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DESIGN CALCULATION OF HYDROTRANSPORT PLANT FOR TECHNOLOGIES OF HIGHLY-CONCENTRATED PULPS STORING

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ПРОЕКТУВАЛЬНИЙ РОЗРАХУНОК ГІДРОТРАНСПОРТНОГО УСТАТКУВАННЯ ДЛЯ ТЕХНОЛОГІЙ СКЛАДУВАННЯ ПУЛЬП З ВИСОКОЮ КОНЦЕНТРАЦІЄЮ

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ПРОЕКТИРОВОЧНЫЙ РАСЧЕТ ГИДРОТРАНСПОРТНОЙ УСТАНОВКИ ДЛЯ ТЕХНОЛОГИЙ СКЛАДИРОВАНИЯ ПУЛЬП ВЫСОКОЙ КОНЦЕНТРАЦИИ

Abstract. It is for the first time when a method of design calculation based on universal dimensionless quantities and analytical linear dependence between hydraulic gradient, initial shear stress, effective suspension viscosity and volumetric flow rate was proposed for systems for storing tailings in the form of highly-concentrated slurry. A distinctive feature of the proposed non-linear dependence between diameter of the pipeline, initial shear stress, effective suspension viscosity and volumetric flow rate is versatility of coefficients, which do not depend on the properties of solid phase and diameter or material of the pipeline.

The findings have been resulted in a decision which helps specifying diameter of the trunk hydrotransport complex providing controllable flow of highly-concentrated pulp, in accordance with the Bingam-Shvedov rheological law, in a structured flow regime with taking into account flow-pressure characteristics of the intended pumping equipment.

Keyword: cleaning rejects, paste, flow, slope of waste storage, cleaning rejects mass.

Mining Processing Plants (MPP) are the basis for industrial regions of Ukraine sustainable development and simultaneously the source of the greatest environmental threat. MPPs consume the considerable amount of the primary ecological resource – clean water and also require more land areas for enrichment process wastes storage [1]. However the amount of process water becomes less and there is no land allotment for new wastes storages.

In these circumstances the only way to save the functionality of MPPs and the sustainable development of regions where MPP are located is an implementation of the retrofit technologies which assume getting of the enrichment process wastes in a form of the high concentrated pulps (HCP) with more than 30% of the solid particles inclusion volume fraction.

Today the technologies are known that make it possible to thicken the enrichment process wastes up to such concentration but the resultant HCP has rheological properties and also plastic fluid properties appear. For those fluids the dependences of rheological properties and some of hydraulic characteristics while flowing over the pipeline are known. Modes and operating standards of hydrotransportation and storage technologies of such wastes are unknown that restrains those prospective technologies implementation at the homeland MPPs.

While calculating of the hydrotransportation parameters the goal of the calculation is the evaluation of the critical speed value, the hydraulic gradient or the pipeline critical diameter for the chosen material, the specified pipeline diameter with the prescribed pulp charge or the stream of supply depending on the suspension concentration. However the definition of the critical speed for HCP does not correspond to the same definition for the low concentrated pulps [1]. The most part of HCP generated from the enrichment process wastes are plastic fluids and correspond the Bingham-Shvedov Rheological Law. Some researchers offer to calculate the critical speed for HCP according to the condition of the complete flow core destruction and structural flow regime finishing[2-4]. Other scientists suggest to use the evaluation of input into the hydraulic gradient of an item that contains the viscosity of the suspension [1, 5].

This work has as its goal to ground the possible modes of operation for the hydrotransportational complexes that provide enrichment process wastes storage in a form of and also to develop the method of their designed calculation.

For the grounding of the modes of HCP pumped flow regimes it is reasonable to overwrite the dependence for the hydraulic gradient using the dimensional quantities scales included into it. [3, 5].

$$i = \frac{\tilde{\tau}_0}{\lambda} + \frac{Q}{\mu}, \tag{1}$$

$$\lambda = \frac{\rho_0 g D}{2}, \tag{2}$$

$$\mu = \frac{\rho_0 g \pi D^4}{16\tilde{\eta}}, \tag{3}$$

$$\tilde{\tau}_0 = \alpha \tau_0, \tag{4}$$

$$\tilde{\eta} = \beta \eta, \tag{5}$$

where i – hydraulic gradient; λ – upper yield point module; μ – rate of discharge of hydrotransportational complex line [1]; ρ_0 – water density; g – gravity acceleration; τ_0 – upper yield point (UYP); η – pulp effective viscosity (EV); Q – HCP volume flow rate; $\tilde{\tau}_0$ – UYP effective value; $\tilde{\eta}$ – EV effective value; D – pipeline diameter; α, β – coefficients of approximation indices of the Buckingham’s complete equation solution.

The expression (1) includes two items, each of them dominates in its flow regime.

The first item dominates in the Shvedovskiy regime, the second item dominates in the pseudo-laminar regime. Thus the Bingham's regime is the flow regime where the influence of both of the items is comparable to each other [3, 8 – 10].

It is not difficult to show that the Shvedovskiy regime is realized with the volume flow rates complying with the following inequation [2 – 7]:

$$Q \le Q_S , \tag{6}$$

$$Q_S = 0{,}1 Q_* , \tag{7}$$

$$Q_* = \frac{\pi D^3 \tilde{\tau}_0}{8\tilde{\eta}} , \tag{8}$$

the hydraulic gradient in such regime can be calculated by the formula:

$$i = 1{,}1 \frac{\tilde{\tau}_0}{\lambda} , \tag{9}$$

where Q_* - line input equivalent value.

In much the same way for the pseudo-laminar regime the volume rate should be [2 – 5]:

$$Q_L \le Q , \tag{10}$$

$$Q_L = 10 Q_* , \tag{11}$$

the hydraulic gradient in this regime can be calculated by the formula:

$$i = 1{,}1 \frac{Q}{\mu} , \tag{12}$$

after simple transformations it can be rewritten in this way:

$$i = \frac{\rho}{\rho_0} \frac{\lambda_* Q^2}{\pi^2 g D^5} , \tag{13}$$

$$\lambda_* = 1{,}1 \beta \frac{64}{\mathrm{Re}} , \tag{14}$$

where λ_* - adjusted coefficient of hydraulic friction.

For the grounding of an adequacy of using the suggested formulas it is necessary to investigate their correlation with the limit values of Reynolds criterion:

$$\mathrm{Re} = Kr\frac{Q}{Q_*}, \tag{15}$$

$$Kr = \frac{\rho\beta D^2\tilde{\tau}_0}{2\tilde{\eta}^2}. \tag{16}$$

On the basis of the expression (15) and taking into consideration the inequations (6) and (10) the following limitations for Reynolds number in the Binghamovskiy flow regime were received:

$$0{,}1Kr \le \mathrm{Re} \le 10Kr. \tag{17}$$

According to this the hydraulic gradient is calculated by the formula (13).

In HCP flow regimes for which the Reynolds number value exceeds the upper limit from the set of inequalities (17), the hydraulic grade can be calculated by the formulas (12) and (13). While the exceeding of the HCP consumption and the start of the turbulent conditions the hydraulic calculation for the hydrotransportational complex is calculated similar to the flow regime of the low concentrated hydromixture but the coefficient of hydraulic friction in the formula (13) is calculated by the following expression [2, 7]:

$$\lambda_T = \frac{0{,}075}{\sqrt[8]{\mathrm{Re}}}, \tag{18}$$

where λ_T - coefficient of hydraulic friction for the turbulent flow regime.

Alternatively to the majority of all known recommendations the inequations (17) take into consideration not only the rheological parameters of HCP, the density of the solid phase particles but also the pipeline diameter. The adherence of Reynolds criterion limits (17) as it is not difficult to show make it possible to implement the core or structure flow regimes of HCP for the relative flow core radii over the range between 0,132-0,753.

The designed calculation is made with the aim to fix the pump applicability factors that are the pipe diameter and the pumps total pressure head and that are necessary for the scheduled parameters and operative modes for the hydrotransportational complex if to follow the conditions (17) and the given pulp intake [2 – 5].

With the given productivity of hydrotransportational complex for HCP

$$Q_S < Q < Q_L, \tag{19}$$

it is easy to introduce the limits in a form of the pipeline diameter limitations

$$0{,}464 < \frac{D}{2R_*} < 2{,}154, \tag{20}$$

$$R_* = \sqrt[3]{\frac{\tilde{\eta} Q_P}{\pi \tilde{\tau}_0}}, \tag{21}$$

and corresponding limitations for the hydraulic gradient

$$\frac{0{,}511}{\rho_0 g}\sqrt[3]{\frac{\pi \tilde{\tau}_0^4}{\tilde{\eta} Q_P}} < i < \frac{23{,}729}{\rho_0 g}\sqrt[3]{\frac{\pi \tilde{\tau}_0^4}{\tilde{\eta} Q_P}}, \tag{22}$$

where Q_P - scheduled suspension flow; R_* - pipeline typical radius.

Formulas (20) – (22) allow choosing the possible pipeline diameter variation range and the necessary pipe pressure due to the given consumption, the concentration and the rheological properties of the pulp. For that firstly the relative input of the installation is calculated

$$q = \frac{Q_P}{Q_K}, \tag{23}$$

$$Q_K = \frac{\tilde{\tau}_0^4}{\pi \tilde{\eta} (\rho_0 g)^3}, \tag{24}$$

where q – relative input of the installation; Q_K – rheological input module.

Then due to the q value limits of the acceptable values for pipe diameters and pumps pressure are calculated:

$$0{,}43\sqrt[3]{q}\,\frac{\tilde{\tau}_0}{\rho_0 g} < D < 2{,}01\sqrt[3]{q}\,\frac{\tilde{\tau}_0}{\rho_0 g}, \tag{25}$$

$$\frac{0{,}51 k_Z L}{\sqrt[3]{q}} + \rho \Delta Z < \chi H(Q_P) < \frac{23{,}7 k_Z L}{\sqrt[3]{q}} + \rho \Delta Z, \tag{26}$$

where $H(Q_P)$ – flow pump pressure certified value with the input of Q_P; χ – coefficient of recalculation of consumption and pressure peculiarities (CPP) of the pump changing water to HCP; ΔZ – difference of line dead lifts; k_Z – coefficient that takes into consideration local hydraulic resistances.

Formulas (23) - (26) make it possible to estimate the variation ranges of mentioned values. For calculating of the specific value it is necessary to choose the pump an operational field of which will obey all the parameters (26) and then to calculate the modified pressure linear head:

$$\tilde{i} = \frac{\chi H(Q_P) - \rho \Delta Z}{k_Z L}, \tag{27}$$

and to estimate the necessary pipeline diameter value with the solution of the equation (27)

$$\tilde{i} = \frac{2\tilde{\tau}_0}{\rho_0 g D} + \frac{16 \tilde{\eta} Q_P}{\rho_0 g \pi D^4}, \tag{28}$$

where $\tilde{i}$ - modified pressure linear head; ρ - relative density of the suspension.

The equation (28) according to D is not complete algebraic quartic equation that after simple substitutions can be reduced to

$$y^4 + \theta y - 1 = 0, \tag{29}$$

$$y = \sqrt[4]{\frac{\tilde{\eta} Q_P}{\pi \rho_0 g \tilde{i}}} \frac{2}{D}, \tag{30}$$

$$\theta = \frac{\tilde{\tau}_0}{\rho_0 g \tilde{i}} \sqrt[4]{\frac{\pi \rho_0 g \tilde{i}}{\tilde{\eta} Q_P}}. \tag{31}$$

Real roots of the equation (29) are cross points of quartic parabola with turned up branch lines and parabola vertex in the coordinate origin and direct line that cross axis of ordinates and axis of abscises in points $(0;1)$ and $(\theta^{-1};0)$ respectively. Function charts of such functions always intercross in the first and the second quadrants of the coordinate plane. In this case there can be only two cross points. On the ground of this it can be concluded that the equation (29) has two real and two complex roots thus it can be represented in the following form:

$$\left((y-e)^2 - f^2\right)\left((y-c)^2 + d^2\right) = 0, \tag{32}$$

where e, f, c, d - real numbers.

Removing the parentheses in the expressions (32), collecting similar and equating expressions for coefficients with argument coherent degrees to coefficients in the equation (29) the system of non-linear algebraic equations to figure out e, f, c, d is obtained. The solution of this set of equations resolves itself into finding the real roots of cubic equation with constantly positive discriminant. Thereby considering that the root of the equation (29) must be real and positive, analytic expression for calculation can be shown in the form of (Fig. 1, 2):

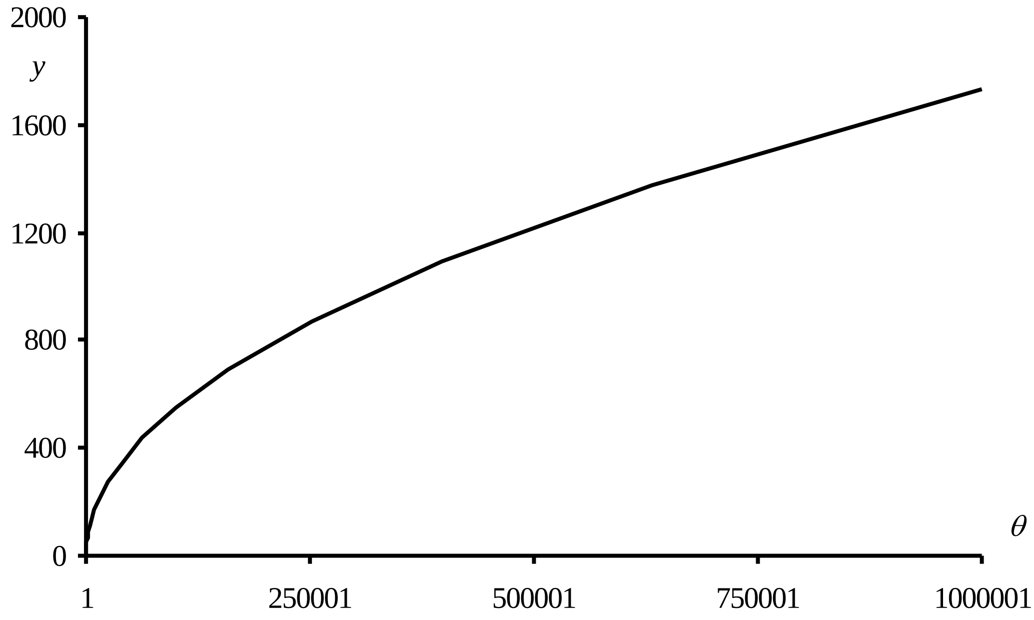

Figure 1 - The dependence of value y on the parameter θ for $1<\theta$

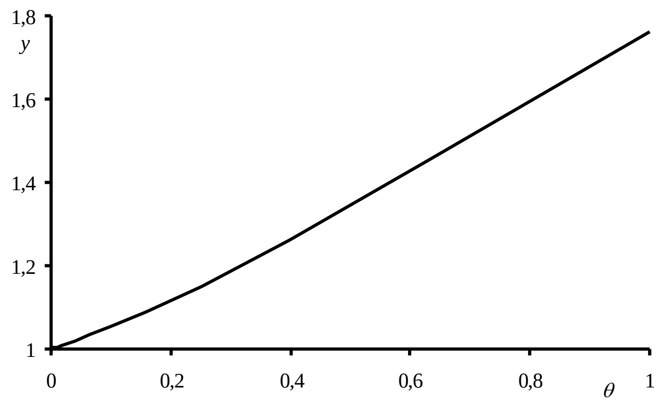

Figure 2 - The dependence of value y on the parameter θ for $1<\theta$

$$D=\frac{2^{\frac{7}{6}}\sqrt{\sigma(\theta)}}{\sqrt{\left(\frac{2}{\sigma(\theta)}\right)^{\frac{3}{2}}-1}-1}\sqrt[3]{\frac{\tilde{\eta}Q_P}{\pi\tilde{\tau}_0}}, \tag{33}$$

$$\sigma(\theta)=\sqrt[3]{\sqrt{\frac{256}{27\theta^4+1}}+1}-\sqrt[3]{\sqrt{\frac{256}{27\theta^4+1}}-1}. \tag{34}$$

The numerical analysis of the dependences (33) and (34) illustrates that the equation solution can be approximated with engineering relevance with the following functions:

$$y = 0{,}999 e^{0{,}5754\theta} \quad \theta < 1$$

$$y = 1{,}737 \theta^{0{,}4997} \quad \theta > 1$$

that after substitution in them the formulas (30) and (31) makes it possible instead of the expression (33) to use these formulas

$$D = \sqrt[4]{\frac{16\tilde{\eta} Q_P}{\pi \rho_0 g \tilde{i}}}\, e^{-\sqrt[4]{\frac{0{,}1097\pi \tilde{\tau}_0^{\,4}}{\tilde{\eta} Q_P \left(\rho_0 g \tilde{i}\right)^3}}} \qquad \theta < 1,$$

$$D = \sqrt{\frac{\rho_0 g \tilde{i}}{0{,}754 \tilde{\tau}_0}} \left(\frac{\tilde{\eta} Q_P}{\pi \rho_0 g \tilde{i}} \right)^{\frac{3}{8}} \quad \theta > 1.$$

The solution sets the essential nonlinear dependence between the diameter of the pipeline that is scheduled by the consumption and rheological properties of HCP. In accordance with the value that was calculated with the last formulas the nearest biggest diameter is chosen from the pipeline assortment. Then the adherence to the specifications (25) is checked. In a case when it is satisfied it is calculated by the formulas (27) and (26) the pressure loss and the prescribed pipe pressure are adjusted. The designed calculation is finished by the conditions checking (19) and the estimation of motors capacity of chosen pumps with the reserve in 30%.

Thus for the first time for the systems of the enrichment process wastes storage in a form of HCP it was suggested a method of pipeline diameter calculation based on universal dimensionless values that take into consideration the high concentrated pulp, flow and pipeline specifications.

For the first time it was grounded the analytic dependence between the pipeline diameter, the upper yield point, the effective viscosity, and the volume flow rate of a suspension, coefficients of which do not depend on the solid phase properties, the diameter or material of the pipeline.

It was obtained the estimation of dimensionless flow rate intervals where the high concentrated pulp viscosity or upper yield point input into the hydraulic gradient value are dominant.

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Аннотация. Впервые для систем складирования отходов обогащения в виде пульпы высокой концентрации предложен метод проектировочного расчета, основанный на универсальных безразмерных величинах и аналитической линейной зависимости между гидравлическим уклоном, начальным напряжением сдвига, эффективной вязкости и объемным расходом суспензии. Отличительной особенностью предложенной в статье нелинейной закономерности между диаметром трубопровода, начальным напряжением сдвига, эффективной вязкости и объемным расходом суспензии является универсальность коэффициентов, не зависящих от свойств твердой фазы, диаметра или материала трубопровода. В результате проведенных исследований получено решение, впервые позволяющее установить диаметр магистрали гидротранспортного комплекса, обеспечивающего регламентированный расход пульпы высокой концентрации, подчиняющейся реологическому закону Бингама-Шведова, в структурированном режиме течения, с учетом расходно-напорной характеристики предполагаемого насосного оборудования.

Ключевые слова: отходы, паста, течение, склон хранилища, масса отходов

Анотація. Вперше запропоновано метод проектувального розрахунку для систем складування відходів збагачення у вигляді пульпи високої концентрації, заснований на універсальних безрозмірних величинах та аналітичної лінійної залежності між гідравлічним ухилом, початковим напруженням зсуву, ефективної в'язкості і об'ємною витратою суспензії. Відмінною особливістю запропонованої в статті нелінійної закономірності між діаметром трубопроводу, початковим напруженням зсуву, ефективної в'язкості і об'ємною витратою суспензії є універсальність коефіцієнтів, які залежать від властивостей твердої фази, діаметра або матеріалу трубопроводу. В результаті проведених досліджень отримано рішення, яке вперше дозволяє встановити діаметр магістралі гідротранспортного комплексу, що забезпечує регламентований витрату пульпи високої концентрації, яка підкоряється реологічному закону Бінгама-Шведова, в структурованому режимі течії, з урахуванням витратно-напірної характеристики насосного обладнання, що передбачається.

Ключові слова: відходи, паста, течія, схил сховища, маса відходів

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