Research of the process of vegetable oil extracting under the influence of a high frequency wave field

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Abstract. Research in a laboratory press equipped with an ultrasonic vibrator was performed to study the nature of a high frequency wave field influence on the process of vegetable oil extracting from safflower seeds. The initial moisture content of safflower seeds, the rotational speed of the press screw, the frequency and amplitude of ultrasonic vibrations have the greatest influence on the oil yield and the cake residual oil content. The analysis of the dependences obtained showed that the parameters of the safflower seed pressing process, the values of which could be varied during the experiments, affect the oil yield identically, namely, with an increase in the rotational speed of the press screw, the oil yield decreases and, consequently, the cake oil content increases. It was found out that moisture content raising increases the oil yield and reduces the residual oil content. Moreover, the most rational value of moisture content in terms of absolutely dry matter is 8.7...11.2%. It was revealed that an increase in the pressure given to the product in the press occurs with a decrease in the effective viscosity inside the surface layer of the mass being pressed due to ultrasonic vibrations imposition. The following parameters should be focused on as rational parameters for safflower seeds pressing providing the minimum residual oil content in the cake: the ultrasonic waves frequency is 22...28 kHz, the amplitude is more than 40 • 10^-3 m and the pressure value in the press is from 12...13 MPa. These values obviously depend directly on the grain behavior and its movement in the press during exposure to high-frequency ultrasonic vibrations.

1. Introduction

Being one of the most important branches of the food industry, the production of vegetable oils is continuously developing and improving. Both food and medicinal drug oil products extracted from crops of various origins are used in modern life. Nowadays, oils obtained from unconventional crops are gaining popularity. Safflower oil belongs to one of these types of vegetable oils by right. The specified oil is extracted from safflower seeds, which are mainly grown in the southern arid regions of Russia, as well as in Central Asia. The taste of safflower oil is in many ways similar to the taste of sunflower oil. At the same time, it found its application in the production of margarines, the preparation of cold snacks and salads, and the high ignition temperature allows it to be used for deep-frying culinary products [1, 2].

Traditionally, vegetable oils are extracted from seeds by screw or hydraulic presses. However, a significant amount of oil is contained in the cake remaining after oil extraction. Therefore, the search for ways to increase the yield of vegetable oil from seeds, as well as to reduce its residual content in
the cake is very important. To achieve this goal, we propose to combine the process of safflower seeds pressing with the physical effect of a high-frequency wave field on the cake removed.

The application of ultrasonic vibrations is known to provide great opportunities for the intensification of technological processes, automation of operations, improving product quality and the overall production culture. The greatest effect is achieved with ultrasonic vibrations applying in viscous, liquid and gaseous media, which allows its use in vegetable cakes processing [3-5]. This research was carried out to study the prospects and influence of ultrasonic vibrations on the nature of the process of safflower seeds oil obtaining.

2. Materials and methods.

The study of the process of safflower seeds pressing under the influence of ultrasonic waves was carried out on an experimental unit - a single-screw press (Figure 1).

The press included a frame 1, a driving mechanism 2, an oil press chamber 5 with a loading hopper 4, a screw 7 (Figure 2), a grain chamber 6 with a device for regulating the cake exit gap 19.

![Figure 1. Single screw press:](image)

**Figure 1.** Single screw press:
a - scheme of the press; b - general view of the press:

1- frame; 2- driving mechanism; 3- unit housing; 4- loading hopper; 5- operating camera; 6-11 - oil outlet holes; 7 - screw; 8 - engine; 9 - chain transmission; 10 - gear; 12 additional oil pressing chamber; 13-grooves; 14- central hole; 15- forcing screw element ; 16-nut; 17- muf; 18 - cake outlet hole; 19- regulatory devices; 20 - piezoceramic ultrasonic emitter; 21 - power amplifier (A); 22-generator (G); 23 - start button; 24 – temperature gauge.

![Figure 2. Press screw](image)

Figure 2. Press screw

The press contained the following sensors: for taking temperature readings at different points simultaneously; to measure the pressure in the grain cylinder, which are connected to a system of
monitoring and controlling of the pressing process properties.

The press driving mechanism was equipped with an alternating current electric motor 8, a worm gearbox 10 and a chain gear 9. The screw shaft was connected to the output shaft of the gearbox through a muft. The design of the driving mechanism allowed to adjust the screw rotation frequency by means of a set of sprockets of various diameters, allowing to control the speed step by step in the range of 15 ... 25 min⁻¹. The press was turned on and turned off with button 11. The power of the press driving mechanism electric motor was 3 kW.

Measurements of the operating parameters of the pressing process were carried out with accepted instruments. The system of sensors - pressure transducers of the KRT-ST-25-0.5 brand was installed to measure prematrix chamber pressure. These sensors made it possible to provide pressure control in the prematrix area of the unit up to 25 MPa and provided pressure readability of ± 1 kPa. The temperature field of the mass processed along the length of the press was measured with a two-channel meter, which included a secondary device of the OVEN TPM 200 brand with thermocouples. The temperature measurement accuracy was about 1°C. Pressure sensors were connected directly to the PC.

The press working element was the screw, shown in figure 2 with a length of 0.33 m and a diameter of 0.075 m. The screw thread had a constant pitch of 0.02 m, the turns had a constant thickness of 0.008 m, the depth of the pitch of the thread was also constant. The grain chamber was attached to the housing from the end.

A device for the annular gap width regulating, which could vary between (0.5 ... 8·10⁻³) m, was used to study the degree of influence of the channel living area for the cake molding on the pressure indicator in the chamber.

Previously, the safflower seeds were cleaned of impurities and weighed. Heating of the press housing 3 and the grain chamber with the screw 15 was carried out before pressing. Then the sawdust weighing 0.3 kg, with the moisture content of 12 - 18%, was charged into the press hopper. The electric motor was turned on, and the rotational speed of the working screw was equal to 25 min⁻¹, all the chamber outlet holes being closed. After the temperature in the chamber and housing approached 328 ... 33 K, safflower seeds weighing 5 kg were loaded into the press funnel. The seeds moisture content, the rotational speed of the working screw, the length of the grain chamber and the area of the cake output hole were changed during the study. A set of chain drive sprockets with specific diameters was used to change the screw speed. The yield of oil and cake was controlled by changing the cross-sectional area of the hole with devices 7 and 14. The grain chamber length was varied by changing the depth of its screwing into the press.

After emptying the loading hopper to push the remaining product out, the sawdust in the amount of 0.1 kg was put in the hopper again and the process was repeated. The pressure values in the grain chamber and the temperature of the grain mass were recorded in each subsequent experiment. The measurement of the volume and mass of the oil obtained and the oil yield in relation to the weight of the loaded seeds was carried out after pressing of the measured portion of safflower seeds.

The first series of experiments was carried out without applying ultrasound. This was necessary to identify the range in which safflower seeds oil was extracted to the fullest extent possible. In the second series of experiments, an ultrasonic generator with an amplifier was turned on. The influence of the amplitude and frequency of the ultrasonic field on the safflower seeds oil yield and the residual oil content of the removed cake was investigated.

The experimental data obtained made it possible to evaluate the processes that take place when pressing the safflower seeds initial mixture with a single screw press.

3. Results and their discussion.
Preliminary studies of safflower seeds pressing with the moisture content of 4.2 ... 16.3% in terms of absolutely dry matter showed the following. The moisture content of the initial seeds has a great effect on the oil yield. With the moisture content increase, the oil yield increases as well, and the residual oil content of the cake decreases to a certain interval corresponding to 8.7 ... 11.2%, after which it increases nonlinearly. This is
explained as follows. At a seed moisture content of less than 8.7%, the cellular structure of the membrane destroyed by the screw adsorbs a certain amount of oil and does not allow it to be separated at appropriate pressures in the grain chamber. When the seed moisture content is more than 11.5%, a sufficiently moistened pulp gets plastic properties and comes back and rotates together with the shaft to a greater extent, due to the gap between the screw shaft and the inner surface of the grain cylinder [6, 7].

It was found out that with an increase in the rotational speed of the press screw, the oil yield decreases and, consequently, the cake oil content increases. This is explained by the fact that oil extracting from seeds, as a dynamic process, occurs in time and the more time the cake is pressed, the longer the oil will drain and, consequently, the residual oil content will decrease [8].

The gap width of the annular hole for the cake output has a significant impact on the oil yield as well. With an increase in the gap width of the outlet annular hole over $2.5 \cdot 10^{-3}$ m, the oil yield decreases significantly, and the cake amount increases, which correlates with the physical picture of the process. Therefore, it was this value of the gap width for the cake exit that was chosen by us in further experiments. The change in pressure $P$, MPa along the press chamber length $L$, m is shown in figure 3.

![Figure 3](image)

**Figure 3.** The change in pressure $P$, MPa along the press chamber length $L$, m with the safflower seeds moisture content of 9% and the gap width of the output annular hole:

1 – $1.5 \cdot 10^{-3}$ m; 2 – $1.5 \cdot 10^{-3}$ m

At first the pressure increases smoothly and then sharply in the grain chamber, as can be seen from the graphs. This is due to the fact that when the gap for oil outlet is reduced, the outlet pressure value increases sharply, while the pressure does not increase significantly at the final turn, since the cake is a rather plastic product, and the pressure gradient is very large in it. The distribution of pressure is also hindered by the screw last turn. It follows from the graphs that the oil outlet is the most difficult in the grain chamber due to the increase in pressure, and clogging of the product pores occurs as a result. It is in the grain chamber that it is necessary to install an ultrasonic emitter to create vibration in the layer and to form channels for additional oil output.

Figures 4...7 show graphs of changes in the frequency response of the kHz frequency and ultrasound impact amplitude. After analyzing the dependence, one can distinguish the characteristic inflection points at which the minimum values are minimal at various amplitude values and ultrasound impact frequency.

It was found out that an increase in pressure is the result of a decrease in viscosity within the surface layer of the system.
A decrease in the coefficient of external friction against the chamber wall concerning the vibrating product layer contributes to an increase in the degree of permeability and equal density of safflower cake. The observed decrease in oil content is explained by higher indices of vibration parameters than the resonance mass range of the pressed material, which leads to the destruction of the boundary layer [9, 10].

**Figure 4.** The influence of the emitter vibration frequency on the cake oil content M, % with the amplitude of ultrasonic vibrations $A_h = 40 \cdot 10^{-3}$ m and the press screw rotational speed $n$, min$^{-1}$:

1 – 15; 2 – 20; 3 – 25

**Figure 5.** The influence of the emitter vibration frequency on the cake oil content M, % at the press screw rotational speed $n = 20$ min$^{-1}$ and the ultrasonic vibrations amplitude $A_h \cdot 10^{-3}$ m:

1 – 30; 2 – 40; 3 – 50

**Figure 6.** The influence of the emitter vibration amplitude on the cake oil content at a rotational speed of the press screw $n = 20$ min$^{-1}$ and the frequency of ultrasonic vibrations $f$, kHz:

1 – 15; 2 – 25; 3 – 40

**Figure 7.** The influence of the emitter vibration amplitude on the finished product oil content on the screw speed $n$, min at the frequency of ultrasonic vibrations $f = 40$ kHz:

1 – 15; 2 – 20; 3 – 25
4. Conclusions
An analysis of the experimental data made it possible to find out the following. The greatest influence on the oil yield and residual cake oil content is made by the initial safflower seeds moisture content, the rotational speed of the press screw, the frequency and amplitude of ultrasonic vibrations passed to the cake removal zone. The observed loss of the adhesive relationship of the polydisperse system (safflower cake) with the vibrating surface exists for a certain range of vibrations, which is localized in a small surface layer. Due to the available energy concentration in the boundary layer, its transition to a highly elastic state can be observed. The product layer examined acquires adhesion-friction characteristics that differ from the mixture total mass. The decrease in near-wall movement is explained by the migration of the binder component - vegetable oil - into the outer layers.

The characteristic features of the process of safflower seeds pressing, providing the maximum oil yield and allowing to evaluate the physical picture of the process under study are identified. It should also be noted that carrying out the process of press production of safflower oil with the identified rational parameters is most effective and expedient.

The most effective values of the safflower seeds pressing parameters providing the minimum oil content in the removed cake are: the frequency of ultrasonic waves in the range of 22 ... 28 kHz, the amplitudes of more than 40 • 10^{-3} m and the pressure in the press of 12 ... 13 MPa. These values obviously depend directly on the behavior of safflower grain and its movement in the press when oil extracting under the influence of high-frequency ultrasonic vibrations.

References
[1] Aydeniz B, Gunester O and Yilmaz E 2014 Physico-chemical, Sensory and Aromatic Properties of Cold Press Produced Safflower Oil. Journal of American Oil Chemist Society. 91 99-110
[2] Galavi M, Ramroudi M and Tavassoli A 2012 Effect of micronutrients foliar application on yield and seed oil content of safflower (Carthamus tinctorius). Afr. J. Agric. Res. 7 482-486
[3] Rozina E Y 2002 Effect of Pulsed Ultrasonic Field on the Filling of a Capillary with a Liquid. Colloid Journal. 64 359–363
[4] Dridi W, Henry D and Ben Hadid H 2010 Stability of Buoyant Convection in a Layer Submitted to Acoustic Streaming. Phys. Rev. 81 056309
[5] Moudjed B, Botton V, Henry D, Ben Hadid H and Garandet J P 2014 Scaling and Dimensional Analysis of Acoustic Streaming Jet. Phys. Fluids. 26 093602
[6] Dentry M B, Yeo L Y, Friend J R 2014 Frequency Effects on the Scale and Behavior of Acoustic Streaming. Phys. Rev. 89 013203
[7] Brand A E, Vershinina S V, Vengerov A A and Mostovaya N A 2015 Applying the technology of hydrodynamic cavitation treatment of high-viscosity oils to increase the efficiency of transportation IOP Conf. Ser.: Mater. Sci. Eng. 93 012005
[8] Vengerov A A and Brand A E 2014 Oil cavitation treatment to prevent formation of paraffin deposits J. Natur. and intellect. resource. of Siberia. 15 36-37
[9] Hossein hamidi, Mohammadian E, Junin R and Rafati R 2014 The Effect of Ultrasonic Waves on Oil Viscosity. Petroleum Science and Technology 32(19) 2387–2395
[10] Mohammadian E, Rahmani O, Junin R and Idris F K 2012 Effects of sonication radiation on oil recovery by ultrasonic waves stimulated water-flooding. Ultrasonics 53(2)