UDC 622.85(048.8)

I. V. ZENKOV[1]*, Professor, Doctor of Engineering Sciences, zenkoviv@mail.ru*
V. N. VOKIN[1]*, Professor, Candidate of Engineering Sciences*
E. V. KIRYUSHINA[1]*, Associate Professor, Candidate of Engineering Sciences*
Yu. A. MAGLINETS[1]*, Professor, Candidate of Engineering Sciences*

[1] *Siberian Federal University, Krasnoyarsk, Russia*

REVIEW OF GLOBAL TRENDS IN MEETING THE ECOLOGICAL CHALLENGES OF THE MINING INDUSTRY. PART II: FIELD TESTS AND LAB-SCALE ANALYTICAL RESEARCH IN RUSSIA

This article describes the applied research outcomes in the field of restoration ecology in the Russian regions which carry out open pit mining of solid minerals of all types. Russian ecologists address the issues connected with the evaluation and recovery of soil cover, improvement of the wildlife habitat quality, as well as with the air, water and vegetation ecosystem refining in open pit mining regions. The infomedia for dealing with ecological challenges have shaped in the course of the field testing and lab-scale analysis. All researchers highlight the large scale of the manmade damage caused to natural landscapes and emphasize the necessity of ecological balance acceleration and maintenance on the lands damaged by the mineral mining and processing industry.

Keywords: *mining industry of Russia, open pit mining, mining industry ecology, ecological challenges, land reclamation, species biodiversity preservation, water and vegetation ecosystem recovery, human ecology*
DOI: *10.17580/em.2022.02.18*

Introduction

Being the largest country in the world and having total area more than 17 million square meters, Russia carries out solid mineral mining nearly in all its regions to support economic activity of the society. Currently more than 400 operating open pit mines range in the annual capacity from 1 to 110 Mt. Open pit mining transforms natural environment into mining landscapes, worsens quality of surface and ground water, generates emissions of toxic gases and mineral dust, shrinks wild life habitats and reduces biodiversity. Whole teams of theoreticians and practitioners work at the ecological recovery in the developed mining regions in Russia. We strongly believe that the research developed by ecology scientists requires systematizing the novel knowledge on restoration ecology in open pit mining regions in Russia.

Applied research in the field of restoration ecology in mining regions in Russia

The scope of open pit mining in Russia embraces all types of minerals in greatly diverse conditions of natural climate. The mining industry is developed across the whole Russia, from the Murmansk Region and Krasnoyarsk Krai in the North to the Krasnodar Krai in the South and Primorye in the East. This belt features the subarctic to subtropical climate which immediately influences the ecological balance of the mining landscapes. The total area of land disturbed by open pit mines, waste dumps and processing tailings is 320 thousand hectares according to our estimates. The Russian science offers many proposals on reduction of the environmental impact of the mining industry. In view of the numerosity of scientific publications, we limit our review to large mining regions as such results are fairly adaptable to small-size open pit mines.

In 1985 in the former USSR, Academician V. V. Rzhevsky formulated a long-term forecast: "The mining industry ecology faces yet unsolved scientific problems connected with preservation of nature during solid mining ..., with land protection ... in course of efficient mine work, as well as with methods of land restoration and use ..." [1].

The mining industry in the Russian Ural and in adjacent areas has been developing for more than 300 years. These territories in Russia feature the highest ecological damage due to mining.

Copper-bearing pyrite has been extracted in the Southern Ural for more than 200 years. Snow melt and rain water wash out heavy metals and toxic elements from the surface of waste dumps and tailings ponds. It is possible to reduce high concentration of toxic elements in runoff water by implementing integrated soil and atmospheric runoff remediation using modular water-absorption gabion systems and perennial plants [2]. The Chelyabinsk Region holds three sites with large-scale mining activity. The ecological damage accumulated in the Karabash industrial cluster and the land pollution which affects health of local population is comprehensively studied, and the rehabilitation measures are developed [3]. The capabilities of native shrub vegetation in phytoextraction of heavy metals from contaminated soil is examined. The absorbed concentration of heavy metals is maximum in such plants as elder berry and barberry. These shrubs are recommended for the revitalization of the most endangered ecosystems in the Southern Ural [4].

The Southern Ural's Chelyabinsk Region accommodates the mined-out Korkino coal open pit 500 m deep. The exposed coal beds at the pit bottom and in the spoil banks are prone to spontaneous combustion. The proposed elimination of ecological consequences in the pit includes extinguishing and prevention of endogenous fires, first, and, second, filling of the pit with waste of porphyry copper ore mining and processing at Tominsky GOK situated 20 km westward. Implementation of this range of work can partly solve the ecological issues in the region [5].

For eliminating seepage of process water from storages of water and mineral slurry generated in complex ore processing, it is proposed to create a protection screen made of processed secondary polyethylene and polypropylene pellets placed at the bottom and on the sloped sidewalls of the storages. The introduction of this method can reduce migration of hazardous substances with seepage water flows and can eliminate pollution of natural water bodies [6].

The Orenburg Region holds large Gai complex ore deposit which is in operation for more than 50 years. When dealing with the water treatment issues, the mechanism and points of outwashing of heavy metals from ore processing waste storages were detected, the outwashing limit was delineated and the treatment methods were proposed for drain water with high concentrations of heavy metals [7].

The environmental impact of large-scale mining in the Murmansk Region shows itself as the amplitudinous pollution of air, soil and water, which eventually deteriorates quality of life [8]. In mining regions in Russia, ecologists pay close attention to usability of mineral mining and processing waste placed in dumps and tailings ponds. Applied science offers the ways of using mining and processing waste in the national economy, including waste of open pit mining of kimberlite pipes in the Arkhangelsk Region, processing tailings of complex ore mining in the Murmansk Region, as well as marble and tungsten–molybdenum ore mining and processing [9–13].

The full-scale monitoring of a magnetic separation tailings pond at an iron ore deposit in the Kursk Magnetic Anomaly reveals elevated concentrations of harmful elements in atmospheric air and in surface and ground water in the influence zones of the waste storage. The method developed for the pond surface isolation with polymeric materials can stop the water and wind erosion and can improve the ecological situation in this locality [14]. The issues connected with reduction of toxic gases and mineral dust emission are addressed at the open pit mines in Kuzbass and at the overburden dumps piled at iron ore deposits in the Kursk and Belgorod Regions. The analysis focuses at feasibility of reducing air pollution inside the pit void by means of plant formation on safety benches. Some proposals are put forward toward mitigation of the adverse effect exerted by blasting in open pit coal mining on the environment. Suppression of dusting on the surface of overburden dumps is possible through seeding graminaceous species which are cheap but highly effective in this regard. The studies show that a root mat appears on a dump surface in a short time and prevents emission and flow of mineral dust with wind and rainfall [15–17].

In Siberia in Borodinsk lignite field in the Krasnoyarsk Krai, the aeroecology and microflora of soil cover of overburden dumps piled 30 years ago are studied. It is found that the fertile soil layer applied to the surface of the dumps accelerates growth of microbial complexes [18]. At the dumps piled five years ago, the influence of organic substrates on biological activity and fertility of the plant environment is assessed. The application of organic substances and farmyard manure improves microbiology of soil and stimulates vegetation cover productivity of the soil cover of the dumps [19].

By estimates, the area of land damaged by open pit coal mining (pits and dumps) is 77000 hectares. Under such global disfigurement of natural landscapes, the large-scale environmental impact of the coal industry is evaluated. The investigation shows that preservation of the natural ecosystem is a regular and very challenging problem in Kuzbass. The measures to preserve the natural ecosystems and to restore the mining-disturbed land are proposed [20]. Inspection of ecological state of the soil cover of dumps after their reclamation in Kuzbass and their colonization by ground beetles shows that the latter less readily colonize sites of forest recultivation as compared with sites covered with steepe vegetation [21].

In the arid zone in Khakassia, open pit mining of bituminous coal features scaling up in the last two decades. It is critical to perform reclamation of overburden dumps. Tree- and bush-planting has partially solved the problem, which is confirmed by the three years-long monitoring of survival rate and growth of young plants. The tree planting technology uses a multifunctional hook-on assembly designed for the biological reclamation of truck-piled dumps [22, 23]. The long-term observation over recovery of vegetation on overburden dumps at open pit coal mines in Khakassia ascertains that the self-sustained healing of the dump surface has the lawny nature. The floristic composition of the plant associations and the biomass of herbosa at different sites of overburden dumps is explored [24, 25].

The scope of the open pit mining method in Siberia encompasses mineral deposits composed of soft sediments (placers and materials of construction). The influence of mining operations at such deposits on land resources is defined. The correlation between the surface slope and its self-healing is found with a view to substantiating cutback size to flatten pitwall slope [26]. Another application domain of the open pit mining method in Siberia and in the Far East of Russia is small- and large-size deposits of gold-bearing ore. The gold recovery process produces huge amounts of waste water containing cyanide and difficult-to-oxidize thiocyanates. These highly toxic compounds reduce efficiency of water treatment. The proposed integrated water treatment method includes photochemical oxidation of contaminants and addition of ferric iron. Water treatment reaches the highest efficiency when added with complimentary persulfates [27–29].

With specific regard to the conditions of Zhireken copper–molybdenum deposit in Transbaikalia, the mining technology is characterized and mining consequences are defined. The proposed procedure for the well-found selection of reclamation methods allows scheduling commencement of rehabilitation at an operating mining project [30].

Overburden dumps in the coal mining regions in Siberia feature intense self-healing. However, it is found that the species diversity at the dumps is lower as compared with the natural landscapes. Coating of the dumps with the fertile soil layer can increase the phytomass of the grass canopy. The overburden dumps at open pit coal mines in Kuzbass served the testing grounds for the land reclamation approach using waste coal. It is noticed that waste coal introduced in the man-made soil creates an alkali environment [31–33]. A long-term open pit mining project in Buryatia is Dzhida tungsten–molybdenum deposit. The overshoot of background concentrations of different elements nearby a tailings storage facilities is as follows: Sb—356 times; Cd—70 times; Mo, Bi, Cu and W—42–55 times; Pb and As—34–37 times. The ecological evaluation of the top soil in the area of the Zakamensk town closely spaced from this mined-out deposit and tailings storage shows that concentrations of Pb, Sb, Cd and As here exceed MAC of the other Russian regions 1.7–7.8 times, which is an essential threat for people health and for the environment [34].

Mining activities indispensably include large-scale emission of toxic gases by operating mining and haulage machines and mineral dust blown from the surface of pitwall and dumps. Dust settles on soil and on water, and it dissolves and becomes mobile. In the Kemerovo Region, there are many events of spontaneous coal combustion on the surface of coal waste dumps. It is proposed to undertake statistical recording of gas emission from operating machines, in blasting and from stationary sources, as well as emission of gases generated in spontaneous combustion of waste coal at dumps [35]. In Kuzbass, towns and open pit coal mines are situated close to each other. Formation of the protective eco-screens can improve viewing value of a landscape for population, reduce noise, enhance dust suppression efficiency and, as a consequence, ensure easing-off of the environmental pressure [36].

The long-term research has identified the open pit mining regions problematic in terms of restoration ecology. Technological innovations in land reclamation are investigated and validated for the areas of coal and diamond mining, quarrying of raw materials used in pebble production for building and road construction, as well as at deposits of gold and nonferrous metals. The reclamation technologies aim at advanced formation of vegetation ecosystems on the surface of mining landscapes, and at reduction of toxic emissions in the air by means of optimization of operation of mining and haulage machines. Furthermore, the reclamation technologies are supported with the science-based justification of integrated mechanization structures for the environmental activity implementation [37–41].

All branches of the mining industry are backing up the idea of using nature-like geotechnologies in the perspective, and the contents of these technologies is to be developed at the present time with spotlight on minimization of the environmental impact of mining [42, 43].

One of the innovation trends in restoration ecology of mining is bioremediation. This means the soil, air and water purification technologies which use metabolic potential of biological objects—plants, fungi, insects and other organisms, including microbiological treatment of waste water using wood-destroying fungi, black yeasts and herbaceous communities. The bioremediation technologies improve ecological performance and at the same time act as the source of making expensive products [44].

The results of the review of the applied science publications and related materials made a framework for grouping the ecological issues which both are solved and to be solved in the mining industry into 8 major trends (**Table**).

To our opinion, these trends are relevant and promising, and need expansion and support by field- and lab-scale experimentation. We believe these multidisciplinary trends should evolve in correlation with one the other. Such system defines the close interaction between the atmosphere, vegetable community, water, animal world and human activities. Regarding the mining industry ecology, such interaction requires persistent elaboration and implementation of measures aimed at improvement of mining industry ecologization and minimization of the environmental impact of mineral mining and processing.

Major trends of restoration ecology in large-scale open pit mining regions in Russia

Problem space in mining industry ecology	Region, Mineral Basin	Source
Geotechnical phase of land reclamation, mining landscape architecture validation with regard to ecology purposes	All types of solid mineral deposits	[26], [30], [37–41]
Biological reclamation, ecological analysis of overburden dumps and tailings ponds	The Ural, Orenburg and Kemerovo Regions, Republic of Khakassia, Siberia and Russian Far East	[22–25], [31–34]
Open pit mine water quality research and development of methods to remove toxic impurities	Nonferrous metals and gold deposits	[6–8], [27–29]
Phytoremediation of disturbed land and water	Nonferrous metals and gold deposits	[2], [4], [44]
Suitability analysis of overburden dumps to be wildlife habitat	Kemerovo Region and Krasnoyarsk Krai	[18–19], [21]
Development of methods to reduce emission of toxic gases and mineral dust in mining operations	Belgorod, Kursk and Kemerovo Regions	[5], [14–17], [35, 36]
Use of mining and processing waste in national economy with simultaneous reduction in anthropogenic load	Murmansk and Arkhangelsk Regions, Republic of Buryatia, Irkutsk Region, Krasnoyarsk Krai	[9–13]
Integrated research of mining ecology towards environmental pressure reduction	All large-scale open pit mining regions	[1], [3], [20], [42, 43],

Conclusions

The review and careful analysis of the applied research in the field of the restoration ecology in the mineral mining industry has identified critical areas for the efforts of ecologists in rich mineral basins in large-scale mining regions of Russia, including all types of solid mineral deposits being mined-out or in process of mining. The problem space of the restoration ecology at the closed and operating mining projects in Russia includes investigation of all components of the Earth's biosphere as well as the science-based justification and development of technologies for waste management in open pit mining of solid minerals. The ecological research and management includes process-specialized lab-scale experimentation, field-service test intelligence and ecological mathematical modeling.

References

1. Rzhevsky V. V. Mining sciences. Moscow : Nedra, 1985. 96 p.
2. Ulrikh D. V. Natural sorbents in treatment technology for mining and processing waste water. *GIAB*. 2018. No. 8 (Special Issue No. 41). pp. 3–10.
3. Ulrikh D. V., Timofeeva S. S., Denisov S. E. Assessment of ecological impact of mineral mining and processing industry in the Chelyabinsk Region. *Gornyi Zhurnal*. 2015. No. 5. pp. 94–99. DOI: 10.17580/gzh.2015.05.20
4. Timofeeva S. S., Ulrikh D. V., Timofeev S. S. Using the phytoremediation potential of ornamental shrubs in the revitalization of technozems of the Karabash industrial complex. *GIAB*. 2020. No. S6. pp. 42–50.
5. Sokolovskiy A. V., Lapaev V. N., Temnikova M. S. Assessment of the possibility of the Korkinsky open-pit mine liquidation by filling with thickened tailings of enrichmen. *Ugol*. 2018. No. 3. pp. 91–95.
6. Babenko D. A., Pashkevich M. A., Alekseenko A. V. Water quality management at the tailings storage facility of the gaisky mining and processing plant. *Rocznik Ochrona Srodowiska*. 2020. Vol. 22, No. 1. pp. 214–225.
7. Plokhov A. S., Kharko P. A., Pashkevich M. A. Effect of tailings storage facility on surface water at copper-pyrite deposit. *GIAB*. 2021. No. 4. pp. 57–68.
8. Pashkevich M. A., Matveeva V. A., Danilov A. S. Migration of pollutants from the mining waste disposal territories on the Kola Peninsula. *Gornyi Zhurnal*. 2019. No. 1. pp. 17–21. DOI: 10.17580/gzh.2019.01.04
9. Kochneva F. V., Tolmacheva N. A., Zelinskaya E. V. et al. Use of marble mining waste in production of constructional materials. *Ekologiya i promyshlennost Rossii*. 2017. Vol. 21, No. 11. pp. 10–14.
10. Melkonyan R. G. Environmental problems of disposal of mining waste for the production of glass and build industry. *GIAB*. 2017. No. S1. pp. 389–405.
11. Melkonyan R. G., Suvorova O. V., Makarov D. V. Use of technogenic raw materials of the mining plants of Murmansk region for manufacturing glass and glassy-crystalline materials. *Fizika i hkimiya stekla*. 2018. Vol. 44, No. 3. pp. 315–323.
12. Hudyakova L. I., Voyloshnikov O. V. Mining industry waste and utilization prospects in the Republic of Buryatia. *Ekologiya i promyshlennost Rossii*. 2016. Vol. 20, No. 2. pp. 55–59.
13. Pashkevich M. A., Alekseenko A. V. Reutilization prospects of diamond clay tailings at the lomonosov mine, northwestern Russia. *Minerals*. 2020. Vol. 10, No. 6. 517 p.
14. Pashkevich M. A., Petrova T. A. Technology of artificial deposit preservation at the kursk magnetic anomaly. *Journal of Ecological Engineering*. 2016. Vol. 17, No. 4. pp. 11–16.
15. Kopytov A. I., Masaev Yu. A., Masaev V. Yu. Impact of blasting technology on the environment in Kuzbass. *Ugol*. 2020. No. 5. pp. 57–62.
16. Pendyurin E. A., Starostina I. V., Smolenskaya L. M. Development of biological method of dump's dust control at the Lebedinsky ore mining and processing enterprise (OMPE). *Ekologiya i promyshlennost Rossii*. 2010. No. 6. pp. 46–48.
17. Petrov A. A., Zorin A. V., Melik-Gaikazov I. V. Gas pollution of in-pit space in open mining: Problems and solutions. *Gornyi Zhurnal*. 2019. No. 6. pp. 67–71. DOI: 10.17580/gzh.2019.06.09
18. Bogorodskaya A. V., Trefilova O. V., Shishikin A. S. Processes of primary soil formation in technogenic ecosystems at the dumps of the Borodino brown coal deposit (Eastern Part of the Kansk-Achinsk fuel-energy complex). *Tomsk State University Journal*. 2014. No. 382. pp. 214–220.
19. Bogorodskaya A. V. Effect of organic substrates and bacteriological preparation on biological activityand productivity of coal mine dumps of Kansk forest-steppe. *Agrohimia*. 2018. No. 8. pp. 12–21.
20. Kopytov A. I., Manakov Yu. A., Kupriyanov A. N. Coal mining and issued of ecosystem preservation in Kuzbass. *Ugol*. 2017. No. 3. pp. 72–77.

21. Bespalov A. N., Androkhanov V. A. The influence of the specificity of the soil cover of post-technogenic landscapes of kuzbass on the restoration of communities of carabid beetles (coleoptera). *Ekologiya i promyslennost Rossii.* 2019. Vol. 23, No. 1. pp. 55–59.
22. Lavrinenko A. T., Ostapova N. A., Safronova O. S. et al. Biological reclamation of re-compacted automobile dumps of coal mining enterprises. *Ugol*. 2020. No. 7. pp. 92–95.
23. Lavrinenko A. T., Ostapova N. A., Safronova O. S. et al. A method of growing trees and shrub species for biological recultivation of technogenic dumps in the arid environment of the republic of Khakassia. *Ugol*. 2018. No. 11. pp. 92–94.
24. Doronkin V. M., Safronova O. S., Lamanova T. G. the results of the study of natural revegetation on overburden piles, resulting in 2000 years in the Republic of Khakassia. *Ugol*. 2019. No. 11. pp. 94–97.
25. Safronova O. S., Lamanova T. G., Sheremet N. V. the results of the study of natural regeneration of vegetation cover on overburden dumps in the Republic of Khakassia, which emerged in the 90-years of the twentieth century. *Ugol*. 2018. No. 7. pp. 68–71.
26. Talgamer B. L., Murzin N. V., Roslavtseva Yu. G. Cutback angles for slope flattening during rehabilitation of degraded landscape due to open pit mining in friable sediments. *GIAB*. 2021. No. 3. pp. 128–141.
27. Batoeva A. A., Sizykh M. R., Munkoeva V. A. et al. Solar irradiation prospects in cyanide-bearing wastewater decontamination. *GIAB*. 2021. No. 7. pp. 53–69.
28. Budaev S. L., Batoeva A. A., Tsybikova B. A. Degradation of thiocyanate in aqueous solution by persulfate activated ferric ion. *Minerals Engineering*. 2015. Vol. 81. pp. 88–95.
29. Budaev S. L., Batoeva A. A., Tsybikova B. A., Khandarkhaeva M. S., Aseev D. G. Photochemical degradation of thiocyanate by sulfate radical-based advanced oxidation process using UVC KrCl-excilamp. *Journal of Environmental Chemical Engineering*. 2021. Vol. 9, No. 4. 105584.
30. Oveshnikov Yu. M., Ryazantsev S. S. Main trends of the remediation work in the development of ore deposits Zabaikalya. *GIAB*. 2013. No. 4. pp. 151–155.
31. Semina I. S., Androkhanov V. A. Environmental and soil survey of sites reclaimed using coal processing wastes, as exemplified by the Kemerovo region, Kuzbass. *Ugol.* 2021. No. 7. pp. 57–62.
32. Ufimtsev V. I., Androkhanov V. A., Kupriyanov O. A. et al. Fertile soil layer as a factor of recovery of zonal phytocenoses on coal industry dumps. *Bulletin of the Kuzbass State Technical University*. 2019. No. 6. pp. 64–71.
33. Androkhanov V. Transformation of the Ecological Function of Soil in the Coal Mining Regions of Kuzbass. *Journal of Arid Land Studies*. 2015. Vol. 25, Iss. 3. pp. 173–175.
34. Timofeev I., Kosheleva N., Kasimov N. Contamination of soils by potentially toxic elements in the impact zone of tungsten-molybdenum ore mine in the Baikal region: A survey and risk assessment. *The Science of the Total Environment.* 2018. Vol. 642. pp 63–76.
35. Lugovtsova N. Yu., Timofeeva S. S., Demenkova L. G. et al. Studies of total harmful gas flows on the ground surface from spontaneous mine fires in Kuzbass. *Eurasian Mining.* 2017. No. 2. pp. 43–48. DOI: 10.17580/em.2017.02.11
36. Burtsev S. V., Korchagina T. V., Turgeneva L. A., Donich A. V., Ozerov S. A. Protective environmental screen as an additional tool for mitigation of negative surface mining impact on environment and population. *Ugol*. 2018. No. 9. pp. 83–87.
37. Zenkov I. V., Baradulin I. M. Reclamation technology for spoil banks of ballast quarries. *Ekologiya i promyshlennost Rossii*. 2016. Vol. 20, No. 2. pp. 9–13.
3. Zenkov I. V., Zhukova V. V., Gilts N. E. et al. Development of technologies for filling dumps of coal mines based on the prediction of forest reclamation results. *Ekologiya i promyshlennost Rossii*. 2019. No. 6. pp. 46–51.
39. Zenkov I. V., Nefedov N. B., Morin A. S. et al. Land remediation technology in the development of coal deposits in the northern regions of Russia. *Ugol*. 2020. No. 4. pp. 62–67.
40. Zenkov I. V., Loginova E. V., Gilts N. E. et al. Technological solutions to environmental problems in the development of quarries of copper-zinc ore deposits in the South Urals. *Ekologiya i promyshlennost Rossii*. 2021. Vol. 25, No. 1. pp. 54–59.
41. Zenkov I. V., Morin A. S., Vokin V. N. et al. Justification of disturbed land reclamation after open pit mining of kimberlite pipes in the Republic of Sakha (Yakutia). *Eurasian mining*. 2020. No. 1. pp. 65–69. DOI: 10.17580/em.2020.01.13
42. Trubetskoy K. N., Zakharov V. N., Galchenko Yu. P. et al. Technological backup for ecological strategy of mineral mining in the permafrost zone. *Gornyi Zhurnal*. 2019. No. 6. pp. 39–44. DOI: 10.17580/gzh.2019.06.04
43. Trubetskoy K. N. Solution of the problem of ecological balance in open pit mineral mining. *Gornyi Zhurnal*. 2018. No. 6. pp. 71–76. DOI: 10.17580/gzh.2018.06.15
44. Timofeeva S. S. Modern Technologies of Bioremediation for Environment. *Ekologiya i promyshlennost Rossii*. 2016. No. 1. pp. 54–58. EM