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A REVIEW OF MAJOR APPLIED RESEARCH ON RESTORATION OF ECOLOGICAL BALANCE ON MINING LANDS IN GLOBAL SUBSOIL USE*

The authors review the applied research on reclamation and phytoremediation of lands disturbed in global subsoil management. The reviewed ecological studies encompass all continents and natural climate zones, and are targeted at accelerated restoration of ecological balance in the regions of operating or previously operated mines. The information environment for the decision-making on reclamation and phytoremediation of disturbed lands is aggregated in the course of field experimentation and monitoring of quality indicators of soil cover on the mining landscapes with subsequent processing and analysis of the field data on a laboratory scale. In all studies, ecologists emphasize expediency of the early ecological balance restoration on the mining-disturbed lands via special geotechnical and biological reclamation activities, as well as phytoremediation.

Keywords: *global mining industry, opencast mining, mining industry ecology, disturbed lands, ecological balance restoration, land reclamation, phytoremediation, human ecology*
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Introduction

Solid minerals are produced on all continents of our planet, and are used in all sectors of global economy. As known, opencast mining has a considerable economic weight in the global mineral resource industry. At present, on all continents, tens of thousands opencast mines operate at an annual capacity of 0.1 to 200 Mt. Opencast mining drastically changes the land surface layout—a natural landscape transforms to an industrial landscape. Moreover, agricultural land undergoes damage. Industrial landscapes in mining regions curtail habitat and biodiversity of flora and fauna. The problem of restoration of ecological balance on the mining-disturbed lands is effectively solved by professional teams of ecologists in specific nature and climate conditions of a certain continent. In the authors' opinion, at the late development stage of this basic and applied research area, it is actual to review the new knowledge on ecological restoration of lands disturbed by opencast mining on the global scale.

Review of applied problem solutions in ecological balance restoration on mining-disturbed land

Opencast mineral mining and further processing activities form an industrial landscape, including its main objects in the form of open casts, waste dumps and tailings ponds. Open casts are filled with water, as a rule, and waste dumps and tailings ponds undergo surface reclamation. In the world subsoil management, there are four major trends of disturbed land reclamation: agriculture, forest, water resources (fishery) and recreation. Reclamation of surfaces of waste dumps and tailings ponds is mostly planting of trees and bushes, or, seldom, agricultural. Reclamation aimed at water utilization (fishery) or recreation is only isolated instances.

Regarding land reclamation, all researchers highlight that during opencast mining, it is impossible to preserve primeval soil layer, or it is only scarce saved within the limits of mine leases. Neither way allows eco-friendly reclamation of waste dumps and tailings ponds. Therefore, it is often recommended to add soil mixtures meant for covering waste dumps and tailings ponds with mineral and organic admixtures. The review of the selected studies by the authors shows that reclamation starts with the analysis of the soil layer quality within the mining lease limits and on the previously reclaimed sites [1–55]. The basic inference made in all studies says that the soil layer placed on the surface of the mining landscape objects features much poorer quality than the natural soil has. All researchers point at the slower growth rate and poverty of vegetation cover on the reclaimed land.

The problem of deficient nutrients for the eco-friendly recovery of vegetation cover at the mining landscape facilities is solved by means of introduction of various additives in the soil layer to be placed on the surface of waste dumps and tailings ponds during reclamation activities. For the mines operated in the north of Russia, it was proposed to add the reclamation soil layer with the paper-and-pulp industry waste [1]. For a sulfur mine and coal pits in Poland, scientists recommended using settlings of sewage from urban storm systems, with high content of organic substances [2, 24]. For the mines situated in the Iberian Pyrite Belt on the Iberian Peninsula, it is recommended to introduce the soil layer with fly ash after biomass combustion and with paper-and-pulp industry sludge, as well as with processing tailings with low concentration of sulfides, and with waste rock [3, 11]. In Brazil, it is proposed to perform reclamation of land disturbed during iron ore and gold mining with adding the soil mixture with biocoal and organic compost in the former case, and with coffee grouts, tegument of Brazil nuts and biocoal in the latter case [5, 6]. In Inner Mongolia in China, the recommended soil admixtures are cornstalks, sheep and black cattle manure and microbial agents [29]. In France recovery of mined-out open pits included reclamation with the soil–pebble–sand mixture for making the top soil layer [30]. Also in France, to bind mobile arsenic and lead species in the surface layer of dumps at tin mines, it is proposed to introduce the layer with iron sulfate, biocoal and poultry droppings [32]. The research performed in Mexico produced a contradictory result—addition of compost in the soil mixture accelerated vegetation growth but also increased concentrations of arsenic, copper and zinc solvable in the soil medium applied on the surface of waste dumps during reclamation [33].

For the conditions of Kuzbass in Siberia, some limiting factors are revealed for the introduction of coal preparation waste in the root layer placed on the surface of waste dumps, and the formation of an underlayer made of coal preparation waste covered with the root layer is validated as it improves the vegetation cover [41–43]. For the conditions of the Far North in Russia, it is recommended to add coarse chipped wood of trees growing within the limits of mine leases and the root systems of these trees in the soil mixture prepared while stripping the upper root layer during geotechnical stage of reclamation [54]. For the conditions of Kalimantan of Indonesia, it is suggested to add lime, phosphate and compost in the soil medium placed on the waste dumps at open pit coal mines; these measures have improved soil quality and ensure rapid recovery of vegetation cover [12]. The relevancy of adding humic substances, soil biota (arbuscular mycorrhizal fungi) and fertilizers in the soil mixture in reclamation of opencast coal mining-disturbed land is comprehensively substantiated in [14, 25].

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The studies into the ecological restoration of mining areas show that researchers prefer analyzing reclaimed land monitoring data by the criteria of quality and species composition of vegetation cover. A great part in the land reclamation efficiency is given by scientists to the biological stage and, lately, to the monitoring and evaluation of quality indicators of land being reclaimed at certain times. The research emphasizes the necessity of monitoring in decision-making on correction of situations connected with improper rates of ecological restoration. In the recent decades, investigations are started to analyze the quality indicators of soil covers in the areas adjacent to the mineral mining and processing facilities. The aim of such investigations is to eliminate the entry of toxic elements in the foodchains of all living organisms.

The Spanish specialists determined residual contamination after an accident in a pyrite mine by studying concentrations of Cu, Zn, Cd, As and Pb in the neighborhood soil and bioaccumulation of the elements in plants [4, 9]. In India and in the United States (Apalachee Bay), the change in the organic carbon concentration was examined in the areas of dumps which underwent reclamation at different times [13, 16,]. In China and in the USA, it was studied how the soil substrate quality influenced planting on the post-reclamation waste dumps [17, 27]. In the southeast of Brazil and in India, phosphorus recovery on the land disturbed by bauxite and coal mining was investigated, and in Wyoming in the USA, in opencast coal mines, the geomorphological reclamation method based on the natural terrain forms was used [20, 21, 23]. In Iran the suitability of the mining-disturbed land for reclamation was analyzed [28]. In Western Australia, in the area of tailings ponds of iron ore mining, researchers found the local species of leguminous crops, which greatly contributed to the formation of young soils on the surface of the tailings ponds [31].

In the late 30 years in Germany, more than 130 thousand hectares of disturbed land were reclaimed. During mining landscape rehabilitation, new knowledge was obtained towards the optimized joint solution of economic and ecological problems. The investigation work in the sphere of reclamation shows that landscape restoration can run in two directions—agriculture and forestry, with regard to the nature protection goals. Furthermore, post-reclamation landscapes enable sustainable growth of regional biodiversity [35]. A case-story is the law of forest reclamation on waste rock dumps of opencast coal mining [36]. The dump areas were treated with individual reclamation projects with regard to the environmental standards [37].

In the Czech Republic, the waste dump areas were ranked with regard to their habitability conditions for the living world. This approach allowed decision-making on ecobalance restoration control on waste dumps [19].

On different continents, in semiarid regions (Kentucky, USA; British Columbia, Canada; Khakassia, Russia), during forest reclamation of over-compacted waste rocks dumped using large trucks, researchers exposed some ecological problems. The resultant technological and biological recommendations allowed efficient recovery of ecological balance in the areas of mining landscapes [8, 10, 44–46].

A highly effective way of ecological restoration of waste rock dumps is forest reclamation. The investigation of the soil cover formation in manmade forests on waste dumps was carried out in the Apalachee Province and in the south of Indiana in the United States, in India and in Poland [7, 15, 22, 34]. In the United Sates, the concentrations of aluminum, magnesium, manganese and sodium in young forest soils were analyzed retrospectively subject to the reclamation time [7]. The other experiments involved planting of nursery trees on the waste rock dumps in pots and with open root systems [22]. In India and in Poland, the dynamics of the organic carbon concentration in the soil substrate on the post-reclamation waste dumps was analyzed depending on planted trees [15, 34]. In Russia the shape and geometrics of pitwall are substantiated with regard to the geographical orientation, which enables maximizing the forest reclamation efficiency [52].

The case-study of a city park created on the coal mining-disturbed area of 36 hectares nearby the city of Xuzhou in China is described in [26]. The city park was a part of a land reclamation project. This case is not a mass phenomenon in the global subsoil use. In the region of the Caucasian Mineral Waters in Russia, the environmental impact of tailings ponds of uranium production and milling was evaluated, and the prospects of including the reclamation areas in the resort cluster were validated [49]. For the Perm Krai in Russia, for the area of long-term mining operations at the Upper Kama Potassium–Magnesium Salt Deposit, a package of reclamation activities was developed based on the long-term soil salination monitoring, and a set of measures aimed at reduction of the environmental impact of halite waste was proposed [50].

The Russian researchers demonstrated the necessity of systematic observations over waste dumps after reclamation to undertake prompt slope reinforcement in case of deformation detection [51]. The geotechnical land reclamation technology, which enables maximum preservation of the soil layer to be later on placed on the surface of waste rock dumps and allows maximal reduction of greenhouse gas emission, is in detail described in the study [53]. For the conditions of Siberia in Russia, the procedure of geotechnical land reclamation in combination with overburden stripping on the upper bench of open pits is scientifically substantiated [55].

By now, in the analyzes of ecological balance on lands disturbed in the course of subsoil use, a few research address phytoremediation and phytostabilization [18, 38–40, 47, 48]. An action plan on the phytoremediation strategy including the physicochemical analysis of soil, description of climate, identification of plants capable to grow in the test region and evaluation of the phytoremediation capacities is developed for the abandoned mines in Spain, Italy and Portugal [18].

In Africa in Morocco, after implementation of two vegetation seasons, it is found that in the root systems of *Atriplex semibaccata*, *Vicia sativa*, *Launaea arborescens*, *Peganum harmala* and *Asparagus horridus* planted on the surface of tailings dumps containing sulfides, the concentration of As, Cd, Cu, Ni and Zn has increased greatly. It is concluded on suitability of these plants for the phytostabilization of the entire surface of the tailings storage facility [38].

In Zambia, nearby the cities of Chingola and Kabwe, large copper mines were operated for a long time. In the adjacent areas, the concentration of heavy metals of Cu, Co, Ba, Ni, As, Zn, Pb, Cr, V and Cd exceeded the maximum allowable concentrations by a few tens of times. Aiming at reduction of high content of heavy metals in agricultural soil, the soil was introduced with a mixture of poultry manure, triple superphosphate and complex fertilizers (N, P, K). As a result, in the corn field, the concentrations of Pb and Zn in straw and grain was decreased by 25 and 18%, respectively. Vice versa, the concentration of mobile Cd species in grain increased. It is concluded that introduction of these admixtures reduces the content of heavy metals in grain, while the problem of bioaccumulation of Cd deserves a special care [39, 40].

In the Ural region in Russia, the long-term mining operations severely affected the environment. For the minimization of the environmental damage, the nature preservation actions are developed, which improve the ecological balance indicators and use the phytoremediation strategy for soils contaminated with toxic pollutants [47, 48].

Conclusions

In this manner, the careful and thorough analysis of the recent applied research in the sphere of restoration of ecological balance on the mining-disturbed lands on a global scale has identified the promising trends of the environmental research in the areas of large mineral basins being mined or mined-out on all continents and composed of any solid minerals. The challenges in reclamation of lands disturbed by the mineral mining industry include development and implementation of a set of special works connected with the biology and technology up to the ecologically admissible balance in the areas of mining landscapes. Both field works and laboratory-scale processing of the results feature high technology. Any object of mining landscape in the global subsoil use is subjected to long-term monitoring of soil cover quality toward managerial decision-making on land reclamation. In these latter days, spotlight is on the new area in human ecology—phytoremediation which is the investigation of the capacity of plants to concentrate toxic elements from the soil cover in the areas of solid mineral mining and processing.

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REDUCTION OF GREENHOUSE GAS EMISSION THROUGH PROCESSING OF COAL MINE METHANE USING ENERGY-CONVERSION TECHNOLOGY

High-rate and high-output mining of gas-bearing coal includes currently a set of gas drainage activities. Coal methane is both an industrial hazard and ecological peril as its atmospheric emission aggravates greenhouse gas effect, but at the same time, methane is a valued basic material. The concern in connection with the environmental aspect of coal methane problem has lately grown essentially. This article addresses the problem of improvement of the coal mine methane utilization technology with a view to reducing atmospheric emission of greenhouse gases. The author substantiates the need to develop the smaller scale chemistry approaches to utilization of methane recovered in gas drainage. This trend seems to be promising for the coal sector due to the specific nature of gas release sources. The test data of the energy-conversion technology in processing of methane recovered in pre-mine drainage, with production of colloidal carbon using recuperative heat exchanger are presented. This technology features unique ecological measures. The challenging trends of the technology improvement are planned, including utilization of decontamination gas.

The existing systems of methane utilization are insufficiently effective because of inconstant parameters of methane–air mixtures.

Gas recovered in pre-mine drainage has the most stable composition. However, pre-mine drainage is only used in 2–3 mines in Russia. The main reasons for the slow pace of the pre-mine drainage expansion are the organizational and financial complexities because of necessity of long-term completion of wells after hydraulic impact. Extensive employment of the technology can promote a dramatic reduction in greenhouse gas emission and the enhanced mining safety.

Keywords: *methane, hydrogen, mine, gas drainage, greenhouse effect, longwall, utilization, emission, gas release*
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Introduction

Increasingly much attention is paid lately to the challenging problem of reduction in greenhouse gas emission in underground coal mining [1, 2]. The top priority is methane-related safety of mining. In view of the higher rate of coal production, gas drainage becomes indispensable technology even in mines ranked within category II by methane hazard. Wide application of gas drainage is a framework for the mine methane utilization and, as a consequence, for the integrated use of coal and gas resources.

Methane is mostly removed from underground openings by ventilation facilities (except for the Vorkuta mines) [3, 4], and methane concentration is under 0.75% in this case, which disables commercial use of the gas. This is one of the major causes of atmospheric emission of