Ecology and safety in the technosphere: current problems and solutions IOP Publishing
IOP Conf. Series: Earth and Environmental Science **50** (2017) 012035 doi:10.1088/1755-1315/50/1/012035

A Method of Effective Quarry Water Purifying Using Artificial Filtering Arrays

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Abstract. The development of open pit mining in the large coal basins of Russia and other countries increases their negative impact on the environment. Along with the damage of land and air pollution by dust and combustion gases of blasting, coal pits have a significant negative impact on water resources. Polluted quarry water worsens the ecological situation on a much larger area than covered by air pollution and land damage. This significantly worsens the conditions of people living in cities and towns located near the coal pits, and complicates the subsequent restoration of the environment, irreversibly destroying the nature. Therefore, the research of quarry wastewater purifying is becoming an important mater for scholars of technical colleges and universities in the regions with developing open-pit mining. This paper describes the method of determining the basic parameters of the artificial filtering arrays formed on coal pits of Kuzbass (Western Siberia, Russia), and gives recommendations on its application.

Introduction

Industrial complexes concentrated in the most developed part of the biggest Russian coal basin – Kuzbass (Kemerovo Region, Western Siberia) – have the decisive influence on the ecological condition of environmental objects [1]. The decrease of production from the mid-1990s in the coal-mining areas of Kemerovo region has not led to the improvement of its environment [2-3]. The negative effect made by coal-mining enterprises on the natural environment has complex origination. We observe an intensive pollution as a result of the influence of coal deposits open-pit mining on the atmosphere, water resources and landscape complexes. Complex processes of environmental anthropogenic changes caused by open pits' operations have brought to light the problem of surface water pollution near large mining segments [4-5]. Currently, the volume of coal production in Kemerovo region amount to more than 210 million tons per year [6-7]. According to the report of supervisory environmental authorities in 2015, coal-mining enterprises of Kemerovo region disposed 1.239 billion m3 of wastewater, including inadequately treated – 228.8 million m3 [8-9].

The main source of pollutants' transportation into the surface waters near the territories of open-pit mines is quarry water, resulting from massive extraction of groundwater of developed coal seams for draining purpose [10-11].

The issue of wastewater treatment in open pit mining of mineral deposits causes great ecological problems [12-15]. Due to the constant tightening of the requirements to the quality of discharged wastewater their treatment in settling basins and purifying ponds does not provide the parameters of maximum permissible concentration (MPC). Moreover these treatment facilities occupy large areas of land. Also it should be noted that usually there are several distanced weir wastes, which location is changed during development of mining. For example, JSC "KuzbassRazrezUgol" (Kuzbass, Western Siberia, Russia) has 32 places of water use, taking into consideration that the structure of this coal company consists of 7 large open pits [16-18].

As an alternative coal enterprises may use expensive wastewater purifying equipment, which include different devices like hydroclassifiers, electrocoagulators, modules of water clarifying and sludge thickening, modules of sludge dewatering, finalizers, aerators and so on [19-24]. Complex of such equipment for purifying highly voluminous quarry wastewater may totally cost up to several million dollars. So because of these large expenses at present time even prosperous Kuzbass coal open pits conduct wastewater treatment in artificial filter arrays made of waste coal [9]. But the quality of purifying this way is quite low and does not match MPC [6].

Taking into account the upward trend in open pit mining of coal in Kuzbass, and as a consequence inevitable growth of the volume of discharged water by the coal enterprises, further study of improvement the environmental safety of mining operations is needed.

Materials and methods

The main pollutants of waste waters sent from the open-pit territory to the water reservoirs are suspended solids and oil. However, the qualitative composition of mining waste water is specific in every open-pit mine of Kuzbass and depends on the formation conditions, climatic factors, and the way of coal seams mining within the boundaries of a particular open-pit area. Reducing the level of anthropogenic impact on water bodies adjoining the territories of Kuzbass open-pit mines is one of the urgent problems of water use ecological safety.

Currently the most common method of wastewater treatment on the Kuzbass open-pits is a mechanical purifying by clarification in settling ponds and filtration through arrays of overburden rocks [9].

Except specially piled rock arrays, already existing open-pit dumps can be also used as the filters.

For using waste dumps or any other similar arrays of rock in water purification schemes it is strictly necessary:

- to choose one or another particular dump (filtering array) and identify the ways of supplying and discharging water;
- to test the ability of the dump to pass all the clarified water at the given water disposal in the period of maximum flow;
- to test the ability of the selected dump to clarify water to the maximum permissible concentration rates.

It is desirable to use both active and inactive truck and railway external dumps, located near the water disposal. The content of the slacking rocks in the array must not exceed 30%. When choosing a dump the following issues should be observed: topography of the bedding surface in order to determine the most appropriate places of clarified water supply, the direction and length of the filter, the area of water seepage from the dump [25-31]. Water may be supplied to the dump by gravity or by pumping. To avoid infiltration into the bed of the dump rock the bases should be low permeable [32-36].

The check of the selected dump's (filtering array's) ability to purify water from suspended solids to the required extent is made by the following formula:

$$C_{out} = C_{in} \exp\left(-\eta L\right) \leq C_{mpc}, \tag{1}$$

where C_{out} – the concentration of suspended solids in the water outlet from the filter array, mg/l; C_{out} – the concentration of suspended solids in contaminated water, mg/l; L – filter length, m; C_{mpc} – the maximum permissible concentration of suspended solids , set for the water disposal, mg/l .

So when $C_{out} < C_{mpc}$ it can be assumed that this dump meets water purification requirements.

The technical solution to the problem of wastewater treatment from suspended solids in the filters of coarse rocks can be searched in two ways. The first of them is to use the discrete rocks arrays existing at enterprises as filters, after a preliminary examination. Such arrays include overburden rock arrays, refuse heaps and various technological dumps.

The second way is the purification of water in specially constructed filtering arrays of rocks and semi-rocks, which are, as a rule, the mining waste.

The filters' design depends on the terrain and the properties of the upper layers of the ground of the underlying surface, and the parameters are determined by the volume of water supply, its pollution density and filtration characteristics of the filtering material.

The main filter elements are the unit for supplying polluted water, filtering array, filter body, a device for collecting and draining the purified water. If there are any natural or artificial hollows (ravines, logs, river beds of dried-up rivers, trenches, ditches, abandoned mines and others) near the water disposal and low permeable rocks that lie at their sides and bottom, the latter can be the body of the filter, fig. 1. In this case, water may be supplied to the filter array by gravity on a surface or pipe and by pumping. The filter array is piled from rocks that meet the relevant requirements using trucks and bulldozers.

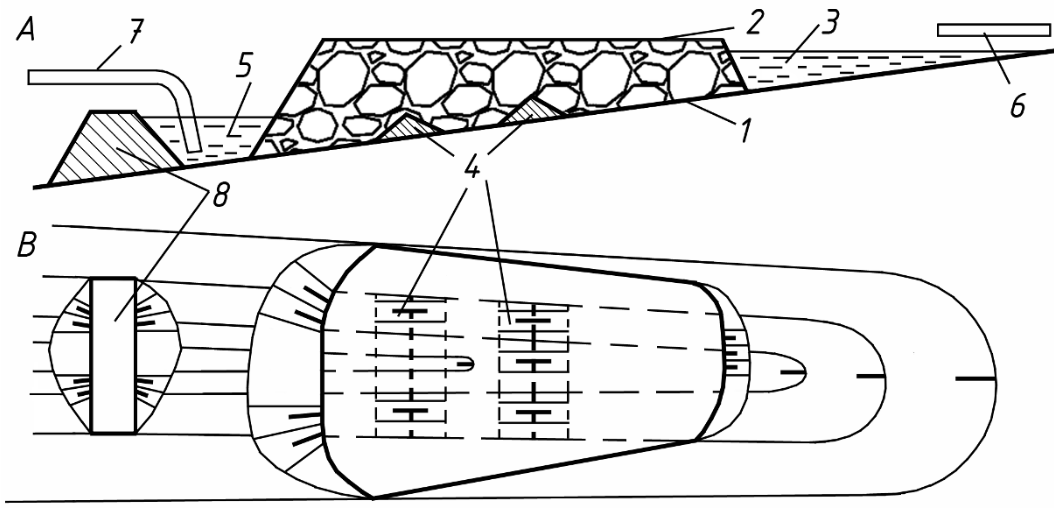

Figure 1 - Construction of the filtering array with waterproof stopping: A – longitudinal section; B – plan view; 1 – the bottom of the filter; 2 – filtering array; 3 – receiver for contaminated water; 4 – waterproof stopping; 5 – lodgement of purified water; 6 – conduit for feeding for contaminated water; 7 – conduit for purified water removing; 8 – water retention levee.

A pond appeared as the result of water infiltration becomes a device for supplying and routing water in the filter. The retaining dam for collection and turning out the purified water must be constructed of the rocks with low hydraulic permeability lower filter array. The disposal of pure water from water reservoir is produced by gravity in chutes or pipes in order to prevent the erosion of soil and new water pollution. When water discharge by gravity is impossible or there is a necessity of its subsequent use for enterprise needs pumping station should be installed.

If rocks of the sides and bottom of the hollows are characterized by high hydraulic permeability, to prevent infiltration of water into the ground and possible pollution of aquifers bottom filter forming is necessary. The bottom is arranged by dumping the low permeable rocks, followed by their layout and thickening by bulldozers. To prevent losses the water for cleaning must be supplied by chutes or pipeline.

When surface is horizontal and rock foundation has low filtration rate, for receiving polluted water and direction of seepage the filter body in the filter array is used (Fig. 2).

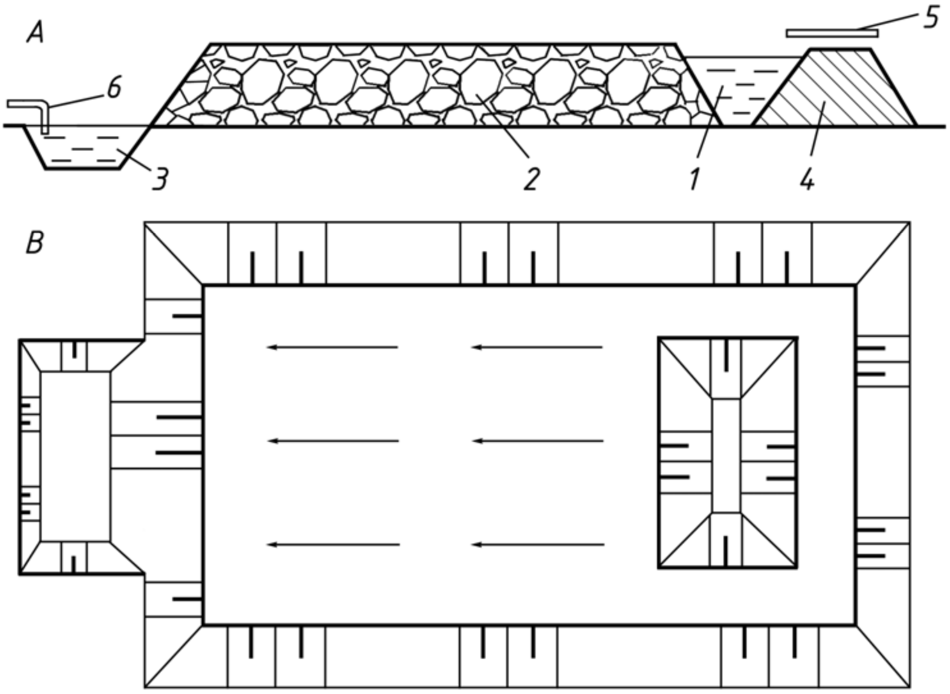

Figure 2 - Artificial filtering array on the flat surface: A – longitudinal section; B – plan view; 1 – receiver for contaminated water; 2 – filtering array; 3 – lodgment of purified water; 4 – water retention levee; 5 – conduit for feeding for contaminated water; 6 – conduit for purified water removing.

The filter body is a water-holding dam, piled of rocks with low hydraulic permeability. For supplying purified water to the filter array at one of its ends with the help of the dam a container is formed. Water reservoir with purified water is a pit created by the excavators and bulldozers at the base of the filter at the filter array open end. The movement of water in the filter is carried out by the pressure created by a column of water in the receptacle. The purified water is pumped from the water reservoir, and supplied to water bodies spillage or to meet the needs of the enterprise.

If the base rocks have low filtration coefficient, to prevent the infiltration and loss of water the filter bottom is made.

In this case water reservoir is formed by piling water retaining dam. Dam is formed of the same rocks that are used for the construction of filter body and bottom. The movement of water in the filter is carried out by the pressure generated by the difference in water levels in the receiving tank and water reservoir.

Results and discussion

Calculation of water filtration in filter rock array is performed on the basis of two conditions:

- first, the length of the filtration should provide water purification up to the required condition;
- secondly, the width and depth of the filtering flow should match the size of the filter array, i.e. array must provide a pass for the whole water inflow at this water disposal.

The minimum length of the filtration, providing water purification up to required degree, is found out of the equation (1) when $C_{out} = C_{mpc}$:

$$L = \frac{1}{\eta} \ln \frac{C_{out}}{C_{mpc}}, \tag{2}$$

where C_{mpc} – maximum permissible concentration of suspended solids in the clarified water.

Water filtration in the array is considered to be a steady uneven movement of water in a wide rectangular channel, which makes it possible to solve the problem as a two-dimensional one.

The equation that determines the change in the depth of filtration flow h in rock array with a linear filtration has the following form:

$$\frac{dh}{dx} = i - \frac{q}{kh}, \tag{3}$$

where x – distance from the water entry points to the array; i – inclination of water pressure (the underlying surface of the array); q – specific water flow rate per unit width; k – filtration rate for linear filtration.

Within the quadratic dependency filtration equation (3) is written as:

$$\frac{dh}{dx} = i - \left(\frac{q}{k_q h} \right)^2, \tag{4}$$

where k_q – filtration rate for quadratic filtration.

Equations (3) and (4) should be solved with the following limiting conditions: at the site of the water entering the filter array $x = 0$, and the seepage depth $h = h\varphi$. Filtrating flow should be at a distance of L, that is under $x = L$, $h = 0$.

When filtering water three situations are possible: the first, when underlying surface is horizontal, i.e. water pressure gradient i is equal to zero; the second, when water pressure gradient has a positive value ($i > 0$), i.e., elevation point of water entry to an array is higher than elevation point of the water exit; the third, with negative water pressure gradient ($i < 0$) .

The solution of equation (3) with the imitating conditions described above is given by the following formulae, depending on the incline of water pressure plate:

a) with $i = 0$:

$$L = \frac{h_1^0}{2} z_1^2, \tag{5}$$

where $h_1^0 = q/k$ – normal flow depth resulting steady water movement; $z_1 = h_\varphi / h_1^0$ – relative flow depth;

b) $i > 0$

$$L = -\frac{h_1^+}{i} \left[z_1^+ + \ln \left| z_1^+ - 1 \right| \right], \tag{6}$$

where $h_1^+ = q/k$; $Z_1^+ = h_\varphi / h_1^+$;

c) $i < 0$

$$L = \frac{h_1^-}{i} \left[Z_1^- - \ln | Z_1^- - 1 | \right], \tag{7}$$

where $h_1^- = -q / k_i$; $z_1^- = h_\varphi / h_1^-$.

The solution of equation (4) is expressed by the following formulae under the same limitating conditions:

a) with i = 0

$$L = \frac{h_2^0}{3} Z_2^3 , \tag{8}$$

where: $h_2^0 = q / k_{\kappa}$; $Z_2^3 = h_{\varphi} / h_2^0$;

b) with i > 0

$$L = \frac{h_2^+}{i}\left(\frac{1}{2}\ln\frac{Z_2^+ + 1}{Z_2^+ - 1} - Z_2^+\right), \tag{9}$$

where $h_2^+ = q / k_k \sqrt{i}\,; z_2^+ = h_{\varphi} / h_2^+;$

c) with i < 0

$$L = -\frac{h_2^-}{i}\left(Z_2^- - arctg\, Z_2^-\right), \tag{10}$$

where $h_2^- = q / k_k \sqrt{-i}\,; z_2^- = h_{\varphi} / h_2^-.$

Thus, for a given length of filter *L* and for a linear filtration the depth and width of the filtrating flow, and also the height and width of the filtering array are determined by formulae (5-7). For quadratic filtration these parameters should be calculated by formulae (8-10). They provide passage of all incoming water without overflowing on the array surface.

Conclusions

Development of effective quarry water purifying technology requires cooperation of technical universities, research organizations and mining enterprises for saving the environment in coal basins. Geoecological effect of this technological platform is connected with the growth of wellbeing of communities located near open pits. It can be achieved with decrease of harmful contaminants' content in quarry water disposed to the rivers to MPC during filtering through artificial overburden arrays. Technology of forming and using filter arrays allows substituting expensive water treatment equipment what was proved by conducted research. Despite low capital expenditures of filtering arrays creation (equally to the costs of peripheral dozer dumping), further research within technological platform is required for improving the methods of selective arrays' filling due to raise the quality of filtering. In general high perspectives of the new technologies of quarry water treatment implementation at surface mining are expected to expand the limits of using mining machines [37-39].

Acknowledgment

The research was made in T.F. Gorbachev Kuzbass State Technical University under State Assignment N10.782.2014 K "Development of high-performance process for complex processing of low-grade coals and waste coal with producing a low ash coal-and-oil concentrate, composite fuels, rare earth and trace elements".

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