INFLUENCE OF ULTRASONIC CAVITATION ON THE STRUCTURE OF PLANT RAW MATERIAL

Ostapenko Z., Honcharenko K.
Igor Sikorsky Kyiv Polytechnic Institute, zhanna.ost@gmail.com

Abstract.
During ultrasonic extraction, the process of formation and implosion of cavitation bubbles takes place in the solvent. This process is accompanied by physical phenomena, such as high-speed solvent flows and shock waves, which lead to the enlargement of existing cracks and the formation of new cracks in the plant raw material. Physical processes occurring inside the plant raw material during ultrasonic cavitation contribute to the intensification of the process of extraction of biologically active substances.
Keywords: *Ultrasonic cavitation, plant raw material, biologically active substances extraction.*

Introduction. The process of extracting biologically active substances from plant raw material with organic solvents is carried out due to convective diffusion on the surface of solid raw material particles and molecular diffusion inside the raw material particles. The diffusion process depends on the size of plant raw material particles, operational temperature, solvent properties, such as viscosity and diffusion coefficient of biologically active substances inside and outside solid particles of plant raw material.

Acceleration of the extraction of biologically active substances processes from plant raw material under the ultrasonic cavitation conditions is associated with the destruction of individual particles of plant raw material and improved access of the solvent to biologically active substances located in the intercellular and cellular space. The destruction occurs due to the energy released during the collapse of the cavitation bubble.

The aim of the work is researching the physical processes inside the plant raw material and the effect of ultrasonic cavitation on the structure of the plant material during the extraction of biologically active substances.

Materials and methods. During ultrasonic irradiation of a solid-liquid mixture, shear forces arise inside the solvent and near the solid particles of the plant raw material. Shear and turbulence forces arise because of the formation and collapse of a cavitation bubble in a liquid [1]. Several studies show that, depending on the properties of the extraction medium, high ultrasound power causes significant changes in plant material, causing greater shear stress [2].

The phenomenon of formation and collapse of cavitation bubbles is accompanied by strong hydraulic shocks. The shock wave transmits a significant acceleration to the solvent in the collapse area. As the acceleration increases, the force of the mass of the solvent, which can perform the destruction work, increases.

Analysis of the structure of solid particles of plant raw material used in the extraction processes of biologically active substances shows the presence of many cracks in the material of solid particles. The sizes of these cracks increase under the influence of ultrasonic cavitation. Figure 1 shows the scheme of the central crack in the plant material.

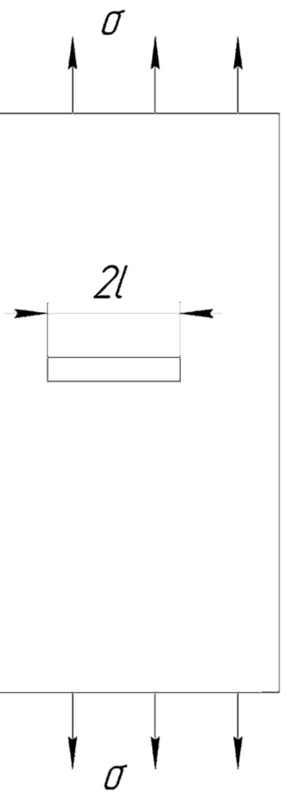

Fig. 1. Scheme of the central crack in plant raw material:
2*l* – the size of the central crack; *σ* – stresses acting on plant raw material

According to the research of the Alan Arnold Griffith, the decrease in the theoretical strength of particles is explained by the presence of defects in them, the sizes of which are large compared to the intermolecular distance. According to Griffith's concept, sufficient energy must be applied to the tip of the crack to develop.

Results and discussion. To evaluate the processes of initiation, development, and destruction of cracks inside the plant raw material, it is necessary to consider the tensely-deformed state of the raw material, in which the cracks formed and have a tendency to grow.

The cracks creation work with length is equal $2l$:

$$\Gamma = 4 \cdot \gamma \cdot l, \tag{1}$$

where γ – work of destruction per unit area of the new surface.

The energy released when cracks grow by the length Δl:

$$\Delta W = W(l + \Delta l) - W(l) = \frac{\pi \cdot \sigma^2 \cdot l \cdot 2\Delta l}{E}, \tag{2}$$

where σ – stresses acting on plant raw material;

E – Young's modulus.

The work that is spent on increasing the length of the crack:

$$\Delta \Gamma = 4 \cdot \gamma (l + \Delta l) - 4 \cdot \gamma \cdot l = 4 \cdot \gamma \cdot \Delta l . \qquad (3)$$

The crack will develop under the condition:

$$\Delta W > \Delta \Gamma . \qquad (4)$$

For a central crack in plant material, the condition can be:

$$\frac{2\pi \cdot \sigma^2 \cdot l \cdot 2\Delta l}{E} \cdot \Delta l = 4 \cdot \gamma \cdot \Delta l . \qquad (5)$$

The stress for the initiation of crack development at a given length, as well as the critical length of a crack capable of growing at a given stress can be determined from equations (5):

$$\sigma = \sqrt{\frac{4 \cdot E \cdot \gamma}{2\pi \cdot l}} , \qquad (6)$$

$$l = \frac{2E \cdot \gamma}{\pi \cdot \sigma^2} . \qquad (7)$$

Conclusions. The phenomenon of the cavitation bubbles collapse on the surface of plant raw material provokes a number of physical effects, such as the formation of high-speed solvent flows, shock waves and the occurrence of significant shear forces. These effects can lead to the destruction of existing and formation of new cracks in the structure of plant material, crushing of fragile plant material and local erosion. As a result of these effects, there is an increase in the contact area of the solvent with plant raw material and an intensification of the mass transfer processes of extraction of biologically active substances.

Reference:

1. Ultrasound assisted extraction of food and natural products. Mechanisms, techniques, combinations, protocols and applications. A review / F. Chemat et al. *Ultrasonics Sonochemistry*. 2017. Vol. 34. P. 540–560. URL: https://doi.org/10.1016/j.ultsonch.2016.06.035
2. Bermúdez-Aguirre D., Mobbs T., Barbosa-Cánovas G. V. Ultrasound Applications in Food Processing. *Food Engineering Series*. New York, NY, 2010. P. 65–105. URL: https://doi.org/10.1007/978-1-4419-7472-3_3