Open pit mine wastewater filtration in the overburden rock debris: case study

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Abstract. Discharge of untreated quarry water into natural water reservoirs is unacceptable for environmental reasons. This circumstance is especially relevant for coal mining regions with a high density of mining enterprises. Treatment of quarry waste water at mining enterprises is a necessary process, provided for in the design documentation. It is due to the significant pollution of quarry water by suspended solids, dissolved salts and organic substances. In addition to expensive sorbents (e.g. zeolite), overburden rocks, confined to the mined area of coal deposit, are used for construction of filtering dams. They are used to construct treatment facilities designed for the entire lifetime of the mining enterprise. Thus, their permeability and purification capacity should be maintained for decades. The movement of filtered water in such massifs is subject to the known laws of filtration. Filtering dams should provide both a free movement of water and the required level of its purification. This is achieved by selecting the appropriate geometry of filter dams (their sizes, base slopes) and the choice of overburden capable of providing the required level of purification in a long and qualitative term. The article presents the results of studies of the geometry of the filtering massif and the methodology of selection of overburden used for the construction of filtering dams.

1 Introduction

Typical schemes of water treatment in open pit coal mining include the collection of all water inflows in the pit sump, their transportation to treatment facilities, accumulation and primary treatment of large suspended solids in the settling pond, accumulation of pre-

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treated water in the clarified water pond, treatment through the filtering dam, ultraviolet after treatment at the disinfection station and discharge into the natural water reservoirs.

It is important to note that a large number of studies by national and foreign authors are devoted to the issue of filtering and treatment of pit and mine water, including the use of innovative technologies and nanomaterials [1-15]. The use of zeolites, usually provided by the project of water treatment facilities of a quarries, allows maximum purification of water from harmful impurities, which is especially relevant at an increasing anthropogenic load on the region [16, 17]. At the same time zeolites themselves are quite a rare and valuable sorbent, which limits their wide application in conditions of intensification of mining operations in the Kemerovo region. Application of overburden rocks, extracted during deposit development, as filtering load will allow to reduce the technogenic load of mining works on ecology of the region and to reduce costs for construction of filtering massifs as the main elements of purification facilities [18-25].

2 Materials and Methods

The purpose of the study is to establish the influence of the granulometric and petrographic composition of overburden rocks used to build filter dams, the mineral content of rocks and their physical properties on the quality of catching suspended and dissolved substances.

The experiment consisted in the construction of three ditches at the top site of the dump of Kamyshansky open pit, which are trenches of trapezoidal cross-section with a slope towards the slope of the dump. The appearance of the ditches is shown in Fig. 1.

Fig. 1. Trenches in the experimental site

The dimensions of the ditches were chosen as follows: length 15 m (0.64 of the length at the bottom of the filtering dam of the waste water treatment facility), width 2.5 m, depth from 0 m in the start part to 1.5 m at the end. The width and depth were chosen based on the possibility of further waterproofing of the bottom and slopes of the ditch in order to prevent infiltration of the pit effluents, passed through the waste water treatment facility (WWTF), into the body of the dump. Waterproofing was carried out in 2 longitudinal strips of polyethylene film 3 m wide (Fig. 2).

Fig. 2. Waterproofing of the bottom and slopes of the WWTF ditch

In the experiment were used coarse-clastic blasted rocks (fine-grained and coarse-grained sandstone on carbonate cement) and loose coal in order to identify the possibility of their use as a filtering load.

Since the coal was a fine-dispersed soil, its granulometric analysis was carried out by a sieve method without washing with water.

The data of particle size distribution of coal are shown in Fig. 3.

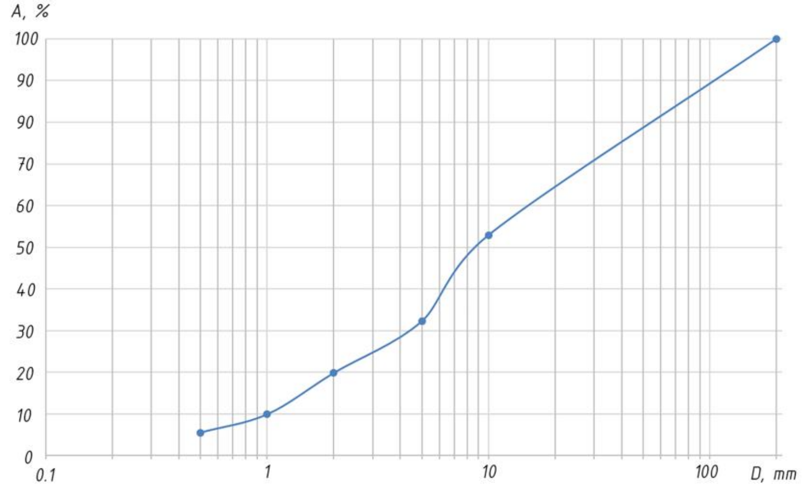

Fig. 3. Integral curve of coal particle size distribution

Analysis of the data of the particle size distribution showed that the effective diameter of coal particles d_{10} = 1.01 mm, the control diameter $d_{60} \approx$ 10.4 mm, the median one $d_{50} \approx$ 8.4 mm.

The shape of soil fragments is roughly coarse. The ground belongs to the coarse-clastic clayey ground with clay aggregate. The coefficient of uniformity of the soil

$$C_u = \frac{d_{60}}{d_{10}} = 10.3 \quad (1)$$

shows that this rock belongs to the soils with heterogeneous grain size distribution. At the same time, mechanical suffosion in this soil is unlikely ($C_u < 30$) and is possible only at the edge of the massif at the outlet of water from the water-saturated layer.

Significant content of blue clays (up to 20% by weight, in the data of grain size distribution clays content are not considered) excludes the use of this soil as a filtering load for cleaning of quarry wastewater.

At the same time if there is a technical possibility for removal of clay admixture this soil can be used as filtering loading. This is confirmed by the data of the study of its water permeability.

Without clay admixture, according to the current classification, the soil would be highly permeable, as its permeability coefficient took values from 3 to 30 m/day.

Clay admixtures lead to the fact that in the field conditions, the water poured into the receiving pond escapes extremely slowly: the volume of water of about 300-400 liters passes through a 3 m long massif within 3-4 hours. The rock, represented by fine-, medium- and coarse-grained sandstones, is much more permeable due to complete absence of clay inclusions. The granulometric composition of the blasted sandstones was not investigated due to the significant content of coarse (>200 mm) material.

Further, rock was placed into the prepared excavations with a loader.

After the forming of the WWTF, a leveling of the bottom of the ditches was carried out in order to establish the exact distances between the sampling points, the slopes of the corresponding segments and the total length of the WWTF.

Leveling was carried out by means of an exact leveller and a levelling rod with checkerboard centimeter divisions. Thus in points 1 and 5 a levelling rod was installed directly near the body of WWTF, and in points 2, 3, 4 a levelling rod was installed in a piezometer for water sampling.

The obtained longitudinal profile of the WWTF is shown in Fig. 4.

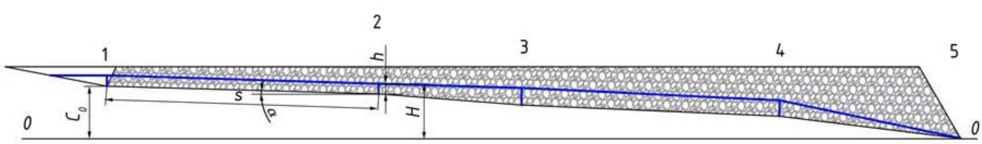

Fig. 4. Longitudinal profile of the filtering massif: 1, 2, 3, 4 – water sampling points; piezometers are installed at points 2, 3, 4

After the installation of the WWTF, they were washed with water. Washing within 10 days was carried out to reduce the content of dust particles present on the pieces of rock.

Further, were carried out measurements of such parameters of water flow in the body of WWTF as its level in piezometers and in point 1, pressure gradient between sampling points, speed of level decrease from the moment when water supply to the receiving pond was stopped. Mechanized water withdrawal (water dewatering) in the sampling points was not carried out, so the dynamic head h_d of water flow in piezometers corresponds to the static head H.

3 Results and Discussion

To calculate the hydraulic characteristics of the steady non-uniform movement of the filtered water, consider the drawing in Fig. 4. It's distinguished the conventional plane of comparison *0–0*. Without taking into account velocity pressures, which are extremely low in real conditions of filtering water motion in the body of the WWTF, and with the head in any flow section equal to the mark of free water surface in this section [26-28], it was expressed the head H in the section of point 2 above the comparison plane *0–0* through the height of water column h, measured vertically:

$$H = C_0 - s \cdot i_0 + h\,, \tag{2}$$

where C_0 – distance from the reference plane *0–0* to the waterproof bottom of the WWTF in point 1 ($s = 0$); s – distance from the initial section (from point 1), counted along the bottom of the WWTF; $i_0 = \sin\alpha$ – slope of the WWTF bottom, α – slope angle of the WWTF bottom at the considered segment.

Piezometric slope of the flow is:

$$I = -\frac{dH}{ds} = i_0 - \frac{dh}{ds} \tag{3}$$

As geometrical parameters of the flow at each section *n* (1-2, 2-3, 3-4, 4-5) repeat configuration of the bottom of the WWTF, the filtration path length L_n can be taken as the length of the bottom of the corresponding section s_n, including flow section 2-3, corresponding to the straight underpressure.

Filtration of water in the body of WWTF occurs in the zone of complete saturation. Since the blasted rock mass, of which the filtering load is formed, contains a sufficient number of small fractions, which is confirmed by studies of the grain size distribution of overburden, deposited in the dumps, the flow rate *u* and the pressure gradient (piezometric flow gradient) *I* are connected by the linear law of filtration:

$$u = k\left(i_0 - \frac{dh}{ds}\right) = k\left(-\frac{dH}{ds}\right) = kI. \tag{4}$$

Based on the data obtained as a result of technical leveling, excesses of water level *dh* in piezometers and head *dH* relative to the reference plane *0–0*, corresponding to the elevation of sampling point 5, along the length of filtration path have been calculated. Corresponding values are given in Table 1.

Table 1. The values of pressure drops on the segments of the filtration path in the WWTF during steady-state movement

Section between the points	Head drop *dH*, m, relative to the reference plane *0–0*	Head drop in piezometers *dh*, m	Section length *s*, m
1–2	0.36	0.012	5.25
2–3	0.378	- 0.137	2.75
3–4	0.555	0.025	5.0
4–5	0.745	0.3	3.5

Table 1 shows that the head values *dH* relative to the reference plane *0–0*, corresponding to the height mark of sampling point No. 5, are equal to the sum of the water column height in the corresponding point and the excess of this point h_n relative to the next point along the filtration path length.

Positive values of *dh* correspond to a relative drop in head, negative – to its relative increase. These values are quite difficult to operate in their pure form, since different sections in the filtration direction have different significance in hydrodynamic relation, changing from discharge sections with positive values of dh to back-up sections with negative values of *dh*.

Measurement of filtration rate u at individual sections of the WWTF, planned in further studies, will allow to calculate in situ permeability coefficient of rock mass used for construction of filter arrays [29-32].

The filtration coefficient is a constant value for this particular filter media used in the experiment. Mechanical and chemical suffosion can be neglected, since no increase in suspended solids removal and deformation of the WWTF body in the process of water filtration was observed.

The magnitude of the head H after the water supply to the receiving pond is stopped changes nonlinearly with time. Fig. 5 shows the character of changes in the height of the water column at points 1–4.

The dynamics of water column change was not carried out at the end point 5 of the WWTF, i.e. at the place of filtered water flow discharge, due to the complex configuration of the flow (very unstable in height and width), as well as the uneven bottom of the ditch and the presence of large debris of the rock mass [33-38].

Analysis of the data shown in Fig. 5 showed that in the points characterizing the beginning and the end of the section of the water-supply curve (points 2 and 3), intensity of water level reduction in the body of WWTF after stopping water supply to the pond-receiver sharply decreases with time: $\frac{dh_t}{dt} = 0.875$ mm/minute for point 2; $\frac{dh_t}{dt} = 2.75$ mm/minute for point 3 (dh_t is the change in the head in the piezometer over the time interval dt) compared to the points characteristic of the beginning of the discharge curves (points 1 and 4), where such a pattern is not observed: $\frac{dh_t}{dt} = 5.25$ mm/minute for point 1 and $\frac{dh_t}{dt} = 6.875$ mm/minute for point 4.

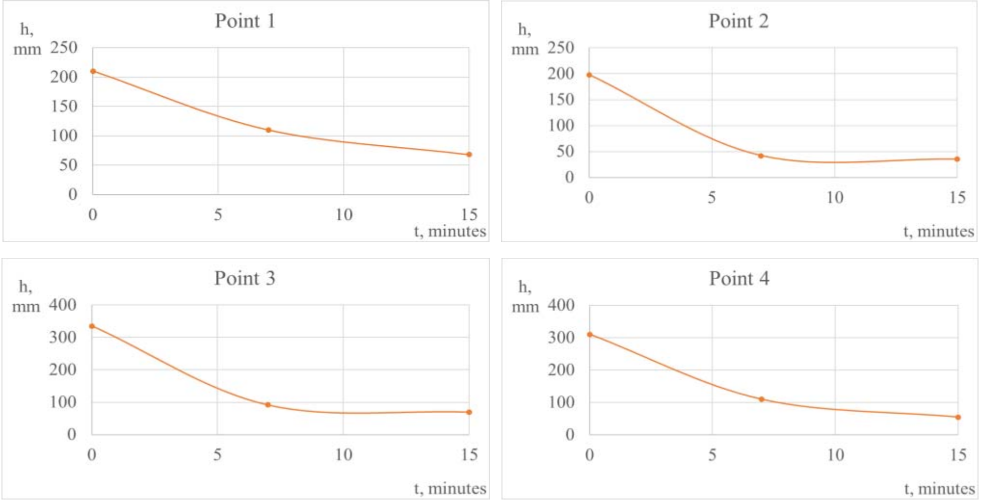

Fig. 5. Dependence of water column height (h) at sampling points on time (t) after stopping water supply to the WWTF pond-receiver

This is due to the fact that recharge of the section of the back-up head curve 2–3 is carried out for some time after the stop of water supply to the pond-receiver due to the volumes of liquid contained in the section of the discharge curve 1–2. At point 4, due to a sharp increase in the slope of section 4–5, intensification of discharge occurs (i.e. increase in the pressure gradient and, consequently, the speed of filtering flow). This is confirmed by more intensive reduction of water level in the piezometer of this point in comparison with points 2 and 3.

Conclusions

The obtained dependence of pressure gradients in the body of the artificial filtering massif in relation to the waterproof base can be used for the design of filtering dams of treatment facilities in order to control the flow rate in different lithological sections of the filtering dam to improve the quality of treatment of quarry waste water.

The lithologic contents of the overburden rocks have a decisive influence on their use as filter loading for treatment dams. If such factors as granulometric composition, base slope, etc., favor the use of overburden rocks as a natural filter, then 10-20% clay content completely prohibits their use for treatment facilities of mining enterprises.

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