Using the industrial wastes for remediation of sites affected by acid mine water dumping

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Abstract

Kizelovsky coal basin is located in the Urals in the Perm region. Coal mining was carried out during 200 years. The high water content of coal mines and substantial sulfur content in the rocks of coal-bearing strata affected the worsening of the environmental situation. As a result of sulfur oxidation in mine workings, acid mine waters (pH≈2-3) with a high content of SO_4^{2-}, Fe^{3+}, Fe^{2+}, Al^{3+} and potentially toxic metals are formed. Parts of the former mine water discharge are polluted. They are not overgrown with vegetation even since 25 years after the closure of mines. Method of these sites reclamation with using alkaline waste of soda production and activated sludge of biological treatment facilities as reagents have been developed and tested by the authors.

Keywords: coal basin, acid mine waters, spillway, disturbed lands, technogenic soils, neutralization of soils, reclamation

Introduction

The oldest in the Urals Kizelovsky coal basin is located in the Perm region. It is stretched in the meridional direction, and has a length of more than 100 km and a width of 15-20 km.

The history of coal mining begins at the end of the XVIII century. In the first decades, coal mining was performed in small volumes to meet the demand of local enterprises. The increase of coal mining began after the Mining railway construction in 1879. Further, a substantial increase of coal mining happened during the first five years of the USSR (since 1928) and, especially during the Great Patriotic war, when Donbass was captured by the Nazis, and the country needed coal to win. In the first post-war decades, production volumes also grew, but then because of difficult geological, hydrogeological and mining conditions, the growth stopped, and then lowering of production followed. In the 1990s coal mining in the Kizel basin had to be unprofitable and all mines of Kizel mine assosiation were closed until 2000.

The environmental problems of the territory were not solved by the closure of mines. On the tributaries of the Kama and Chusovaya rivers extremely high levels of water pollution and sediments are constantly recorded. Currently, the main sources of pollution are acid mine waters, which spontaneously flow to the surface (Imaykin 2014). Together with them, more than 90% of the total amount of pollutants enter the rivers. Rivers pollution happens due to the effluents of 53 rock dumps of coal mines with an area of more than 300 ha.

Source of environmental pollution are areas of former mine water discharge (Imaykin and Imaykin 2018). During the coal mines working acidic water with high mineralization was pumped to the surface and dumped into ravines. The soil and vegetation layer is absent here. The upper part of the section is represented by man-made soils with pH≈3 and high content of water-soluble sulphates, iron, aluminum and potentially toxic metals. There is no spontaneous overgrowth of these areas, although mine water has not been discharged for 17-25 years. Removal of chemical elements from these areas with water flows leads to pollution of surface and groundwater, and of adjacent areas, and causes degradation of existing ecosystems.

Methods and results

The exploration of Shirokovskaya coal mine acid water former discharge area. The mine was commissioned in 1945 and closed in April 1997.

In the flooding of mine groundwater in coal-bearing strata, confined to Sandstone packs, played the main role. Much less fissure-karst waters of the visean aquifer took part. In the period from 1977 to 1996, the highest inflow of water into the mine was 2.7 thousand m^3/h, the average annual – about 1.0 thousand m^3/h (Krasavin 2005).

Mine's drainage was equipped with a wooden box from the dump site to the river Poludennyi Kizel. Over time, the box became unusable, and mine water flowed directly on the earth's surface, resulting the formation of the largest area of disturbed land (fig. 1). A detailed survey of the object showed that the site is extended in the North-West direction from the mine site to the river Poludennyi Kizel. The length of the plot is about 2 km, width-100 m and more.

At the "Shirokovskaya" mine during one of the periods of its work there was a mine waters neutralization with lime. As a result, a substantial amount of finely dispersed iron hydroxides was accumulated at the discharge site. Currently, from the surface of the site there lies a layer of man-made soils with a capacity up to 1 m, represented by finely dispersed iron hydroxides with fragments of mine dumps rocks. There are technogenically metamorphosed loams below.

To study the properties and composition of man-made deposits and modified loams, 36 soil samples on six transverse profiles, evenly spaced throughout the site were taken.

Analysis of the water extract showed that the soils from the contaminated area have an acidic reaction of the environment. The hydrogen index of soils profile water extraction, closest to the source of pollution (mine) is 2.3-2.6. With the distance from the industrial site, it increases slightly and on the profile, which is located near the Poludennyi Kizel river, it is 2.7-3.0. The content of water-soluble salts near the source of pollution is about 3 g/kg. On the profiles, which are located near Poludenny Kizel river it is reduced to 1-1.5 g/kg.

According to the microelement gross analysis, there is an increased content of pollutants, particular to the Kizel coal basin. In technogenic soils, the highest concentrations for Cu, Zn, Pb and Mo are observed, their content is several times higher than the background. Changed and underlying loams are also polluted. There is a migration of elements from the surface hydroxide-ferruginous layer of technogenic soils to the underlying loams and their accumulation in

Figure 1 An area of the former acid water discharge of mine "Shirokovskaya".

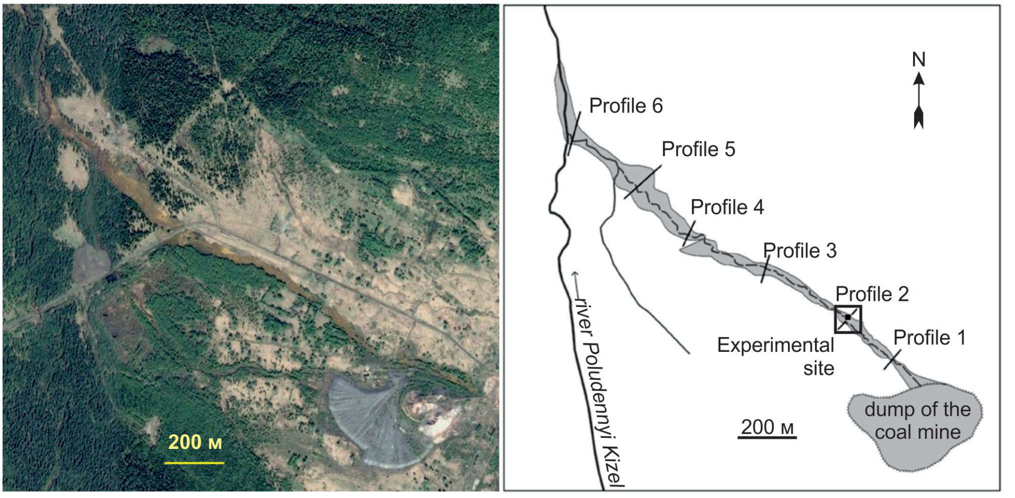

Figure 2 *A snapshot and scheme of the former acid water discharge of mine "Shirokovskaya"*

the clay substrate. Loams are good sorbents and accumulators of pollutants.

To determine the changeability of man-made soils material composition in the section of the pit there were selected 5 samples layer by layer and their x-ray phase analysis. The section of man-made soils in zone of acid mine drains influence is stratified. The upper horizon is composed of x-ray amorphous iron hydroxide and goethite technogenic sediments. Loams, lyied under it, metamorphised with the formation of newly formed minerals goethite and jarosite in them.

In the space snapshot an area of the former discharge of "Shirokovskaya" mine is clearly visible due to the lack of soil cover, and also due to the high content of iron hydroxides, which give the surface a bright brown color (fig. 2).

Comparison of the site boundaries in the modern space snapshot with the plan, drawn in the period after the closure of the mine, showed that there is no spontaneous overgrowth of disturbed lands, although 22 years have passed after the closure of mine. This area requires environmental measures, including the neutralization of acidic soils and remediation.

A new method of acidic soil reclamation using industrial waste. The authors have developed an effective and economical method of acid mine water discharge sites recultivation. Industrial wastes of local enterprises were chosen as reagents and additives. To reduce the acidity of the soil areas of the former mine spillway, the waste of Open Joint Stock Company (OJSC) "Bereznikovskyi soda plant" was used as a reagent. As an organic fertilizer, which contains elements necessary for the plants development in accessible forms, the active sludge of OJSC "Metafrax" was applied (Blinov et al. 2008).

Waste of soda production belong to the 5th class of danger. They are more than 90% composed of finely dispersed calcium carbonate. The pH value of the extraction is 9. The content of water-soluble chlorides, sulfates and sodium in waste of this layer has low values. The content of trace elements does not exceed the MPC for the gross content in soils. There are no harmful organic impurities in the soda waste. The volume of waste, which is ready for use as a reagent for reclamation of disturbed lands without any preparation exceeds 1 million m^3.

Acidic soil neutralization method for reclamation of disturbed land was used in Korea (Jae et al. 2006). Achieved positive effect from the use of waste for the formation of vegetation on the surface.

Studies of activated sludge showed high quality when used for remediation. It represents a hygroscopic (humidity 49-54%) mixture of mineral (53-78%) and organic

(22-47%) substances with a sufficiently high content of total nitrogen – up to 3.6% and phosphorus – up to 4.8 %. The pH value of the extract is 4.5–6.0. The concentration of potentially toxic metals does not exceed the MPC (Maximum Permitted Concentrations) for soils in residential areas and non-agricultural ecosystems. The content of radionuclides is normal.

As a result of laboratory experiments, the optimal amount of waste soda production introduction and activated sludge for the reclamation of acidic soils were determined. The optimal amount is about 20 kg per 1 m^2. The required amount of soda production added waste was determining from the condition of bringing the man-made pH soils to the background values of ≈ 6.0. The required amount of activated sludge was determined by the best development of plants, used for reclamation.

Experiments were carried out on the site of the former discharge of acidic water on the "Shirokovskaya" mine. On the area of 150 m^2, experimental sites with three variants of experiment conditions were laid – the lack, the optimal amount and the excess of the introduced reagent amount. To create a stable blackening of the surface of man-made soils, the selection of grass mixtures, taking into account the edaphic conditions and biophysiological features of plants, was carried out. The composition of grass mixtures included turf-forming species (cereals) in combination with soil-improving siderophilic (bean) species.

After reclamation, the chemical properties of soils have improved. General chemical and microelement analysis of water extraction, microelement analysis of soils showed that the content of pollutants meet the criteria for soils in residential areas.

As a result of the full-scale experiment, a stable vegetation cover was formed (fig. 3). The rate of phytoproduction in the first year of observation was 3.5 to 9.7 centner/ha in the second year – 4.2-14.0 centner/ha of dry weight. It corresponds to the background productivity of zonal dry pastures - 10 centner/ha of dry mass. The assessment of vegetation cover state is given as prosperous, because in the composition of vegetation in the optimal proportion for the sod formation, legumes and cereals are presented.

Microelement analysis showed that the

Figure 3 Results of the former acid water discharge of mine "Shirokovskaya" area reclamation: at the top is the technical stage of reclamation, below are the results of experiment

concentrations of chemical elements in the phytomass of the experimental sites do not have an environmental danger. Their content in most of cases do not go beyond the natural background frames and do not exceed the maximum allowable levels. A slight excess of Cr, V, Ti and Sr has a tendency to decrease on the 2nd year of observations (Krasilnikova and Blinov 2016).

Conclusions

Successful large-scale pilot industrial tests of the method on the area of 0.25 ha were carried out. Effectiveness and efficiency of the offered method is confirmed by an independent examination with the participation of regional and Federal representatives. Due to the use of industrial waste, the cost of environmental protection measures is reduced 4 times compared with lime use. The authors obtained a patent for the invention «Method of disturbed lands reclamation» (Blinov at al. 2008).

The introduction of the method will ensure the effective restoration of biological productivity of disturbed lands and eliminate the negative consequences of the exhausted mines production activities on land resources. With distinct adaptation, the method can be used for reclamation of disturbed lands, mine dumps and sludge storage on enterprises which produce and process minerals, containing sulfide, sulfur, and also industrial sites of sulfuric acid production enterprises.

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