

Theoretical Background of Quarry Wastewater Filtering Through Filters of Coarse-Grained Blasted Overburden Rocks

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Abstract. Quarry wastewater is the main pollutant for the surface and underground natural water bodies during mining operations. Negative impact is expressed in contamination of natural reservoirs with fine suspended particles and salt solutions. To reduce the harmful impact of quarry wastewater they are treated using artificial filtering massifs. Such massifs are commonly constructed using artificial and natural sorbents. The retention of particles in the filtering layer is the result of two main processes: the adhesion of fine particles of suspension to the surface of the particles of the artificial filtering massif and the jamming of coarser particles in the pores of the filter layer. Simultaneously with the processes of contaminants capture, the process of contaminants washing out of the filter array may occur. It occurs when the particle size distribution of the filter layer is unappropriated and filtration speeds are high, and may be accompanied by deformation of the filter media.

1 Introduction

When a mine wastewater containing solid suspended particles is filtered, the basic physical properties of the porous medium – porosity, permeability, water saturation and volume weight – are changed. These phenomena are called filtration deformations of the soil.

Such filtration deformations refer to:

- soil colmation or silting – settling in the pores by coarser soil of small particles transported by a filtration flow. In this case, the permeability of the soil (if it is colmated) may be significantly reduced and filtration heads may increase, which may cause other filtration deformations or reduce the stability of slope structures [1];
- mechanical suffosion or the removal of sand particles from coarser soil, or the movement of fine particles from one part of the soil to another one; and chemical suffocation, manifested by the dissolution of salts in the soil [2, 3]. Suffosion is a very common type of filtration deformation, which may occur at the base of dams, in earth dams and in stone mounts of slopes with high uniformity coefficient of size distribution of the soil;

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- seepage head, or destruction of an unloaded part of a rock massif. This type of the filtration deformation usually occurs in sandy soils. Such deformation is accompanied by increased localized filtration. The weight of the soil itself, the weight of the load suspended in water, and the adhesion of the soil are impeded to seepage head. Works of K. Tertsagi, R. N. Davidenkov, B. C. Baumgart, B. C. Istomina, A. A. Nichyporovich and others are devoted to the problems of prevention such filtration deformations.

2 Materials and Methods

In general, the filtration process is the movement in a porous medium of a liquid carrying solid and gaseous particles and deforming the soil.

It is possible to observe uniform and non-uniform filtration deformations. Uniform filtration deformation is defined as deformation in which the cross-section ω of the "effective filtration stream" changes only in time, but does not change in coordinate, i.e. $\partial\omega/\partial x = 0$. Non-uniform filtration deformation is defined as deformation in which the cross-section of the filtration jet changes both in time and length.

The case of "pure" suffosion is an example of uniform filtration deformation, when along the length of the pore channel evenly detach small particles that no longer precipitate, and are carried out by the filtration flow outside the boundaries of the considered section of the porous medium. An example of non-uniform filtration deformation is the case of suffosion, when fine particles are detach and deposited during the filtration process. In this case the degree of pore channel filling changes both in time and in coordinate. The same can be said about the process of siltation or colmation of the porous medium by the incoming flow with suspended fine particles, when the cross-section of the pore channels changes in time and along the length of the filtration path.

The volume of suspended solids a^* carried in a unit of time by the filtration flow will be

$$a^* = \eta_1 u \quad (1)$$

where u – true speed of liquid movement in pore channels; η_1 - "reduced" value of solids flow at $u = 1.0$.

The differential equation of colmation in this case takes the form of

$$\frac{\partial\omega}{\partial t} = \bar{A} \frac{\partial u}{\partial x} \quad (2)$$

where $\bar{A} = \eta_1 \cdot \eta_2$, η_2 – proportionality coefficient.

Further, on the basis of the Saint-Wennan equation:

$$\frac{\partial\omega}{\partial t} - \frac{\partial Q}{\partial x} = 0, \quad (3)$$

which expresses the relationship between the change in square ω in time and the change in fluid flow Q along the length of the flow with unsteady motion, we get the dependence between the change of porosity in time and the change of filtration speed by length in the form:

$$\frac{\partial n}{\partial t} + \frac{\partial v}{\partial x} = 0, \quad (4)$$

where n is the porosity of the colmated soil; v is the average filtration rate.

In [4] considered the pressured laminar flow of liquid with suspended solids through porous media and attempted to determine the dependencies between the main elements of the flow.

The most important in this study can be considered the establishment of a parameter characterizing the possibility of penetration and retention of suspended solids in the pores of the soil, determining the value of the coefficient of permeability during the movement of

the suspension and finding the time required for soil colmation. As the mentioned parameter the author accepted the ratio of average diameter D of soil pores to the size d of parts of the suspension:

$$\eta_i = \frac{D_i}{d_i} \tag{5}$$

From the experiments of A.N. Patrashev [4] it was obtained that the value η for colmation should be about 5-6 and that the smaller particles of suspension will be mainly carried by filtration flow outside the colmatable soil section.

It is obtained the expression to determine the average value of the coefficient of permeability k at a depth of l_k after time t (t – duration of the colmation process):

$$k = \frac{k_0}{\left(1 + \frac{u_0 \delta^2 t}{2D}\right)^2}, \tag{6}$$

where k_0 is the initial value of the coefficient permeability of the colmatured soil; u_0 is the initial true speed of the liquid in the soil pores; D is the average value of the soil pore diameter; δ is concentration of the suspension.

The thickness of the colmated layer of soil l_k , to which the given value of average coefficient of permeability k belongs, is equal to the maximum depth of mass penetration of suspended particles into the soil. It is expressed in the form of

$$l_k = \delta \cdot u_0 \cdot t \tag{7}$$

To determine the time T_k required for soil colmation by particles of a given size (when the size of the pore in the volume of the colmated soil becomes smaller than the size of suspended particles, the process of colmation is considered complete), the author gets the dependence

$$T_k = \frac{2D}{u_0 \delta^2} \left(\frac{D}{d} - 1 \right) \tag{8}$$

A.N. Patrashev in his studies accepts that the main forces (friction and centrifugal forces) affecting suspended solid particles in terms of their retention by the porous medium during filtration are gravity. The latter forces are caused by the curvature of the pore channels.

It should be noted, however, that such assumptions are true for filtration of a suspension containing fine quartz particles. In the case of filtration of clayey and similar suspensions, the physical and chemical factor of suspended solids adhesion to soil particles and then to settled solids appears [5-10].

The theory of water filtration through a layer of granular material by D.M. Mints is most widespread [7, 8]. This theory considers the filtering effect ΔC as the total result of two processes:

1) the suspended particles concentration decrease ΔC_1 due to their adhesion to the grains of the filter layer;

2) the suspended particles concentration increase ΔC_2 due to filtering water dissipation of previously adhered particles, i.e.

$$\Delta C = \Delta C_1 - \Delta C_2, \tag{9}$$

where ΔC the amount of suspended solids detained by the filter layer with thickness x in the time period t .

Thus, the filtering kinetics equation is written as

$$-\frac{\partial C}{\partial x} = b \cdot C - a \cdot \rho, \tag{10}$$

where b and a – filtration parameters that determine the intensity of adhesion and detachment of particles, respectively, and depend on the conditions of filtration; ρ – saturation density of the granular layer by sediment.

The equation of the balance of substances in this case has the form:

$$\frac{\partial \rho}{\partial t} = -V \frac{\partial C}{\partial x}, \quad (11)$$

where V is the filtering speed.

The following general process equation is obtained in private derivatives:

$$\frac{\partial^2 C}{\partial x \cdot \partial t} + a \cdot V \frac{\partial C}{\partial x} + b \frac{\partial C}{\partial t} = 0 \quad (12)$$

Equation (12) has an infinite solution series and is difficult to use in practice. By introducing new independent variables, the equation is transformed into a functional dependence [11]:

$$\frac{C}{C_0} = f(x, t), \quad (13)$$

in which parameters b and a are presented in a criterial form and are compared with reference materials when testing new filter media.

A number of researchers believe that there is no detachment of stuck particles from the soil grains, citing the fact that is not observed removal of stuck particles with the passage of clean water through the colmated soil.

K. Ives [12, 13] offer the equation linking coefficient of permeability with geometrical characteristics of filter media and sedimentation function:

$$\lambda = \lambda_0 (1 + \beta \cdot \delta)^y \cdot \left(1 - \frac{\delta}{f}\right)^z \cdot \left(1 - \frac{\delta}{\delta_y}\right)^x, \quad (14)$$

where β is the geometric constant characterizing the density of the grain layer packing; δ is the specific sedimentation of particles in a unit of the layer volume; δ_y is the limit value of specific sedimentation corresponding to the layer saturation; x, y, z is the empirical degree indicators; λ_0 is the filtering coefficient at $t = 0$.

3 Results and Discussion

It is indicated that the mathematical formulas describing the process of particle capture, allow to calculate the parameters of filtration with a certain degree of accuracy only in the auto model areas, limited by the condition of the experiment [14] as a result of the analysis of the current state of the theory of water filtration in granular media. In this case it is necessary to carry out preliminary experiments to determine the parameters of technological modeling or correction factors. It is concluded that the creation of a single filtering theory is a difficult task.

It is shown for suspensions occurring in water supply practice the main cause of suspension particles retention by porous medium is the adhesion of these particles to the sand particles and to the settled particles of the suspension [15].

Significant experimental work on the study of river water pollution of sand filters was carried out by Eliassen R. etc. [16-18]. The experiment concepts was as follows. The experimental rectangular cross section filter with three metal and one glass walls was arranged vertically. Five piezometers were positioned at the height of the filter to measure pressure, which also served to sample the moving mixture. The filter was filled with sorted sand. The initial average porosity of the sand load was 40.8%. River water, containing

(after its settling) suspended particles by volume about 0.005%, was passed through the filter. At the same time, the filter clogging time (and thus the time of experience) was about 100-120 hours. After proper preparation of the filter, samples of the mixture moving in the filter were taken from all five tubes at different times. During each experience, two or three microscopic analyses were made to determine the average particle size of the samples taken.

The total filtration flow rate (and therefore the average filtration rate) was kept constant by means of a speed regulator and the pressure varied accordingly. Further studies have shown that the suspension concentration is kept constant during the filtration of the suspension only when the speed in the pore channels does not change. Concentration will increase with increasing speed of the suspension, and, conversely, concentration of the suspension δ will decrease with decreasing speed of the mixture [19].

In Kuzbass quarry wastewaters before the artificial filtering massifs has the following main pollutants:

- suspended solids (containing mineral and coal particles);
- soluble salts (sulfates, carbonates, chlorides, nitrates, nitrites entering the water as a result of leaching activated by the infiltration of groundwater and surface water through the destroyed rocks, as well as the washout of explosion products during drilling and blasting operations);
- oil products (entering the soils and then into the water during the work of the extraction, loading and transport equipment).

Waters are subject to biological contamination in the smallest degree during mining. It contamination is activated when the water is saturated with oxygen and, therefore, the subsequent active growth of microalgae and aerobic bacteria.

The negative impact on the environment of discharged wastewaters from mining enterprises is the chemical contamination of natural surface waters with salts of heavy metals, organic substances (oil products), as well as particles of coal and overburden rocks.

Average concentrations of suspended solids and oil products in Kuzbass wastewaters are given in the table.

Table 1. Content of some contaminants in quarry wastewaters of Kuzbass open pit mines.

Enterprises (open pit mines)	Pollutants content, milligram per liter (mg / l)	
	suspended particles	petroleum products
“Kedrovsky”	20.5/67.2	0.42/0.8
“Chernigovets”	73.5/200	0.03/0.08
“Mokhovsky”	316.6/1094	4.82/20
“Krasnobrodsky”, site #1	712/5964	4.36/13
“Krasnobrodsky”, site #2	11.2/65.6	1.5/5
“Krasnobrodsky”, site #3	158.9/3300	2.81/10.2
“Kiselevsky”	93.5/210	8.26/28
“Prokopyevsky”	21.3/254	0.32/2.2
“Krasnogorsky”	36.7/142	0.03/0.07
“Tomusinsky”	979.7/1315.5	0.12/5
“Mezhdurechye”	398/1103.1	1.43/4.0
“Sibirginsky”	71.2/2580	0.02/0.12
“Olzherassky”	47.9/493.5	0.68/7.0
“Zadubrovsky”	23.4/40	0.012/0.012
Mean value (to mean values)	211.74	1.77

Note: The numerator has the mean values and the denominator has the maximum ones.

Special attention should be paid to the cleaning of industrial wastes from oil products. Oil products are one of the most toxic contaminants, the content of which, like suspended solids, also varies widely.

Taking into account the fact that the maximum allowable concentration for petroleum products for pure water in different regions varies from 0.1 to 1 and more mg / l, and for waters of fishery this value is 0.05 mg / l, treatment of quarry waste water from those contaminant is also an actual task [20, 22, 23].

Microelement analysis of industrial effluents was carried out on specific pollutants in the quarry effluents.

The content of dissolved calcium salts in water and changes in their concentration depend in vivo on the equilibrium of carbon salts and carbon dioxide. In very hard waters, calcium carbonate may be released if the carbon dioxide balance is disturbed and the concentration of carbon decreases.

Analyses have shown that manganese is usually present in water in dissolved form as divalent ions, and in non-dissolved form as hydroxides of higher oxidation levels.

At the initial concentration of manganese 0.42 mg / l (“Kedrovsky” open pit mine) after purification its amount decreases to 0.27 mg / l. At small concentrations (10^{-2} - 10^{-4} mg / l) the amounts of arsenic, selenium and fluorine remain constant. Reduction of lead concentration by 10^{-3} mg / l and increase of strontium by 0.4-1.1 mg / l have been noted.

The data obtained in the laboratory confirm our conclusions about the possibility to influence the microcomponent and macrocomponent composition of the industrial effluents as a result of their filtration through the overburden rock massif.

The composition of mine water after soaking in it various samples of sandstone and siltstones showed that the number of macroelements can increase, or decrease or remain constant depending on the composition of the rock. For example, the number of calcium cations decreases on all samples, while magnesium increases on three samples of rock and decreases on one siltstone.

The amount of iron ions is constant on three samples (0.5 mg / l), and on the fourth (siltstone) increased to 2 mg / l. Dependence of macroelement composition of water on different composition of carbon waste (siltstones, sandstones) can be traced on other indicators: chlorides, nitrates, carbonates, ammonia, hardness and oxidation [21].

Concentrations of strontium, barium, titanium decrease on all samples. Concentrations of aluminium, iron, silicon, copper, nickel, zirconium may decrease or increase with respect to the original values.

4 Conclusion

1. The existing scheme of quarry wastewaters treatment at the enterprise has both advantages and disadvantages; taking into account further development of mining works and potential increase of production capacity, it is necessary to reconstruct treatment facilities and adjust their parameters.

2. Preliminary assessment of overburden rocks in the “Kamyshansky” open pit shows that it can be used as an artificial filtering massif load.

3. The location of the artificial filtering massif prototype with three parallel branches has been selected to determine the best cleaning performance. It is proposed to use a reinforced concrete tray, a metal pipe and natural soil as a bedding surface.

4. Geometric parameters of the artificial filtering massif are proposed to be preliminary determined by the existing methodology, taking into account amendments to the qualitative and quantitative composition of the quarry wastewaters, as well as physical and mechanical properties of overburden rocks of the site.

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