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Assessment of the efficiency of wastewater treatment from coal enterprises for suspended solids using various filtering materials

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Abstract

Suspended solids are the predominant pollutants in the wastewater of coal enterprises. The basic wastewater treatment system regulated in BAT No. 15 ITC-37–2017 does not ensure water quality meets the discharge standards for fishery water bodies. The gravitational sedimentation method used in this technology is effective for coarse particles. However, colloidal systems formed from fine insoluble fractions are challenging to separate in a gravitational field. As an effective method for removing suspended solids from wastewater, we recommend filtering through a stationary layer of granular filtering materials. The study investigates the kinetics and dynamics of filtering suspended particles from the wastewater of coal enterprises using various filtering materials. Sedimentation curves of suspended solids from quarry wastewater have been constructed. The dependence of wastewater treatment efficiency on the size of filtering material fractions has been identified. The study provides an evaluation of the effectiveness of using natural filtering materials for treating wastewater from coal enterprises. The experiments demonstrated that the most efficient and cost-effective granular filtering material is quartzite from the Bobrovskoye deposit, which we recommend using in a combination of fractions 20–50 and 0.7–12 mm (in a ratio of 1 : 2). The optimal flow rate of wash water during the regeneration of the granular filter is also determined.

Keywords

coal enterprises, quartzite, suspended solids, wastewater, filtration, mechanical treatment

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ТЕХНОЛОГИЧЕСКАЯ БЕЗОПАСНОСТЬ В МИНЕРАЛЬНО-СЫРЬЕВОМ КОМПЛЕКСЕ И ОХРАНА ОКРУЖАЮЩЕЙ СРЕДЫ

Научная статья

Оценка эффективности очистки сточных вод угольных предприятий от взвешенных веществ различными фильтрующими материалами

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Аннотация

Взвешенные вещества являются преобладающими загрязнителями сточных вод угольных предприятий. Базовая система очистки сточных вод, регламентируемая в НДТ № 15 ИТС-37–2017, не обеспечивает качества очистки до нормативных значений сброса в водоемы рыбохозяйственного назначения.

Используемый в данной технологии метод гравитационного осаждения в прудах-отстойниках эффективен для грубодисперсных частиц. Однако формирующиеся коллоидные системы из мелкодисперсных нерастворимых фракций являются сложными для разделения в условиях гравитационного поля. В качестве эффективного метода удаления взвешенных веществ из сточных вод рекомендуем использовать фильтрование через стационарный слой фильтрующих зернистых материалов. В работе проведено исследование кинетики и динамики фильтрования взвешенных частиц из сточных вод угольных предприятий на фильтрующих материалах различной природы. Построены кривые гравитационного осаждения взвешенных веществ из карьерных сточных вод. Выявлена зависимость степени очистки сточных вод от размера фракций фильтрующих материалов. В работе приведены результаты оценки эффективности применения фильтрующих материалов природного происхождения для очистки сточных вод угольных предприятий от взвешенных веществ. Результаты экспериментов показали, что наиболее эффективным и доступным зернистым фильтрующим материалом является кварцит Бобровского месторождения, который мы рекомендуем использовать, комбинируя его фракции 2,0–5,0 и 0,7–1,2 (в соотношении 1 : 2). Определена оптимальная скорость подачи промывочных вод на этапе регенерации фильтра с зернистой загрузкой.

Ключевые слова

угольные предприятия, кварцит, взвешенные вещества, сточные воды, фильтрование, механическая очистка

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Introduction

Suspended insoluble substances, formed as a result of drilling, blasting, excavation, and transportation of coal and rock at coal mines, are among the predominant pollutants in coal enterprise wastewater [1].

When organizing recirculating water supply systems, such as using wastewater to supply beneficiation plants, the high content of suspended solids in the water can lead to a reduction in the quality of the obtained concentrates, as well as increased wear on pipes and pumps.

Mineral dust particles form various systems in water depending on the degree of dispersion, such as suspensions, emulsions, colloidal solutions, etc.

Most coal mines located in the Kemerovo region (Kuzbass) have a wastewater treatment system corresponding to the basic treatment regulated by BAT No. 15 ITC-37–2017 "Coal Mining and Beneficiation", which includes the process of sedimentation of suspended solids under the action of gravity in sedimentation ponds and filtration through the dam filter material [2].

Settling of quarry wastewater in sedimentation ponds is the most common method and is used in the first stage of treatment. This method is effective for removing large particles with a size greater than 2 mm. For such particles, the efficiency of sedimentation reaches 90–100%. Moreover, this method allows the removal of 40–60% of coarse and medium sand particles with a size greater than 0.25 mm [3]. The presence of difficult-to-settle silty and clay particles smaller than 10 μm in high concentrations makes sedimentation ponds insufficiently effective. Typically, they do not allow achieving regulatory concentrations for suspended solids in discharged wastewater, even when using a cascade of filtering dams. Furthermore, sedimentation ponds with regulated water discharge are not adapted to function under conditions of sharp and significant changes in wastewater flow rates, which may be caused by the peculiarities of mining and meteorological conditions [4].

The main body of the filtering array is often made of [5]:

- native overburden rocks;
- coarse gravel with fractions of 100–200 mm;
- medium gravel with fractions of 60–100 mm;
- burnt rock;
- quartz sand or zeolite.

The use of native overburden rocks as a filtering material for the cascade of dams for treating quarry wastewater has a significant drawback, which is the accumulation of predominant pollutants during operation, followed by their leaching, leading to an increase in their concentration in the treated water.

Monitoring the quality of discharged wastewater from coal mines showed that the quantitative content of suspended solids exceeds the regulatory values and varies throughout the year, with the maximum peak observed from May to July [6].

The aim of this study is to assess the efficiency of treating coal mine wastewater from suspended insoluble anthropogenic contaminants by filtration through a granular media layer.

The research tasks included:

– conducting field measurements of suspended solids content in coal mine wastewater;

– investigating the kinetics of gravitational sedimentation of suspended solids from wastewater;

– analyzing the filtering capacity of natural materials;

– determining the effectiveness of wastewater treatment from suspended solids by forming a working layer through a combination of different materials and fractions;

– determining the optimal flow rate of wash water during the regeneration of the granular filter.

Research Methods

We recommend using a non-reagent method of treating quarry wastewater from suspended solids – filtration [7–9]. This method can be used either independently or as one of the stages of a comprehensive zero-discharge technology, depending on the concentration of contaminants in the source water [10].

For analyzing suspended solids, we used the method described in PND F 14.1:2:4.254–2009 “Quantitative Chemical Analysis of Water. Method for Measuring Mass Concentrations of Suspended Solids and Ignited Suspended Solids in Samples of Drinking, Natural, and Wastewater by Gravimetric Method”.

The dispersed composition of suspended particles in wastewater was determined using a particle size analyzer according to GOST 8.774–2011.

Laboratory studies were conducted to select a filtering material for loading into a filter column installed at the inlet of the comprehensive zero-discharge wastewater treatment technology system.

Characteristics of research objects

To analyze the efficiency of wastewater treatment from suspended solids by filtration, natural materials of different chemical compositions were chosen as research objects (Table 1).

Results of research on wastewater treatment from suspended solids using filtering materials

The study of sedimentation of suspended solids under kinetic conditions was carried out using quarry water sampled from a sump in autumn and spring (with concentrations of 103 and 126 mg/dm^3, respectively), where clay particles with a fraction size of 0.005 µm predominated.

The kinetics of gravitational sedimentation of suspended solids from wastewater is shown in Fig. 1. The analysis of the sedimentation curves reveals two stages, each with different process speeds. In the first 100 minutes, a significant reduction in the concentration of suspended solids is observed due to the sedimentation of particles predominantly larger than 0.005 µm. Subsequently, a significant decrease in the sedimentation rate of fine particles smaller than 0.002 µm occurs, which are difficult to separate under gravitational field conditions. The concentration of suspended solids in the samples reached its minimum value (20 mg/dm^3) only on the fifth day and then remained unchanged.

The results of gravitational sedimentation showed that gravitational forces are insufficient to cause the settling of colloidal impurities. Another characteristic feature is the sediment’s instability in both sedimentation and aggregation [11].

Table1 1

Chemical composition of filtering materials, %

Filtering material	SiO_2	Al_2O_3	Fe_2O_3 общ	MnO	CaO	MgO	Na_2O	K_2O
Zeolite from Holinsky deposit (Chita Region, Russia)	56.27	5.37	2.30	< 0.01	14.90	1.26	0.14	1.24
Sorbent AS (catalytic aluminosilicate) (Russia)	46.8	1.0	6.12	< 0.01	0.6	0.1	0.72	–
Filter-Ag (USA)	70–73	14	1.5–3.5	0.2–2.5	–	–	2.5	1.5
Filtering Material MFU (Russia)	80	7	5	4		–	3	
Sorbent MS (catalytic aluminosilicate) (Russia)	16.9	0	9.53	1.7	0.34	6.2	0	
Quartzite from Bobrovskoye deposit (Russia)	98.7	1.3	0.6	–	–	–	–	

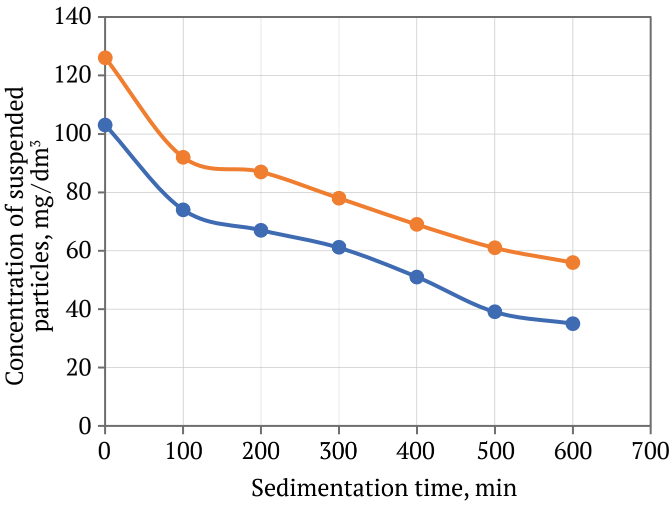

Fig. 1. Kinetics of gravitational sedimentation of suspended solids

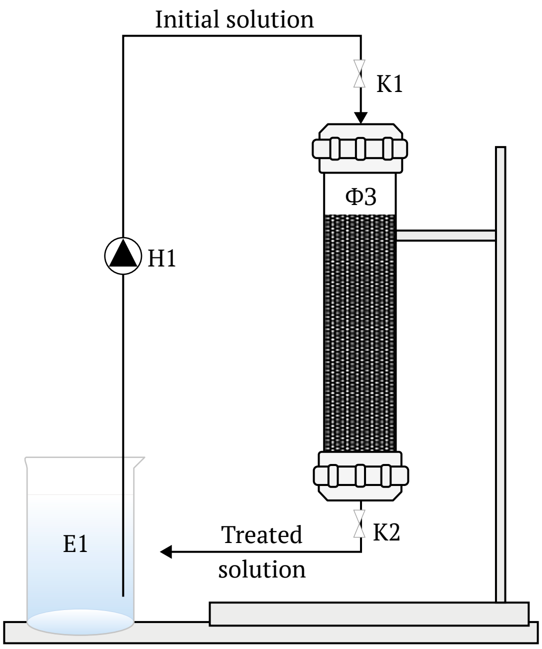

Fig. 2. Schematic diagram of the laboratory mechanical filtration setup

The obtained results confirm the need for further treatment of wastewater from suspended solids in the colloidal group after the sedimentation ponds, where laminar flow is organized for sufficient removal of coarse particles. An effective method for further treating wastewater from colloidal particles is dynamic filtration using column-type apparatuses with granular media [12].

Wastewater exiting sedimentation ponds, with a suspended solids concentration of 62 mg/dm³ and a predominant particle size of 0.005–0.02 μm, was passed through a laboratory setup, the schematic of which is shown in Fig. 2, where the filtering granular media was varied.

The laboratory setup consists of a filtering column with a granular media layer height of 0.50 m and a diameter of 0.1 m. The treated water is fed from the top at an initial rate of 8 m/h. The degree of wastewater treatment using various filtering media was determined after passing 200 liters.

Before the start of mechanical filtration, pre-treated and settled water was poured into tank E1, from which it was pumped by pump N1 into the filtering column FZ with granular media. The filtration rate was adjusted by valves K1 and K2. The resulting filtrate was collected in an intermediate tank.

The degree of wastewater treatment from suspended solids was calculated using the formula [13]:

$$\varepsilon = \frac{C_0 - C_k}{C_0} 100,$$

where ε is the degree of wastewater treatment, %; C_0 is the initial concentration of suspended solids, mg/L; C_k is the concentration of suspended solids at the column outlet after passing 200 liters of wastewater, mg/L.

The experiment results are presented in Table 2.

The laboratory experiment data showed that Filter Ag and quartzite from the Bobrovskoye deposit provide the highest degree of treatment of model solutions from suspended solids.

Table 2

Concentration of suspended particles and degree of wastewater treatment

Filtering material	Initial concentration of suspended solids, mg/L	Concentration of suspended solids at column outlet after passing 200 L of wastewater, mg/L	Degree of treatment, %
Filter Ag	62.32	1.47	97.64
Filtering material MFU	60.54	42.94	29.02
Sorbent AS	59.42	54.74	7.84
Zeolite from Holinsky deposit	68.20	22.73	66.67
Sorbent MS	62.34	29.75	52.24
Quartzite from Bobrovskoye deposit (fraction 2–5)	64.50	9.28	85.61

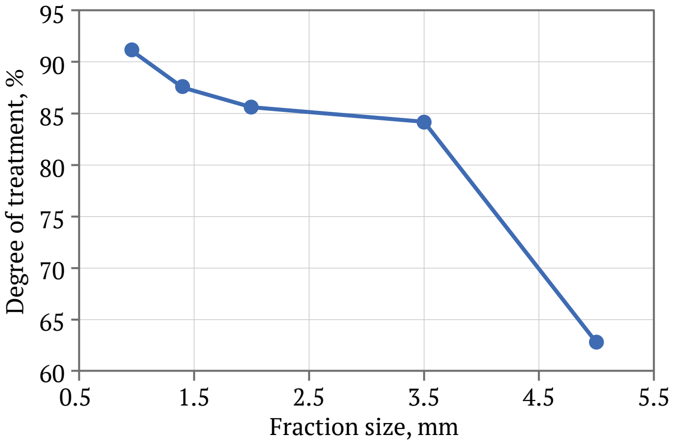

Fig. 3. Dependence of treatment degree on the fraction size of quartzite material from the Bobrovskoye deposit

The results of studying the influence of the fractional composition of the filtering material on the degree of treatment of model solutions from suspended solids were conducted on quartzite material from the Bobrovskoye deposit. The results are presented in Fig. 3.

As the experimental data indicated, the treatment degree decreases with increasing fraction size. This is explained by the increase in the size of the channels between the particles of the granular material, which reduces the hydraulic resistance of the stationary material layer and, accordingly, insufficiently decreases the kinetic energy of suspended particles for their retention in the filtering media layer.

A literature review showed that one of the ways to improve the efficiency of wastewater treatment from suspensions is to form a combined granular media loading [14]. Typically, the material with the largest particle size is used first in the direction of the treated wastewater flow, gradually decreasing it towards the column exit. Additionally, using the principle of combining filtering materials allows for a reduction in wastewater treatment costs [15, 16].

To compare the efficiency of combining granular media loading, a model setup with two layers of different fractions or filtering materials was assembled. The experiment results are presented in Table 3.

The analysis of experimental data showed that the highest degree of suspended solids removal is achieved when using a combination of filtering materials – quartz sand and Filter Ag (in a ratio of 1 : 2). The lowest degree of suspended solids removal was observed when using a combination of filtering materials—quartz sand with particles of 1.0–2.0 mm and zeolite (in a ratio of 1 : 2). At the same time, the highest unit cost of wastewater treatment is associated with loadings that include zeolites (which have a low degree of suspended solids removal) and Filter Ag (which is high cost and lacks local production in Russia).

Thus, the most effective and accessible granular filtering material is quartzite from the Bobrovskoye deposit, which we recommend using in a combination of fractions 2.0–5.0 and 0.7–1.2 (in a ratio of 1 : 2).

Table 3

Degree of wastewater treatment from suspended particles using a combined granular media layer

Filtering material	Amount of treated water before reaching MAC, L	Cost of loading for laboratory setup, Rubles	Unit cost of wastewater treatment per liter, Rubles/L
Quartzite from Bobrovskoye deposit, fraction 2.0–5.0/0.7–1.2 (in ratio 1 : 2)	480	150	0.31
Quartzite from Bobrovskoye deposit, fraction 2.0–5.0/0.8–2.0 (in ratio 1 : 2)	250	145	0.58
Quartzite from Bobrovskoye deposit, fraction 1.0–3.0/zeolite (in ratio 1 : 1)	180	162	0.90
Quartzite from Bobrovskoye deposit, fraction 1.0–3.0/zeolite (in ratio 1 : 2)	100	123	1.23
Quartzite from Bobrovskoye deposit, medium fraction 1.0–3.0/zeolite (in ratio 2 : 1)	250	140	0.56
Quartzite from Bobrovskoye deposit, fraction 2.0–5.0/Filter Ag (in ratio 1 : 2)	720	433	0.60
Quartzite from Bobrovskoye deposit, fraction 2.0–5.0/quartzite from Bobrovskoye deposit, fraction 0.7–1.2/Filter Ag (in ratio 1 : 1 : 1)	580	291	0.50

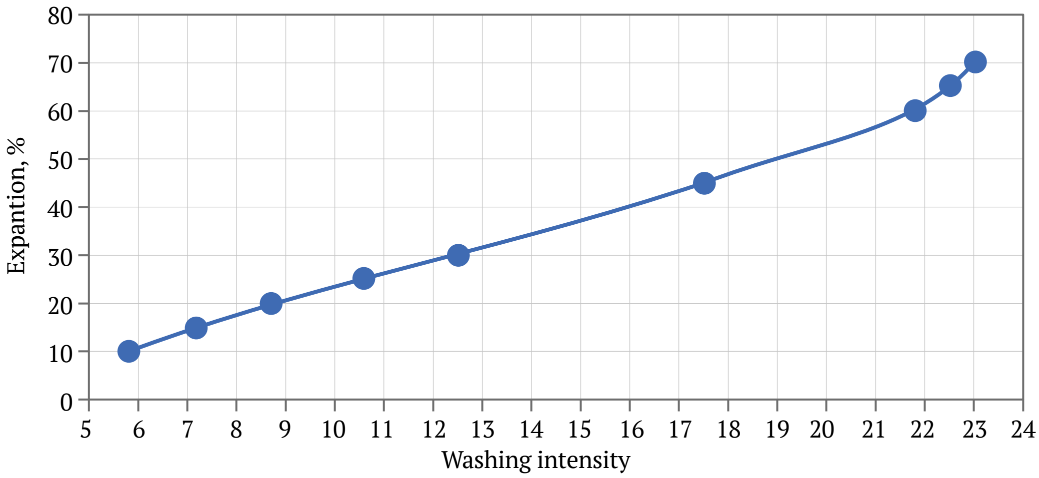

Fig. 4. Dependence of the expansion of quartzite media from the Bobrovskoye deposit, fraction 2.0–5.0/0.7–1.2 (in ratio 1 : 2), on washing intensity

To restore the filtering capacity of the granular media, its regeneration is carried out through backwashing.

The optimal percentage of granular media expansion during regeneration is 30% [17]. To achieve the desired expansion, each type of granular media requires its specific wash water flow rate.

To determine the optimal intensity of backwashing for the studied filtering materials, a series of experiments was conducted. The dependence of the filter layer expansion on the wash water flow rate was recorded on the filtering column described above. Wash water was supplied to the filtering column from below and drained from the top, with the washing intensity regulated by valve K2.

For each type of filter media, the dependence of its expansion on the wash water flow rate was determined. The graph of the expansion dependence for the quartzite media from the Bobrovskoye deposit, fraction 2.0–5.0/0.7–1.2 (in a ratio of 1 : 2), is presented in Figure 4.

Based on the analysis of the data, it can be concluded that the optimal wash water flow rate for effectively regenerating the combined filtering media – quartzite from the Bobrovskoye deposit, fractions 2.0–5.0/0.7–1.2 (in a 1 : 2 ratio)—is 12–13 L/m^2·s.

Conclusion

Insoluble suspended substances are the primary pollutants in quarry wastewater. The simplest and most cost-effective method for treating this type of wastewater is filtration through a stationary granular layer of filtering material. Coal mining enterprises commonly use the wastewater treatment system recommended by BAT No. 15 ITC-37–2017 “Coal Mining and Beneficiation”. This system includes sedimentation ponds, which are open earthen basins constructed either by excavation (e.g., pit-type sedimentation ponds) or by damming natural ravines with combined mineral material dams (e.g., ravine-type sedimentation ponds). For additional treatment of quarry wastewater, we recommend filtration using granular media filters.

Among the materials studied, quartzite from the Bobrovskoye deposit, used in combination with various fractions for two-stage filtration, demonstrated the highest efficiency. To restore the filtering capacity of the granular media, backwashing is used for regeneration. For effective regeneration of the combined filtering media—quartzite from the Bobrovskoye deposit, fractions 2.0–5.0/0.7–1.2 (in a 1 : 2 ratio) – the optimal wash water flow rate is 12–13 L/m^2·s.

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