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THE TECHNOLOGIES FOR THE REMOVAL OF COAL TECHNOGENIC DEPOSITS IN THE FORM OF HIGHLY CONCENTRATED HYDRO MIXTURES

[1]Semenenko Ye.V., [1]Slobodiannykova I.L., [2]Medianyk V.Yu., [1]Kyrychko S.M., [1]Tepla T.D.
[1]Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine, [2]Dnipro University of Technology

Abstract. An analysis of the existing beneficiation coal waste storage facilities was carried out and ecologically friendly ways of lowering the water level and removing man-made deposits in the form of highly concentrated aqueous mixtures were carried out. The methodology for calculating the parameters and regimes of transportation for the man-made deposits waste with a high content of pollutants in the form of highly concentrated aqueous mixtures was developed. Models of the processes that occur during the extraction and transportation of man-made deposits in the form of highly concentrated aqueous mixtures were developed taking into account promising technologies. In case of an aqueous mixture with the significant initial tangential stress value, the transport of a highly concentrated aqueous mixture model along a vertical pipeline using a screw conveyor was developed. In this case, it is assumed that the aquous mixture will be lifted up at a height that ensures a nonpressure flow to the levee, where the aqueous mixture will be liquefied and its further transportation by pressure transport, vehicles or railway transport. The model of the process of the pressure flow of a highly concentrated aqueous mixture through the horizontal pipeline, depending on the transportation distance, provides for the use of centrifugal type pumps or piston pumps. Depending on the relative radius value for the undisturbed core of flow, the model takes into account the three most probable flow modes of highly concentrated aqueous mixtures through a circular cross-section pipeline and allows to perform both design and verification calculations. When the gravity force is used to transport a highly concentrated aqueous mixture to the shore, a mathematical model of nonpressure flow process of an aqueous mixture along an inclined channel with a rectangular cross-section was developed. This model takes into account the channel inclination angle, its width and the rheological parameters of the aqueous mixture and allows to calculate the geometric parameters of the channel, which are necessary to ensure the predefined transportation distance with the required flow rate. The results of the study could be applied for coal beneficiation waste storage facilities when they are out of maintenance, which will contribute to the elimination of technogenic impact on the environment, while for waste storage facilities that operate, appliance of the proposed technologies is a way of their size containing.

Keywords: coal beneficiation waste storage, man-made deposits, highly concentrated aqueous mixtures.

1. Introduction

The intensive industry development, rapid growth of cities and industrial agglomerations leads to the accumulation of waste, a significant part of which is produced by the mining and processing industries. The accumulation of these wastes in the form of man-made storages of solid deposits and polluted water leads to the emergence of adverse ecological conditions for the territories that occupy significant areas and are obstacles to the land exploitation for tourism industry, recreation as well as agricultural needs.

For industrial regions, which are the largest centers of mines, total amount of man-made resources, which are out of use, is growing steadily. However, even with the most advanced technologies involved, it is impossible to prevent waste build up. High level of waste formation is a consequence of inefficient use of natural resources in production processes. The generation of waste leads to the loss of materials and energy, as well as additional economic impact for society in connection with waste collection, transportation, processing and disposal. Despite a number of reasons (ecological, organizational, economic, institutional and technological ones) that lead to the accumulation of waste, a solution to this problem is to identify possibilities of their involvement in economic cycle as well as usage as sources of raw materials and energy. This determines the relevance, social and economic importance of the study, which is aimed at researching the state of coal beneficiation waste storage facilities, developing measures to improve the environmental conditions and ensure the environmental safety for their further exploitation.

Various technologies and measures for lowering the water level in coal beneficiation waste storage facilities were elaborated, which take into account the special environmental hazard of liquid and solid waste accumulated, which assume the presence of residues [1]. The most efficient use of liquid traces and solid waste is transportation in the form of a highly concentrated aqueous mixture for hydrocarbon fuel processing or for use as raw materials for the construction industry [2, 3]. For non-operating storage facilities, the use of these technologies and tools means complete elimination of man-made impact on the environment, while for storage facilities being operated, the use of these technologies is predominantly a way of containing their size growth.

The purpose of this study is the selection and substantiation of promising technological solutions for the residue utilization and improvement of the environmental conditions for coal beneficiation waste storage facilities.

Operating of coal mining and coal beneficiation plants is impossible without the creation and operation of coal beneficiation waste storage facilities (SF), the so-called sludge settling tanks and sludge accumulators, as well as mine water ponds (MWP), which remain and do not disappear even if mines and coal beneficiation plants (CBP) operate no more. Moreover, the MWP continue to be involved for the accumulation of mine waters even if mines operate no more, since in most cases the drainage process for these mines is under way.

SF survey [4–7] shows that only a certain part of the sludge products stored could be considered as a raw material for additional fuel obtaining (Fig. 1).

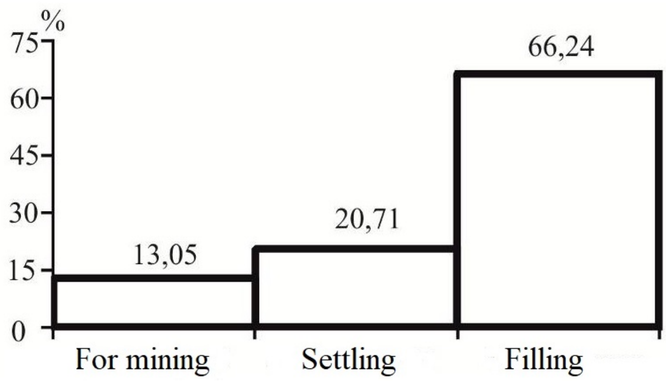


Figure 1 – Histogram of the volume distribution for sludges of all types of ash content according to the degree of suitability for mining from the SF of CBP of Ukraine [4–7]

In particular, for more than 30 years, at the most plants sludge products with an ash content of up to 45% have been removed from sludge settling tanks once their settling and drying processes terminated and further shipping it as a commercial product to the power plants (Fig. 2). Stockspiles of such additional fuel do not exceed 2% of the total volume of products stored in the SF. Sludge products with ash content from 45 up to 60%, the share of which is approximately 35%, are considered the most likely sources for extracting additional fuel (Fig. 3). Ash content for the rest of coal beneficiation waste products (almost 64% of waste accumulated in the SF) is more than 60% (Fig. 4), so they could not be considered as reserved resources of additional fuel and form man-made hydrotechnical structures.

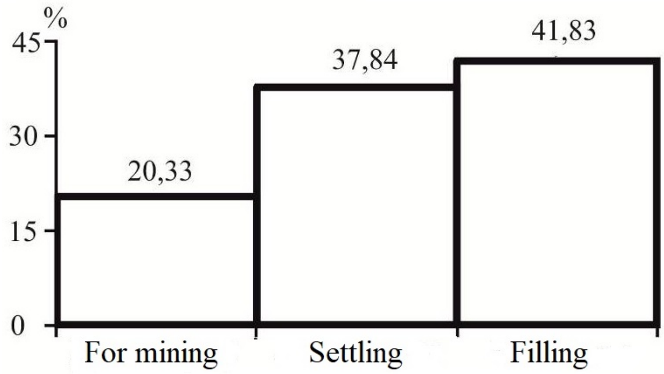


Figure 2 – Histogram of the volume distribution for sludges with ash content up to 40% according to the degree of suitability for extraction from the SF of CBP of Ukraine [4–7]

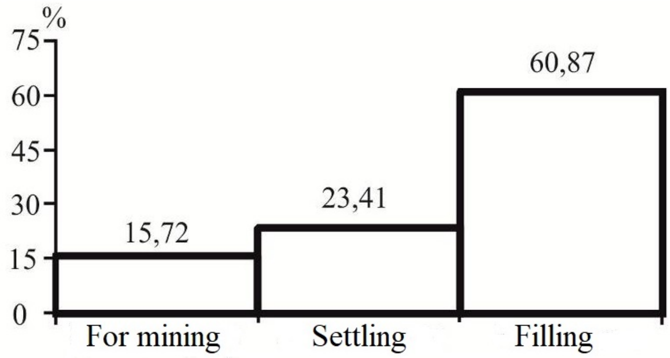


Figure 3 – Histogram of the volume distribution of sludges with ash content from 40 up to 60% according to the degree of suitability for extraction from the SF of CBP of Ukraine [4–7]

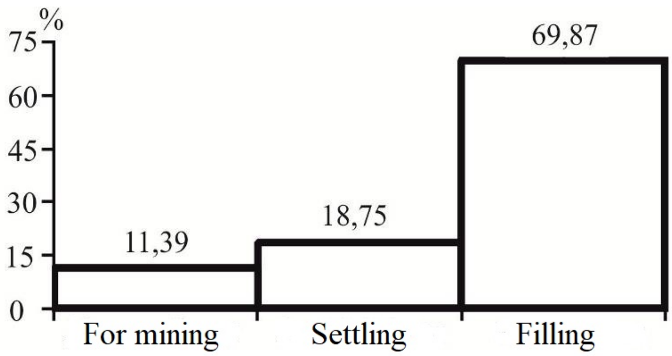


Figure 4 – Histogram of the distribution of sludge volume with an ash content of more than 60% according to the degree of suitability for extracting from the SF of CBP of Ukraine [4–7]

Such sludges are considered to be unsuitable for processing or utilization without additional beneficiation [4–7]. A significant part of such sludge is flotation waste and sludge with a high ash content, which can exist only in the form of a high-concentration aqueous mixture (HCAM) and is barely dewatered. The storage of these wastes creates an ecological threat to the environment, as they must be kept under a layer of water, which leads to an increase in the level of groundwater, terrain waterlogging as well as shrinking of the agricultural land area.

In addition to the environmental threat, there is a problem with the further operating of the CBP since most of the SF are filled in up to 60–90% of the designed capacity, which requires the allocation of terrain area for new SF. Taking this features into account, the release of the SF capacity (Fig. 5) due to the extraction of additional fuel allows to use currently operating sludge settling tanks and sludge accumulators for the collection of waste and their further processing.

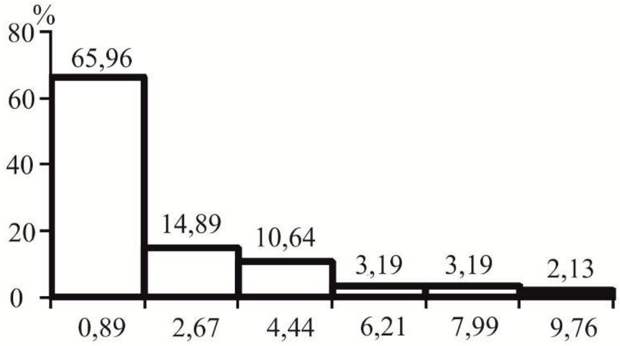


Figure 5 – Histogram of capacity distribution (thousands of m^3) of the SF of CBP of Ukraine [4–7]

The implementation of this approach will allow to increase environmental safety, integrated approach to comprehensive utilization of natural resources, reduce the cost of product concentrates and keep an agricultural usage of terrain area (Fig. 6).

Taking into account the environmental conditions of the coal-mining regions, it is clear that along with additional extraction of fuel, it is necessary to solve another environmental problem - utilization of mine water as well as water entrapped into the SF along with the waste.

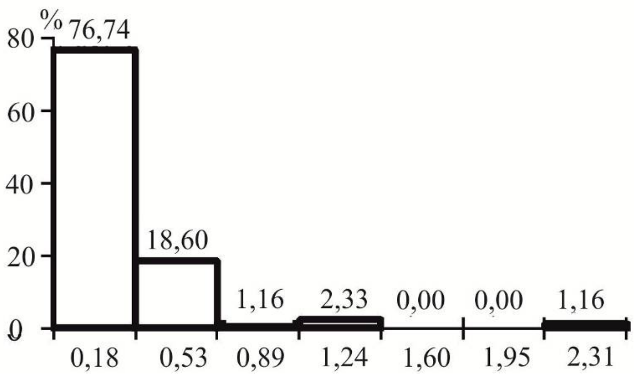


Figure 6 – Histogram of the distribution of the clarification area (thousand m^2) for SF of CBP of Ukraine [4–7]

This component of the problem of ecological and technogenic impact on the environment is getting more relevant, since in most cases products of waste beneficiation as well as mine water are stored in the underground sludge settling tanks. Thus, the probability of liquid filtration from the sludge settling tanks into the soil porous media is high enough, especially considering the depths of the SF arrangement (Fig. 7).

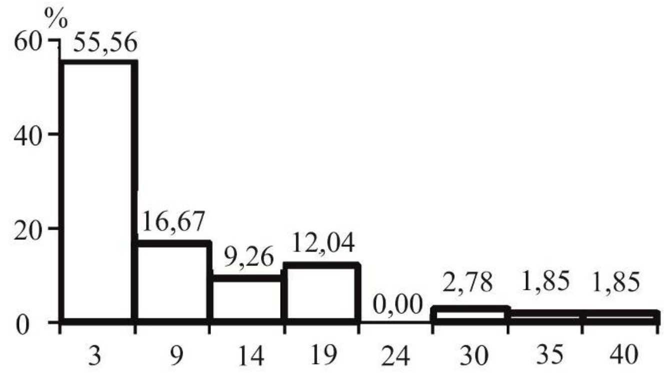


Figure 7 – Histogram of the distribution of the maximum depth value (m) for SF of CBP of Ukraine [4–7]

The analysis show that approximately 80% of the SF are located at a distance of no more than 3 km from the CBP (Fig. 8), which makes it convenient to use pipeline transport for moving processing products in the form of HCAM and leaves enough space for location of additional equipment or planting around the SF provided by biotechnologies.

It should be noted that not only SF are an ecological threat for the environment of coal regions. From 850 up to 960 million m^3 of mine water enters the watercourses per year, which is accumulated in the MWPs which adversely impact environment.

MWPs are usually located in ravines and denes. In most cases, there is no waterproofing of the bottom and walls for these hydrotechnical structures, so they are an intensive source of filtration into groundwater and contamination of water resources with phenols, nitrates, petroleum products, cyanides, radon compounds and other toxic elements.

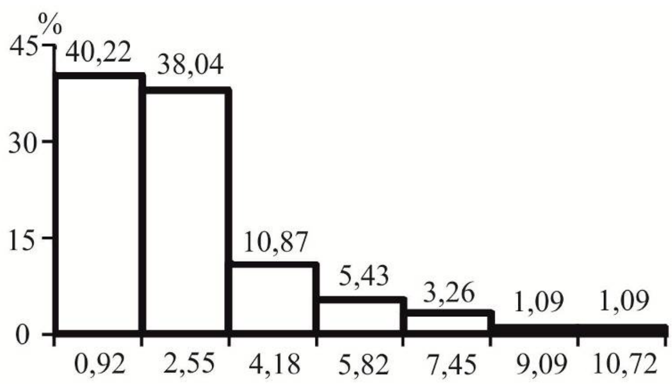


Figure 8 – Histogram of distribution of transportation distance for beneficiation waste (thousand m) to the SF of CBP of Ukraine [1–4]

It is believed that, due to biotechnology, it is possible to remove most of the liquid from SF and SBF [8], but after that, a layer of sludge will remain, where the solid fraction of mineral processing waste will be concentrated. The use of biotechnologies for dewatering this part of the storage requires additional substantiation, but taking into account the carbon content, its processing or utilization for obtaining of electrical and thermal energy is considered acceptable.

Therefore, an analysis of modern environmentally friendly technologies was performed, which allow the removal of man-made deposits in the form of HCAM from the locations of their accumulation to the possible processing points. The results of the reference literature analysis, modern publications in scientific journals show the following [9–11].

Man-made deposits accumulated in domestic coal beneficiation plants, if it is possible to extract and transfer these deposits, should be divided into two parts: dehydrated deposits forming the storage beach, and bottom deposits located under the water surface.

Dewatered deposits have been mined and shipped to consumers as domestic fuel for more than 30 years at most CBP. In some cases, these deposits are used as an admixture for the coal concentrates used for heating of the facilities. Since the main purpose of these deposits is combustion in stoves, boilers and small thermal plants, their extraction and transportation technologies eliminate the use of liquid as a carrier and do not require an extensive, flexible, unstable supply network. Excavators and draglines are used for extraction in this case, while for transportation road transport is used predominantly.

Bottom deposits are hydrocarbon suspensions with a weight concentration more than 60% of which is a solid phase containing a large number of fractions with a size that does not exceed 100 μm. This determines the non-Newtonian rheological parameters of these suspensions, complicates their thickening and drying, and makes promising the use of screw conveyor and conveyor transport for their extraction; conveyor, automobile and railway transport for their transfer, while pipeline hydraulic transport could be used for both cases.

Technologies of the hydrocarbon fuel combustion in fluidized bed boilers provide a prospect for processing and utilization of bottom deposits. This technology allows to solve several important tasks at once: costs saving when replacing coal with a cheaper fuel, optimizing the production process by means of automatization and, yet another important feature, improving the environment, because the efficiency of hydrocarbon fuel combustion is 98%, which allows to minimize harmful emissions [12]. For all instances, the presence of a liquid phase is considered a positive factor that outlines the advantage of pipeline transport as a technologically uniform operation of transportation and processing.

The choice of transportation type for transfering bottom deposits from their extraction location to the location of processing is, to some extent, determined by the transportation distance (Fig. 8). Conveyor transport is preferred for short distances. It is promising to use vehicles for medium distance transportation. While for long-distance transportation railway transport is preferable. It should be noted that pipeline transport has an advantage over any transportation distance.

2. Methods

As it was mentioned above, the screw-conveyor type of transportation has the prospect of being used only for the extraction of bottom deposits of the SF in combination with pipeline transport. Due to the use of a screw conveyor for scooping and lifting the suspension from the bottom of the storage, a non-cavitational flow in the suction nozzle of the pump is ensured. This technological solution for the most part of Ukrainian CBP allows to propose pipeline transport as the most promising one for the extraction and transportation of bottom deposits.

It is recommended to calculate the hydraulic gradient during pressure flow of man-made deposits in the form of HCAM in both horizontal and vertical pipelines according to the following expressions [9, 13–17]:

$$i = \begin{cases} \dfrac{2{,}24\tau_0}{\rho_0 g D}, & \theta < 0{,}016, \\ \dfrac{3{,}326\tau_0}{\rho_0 g D} + \dfrac{128{,}224\eta Q}{\rho_0 g \pi D^4}, & 0{,}016 < \theta < 1{,}577, \\ \dfrac{140{,}96\eta Q}{\rho_0 g \pi D^4}, & \theta > 1{,}577, \end{cases} \quad (1)$$

$$\theta = \frac{8\eta Q}{\pi D^3 \tau_0}, \quad (2)$$

where i – hydraulic gradient; D – pipeline diameter, m; Q – slurry consumption, m^3/h; θ – dimensionless supply; τ_0 – initial tangential stress, Pa; η – effective viscosity, Pa·s; ρ_0 –water density, kg/m^3; g– gravitational acceleration, m/s^2.

Expressions (1) and (2) that the efficiency of pipeline transport use in this case can be adjusted by selecting the concentration of the slurry transported. During the enriched waste transporting to remote SF of CBP, the equipment of which is configured for processing and combustion of the waste in the form of hydrocarbon fuel, the concentration of the aqueous mixture is determined by the condition of the minimum value for pipeline hydraulic resistance. In case the equipment for processing and utilization is located next to the coal beneficiation plant, then it is possible to transport structured suspensions with a concentration of paste-like substance, which significantly increases the efficiency of the entire technological process.

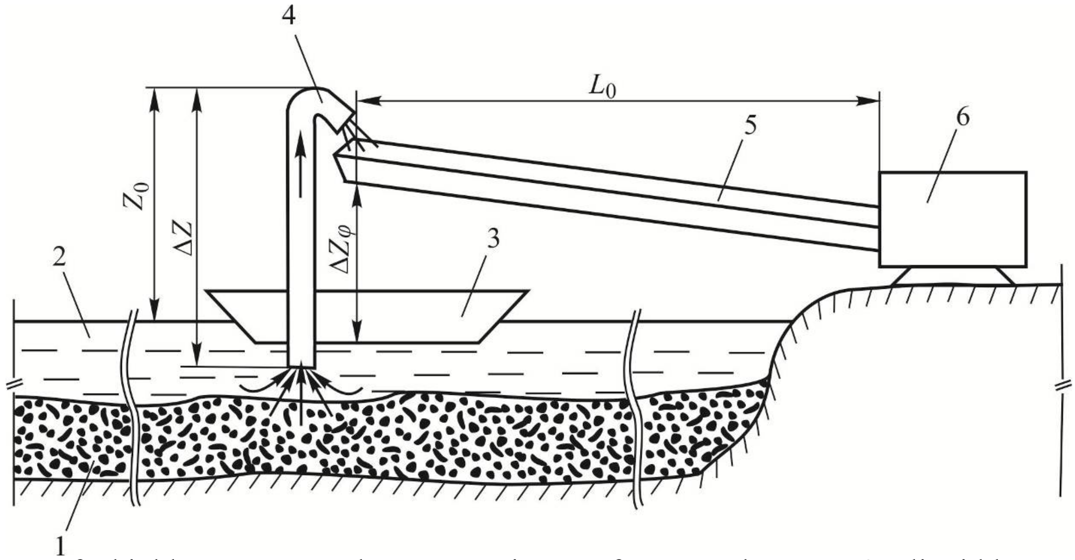
Extraction and utilization of man-made deposits from the SF of the coal beneficiation products assumes their aqueous mixture (slurry) form. That is why it is convenient to use the following sequence of operations for dewatering the SF: the use of biotechnologies to lower the water level in the SF to create conditions for efficient extraction of man-made placers from SF bottom; simultaneous extraction of placers and maintenance of the water level in the SF due to the process of transaspiration; continued lowering of the water level in the SF after the completion of mining to a level that allows ordinary plants growing.

Promising technologies for the production and transportation of man-made deposits in the form of HCAM involve the use of dredgers with special suction pipelines that ensure the supply of a high-density aqueous mixture to the pump or at a geodetic height, which allows its transport to the SF shore under the influence of gravity (Fig. 9).

Taking this into account, the following technologies are promising for the extraction and transportation of man-made deposits in the form of HCAM: pressure HCAM transportation through a vertical pipeline; HCAM flow through a vertical pipeline with aeration; HCAM flow along a vertical pipeline by means of screw conveyor; pressure HCAM flow through a horizontal pipeline; nonpressure HCAM flow through an inclined channel with a rectangular cross-section.

Two cases must be considered for the HCAM pressure flow through a vertical pipeline: extraction of man-made deposits in the form of HCAM from the SF bottom; removal of man-made deposits in the form of HCAM from a water layer with a layer thickness that barely affects the pressure flow of the aqueous mixture.

In case when man-made deposits were removed from a water layer of a significant thickness, it is additionally necessary to consider the process of HCAM flow through a vertical pipeline with aeration: to the aqueous mixture in the vertical pipeline, air is added to the lower part of the pipeline, which reduces the density of aqueous mixture and ensures its transport to the upper section of the pipe. This technique could be considered as an additional influence on the flow of the aqueous mixture in order to prevent cavitation in the pump, although it could be considered as a separate tool of lifting the aqueous mixture of high concentration to the water surface.



1 – a layer of a highly concentrated aqueous mixture of man-made waste; 2 – liquid layer of man-made waste; 3 – dredger; 4 – air lift pipe; 5 – a channel with a rectangular cross-section; 6 – technological object of processing or transportation of the hydrocarbon fuel

Figure 9 – Technology setup for extraction and transport of man-made deposits in the form of HCAM

The HCAM consumption in a vertical pipeline when air is added to the pipeline is calculated according to the following relationship [18]:

$$Q_a = \frac{\rho_0 g \pi D^4}{128{,}224 k_Z \eta}\left[\frac{\Delta Z_0}{\Delta Z} - k_Z \frac{3{,}326\tau_0}{\rho_0 g D} - \frac{1}{1 - a_s C + a_0 P}\right], \quad (3)$$

$$a_s = \frac{\rho_s - \rho_0}{\rho_s}, \qquad a_0 = \frac{\rho_0 - \rho_a}{\rho_a}, \quad (4)$$

where Q_a – consumption of HCAM in a vertical pipeline with added air, m^3/h; k_Z – local hydraulic resistance coefficient; ΔZ_0 – the difference of geodetic heights between the outlet of the main pipeline and the SF surface, m; ΔZ – the difference of geodetic heights between the outlet and inlet of the main pipeline, m; C – weight concentration of the aqueous mixture; P – mass fraction of air in the aqueous mixture; ρ_s – density of man-made placer, kg/m^3; ρ_a – air density, kg/m^3.

Relationship (3) shows that the HCAM transport by means of the added air occurs if the mass fraction of air in the aqueous mixture exceeds a certain value:

$$P > P_0 + \frac{1 - \dfrac{\Delta Z_0}{\Delta Z} + k_Z \dfrac{3{,}326\tau_0}{\rho_0 g D}}{a_0\left(\dfrac{\Delta Z_0}{\Delta Z} - k_Z \dfrac{3{,}326\tau_0}{\rho_0 g D}\right)}, \quad P_0 = \frac{\rho_a}{\rho_s}\frac{\rho_s - \rho_0}{\rho_0 - \rho_a} C, \quad (5)$$

where P_0 – mass fraction of air in the aqueous mixture at which the density of HCAM is equal to the density of water.

In case aqueous mixture with significant values of the initial tangential stress, it is necessary to consider the option of transfering the HCAM along a vertical pipeline by means of screw conveyor. In this case, it is assumed that the aqueous mixture will be lifted up to a height that ensures a nonpressure flow to the shores, where the aqueous mixture will be diluted and its further transportation using pressure transport, vehicles or railway transport:

$$\Delta Z_\varphi = \frac{k_\varphi \tau_0}{\rho^2 g^2}\left(\frac{B}{\eta Q}\right)^{\frac{3}{2}} L_0, \qquad k_\varphi = 1{,}11\sqrt{k_\eta^2 - \frac{3}{2}k_\eta + \frac{1}{2}}, \quad (6)$$

where ΔZ_φ – the lifting height of the aqueous mixture above the SF water surface, which ensures a nonpressure flow in the channel for a distance of L_0, m; ρ – relative density of the aqueous mixture; B – width of the rectangular channel, m; L_0 – transportation distance, m; k_η – channel filling factor which is greater than 1.

In case when the HCAM is delayed between the turns of the screw due to the initial tangential stress, the productivity and power of the screw are determined by the relationships [9, 13–17, 19–21]:

$$Q_0 = \frac{\pi\left(d^2 - d_0^2\right)}{4}\left(\frac{1{,}0539\tau_0}{\rho g \sin{}_0} - \frac{b}{\cos{}_0}\right)nK_0, \qquad N_0 = \left(\frac{\rho Q_0}{1321} + \pi d\tau_0\right)\Delta Z, \qquad (7)$$

where Q_0– volumetric productivity of the vertical screw, m^3/h; d – outer diameter of the screw, m; d_0 – inner diameter of the screw, m; φ_0 – inclination angle of the screw turn, degree; b – thickness of the screw turn, m; n – screw rotation frequency, s^{-1}; K_0 – generalized coefficient of the screw productivity [19, 20]; N_0 – screw's electric motor power, kW.

Depending on the distance of transportation, it is necessary to provide the use of centrifugal type pumps or piston pumps for the technology of HCAM pressure flow through a horizontal pipeline. It is expedient to consider the possibility of the technology of HCAM transporting to the shore using the force of gravity in the form of a nonpressure HCAM flow along an inclined channel with a rectangular cross-section.

3. Results and discussion

The design calculation is performed in order to determine the pump parameters, the pipeline diameter and the total pressure of the pumps, which are necessary to ensure the regulated operating modes of the integrated transportation system with the required flow rate and concentration of the aqueous mixture [7, 13 – 17].

According to expressions (1) and (2), when calculating transportation modes, it is required that the total pressure of the pumps satisfies the following restrictions for the regulated concentration of the aqueous mixture [9, 13 – 17]:

$$\frac{0{,}511}{\sqrt[3]{q}}k_Z L + \rho\Delta Z < \chi H\left(Q_P\right) < \frac{23{,}729}{\sqrt[3]{q}}k_Z L + \rho\Delta Z, \qquad (8)$$

$$\chi = \frac{0{,}3377}{\rho} + 0{,}6623, \qquad q = \frac{Q_P}{Q_K}, \quad Q_K = \frac{\tau_0^4}{\eta\left(\rho_0 g\right)^3}, \qquad (9)$$

where $H(Q_P)$ – data-sheet value of the pump total pressure for the consumption value Q_P, m; χ – conversion coefficient of the flow-pressure parameters (FPP) of pumps from water to HCAM [22]; q – relative consumption of the unit; Q_P– regulated flow rate of the aqueous mixture, m^3/h; Q_K – flow rheological module, m^3/h; L – length of the main pipeline, m; ρ – relative density of the aqueous mixture.

If the use of centrifugal type pumps is intended, then for the regulated concentration of the aqueous mixture, the critical value of the rotation frequency of the impeller is calculated as follows [9]:

$$\omega_{kp} = \frac{3}{\sqrt{\Phi}}\sqrt{\frac{\tau_0}{\rho R^2}}, \qquad \Phi = \frac{R_0}{R}\left(1 + \frac{R_0}{R}\right)\sqrt{\frac{b}{R_0}\left(\frac{2\pi}{z} - \frac{\sigma_l}{R_0}\right)}, \qquad (10)$$

where w_{kp} – critical frequency of rotation of the pump's impeller, s^{-1}; Φ – coefficient that takes into account the geometric and design features of the impeller for the centrifugal pump; b – impeller channel width, m; z – the number of blades of the impeller; σ_l – blade thickness, m; R – outer radius of the impeller, m; R_0 – inner radius of the impeller, m.

When choosing the appropriate curve from the pump characteristic of a centrifugal pump according to requirements (1), the following limitation should be imposed [6]:

$$\omega > \omega_{kp}, \tag{11}$$

where ω – rotation velocity of the pump impeller, s^{-1}.

The diameter of the main pipeline of the integrated transportation system is calculated as follows [9, 13–17]:

$$D = \frac{\alpha' \tau_0}{\rho_0 g \tilde{i}} + \beta' \sqrt[4]{\frac{\eta Q_P}{\rho_0 g \tilde{i}}}, \qquad \tilde{i} = \frac{\chi H(Q_P) - \rho \Delta Z}{k_Z L}, \tag{12}$$

$$\alpha' = \begin{cases} 3{,}522, & q < 0{,}482, \\ 0{,}992, & q > 0{,}482, \end{cases} \quad \beta' = \begin{cases} 0{,}264, & q < 0{,}482, \\ 2{,}458, & q > 0{,}482, \end{cases} \tag{13}$$

where $\tilde{i}$ – effective hydraulic gradient.

According to the calculation results by means of expression (12), the largest value of the diameter is chosen from the standard pipe diameters. After that, the satisfaction of the condition should be checked out:

$$0{,}543 \sqrt[3]{q} \frac{\tau_0}{\rho_0 g} < D < 2{,}54 \sqrt[3]{q} \frac{\tau_0}{\rho_0 g}. \tag{14}$$

If it is satisfied with the condition (14), then by means of equations (1) and (2), the data-sheet value for the pump pressure is specified by the following relationship:

$$H(Q_P) = \frac{k_Z L}{\chi} i + \frac{\rho}{\chi} \Delta Z. \tag{15}$$

The design calculation is completed by checking out the condition (11) and evaluating the power of the electric motors of the selected centrifugal pumps with a 30% margin.

The verification calculation is performed to determine the technological parameters of the integrated transportation system, especially for the calculation of the flow rate and concentration of the aqueous mixture for the operating pump equipment as well as pipeline.

If centrifugal type pumps are used, the pump characteristic curve in the operating area is approximated by the linear function [7–10, 21–24]

$$H_P = \chi(\gamma - \quad Q), \tag{16}$$

where H_P – pump's head during HCAM transportation, m; γ – fictitious pump head when the flow rate is absent [7, 10, 23, 24], m; φ – pressure reduction coefficient [7, 10, 23, 24], s/m^2.

If condition (11) is not satisfied, then another frequency of rotation of the impeller should be selected. For another version, the satisfaction of the restriction for the main pipeline should be checked out:

$$\tilde{\gamma} + \tilde{\varphi}\frac{G}{M}\Theta \geq \tilde{\varphi}\frac{G}{M} + \frac{G}{m}\Theta, \tag{17}$$

$$m = 32{,}05\frac{k_Z\eta}{D^3}, \quad M = \frac{2{,}528}{\rho_0 g D} + \tilde{\varphi}, \quad G = \tilde{\gamma} - \frac{\rho}{k_Z} i_Z, \tag{18}$$

$$\Theta = \frac{40{,}83\eta\tau_0}{\rho_0 g D^4 G}, \quad \tilde{\varphi} = \frac{\varphi\chi}{k_Z L}, \quad \tilde{\gamma} = \frac{\chi\gamma}{k_Z L}, \quad i_Z = \frac{\Delta Z}{L}, \tag{19}$$

where i_Z – geodetic inclination of the main pipeline.

When condition (17) is satisfied, the consumption of the HCAM is calculated according to the following expression:

$$Q = \frac{G}{M}(1 - \Theta). \tag{20}$$

In case of using piston pumps, their flow rate, pressure and power are determined by the following design parameters [13]:

$$Q = 1800z\left(1 - \frac{f}{2F}\right)F\eta_0\frac{Sn}{30}, \tag{21}$$

$$H = k_Z L\frac{128{,}224\eta Q}{\rho_0 g\pi D^4} + k_Z L\frac{3{,}326\tau_0}{\rho_0 g D} + \rho\Delta Z, \quad N = \frac{QH}{270\eta_H}, \tag{22}$$

where z – the number of operating cylinders; F – plunger area, m^2; h_0 – pump volumetric efficiency; f – rod area, m^2; S – stroke of the piston, m; n – the number of two strokes of the piston per minute; h_H – total efficiency of the pump equals 0.3–0.8.

By means of the developed models of the processes that occur during the production and transportation of man-made deposits in the form of HCAM according to promising technologies, requirements for the operation modes of technological systems for the extraction of man-made deposits in the form of HCAM could be described, which allow to prevent the occurrence of critical and cavitation modes, as well as allow to approve the modes and parameters of various types of equipment used in technological systems such as "centrifugal pump + screw conveyor", "centrifugal pump + air lift" and "centrifugal pump + inclined channel". The adaptation of the requirements, approved for the operation modes of technological systems for the extraction of man-made deposits in the form of HCAM, to the conditions of mineral raw material processing waste storage facilities will allow to assess possible technical means and equipment required for the implementation of these technologies.

4. Conclusions

The study has shown that the bottom deposits are hydrocarbon suspensions with a weight concentration more than 60% of which is a solid phase containing a large number of fractions with a size that does not exceed 100 μm. This determines the non-Newtonian rheological parameters of these suspensions, complicates their thickening and drying, and makes promising the use of screw conveyor and conveyor transport for their extraction; conveyor, automobile and railway transport for their transfer, while pipeline hydraulic transport could be used for both cases.

Models of the processes that occur during the extraction and transportation of man-made deposits in the form of highly concentrated aqueous mixtures using promising technologies were developed: pressure HCAM transportation through a vertical pipeline; HCAM flow through a vertical pipeline with aeration; HCAM flow along a vertical pipeline by means of screw conveyor; pressure HCAM flow through a horizontal pipeline; nonpressure HCAM flow through an inclined channel with a rectangular cross-section.

In case aqueous mixture with significant values of the initial tangential stress, it is necessary to consider the option of transfering the HCAM along a vertical pipeline by means of screw conveyor. In this case, it is assumed that the aqueous mixture will be lifted up to a height that ensures a nonpressure flow to the shores, where the aqueous mixture will be diluted and its further transportation using pressure transport, vehicles or railway transport

The model of the process of the pressure flow of a highly concentrated aqueous mixture through the horizontal pipeline, depending on the transportation distance, provides for the use of centrifugal type pumps or piston pumps. Depending on the relative radius value for the undisturbed core of flow, the model takes into account the three most probable flow modes of highly concentrated aqueous mixtures through a circular cross-section pipeline and allows to perform both design and verification calculations.

When the gravity force is used to transport a highly concentrated aqueous mixture to the shore, a mathematical model of nonpressure flow process of an aqueous mixture along an inclined channel with a rectangular cross-section was developed. This model takes into account the channel inclination angle, its width and the rheological parameters of the aqueous mixture and allows to calculate the geometric parameters of the channel, which are necessary to ensure the predefined transportation distance with the required flow rate.

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About authors

Semenenko Yevhen Volodymyrovych, Doctor of Technical Sciences (D.Sc), Senior Researcher, Head in Department of Mine Energy Complexes, Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine (IGTM NAS of Ukraine), Dnipro, Ukraine, evs_igtm@i.ua

Slobodiannykova Inna Leonidivna, Candidate of Technical Sciences (Ph.D), Senior Researcher in Department of Mine Energy Complexes, Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine (IGTM NAS of Ukraine), Dnipro, Ukraine, slobodiannykova@ukr.net

Medianyk Volodymyr Yuriiovych, Candidate of Technical Sciences (Ph.D), Associate Professor, Associate Professor of the Department of Mining Engineering and Education, Dnipro University of Technology, Dnipro, Ukraine, Medianyk.v.yu@nmu.one

Kyrychko Serhii Mykolayovych, Candidate of Technical Sciences (Ph.D), Senior Researcher in Department of Ecology of Natural Resources Development, Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine (IGTM NAS of Ukraine), Dnipro, Ukraine, SMKirichko@nas.gov.ua

Tepla Tetyana Dmytrivna, Master of Science, Senior Engineer of Department of Mine Energy Complexes, Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine (IGTM NAS of Ukraine), Dnipro, Ukraine, tanialitan9@gmail.com

ТЕХНОЛОГІЇ ВІДВЕДЕННЯ ВУГІЛЬНИХ ТЕХНОГЕННИХ ПОКЛАДІВ У ВИГЛЯДІ ВИСОКОКОНЦЕНТРОВАНИХ ГІДРОСУМІШЕЙ

Семененко Є.В., Слободянникова І.Л., Медяник В.Ю., Киричко С.М., Тепла Т.Д.

Анотація. Проведено аналіз існуючих сховищ відходів вуглезбагачення та обґрунтовано перспективні екологічно безпечні шляхи зниження рівня води та відведення техногенних покладів у вигляді висококонцентрованих гідросумішей. На основі проведеного аналізу розроблена методика розрахунку параметрів та режимів гідротранспорту залишків техногенних покладів, що мають високий вміст забруднень у вигляді висококонцентрованих гідросумішей. Розроблено моделі процесів, що відбуваються при видобутку та транспортуванні техногенних покладів у вигляді висококонцентрованих гідросумішей за перспективними технологіями. У випадку гідросуміші зі значними величинами початкового дотичного напруження розроблено модель руху висококонцентрованої гідросуміші по вертикальному трубопроводу при використанні шнеку. В цьому випадку передбачається підйом гідросуміші на висоту, що забезпечує безнапірну течію до дамби обвалування, де відбувається розрідження гідросуміші та її подальше транспортування шляхом напірного гідротранспорту, автотранспорту чи залізничного транспорту. Модель процесу напірної течії висококонцентрованої гідросуміші по горизонтальному трубопроводу в залежності від величини відносного радіусу недеформованого ядра потоку враховує три найймовірніші режими течії висококонцентрованих гідросумішей по трубопроводу круглого перерізу та в залежності від відстані транспортування передбачає використання насосів відцентрового типу або поршневих насосів, що дозволить проводити проектний та перевірочний розрахунки. Для випадку транспортування висококонцентрованої гідросуміші на дамбу обвалування сховища відходів за допомогою сили гравітації розроблено математичну модель процесу безнапірної течії висококонцентрованої гідросуміші по нахиленому каналу з прямокутним поперечним перетином. Дана модель враховує кут нахилу каналу, його ширину та реологічні характеристики гідросуміші та дозволяє розрахувати геометричні параметри каналу, які необхідні для забезпечення транспортування гідросуміші на завдану відстань з потрібної витратою. Результати роботи можуть бути використані для сховищ відходів вуглезбагачення після завершення експлуатації, що сприятиме повному виключенню техногенного впливу на навколишнє середовище, а для сховищ, які знаходяться в експлуатації, застосування запропонованих технологій є способом збереження та обмеження розмірів.

Ключові слова: сховище відходів вуглезбагачення, техногенні поклади, висококонцентровані гідросуміші.