \text{ for } \mathrm{Re} < 2300 \qquad (2)$$

$$\mathrm{Sh} = 1.71\ 10^{-3}\mathrm{Re}^{1.0}\mathrm{Sc}^{0.5} \text{ for } \mathrm{Re} > 2300 \qquad (3)$$

The operation of a periodically acting apparatus (Fig. 4) is based on the formation of pulsing turbulent flows of a medium due to low-frequency mechanical vibrations of a perforated disk (5) and periodic squeezing of vegetable raw materials in a screening container (6), connected to this disk.

The vibratory extractor consists of a cylindrical body (1) with a heating casing (9), vibratory system, which consists of a mixing device of special design, namely, a flexible container (6), fixed on a lower screening support (7) and connected to a vibratory drive (3) by a rod (4) through the upper perforated disk (5) (the design of the vibratory mixing system is determined by the type of the raw material).

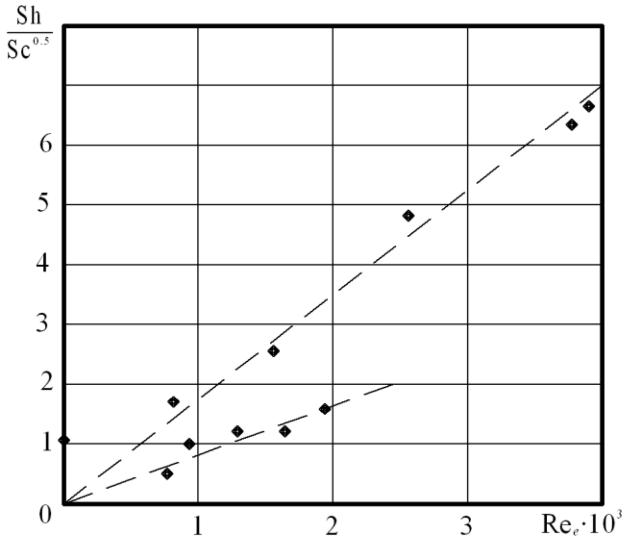

Figure 3. *Generalization of experimental data of the investigation of mass exchange in continuous vibratory extraction*

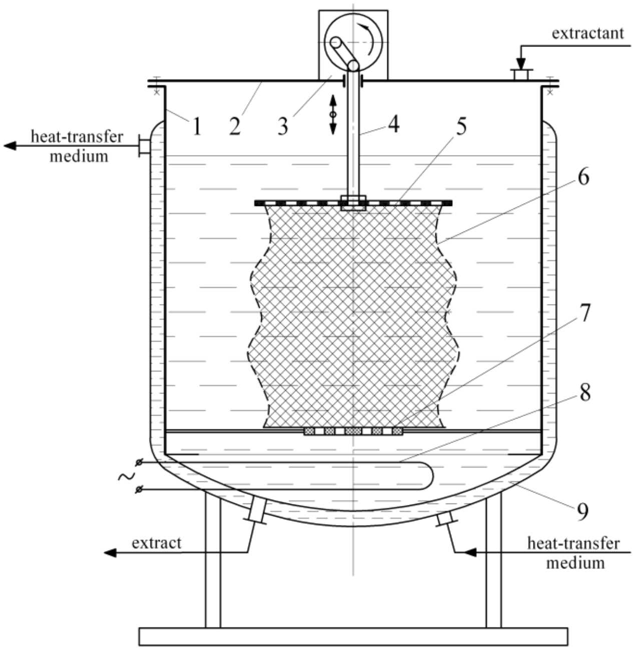

Figure 4. *Scheme of a periodic vibratory extractor:*

(1) apparatus body; (2) cover; (3) vibratory drive; (4) rod; (5) perforated disk;(6) screening container; (7) lower screening static support; (8) vibratory drive;(9) heating casing

Investigations of mass exchange were performed in wide ranges of the regime and technological parameters of operation of the apparatus (water consumption per unit time and area, frequency and amplitude of vibrations, temperature, and rarefaction of the system). In Fig. 5, we show the variation in the Biot number with time as a variant of the generalization of experimental results.

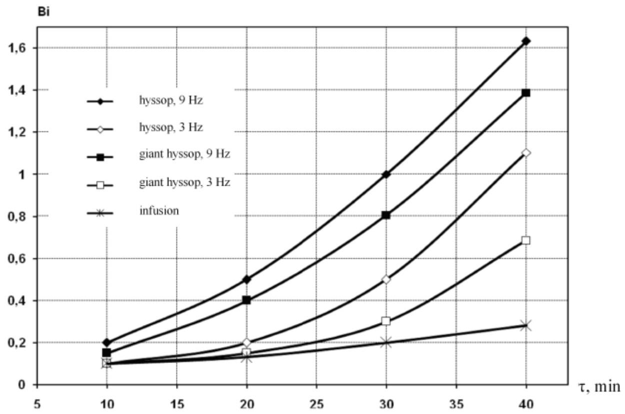

Figure 5. *Variation in the Biot criterion (Bi) with time in vibratory extraction of flavonoid matters from giant hyssop and hyssop*

In the case where the driving force of the process is represented as the difference between the concentration in the extractant on the interface and the concentration in the volume of the extractant ($\hat{c}-c$), on condition that resistance is absent on the interface, we can write

$$\begin{cases} \dfrac{dc}{d\tau} = K_V(\hat{c}-c); \\ c(\tau_0) = c_{0_i}, \end{cases} \qquad (4)$$

where K_V is the volume mass-transfer coefficient, s^{-1}, and τ is the process time.

Taking into account that, at the initial moment of time, $\tau_0 = 0$ and $c_0 = 0$, system (4) can be transformed to the form

$$c(\tau) = \hat{c}\left(1^{-K_V\cdot\tau}\right) \qquad (5)$$

The obtained equation enables us to predict the change in the current concentration of the desired component in the volume of the apparatus in extraction from vegetable raw materials and determine the maximum time of the process.

IV. Conclusions

The application of a field of low-frequency mechanical vibrations on interacting phases in extraction is an efficient method of the formation of hydrodynamic conditions and a strong source of intensification of the process due to an increase in the velocity of relative motion of the phases.

If in the counterflow extraction process, only 20–25% of the whole external surface of particles takes part, then the application of the field of vibrations promotes a decrease in the external diffusion resistance and brings the fraction of the active surface closer to 100%. Thus, the developed periodic and continuous vibratory extractors can be successfully used in different processing industries for processing of vegetable raw materials of herbal, root, cereal, and fruit–berry origin.

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