Prospects for reforestation in the Far East by reclamation using innovative technologies

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Abstract. The article presents the results of long-term studies within the limits of closed mining enterprises impact in Priamurie and Primorye of the Far Eastern Federal District (FEFD), where the lands from the forest land fund have been withdrawn earlier for mineral development. As a result, tailing dumps containing highly sulfidized waste have a negative impact on ecosystems. The urgency of the topic is undoubted. In this regard, the aim of the study was to create technology for the forests reproduction on technologically contaminated and disturbed land using innovative achievements (bioremediation) to ensure their environmental and social security. Natural and mining systems formed by the activities of the closed mining enterprises of the Priamurie and Primorye regions were the object of the problem under study, they located in the basin of the Amur River of large biosphere value (Solnechny GOK (Mining and Processing Works), Khrustalnensky GOK. The necessity of effective solution of the mentioned problem was substantiated. It has been established that the level of technogenic pollution of environment objects exceeds in dozens and even hundreds of times the regional background indicators and MPC. A reclamation method was created using the potential of biological systems. The novelty of the proposed methods is confirmed by Pavtvent.

1. Introduction

The reclamation of mining disturbed lands by the accelerated technology using bioremediation has promoted not only its time reduction, but also creation of conditions for fast restoration of soil and ecological functions of the reclaimed lands and, consequently, formation of a stable phytocoenosis.

Intensive development of mineral resources leads to biosphere destruction [1]. On the lands disturbed by mining operations (technogenic formations) landscapes with low biological productivity and specific geophysical and geochemical properties arose, forming peculiar "holes" and "barriers" on the ways of planetary substance and energy migration. They distort the "normal" course of fundamental processes in the biosphere. Productive forest ecosystems, soils, vegetation and wildlife, surface and ground waters, atmospheric air and subsoil are subjected to technological stress and transformation, their ecological state assessment was carried out according to traditional methods [2-
5. A characteristic feature of technogenic landscapes is the disturbance of the integrity of the "life film" in the biosphere, up to the complete destruction of soil and vegetation cover as a result of human activity (for example, on tailing dumps), which has long been comparable in importance with geological processes [1].

As a result of mineral development, natural and mining systems are formed, where an active negative component of a newly created system is a mining enterprise and its technology, as well as a large amount of accumulated mining waste. There are also large volumes of toxic sulphidized mineral processing waste stockpiled in tailing dumps, which have a negative impact on the ecosphere. Within the boundaries of their impact, hypergenic processes result in transformation of primary mineral substances and release of toxic elements and their compounds. It is obvious that the waste is more actively subjected to oxidation, dissolution and transformation into other mineral forms and water solutions, which significantly worsens the ecological situation in large areas. As a result of mining operations, especially in open-cast mining, all biological components of the environment are destroyed. Negative consequences of mining activities include removal of significant land areas from the forest fund and their disturbance, change of hydrological and hydrogeological conditions in the area of adjacent territories, development of erosion processes, as well as removal of infertile and even toxic rocks to the surface. The consequence of this is unforeseen and dangerous disturbance of the ecological balance in nature, intensive technogenic pollution of adjacent forest areas. Radical reconstruction of the geological foundation contributes to the formation of technogenic complexes, where the development of life becomes difficult or impossible. The most common types of technogenic formations are quarries, waste rock dumps, tailings dumps including those containing toxic heavy metals. For a long time they remain to a great extent not determined and unpredictable in environmental and ecological-economic aspects. At the same time, forest ecosystems located in the adjacent areas are degraded and destroyed due to their high content of hazardous toxic substances exceeding their maximum permissible concentrations by tens, hundreds and thousands of times. This requires the measures to prevent their negative impact on the environment, including reclamation. However, the present methods do not ensure environment safety of the mineral extraction and processing, including the processing wastes. The reason for the impossibility to ensure the proper quality of the environment here, including reclamation, is the insufficient elaboration of the methodology of substantiation and decision-making of environmental activities in the mineral complex enterprises. Thus, the productivity of restored lands in general is much lower than it was before their violation. There is a need to promptly eliminate the negative impact of mineral development processes, including technogenic pollution of forest areas. In this regard, mankind has a primary task to find the ways to save the land as our habitat from destruction. Therefore, the studies aimed at reducing the negative impact of mining on natural systems, including forest areas, are of particular importance. Therefore, the purpose of the study was to create the technology for forests reproduction on technogenically contaminated and disturbed lands using innovative achievements (bioremediation) to ensure their environmental and social safety. On the basis of the objective, the following tasks were identified: 1. To analyze, summarize and systematize literary sources and perform a patent search for the reproduction of technogenic formations productivity using bioremediation; 2. To study and assess the effectiveness of various methods of forest vegetation restoration on technogenic formations in Russia and abroad, to assess the waste impact on the ecosphere as a potential source of technogenic pollution of the environment; 3. To carry out experimental research on creation of technology for the reproduction of forests on technogenically contaminated and disturbed lands using innovative achievements (bioremediation).

In the works by N F Reimers [6, 7], S I Mironova [8] the concept of natural and resource potential was defined, which means the possibilities to use disturbed lands for reclamation. Vegetation, technogenic relief and soils were chosen as the main indicators of reclamation potential.

In the conditions of the area under research biological (forest) reclamation as a complex of restoration measures of the disturbed biota has its own peculiarities (complexity of seed germination, absence of a fertile layer, seed survival after long frosts, etc.) and is conditioned by a high degree of
ecosystem fragility and complexity of species selection - recultivants. Here, special researches for development of bioremediation methods for forest areas contaminated with toxic solid mining wastes have not been practically conducted. The problem of selection of living organisms in forest communities, capable to the maximum biological productivity and the fastest recovery of the post-industrial landscape in a particular bioclimatic environment, has not been studied. Possibilities of accelerated creation of efficiently functioning soil and ground horizons as the most important structural units of recovering biogeocenoses on the disturbed areas have not been studied. All this testifies to urgency of the research problem.

Efficient use of forest lands negatively affected by mining in the Far Eastern Federal District (FEED) is impossible without special rehabilitation measures. The technologies used in different regions, including the FEFD, to reproduce productivity of disturbed lands cannot efficiently contribute to creation of forest ecosystems and rehabilitation of disturbed areas. At the same time, technogenic landscapes sharply differ by their properties and regimes from natural landscapes. Properties of newly formed soils on dumps and their functioning regimes have not been practically studied. The patent search testifies that methods of bioremediation (using the biological systems potential) are the most promising and ecologically safe for elimination of negative impacts [9-13]. The authors from Portugal [14] are studying the microbiome of tailing dumps and their metabolic possibilities, which can provide the direction for the management of the tailings disposal sites and maximize their potential as secondary resources. No less important studies are being carried out in Spain [15]. Arranz-González J.C with co-authors, is developing a new methodology for ranking the potential contamination of abandoned tailing dumps. As a result of the development of new methods for restoration of degraded lands using the biological systems potential, innovative methods to solve this problem using mycorrhizal fungi, bacteria and higher plants are emerging. To date, there is a great deal of scientific data testifying to their effectiveness [16-18]. The scientists from India [19] suggest to use microbiologically enhanced phytoremediation and nanotechnology for more effective reclamation.

Unfortunately, at present the FEFD lacks effective and safe methods and regulations that clearly govern the procedure, methods, and technology of these activities depending on the specific natural conditions and pollution form. This theme performance will allow to develop methods and ways to restore productivity of forest lands transferred after the solid minerals development to the forest fund, and provide recommendations for their further use.

The research in this area is in accordance with:

- Ensuring the Use, Protection and Regeneration of Forests Subprogram of the Forestry Development State Program of the Russian Federation for 2013 - 2020, approved by the Government of the Russian Federation of 15.04.2014 No 318 (as amended by the Government of the Russian Federation of March 30, 2018, No 370), the following objectives: creating conditions for rational, multi-purpose, sustainable and efficient forests use; improving the efficiency of restoration of lost and felled forests.
- Priority researches in the field of use, protection, conservation and regeneration of forests, ensuring sustainable forest management and development of the forest complex, approved by the Order of the Federal Forestry Agency of 19.12.2012 No 519. Guideline: Development of ecologically safe systems of forest management and forest use, forestry and environmental requirements to technological processes and equipment, modern technologies and technological protection, protection and regeneration of forests and afforestation. In this regard, the purpose of the study is to develop the methods of bioremediation of forest areas contaminated with toxic solid wastes of mining industry for the Far Eastern taiga and Primorye-coniferous-broadleaved forest areas. Proceeding from the purpose, the following tasks have been defined: 1. To study the experience of the forest vegetation restoration on the technogenic formations in Russia and abroad; 2. To carry out the patent search on the reproduction of the technogenic formations productivity using bioremediation; 3. To study and estimate the efficiency of different methods of the forest vegetation restoration on the technogenic formations in the Far Eastern Federal District of Russia.
In the areas under research the processes of natural vegetation renewal on various forms of the forest areas relief polluted by heavy metal compounds during development of solid minerals have been studied. The features of forest sites transformation in the course of mineral extraction and processing in various forest sites conditions, at the territory of the Far East taiga and Primurye-Primorye coniferous-broadleaved forest areas of the FEFD have been studied. The patent search was carried out, literary and report data of forestries, mining enterprises, geological and hydrological parties were analyzed and generalized, the experiments were set up in the greenhouse of the Federal Budgetary Institution Far East Forestry Research Institute on reproduction of productivity of forest lands withdrawn from the forest fund for mineral development, using bioremediation.

2. Methods and Materials
The researches were carried out over 1988-2019 within the limits of the closed mining enterprises impact in Primurye and Primorye: Solnechny GOK (Khabarovsky Krai), Khrustalnensky GOK (Primorsky Krai), Khingansky GOK (Jewish Autonomous Region).

Natural and mining systems formed by activity of the closed mining enterprises of the Primurye and Primorsky Krai in the basin of the Amur River of a large biosphere value are the object of study of the problem. Its components are forest ecosystems, mosses, lichens, microorganisms and technogenic soils, artificial forest ecosystems on reclaimed areas, seedlings of fescue grass and clover, larch.

The teaching of academician V I Vernadsky about the biosphere and noosphere [1] and the main provisions stated in the Program and Methods of Technogenic Biogeocenoses Studying by B P Kolesnikov and L V Motorina [4] served as a methodological basis. Geobotanical, forestry, geomorphological and forest-taxation methods have been used in the implementation of the Programme, as well as complex landscape ecological approach [20-22] and vegetation maps. Species composition of vegetation on technogenic objects was studied by the route method. Methods of registration sites and profiles laying have been used. The researches were carried out taking into account methodical developments by V N Sukachev, V D Aleksandrova, T A Rabotnov, P D Yaroshenko, A G Voronova, B A Bykov and others. [2, 3, 5-8, 20-29]. Sample areas were laid down in the most typical forest areas contaminated with toxic solid mining wastes and in reclaimed areas according to generally accepted methods of forest surveys. Accounting lines of 10 m wide were laid through 100-200 m depending on a degree of stand homogeneity along the whole length of the investigated area, including reclaimed areas. Callipers were used to determine diameters, and height was measured with a Suonto height meter. Layers of the forest biogeocenosis were studied: a tree canopy, undergrowth, underwood, live soil cover [3]. Sample strips were laid out, they allow to take into account the cluster location of trees. The estimation of growth course was carried out by diameter and height equal to average characteristics of a stand on a sample tree. Enumeration of the stand was carried out by a two-centimeter diameter class. The composition was determined by the stock and the number of trunks. Forestry and taxation characteristics of the plantations were determined by the results of the enumeration at the sample areas. Herbarium has been collected. Statistical data processing was carried out using EXCEL 2007 computer packets.

The species composition of the living soil cover at the discount areas was studied using the generally accepted procedures. The abundance of grass and moss vegetation was determined by Drude scale. In accordance with V.N. Sukachev's methodical guidelines [26-29] the natural renewal of vegetation as a component of biogeocenosis in technogenic ecosystems has been studied. The study of natural overgrowth of dumps was carried out according to the methods known in geobotany with the emphasis on quantitative evaluation methods at model sample areas.

Not only the conditions of natural regeneration of plants in forest areas contaminated with toxic solid waste of mining industry and productivity at various stages of development of phytocoenosis, but also the formation of technogenic soils by well-known methods [30-43] have been studied. The development of "young soils" at different age dumps as a component of biogeocenosis in technogenic ecosystems has been studied in accordance with the methodological guidelines of S V Zonn [44].
Analysis of soil samples for the content of heavy toxic metal compounds and arsenic was carried out in the Center of Collective Use by the method of mass spectrometry with inductively coupled plasma using the ICP-MS ELASN DRC II PerkinElmer.

3. Results and Discussion

In 1988, the authors of the article together with employees of VNIIOSugol (Research Institute of Environment and Coal), made an attempt to introduce at the gold placer and coal mining enterprises developing the deposits of the southern Russian Far East, the effective accelerated method of productivity reproduction violated by mining without fertile soil layer application [45], using the preparations of humic acids and complex of active soil microorganisms strains. Technical preparation consisted in planning and leveling of the dumps surface, their surface loosening by a disk harrow to the depth of the root layer. At the biological stage, it was planned to apply coal wastes, to bacterize the leguminous grass mixture seeds by bacterial culture of soil microorganisms, to sow and water with humic preparation. The monitoring of the recultivated areas of sanitary and hygienic direction at the dredge dumps of gold mining, consisting mainly of destroyed sandstones and phyllitic slates, indicates that complex multi-species communities of more than 30-year age formed here. Forest restoration is carried out by local tree-shrubbery species. The dominating position is occupied by woody vegetation, with closure of 0.8-0.9. The received results testify that the technology on the basis of humic acids preparations and complex of soil microorganisms active strains which define increase of the general biological activity of soil, provides on restored sites the conditions for creation of not only steady phytocoenosis, but also accelerated soil formation process, a fertile soil layer formation.

It has been experimentally established that the intensity of biogeocenotic processes is determined by the following conditions: humidity, temperature, medium pH, water-soluble salts content, etc. Moreover, these processes in technogenic landscapes are more dynamic and contrasting. Regeneration phytocenoses at all stages of syngenetic development are formed at the expense of dominant species of surrounding or natural landscapes. The productivity of plant communities at dumps increases with the complication of layering and floristic composition. Grassland regeneration communities ensure fast development of soil formation process and prevent erosion destruction of dump slopes. The results of past years of research indicate high rates of decomposition of plant residues in young technogenic soils in reclaimed, rather than in zonal soils (approximately by 1.5 times), due to the vital activity of all components of technogenic ecosystems. Such situation is one of the reasons for rather significant accumulation of organic matter here (content in the upper layer of technogenic soils is up to 3 %).

It was found out that abiotic and biotic processes are actively shown, transforming the lands disturbed by mining into young soils. There is a rapid and clear differentiation of the mineral stratum of technogenic eluvia by morphological features, particle size distribution and vertical migration of dispersed particles (silt) with atmospheric precipitation due to slope processes manifestation. As a result, an organ-accumulative horizon is formed (figure 1).

![Figure 1. Soil profile cut of earlier reclaimed technogenic surface.](image-url)
Formation of young soils on naturally overgrowing dumps and reclaimed areas is performed by zonal soils type. On the basis of carried out researches it is revealed, that in a root layer of technozems favorable soil-ecological conditions for occurrence here of artificial forest phytocoenosis , and other biocoenoses are created syngenetically connected with it. At the same time, in their profile there were significant changes of soil genetic plan (figure 1): morphologically well-defined organ-accumulating horizon 1-5 cm thick, almost entirely consisting of living and dead roots of growing plants, was formed in the root-containing layer. From 60% to 80% of the whole root mass of technozem is concentrated in it. It should be noted that the appearance of the organic accumulation layer in the soil profile means a qualitative shift of some of the most important soil and ecological functions, namely: 1) this layer is characterized by very strong water-holding ability, as a result the function of water supply of developing phytocoenosis turns out to be powerful enough and able to protect it from soil drought; 2) presence of horizon with high water-holding ability in technozem profile allows plants to concentrate the main mass of roots in this layer and protects the formed soil from deflationary and water-erosion destruction.

Thus, the reclamation of lands disturbed by mining works, carried out in 1988, by accelerated technology, using soil microorganisms, contributed not only to the reduction of its period, but also to creation of conditions for the rapid soil and ecological functions on reclaimed lands restoration and hence, the formation of a sustainable forest phytocoenosis. It allows the most effective development of all disturbed ecosystem components and in the future to have a national, ecological and aesthetic value of them not lower than before the deposits development.

In addition, positive results have been obtained from experimental studies using phototrophic bacteria (PTB) [46], as well as from mixed bark compost on the basis of forest waste. The novelty of the proposed method is confirmed by the Patent of the Russian Federation [47], which contains a technological solution for forest reclamation of technogenic surface formations (TSF) and the surface of tailings dumps, using the potential of biological systems (bioremediation). The recommended composition for dust suppression and reclamation of the TSF and the surface of the tailing dumps includes: 1) bio-coal - 30%; 2) natural zeolites - 5%; 3) humic acids - 5% and polymetallic ore processing waste - 60%. The proposed composition improves water-physical properties of the substrate and contains energetically rich organic matter. The method provides a successful solution of the problem of reducing the negative impact of toxic tin processing waste compounds on the environment and improving the efficiency of forest reclamation. The novelty of this method is confirmed by the Patent of RF [48]. These researches allowed to draw a conclusion that the main requirement in choosing the range of crops for forest reclamation is to use local flora species, ecologically adapted to the existence conditions in the given climatic zone.

At the first stages of reforestation it is necessary to use rapidly growing species: poplars and willows. Accommodation and growth of forest species depend mainly on the particle size distribution of the rock and its pH. Optimal pH value: for conifers - 4.5 ... 6.0 and for broadleaved species - 6.0 ... 0.5. According to the particle size distribution of rocks, it is necessary to distribute it in the following descending sequence: loams - clay - sand. The experience of reforestation of dumps shows that tree species sowing by seeds is not suitable. Planting of deciduous species by yearlings, while planting of conifers by two-year saplings is most rational. Types of species are selected experimentally.

In the FEFD, pine, flat-leaved birch, and elm, ash, and maple to a lesser extent should be used for reforestation on dumps. When establishing ecologically stable green planting, it is recommended to create mixed crops in the following proportions: main species - up to 60 percent, accompanying species - up to 20 percent, shrubs - up to 20 percent.

4. Conclusion

To ensure environment safety of technogenic formations we have proposed technological solutions, novelty of which was confirmed by the Patents of the Russian Federation. For the last ten years we have developed 7 Russian Federation Patents. It is difficult to overestimate the role of forest vegetation, which is restored by means of forest reclamation, especially on technogenic contaminated
lands, for the life of nature and society. After all, these plants are producers of organic matter and molecular oxygen, organisms that form elements of climate and microclimate. Moreover, this role of plants makes them highly exploited objects that are used not only in agriculture, but also in forestry, pulp and paper and other industries and health care. The significance of the research results is a positive solution of the problem of creating a comfortable environment in the mining settlements of the Far Eastern Federal District, which is one of the important aspects of the strategy for socio-economic development of the Far Eastern Federal Region.

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