Waste Disposal In The Open Pits: The Hydrogeological Aspects And The Influence On the Environment (The South Urals, Russia)

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Abstract The activities of the mining and processing industries lead to the formation of a mining landscape. Reclamation of mined-out space is an effective way of solving environmental problems in the mining areas. It is advisable to use wastes from the mining and processing industries to bring the disturbed areas of land to satisfy the development condition. Hydrodynamic and hydrochemical history of the object, sampling and laboratory study of the interaction of filling mixes with quarry water, hydrogeomigration modeling were used to substantiate the technology of waste disposal in the exhausted Vostochniy quarry of the Magnetic Mountain (Chelyabinsk region, Russia).

Key words waste disposal, open pit, filling mixture, remediation, hydrogeolocical forecast, pollution prediction.

Introduction

The purpose of the work is to justify the expediency and ecological safety of reclamation of the Vostochniy quarry of the Magnetic Mountain (Chelyabinsk region, Russia) using slag processing products as stowing materials. For such a substantiation, it is necessary to evaluate the hydrogeoecological consequences of the disposal of waste in the developed space.

For OJSC "Magnitogorsk Iron and Steel Works" the solution of a number of interrelated problems is extremely urgent: reclamation of worked quarries and waste disposal of own-made wastes during the formation of filling mixes. Their solution will allow us to approach the issue of the restoration of territories that have been disturbed by years of mining activity. Magnitogorsk iron ore deposit is located in the South Urals, 12 km from the center of Magnitogorsk. Distance to the nearest water bodies: 5 km to the west towards the Magnitogorsk reservoir on the river Urals, 5 km to the east to the river Suhaya (left-bank tributary of the Ural River) and sludge storage on it. The Magnitogorsk deposit is located mainly in the limestone (marble) of the Magnetic Mountain.

The Magnitogorsk iron ore deposit has been worked out since 1747. The deposit "The Magnetic Mountain" was worked by two quarries: Zapadniy, 105 m deep, in the period 1929 – 1994; Vostochniy, depth of 130 m, from 1946 to 2006. The total area of the worked out space of the Vostochniy pit is 163 hectares, the length of 1945 m, the width of 1015 m, the height of the ledges is 10 m. To date, the deposit has been worked out, 538 million tons of ore were mined.

During the development of the Zapadniy and Vostochniy quarries of the deposit, drainage was carried out by deep dewatering wells in combination with sump pumping. Fracture-karst waters, associated with Paleozoic rocks, have the greatest influence on the water cut of open pits.

Formation of the chemical composition of the underground waters of the deposit is associated with the mineralogical composition of the ore zone and the presence of sulphides in the composition of magnetite ores. Under natural conditions, they did not exert a significant influence due to poor solubility. In the process of strip mining with dewatering, the oxidation of sulfides begins, the groundwater acquires a sulphate composition (the sulfate ion content is up to 1.5 g/dm^3), the mineralization rises to 2.2 g/dm^3.

Testing and chemical analysis

It is planned to use filling mixes based on slag processing products with the addition of some types of waste as a material for filling the quarry. The share of metallurgical slag in the volume of industrial waste of the plant without waste of ore-dressing production is about 80%. The basis of metallurgical slags is composed of oxides of CaO, SiO_2, MgO, and FeO. Sulfur in slags is in the form of sulfides or sulphates Ca^{2+}, Mn^{2+} and Fe^{2+}.

The composition of the waters formed during the storage of filling mixtures is determined by the influence of environmental factors: water composition, temperature (Lottermoser 2010; Mironenko and Rumynin 1999). The active behavior of the filling material in the water can have a negative effect on the quality of underground and surface water.

To assess the environmental hazard of wastes that will be used for filling mixtures during reclamation of the Vostochniy quarry, laboratory experiments were conducted: 10 samples of slags were selected and one sample from a mixture of basic metallurgical wastes was additionally prepared. The results of the investigation of the interaction of slag materials with a quarry (11 samples) and distilled water (11 samples) make it possible to evaluate, by analysis of aqueous extracts, the time variation in pH and the degree of leaching of the components. We performed advanced laboratory studies of main and micro – component composition of water samples using methods of mass spectrometry with inductively coupled plasma ICP-MS.

The change in the hydrogen index occurs in the first 7 days, it increases from 7 to 10 – 12 units, in the future it does not change (experiments were conducted for 21 days). Ten-fold dilution with water reduced the pH by only one unit. Table 1 shows the results of the analysis of the micro-component composition of quarry waters and aqueous extracts. Comparing them with the indicators of the waters of the Zapadniy quarry (re-cultivated at the present time) allows us to conclude that in the course of the reclamation of the Vostochniy quarry its water can be enriched with a number of components, including an increase in the content of sodium, aluminum, calcium, copper, zinc, strontium, mercury, lead, but this process will not lead to a noticeable contamination of the hydrosphere. The composition of water will change from sulphate magnesium-calcium to chloride potassium-sodium-calcium.

Table 1 *Composition of water extracts and quarry waters, mg/dm³ (including ICP-MS results)*

Index	Water extracts		Quarry			Russian MAC/ MPC (for fishery purposes rivers and ponds)
	Q*	D**	Vostochniy	Podotvalniy	Zapadniy	
pH	11.0	11.0	7.9	7.9	12.0	–
B^+	0.04	0.03	**0.19**	**0.63**	0.03	0.10
Na^+	**147**	98	45	112	180	120
Mg^{2+}	0	0	**79**	**88**	< d. e.	40
Al^{3+}	**0.42**	**2.55**	**0.10**	0.03	**0.07**	0.04
Si^{2+}	**4.2**	2.5	2.9	8.6	0.6	–
K^+	48	36	3	2	84	–
Ca^{2+}	**234**	**217**	**354**	**267**	**389**	180
Mn^{2+}	**0.016**	0.005	**0.013**	**0.235**	4.0 10^{-4}	0.01
$Fe_{общ}$	0.10	0.04	**0.24**	**0.21**	< п. о.	0.10
Cu^{2+}	**0.014**	**0.016**	**0.006**	0.001	0.001	0.001
Zn^{2+}	0.10	0.129	0.03	< d. e.	< d. e.	0.01
Br^+	0.162	0.099	0.051	0.360	0.466	1.35
Sr^{2+}	2.31	1.70	0.69	1.38	2.08	0.40
Ba^{2+}	0.18	0.63	0.01	0.02	0.84	–
Hg^{2+}	**2.3 10^{-4}**	**1.4 10^{-4}**	< d. e.	< d. e.	< d. e.	1.0 10^{-5}
Pb^{2+}	4.7 10^{-3}	4.3 10^{-3}	9.4 10^{-4}	1.7 10^{-4}	6.8 10^{-5}	6.0 10^{-3}
SO_4^{2-}	**579**	**118**	**1156**	**984**	**318**	100

*Interaction of filling material and quarry water; **Interaction of filling material and distilled water; d. e. — chemical determination error; bold are values greater than Russian MAC/MPC (for fishery purposes rivers and ponds)

Mathematic modeling

A number of forecasting tasks were solved for the hydrogeological justification possibility of reclamation of the Vostochniy quarry. The purpose of their solution was: assessment of the necessary flow rate of the drainage to ensure storage in a dry state; forecast of groundwater levels with a change in the ratio of drainage from the Zapadniy and Vostochniy quarries; an estimation of probability of flooding of territories in case of complete cessation of a drainage; the forecast of distribution of polluting substances to the discharging zones in the process of reclamation of the Vostochniy quarry and after its completion.

Mathematical modeling was used to predict changes in the hydrodynamic and geomigration situation: Modflow and MT3D included in the PMwin package (Chiang and Kinzelbach 2001). The outer contour of the model is adopted in accordance with the natural boundaries of the formation of groundwater flows, based on the assumption of the coincidence of the boundaries of formation of surface and underground runoff (treated as one watershed). In the west and east, the boundaries correspond to regional drains; In the south and north, the boundaries are drawn in accordance with local watersheds (impermeable boundary).

The internal boundary conditions are the drainage systems of quarries, to simulate the discharge of groundwater into the sump in the corresponding blocks, a third-kind boundary condition (drain) was specified. The depth of the drain corresponds to the marks of the bottom of the quarry. Surface water bodies and streams are schematized as a boundary condition of the third kind, taking into account the filtration resistance of the bed (river hydraulic conductance). The mean annual value of infiltration intensity (recharge) was taken as equivalent to a regional module of underground runoff (about 50 mm/year). At the metallurgical site, the infiltration rate increases to 100 mm / year due to leaks from water-bearing communications.

Changes in the filtration properties (hydraulic conductivity) of the fissured-karst (fracture-karst) aquifer are associated with lithological differences and geomorphological position: the highest values of the order of 1 m/day (transmissivity about 100-150 m^2/day) are inherent in the Ural and Sukhaya river valleys, they decrease to 0.1-0.05 m/day (transmissivity about 10-30 m^2/day) by the watershed (Lukner and Shestakov 1976).

The solution of transient migration tasks was carried out for the conservative component, (for example, the chlorine ion). Its content in the water of the Zapadniy quarry is 350 – 400 mg/dm^3 with a background value of 100 mg/dm^3. As the main process, which regulates mass transfer, advection (convection) was considered.

The simulation was carried out in two stages. For calibrating the model, a number of inverse tasks were solved at the first one: the hydraulic conductivity, storage coefficients, and recharge conditions were refined; the sensitivity of the model was checked. The criterion of consistency of the model is the coincidence of the model and actual levels of groundwater, as well as the balance components of the watershed. For the calibration of parameters, the following stages of territory development provided with monitoring information were considered: 1 – natural (undisturbed) conditions (steady state); 2 – situation at the end of excavation at quarries (steady state); 3 – period from 1991 to 2013 (transient).

The main task of the second stage of modeling: justification of the operating mode of the drainage system, allowing to ensure the storage of the filling mixture above the groundwater level in dry form.

At this stage, the forecast tasks are solved, three scenarios are considered:

1) drainage is carried out from both quarries: from the Vostochniy – to ensure the possibility of storing filling mixes in a dry state, the drainage from the Zapadniy one remains at the level that has developed to date;

2) there is no drainage from both quarries: the filling of the Vostochniy quarry continues; Drainage from the Zapadniy quarry is terminated and its filling begins;

3) drainage is performed only from the Vostochniy quarry – to ensure the possibility of storing filling mixes in it in a dry state.

The results of solving the forecast tasks show that the first scenario is the safest: there is no flooding of the adjacent territories, the potential pollution does not extend to regional drains and is localized in the immediate vicinity of quarries.

The second scenario is the worst (fig 1): there is flooding of the territory, after 5 years, pollution from both the Zapadniy and Vostochniy quarries reaches regional drains. In the center of the industrial site of the metallurgical plant, the groundwater level will rise by 2 to 4 meters, and the concentration of the conservative polluting component will increase by 1.5 to 2 times. In Figure 1, the position of the front of pollution from the Zapadniy and Vostochniy quarries with complete cessation of the water outflow in 50 years is shown.

The third scenario is intermediate in degree of danger: to the east into the valley of the river Suhaya pollution does not extend, the rise in the level in the center of the industrial site will be about 2 m, and the concentration of the conservative polluting component may increase by 1.5 times.

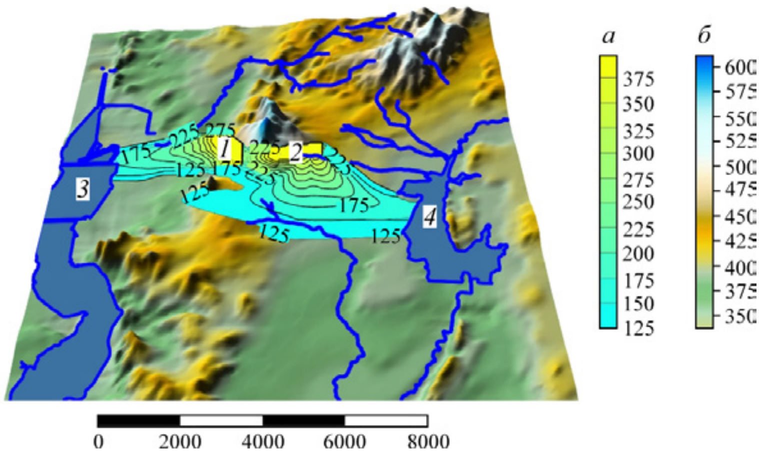

Figure 1 *Forecast concentration of the conservative component in groundwater 50 years after the complete cessation of the drainage (the second scenario): 1 — Zapadniy quarry; 2 — Vostochniy quarry; 3 — Magnitogorsk reservoir; 4 — sludge storage; a — concentration scale, mg/dm³; б — relief altitude scale, absolute marks, m*

Recommendations for reclamation

The safe filling of the Vostochniy quarry with filling mixtures is possible when drainage of both quarries is working: this will ensure the preservation of the groundwater level on the marks excluding the influence on the residential and industrial zone during the work. In the process of reclamation (about 10 years), the depth of the water level in the area of the Eastern pit is determined by the reclamation technology. In accordance with this technology, it should be possible to store the filling mixture in a dry state. Backfill with filling mixtures will be done in layers of 2 m with the preliminary formation of a impermeable waterproofing screen (from clay or geomembrane). As the developed space is filled, the depth of drainage and the discharge of the drainage can decrease after the increase in the mark of the bottom of the reclamation space.

From the perspective of mass transfer, the reclamation process is divided into three stages. At the initial stage, the groundwater level should be maintained below the bottom of the quarry, groundwater pollution occurs in the immediate vicinity of the quarry. At the second stage, water drainage can be reduced (approximately 2 times compared with the initial stage), the direction of movement of groundwater and the development of the pollution area will change significantly. At this stage, it is necessary to provide for the expansion of the monitoring network to provide information on the extent of flooding of the territory, processes and intensity of groundwater pollution. At the third stage (after filling the worked out space to about the level of the earth's surface), drainage can be stopped, but only on condition that monitoring results do not record flooding of territories and groundwater contamination.

Conclusion

If the technical requirements are met, the use of mining and processing waste to reclamation of quarries is a potentially environmental friendly technology.

The main requirement for the reclamation of the Vostchoniy quarry is the control over the position of the groundwater level in the process of reclamation. There should be chosen such a flow rate of drainage that each new layer of the filling mixture is in the dried state until it is covered with a waterproof layer.

After filling the waste space with filling materials, drainage can be terminated, provided that monitoring results show no flooding of territories and groundwater contamination.

Reclamation of the Eastern quarry of the Magnetic Mountain with the use of filling mixes will lead to the improvement of the ecological situation, which is especially important for the area of the metallurgical plant, where a huge volume of metallurgical wastes is accumulated.

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