The General Concept of Kizel Coal Basin Remediation

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Abstract

Acid rock drainage (ARD) is worldwide environmental problem. Development of ARD is especially characteristic of coal fields. We studied the effect of ARD on the environment in Kizel coal basin, Russia.

Kizel coal basin (KCB) is located on the east part of Perm region, Russia, within the West Urals folding zone adjacent to the pre-Ural boundary deflection. Exploitation of basin started in 1796. Folded geological structure of the basin and intensive karst processes within carbonate rocks determine a big amount of water inflow in mines. There is an elevated content of sulphur in basin's coal also. These factors determine the generation of large volume of acid mine water and drainage from waste piles. Cessation of mines in 1990s led to the raising of watertable level, mine flooding and starting of acid mine water (pH 2-3) discharge on surface. Over 35 million cubic meters of waste rocks were accumulated in more than 100 waste piles after the cessation, which provide generation of enormous amount of acid rock drainage water. As a result these processes have led to the deforestation of large area, river water contamination with metals and metalloids, and accumulation of yellowboy precipitate covering river beds. Thus, over than 500 kilometres of river streams was degraded. The yellowboy precipitate contains high content of such components as Fe, Al, Mn, Cu and other chemical elements. So, this precipitate is considered as the secondary source of pollution.

Investigations of the environmental problems of the basin began in 1980s. Some treatment methods were proposed: the passive treatment based on geochemical barriers installed at the floor of waste pile, and the active mine water treatment constructions. At present we study the possibility of using various methods of the environment remediation in KCB. It is planned to use both active and passive treatments: injection of alkaline reagents into mine voids, sealing and recultivation of waste piles and some other techniques to neutralize acid discharges. We also plan to use GIS-modeling to choose the proper displacement of treatment systems.

Keywords: Coal basin, acid rock drainage, remediation, active treatment, passive treatment

Introduction

The development of coal deposits is one of the leading mining industries. The share of coal is about 25% of the global energy balance (Gonzalez-Toril et al. 2003; Maksimovich, Khayrulina 2011; Maksimovich et al. 2018). However, the process of coal mining leads to various environmental problems, such as:

- the formation of acid mine water (AMW). AMW is formed as a result of the interaction of ground- and rainwater with sulfur-containing coal-bearing rocks, leading to the increasing of water acidity and the formation of water which had the excess of sulfate ions and metal ions (Fe, Al, Cu, Mn, etc.) in thousands times of MPC;
- the accumulation of waste rock in the form of waste piles and sludges, emerging drains from which contain a large amount of pollutants;
- the violation of the natural hydrogeological conditions of the territories;
- the deforestation of land surface.

All these problems are characteristics of the liquidated Kizel coal basin (KCB), Russia.

Object and geological settings

Kizel coal basin is located in Perm region within the West Urals folding zone adjacent to the pre-Ural boundary deflection and occupied the area of about 1500 km^2. Rocks of the basin are represented by sandstones, mudstones, siltstones, shales, limestones, dolomites, marls, coals, and others. Carbonate rocks are intensely karsted, especially in the upper part of geologic cross-section. Coal of the basin exhibits elevated content of sulfur (mainly as a pyrite) – 5.8% (Maksimovich et al. 2018).

The increased amount of precipitation falls on the territory of KCB – up to 900 mm annually – is the result of the barrier effect of the Ural Mountains. At the same time the average annual amount of precipitation in the region is 600-700 mm (Pyankov, Shikhov 2014)

The complicated geological structure and hydrogeological conditions, intensive karst processes and abundant rainfalls ensured extremely high water content of the basin's coal-bearing stratum. The water inflow into the basin's mines reached 2500 $m^3 h^{-1}$. Every 4 tons of mined coal demanded the pumping of about 7 m3 of mine water out (Maksimovich 1997).

During the basin exploitation, the mine water containing large amount of sulfur, iron, aluminum, manganese compounds, etc., were discharged into the drainage system without any treatment. The constant and intensive inflow of mine water to rivers led to the fact that the chemical composition of river water tended to approach one of mine water. The river water had a hydrocarbonate-calcium composition and a total salinity of 90–150 mg dm^{-3}. Downstream after the confluence with mine waters, they acquired a sulphate composition and characterised with extremely high concentrations of Fe, Al, Mn, and salinity ranged from 640 to 6000 mg dm^{-3}. The pH value of river water decreased from 6.5-7.0 to 2.5-2.9 under the influence of mine water (Maksimovich et al. 2017).

Environmental situation at present

Cessation of mines in the 1990s led to a gradual restoration of the groundwater level and the formation of mine water discharges through various adits, wells, boreholes, etc. Currently, there are about 18 discharges of mine water to the surface on the territory of KCB (table 1)

Acid drainage from waste piles. Waste piles have a substantial effect on the environment.

Table 1 *Mine water discharges in the territory of KCB*

Mine	Mine water discharge source	Average pH	Average acidity, mg dm^{-3}	Average discharge, m3 $year^{-1}$	Average acid load, tons $year^{-1}$
Lenin	Main and auxiliary shafts	3,9	7386	137623	1016
	Sloping shaft 8	3,4	4640	3024205	14033
Volodarsky	Adit	2,5	1328	155155	206
Krupskoy	Adit	3,1	4052	157785	639
Us'va-3	Adit	3,0	345	902879	312
Chkalov	Kamenka adit	2,9	444	362401	161
	Claudinskaya adit	3,0	608	277000	168
Nagornaya	Sloping shaft	3,7	1387	657436	912
40 years of October	Adit	2,9	344	374037	129
	Hole 17	3,4	699	4777368	3338
	Holes 56-62	3,2	566	88535	50
	Well 13	4,9	486	87600	43
1st May	Adit	2,6	542	571531	310
Kalinin	Adit	3,0	4865	3322243	16164
Shumikhinskaya	Well 634	4,9	111	87600	10
Taezhnaya	Nothern adit	3,2	2095	5426038	11370
Kospashskaya	Hole 2-bis	3,5	4659	1814523	8454
Belyi Spoy	Hole 63	3,3	771	555753	428
			Total:	*22779712*	*57743*

Total number of waste piles in KCB is more than 100 (fig. 1). Excavation of rocks from the mines and storing them in the piles resulted in oxidation of sulfur-contained minerals and heat generation together with spontaneous combustion of piles. As a result of burning, a large amounts of hydrogen sulfide and carbon dioxide were released into the atmosphere (Maksimovich & Khayrulina 2011). Rainfall and groundwater interacting with the piles' rocks are saturated with various macro- and microcomponents, acquire the mineralization of up to 50 g dm^{-3}, and contaminate groundwater and surface water in the zone of influence of the coal basin.

River water contamination. Mine water discharges contaminate the catchment areas of 4 large rivers of the Perm region. The total length of polluted watercourses is over 500 km. The substantial amounts of technogenic yellowboy precipitate, contained high concentrations of mobilized contaminants, have been accumulated in rivers and floodplains (Maksimovich 2011; Maksimovich, Khayrulina 2011; Maksimovich, Berezina 2018). The dynamic of yellowboy accumulation is shown on fig. 3.

Planned treatment measures

In 2018 and the beginning of 2019, we developed the schedule of measures to minimize and eliminate the negative effect of KCB contamination sources on the environment, based on laboratory experiments and field works.

AMD treatment. Hydrogeological GIS-modeling was used to determine the proper location of the first-step treatment measures. It allowed to evaluate the hypothetical efficiency of these measures applying also (Table 2).

Waste piles treatment. We plan to cover piles with alkaline waste products. Laboratory experiments revealed the high efficiency of

Figure 1 *Waste pile of Kospashskaya mine*

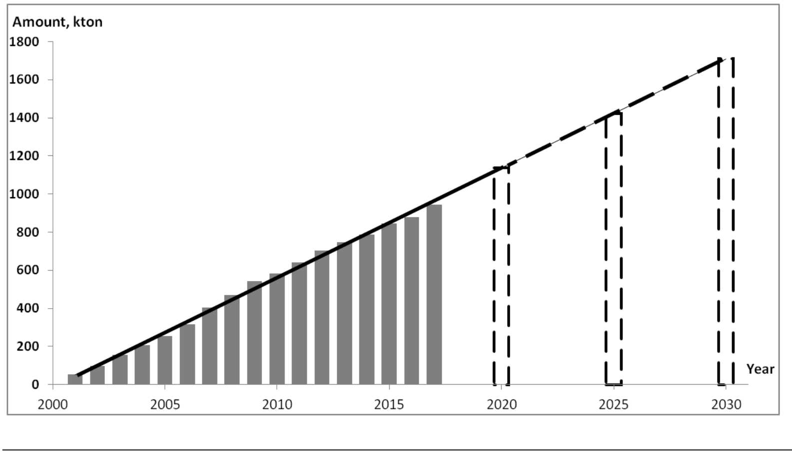

Figure 3 *Accumulation of yellowboy in the rivers of KCB (with forecast up to 2030)*

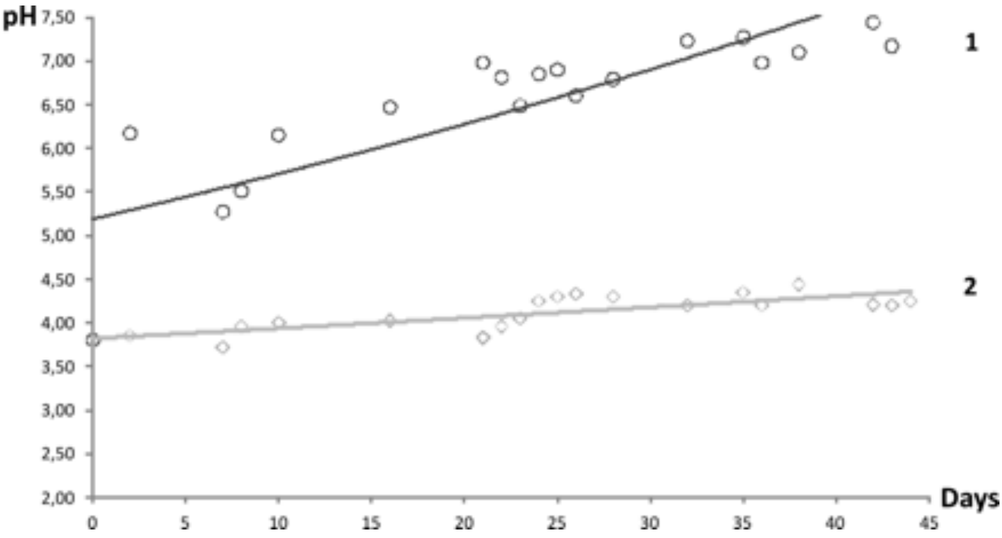

Figure 4 pH of water draining covered (1) and uncovered (2) waste pile

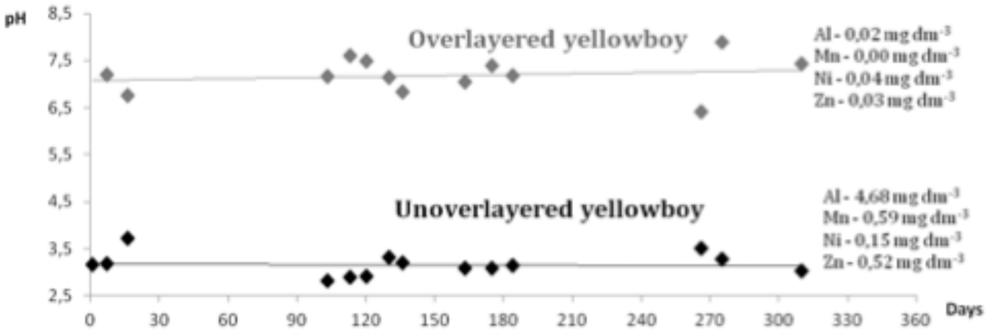

Figure 5 Chemical characteristics of river water after overlaying yellowboy with limestone rocks

Table 2 The first-step treatment measures in the territory of KCB

Mine	Mine water discharge source	Average discharge, m3/year	Treatment measure	Efficiency
Lenin	Main and auxiliary shafts	137623	Tamponage	Liquidation
Volodarsky	Adit	155155	Tamponage	Liquidation
Krupskoy	Adit	157785	Diversion of surface water	Decrease on 80%
Us'va-3	Adit	902879	Diversion of surface water	Decrease on 60%
Chkalov	Kamenka adit	362401	Injection of alkaline reagents	Decrease on 30%
	Claudinskaya adit	277000	Injection of alkaline reagents	Decrease on 50%
Nagornaya	Sloping shaft	657436	Diversion of surface water	Liquidation
40 years of October	Holes 56-62	88535	Tamponage	Liquidation
	Well 13	87600	Tamponage	Liquidation
1st May	Adit	571531	Diversion of surface water	Liquidation
Kalinin	Adit	3322243	Diversion of surface water	Decrease on 50%
Shumikhinskaya	Well 634	87600	Tamponage	Liquidation
Taezhnaya	Nothern adit	5426038	Diversion of surface water Injection of alkaline reagents	Decrease on 40%
Kospashskaya	Hole 2-bis	1814523	Diversion of surface water	Decrease on 50%
Belyy Spoy	Hole 63	555753	Diversion of surface water	Decrease on 50%

using them to neutralize water draining piles' rocks (Sedinin 2018 a ,b) (fig. 4).

Yellowboy treatment. We plan to use limestone rocks to overlay yellowboy covering riverbeds. Laboratory experiments revealed that 0,5 cm thickness cover of limestone over yellowboy is sufficiently effective to keep neutral pH of river water during 310 days at least (fig. 5).

Conclusion

Hydrogeological GIS-modelling revealed that the first step treatment measures could lead to 40% decrease of negative effect of ARD in KCB. To achieve complete remediation of KCB territory, we plan to use active and passive treatment systems. GIS-modeling was applied to choose proper displacement of them.

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