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IDENTIFICATION OF RHEOLOGICAL DEPENDENCIES OF OIL MATERIAL PROCESSED IN A SCREW PRESS

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ABSTRACT

In the present work it has been found that the volume flow rate of structured fluid, defined for Bingham plastic through an exhaust device of a press, is rigid core flow. With that, the strain in this area does not exceed the yield point of a Bingham plastic. An equation has been obtained that generalizes the known one-dimensional Poiseuille equation, which allows to determine functional dependency of volume flow rate of a structured Bingham plastic through the discharge device of the press, which significantly increases the accuracy of identifying rheological indicators of the flow with known geometric parameters of the outlet device.

Keywords: layered steady flow; Heaviside step function; yield point; plastic viscosity.

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1. INTRODUCTION

Oil-bearing material is pressed in single-rotor screw presses [1]. When a screw with variable geometry of coils that reduce the free volume of filled oil-bearing material is rotating, pressure occurs, which transports the material, and oil is pressed through the gaps between molder straps combined into a molder cylinder that covers the screw shaft [2]. Filtering of oil through plastically deformed porous mixture and extraction of oil to the outside of the channel of the extruder through a molder chamber cause radial pressure drop in the oil [3]. The material in the channel of the rotating screw that is limited by the stationary housing will start moving steadily through the channel due to the shear strain that occurs in it — the forced (straight) stream appears. The main parameters that determine the volume flow [4] are channel depth and width, screw diameter, and frequency of rotation. The condition for return flow occurrence is the excessive pressure created by head resistance. The overall performance of the screw compressor is the sum of flow rates. Thus, performance of screw presses is determined by interaction of the supercharger and the forming head (cone) through the molder extraction area that determines the volumetric flow rate of the material entering the forming head. In the first approximation, we analyze three areas of the press. The first one is the compressor, which is the area of the feed screw [5]. The second one is the area of pressing, which may be represented by a rectangular cross-section channel that narrows with height and width [6], and is adjacent to the head, which is regarded as the third zone of the extruder, being a combination of a cylindrical and a conical channel with variable geometry [7]. The existing models of filtering fluids through non-deformable porous media [8] and the models of filtering in elastic deformable environments [9] do not allow modeling the flow of the viscous-plastic non-Newtonian fluid complicated with the processes of compressibility, diffusion and mass transfer in the existing industrial installations.

This work is aimed at determining functional dependence of the parameters of the volumetric flow mathematical model in the flow of viscous-plastic medium in pressing oil during extrusion of oil cultures in a production installation.

2. METHODS

Identification of material flow in a screw extruder is based on reverse motion that is similar to the Couette flow problem (the screw is stationary, and the body is rotating). In this case, the screw channel unfolds onto the plane, and the longitudinal section srands out, the lower border of which remains stationary, while the upper section is moving with specified speed. The height of this channel H corresponds to the cutting depth of the feed screw, and length L corresponds to the length of the generatrix of the helix. The second zone corresponds to the cubic spline approximation of the cross section of molder coils in the beginning, in the middle and in the end of the cutting depth of each of these coils. It may be represented in a simplified form as a pressing zone that is narrowing with height. This area is adjacent to the head that is regarded as the third zone of the extruder, which is a combination of a cylindrical and a conical channel with variable geometry. Taking into account the ratio of these channels' lengths of a real production press [10], this area may be represented as a flat Poiseuille flow. The extruded material that passes the molder zone is two-component viscous-plastic non-Newtonian fluid that consists of fibers that form a porous structure, and Newtonian fluid (oil) distributed within its pores [11]. Densities of the fibers and oil do not change, but when oil is pressed in the molder, this system shows compressibility associated with the filtering properties of the mixture. In this case, the cake plays the role of the porous skeleton saturated with oil. During pressing, the working area is considered completely filled with the mixture. The pressing process is considered isothermal [12]. Small speeds determine the mixture flow as laminar for describing the saturated fluid of the porous medium. Cake of the oil culture serves as the first phase, the second phase is oil [13]. Movement of the material through the first and the third zones of the press is modeled as rheological flow defined by shear rate $\boldsymbol{\tau}$, (Pa) containing two coefficients: yield point - $\boldsymbol{\tau_T}$ (Pa) and plastic viscosity – $\boldsymbol{\eta_{area}}$ (PA·sec), combined in flow equation [14] for Bingham structured fluids:

$$\tau = \tau_T + \eta_{area} \cdot \dot{\gamma} \tag{1}$$

Where $\dot{\gamma}$ is the shear rate, (Hz). Thus, in the first approximation, the flow of material in the first and the third zone of the extruder may be represented by layered flow where the velocity component of one of the coordinate lines is not equal to zero [15]. In the Cartesian coordinate system $v_x \equiv U \neq 0, v_y = 0, v_z = 0$. Therefore, from the continuity equation $U = U(y, z, t)$. In this case, from the Navier – Stokes equation it follows that $p = p(x, t)$. These ratios determine the stationary Poiseuille - Couette layered flow in the first zone, and the stationary layered Poiseuille flow in the third zone of the extruder. The material of the phases is incompressible. In this case, densities of the components remain unchanged, but the volumetric densities change during the process of pressing.

The Poiseuille layered steady flow in the third zone of the extruder is determined by equation $\frac{\partial p(x)}{\partial x} = \mu \cdot \left[\frac{\partial^2 U(y,z)}{\partial y^2} + \frac{\partial^2 U(y,z)}{\partial z^2}\right]$. The right side of the equation does not depend on variable *x*. Therefore, $\frac{\partial^2 p(x)}{\partial x^2} = 0$, from where $\frac{\partial p(x)}{\partial x} = Const$. In this case, for the steady-state flow $\tau = \frac{y \cdot \Delta p}{2 \cdot l}$, where *l* is channel length in the third zone of the extruder; Δp is the pressure difference at the boundaries of the zone. For Bingham plastic, rheological equation with regard to $\dot{\gamma} = \frac{d}{dy}U(y)$ may be converted to the one-dimensional steady-state flow defined by equation:

$$\eta_{area} \cdot \frac{d}{dy}U(y) = \frac{y \cdot \Delta p}{2 \cdot l} - \tau_T \tag{2}$$

Using the Laplace transform, $\frac{\tau_T}{s} - C \cdot \eta_{area} + L \cdot s \cdot \eta_{area} - \frac{\Delta p}{2 \cdot l \cdot s^2} = 0$, we get the solution of $L = \frac{C}{s} - \cdot \frac{\tau_T}{s^2 \cdot \eta_{area}} + \frac{\Delta p}{2 \cdot l \cdot s^3 \cdot \eta_{area}}$ differential equation **Error! Reference source not found.**with regard to integration constant *C*:

$$U(y) = C - \frac{\tau_T \cdot y}{\eta_{area}} + \frac{\Delta p \cdot y^2}{4 \cdot l \cdot \eta_{area}} \tag{3}$$

In a viscous fluid shear stresses in the central plane of the flow are equal to zero. Therefore, laminar core will be formed close to this plane, where $\tau \leq \tau_T$. The strain inside this area will be purely elastic, and it will move as a rigid whole. With *y* = *y*, we have $\frac{d}{dy}U(y) = 0$. Therefore, for $y \leq y_o$, although there is movement, flow is missing. The half-width of this area is determined by equation:

$$\frac{d}{dy}\left[C - \frac{\tau_T \cdot y}{\eta_{area}} + \frac{\Delta p \cdot y^2}{4 \cdot l \cdot \eta_{area}}\right]_{y=y_0} = 0 \tag{4}$$

From equation, $y_O = \frac{2 \cdot l \cdot \tau_T}{\Delta p}$. Thus, the flow in the third zone of the extruder is a rigid core flow with half-width y_o determined by equality $\tau_T = \frac{y_O \cdot \Delta p}{2 \cdot l}$. The strain in this zone does not exceed the yield point. To determine the speed of a hard plate, from equation we define *C*, assuming that slippage of the material is absent on the walls of the examined zone ±*h* (*h* is half-height of the channel). In this case, the integration constant *C* of equation is determined by equation:

$$C = \frac{h \cdot \tau_T}{\eta_{area}} - \frac{h^2 \cdot \Delta p}{4 \cdot l \cdot \eta_{area}} \tag{5}$$

The speed of rigid cylinder v_o with half-thickness y_o is found by substitution of $y_O = \frac{2 \cdot l \cdot \tau_T}{\Delta p}$ in equation given that:

$$v_0 = \frac{(h \cdot \Delta p - 2 \cdot l \cdot \tau_T)^2}{4 \cdot l \cdot \Delta p \cdot \eta_{area}} \qquad (6)$$

The flow rate of viscous material in the zone adjajcent to the walls of the channel is determined by formula:

$$v(y) = \frac{(h - y) \cdot (h \cdot \Delta p - 4 \cdot l \cdot \tau_T + \Delta p \cdot y)}{4 \cdot l \cdot \eta_{area}} \qquad (7)$$

The overall flow rate of the material in the third zone of the channel that is defined by formulas and may be represented by generalized relationship:

$$U(y) = \begin{cases} \frac{2 \cdot h^2 \cdot \Delta p^2 - 8 \cdot h \cdot l \cdot \Delta p \cdot \tau_T + 4 \cdot l^2 \cdot \tau_T{}^2 + 4 \cdot l \cdot \Delta p \cdot \tau_T \cdot y - \Delta p^2 \cdot y^2}{4 \cdot l \cdot \Delta p \cdot \eta_{area}} \cdot F(y) + \\ + \frac{4 \cdot l^2 \cdot \tau_T{}^2 - 4 \cdot l \cdot \Delta p \cdot \tau_T \cdot y + \Delta p^2 \cdot y^2}{4 \cdot l \cdot \Delta p \cdot \eta_{area}} \cdot F\left(\frac{2 \cdot l \cdot \tau_T}{\Delta p} - y\right) - \\ - \frac{h^2 \cdot \Delta p^2 - 4 \cdot h \cdot l \cdot \Delta p \cdot \tau_T + 4 \cdot l^2 \cdot \tau_T{}^2}{4 \cdot l \cdot \Delta p \cdot \eta_{area}} \end{cases} \qquad (8)$$

Where F(y) is a Heaviside step function.

Graphically, this dependence is a piecewise continuous function (Figure 1).

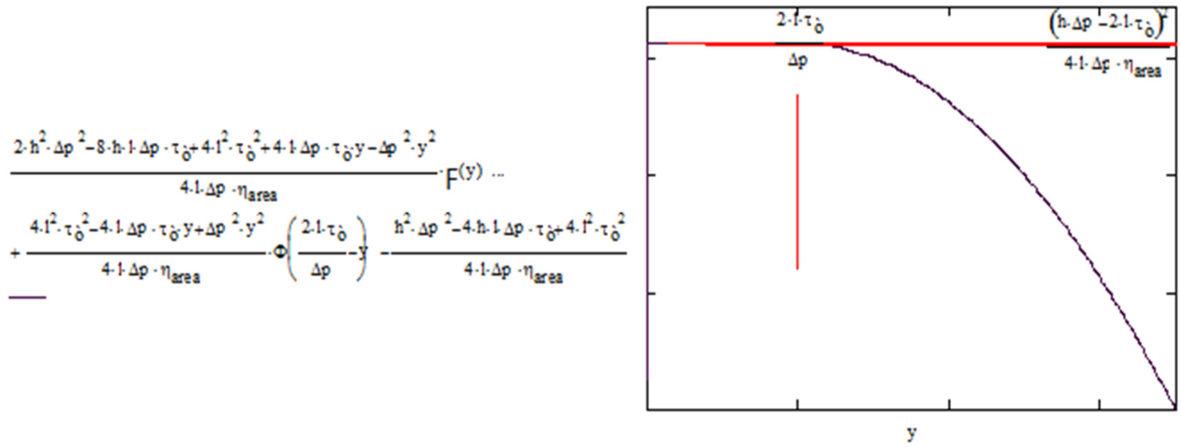

Figure 1 Dependence of flow speed (U) on its height (y).

Integration of formula **Error! Reference source not found.** by the area of channel ×2·*h* allows to determine the volumetric flow rate of structured fluid through the discharge device of the press:

$$Q(b, h, l, \tau_T, \Delta p, \eta_{area}) = 2 \cdot b \cdot \int_0^h U(y) dy = \frac{b \cdot (h \cdot \Delta p + l \cdot \tau_T) \cdot (h \cdot \Delta p + 2 \cdot l \cdot \tau_T)^2}{3 \cdot l \cdot \Delta p^2 \cdot \eta_{area}} \qquad (9)$$

The volumetric flow rate defined by equation generalizes the well-known one-dimensional Poiseuille equation with $\tau \to 0$. The use of formula allows to specify functional dependence of the volumetric flow rate of a structured Bingham plastic through the discharge device of the press, which significantly increases its accuracy [16].

3. RESULTS AND DISCUSSION

To identify the rheological flow indicators included in equation with the known geometric parameters of the discharge device, let us consider the linearized variant of the pressing process, which is characterized by the following basic geometrical parameters (Table 1).

Table 1 Basic geometric parameters of the press

No.	Coil			Diameter		blade		
coil	**depth**	**step**	**length**	**of the moulder**	**of the shaft**	**bottom**	**top**	**height**
0	62.5	290	260	250	122	32	22	62.5
1	62.5	235	210	250	122	30	20	62.5
2	62.5	155	170	250	122	24	15	62.5
3	37.5	130	145	200	122	23	13	37.5
4	31.5	115	140	200	134	21	13	31.5
5	20.5	110	135	220	174	20	14	20.5
6	16.5	100	135	220	184	20	14	16.5
7	16.5	84	100	240	204	20	14	16.5
i	H_B, mm	S_B, mm	L_B, mm	D_3, mm	D_B, mm	a, mm	b, mm	h, mm

Considering the linearized three-zone model of the press, calculation of the geometrical characteristics of these zones (Table 2) was made.

Table 2 Linearized geometric parameters of three zones of the press

Press zone		coil depth	coil width	length along the helix
compressor		62.5	271.6	742.7
pressing zone	at the intake	62.5	271.6	5,733.8
	at discharge	12.2	83.5	
head (average)		12.2	$\pi \cdot (107.9 + 120)$	107.2
unit of meas.		mm		

The use of the linearized model geometry (Table 2) allows identifying the boundary conditions of the central extraction zones of the compressor (the plane-parallel Couette flow) [17] and the discharge device (plane-parallel Poiseuille flow) where oil extraction is absent. The data are presented in the form of five experiments (Table 3).

Table 3 Test data

No.	*L*	*N*	*t*	*M*	F_c
0	7.6	1.571	87	1,457	16.65
1	9	2.094	89	1,831	16.8
2	9	2.827	88	1,868	19.94
3	10.5	2.827	89	2,028	21.28
4	12.1	2.827	88	2,064	22.4
Meas.	mm	Hz	^{o}C	kg/hour	%
Designations	X_1	X_2	X_3	Y_1	Y_2

Experiments aimed at identifying parameters of the mathematical model that describes the operation of the screw press (Table) were performed at four levels of the press discharge device throughput capacity (the width of the output slit L, mm); three levels of screw rpm (N, Hz) and three levels of temperature (t, ^{o}C). The presented data (Table 3) show that this resulted in the changed screw press throughput performance (M, kg/h), and the residual oil content in the cake (Fc, %). We shall consider the isothermal task without the energy equation (temperature is conventionally considered as constant value). Given the nature of the material, we shall consider it virtually incompressible – the density of the components (oil and fiber) is constant. Let us consider changes of the mash in the process of pressing. Let's assume that its density in the beginning of pressing (mashing) is equal to (1,050+1,250)/2=1,150 kg/m^3. This density is determined by equation:

$$F_{in}\,\text{oil} \quad + (1 - F_{In})\cdot\text{material} \quad \text{mash}_{\;in} \tag{10}$$

Where F_{in} = 50% is the initial oil content. Then the material density according to equation is equal to 1,429 kg/m^3. In this case, final density is determined by equation:

$$F_c\cdot\text{oil} \quad \cdot(1 - F_c)\cdot\text{material} \quad \rho_c \tag{11}$$

where F is final oil content determined according to the experimental data. With regard to the data of equation, we get mash density on the cone of the press. Considering incompressibility of oil and material in the process of pressing, we find the volume of the mash at the entrance to the press by the following ratio:

$$M_{in} \quad \left[F_{in}\cdot 871\cdot\frac{kg}{m^3} + (1 - F_{in})\cdot 1429\cdot\frac{kg}{m^3}\right]\cdot Q_{in} \tag{12}$$

Thus, material density is determined by equation:

$$\rho_m(f_m) = 1{,}429 - 558\cdot f_m \tag{13}$$

Where f_m is oil content in the material in the process of pressing, kg/kg. Let us use the obtained data for calculating the dependence of the mash density on its oil content. Analysis of the experimental data shows the possibility of using linear approximation of dependence of the desired mash density on oil concentration in it [18]. Knowing the reduction in the oil content (Table 4) in the process of pressing, and oil density, let us determine flow rate of the mash with regard to equation at the exit from the press by the difference between these flow rates (Table 4). Thus, the flow rates at the exit from the press were obtained in the experiment. Data analysis (Table 4) showed that the throughput capacity of the press depended on the geometry of the forming body, and on the screw rotation speed [19].

Table 4 Volumetric flow rate of the press

	No.	**1**	**2**	**3**	**4**	**5**	**Meas.**
Experimental data	M_{init}	1,457	1,831	1,868	2,028	2,064	kg/hour
	N_v	1.571	2.094	2.827	2.827	2.827	Hz
	t	87	89	88	89	88	°C
	δ	7.6	9	9	10.5	12.1	mm
	F_c	16.65	16.8	19.94	21.28	22.4	%
Mash density in the cone	ρ_c	1,336	1,335	1,318	1,310	1,304	kg/m^3
Mash flow rate at the entrance	Q_{init}	1,267	1,592	1,624	1,763	1,795	liters/hour

to the press							
Mash flow rate at the exit from the press	Q_c	709	894	980	1,095	1,141	liters/hour

Therefore, one can make a conclusion about the Bingham flow of the material at the discharge device of the press [20]. Otherwise, the throughput capacity will be determined only by the geometry of coils, which contradicts the experimental data. To determine the shares of these currents, the data were analyzed with regard to the area of the annular gap, which was changed during the experiments.

Table 5 Test data with regard to the changes in the area of the output device of the press (δ^2) and the Bingham flow in the annular gap

No.	M_{init}	N	t	δ	δ^2	F_c	M_{end}	Parabola		Piston ΔS_{area}	
1	1,457	**1.571**	87	7.6	**57.76**	16.65	485	326	67%	159	33%
2	1,831	**2.094**	89	9	**81**	16.8	615	397	64%	223	36%
3	1,868	**2.827**	88	9	**81**	19.94	745	522	70%	223	30%
4	2,028	**2.827**	89	10.5	**110.25**	21.28	863	522	63%	303	37%
5	2,064	**2.827**	88	12.1	**146.41**	22.4	925	522	56%	402	44%
meas.	kg/hour	**Hz**	°C	mm	**mm²**	%	kg/hour	kg/hour	%	kg/hour	%

Statistical analysis of the data (Table) showed that with the reliability of 95%, the dependence of initial performance on the rheological performance of the press was described by the following relationship:

$$M_{init}\left(N;\delta\right)=a_0\cdot e^{a_1\cdot N}+b_0\cdot\delta^2 \tag{14}$$

a_0 = 181 kg/h; a_1 = 0.374 sec; b_0 = 2.748 kg/(hour·mm^2).

With that, the relative error of this dependence is 1%. Considering the additive nature of the obtained regression relationship, one can estimate the contribution of the parabolic and the piston flow. This conclusion helps explain the additive nature of the obtained regression equation, the first summand of which corresponds to perfectly plastic flow (parabolic profile) and second one - to the shift (piston) flow of plastic material exiting the press. Besides, this equation may be used for first approximation assessing the contribution of these currents by taking the estimated performance as 100%, and the respective summands as shares of the respective flows (Table 5). As one can see from the shown data, the share of piston flow increases with increased productivity (from 33% to 44%), which confirms the nature of the Bingham flow in the annular gap of the discharge device of the press. The considerable dependence of the accuracy of describing the experimental data on rotation speed and the gap area shows redundancy of the studied number of factors in the experiment, namely, the temperature variation in the experiments may be neglected.

Let us consider the Bingham flow in the annular gap of the discharge device between the coaxial fixed cylinders without slipping, relative to the channel walls. The channel length will be determined based on the throughput capacity of the discharge device. This device includes a coaxial cylindrical and a narrowing conical channels, the geometry of which varied during the press parameters identification experiments (Table 6) [21].

Table 6 Geometrical parameters of the die (cone) of the press

No. of experiment			1	2	3	4	5	meas.
Geometrical parameters of the flow at the exit	cylinder	R_i	107.818	107.818	107.818	107.818	107.818	mm
		R_o	120	120	120	120	120	mm
		L_c	67.21	79.59	79.59	92.85	107	mm
	cone	r_{2e}	107.9	107.9	107.9	107.9	107.9	mm
		r_{1e}	120	120	120	120	120	mm
		r_{1a}	112.4	111.0	111.0	109.5	107.9	mm
		r_{2a}	120	120	120	120	120	mm
		L_c	39.79	27.41	27.41	14.15	1	mm

Movement of the material in this zone of the press is modeled as rheological flow defined by shear rate $\boldsymbol{\tau}$, (Pa) containing two coefficient: yield point - $\boldsymbol{\tau_T}$ (Pa) and plastic viscosity – $\boldsymbol{\eta_{area}}$ (PA·sec), combined in flow equation for Bingham structured fluids. The overall flow rate of the material in the third zone of the channel defined by formulas and may be represented by generalized relationship. Substituting $\Delta p = \frac{2 \cdot l \cdot \tau_T}{y_O}$, one can convert into a more convenient form, integration of which over the area of channel b×2·h allows to determine the flow rate of structured fluid through the discharge device of the press:

$$Qc(b,h,y_0,\gamma) = 2 \cdot b \cdot \gamma \int_0^h \begin{bmatrix} \frac{2 \cdot h^2 - 4 \cdot h \cdot y_0 - y^2 + 2 \cdot y \cdot y_0 + y_0^2}{2 \cdot y_0} \Phi(y) - \\ -\frac{y^2 - 2 \cdot y \cdot y_0 + y_0^2}{2 \cdot y \cdot_0} \Phi(y - y_0) - \frac{h^2 - 2 \cdot h \cdot y_0 - y^2 + 2 \cdot y \cdot y_0}{2 y_0} \end{bmatrix} dy \qquad (1)$$

Where $\gamma = \frac{\tau_m}{\eta_{area}}$ is the coefficient that is proportional to the material shear rate in the die.
The volumetric flow rate defined by equation generalizes the well-known one-dimensional Poiseuille equation with $\tau_T \rightarrow 0$. The use of formula allows to determine functional dependency of the volume flow rate of structured Bingham plastic through the discharge device of the press, which significantly increases the accuracy of identifying rheological indicators of the flow with the known geometric parameters of the outlet device (Table 6). In the zone of piston flow with radii $\boldsymbol{a}$, $\boldsymbol{b}$ ($\boldsymbol{R_1<a<b<R_2}$) (where $\boldsymbol{R_1}$, $\boldsymbol{R_2}$ are the radii of coaxial cylinders), the material moves plastically, while outside of this section the flow is viscous. Given the fact that the curvature of the circular channel does not exceed 1%, we believe that the geometry of the structured fluid plastic flow through the discharge device of the press ($\boldsymbol{a=b}$) is determined by dependence. The overall flow rate at given pressure drop $\boldsymbol{\Delta p}$ is defined as the sum of the flow rates of the three annular sections. Using functional dependence, it was possible to highlight rheological parameters $\frac{\tau_m}{\eta_{area}} = \gamma$ relative to shear rate coefficient (γ). Solution with regard to the area of existence of solution $0 \le y_0 \le \frac{R_1 + R_2}{2} - R_1$ allows to determine the flow rate in the third zone of the press as a function of half-width of this zone ($\boldsymbol{y_0}$) to the shear rate coefficient (γ). Combining the system of equations that conbines the geometry of the plastic flow channel with the volumetric flow rate of the discharge device, we get an equation for identifying parameters of half-width of the rigid core zone in the central part ($\boldsymbol{y_0}$), and the coefficient of shear rate (γ):

$$Z(y_0, y_1, y_2, y_3, y_4, \gamma) = \left[\frac{Qc(b,h,y_0\cdot mm,\gamma\cdot Hz)-Q_{k_0}}{Q_{k_0}}\right]^2 + \left[\frac{Qc(b,h,y_1\cdot mm,\gamma\cdot Hz)-Q_{k_1}}{Q_{k_1}}\right]^2 + \left[\frac{Qc(b,h,y_2\cdot mm,\gamma\cdot Hz)-Q_{k_2}}{Q_{k_2}}\right]^2 + \left[\frac{Qc(b,h,y_3\cdot mm,\gamma\cdot Hz)-Q_{k_3}}{Q_{k_3}}\right]^2 + \left[\frac{Qc(b,h,y_4\cdot mm,\gamma\cdot Hz)-Q_{k_4}}{Q_{k_4}}\right]^2 \quad (16)$$

Where y_i is half-width of the rigid core zone; i is the number of the identified experiment, i=0,1,...,4 (Table). The minimum of target function defines the geometry of the plastic core and the rheological properties of the flow with regard to the existence of a solution of equation set by the following system of inequalities:

$$0 \le y_0 \le \frac{mean(R_1, R_2) - R_1}{mm} \quad 0 \le y_1 \le \frac{mean(R_1, R_2) - R_1}{mm} \quad 0 \le y_2 \le \frac{mean(R_1, R_2) - R_1}{mm} \quad 0 \le y_3 \le \frac{mean(R_1, R_2) - R_1}{mm} \quad 0 \le y_4 \le \frac{mean(R_1, R_2) - R_1}{mm} \quad (17)$$

The result of minimization with regard to constraints shows the presence of a plastic core, the thickness of which decreases with increasing throughput capacity of the press (Table 7).

Table 7 Identification of rheological parameters of the press die operation

Experimental data	No.	1	2	3	4	5	Meas.
	M_{init}	1,457	1,831	1,868	2,028	2,064	kg/hour
Mash density in the cone	ρ_c	1,336	1,335	1,318	1,310	1,304	kg/m^3
Mash flow rate at the exit from the press	Q_c	709	894	980	1,095	1,141	liters/hour
Half-width of the rigid core zone	y_0	1.716	1.484	1.397	1.295	1.258	mm
Shear rate coefficient	γ	5.325					Hz

4. CONCLUSION

As a result of experimental data identification according to the Bingham model of viscoplastic flow, the presence of a rigid core without shear strains has been established. With increasing material flow through the discharge device of the press, the rigid core zone decreases. In all experiments, the shear rate coefficient in the laminar flow zone adjacent to the walls of the discharge device remained constant. Thus, the pressure developed by the press exceeds the pressure of plastic flow. The identified flow modes are to be considered in development of the processes limited by laminar flow modes in multiphase systems.

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