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# Artificial geochemical barriers for environmental improvement in a coal basin region

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**Abstract** In the Urals (Russia), in the territory of the closed Kisel Coal basin acid mine water is a source of contamination. The authors suggest using artificial geochemical barriers as an efficient method for environmental improvement in this coal basin region. Alkaline waste products were used for barrier creation. Waste products are non-toxic and consist of 70–80 % calcite (CaCO<sub>3</sub>). According to tests they are capable of neutralizing mine water and to precipitate iron, aluminum, heavy metals. The scientific basis for the creation of geochemical barriers for environmental improvement is presented.

**Keywords** Geochemical barrier · Acid mine water · Neutralization · Alkaline waste product

## Introduction

Coal-bearing formations occupy 15 % in the earth's crust over all the continents. Coal mining can result in a significant deterioration of the environment, largely due to the lithological and geochemical characteristics of the coalbearing formations. Coal-bearing strata have a complex structure. Limestones, argillite, siltstone, sandstones and other rocks occur between the coal beds. In the presence of favorable conditions karst processes can develop in the limestone.

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Coal-bearing strata have a number of unique geochemical features. The sulfur content in the coal can be as high as 20 weight percent. The average for the deposits of the former Soviet Union is 1.5 %, which is 50 times more than its average content in the crust, and 10 times more than the average sulfur content in sedimentary rocks. In the Russian European basins, the average sulfur content is 3.8 %, in Siberia 2.7 %, in Kazakhstan 2.0 %, in Primorye 0.4 % (Kler et al. 1988) and in the US 1.8 % (Orem and Finkelman 2003). Sulfur occurs in various forms as sulfides and sulfates, as well as in organic and elementary forms. Almost 80 elements have been found in coal, 12 of which have 10-1,000 times higher concentration than background strata and many of the elements in elevated concentrations are potentially harmful to the environment and to human health.

These geochemical features can significantly influence the environment in coal mining areas during the development and operation of the fields as well as after their closure. Investigations in the UK, Japan, India, USA and other coal basins show that the closure of mines in many cases resulted in environmental deterioration caused by uncontrolled discharge of contaminated groundwater to the surface (Younger 1993; Burrell and Whitworth 2000; Okamoto et al. 2006; Siddharth et al. 2002; Donovan et al. 2003; Maximovich and Gorbunova 1990). The need to protect and improve the environment in coal regions is extremely important. Pollutants released from mine water and burning coal waste piles are known to cause health problems in humans (Finkelman et al. 2002; Finkelman and Stracher 2011).

The main focus for protecting and improving environmental conditions should be to develop and modernize the technological solutions used in commerce and industry for wastewater and emission treatment systems, waste management, etc. Modern environmental facilities for wastewater, air emissions and solid and liquid toxic wastes storage typically require large capital expenditure, significant energy and material resources for their operation. In addition, in most cases they themselves are significant sources of pollution. Thus, to minimize the industrial impact on the environment using cost-effective ways presents a considerable challenge.

In this paper, the authors aim to establish a scientific basis for the creation of geochemical barriers for environmental improvement and present examples of their own solutions to this problem.

### **Theoretical basis**

In recent decades, there has been a trend to use geochemical barriers for environmental protection, the application of which, in some cases, eliminates the complicated construction of sewage treatment plants and other costly environmental measures (Sergeev et al. 1996; Langer 2001; Masferrer 2002; Maximovich 2010). Widespread use of geochemical barriers is limited by the lack of theoretical knowledge of how they might be used in practical application.

According to Russian scientist Perel'man (1986), a geochemical barrier represents a zone where the intensity of element migration decreases sharply, causing accumulation of elements. In natural environments, geochemical barriers determine the geochemistry of different soil horizons, sediments and ore deposits.

Mining practice and processes have had considerable impact on the earth's surface, especially where anthropogenic processes predominate over the natural. Along with the processes of pollutant dispersion, the accumulation of substances has resulted in the creation of technogenic geochemical barriers.

Such geochemical barriers can be used for limitation of technogenic migration. Successful experience of their application has allowed the formulation of principles for a strategic approach to environmental protection based on the acceleration of the natural transformation of pollutants into non-migratory forms or purposeful pollutant accumulation within a confined area in the lithosphere, i.e., construction of geochemical barriers.

Different types of geochemical barriers are used for environmental protection (Fig. 1).

Experience has shown that technogenic geochemical barriers used for these purposes can be divided into barriers where natural barrier properties of the environment spontaneously or purposefully are used and artificial, created by special technology. In some cases, geochemical technogenic barriers can be created using both of these principles.



Fig. 1 Types of technogenic geochemical barriers used in environmental protection



Fig. 2 Construction materials used in artificial geochemical barriers

Industrial activity causes uncontrolled pollution. In some cases, features of soils, rocks, surface and groundwater, topography are responsible for the appearance of geochemical barriers. Such barriers are spontaneously appeared. There are cases, when natural barrier properties of the environment were used purposefully. For example, on the territory of Kisel coal basin acid mine waters were dumped to areas of carbonate rock outcrops for neutralization.

Different materials have been used in the construction of artificial barriers, depending on the targets to be protected and economic efficiency (Fig. 2).

Technogenic geochemical barriers can be created specifically for different purposes, such as environmental protection, mineral processing, engineering protection and, etc. Such barriers are called as artificial barriers. Special technologies are developed for creation of artificial barriers. Different materials and substances are used, depending on the specific barriers and economic efficient. Natural materials are used in the creation of sorption barrier (clay, loam, peat), alkaline barriers (carbonates) and other barriers. The advantage of natural substances is their widespread reduction of transportation expenses and low cost. Another perspective way is the use of waste products for creation of artificial barriers. It helps to solve other environmental issue—recycling. In the case where natural substances and wastes are ineffective to construct a barrier, special chemicals are tested. They allow providing the required barrier effectiveness.

#### Geochemical barrier construction

The construction of artificial geochemical barriers for the protection of the environment is based on wide-ranging research (Sergeev et al. 1996; Langer 2001; Masferrer 2002; Maximovich 2010). For any environmental issues associated with the migration of contaminants, it is necessary to (a) identify and characterize the source of pollution, (b) study the impact and (c) make a prediction of environmental change resulting from the construction of barrier. To this end, relevant data are collected and field and laboratory researches are carried out. A model can then be created.

The information obtained allows researchers to evaluate the possibility of using geochemical barriers for the solution of already existing and potentially developing problems. At the same time, the study of natural and technogenic analogs of geochemical barriers can provide



Fig. 3 Middle part of Kizel coal basin and place of experimentation

useful information. To select what type of barrier is best, it is necessary to carry out comprehensive laboratory research that will evaluate the natural protective properties of the environment or select the necessary reagents. After that, it is possible to create a model of the barrier and a flow chart of its creation: the number of reagents, methods of their application, design features, etc. Then industrial tests are conducted, the technology is adjusted and the project to create the barrier is developed. During operation of the barrier its effectiveness is monitored, and necessary adjustments in the technology are made.

The given scheme or some of its elements have been tested on a number of industrial facilities with various anthropogenic impacts. This paper presents the authors' practical experience of using geochemical barriers for environmental protection in coal basin region.

#### Description of the study area

Mining in the Kizel coal basin (West Urals, Russia) has been carried out for more than 200 years. During this time over 35 million  $m^3$  of rocks have accumulated in more than 70 waste piles (Fig. 3).

The geology of the Kizel Coal Basin is largely Carboniferous. Recent cessation of mining in the area and subsequent water table rebound has caused serious environmental problems. Following mine closures, geochemical interaction between acid mine water and the surrounding geology has resulted in high concentrations of iron, aluminum, and trace metals in the tributaries of Kama and Chusovaya rivers. Water from these rivers is used as a water supply for more than 2 million people. The coal in the Kizel Coal Basin differs from other basins in the region in that it exhibits a high content of sulfur (mainly as a pyrite) (5.8 %) and ash (21.5 %) (Kler et al. 1988).



Fig. 4 Discharged acid mine water after mine closures

The mine water chemistry largely depends on the levels of sulfur, carbonate, and trace elements found within the carboniferous strata. Sulfate chemistry in ground and surface water is caused when concentration of pyrite reaches more than 4 %. Total dissolved solids (TDS) concentrations of the sulfate (Fe–Al, Na–Ca) water of the Kizel Coal Basin were 2.5–19 g/L and levels higher than this value were observed during the exploitation of the coal. Contents of lead, copper, zinc, silver, nickel, cobalt, and other trace elements in the acid mine water increased compared to ambient groundwater (Maximovich and Gorbunova 1990).

During the exploitation of the basin, mine waters were released to the surface without any prior purification or treatment. Before mine waters entered the river network, natural waters had HCO<sub>3</sub>–Ca–Na hydrochemical facies, TDS of 90–150 mg/L, and pH was circumneutral. After the discharge, the hydrochemical facies is  $SO_4$ –Fe–Al, TDS ranges from 640 to 6,000 mg/L, sulfate concentration ranged from 1,000 to 3,700, iron from 70 to 900, aluminum from 11 to 160 mg/L, and pH 2.5–2.9 (Maximovich et al. 1995).

Mine closures occurred in the 1990s but this did not resolve the environmental problems. Although acid mine waters were no longer pumped to the surface, 12 disused mine adits (Fig. 4) started discharging water to the surface once the groundwater table rose to its natural level. The total average annual discharge entering River Kos'va is 2,500 m<sup>3</sup>/h. This is several times less than it was during the mining activity. However, the TDS of the discharge increased greatly—in some cases, to over 25 g/L. The ferrous iron content increased sharply as well up to 5 g/L. Discharged water entered 19 rivers, 15 of which are water sources for human use in the area.

In the more polluted river sections, several tons of technogenic bottom deposits are accumulated. The accumulation included amorphous iron and aluminum hydroxides with high concentration of Mn, Cu, Ni, Zn, Pb and other elements. These bottom deposits were washed downstream to the Kama and Chusovaya Rivers, where they become a secondary source of water pollution.

# **Experimental setup**

Since the 1980s, the authors have been working on the problem of acid mine water purification and coal waste pile drainage to find a method for removing harmful elements using artificial geochemical barriers with industrial waste as a reagent.

At the end of the 1980s, alkaline waste products (socalled "white seas", Fig. 5) from the Bereznikovsky soda factory (BSF) were tested as a potential reagent for acid



Fig. 5 Mud collector of alkaline waste products, Bereznikovsky soda factory (BSF)

discharge neutralization. The neutralization technique was developed by Maximovich et al. (2007) (Fig. 6).

The mine water enters into simple construction, where alkaline waste and mine water mix. The resulting pulp flows directly into the channel of discharge to the first water reservoir where preliminary chemicals are precipitated due to increasing of the pH. Then, water naturally enters into existing techogenic Rahmatul'skii water reservoir. In this reservoir water is cleaned up to standards (MPS) and enters into the river. Sediments, obtained by neutralization, cover existing acid sediments in Rahmatul'skii water reservoir.

Alkaline waste products consisted of 70–80 % calcite  $(CaCO_3)$  with a pH from 9 to 12. The average contents of 38 elements did not exceed MPC (maximum permissible concentration) in soils (Table 1) and there were no harmful organic compounds. The volume of waste suitable for use

as a reagent for the neutralization of acid mine water without any treatment exceeds 1 million  $m^3$ .

Soda waste recycling and acid mine water purification are based on neutralization and precipitation reactions. The main reagent that is calcium carbonate reacts with mine water as follows:

$$H_{(aq)}^{+} + CaCO_{3(s)} = HCO_{3(aq)}^{-} + Ca_{(aq)}^{2+}$$
(1)

$$SO_{4(aq)}^{2-} + Ca_{aq}^{2+} = CaSO_{4(s)}$$
 (2)

$$H^+_{(aq)} + \text{CaCO}_{3(s)} + \text{SO}^{2-}_{4(aq)} = \text{HCO}^-_{3(aq)} + \text{CaSO}_{4(s)}$$
 (3)

$$CO_{3(aq)}^{2-} + Fe_{(aq)}^{2+} = FeCO_{3(s)}.$$
 (4)

As a result of the reactions hydrogen ions are consumed, and sulfate ions form a precipitate of less soluble calcium sulfate. The pH change enables the precipitation of iron and aluminum hydroxides.



Fig. 6 Technological schema of mine water neutralization using alkaline waste products

No. of sample	Depth (m)	pН	Ni	Co	Cr	Mn	V	Sc	Ye	Cu	Zn	Pb	Ва	Sr	Be	Zr	Y	La	Li	Nb
1	0		7	3	10	500	10	3	_	20	70	10	5	500	_	50	20	15	15	_
3	0	8.8	10	5	30	700	10	_	_	15	50	4	200	500	<1	30	40	_	_	_
2	1.6	11.8	9	4	30	500	10	3	_	18	_	7	300	400	1	30	30	_	_	7
5	0	8.7	7	3	18	1,000	10	3	_	15	_	7	200	400	_	20	40	_	_	_
4	1.0	11.8	6	3	15	400	10	_	_	10	_	30	200	300	1.5	20	30	_	_	7
8	0	9.9	6	3	30	700	10	_	_	10	_	7	200	300	1	20	40	_	_	_
7	1.0	11.4	9	3	30	700	10	_	_	10	_	70	200	300	1	50	40	_	_	_
6	3.5	11.8	10	3	40	1,500	10	3	_	20	50	180	200	400	1	20	40	_	_	7
11	0	9.2	7	3	30	1,000	10	_	_	10	_	20	200	300	_	20	40	_	_	_
10	1.5	11.5	9	3	50	1,000	10	3	_	20	_	180	200	300	15	20	50	_	_	_
9	4.0	1.6	9	3	70	1,000	10	4	_	18	_	180	1,500	500	1	30	50	_	_	_
12	0	2.3	5	_	15	1,000	10	3	_	18	_	15	200	200	1	20	15	_	_	_
13	2.5	12.4	7	3	30	700	10	3	1	18	_	100	200	200	1.5	40	18	_	_	_
14	3.5	12.4	9	3	30	900	10	3	_	20	50	150	200	300	1	40	18	_	_	_
MPC			40 <sup>b</sup>			1,500 <sup>a</sup>	150 <sup>a</sup>			66 <sup>b</sup>	110 <sup>b</sup>	32 <sup>a</sup>								

 Table 1
 Average data for the alkaline waste products (ppm)

<sup>a</sup> GN 2.1.7.2511-09. Sanitary-hygienic standard

<sup>b</sup> GN 2/1/7/2511-09. Sanitary-hygienic standard

Significant influence on the purification of mine water can be exerted by sorption. A considerable part of the precipitate formed by neutralization is a colloidal system with a highly developed surface. This system consists mainly of  $Fe(OH)_3$ . The  $Fe(OH)_3$  colloids are highly sorptive. Their precipitation on the oxidative geochemical barrier can result in co-precipitation with ions of other elements according to (Antonov et al. 2013).

During the process of neutralizing mine waters calcium ions enter the solution. Excess  $SO_4^{2-}$  and  $Ca^{2+}$  ions precipitate as gypsum. This is confirmed by X-ray diffraction studies of sediment. Thus, under the conditions provided in the process we can also expect partial purification of mine water due to the precipitation of  $SO_4^{2-}$  ions.

Mine water and waste product at the BSF mud collector were sampled for laboratory testing research, where experiments and chemical analyses were carried out.

The mine water for laboratory experiments was sampled from the adit "40 let Octyabrya" in summer at low water levels. During this period, the water is characterized by maximal mineralization and concentrations of pollutants.

The studies involved a series of experiments to determine the optimum amount of reagent and the time required to neutralize the mine water. The chemical composition of the water before and after neutralization was also examined.

The natural environment in which neutralization occurs was simulated to determine the optimal amount of reagent required. For this purpose, 0.5 L of mine water was added to certain BSF waste samples and stirred vigorously for 5 min. Thereafter, the water was desilted for 20 min, and the pH was measured. Four series of experiments were conducted with the mine water. The results are shown in Fig. 7. It was established that the optimal amount of alkaline waste products for increasing mine water pH to 6.5–7.0 is 1.2–1.5 g/L.

Another laboratory experiment established the dependence of raised pH in mine water on the time of contact with alkaline waste products. One liter of mine water was stirred with the optimal amount of reagent (1.35 g) and the pH was measured at regular intervals. The same was repeated with another sample. It was found that vigorous stirring accelerated neutralization. More than 90 % of the rise in pH was observed during the first 20 min of the experiment (Fig. 8).

#### **Experimental results**

A pilot field experiment was conducted in "40 let Octyabrya" mine (Fig. 9) in Fall, where water discharge varied from 180 to 220 m<sup>3</sup>/h in summer to 300–400 m<sup>3</sup>/h during the flood period in spring. Mineralization ranged from 400–600 to 800–900 mg/L with pH of 2.6–2.9. The





Fig. 7 pH of mine water from "40 let Octyabrya" mine after addition of alkaline waste products



Fig. 8 Dependence of mine water pH on time of reaction



Fig. 9 Experimental test facility of mine water neutralization using alkaline waste products ("40 let Octyabrya" mine)

concentrations of some elements exceed MPC: Fe by 400, Al by 46, SO<sub>4</sub> by 1.3, Be by 52.8, Mn by 36.9, Ni by 2.5, Cd by 1.9, Co by 1.6, Ba by 1.5, and Ti by 1.2 times (Table 2).

In this experiment, the pH of the discharged mine water increased from 2.6–2.9 to 7, resulting in a decrease of iron concentration from 30–40 to 0.2–0.3 mg/L. The content of Al, Be, Li, Ni, Cd, Co, and Ti does not exceed MPC (Table 3). Ge, As, Sb, Cd, Bi, W, Sn, La, Li were not found by spectral analysis. Elevation of content of Ca and SO<sub>4</sub> is connected with short period of reaction before sampling.

Sample 10.	Sampling conditions	$HCO_3^-$	$\mathrm{SO_4}^{2-}$	Cl_	$NO_3^-$	$NO_2^-$	Ca <sup>2+</sup>	${\rm Mg}^{2+}$	$Na^++K^+$	$\mathrm{NH_4}^+$	$\mathrm{Fe}^{2+}$	$\mathrm{Fe}^{3+}$	$Al^{3+}$	Mineralization	Hq
32	Before neutralization	n.f.	329.49	5.67	1.60	0.06	24.05	12.15	9.89	0.40	n.f.	30.72	10.79	426.38	2.81
34	After neutralization	73.22	348.22	5.67	2.30	0.01	140.28	14.58	7.82	1.80	n.f.	0.23	n.f.	594.12	6.70
36	Before neutralization	n.f.	355.43	21.27	1.70	n.f.	36.07	12.15	32.72	1.00	n.f.	40.00	14.39	516.35	2.85
38	After neutralization	73.22	376.56	9.93	1.50	0.01	156.31	14.58	6.90	0.66	n.f.	n.f.	n.f.	639.67	7.32
39	Before neutralization	n.f.	320.37	14.18	1.55	0.03	24.05	12.15	4.14	0.74	2.90	32.11	14.03	427.55	2.89
40	After neutralization 1 h after experiment started	73.22	357.83	12.76	1.50	0.01	150.30	14.58	6.90	0.60	n.f.	n.f.	n.f.	617.70	7.26
41	After neutralization 1 h 20 min after experiment started	67.12	357.83	14.18	1.50	0.01	148.30	14.58	7.13	0.66	n.f.	0.37	n.f.	611.68	7.15
	MPC <sup>a</sup>		500	350	45	3.3		50	200			0.3	0.2	1,000	
<i>i.f.</i> not fo	ound by chemical analysis 1 5 1315-03 Maximum nermissible concentrations of	f chemical	s in wate	r hodies	of drin	kino and	cultural	mon bue	munity wat	er sunnl	20				
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Table 2 Chemistry of water from "40 let Octyabrya" mine before and after mine water neutralization (mg/L)

Calcite (CaCO<sub>3</sub>) of alkaline wastes and sulfate ions form a calcium sulfate in water reservoirs.

Following neutralization, the sediment comprised a mixture of iron and gypsum hydroxide and calcium carbonate with a neutral pH. Total content of Ni, Mn, Pb, Zn, Sr, Y raised more than three times. Mobile forms of Fe, Al, Mn, Pb and other elements were not found (Table 4).

One of the major problems of the neutralization of mine water is the disposal of the sludge. To determine the phytotoxicity of sludge, experiments were conducted on these substrates: sediments, obtained by neutralization of discharge; mixture of sediments, obtained by mine water neutralization, and rocks of coal waste piles; technogenic acid sediment, formed in the Rahmatul'skii water reservoir. For more favorable nutrient regime of plants, the fertilizers (0.2 % KNO<sub>3</sub> and K<sub>2</sub>HPO<sub>4</sub>) were introduced as an additional option with fertilizers. After 10 days a visual inspection of perennial grasses as well as measurement of length and weight of above-ground and below-ground parts of wheat and perennial grasses was carried out.

It is established that the substrate as a mixture of sediment and rocks of coal waste piles has the most favorable conditions for perennial grasses (timothy, fescue, couch grass, and alfalfa) especially with fertilizers (Fig. 10).

At the sediment, obtained by neutralization and without any impurities, plants grew more slowly. The sediment consists of fine particles, which slows down the growth of the plant compared to check sample. Using of fertilizers substrate increases plant height and weight. So, the sediment, obtained by neutralization, is ready for remediation of mine piles.

# Conclusion

The pilot field experiment demonstrated the possibility of using alkaline geochemical barriers to neutralize and decrease the contamination of chemical elements in acid mine water. In addition, this method of mine water purification helps to resolve the urgent problem of the disposal of alkaline waste products. To implement the method, technological schemes for different natural and anthropogenic conditions were worked out.

This and other examples show the relative simplicity and low cost of using geochemical barriers to solve environmental problems in coal basin regions. The calculation of the basic technical and economic parameters of mine water neutralization by alkaline waste showed that the cost of neutralization of 1 m<sup>3</sup> of mine water is approximately about 0.03 \$.

Table 3	Trace element co.	mposit	ion of	the discharged acid	l wate	r from "	40 let	Octyabı	rya" mi	ne bef	ore and	after the	mine wa	ater neut	ralizatic	n in ppn	_				
Sample no.	Sampling conditions	Ni	Co	Cr 1	Mn	` ^	Li	Sc	Cu	Zn	Pb	Ag	Mo	Ba	Sr	Be	Zr	Ga	Υ	Yb	ЧN
39	Before neutralization	0.25	0.17	0.025	3.28	0.008	0.12 (	0.008	0.075	0.75	0.005	0.0008	0.0015	0.083	0.083	0.012	0.012	0.0017	0.17	0.017	0.008
43	After neutralization location no 1 1 h after experiment started	0.05	0.03	n.f.	3.60	n.f.	n.f.	n.f.	0.007	n.f.	n.f.	0.0007	n.f.	0.144	0.288	n.f.	0.013	n.f.	n.f.	n.f.	n.f.
44	After neutralization location no 1 1 h 20 min after experiment started	0.07	0.04	n.f.	4.20	ı. T	n.f. 1	n.f.	0.007	n.f.	n.f.	0.0014	n.f.	0.070	0.210	n.f.	n.f.	n.f.	n.f.	n.f.	n.f.
42	After neutralization location no 2 1 h 20 min after experiment started	0.07	0.04	n.f.	1.06	n.f.	n.f.	n.f.	0.007	0.05	0.003	0.0047	n.f.	0.135	0.271	n.f.	0.014	n.f.	n.f.	n.f.	n.f.
	MPC	0.1	0.1	$\begin{array}{c} 0.5 \ (\mathrm{Cr}^{+3}) \\ 0.005 \ (\mathrm{Cr}^{+6}) \end{array} $	).1	0.1	0.1		1.0	1.0	0.03	0.05	0.25	0.1	7.0	0.0002					
<i>n.f.</i> not f <i>MPC</i> acc	ound by spectral ar ording to Russian	nalysis standar	sp.																		

ample	Hq	Ni	Co	Cr	Mn	Λ	Sc	Cu	Zn	Pb	Ag	Mo	Ba	Sr	Be	Zr	Υ	ЧN
Cotal content																		
Before neutralization	2.92	30	6	150	100	150	1.5	100	100	30	0.2	2	300	150	10	300	60	30
After neutralization	7.22	70	30	90	1,500	40	6	100	500	90	0.2	3	300	180	10	100	90	15
	No data	40	18	100	1,000	30	7	90	400	90	0.1	1.5	300	150	6	100	70	10
MPC		$40^{\mathrm{b}}$			$1,500^{a}$	$150^{a}$		$66^{\mathrm{b}}$	$110^{\mathrm{b}}$	$32^{a}$								
Vater soluble (mobile)	forms																	
Before neutralization	2.92	0.81	0.81	0.08	27.1	0.03	0.02	27.1	27.1	0.04	I	0.005	0.8	0.8	0.108	0.14	0.4	0.03
After neutralization	7.22	0.02	I	<0.06	Ι	<0.06	Ι	<0.06	0.3	Ι	I	0.009	1.8	0.6	0.006	0.24	<0.06	0.05
MPC <sup>b</sup>		4.0	5.0		700			3.0	23	6.0								
GN 2.1.7.2511-09. Sa	nitary-hygien	uic standa	urd															
GN 2/1/7/2511-09 Sa	nitarv-hvoier	in stands	ard															

**Table 4** Chemistry of sediments before and after mine water neutralization in ppm

Mixture of sediment received by mine water neutralization and rocks of coal waste piles



Check sample without fertilizer with fertilizer

Sediment received by mine water neutralization



Technogenic acid sediment formed in the Rahmatul'skii water reservoir



without fertilizer with fertilizer

without fertilizer with fertilizer

Fig. 10 Grass growth on sediment obtained by neutralization of discharge and coal waste piles

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