An innovative solution to the problem of reclamation of the dusting surface of the tailings of a closed mining enterprise in the Primorsky territory

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Abstract. The article discusses the innovative solution of the issues of reclamation of dusting surfaces of the tailing dump man-made surface formations (MSF) containing toxic waste from the processing of polymetallic ore raw materials of a closed mining enterprise in the Primorsky Territory of the Far Eastern Federal District (FEFD). It is shown that the large amounts of enrichment waste accumulated in the last century during the intensive development of tin mineral deposits led to the destruction and degradation of forest ecosystems, which create a real threat to the health of the population of the mining village. Dangerous disturbances of ecological equilibrium, pollution of the atmosphere, lithosphere, hydrosphere and biosphere by a wide range of compounds of toxic heavy metals and arsenic are revealed. The enrichment wastes stored in tailings, the conservation and reclamation of which were not carried out contrary to Russian legislation, contributed to the large-scale transformation of the basic component of ecosystems - soil, as well as vegetation. In the vicinity of a closed mining enterprise, the migration of pollutants and erosion processes (water and wind) led to a crisis ecological situation. A negative factor for the soil and vegetation cover is atmospheric precipitation, dissolving a large amount of toxic substances. The relevance of research of the above issue is related to the need to preserve and restore an environmentally friendly environment within the influence of the man-made system. In this regard, the purpose of the study was to recreate the productivity of man-made surface formations (disturbed by the tailing of land) using bioremediation to ensure the environmental and social safety of toxic waste from the processing of polymetallic ores in the Primorye Territory. Based on experimental studies, an assessment was made of waste as a potential source of technogenic pollution of the ecosphere and an innovative technological solution was developed to rehabilitate the dusting surface of the tailings pond is developed. Experimentally proved the possibility of using to recreate the productivity of technologically polluted substrate tailings of the following composition: 1) biochar – 30%; 2) zeolites – 5%; 3) humic acids – 5%; 4) waste of ore-enrichment of tin-containing raw materials – 60%. The novelty of the proposed composition is confirmed by the Patent of the Russian Federation (2018).
1. Introduction

During the last century the development of the Earth's subsoil by mankind has been intensified dramatically, which has led not only to an increase of mineral production, but also to the formation of a large amount of mineral processing toxic waste, which is a powerful source of environmental hazard to the ecosphere and all living beings. This is evidenced by our analysis of literary data and the patent search [1-4]. It should be born in mind that the entire system regulating technogenic impact shall be based on biological laws, and the ability to comply with existing sanitary standards depends solely on the level of knowledge in technology. There is a need to define biological limitations and technological capabilities. Therefore, the preservation or irreversible destruction of the mobile ecological equilibrium in the natural environment depends on how in the next half of the century, mining production will be organized, what restrictions and tolerances will be imposed on its development [5]. The situation is aggravated by the fact that as a result of the restructuring of the Russian economy, many mining facilities have not undergone reconstruction and technical re-equipment, which significantly increases the risk of undesirable changes in environment objects: degradation of the natural landscape, pollution of water sources, air and soil by solid, liquid and gaseous waste [6]. The greatest danger is the emergency contamination of natural environment, which manifold exceeds the permissible norm [7]. Their destruction not only damages the mining company, but also is associated with the threat to people's lives [8]. The high level of their activities environmental hazard leads to a decline of the mining industry efficiency [9]. However, the environmental hazard of mineral waste has so far been paid insufficient attention, so, there are still many unresolved challenges and problems associated with its assessment and management [10]. With the development of market relations in Russia and the Far Eastern Federal District (FEFD), in particular, management of environmental hazard and risk becomes significant, as the influence of uncertainty of conditions and processes of mining enterprise operations increases in the mining areas of Russia and the Far Eastern Federal District [11]. In the mining sector of the FEFD and Dalnegorsky District of the Primorsky Territory, where the concentration of mining is particularly high, several negative trends have developed and are steadily manifesting at present. Under these conditions, attention to environmental problems in mining has decreased significantly, leading to a deterioration of the quality of human habitat and a negative impact on the health of the population. The problem of rehabilitation (reclamation) of technogenic surface formations (TSF, tailings dumps) (containing toxic waste), in the FEFD and the Primorsky Territory, in particular, is practically unstudied. Emergency and effective measures should be taken in the coming years to prevent further aggravation of the environmental situation here. Therefore, the idea of improving environmental activities and implementing effective measures to rehabilitate the environmental situation in the research area becomes relevant. Only the methods of bioindication (bioremediation) using higher plants, microorganisms and enzymes as test objects will allow to estimate the technogenesis associated with mining. The generalization and systematization of literary data and the authors' own research lead to the conclusion that under the conditions of mining enterprises in the FEFD, including the Primorsky Territory, toxic wastes of the mineral resource complex activities, stored in the tailings dumps (TSF) are the main source of pollution in the ecosphere. Therefore, the aim of the study was to recreate the productivity of the land violated by TSF using bioremediation for ensuring environmental and social safety of toxic polymetallic ore waste in the Primorsky Territory. Based on the purpose of the study, the objectives have been formulated as follows: 1. To summarize the existing experience of rehabilitation of the tailings dumps surface in Russia and abroad; 2. To describe technogenic surface formations (TSF) as a reclamation site; 3. To develop a technological solution for reducing the negative impact of toxic tin waste on the ecosphere.
2. Materials and Methods

During 2009-2018 the studies have been carried out within the boundaries of tailings dumps (technological surface formations – TSF) of Primorsky mining enterprise. The objects of the study were natural mining technogenic systems formed by the activities of Dalpolimetall mining company. The methodological basis of the study was the doctrine of the academician V.I. Vernadsky on the biosphere and noosphere and the main provisions set out in the Program and Methodology for the Study of Technogenic Biogeocenosis [12, 13]. In the process of implementation a set of methods and procedures was used, namely: generalization, scientific forecasting, modern instrumental and traditional physical-chemical and chemical methods, as well as biological methods, mathematical methods modeling, system and correlation analysis, statistical data processing.

3. Results and Discussion

The analyzed and summarized literary sources on the above problem, as well as the patent search, allow us to assert that it has not been studied enough [14-22]. An assessment of the current state of technogenic surface formations (TSF, tailings dumps) occupying large areas removed from the forest fund of productive land, and located near settlements (at 1-2 km distances) was made. Assessing the waste of Dalpolimetal mineral processing (TSF) as a reclamation object and a potential source of technogenic pollution of the ecosphere, a large variety of mineral and material composition of the waste was revealed. It should be noted that in the waste there are ore rocks with sulphide impregnation. It has been established that the sulphide component of waste includes arsenopyrite, chalcopyrite, sphalerite, pyrite, pyrothine and galena. Chemical composition of waste (%) is characterized by the following: Zn – 0.27-0.29%; Pb – 0.11-0.18; Cu – 0.01-0.03; Fe – 4.37-4.60; Ag – 5-6 g/t. Intensification of their oxidation processes with the formation of sulphate solutions is due to the fact that the rocks here are crushed, which ensures their loose structure in the body of the tailings dump. As a result, toxic elements passed into a mobile state, and they are taken away into a natural water flow system. In the monsoon climate in the south of the Far Eastern Federal District (the Primorye Territory, etc.) the surface of tailings dumps is subjected to erosion processes and a large amount of toxic material is washed away (mostly suspended material, up to 80-85%) into the river, finally, into the sea. It has been found that waste belongs to the second class of toxicity (highly hazardous). Experimentally, biotesting of the substrate (tailings from the tailings dump), conducted by the authors for mustard seed sprouts, showed extremely high toxicity of the top layer of alluvial deposits (0-20 cm). It was found that the sprouts didn't even appear in any Petrie dish. However, good results were obtained in the control version (substrate water). In addition, the actual content of toxic chemical compounds in the waste, such as As, Pb, Zn, Cu, was found to exceed the background and clark by several hundred times, and Fe, etc. – by a few dozen times. The study of the general and specific characteristics of TSF shows that they (wastes) are characterized by loose structure, adverse mechanical composition, high filtration ability, lack of organic matter and nitrogen, lack of elements of ash nutrition, microbiological sterilization, lack of natural self-healing processes, because of their high toxicity. Dangerous ecological disruptions, pollution of the atmosphere, lithosphere, hydrosphere and biosphere by a wide range of toxic compounds of heavy metals and arsenic have been revealed. The studies have shown that air pollution is at an extremely high level, where excess, for example, of aerosols concentration near the tailings dump was more than 50 times higher than the background. Increased hydrogen sulphide air pollution range between 2.5 and 4 MAC, as well as a significant number of carcinogenic compounds (antimony, arsenic and chromium) in dust samples selected for analysis in the kindergarten and school – (mg/kg) 5 - 31; 20 - 90 and 22 - 78, respectively. Concentration waste stored in tailings dumps contributed to the large-scale transformation of the main component of ecosystems – soil, as well as vegetation. In the vicinity of the mining plant, the migration of pollutants and erosion (water and wind) processes have led to an environmental crisis. A negative factor for soil and vegetation cover is atmospheric precipitation,
dissolving a large number of toxic substances. Technogenic soils are characterized by high concentration of toxic heavy metal compounds, exceeding the background values by 2-29 times, in plants – 2-19 times.

Thus, technogenic surface formations (TSF, tailings dumps) have harmful properties. Moreover, a comprehensive geoeocological assessment of the technogenic system impact on the ecosphere using various methods, mathematical modeling including, allowed to ascertain that the ecological state of the study area is estimated as critical and catastrophic at a distance from the tailings dump to 9-10 km, unsatisfactory – 14-15 km, partially satisfactory – 20-21 km. Due to the current complicated ecological situation, there was a need for pilot studies aimed at finding environmentally friendly technologies aimed at reducing the negative environmental impact of technogenic surface formations (tailings dumps). The relevance of research is related to the inevitability of preserving and restoring clean habitat within the boundaries of the technogenic system impact. Based on the patent search and the authors' own research, an innovative method of the tailings dump surface reclamation was proposed using an innovative approach and taking into account the natural and climatic conditions of the area under study. The proposed method is implemented as follows: initially, mining stage, which consists in the planning of technogenic surface formations was proposed using an innovative approach for bioremediation (the potential of biological systems) for creation of favorable plant growth conditions on the reclaimed surface (TSF) containing toxic waste has been experimentally proven for the first time. To this aim, pilot studies were carried out (in the greenhouse and under production conditions) to create a dust-suppression composition aimed to improve dust control efficiency, reducing the negative impact of tailings waste on the environment objects and extension of its expiry. An innovative solution of the problem of the dusting tailings surface reclamation was to create the following composition: 1) biocoal – 30%; 2) zeolites – 5%; 3) humic acids – 5%; 4) waste of tin ore processing – 60%. The essence of the experiment was that the proposed composition was applied to the containers with toxic substrate, selected from the tailings dump, the contents were mixed, and then the seeds of bean-grain mixture and Dahurian larch were sown. Accounting of the harvest was carried out by mowing in the grass heading stage. The yield of legume-grass mixture, when the composition was applied, was equal to 24100 kg/ha. Positive result in the greenhouse allowed to put the experiment under production conditions (on the surface of the tailings dump in the Dalnegorsky district, the Primorsky territory). The recommended composition guaranteed a successful solution of the problem of the negative impact of TSF (toxic waste) on the ecosphere reducing, contributed to the improvement of the substrate water-physical properties and contained energy-rich organic material in the form of biochar and humic acids. The proposed technology ensures the restoration of soil-environmental functions on the toxic surface of the tailings dump (TSF), which allows the successful development of all components of previously disturbed ecosystems. The scientific novelty of the proposed composition has been confirmed by the Patent [25].

4. Conclusion
Based on a comprehensive assessment of the impact of technogenic surface formations (TSF, tailings dump, mineral waste), being a great threat to the ecosphere, including biosphere and human, an innovative method of reclamation of their dusting surface using bioremediation for the environmental rehabilitation of TSF was developed. The following composition for the reclamation of the TSF disturbed lands was proposed: 1) biocoal – 30%; 2) zeolites – 5%, 3) humic acids – 5%; 4) waste of polymetallic ores processing – 60%. Scientific novelty is confirmed by the Patent of Russian Federation (2018).
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