# The Kizel Coal Basin (the Western Urals, Russia): Environmental problems and Solutions

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## Abstract

Coal mining usually causes severe anthropogenic changes by which the ground- or surface water might be significantly polluted. One of the main problem of coal mining industry is acid mine water containing high concentration of metals that have harmful consequences for aquatic life and the environment. Mine closure is not the solution of the environmental problem – waters discharging from abandoned coal mines, as well as those draining mine wastes containing pyrite are acid and highly enriched with soluble iron, sulfate, and metals.

Mining in the Kizel coal basin (the Western Urals, Russia) had been carried out for more than 200 years. Over 35 million $m^3$ of waste rocks had been accumulated in more than 70 tailingspiles. Since the 1980s the authors have been working on the problem of acid mine water and tailingspiles' drainage water neutralization and purification. This paper presents authors' experience in geochemical barriers using for environmental protection in the Kizel coal basin.

Laboratory and field-scale experiments have demonstrated the possibility to neutralize both discharging acid mine water and tailingspiles' drainage water using geochemical barriers filled with industrial wastes as reagents. Application of geochemical barriers demands considerably less costs and allows to avoid building of expensive cleaning constructions and to realize another measures of environment protection.

Key words: Acid mine water, tailingspile, drainage water, geochemical barriers

## Introduction

Coal-bearing formations occupy 15% in the earth continental crust and have a complex structure – limestones, argillites, siltstones, sandstones, and other rocks occur between the coal beds. Almost 80 elements have been found in coal, 12 of which have 10–1,000 times higher concentration in coal than in background strata. Total sulfur content can be as high in coal as 20 weight percent. Average sulfur content in the Russian European coal basins is 3.8%. Sulfur occurs in forms of sulfides and sulfates, as well as of organic and elementary ones (Kler 1988).

These geochemical features can significantly influence the environment in coal mining areas: the oxidation of sulfur and iron containing minerals releases iron-rich, acidic solutions (acid mine water) which may contain elevated level of metals (Nordstrom & Alpers 1999a, Winland *et al.* 1991). Overall rates of sulfide oxidation and metal release in areas affected by mining are estimated to be orders of magnitude faster than natural rates (Nordstrom & Alpers 1999b). Sulfide-bearing mine tailings are known for their potential to form acid drainage water upon weathering (Dold & Fontboté 2002, Graupner *et al.* 2007, McGregor & Blowes 2002, Moncur *et al.* 2005, Sergeev *et al.* 1996). When acid mine and drainage waters enter natural waterways, changes in pH and the formation of ochreous precipitates can have devastating effects on aquatic ecosystems (Furrer *et al.* 2002, Gray 1998, Nordstrom *et al.* 2000, Sivakumar *et al.* 1994, Tiwary & Dhar 1994, Younger 1997,). So, coal mining can result in a significant deterioration of the environment.

Investigations in the UK, Japan, India, the USA and other coal basins revealed that the closure of mines could result to uncontrolled discharge of contaminated water to the surface (Burrel & Whitworth 2000, Donovan *et al.* 2003, Maksimovich & Gorbunova 1990, Okamoto *et al.* 2006, Siddharth *et al.* 2002, Younger 1993). Mine drainage may persist for decades, making the necessity to protect and improve the environment in coal mining regions is extremely important.

This paper presents authors' practical experience in geochemical barriers using for environmental protection in the Kizel coal basin (the Western Urals, Russia).

**Regional settings and mining-associated problems**

The Kizel coal basin (the Western Urals, Russia) occupies area of 200 $km^2$ and is located within West Urals folding zone adjacent to the pre-Ural boundary deflection. Folds have meridional and close to meridional orientation, are elongated for tens of kilometers, and are complicated by numerous disjunctive dislocations. Rocks of Palaeozoic (Middle Devonian – Late Permian) age are developed in the area. Rocks are represented by sandstones, mudstones, siltstones, shales, limestones, dolomites, marls, coals, and others and have a thickness column of 3–4 km. Carbonate rocks are intensely karsted, especially in the upper part of geologic column. Quaternary deposits are mainly represented by sands, loams, and clays and have often a high content of gravel and pebbles. Coal of the basin exhibits elevated content of sulfur (mainly as pyrite) – 5.8% (Kler 1988).

Mining in the Kizel coal basin had been carried out for more than 200 years. Over 35 million $m^3$ of waste rocks had been accumulated in more than 70 tailingspiles. Mine water was pumped out to the surface without any cleaning or pre-treatment during mining. Mines were closured in the 1990s, but the closure haven't solved the environmental problems.

The cessation of mining has led to gradual restoration of watertable level to it natural value, so 12 adits of abandoned mines have started to discharge acid mine water to the surface. Chemical interaction between acid mine water and surrounding rocks and grounds has resulted in high concentrations of iron, aluminum, and metals in discharged water flowing into 19 rivers, 15 of which were water sources for human use in the area. Several tones of sediments which consisted of amorphous iron and aluminum hydroxides and have a high content of Mn, Cu, Ni, Zn, Pb, and other metals have been accumulated in rivers' bottom. These sediments were washed downstream to the Kama and Chusovaya rivers, where they become a secondary source of water pollution.

Tailingspiles of the Kizel coal basin are composed of fragments of argillite, sandstone, and limestone with inclusions of coal. The content of pyrite in tailingspiles reaches 4%. Processes of physical weathering, oxidation, hydrolysis, hydration, and metasomatism occur within tailingspiles. The oxidation of pyrite releases sulfur acid and is accompanied with heat production. So, self-ignition of tailingspiles, roasting and melting of their rocks, and fumarole processes within tailingspiles were detected. Rainfalls drained tailingspiles are enriched in soluble compounds (sulfate ions – up to 30 g $L^{-1}$, iron – up to 8 g $L^{-1}$) and have a high salinity (up to 50 g $L^{-1}$). Infiltration of these waters into underlying grounds changes physical-mechanical and filtration properties of grounds and pollutes groundwater.

**Solutions of the Problems**

Since the 1980s the authors have been working on the problem of acid mine water and tailingspiles' drainage water neutralization and purification using geochemical barriers filled with industrial wastes as a reagents.

**1. Acid mine water neutralization**

At the end of the 1980s alkaline waste products from the Bereznikovsky Soda Factory (Russian Federation), so-called ''white seas'', were tested as potential reagents for acid mine water neutralization and appropriate technique was developed (Maksimovich *et al.* 2007, Maksimovich 2010, Maksimovich & Khayrulina 2014).

Alkaline waste products consist of calcite mainly (70–80% $CaCO_3$) and have pH 9–12. The quantity of waste suitable for use as a reagent exceeds 1 million $m^3$. Soda waste recycling and acid mine water purification are based on neutralization and precipitation reactions. Theoretically the main reagent, that is calcium carbonate, reacts with acid mine water as follows:

$H^+(aq) + CaCO_3(s) = HCO_3^-(aq) + Ca^{2+}(aq)$ (1)

$SO_4^{2-}(aq) + Ca^{2+}(aq) = CaSO_4(s)$ (2)

$H^+(aq) + CaCO_3(s) + SO_4^{2-}(aq) = HCO_3^-(aq) + CaSO_4(s)$ (3)

$CO_3^{2-}(aq) + Fe^{2+}(aq) = FeCO_3(s)$. (4)

Hydrogen ions are consumed, and sulfate ions form a precipitate of less soluble calcium sulfate as a result of reactions. Rise of pH value enables precipitation of iron and aluminum hydroxides.

We applied the developed technique to neutralize discharging acid water of the “40$^{th}$ Anniversary of the October” Mine. Samples of mine water were taken in summer when water was characterized by maximal values of salinity and concentration of pollutants. Laboratory studies involved a series of experiments to determine optimum amount of alkaline waste products and required period of time to neutralize mine water. Chemical composition of water samples before neutralization and after it was also examined. It was found that vigorous stirring accelerated neutralization.

Then the field-scale experiment was conducted (fig. 1). The part of discharging mine water was pumped in simple construction where it was mixed with paste-shaped alkaline waste products of the Bereznikovsky Soda Factory to form more fluid reagent. Appointed amounts of resulting pulp were periodically added directly in the stream of discharging mine water, where chemical reactions began to proceed. This reacting mix flowed to the pond of preliminary sedimentation, where chemicals formed sediment. The final cleaning of water from precipitate occured in the second pond, where water was cleaned up to standards and then entered into river. Chemical content of the mine water before the experiment and after it is presented (tabs. 1–2).

One of the main problem of mine water neutralization process is the disposal of formed sediment. Laboratory experiments to determine the phytotoxicity of sediment were conducted. It was established that a mixture of sediment and rocks of mine tailingspiles provided the most favourable conditions for growth of perennial grasses (timothy, fescue, couch grass, and alfalfa), especially with fertilizers addition. So, the sediment obtained in the course of neutralization process was suitable for remediation of mine tailingspiles.

The field-scale experiment has demonstrated the possibility of alkaline geochemical barrier using to neutralize acid mine water and to decrease the content of chemical elements in it. Moreover, this technique helped to solve the urgent problem of alkaline waste products disposal. Calculations have shown that the cost of 1 $m^3$ of acid mine water neutralization was about 0.03 $.

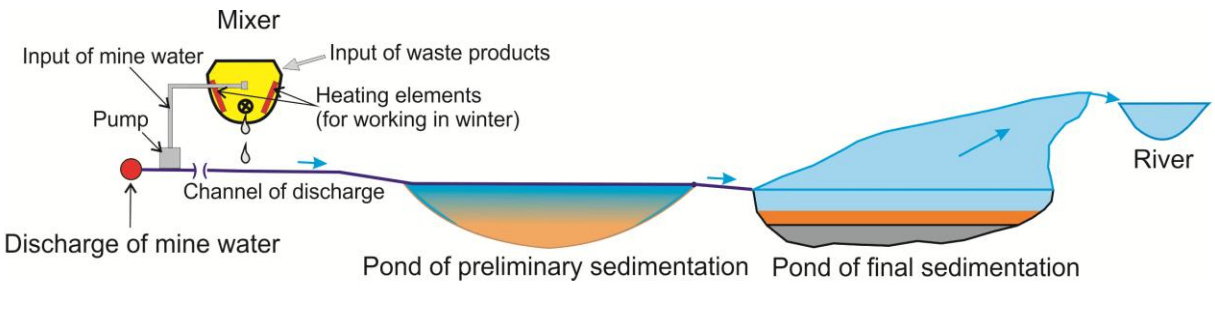


***Figure 1*** *The schema of the field-scale experiment to neutralize discharged acid mine water*

***Table 1** Change of chemical content of the "40th Anniversary of the October" Mine water during the experiment (mg $L^{-1}$)*

| Sample no. | Sampling conditions | $HCO_3^-$ | $SO_4^{2-}$ | $Cl^-$ | $Ca^{2+}$ | $Mg^{2+}$ | $Na^++K^+$ | $Fe^{3+}$ | $Al^{3+}$ | Salinity | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Before neutralization | b.d.l. | 329.49 | 5.67 | 24.05 | 12.15 | 9.89 | 30.72 | 10.79 | 426.38 | 2.81 |
| 2 | Before neutralization | b.d.l. | 355.43 | 21.27 | 36.07 | 12.15 | 32.72 | 40.00 | 14.39 | 516.35 | 2.85 |
| 3 | Before neutralization | b.d.l. | 320.37 | 14.18 | 24.05 | 12.15 | 4.14 | 32.11 | 14.03 | 427.55 | 2.89 |
| 4 | After neutralization | 73.22 | 348.22 | 5.67 | 140.28 | 14.58 | 7.82 | 0.23 | b.d.l. | 594.12 | 6.70 |
| 5 | After neutralization | 73.22 | 376.56 | 9.93 | 156.31 | 14.58 | 6.90 | b.d.l. | b.d.l. | 639.67 | 7.32 |
| 6 | After neutralization | 73.22 | 357.83 | 12.76 | 150.30 | 14.58 | 6.90 | b.d.l. | b.d.l. | 617.70 | 7.26 |

b.d.l. – below detection limit

***Table 2** Change of metals content in the "40th Anniversary of the October" Mine water during the experiment (ppm)*

| Sample no. | Sampling conditions | Ni | Co | Cr | Mn | V | Ti | Sc | Cu | Zn | Pb | Mo | Be | Ga | Y | Yb | Nb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Before neutralization | 0.25 | 0.17 | 0.025 | 8.28 | 0.008 | 0.12 | 0.008 | 0.075 | 0.75 | 0.005 | 0.0015 | 0.012 | 0.0017 | 0.17 | 0.017 | 0.008 |
| 2 | After neutralization | 0.05 | 0.03 | b.d.l. | 3.60 | b.d.l. | b.d.l. | b.d.l. | 0.007 | b.d.l. | b.d.l. | b.d.l. | b.d.l. | b.d.l. | b.d.l. | b.d.l. | b.d.l. |

b.d.l. – below detection limit

## 2. Neutralization of groundwater polluted with tailingspiles' drainage water

An alkaline geochemical barrier was used to clean groundwater polluted with drainage water of tailingspile. Cabonate rocks are wide distributed on the territory of the Kizel coal basin, so waste of limestone mining was used as a reagent. Laboratory studies have demonstrated the efficiency of carbonate rocks usage to neutralize tailingspiles' acid drainage water.

The field-scale experiment was conducted near of one of tailingspiles, whose drainage water polluted groundwater (fig. 2). Trench works were done crosswise the groundwater flow to the depth of confining layer bedding (1–1.2 m). The trench was filled with wastes of limestone mining, two observation wells (before the trench and behind it) were done to monitor neutralization process.

As a result, the pH value of groundwater increased from 1.8 to 6.8 and maintained nearby values during a year. The chemical composition of water changed to sulfate-hydrocarbonate-calcium, water salinity decreased from 28 to 3.5 g $L^{-1}$, and the content of main polluting components decreased also. Filtration properties of grounds changed – there was an intensive precipitation of iron and aluminum hydroxides, as well as some sulfates and hydrosulfates – the formed precipitate filled the pore space and impeded filtration. The modulus of grounds deformation increased two times and more. So, the field-scale experiment has demonstrated the possibility of alkaline geochemical barrier using to clean groundwater polluted with tailingspile's drainage water.

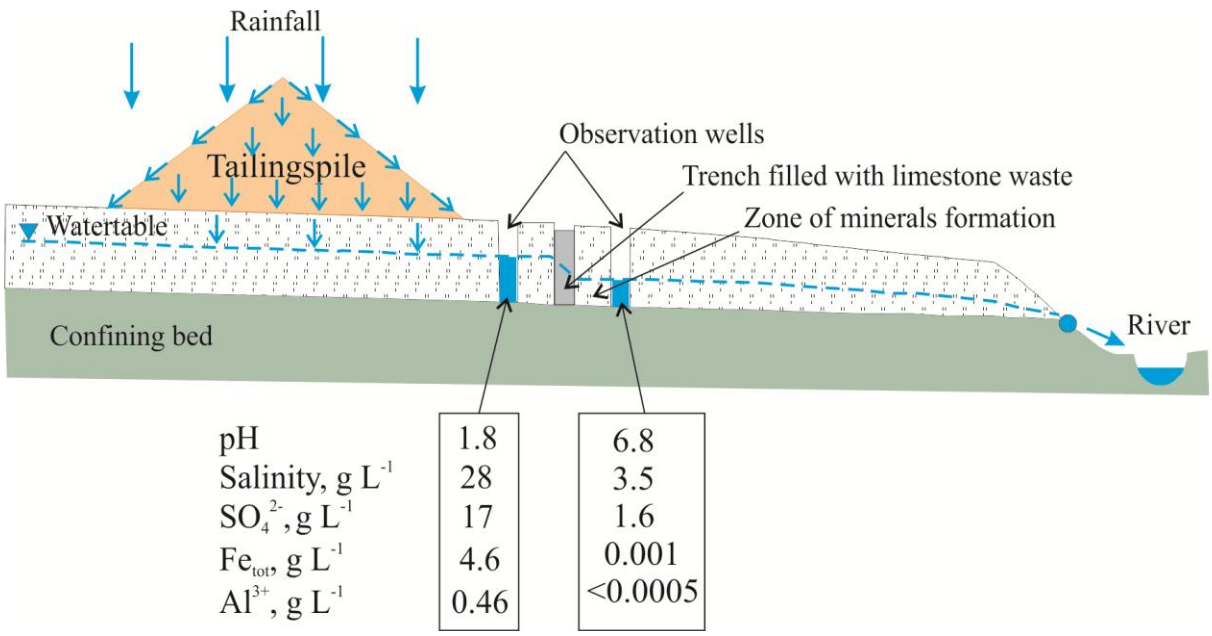


***Figure 2*** *The schema of the field-scale experiment to neutralize polluted groundwater*

## Conclusions

Geochemical barriers could be effectively used to solve environmental problems in coal mining regions. The application of geochemical barriers demands considerably less costs and allows to avoid building of expensive cleaning constructions and to realize another measures of environment protection.



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