Improvement of the Mine Water Purification Efficiency via Modified Settling Tank

Oleksandr Kovrov[1*], Daria Kulikova[1]

[1] Dnipro University of Technology, Department of Ecology and Technologies of Environmental Protection, Dmytro Yavornytskyi avenue 19., Dnipro 49005, Ukraine
* Corresponding author's email: kovralex1@gmail.com

ABSTRACT

Coal mining technologies always lead to tremendous environmental pollution of air, water resources, lands and biodiversity, both in regional and global scale. The level of environmental safety and ecological quality of the coal-mining region significantly decreases due to mining operations. In particular, mine waters with solid particles and dissolved chemicals are discharged to surface reservoirs. The suspended substances of mine waters, both in solid and dissolved forms, pose a high threat for the ecological and chemical balance of natural waters. Due to the ability to adsorb heavy metals, they play a significant role in the pollution of nearby water bodies. Chemicals not only change the quality of water bodies, but also pose an increased environmental risk to aquatic organisms and the health of the population. The purpose of the paper was to revise the mine water drainage technological scheme of the "Stepova" coal mine, as the subdivision of the "DTEK Pavlogradvugillya" Public Joint-Stock Company (Ukraine), and justify the technical considerations concerning implementation of a horizontal settling tank with unique design. It is justified that such mechanical treatment facility with vertical perforated partitions will significantly improve the overall water quality and provide further treatment in the storage pond. The modeling of the mine water purification process for the conditions of the "Stepova" coal mine was carried out due to the investigation of the kinetics of suspended particles precipitation simulated under laboratory conditions. The obtained dependences allow selecting the most optimal design and technological parameters of the proposed settling tank of advanced design. The values of the expected technological parameters of the proposed settling tank were determined, namely the predicted value of mine water purification efficiency, approximate depth of particles sedimentation in the point of treated water removal from the settling tank, and the hydraulic size of suspended solids. It was established that the implementation of the proposed technological scheme of mine water purification will reduce the concentration of suspended solids to the normative concentrations allowed for discharge into surface water bodies.

Keywords: coal mine, mine water, suspended particles, settling tank, storage pond, hydraulic size of suspended particles, water purification efficiency.

INTRODUCTION

The coal mining industry is a powerful man-made factor influencing the environment, causing negative transformations and pollution on adjacent territories, surface reservoirs and groundwater. The constant inflow of groundwater into the mine workings is associated with drainage and pumping operations with subsequent discharge of mine water into surface reservoirs. The mine water discharges pose a threat to the environment and the population of coal-mining regions due to huge influx values and specific physicochemical properties (Rules for protection of surface waters from return water pollution, 1999).

Therefore, the discharge of contaminated mine water into adjacent surface water bodies is an environmental hazard. Almost all mine water is more or less contaminated with suspended solids (in the form of small particles of coal and rock). The impurities have different dispersed sizes: suspended – particles larger than 0.1 mm,

as well as fine particles – from 100 to 0.1 μm, and colloidal fractions with particle sizes from 0.1 to 0.001 μm. The concentration of suspended solids in the mine water varies from 0.045 to 2–3 g/dm³. The particle size of the suspension can be from 10 to 90 μm (Kulikova A.A. et al. 2020). As a result, the mines of the Western Donbass (Ukaraine) annually discharge up to 0.1 thousand tons of the suspended substances into water bodies (Kharitonov M.M. & Anisimova L.B. 2013).

A characteristic feature of any mine water is the presence of fine (less than 10 μm) aggregate-stable coal or rock particles, the amount of which can reach 50-70% of the total mass of the dispersed phase. In general, the content of particles smaller than 50 μm is 99%. The granular composition of the sludge of mine water in Western Donbass is characterized by the following distribution of particles by size (in percent by weight): more than 50 μm – 7–18%; from 50 to 10 μm – 22–77%; from 10 to 5 μm – 15–35%; less than 5 μm – 17–50% (Voitovych S.P. 2015).

Despite the fact that all mines have treatment facilities, the content of solid suspended particles in the mine water remains quite high. Such a high content of suspended solids in the mine water can be explained as follows (Timukhin S.A. et al. 2014, Gulko S.E. & Gomal I.I. 2013).

First of all, the volumes of horizontal settling tanks are insufficient for most of coal mining enterprises. In addition, there are no regulating tanks at the mines. Because of this, during the operation of the main drains in the automated mode of the pump, the mine water is pumped directly from the settling tanks, where the pulp formed after cleaning the reservoirs. As a result, there is excessive pollution of the water in them. That is why, the very dirty mine waters are discharged directly into surface reservoirs. Second, almost all treatment facilities of coal mining enterprises were constructed with violation of the requirements of the State Sanitary Norms and Rules (State sanitary norms and rules "Permissible doses, concentrations, quantities and levels of pesticides in agricultural raw materials, food products, air of the working area, atmospheric air, water of reservoirs, soil". 2001) that establish the required efficiency of water purification. Third, most of the existing storage ponds, which accept the mine water after treatment in horizontal sedimentation tanks, are silted up, some of which have been completely blurred. Due to these phenomena, the mine water in such ponds is practically not

clarified. In addition, during spring floods the reservoirs of mine water are themselves a threat of contamination of the surrounding areas due to the accumulation of solid particles.

Moreover, some substances may contain many chemical pollutants or absorb heavy metals that play a significant role in the pollution of water bodies in the coal-mining regions. As a result, the discharge of contaminated mine water poses an ecological hazard to adjacent surface water bodies, the water quality of which does not meet the established environmental standards for water bodies. This makes the water of reservoirs and streams unsuitable for domestic and technical water supply. It is also losing its fishery value. In addition, the surface water bodies of coal-mining regions are often used for irrigation of agricultural lands, which can negatively affect the condition of terrestrial ecosystems and the quality of agricultural products. The chemicals contained in mine water change not only the composition of water bodies, but also pose an increased environmental risk to aquatic life and public health (Rasputna T.A. 2011, Gorova A. et al. 2013, Kroik A.A. 2014).

Therefore, the purpose of the work was to improve the existing technological scheme of drainage at the "Stepova" coal mine PJSC "DTEK Pavlogradvugillya", based on the introduction of a unique horizontal settling tank of advanced design. It was proven that such technological improvement will reduce the concentration of suspended solids in mine waters to the environmental standards permissible for discharge into adjacent surface water streams and reservoirs.

MATERIAL AND METHODS

The "Stepova" coal mine, which is a subdivision of PJSC DTEK "Pavlogradvugillya", is located in the City of Pershotravensk, Dnipropetrovsk region (Ukraine). The total inflow of water into mine workings is 300 m³/hr. Water is pumped out to the surface by the main drainage system, which is located in the auxiliary shaft and special drainage wells. On the surface, mine water enters a horizontal settling tank with a capacity of 700 m³. Mine water is pumped from the settling tank into the storage pond, located in the Kosminna gully, and further discharged into Samara River after purification. The existing storage pond with a capacity of 5.3 million m³ was designed to accumulate

Table 1. Average indicators for the content of suspended solids in mine water before and after treatment according to the existing technological scheme

Indicator	Mine water (technological)	Mine water after sedimentation		Normative value*
		In horizontal settling tank	In storage pond	
Concentration of suspended solids, mg/dm^3	55.53	29.69	20.67	10+0.75
The efficiency of mine water purification by the content of suspended solids, %	–	46.5	30.4	–

* Maximum permissible concentration (MPC) in water bodies for cultural and domestic use (State sanitary norms and rules "Permissible doses, concentrations, quantities and levels of pesticides in agricultural raw materials, food products, air of the working area, atmospheric air, water of reservoirs, soil". 2001).

an annual inflow of mine water with the amount of 5.16 million m^3/year from the Pershotravneva group of coal mining enterprises (mines "Jubileynaya", "Pershotravneva" and "Stepova") with bearing capacity of 10 days during the spring floods. Due to the development of mining, there is a steady increase in the inflow of mine water that exceeds 20 million m^3/year. Thus, the storage pond located in the Kosminna gully does not provide clarification of mine waters to environmental and sanitary standards before discharge into the Samara River. The concentrations of suspended solids in the mine waters pumped to the surface by the "Stepova" mine and after mechanical treatment with the specified clarification efficiency in settling facilities according to the existing technological scheme are given in Table 1. In addition, the value of the maximum permissible concentrations of suspended solids in the surface waters of the Samara River, which belongs to the reservoirs for cultural and domestic purposes, at the point of discharge of treated mine water, was provided.

According to the values presented in Table 1, it can be concluded that the content of suspended solids after the existing mechanical treatment of mine water and further discharge of clarified effluents into the Samara River exceeds the normative value twice. Thus, the concentration of suspended particles does not correspond to the standards of water bodies for cultural and domestic use. Under the conditions of insufficiency of natural water reserves in the studied region, the population of the areas adjacent to the mine most often use storage ponds, both for irrigation of agricultural lands and for recreational purposes (recreation, swimming, fishing). Therefore, reducing the level of water pollution in them to the normative values becomes especially relevant. The existing settling tanks do not meet modern requirements (Rules for protection of surface waters from return water pollution. 1999), which provide for the discharge

of pollutants into surface water in an amount that should not exceed their maximum permissible concentration. That is why the further increase of the efficiency of mine water purification via removal of fine suspended particles will increase the ecological safety of the region.

However, the methods and technologies (Gao P. et al. 2020), currently in use do not allow performing this in the best way. Nevertheless, implementation of mechanical treatment facilities with innovative innovated design may intensify the process of sedimentation of the smallest suspended particles and increase the quality of mine water. In order to comply with environmental safety conditions in the areas under the influence of mining enterprises, a technological scheme of drainage (Fig. 1) for the "Stepova" mine with application of modified horizontal settling tank was proposed.

Improved design of the settling tank (Kolesnyk V. et al. 2013) is used for purification of mine water from insoluble mechanical impurities of polydisperse composition (Fig. 2). The main difference between the proposed settling tank and the existing ones is that its body is made in the form of a flume. This flume gradually narrows from the point of entry for the treatment of contaminated mine water to the point of the discharge of clarified water. The depth of the proposed settling structure is gradually increasing.

The angle of inclination of the bottom of the proposed settling tank to the horizontal plane is taken $\alpha \approx 30°$. The recommended value of an angle will allow minimizing the length of a settling tank. As a result, the retention time of mine water in the settling tank will be reduced. In addition, it will allow the sediment to effectively slide onto the bottom side of the settling tank.

The angles of narrowing of the settling tank are taken as $\beta \approx 84°$. The recommended values of the angles will provide the best conditions for the precipitation of suspended solids of mine water.
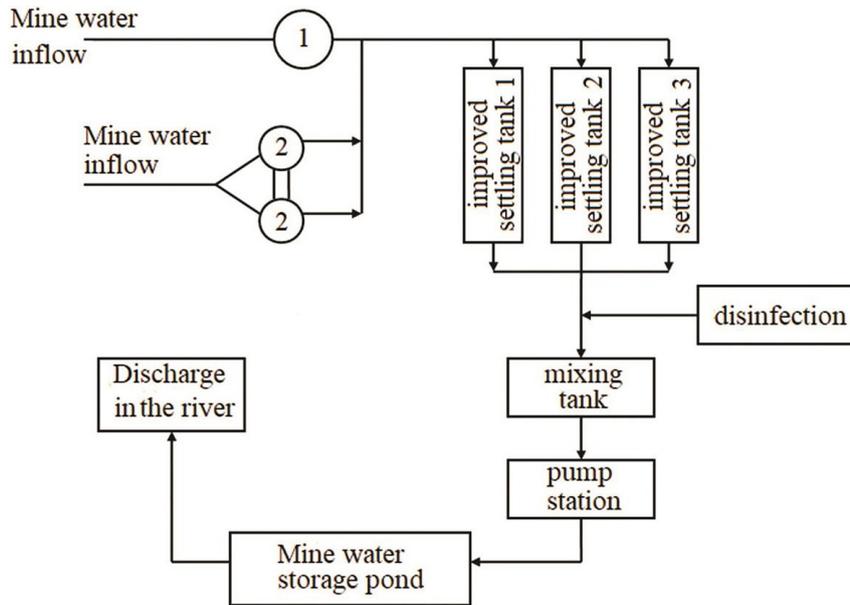
Figure 1. Improved technological scheme of mine water drainage for the
"Stepova" coal mine: 1 – auxiliary shaft; 2 – drainage wells

Thus, based on the accepted values of angles and the initial width of the proposed settling tank $B_0 = 10$ m, its final width will be equal to $B_k = 6$ m. Accepting the general length of the tank is $L = 16$ m, its depth in the point of water outflow will be $B_k = 9.2$ m.

In order to establish the laminar mode of mine water flow mode, perforated partitions are placed inside the proposed settling tank. Equalization of the horizontal velocity of the flow along the depth and length of the settling structure accelerates the process of precipitation of suspension particles on
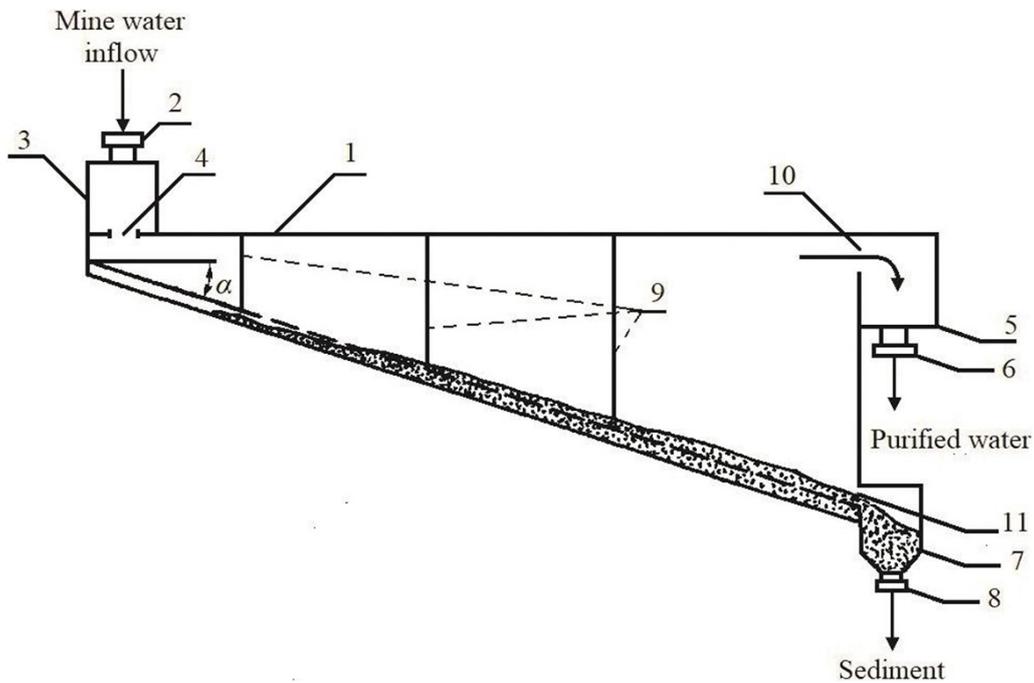
Figure 2. Improved design of the settling tank for mine water purification: 1 – body of the settling tank; 2 – the pipeline for mine water supply; 3 – jet distribution tray; 4 – perforated holes at the bottom of the jet distribution tray; 5 – catchment tray; 6 – pipeline for drainage of clarified mine water; 7 – receiving hopper for the sediment storage and compaction; 8 – the pipeline for removal of compacted sludge; 9 – vertical perforated partitions; 10 – the hole for draining clarified mine water; 11 – the hole for sludge drain; α is the angle of inclination of the settling tank bottom

the bottom of the proposed settling tank, which increases the efficiency of mine water clarification. It is recommended (Kolesnyk V.Ye. & Kulikova D.V. 2013) to install four or five perforated partitions in the proposed settling tank. With this number of partitions, the efficiency of mine water purification will be the highest. In the points of the contaminated mine water inflow and removal of purified water, the partitions are located at a distance of 3.5 m from the end walls of the proposed settling tank. All other partitions are located at equal distances from each other. In addition, the following forms of partition openings and the type of their location relative to each other are proposed: – square perforation with straight rows by square, with offset or with diagonally offset rows; – rectangular perforation with straight or offset rows; – hexagonal perforation with offset rows. The recommended shape of the holes and the type of their location relative to each other allows obtaining the maximum value of the throughput of the perforated area of the partition (k), the value of which will be 0.826. As a result, the indicator of mine water purification efficiency will significantly increase. The calculation of the design parameters of the proposed settling tank was to determine the height (general and working), width and length of the treatment facility at the location of the perforated partitions and the end walls.

The total height of the i-th partition (H_i^0, m) of the advanced settling tank is determined by the formula:

$$tg\alpha = \frac{H_i^0}{L_i}, m \qquad (1)$$

where: L_i – distance from the point of inflow of mine water in the settling tank to the i-th partition.

The working height of the i-th partition (H_i, m) is determined without taking into account the height of the settling tank board, which is 0.3 m according to the recommendations (State building standard "Sewerage. External networks and facilities. The main provisions of the design". 2013), i.e. $H_i = H_i^0 - 0.3$.

The width of the i-th partition (b_i, m) of the settling tank is determined by the formula:

$$b_i = 2 \cdot \left(\frac{L_i}{tg\beta}\right) + B_K, m \qquad (2)$$

where: L_i – length from the i-th partition to the end wall of the settling tank, m. Workspace (S_i, m²) for the i-th partition of the advanced settling tank is determined by the formula:

$$S_i = b_i \cdot H_i \qquad (3)$$

The initial data for the design of settling tanks are dynamic sedimentation curves of suspended solids. Mine water contains many fine clay particles, as well as particles of organic matter, which affect the aggregative and sedimentation stability of suspended solids. These particles cannot precipitate even with prolonged settling, because they are colloidal. In order to purify mine water, which forms a colloid-dispersed system, it is necessary to separate the liquid and solid phases. It is possible to intensify the separation process, i.e. to violate the aggregative stability of such a system, due to the aggregation of particles into larger colloids under the action of coagulants with subsequent separation of aggregated particles by settling. Aluminum sulfate $Al_2(SO_4)_3 \cdot 18H_2O$ has become widespread as coagulant for the treatment of mine water; it is hydrolyzed in water with formation of colloidal aluminum hydroxide $Al(OH)_3$. This leads to the adhesion of contaminant particles with colloidal hydroxide particles. This increases the rate of gravitational deposition of the formed flakes, which, in contact with each other, form larger and larger systems that quickly precipitate. In the process of sedimentation of suspended solids, the size, density and shape of the particles, as well as the physical properties of the polydisperse system are constantly changing. This complicates the establishment of the dependences of the sedimentation process of the substances suspended in mine water without prior investigation of the kinetics of their precipitation, the data on which can be obtained only experimentally. The process of sedimentation of suspended solids can be simulated in laboratory cylinders with a small height of the liquid level. This enables to relatively quickly determine the necessary parameters for the calculation of real settling tanks with high water levels.

Determination of the sedimentation rate for suspended particles (hydraulic size) in laboratory cylinders is recommended to be carried out according to the method described in (Horova A.I. et al. 2012). According to this technique, samples of wastewater, with pre-determined the initial concentration of suspended solids C_0 (mg/dm³), are used for sedimentation in laboratory cylinders of 0.54 m in height. The mine water with suspended solids is poured into eight laboratory cylinders. After adding the coagulant solution (aluminum sulfate), the water is stirred at certain time intervals (15, 30, 45, 60, 75, 90, 105 and 120 minutes) and further water samples are taken from the cylinders, in which the

residual concentration of suspended solids is determined. The selected suspension samples are filtered through paper filters. The weight of the paper filter (M, mg) is determined before filtering. The filter with the precipitate is dried in an oven at a temperature of 105 °C within one hour (to the constant weight), cooled and weighed. The mass concentration of suspension particles in the cylinder sludge at certain time intervals is determined by the formula:

$$C = \frac{(M_1 - M)}{W}, mg/dm^3 \qquad (4)$$

where: M and M_1 – weight of paper filter before and after filtration of suspension sample, mg; W – the volume of the sample of the suspension taken from the cylinder, dm³.

The efficiency of water clarification is determined by the relative number of suspended particles that precipitate over the time, according to the formula:

$$P = \frac{C_0 - C_t}{C_0} \cdot 100, \% \qquad (5)$$

where: C_0 – initial concentration of suspended solids in water before its clarification, mg/dm³; C_t – concentration of suspended solids in clarified water at certain specified intervals, mg/dm³.

The condition under which at different heights of water level equal effects of clarification of sewage are provided, serves as a criterion of sedimentation similarity which is expressed by a nonlinear ratio:

$$\frac{t_i}{T_i} = \left(\frac{h}{H_i}\right)^n \qquad (6)$$

where: t_i – the duration of the process of settling (seconds) of mine water in the laboratory cylinders height $h = 0.54$ m; H_i – variable depth of the real settling tank, which corresponds to the height of the i-th partition and the final end wall, m; T_i – the duration of the process of settling water (seconds) while achieving the same efficiency of its clarification, i.e. the percentage of precipitation of suspended particles (P, %) at a variable depth of the proposed settling tank (H_i, m); n – an indicator characterizing the ability of the particles to aggregation during settling at the rest (for mine water treated with coagulant, $n = 0.25$ is selected). This ratio

allows calculating the time required to obtain a given efficiency of mine water purification based on the results of technological modeling to bring the results of the experiment to natural conditions. Hence, the duration of settling of mine water T_i (in seconds), while achieving the same efficiency of its purification and variable depth of the proposed settling tank, is determined by the formula:

$$T_i = t_i \cdot \left(\frac{H_i}{h}\right)^n \qquad (7)$$

The values of the hydraulic size, i.e. the sedimentation rate of the polydisperse suspension, corresponding to a given percentage of suspended particles precipitation (P, %) are determined by the formula:

$$U_i = \frac{H_i}{T_i}, mm/s \qquad (8)$$

In order to establish the values of the expected technological parameters of the proposed settling tank, calculated for the drainage conditions of the "Stepova" coal mine, the distances l at which the suspended particles with certain hydraulic size will precipitate, were determined according to the formula:

$$l = \frac{b_i}{4 \cdot ctg\beta} - \sqrt{\left(\frac{b_i}{4 \cdot ctg\beta}\right)^2 - \frac{Q}{2 \cdot k \cdot U_i \cdot ctg\beta}}, m \qquad (9)$$

On the basis of the obtained data, a graph of the dependence of the depth of sedimentation of particles depends on the distance at which they can precipitate, at a given value of the efficiency of purification mine water, taking into account the design parameters of the proposed settling tank. The obtained dependences allow determining the settling depth of the suspension particles in the place of discharge of clarified mine water in the end wall of the settling structure at a given value of purification efficiency (P, %) and the accepted length (L, m). The final result of the technological modeling of the mine water purification will be a graphical dependence of the change in the depth of settling of suspended particles on the value of mine water purification efficiency at given design parameters of the proposed settling tank. This dependence will determine the

values of the expected technological parameters of the proposed settling tank, namely the predicted value of the efficiency of mine water purification, the approximate depth of sediment particles in the point of drainage of treated water from the settling tank and the hydraulic size of these particles.

RESULTS

The design parameters of the proposed settling tank of advanced design at the locations of the perforated partitions and the end wall were determined on the basis of formulas (1) – (3). The obtained results, which are necessary for further calculations, are presented in Table 2.

The results of the experiment to determine the amount of suspended solids that sediment to the bottom of the laboratory cylinders, depending on the duration of the process of settling mine water, are presented in Table 3.

The results of calculating the values of the duration of settling of mine water (T_i, seconds) in the proposed settling tank while achieving the same efficiency of its purification (P, %) and variable water level (H_i, m), presented in Table 4.

The calculated values of the hydraulic size (U_i, mm/s), which characterize the mode of sedimentation of the suspended particles in the proposed settling tank at a given percentage of purification efficiency of mine water (P, %) are presented in the Table 5.

On the basis of the results, it was established that the values of the hydraulic particle size of the suspension and the purification efficiency of mine water at a given depth of the proposed settling

Table 2. Design parameters of the proposed settling tank with advanced design

Design parameters	The value of the design parameters of the settling tank at the location				
	Partitions				End wall
	I	II	III	IV	
Overall height H_i^0, m	2.0	3.8	5.5	7.2	9.2
Working height H_i, m	1.7	3.5	5.2	6.9	8.9
Width b_i, m	8.63	8.0	7.37	6.74	6.0
Work area S_i, m²	14.7	28.0	38.3	46.5	53.4
Distance L_i from the place of mine water inflow to the i-th partition of the settling tank, m	3.5	6.5	9.5	12.5	16.0

Table 3. Results of the kinetics of suspended solids precipitation by settling mine water in laboratory cylinders

Parameters	Mine water (technological)	Duration of mine water settling, t_i, min							
		15	30	45	60	75	90	105	120
Concentration of suspended solids, mg/dm³	65.0	46.15	35.1	27.95	20.8	16.9	13.0	10.4	7.8
Efficiency of mine water purification, P, %	–	29	46	57	68	74	80	84	88

Table 4. Dependence of the mine water purification efficiency on the duration of mine water sedimentation at various depths of the proposed settling tank

Efficiency of mine water purification, P, %	The duration of mine water sedimentation in the proposed settling tank at a depth corresponding to the height of the i-th partition and the end wall				
	H_1=1.7 m	H_2=3.5 m	H_3=5.2 m	H_4=6.9 m	H_K=8.9 m
29	1199	1436	1585	1702	1813
46	2398	2872	3171	3403	3627
57	3597	4308	4756	5105	5440
68	4796	5744	6342	6806	7254
74	5995	7180	7927	8508	9067
80	7193	8616	9513	10210	10880
84	8392	10052	11098	11911	12694
88	9591	11488	12683	13613	14507

Table 5. Dependence of mine water purification efficiency on suspended particles sedimentation rate (hydraulic size) at different depths of the proposed settling tank

Efficiency of mine water purification, P, %	Hydraulic size of suspended particles trapped in the settling tank at the depth that corresponds to the height of the *i*-th partition and the end wall, mm/s				
	H_1=1.7 m	H_2=3.5 m	H_3=5.2 m	H_4=6.9 m	H_K=8.9 m
29	1.418	2.437	3.281	4.054	4.909
46	0.709	1.219	1.640	2.028	2.454
57	0.473	0.812	1.093	1.352	1.636
68	0.355	0.609	0.820	1.014	1.227
74	0.284	0.488	0.656	0.811	0.982
80	0.236	0.406	0.547	0.676	0.818
84	0.203	0.348	0.469	0.579	0.701
88	0.177	0.305	0.410	0.507	0.614

tank, which corresponds to the height of the *i*-th partition and end wall, can be described by exponential dependencies, namely:

- at the depth of the settling tank $H_1 = 1.7$ m (height of the first partition): $U_o = 3.6105 \cdot e^{-0.0344 \cdot P}$;
- at the settler depth $H_2 = 3.5$ m (height of the second partition): $U_o = 6.2006 \cdot e^{-0.0344 \cdot P}$;
- at the settler depth $H_3 = 5.2$ m (height of the second partition): $U_o = 8.3462 \cdot e^{-0.0344 \cdot P}$;
- at the settler depth $H_4 = 6.9$ m (height of the second partition): $U_o = 10.32 \cdot e^{-0.0344 \cdot P}$;
- at the settler depth $H_K = 8.9$ m (height of the second partition): $U_o = 12.49 \cdot e^{-0.0344 \cdot P}$.

The reliability of the approximation of the obtained results is $R^2 = 0.9964$.

The obtained dependences allow determining the hydraulic size of the suspended particles,

which settle at a certain depth of the proposed settling tank for a certain period of time, corresponding to the value of the purification efficiency of mine water, presented in Table 3.

On the basis of the actual amount of polluted mine water pumped by the "Stepova" coal mine (300 m³/hr), the improved technological treatment scheme envisages the installation of three settling tanks of improved design. Thus, the inflow of mine water entering the treatment facilities, the proposed settling facility per one settling tank will be $Q = 100$ m³/hr (0.0278 m³/s).

The results of calculating the distances (*l*, m) at which the particles of the suspension with a certain hydraulic size can precipitate at a certain depth (H_i, m) of the proposed settling tank at a given value of mine water efficiency are presented in graphical dependences (Fig. 3).
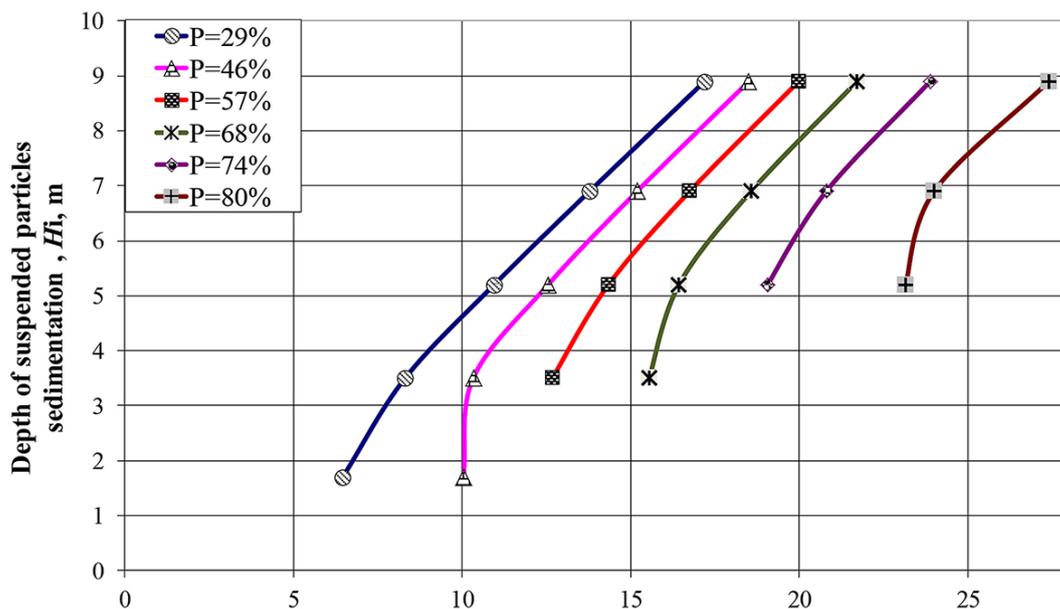
Figure 3. Dependences of the suspended particles sedimentation depth on the distance at which they can precipitate

Table 6. The dependency of the depth of particles sedimentation on a given value of the mine water purification efficiency

Efficiency of mine water purification P, %	29	46	57	68
The depth of sedimentation of the suspension particles H_{os}, m	8.1	7.4	6.4	4.5

Table 7. The value of the expected technological indicators of the proposed settling tank for the conditions of "Stepova" coal mine

Calculated efficiency of mine water purification, P, %	The approximate depth of sedimentation of the suspended particles, H_{os}, m	Hydraulic size of suspended particles, U_0, mm/s
87.0	0.13	0.626

The obtained dependences allow determining the depth (H_{os}, m) of the sedimentation of the suspended particles in the place of removal of clarified water from the settling tank of advanced design (end wall). These depths at a given value of purification efficiency (P, %) of mine water and the accepted length of the proposed settling tank (L = 16 m) are presented in Table 6 and Figure 4.

With the help of this dependence, it is possible to determine the value of the expected technological indicators for the proposed settling tank, namely the predicted value of mine water purification efficiency, approximate depth of sediment particles on the bottom at the point of removal of treated water from the settling tank (end wall with the height H_K = 8.9 m), and the hydraulic size of these particles.

The values of the expected technological indicators at the given design parameters of the proposed settling tank for the drainage conditions of the "Stepova" coal mine PJSC "DTEK Pavlogradvugillya", are presented in Table 7.

$$Hos = -0.0025x^2 + 0.1527P + 5.7677$$
$$R^2 = 0.9979$$
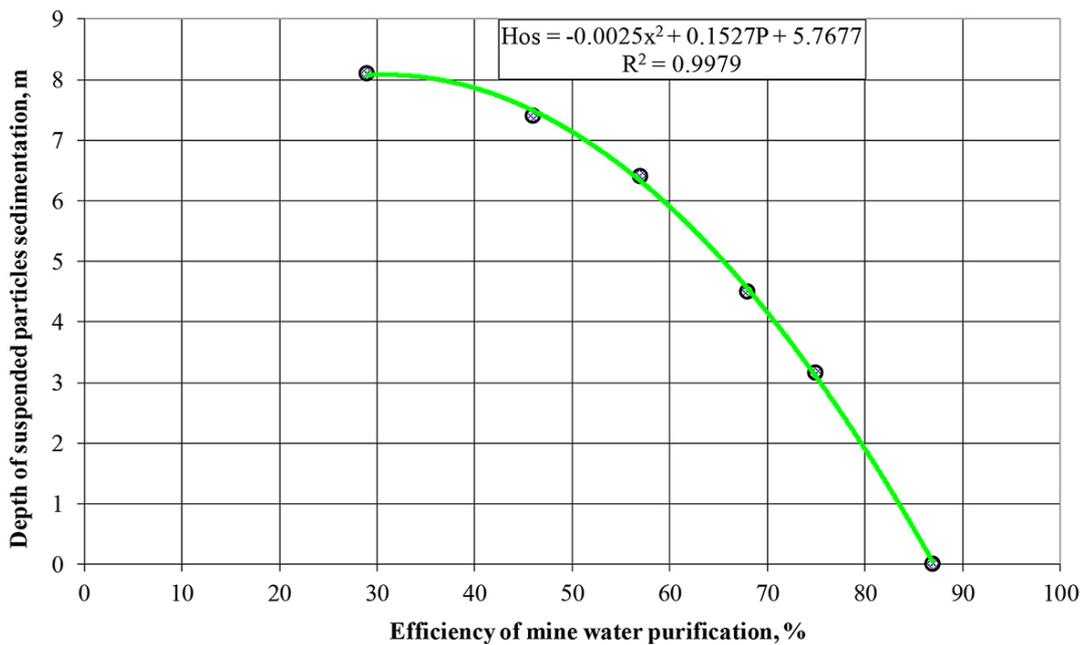
Figure 4. Dependence of the depth of suspended particles sedimentation on the value of the mine water purification efficiency

Table 8. Indicators of the efficiency of mine water purification before and after treatment by application of the improved technological scheme

Indicator	Mine water (technological)	Mine water after sedimentation in:		Normative value*
		improved settling tank	storage pond	
Concentration of suspended solids, mg/dm³	65.0	8.45	5.88	10+0.75
Efficiency of mine water purification, P, %	–	87	30.4	–

* Maximum permissible concentration (MPC) in water bodies for cultural and domestic use [State sanitary norms and rules "Permissible doses, concentrations, quantities and levels of pesticides in agricultural raw materials, food products, air of the working area, atmospheric air, water of reservoirs, soil". 2001].

The concentrations of suspended solids in mine waters pumped by the "Stepova" coal mine before and after mechanical treatment according to the proposed technological scheme are presented in Table 8.

On the basis of the data presented in Table 8, it can be concluded that the total efficiency of purification of the mine waters of the "Stepova" coal mine PJSC "DTEK Pavlogradvugillya" after mechanical treatment will be 87%. Implementing the modified settling tank with vertical partitions proved to be suitable environmental design. According to the Ukrainian sanitary norms and rules regarding water reservoirs for cultural and domestic use the final content of suspended solids in the mine water, the effluent after purification will not exceed the maximum permissible concentrations.

CONCLUSIONS

The paper deals with an urgent scientific and practical problem related to the discharge of polluted mine waters into surface reservoirs in the coal mining regions of Ukraine.

It was proposed to improve the existing technological scheme of drainage and mine water mechanical purification for the conditions of "Stepova" coal mine PJSC "DTEK Pavlogradvugillya" (Ukraine), based on the implementation of the modified horizontal settling tank with further after-treatment in the storage pond.

According to the physical modeling of the mine water purification process, the graphical dependence of the change in the settling depth of suspended particles on the value of mine water purification efficiency of the proposed settling tank was plotted. This dependence allows determining the value of the expected technological parameters of the proposed settling tank, namely the predicted value of the efficiency of mine water purification, the approximate depth of sediment particles in the place of drainage of the treated water from the settling tank and the hydraulic size of these particles. The expected total efficiency of purification of mine waters after mechanical treatment is 87%.

The implementation of the proposed technological scheme of drainage at the existing coal mining enterprise will reduce the concentrations of suspended solids in mine water to the environmental standards.

REFERENCES

1. Rules for protection of surface waters from return water pollution. 1999. Normative Regulation of the Cabinet of Ministers of Ukraine, 65. https://zakon.rada.gov.ua/laws/show/465-99-%D0%BF#Text. (in Ukrainian).

2. Kulikova A.A., Sergeeva Y.A., Ovchinnikova T.I., Khabarova E.I. 2020. Formation of mine water composition and analysis of treatment methods. MIAB. Mining Inf. Anal. Bull., 7, 135–145.

3. Kharitonov M.M., Anisimova L.B. 2013. Ecological assessment of surface waters quality for Dnipro river basin in Dnipropetrovsk region. Ecology and nature management, 17, 75–85.

4. Voitovych S.P. 2015. Geochemical features of groundwater and mine water in coal basins of Ukraine (evidence from Chervonohrad mining area and Central Donbass). Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 2, 23–30.

5. Timukhin S.A., Ugol'nikov A.V., Dolganov A.V. 2014. Problems of design and operation of mine drainage complexes. News of the Ural State Mining University, 3(35), 68–73.

6. Gulko S.E., Gomal I.I. 2013. Analysis of composition and state of hydrotechnical buildings of coal mines. Journal of Donetsk mining institute, 1(32), 78–84.

7. State sanitary norms and rules "Permissible doses, concentrations, quantities and levels of pesticides in agricultural raw materials, food products, air of the working area, atmospheric air, water of reservoirs, soil" №137 dated of 20.09.2001 (DSanPiN 8.8.1.2.3.4–000–2001), 376. (in Ukrainian).

8. Rasputna T.A. 2011. Research of influence regularity by mining on water pond. The Journal of Zhytomyr State Technological University/Engineering, 3(58), 184–188.

9. Gorova A., Pavlychenko A., Kulyna S., Shkremetko O. 2013. The investigation of coal mines influence on ecological state of surface water bodies, Annual Scientific-Technical Collection Mining of Mineral Deposits. Leiden, The Netherlands: CRC Press / Balkema, 303–305.

10. Kroik A.A. 2014. Ecological safety of subterranean water on the territory of mining enterprises. Journal of Water Chemistry and Technology, 36(4), 198–202.

11. Gao P., Wang Yu., Zhang Z., Cao Yi., Liu Z., Zhang D. 2020. The general methods of mine water treatment in China. Desalination and water treatment, 202, 183–205.

12. Kolesnyk V., Kulikova D., Kovrov S. 2013. In-stream settling tank for effective mine water clarification In: Annual Scientific-Technical Collection. Mining of Mineral Deposits. CRC Press/Balkema, Netherlands; Taylor & Fransis Group, London, UK, 285–289.

13. Kolesnyk V.Y., Kulikova D.V. 2013. Justification of quantity perforated partitions and intervals their placement in improved sedimentation tank of mine water. Naukovyi visnyk Natsionalnoho Hirnychoho Universytetu, 4, 92–98.

14. State building standard. Sewerage. External networks and facilities. The main provisions of the design. (DBN B.2.5–75:2013). Kyiv. Minregion Ukrainy, 223 (in Ukrainian).

15. Horova A.I., Kolesnyk V.Y., Kulikova D.V. 2012. Physical modeling of precipitation process of the suspended materials in physical model of sedimentation tank for mine water treatment. Naukovyi visnyk Natsionalnoho Hirnychoho Universytetu, 3, 92–98.