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About motion of grain mixture of variable porosity in the cylindrical sieve of vibrocentrifuge

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Summary. The analytical method of calculation of a withstand motion of fine-grained mixture is worked out in the vertical cylindrical sieve of vibrocentrifuge. Integration of differential equalization of motion is show out the reserved formulas for the calculation of kinematics descriptions of grain flow. The two-parameter continual model of the state of separation mixture is used in researches, as a heterogeneous continuous environment with variable specific mass (by porosity) on the thickness of movable layer of friable material. Change of specific mass on a radial coordinate in the cylindrical layer of mixture approximated by the function of degree, the coefficients of that are certain by the Aitken's method. Due to such approximation, the analytical decision of differential equalization of the grain flow, shown out with the use of two-parameter rheological dependence, in that the constituent of linear viscid resistance is complemented by the constituent of remaining internal dry friction, proportional overpressure in mixture, is built. An analytical decision is expressed as squaring that is not expressed through elementary functions in closed form, the close method of calculation of integral offers that is why, with the use of partial sum of row of degree. The results got close formulas result in that well comport with the results of numerical computer integration of squaring. Such method the continual models of grain flow on vibrosieves, it is assumed in that friable material is fully confined internal dry friction, are generalized known for, as a result of vibrodilution. The examples of calculations are considered, where influence of different factors is investigational, in particular values of rheological coefficients and change of porosity, on kinematics descriptions.

It is set that calculation kinematics descriptions of grain flow substantially depend not only on the thickness of movable layer and rheological constants, and also from the concentration of grains near free surface of the mixture. Thus, worked out here a method of research of vertical grain flow in the cylindrical sieve of vibrocentrifuge can be an alternative to other methods in that for the calculation of motion of grain mixture of variable porosity conducted numerical computer integration of nonlinear differential equalizations.

Key words: vertical cylindrical vibrosieve, a grain flow, change of porosity, approximation of degree, two-parameter rheological dependence, viscid and dry friction, rate of movement, withstands.

INTRODUCTION

Velocity and quality of vibrosieve separation of grain mixtures depend on the size of deformations of change of friable material and intensity of segregation that takes place in it. The adopted factors also influence on efficiency of use grain cleansing technique. Therefore, researches of conformities to law of distribution of porosity in mixture, without that impossible segregation (penetration of particles is through pores for sifting) and to distribution of velocity of change on the thickness of movable separated layer, behave to the actual tasks that paid attention in many publications.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

In well-known researches of motion of heterogeneous separated mixtures for the surfaces of vertical vibrosieve usually on a computer consistently decided the two Cauchy's problems numerical methods [1-3]. The first is sanctified to the calculation of porosity of grain mixture, and second – to the calculation of kinematics descriptions of grain flow. In the second task drew on the numerical results of decision of the first task. Here, unlike the publications indicated higher, the close analytical method of calculation of porosity and kinematics descriptions of grain flow is offered, without numerical integration of differential equalizations. It is based on approximation of change of porosity, that is predefined by mechanical vibrations and action of centrifugal force, by the function of degree, by the Aitken's method [4]. The uses of such approximation and two-parameter rheological dependence in that tangent tension in grain mixture is accepted by proportional to velocity of deformation of change and a dry friction is taken into account result in differential equalization the analytical decision of that is expressed in quadratures. It is therefore succeeded to get in elementary functions the reserved formulas are close for the calculation of kinematics descriptions of motion of layer of mixture that is an alternative to the numerical computer method. Herein basic difference of an offer work from other publications after the indicated theme.

The movement of heterogeneous mixtures on vibrosieves was examined also in [5-8], but there on the thickness of layer the dynamic coefficient of vibroviscidity, but not porosity of mixture, was accepted variables.

Vibrosieve grain flows of homogeneous mixtures, with the use of hydrodynamic models of viscid Newtonian fluid, investigated in [9-12]. There are analytical literary reviews in monographs.

In recent year the printed works [13-16], in that nonlinear rheological dependences are involved between tangent tension in the vibrorarefied mixture and velocity of deformations of change. But in these works the not taken into account change of porosity of mixture on the thickness of movable layer and absent analysis of influence of sieve activators (ribs, reefs and etc.) on its distribution. Possibility of presence in the vibrorarefied mixture of remaining dry friction is not envisaged also.

Coming from the conducted review, farther set forth aim of work.

OBJECTIVES

The aim of the article are deduce and approbation of new calculation formulas for the calculation of velocity of grain flow in the vertical cylindrical sieve of vibrocentrifuge, taking into account the change of porosity on the thickness of movable layer of grain mixture.

THE MAIN RESULTS OF THE RESEARCH

Based on the design scheme vibration sieve shown in Fig. 1.

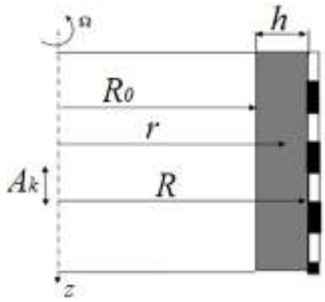

Fig. 1. Design scheme of vertical cylindrical sieve with separated mixture

Here is A_k – amplitude of vertical vibrations of sieve with frequency ω; Ω – angular velocity of rotation sieve around the vertical axis; R – radius of cylindrical sieve; h – thickness of movable layer of mixture; $R_0=R-h$ – radius of cylindrical free surface of mixture; r – radial coordinate; u(r) – velocity of a withstand vertical grain flow in direction to axis OZ.

For the calculation of changes in the concentration of weevils $v=v(r)$ on the thickness of movable layer of grain mixture in works [1-3] on a computer decided the next Cauchy's problems numerical methods:

$$\frac{d}{dr}\left[\alpha(\bar{\Phi}+2)\left(\frac{dv}{dr}\right)^2\right]+\frac{2\alpha}{r}\left(\frac{dv}{dr}\right)^2-\gamma\Omega^2 rv=0;$$

$$v(R_0)=v_0; \qquad \left.\frac{dv}{dr}\right|_{r=R_0}=0. \qquad (1)$$

Here $\bar{\Phi}=\left(\sqrt{1+\varphi^2}-\varphi\right)/\varphi$; $\varphi=\frac{f_0}{2}\left(1+e^{-G}\right)$; $G=\frac{A_k\omega^2}{R\Omega^2}$; v_0 – concentration of weevils near free surface of mixture; f_0 – coefficient of dry friction in the mixture.

Value of the coefficient α depends on a condition sieve surface (presence ribs, reefs and etc.).

Analysis of results of numerical integration of equalization in (1), that is confirmed experimentally in [17], showed that they can be approximated by dependence of degree [18]:

$$v=v(r)=v_0(1+1{,}028\,\eta^{\lambda}), \qquad (2)$$

where: $\eta=X(r-R_0)$; $X=\sqrt[3]{\frac{\gamma\Omega^2(R_0+0{,}5h)}{2\alpha v_0(\Phi+2)}}$; $\lambda=1{,}579$.

In case of flat sieve such dependence is used in [19].

The error of approximation (2) does not exceed one percent. Therefore, approximately, instead of numerical integration of the Cauchy's problems (1) on a computer, we will use the formula (2). For the analytical calculation of kinematics descriptions of grain flow integrate these equalizations of equilibrium element of mixture layer thickness dr:

$$\frac{d}{dr}(r\tau)=-\gamma g v(r)\cdot r,$$

at the initial condition:

$$\tau(R_0)=0,$$

what expresses equality to the zero of tangent tension $\tau=\tau(r)$ on free surface $r=R_0$.

Get expression integration:

$$\tau=-\frac{\gamma g}{r}\int_{R_0}^{r} v(t)\cdot t\cdot dt. \qquad (3)$$

Here γ – specific mass of material of one grain; g – acceleration of the free falling.

To get differential equalization of motion, we will use two-parameter rheological dependence [16, 20]:

$$\tau=\mu\frac{du}{dr}-fp(r)\,\mathrm{sign}(u). \qquad (4)$$

Here μ, f – rheological coefficients; $p(r)$ – internal overpressure in the mixture.

Since, $u\geq 0$, and

$$p(r)=\gamma\Omega^2\int_{R_0}^{r} v(t)tdt,$$

then (4) takes the form:

$$\tau=\mu\frac{du}{dr}-f\gamma\Omega^2\int_{R_0}^{r} v(t)tdt, \qquad (5)$$

Comparing right parts of expressions (3) and (5), get differential equalization of motion:

$$\frac{du}{dr}-\frac{\gamma}{\mu}\left(f\Omega^2-\frac{g}{r}\right)\int_{R_0}^{r} tv(t)dt, \qquad (6)$$

which should be $fR\Omega^2<g$.

Equalization (6), integrate at an initial condition:

$$u(R)=u_0, \qquad (7)$$

where: u_0 – velocity of skidding mixture for the surfaces of sieve.

Decision of Cauchy's task given by expressions (6) and (7) looks like:

$$u=\frac{\gamma}{\mu}\int_{R}^{r}\left[\left(f\Omega^2-\frac{g}{r}\right)\int_{R_0}^{r} tv(t)dt\right]dr+u_0.$$

Putting expression (2) here, after integration for t, get squaring for the calculation of velocity of grain flow:

$$u=\frac{\gamma}{\mu}\int_{R}^{r}\left(f\Omega^2-\frac{g}{r}\right)\left[v_0\frac{r^2-R_0^2}{2}+a\frac{(r-R_0)^{\lambda+2}}{\lambda+2}+aR_0\frac{(r-R_0)^{\lambda+1}}{\lambda+1}\right]dr+u_0. \qquad (8)$$

Here $a=1{,}028v_0\mathrm{X}^{\lambda}$.

Further integration gives:

$$u=\frac{\gamma}{\mu}\left\{\frac{f\Omega^2(r-R)v_0}{6}\left[(r^2+rR+R^2)-3R_0^2\right]-\frac{gv_0}{4}\left[(r^2-R^2)-R_0^2\ln\frac{r^2}{R^2}\right]+af\Omega^2\left[\frac{(r-R_0)^{\lambda+3}-h^{\lambda+3}}{(\lambda+2)(\lambda+3)}+R_0\frac{(r-R_0)^{\lambda+2}-h^{\lambda+2}}{(\lambda+1)(\lambda+2)}\right]-ag\left[S_1(r)+R_0S_2(r)\right]\right\}+u_0. \qquad (9)$$

Thus integrals: $S_1(r)=\frac{1}{\lambda+2}\int_{R}^{r}\frac{(r-R_0)^{\lambda+2}}{r}dr$;

$$S_2(r)=\frac{1}{\lambda+1}\int_{R}^{r}\frac{(r-R_0)^{\lambda+1}}{r}dr,$$

not expressed in elementary functions. But, taking into account, that in practice of separation of $r-R_0\ll R_0$, it is possible to show out simple enough close formulas for the calculation of $S_1(r)$ and $S_2(r)$.

For this purpose we will take advantage of the next approaching of sum members of geometrical progression:

$$\frac{1}{r}=\frac{1}{r-R_0+R_0}=\frac{1}{R_0\left(1+\frac{r-R_0}{R_0}\right)}\approx\frac{1}{R_0}\left(1-\frac{r-R_0}{R_0}+\frac{(r-R_0)^2}{{R_0}^2}\right).$$

Then:

$$S_1(r)\approx\frac{1}{(\lambda+2)R_0}\left[\frac{(r-R_0)^{\lambda+3}-h^{\lambda+3}}{\lambda+3}-\frac{(r-R_0)^{\lambda+4}-h^{\lambda+4}}{R_0(\lambda+4)}+\frac{(r-R_0)^{\lambda+5}-h^{\lambda+5}}{R_0^2(\lambda+5)}\right]; \quad (10)$$

$$S_2(r)\approx\frac{1}{(\lambda+1)R_0}\left[\frac{(r-R_0)^{\lambda+2}-h^{\lambda+2}}{\lambda+2}-\frac{(r-R_0)^{\lambda+3}-h^{\lambda+3}}{R_0(\lambda+3)}+\frac{(r-R_0)^{\lambda+4}-h^{\lambda+4}}{R_0^2(\lambda+4)}\right].$$

Thus formula (9), together with expressions (10), it is possible to consider the close reserved analytical decision the tasks of motion of grain mixture.

If in (9) to put $\gamma v_0=\rho$, $a=0$, this formula will be the same with that which obtained in [16, p. 80], for the calculation of velocity of grain flow homogeneous mixture. From (9), as special cases, resulting formulas derived in [9, 11] based on hydrodynamic model movement.

Using (2) and (9), it is possible analytically to calculate the productivity of vibrosieve:

$$P=2\pi\gamma\int_{R_0}^{R} ru(r)v(r)dr. \quad (11)$$

But analytical integration gives a bulky formula. Therefore, an integral (11) more comfortable to calculate numerical methods on a computer.

Will consider the examples of calculations. For realization of calculations accept: $R=0{,}3075$ m; $\Omega=11{,}77$ s^{-1}; $A_k=0{,}006$ m; $\omega=95$ s^{-1}; $f_0=0{,}47$; $\gamma=1350$ kg/m^3; $u_0=0$; $\alpha=0{,}23$ H; and different μ, f, v_0, h.

Calculated by two methods of value of *u*(*r*), at *h*=0,018 m; μ=1,9 Pa·s; *f*=0,1, written in a Table 1. A value in numerators is got numerical integration of squaring in (8), and in denominators – on formulas (9), (10).

Table 1. Velocities of grain flow at different *r*=(r-Ro)/h*, calculation in two methods

r_*	$v_o=0{,}3$	$v_o=0{,}4$	$v_o=0{,}5$
	Values 10 *u (r)*, m/s		
0	2,2108 2,2109	2,8908 2,8909	3,5653 3,5654
0,2	2,1305 2,1306	2,7839 2,7840	3,4318 3,4319
0,4	1,8849 1,8849	2,4584 2,4585	3,0266 3,0267
0,6	1,4610 1,4611	1,9004 1,9005	2,3352 2,3353
0,8	0,8404 0,8405	1,0895 1,0895	1,3356 1,3356

Small divergences between a numerator and denominator confirm exactness of close formula (9).

Calculations results of velocity *u*(o) on formulas (9), (10) at *h*=0,012 m and *h*=0,016 m and different μ, *f*, v_o are written in Table 2 and Table 3. Calculations confirm, that velocity of grain flow substantially depends not only on the thickness of movable layer of mixture, and also from it specific mass and rheological constants.

Table 2. Value of velocity of grain flow at *h*=0,012 m

μ, Pa·s	*f*	$v_o=0{,}3$	$v_o=0{,}4$	$v_o=0{,}5$
		Values 10 *u* (o), m/s		
0,7	0,05	3,437	4,532	5,623
0,7	0,10	2,499	3,296	4,089
0,7	0,15	1,561	2,059	2,555
0,9	0,05	2,673	3,525	4,373
0,9	0,10	1,944	2,563	3,180
0,9	0,15	1,214	1,602	1,987

Table 3. Value of velocity of grain flow at *h*=0,016 m

μ, Pa·s	*f*	$v_o=0{,}3$	$v_o=0{,}4$	$v_o=0{,}5$
		Values 10 *u* (o), m/s		
0,9	0,05	4,948	6,488	8,018
0,9	0,10	3,605	4,727	5,842
0,9	0,15	2,262	2,966	3,666
1,1	0,05	4,048	5,308	6,560
1,1	0,10	2,949	3,868	4,780
1,1	0,15	1,850	2,427	2,999

About influence of different factors on the productivity of sieve the given information in a table. 4. The value of *P* is got numerical integration in (11) at *h*=0,012 m and different μ, *f*, v_o.

Table 4.Value of the productivity of vibrosieve at *h*=0,012 m

μ, Pa·s	*f*	$v_o=0{,}3$	$v_o=0{,}4$	$v_o=0{,}5$
		Values *P*, kg/s		
0,9	0,10	1,319	2,285	3,508
0,9	0,15	0,821	1,423	2,184
1,2	0,10	0,989	1,714	2,631
1,2	0,15	0,616	1,067	1,638

Here we have substantial dependence of *P* not only from μ and *f*, and also from v_o.

CONCLUSIONS

Approximation of change of specific mass on the thickness of movable layer of heterogeneous grain mixture gave an opportunity to calculate velocity of grain flow without realization of numerical integration of differential equalizations the function of degree. Calculations showed that kinematics descriptions of grain flow substantially depended not only on the thickness of movable layer and rheological constants, and also from the concentration of grains near free surface of mixture.

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О ДВИЖЕНИИ ЗЕРНОСМЕСИ ПЕРЕМЕННОЙ ПОРИСТОСТИ В ЦИЛИНДРИЧЕСКОМ РЕШЕТЕ ВИБРОЦЕНТРИФУГИ

В. Ольшанский, А. Ольшанский, С. Харченко, Ф. Харченко

Аннотация. Разработан аналитический способ расчета установившегося движения зерносмеси в вертикальном цилиндрическом решете виброцентрифуги. Интегрированием дифференциального уравнения движения выведено замкнутые формулы для вычисления кинематических характеристик зернопотока. В исследованиях использована двухпараметрическая континуальная модель состояния сепарированной смеси, как неоднородной сплошной среды с переменной плотностью или пористостью по толщине движущегося слоя сыпучего материала. Изменения удельной массы по радиальной координате в цилиндрическом слое смеси аппроксимировано степенной функцией, коэффициенты которой определены методом Эйткена. Благодаря такой аппроксимации, построено аналитическое решение дифференциального уравнения зернопотока, выведенного с использованием двухпараметрической реологической зависимости, в которой составляющая линейного вязкого сопротивления дополнена составляющей остаточного внутреннего сухого трения, пропорционального избыточного давлению в смеси. Аналитическое решение получено в виде квадратуры, которая не выражается через элементарные функции в замкнутой форме. Поэтому предложен приближенный способ вычисления интеграла, с использованием частичной суммы степенного ряда. Результаты, к которым приводят полученные приближенные формулы, хорошо согласуются с результатами численного компьютерного интегрирования квадратуры. Таким способом обобщено известные континуальные модели зернопотоков по виброрешетах, в которых предполагается, что сыпучий материал полностью лишен внутреннего сухого трения, вследствие виброожижения. Рассмотрено примеры расчетов, где исследовано влияние различных факторов, в частности значений реологических коэффициентов и изменения пористости, на расчетные кинематические характеристики. Установлено, что теоретические кинематические характеристики зернопотоков существенно зависят не только от толщины движущегося слоя и реологических констант, а также и от концентрации зерен у свободной поверхности смеси. В целом разработанный здесь способ исследования вертикального зернопотока в цилиндрическом решете виброцентрифуги может быть альтернативой другим методам, в которых для расчета движения зерносмеси переменной пористости проводили численное компьютерное интегрирование нелинейных дифференциальных уравнений.

Ключевые слова: вертикальное цилиндрическое виброрешето, установившейся зернопоток, переменная пористость, степенная аппроксимация, двухпараметрическая реологическая зависимость, вязкое и сухое трение, скорость движения.