RHEOLOGY OF THE PULP OF CASTOR-OIL SEEDS AND ITS EFFECT ON THE PROCESS OF PRESSING

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Structural and mechanical properties of pulp are represented as a two-phase system, in which phase relation through time varies in the process of deformation. The pulp consists of gel and oil parts. The gel phase is a coarse-dispersed gel powder, which is complex in chemical composition and has hydrophilic properties. The liquid phase is oil with solutes dissolved in it, located on the widely developed inner and outer surface of the particles.

The movement of the raw materials along the channels of the screw is considered assuming that the screw channel is deployed on the flatness, and its upper wall moves at a constant speed determined by the screw's rotation speed, and the rest of the walls are considered to be stationary[2]. The vertical dimension of the channel is determined by the depth of the auger's cutting, and its length coincides with the length of the helix forming. The upper wall of the channel is permeable to oil. The density of the cell, forming a porous structure and oils, is assumed to be the same[1]. It is believed that due to communication with the atmosphere, the pressure gradient is directed along the vertical axis and has a constant value.

Castor oil is obtained from castor seeds by pressing, and has a number of valuable properties. The most important of them are non-drying, high viscosity and low pour point. According to viscosity, castor oil is 18 times higher than sunflower oil. Unlike other vegetable oils, castor oil is completely dissolved in alcohol [4].

The main regularities of the process of fore-pressing the seeds of sunflower, redhead, mustard and corn germs were studied, and rational parameters of the process of their processing were chosen, namely, screw speed, the size of the annular gap, and the gap between the curb plates on a single-screw oil press. A mathematical model of extraction of oil from vegetable raw materials using a two-zone screw auger press, allowing to calculate the values of the average longitudinal velocity, depending on the inlet pressure in the filtration zone at different screw speeds, as well as the effect of pressure in the curb chamber on the oil expression was developed [6]. Thus, neither in Ukraine, nor in Russia, except for our work, on processing castor oil seeds for castor oil and high-protein feed was not found. In describing the process of expression of vegetable oil out of pulp in screw presses, the use of reversed motion has become widespread.

Certain difficulties in the processing of castor occur on the operation of primary oil yield and cleaning. It is known that the main reserve proteins of castor oil seeds - globulins - are represented in the cell by aleurone grains densely surrounded by particles of the eleoplasm.

The high saturation of the seed cell with oil having an increased viscosity, as well as the uniqueness of the properties of the aleurone grains of castor oil [7], apparently, are the reasons that when opening the cellular structures in the process of grinding, frying and pressing into the oil phase, together with the eleoplasma, a large number of aloe-reed grains are entrained. At the same time, press oil sludge, according to Goldov's data, consisting mainly of aleuron grains, as well as of scraps of cellular structures and the fruit shell, reaches 12-15% by weight.

This work objective was to obtain experimentally the equations of the state of the medium of the pulp mill pulp that connect components of the stress and deformation at various exposures while simultaneously studying the filtration process through oil recovery coefficient at different compression ratios and the directions of the liquid phase movement, allowing to close the initial systems of equations of mathematical models of pressing and filtration processes, check their adequacy, and also set the parameters of the consolidation process.

To achieve this goal, it was necessary to carry out the following program of experimental studies:

– to obtain the equation of state of the medium of the pulp, which connects stress and deformation components at different exposures;

– to establish the dependence of the porosity coefficients of the pulp on the stress at different exposures;

– to determine the dependence of the oil recovery coefficient on the degree of compression of the pulp;

– to reduce the amount of substances that determine the sludge by mass during the primary oil recovery by selecting appropriate modes of frying regimes and fore-pressing.

Experimental definition of the law of compression of pulp of castor seeds

The degree of compression of the pulp ε was determined as the ratio of the initial height of the pulp in the curb to the final one at a given specific pressure:

$$\varepsilon = \frac{h_н}{h_к}. \qquad (1)$$

When the body is compressed in a closed space by a force normally directed to the surface of the compressible body, radial pressure will also be developed

$$P_r = \xi p_н, \qquad (2)$$

where $p_н$ - normal pressure, MPa;

ξ - coefficient of lateral pressure:

$$\xi = \frac{\mu}{1 - \mu}, \qquad (3)$$

where: μ - Poisson's ratio; for powder materials

$\mu = 0,28 \div 0,32.$

For the pulp, the average Poisson's ratio was equal to 0.3; then the lateral pressure coefficient

$$\xi = \frac{0,3}{1 - 0,3} = 0,428. \qquad (4)$$

The frequency of rotation of the auger shaft of the press, and hence the compression time (exposure) of the pulp in each screw and the filtration of the oil through the pulp layer is modeled by the time of the piston holding the laboratory plant. To simulate the holding time in laboratory studies, we take the range of rotation speed of the screw auger from 12 to 24 rpm^{-1}, in increments of 3 rpm^{-1}. The holding time for each compression stage is determined from expression

$$t = 60 / \mathrm{n} \qquad (5)$$

where 60 – the number of seconds in a minute, n - rotational speed of auger shaft rpm^{-1}; t - time of piston holding at each compression stage in seconds. The range of the screw speeds and the corresponding holding time are given in Table 1.

Table 1 - Screw speed range (rpm^{-1}) and the corresponding holding time (*t*)

Shaft rotation frequency, rpm^{-1}	12	15	18	21	24
Holding time at each stage, s	5	4	3,3	2,8	2,5

Two pressure systems in the pressable mass

In the pressable mass, there are two pressure systems: neutral and effective, and their sum is the total hydrostatic pressure. The neutral pressure is determined by the head of the filtered oil, the effective pressure is perceived by the skeleton of the pulp.

$$\left.\begin{aligned} \sigma_{\Sigma r} &= \sigma_r + p, \\ \sigma_{\Sigma z} &= \sigma_z + p, \end{aligned}\right\} \qquad (6)$$

where σ_r, σ_z p - pressures in the "skeleton" of the pulp and pore pressure in the oil.

In the process of compression, each of the constituents of the pressures can vary in magnitude. In the consolidation theory, unlike the mechanics of continuous media, the filtration process is considered under conditions of a continuous decrease in the porosity of the material. However, the process of pressing vegetable oils in a screw press is accompanied by a mutual movement of the skeleton of pulp and oil, and a continuous decrease in the porosity of the pulp. Here, by p we mean the hydrodynamic pressure of the oil moving in an unevenly deformed porous medium, which is observed in oil-extracting presses. For example, in screw presses the speed of oil movement in the radial and axial directions is different, therefore, in these directions the hydrodynamic pressures are also different.

In this work, the total hydrostatic pressure is determined. The development of the theory of the distribution for any time of the pressure in a pore fluid is the main task of the theory of consolidation. The oil filtration rate is determined by Darcy's law.

For the selection of the optimum compression law, experiments were carried out with the compression holding time in each screw of the press according to Table 1. During the experiments, voltages are measured and oil is taken at each compression stage. According to the selected oil samples, for each screw of the fore-pressing, the coefficients of oil recovery $k_{м}$ are determined by the following expression:

$$k_{м} = \frac{G_{пр}}{G_{м}} \qquad (7)$$

where $G_{пр}$ - amount of pressed oil;

$G_{м}$ - amount of oil in the original pulp.

By the smoothness of the oil filtration curve, it is concluded that the compression ratio of each auger is correct. On the total output of oil the best option is chosen for the holding time of each compression stage.

Oil recovery factors are determined at a compression ratio modeling the work of each press coil, and the holding time modeling the rotation speed of the screw shaft. With each compression stage, we take out the pressed oil, determine its weight and volume in cm^3. By the volume of the filtered oil, the holding time for each compression stage and the filtration area, we determine the rate of oil filtration

$$u = \frac{V_{м}}{\omega t} \qquad (8)$$

where $V_{м}$ - the volume of weight of oil, cm^3;

t - the holding time for each compression stage (s), is determined by formula;

$\omega = \pi D h$ - the area of oil filtration through the pulp in the curb chamber, cm^2;

D - internal diameter of the curb, cm;

h - height of the compressed pulp (cm) in the curb cylinder at the measured compression stage;

u - the filtration rate ($cm \cdot s^{-1}$) at the measured compression stage.

According to Darcy's law, the rate of oil filtration through a layer of pulp along the radius of the cylinder can be expressed by the formula

$$u = -k \frac{p_1 - p_2}{\rho r}; \tag{9}$$

Hence the filtration coefficient is

$$k = -\frac{u \rho r}{p_1 - p_2}, \tag{10}$$

where ρ - density of pore fluid (oil);

p_1 - hydrodynamic pressure in the vapor liquid along the axis of the curb cylinder;

p_2 - the hydrodynamic pressure in the vapor liquid at the exit from the curb cylinder. We take pressure $p_2 = 0$.

Assuming $p_1 - p_2 = 1$, we find that $u = -k$. These data indicate that the filtration coefficient is numerically equal to the value of the filtration rate with a pressure gradient equal to unity. The coefficient of filtration depends on the nature of the filtering liquid

$$k = k_0 \frac{g}{\nu}, \tag{11}$$

where ν - kinematic coefficient of the fluid viscosity;

g - acceleration of gravity;

k_0 - the permeability of the material (pulp), is characterized only by its geometric properties, regardless of the nature of the filtering fluid.

Based on the data obtained, graphs of the dependence of the oil recovery coefficients on the compression ratio at different holding times are plotted.

In preparation for carrying out the experimental studies, the sensors were calibrated according to the existing method. Based on the data obtained, a diagram of the dependence of deformation of the tenso-beam on the load was constructed.

The process of pressing oil from the pulp as a two-phase system is associated with both creeping phenomena of the "skeleton" of the pulp, and with the phenomena of filtration extrusion of oil.

During the experiments, joint measurements of the parameters of both processes were carried out. Prepared according to the planned mode of moisturethermal treatment, the pulp is placed in a preheated to 80-85 °C curb chamber 1 (see Fig. 1), installed in a laboratory press (see Fig. 4). Laboratory press is installed on the bed of the industrial press. With the help of the press (Fig.1), a volume compression of the is carried out pulp through piston 4 of the curb chamber 1 according to the previously established compression modes. During the experiments the laboratory press is installed on the working table of the industrial press. The oil to be separated is filtered through the layers of the pulp and the curbs of chamber 1.

Statistical processing of the experimental data was carried out according to generally accepted methods (Volf V.G., 1966), (Vasilenko P.M. 1958).

Figure 1 Dependence of the specific pressure in the pulp of castor seeds on its compression ratio

Figure 1 shows the dependence of the specific pressure in the pulp of castor seeds on its compression ratio at the temperature of the pulp, fed to the press 115 °C and humidity 5.0%. The dependence obtained is described by an exponential equation with a correlation ratio $\eta_{y/x} = 0{,}994^{-1}$

$$p = a \cdot \exp(b\varepsilon_v), \tag{12}$$

where $p -$ specific pressure in the pulp in kg·m^2; $\varepsilon_v -$ volume compression ratio of the pulp; $a = 8{,}30E-02;\ b = 1{,}232 -$ experimental coefficients

The obtained values of the coefficients of equation (12) in relation to the moisture content of the pulp are shown in Table 2

Table 2 - The coefficients of logarithmic functions of porosity coefficients

Coefficients	Obtained dependencies	Coefficients correlations
a	$0{,}0564w - 0{,}592$	0,9855
b	$-0{,}4457w + 4{,}5156$	0,9912

In the dependences obtained, the moisture range varied from 2% to 7.5%.

The dependence of the porosity coefficient of pulp of castor seeds on the specific pressure is presented in Table 3

Table 3 - dependence of the porosity coefficient of the pulp of castor seeds on the specific pressure

p	4,67	10,67	28,62	43,33	58	82,67	96,65	111,33	123,6	140
ε_v	0,4	0,354	0,246	0,185	0,138	0,092	0,061	0,046	0,023	0,015

Figure 2 shows the dependence of castor oil recovery coefficient

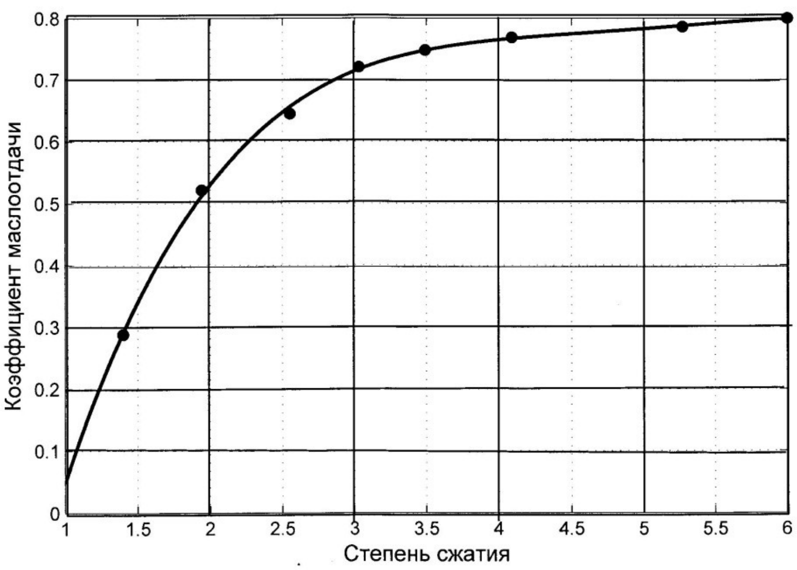

Fig. 2 Dependence of the coefficient of oil recovery on the degree of compression of the pulp of castor seeds and on compression ratio of the pulp. The dependence obtained is expressed by a polynomial of the fourth degree

$$k_м = -0.0028\varepsilon_v^4 + 0.0563\varepsilon_v^3 - 0.4168\varepsilon_v^2 + 1.3819\varepsilon_v - 0.9702 \qquad (13)$$

where $k_м$ - oil recovery coefficient equal to the ratio of the amount of pressed oil to the amount of oil present in the initial pulp.

Conclusions.

1. The obtained equations of the state of medium of the pulp of castor-oil seeds, which relate the stresses from 4.67 to 140 kg·cm^2 and the compression ratio from 1 to 6 with the simultaneous description of the filtration process through the coefficient of oil

recovery when it increases to 0.8 and higher allow to close the original systems of differential equations of mathematical models of the processes of pressing and filtration.

2. The following frying and pressing modes have been experimentally established during the processing of untreated castor seeds in primary oil recovery operations: the moistening of the castor seed meat in the first zft up to 14%, the moisture of the pulp entering the fore-press 5%, the temperature of the pulp entering the press 115 °C, the degree of compression of the pulp up to 6, the developed specific pressure up to 130 kg·cm^{-2}. This makes it possible to obtain oil recovery coefficient of 0.9; oil content of fore-press cake 12%, press oil moisture up to 0.25%, reduction of sludge in oil in weight from 12-15% to 5%. The quality of the castor oil produced is in accordance with the requirements of GOST 6757-73.

3. In future, it is advisable to optimize technological processes of wet-heat treatment and filtration consolidation of the pulp of castor seeds and introduce the results obtained when creating small-scale enterprises for the production of castor oil and high-protein feeds.

REFERENCES

1. Anfilov, S. – Skulskii, O. 2014. Modeling of filtration through plastically deformed medium in the process of extrusion. Vestnik Permskogo natsionalnogo issledovatelskogo politekhnicheskogo universiteta, Issue 2, p. 29-47
2. Vasilenko, V. – Kopylov, M. – Dragan, I. – Frolova,L. 2013. Mathematical model of the movement of raw materials in the screw channel of the oil press. Vestnik Voronezhskogo gosudarstvennogo universiteta inzhenernykh tekhnologii, Issue 3 (seriia processy i apparaty pischevykh proizvodstv), p. 18-22
3. Vasilenko, P. 1958. Elements of the method of mathematical processing of the results of experimental studies. – M.:Kolos, 59 p.
4. Viter, V. 2013. Castor-oil plant, castor oil, ricin. Chemistry and Chemists, Issue 6, p. 15-20

5. .Goldovskii, A. 1939. Chemistry of oilseeds and products of their processing. – M.: Pishchepromizdat, 150 p.

6. Didur, V. – Tkachenko, V. – Tkachenko, A. – Didur, V. – Vereshchaga, A. 2017. Structural and mechanical properties of the pulp of oil seeds. Visnyk Ukrainskogo viddilennia Mizhnarodnoi akademii ahrarnoi osvity, Issue 5, p. 7-25

7. Dragan, I. 2015. Scientific support of the process of fore-pressing of oil crops and processing of compositions of vegetable oils of functional purpose. Specialty 05.18.12 - "Processes and apparatuses of food production". The thesis abstract on competition of a scientific degree of a Cand.Tech.Sci. Voronezh, 20 p.

8. Sobolev, A. – Butenko, R. – Suvorov, V. 1971. Tissue culture of endosperm as a model for studying the biosynthesis of reserve proteins and phytin. – M.: Physiology of plants, Vol.18, Issue 2, p.281-288.