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CONSOLIDATION COEFFICIENTS IDENTIFICATION OF SOLID-LIQUID EXPRESSION FROM CONSOLIDATED MEDIUM OF MICRO-POROUS PARTICLES

The identification problems of the model kinetic parameters of solid-liquid expression from liquid containing plant materials of micro-porous particles using residual functional, taking into account the total liquid flow changes on the measurement surface is formulated is presented in one-dimensional formulation. Computational identification of consolidation coefficients in extraparticle and intraparticle space versus time for different layer sections has been conducted,.

Keywords: mathematical modeling, identefication, kinetic parameters, micro porous particles

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ІДЕНТИФІКАЦІЯ КОЕФІЦІЄНТІВ КОНСОЛІДАЦІЇ ПРОЦЕСУ ВІДТИСКУ "ТВЕРДЕ ТІЛО - РІДИНА" ДЛЯ КОНСОЛІДОВАНИХ СЕРЕДОВИЩ ЧАСТИНОК МІКРОПОРИСТОЇ СТРУКТУРИ

Сформульовано задачі ідентифікації кінетичних параметрів процесу відтиску "тверде тіло – рідина" для рослинних матеріалів мікропористих частинок з використанням залишкового функціоналу з урахуванням загальної зміни потоку рідини на поверхню дослідження. Проведено комп'ютерне моделювання та ідентифікацію значень коефіцієнтів консолідації в міжчастинковому та внутрішньочастинковому просторах для різних моментів процесу відтиску та шарів середовища.

Ключові слова: математичне моделювання, ідентифікація, кінетичні параметри, мікропористі частинки

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ИДЕНТИФИКАЦИЯ КОЭФФИЦИЕНТОВ КОНСОЛИДАЦИИ ПРОЦЕССА ОТТИСКА "ТВЕРДОЕ ТЕЛО - ЖИДКОСТЬ" ДЛЯ КОНСОЛИДИРОВАННЫХ СРЕД ЧАСТИЦ МИКРОПОРИСТОЙ СТРУКТУРЫ

Сформулированы задачи идентификации кинетических параметров процесса оттиска "твердое тело - жидкость" для растительных материалов микропористых частиц с использованием остаточного функционала с учетом общего изменения потока жидкости на поверхность исследования. Проведено компьютерное моделирование и идентификация значений коэффициентов консолидации в межчастичном и внутричастичном пространствах для различных моментов процесса оттиска и слоев среды.

Ключевые слова: математическое моделирование, идентификация, кинетические параметры, микропористые частицы

Analysis of Recent Researches and Publications

Solid-liquid expression of biological materials is an important unit operation in the food, chemical,energy and related industries, which is used for the extraction of vegetable oils, dehydration of fibrous materials, dewatering of waste water sludge and so forth [1]. During expression, the porous layer formed by a whole grain or fragmentized material is subjected to compression in industrial presses . Such compression can be carried out under constant or variable parameters (pressure, deformation rate). Raw biological materials contain liquid filled cells, hydrated cell walls, micro-channels between cells and intercellular spaces containing air, i.e. are a porous media with different types of pores and channels [1, 2].

The kinetic mechanisms of solid-liquid expression from a celular materials and the cell breaking phenomena in a fresh tissue depend on many factors: the applied pressure, rate of deformation, the structural tissue characteristics (cell size and shape, thickness of the cell wall, osmotic pressure inside a cell, etc.). Liquid flow from the plant tissue depends on kinetics of cells destruction and can be very long [1,3].

However, when an external pressure is applied to micro porous particles layer, the latter consisting of a "soft" tissue, begin to shrink and a decrease in intraparticle space of channels and intraparticle spaces, affecting the layer permeability. In [4] to evaluate the consolidation and creep component layer model is proposed, based on the assumption that the intensity of the flow of particles in extraparticle space proportional to the difference of pressures: pressure inside particle averaged coordinate size and pressure from the outside of the particle, which is very approximate. A more realistic model has a solid and a liquid phase in bi-porous layer of microporous particles and transport channels, taking into account the effect of changes in the permeability of the particle layer on the overall permeability [5, 6].

Problem Statement

We consider the sliced cellular particles containing liquid as a porous layer subjected to unidimensional pressing [5, 6]. The liquid flows occurs inside the particles of intraparticle space, outside the particles of extraparticle space and between these two spaces. The sliced particles are rectangular parallelepipeds separated by the porous network. The layer of sliced particles is considered as a double-porosity medium. The extraparticles network forms the first porosity with low storage capacity and high hydraulic permeability. The sliced liquid containing particles form a second porosity with high storage capacity and low hydraulic permeability. Flow occurs separately through the two porosities and between them.

The Purpose of the Study

In this paper the direct and inverse identification problems of the consolodation confficients in intrapsrticles space and extraparticle space of solid-liquid expression from soft plant microporous particles materials using residual functional, taking into account the total liquid flow changes on the measurement surface is formulated. Efective methods of identification problems implementation based on the analytical solutions of the direct and conjugate problems is proposed. Explicit analytical expressions of residual functional gradients for the model parameters identification by Heaviside operational method, transformation integral and gradient methods are obtained. Computational identification of consolidation coefficients in extraparticle and intraparticle space versus time for different layer sections was done for real plant material with two different compressibility-permeability characteristics corresponding to different degrees of tissue destroying.

Description of Main Material of Research

Direct problem. In the domains $\Omega_T = (0,T)\times(0,h_m)$ and $\Omega_T \times (0,R_m)$ the distribution of pressures in the liquid phase $P_1(t,z_m)$ and $P_2(t,x_m,z_m)$ and thus satisfy the system of consolidation of partial differential equations [5]:

$$\frac{\partial P_1(t,z_m)}{\partial t} = b_1 \frac{\partial^2 P_1}{\partial z_m{}^2} - \beta \frac{\partial \bar{P}_2(t,z_m)}{\partial t}, \ z_m \in (0,h_m), \tag{1}$$

$$\frac{\partial P_2(t,x_m,z_m)}{\partial t} = b_2 \frac{\partial^2 P_2}{\partial x_m{}^2}, \ x_m \in (0,R_m), \ z_m \in (0,h_m), \ t \in (0,T), \tag{2}$$

Initial conditions:

$$P_1(t,z_m)\big|_{t=0} = P_{1_0} \equiv P_e, \qquad P_2(t,z_m)\big|_{t=0} = P_{2_0} \equiv P_e \tag{3}$$

Boundary conditions:

$$P_1(t,z_m)\big|_{z_m=0} = 0, \qquad \frac{\partial P_1}{\partial z}\bigg|_{z_m=h_m} = 0; \qquad \frac{\partial P_2}{\partial x_m}\bigg|_{x_m=0} = 0; \ P_2(t,x_m,z_m)\big|_{x_m=R} = P_1(t,z_m) \tag{4}$$

where $\bar{P}_2$ is average liquid in intraparticle space, $b_1 = G_1/\mu r_1$ is the consolidation coefficient of the extraparticles space, $b_2 = G_2/\mu r_2$ is the consolidation of cellular particles, r_1 is the specific resistance of the extraparticles space based on the volume of LCP, and r_2 is the specific resistance of the intraparticle space (cellular particles) based on the volume of IS, β is the elasticity factor of the material, h_m is the thickness of IS layer, h_m , R_m is the thickness of the half of particle containing IS, R_m, $X = x_m / R_m$ and $Z = z_m / h_m$ are dimensionless geometrical coordinates.

$$\bar{P}_2 = \frac{1}{R_m}\int_0^{R_m} P_2(t,x_m,z_m)dx_m \tag{5}$$

In the equations (1) and (4) it is assumed that b_1, b_2 and β are the constants. Variables k_1, k_2 can markedly decrease during pressing and r_1, r_2 can markedly increase. But, if G_1 and G_2 also increase in similar fashion, b_1 and b_2 will remain constant.

It assume that the measurement surface $z_m = \gamma \equiv 0$, $\gamma \subset \Omega = [0,h_m]$, the liquid flow is known:

$$u(t,z_m)\bigg|_{z_m=\gamma} \equiv -\left(\frac{1}{\mu r_1}\frac{\partial}{\partial z_m}P_1(t,z_m;b_1,b_2,\beta) + \frac{1}{\mu r_2}\frac{\partial}{\partial z_m}\bar{P}_2(t,z_m;b_1,b_2,\beta)\right)_{z_m=\gamma} = M_{\exp er}(t)\big|_{z=\gamma} \tag{6}$$

Choosing the Residual Functional. We will write the residual functional that minimizes the deviation of the model solution from values of experimental trace, which is used for the implementation of procedures to identify the unknown consilidation coefficients in extraparticle space and intraparticle spaces and ellastichnogo factor) as [7]:

$$J(b_1,b_2,\beta)=\frac{1}{2}\int_0^T\left[E_{error}(b_1,b_2,\beta,t,\gamma)\right]^2 dt\,, \qquad (7)$$

where $E_{error}(b_1,b_2,\beta,t,\gamma)$ – residual expression between the model and the experimental values of the unknown parameters:

$$E_{error}(b_1,b_2,\beta,t,\gamma)=\left[-\left(\frac{1}{\mu r_1}\frac{\partial}{\partial z_m}P_1(t,z_m;b_1,b_2,\beta)+\frac{1}{\mu r_2}\frac{\partial}{\partial z_m}\bar{P}_2(t,z_m;b_1,b_2,\beta)\right)-M_{\exp er}(t)\right]_{z_m=\gamma} \qquad (8)$$

where $M_{\exp er}(t)$ – the vector of experimental data (values of liquid flow) on the measurement surface $\gamma\in\Omega$.

As a result, we get the identification problem (1)–(6): to find the unknown functions $b_1\in\Omega_T$, $b_2\in\Omega_T$, $\beta\in\Omega_T$, $\Omega_T=D_1\ (b_1>0, b_2>0, \beta>0)$, were functions $P_1(t,z_m)+\bar{P}_2(t,z_m)$ satisfy the conditions (6) on the measurement surface $\gamma\subset\Omega$ in the domain Ω_T (Sergienko, Deineka 2005, Sergienko, Petryk et al. 2015).

Gradient method of solution. The solution of identification problem (1)-(4) reduces to the optimization of residual functional (7) by gradually improving the solution by means of a special regularization procedure with the of high-performance gradients methods. Following [7,8] and using the gradient method of error for the identification of consolidation coefficients in extraparticle space b_1 and intra particle space b_2 elasticity coefficient β, we obtain the regularization expressions for the ($n+1$)-th identification step:

$$b_1^{n+1}(t)=b_1^n(t)-\nabla J_{b_1}^n(t)\frac{E_{error}(b_1^n,b_2^n,\beta;t,\gamma)^2}{\left\|\nabla J_{b_1}^n(t)\right\|^2+\left\|\nabla J_{b_2}^n(t)\right\|^2+\left\|\nabla J_{\beta}^n(t)\right\|^2},\quad t\in(0,T),$$

$$b_2^{n+1}(t)=b_2^n(t)-\nabla J_{b_2}^n(t)\frac{E_{error}(b_1^n,b_2^n,\beta;t,\gamma)^2}{\left\|\nabla J_{b_1}^n(t)\right\|^2+\left\|\nabla J_{b_2}^n(t)\right\|^2+\left\|\nabla J_{\beta}^n(t)\right\|^2},\quad t\in(0,T), \qquad (9)$$

$$\beta^{n+1}(t)=\beta^n(t)-\nabla J_{\beta}^n(t)\frac{E_{error}(b_1^n,b_2^n,\beta;t,\gamma)^2}{\left\|\nabla J_{b_1}^n(t)\right\|^2+\left\|\nabla J_{b_2}^n(t)\right\|^2+\left\|\nabla J_{\beta}^n(t)\right\|^2},\quad t\in(0,T),$$

where $J(b_1,b_2,\beta,\ldots)$ - the residual functional on the measurement surface $\gamma\in\Omega_T$;

$\nabla J_{b_1}^n(t)$, $\nabla J_{b_2}^n(t)$, $\nabla J_{\beta}^n(t)$ are gradient components of residual functional $J(b_1,b_2,\beta,\ldots)$ for unknown functions $b_1\in\Omega_T, b_2\in\Omega_T, \beta\in\Omega_T$;

$\left\|\nabla J_n^n(t)\right\|^2=\int_0^T\left[\nabla J_n^n(t)\right]^2 dt,\quad u\in\{b_1,b_2,,\beta,\ldots\}$ – is squared norm of gradient of the residual functional.

Conjugate problem. The calculation of increments ΔJ_s, ΔJ_{s_1}, ΔJ_{s_2} leads to solving the additional conjugate problem to determine the Lagrange factors ϕ, ψ of the functional (14):

$$\frac{\partial\varphi(t,z_m)}{\partial t}+b_1\frac{\partial^2\varphi}{\partial z_m{}^2}+\beta\frac{\partial\bar{\psi}(t,z_m)}{\partial t}=-\frac{1}{\mu r_1}\frac{\partial}{\partial z_m}E_{error}^n(t,\gamma)\delta(z_m-\gamma)\,, \qquad (10)$$

$$\frac{\partial\psi(t,x_m,z_m)}{\partial t}+b_2\frac{\partial^2\psi}{\partial x_m{}^2}=-\frac{1}{\mu r_1}\frac{\partial}{\partial z_m}E_{error}^n(t,\gamma)\delta(z_m-\gamma)\,, \qquad (11)$$

$$\varphi(t,z_m)\big|_{t=T}=0;\qquad \psi(t,x_m,z_m)\big|_{t=T}=0 \text{ (condition for } t=T\text{)}; \qquad (12)$$

$$\frac{\partial}{\partial z}\varphi(t,z_m=h_m)=0,\ \ \varphi(t,z_m=0)\,, \qquad (13)$$

$$\frac{\partial}{\partial x}\psi(t,x_m,z_m)\big|_{x_m=0}=0,\ \ \psi(t,x_m,z_m)\big|_{x_m=R}=\varphi(t,z_m)\,; \qquad (14)$$

where $E_{error}^{n}(t)$ – *n*-th approximation of the residual (to be minimized at every step of regularization,
$\bar{\psi}(t, z_m) = \frac{1}{R_m} \int_{0}^{R_m} \psi(t, x_m, z_m) dx_m$, $\delta(z)$ – function of Dirac.

Analytical solutions. The exact analytical solution of direct problem (1)-(5) (for modeling pressure distribution on the assumption that consolidation coefficients b_1, b_2 and elasticity factor are knows) is constructed with the use of the Fourier integral transformation and Heviside operation method [9] according [5, 6].

We have obtained solution ϕ, ψ of the conjugate problem (10) – (14) using Fourier integral transformation and Heaviside's operational method according [5, 9].

Numerical analysis. Results of numerical modeling and parameter identification are shown below. Figure 1 illustrates the process of convergence model curves dimensionless liquid flow distribution at the outlet of the compressed water-containing particulate layer on the measurement (observation) surface z = 0 to the observation (measurement) curve (number 8) for implementing stepwise procedure of identification consolidation coefficients in extraparticle and intraparticle spaces, and respectively. The values of the input parameters, the properties of the particles and the observation data taken from [5, 6], since this work is the development outlined in these results.

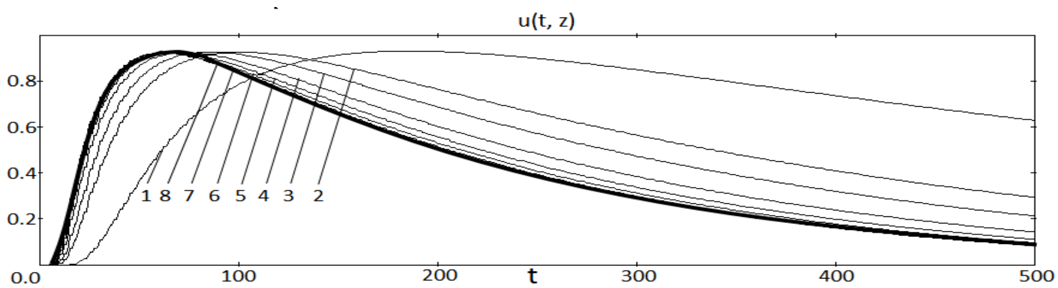
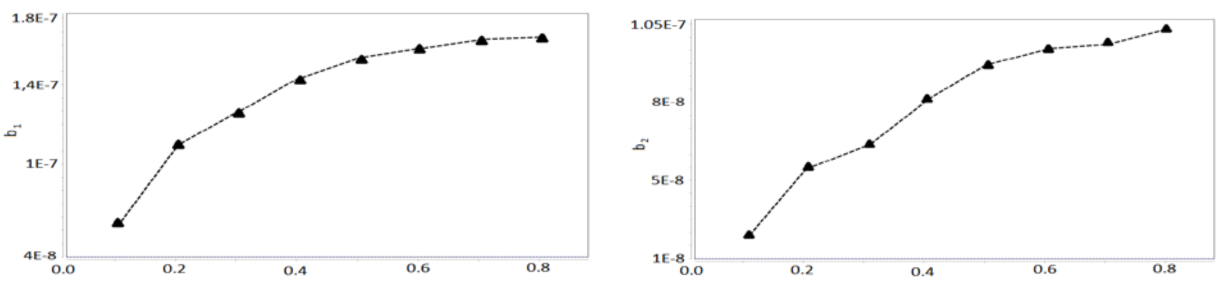


Fig. 1. Process of convergence model curves dimensionless liquid flow distribution at the outlet of the compressed water-containing particulate layer

The initial approches of consolidation coefficients in extraparticl space and intraparticle space are for better disrupted tissue: $b_1 = 6.0 \cdot 10^{-8}\,\mathrm{m}^2$ /s and $b_2 = 1.0 \cdot 10^{-8}$ m^2 /s respectively. The numbers 1–7 in curves of Fig.1 correspond to numbers of regularization block iterations for two parameters (b_1 and b_2). The total of iterations number for exterior cycle and interior cycle for each block are from 700 to 900 iterations.



a) **b)**

Fig. 2. Evolution of restored consolidation coefficients in extraparticle space and intra intraparticle space

Figure 2 (a, b) shows the corresponding evolution pictures of consolidation coefficients (averaged over the time interval of the consolidation process and displace moisture from the layer) in extraparticle space and intra intraparticle space, restored according regularization formulas (15) from the above to the total number of iterations performed. As can be seen for the last two blocks of iterations (the position 0.6 – 0.8) there is stabilization of the averaged profiles consolidation coefficients.

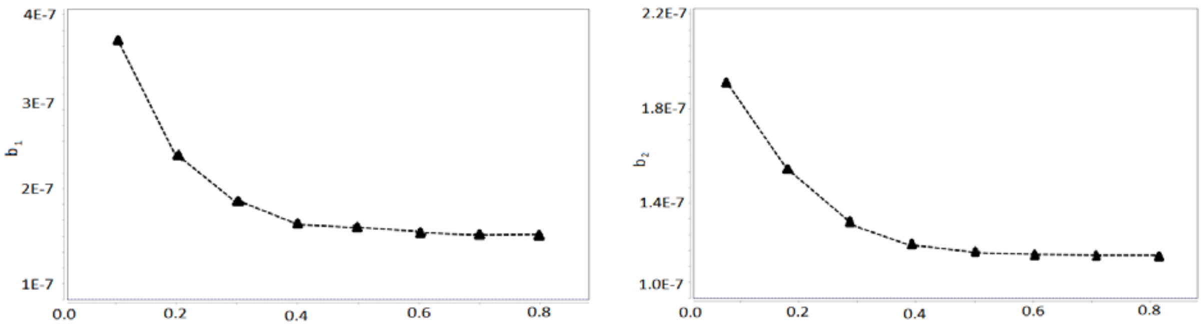


Fig. 3. Evolution of restored consolidation coefficients in extraparticle space and intra intraparticle space

Similar results were obtained in the choice of other initial approximations. In the above privacy, when setting the initial approximation are smaller values than these measurement data, we can observe a similar convergence process of model distributions of fluid flow to the measurement curve from opposite side (processes "from below"). This provided similar evolution picture of the consolidation coefficients in the macro- and micropores space, and, respectively, to the same values of $1.8\cdot10^{-7}$ m^2/c and $1.0\cdot10^{-7}$ m^2/c (Figure 3 a, b).

Conclusions

In this work the coefficients identification problems of solid-liquid expression from liquid containing plant materials of micro-porous particles using residual functional, taking into account the total liquid flow changes on the measurement surface is formulated. Highly productivity methods of identification problems implementation based on the analytical solutions of the direct and inverse problems is proposed. Numerical identification of consolidation coefficients in extraparticle and intraparticle space versus time for different layer sections was done for real plant material with two different compressibility-permeability characteristics corresponding to different degrees of tissue destroying.

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