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ARTIFICIAL SOILS FOR RESTORATION OF DISTURBED LAND PRODUCTIVITY

The purpose of this research is to develop an innovative product for restoring the disturbed lands productivity with the prospect of using it in an urban environment. The innovative product is organic-mineral soils, developed based on large-tonnage wastes: ash from the incineration of municipal sewage sludge, lignin sludge, phosphogypsum, brown coal crop. Studies of the composition and properties of wastes and artificial soils based on them were carried out using laboratory analysis and biotesting methods to confirm the possibility of the useful use of the proposed products with the issuance of appropriate recommendations. Artificial soils based on available production waste can be successfully sold to developers, road facilities, companies engaged in landscaping and improvement, as well as individuals as a recultivator. Based on the research results, recommendations were prepared for the implementation of the authors' method to restore the disturbed lands productivity at various urban construction sites to the Committee for the Improvement of St. Petersburg and the Ministry of Construction and Housing and Communal Services of Russia. The article provides recommendations for carrying out work using artificial soil, taking into account the requirements for design and working documentation, agreed in accordance with the procedure established by Russian environmental legislation. The development of innovative products is carried out by supporting the laboratory and experimental base of the accredited Center for Collective Use of High-Tech Equipment of the St. Petersburg Mining University.

Keywords: *artificial soil, brown coal crop, lignin sludge, phosphogypsum, reclamation, sewage sludge ash, urban landscaping*
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Introduction

The problem of manmade pollution and soil degradation is extremely relevant for megacities [1]. Urban soils should have resistance to the unfavorable factors [2]. One of the ways to solve this problem is the use of soils based on available processing waste. The importance of artificial soils in urban conditions is emphasized in the research of Russian [3, 4] and foreign [5, 6] scientists. There are also reports on the future of using processing waste to develop soils [7–9] and on the effectiveness of the reclamation using such soils [10–13].

The goal of this research is to develop an innovative product for the rehabilitation of disturbed lands with the possibility of its use in an urban environment. The product represents an artificial soil based on large-tonnage waste: refuse burnout from the sludge incineration of municipal sewage (SIMS), lignin slurry, phosphogypsum, brown coal crop. The same processes take place in artificial soils as in natural soils, so they can successfully replace them in the processes of landscaping [14–16]. The proposed compositions are the most promising for the reclamation and rehabilitation of disturbed lands, which makes the product suitable for use by both enterprises of housing and communal services and of private ones. The development of an innovative product is carried out according to the following scheme:

The first stage:

- patent, literary analysis and analysis of official documentation on the processing and consumption waste management;
- review and analysis of promising areas for these large-tonnage waste disposal;
- evaluation of the management system of artificial soils and their control in Russia.

The second stage:

- evaluation of the composition and properties of these wastes;
- experiments to evaluate the effectiveness of the use of artificial soils based on them. Examining indicators of artificial soils is the most important aspect of their development [17–19]; this is also confirmed by the research of scientists from the universities of Hohenheim [20] and Plymouth [21];
- development of the formulation of organomineral mixtures, as well as assessment of the possibility of their use during rehabilitation works;
- development of technical and licensing documentation necessary to obtain the conclusion of the State Environmental Expert Review (SEER) on the technology of processing waste disposal with the production of market products.

The theory of the issue

Major studies contain information about the high potential of wastewater (sewage sludge) when using it as a secondary resource due to its physicochemical properties [22, 23]. The use of SIMS for agricultural purposes would be the solution for the environmental problems of artificial ecosystems (including urban ones) [24]. There are examples of effective development of disturbed lands with the use of SIMS due to the active impact of waste on the process of soil formation, which is described in [25, 26]. Heat-treated waste, in particular ash from the incineration of SIMS, also has great potential for use in the reclamation of disturbed lands [27, 28].

Phosphogypsum is a large-tonnage waste from the processing of mineral fertilizers [29, 30]. At the same time, the waste has considerable economic potential [31, 32]. A large-scale joint study of scientists from Tunisia, Germany and Portugal is known, confirming the prospects for using waste [33, 34]. The effectiveness of phosphogypsum as a useful component of the soil is demonstrated by studies for the conditions of Russia [35, 36], for the soils of southern Kazakhstan [37], for loam of Tunisia [38] and for agricultural purposes in Croatia [39].

Lignin slurry is the sludge of waste water treatment in the pulp-and-paper industry, which is characterized by high water cut (more than 95%) [40]. The suitability of lignin slurries for the reclamation purposes has been evaluated in a study of the St. Petersburg Mining University [41]. Similar studies were carried out for the conditions of the Baikal region [42, 43]. Confirmation of this method of using waste is also in foreign studies [44].

Waste from the extractive coal industry is used in the agricultural sector due to the uniqueness of its chemical composition [45, 46]. The prospects for creating soils based on brown coal waste are reflected in the works of teams from Russia [47–49], Belarus [50], India and China [51], as well as from South Korea [52].

To achieve optimal agrochemical properties of the soil used in urban conditions, the composition of the soil should contain particles <0.001 mm [53].

In accordance with the Federal Law of the Russian Federation No. 174 of 23.11.1995: On Environmental Expertise, and on the basis of the order of Federal Supervisory Natural Resources Management Service No. 283 of 29.09.2010, the following materials must be provided for the State Environmental Expert Review (SEER) on the technology of industrial waste disposal with the production of market products: draft technological regulations for waste disposal with the production of artificial soil; draft technical conditions on artificial soil; certificate of conformity and sanitary permission on the resulting soil; materials for assessing the impact of the technology on the environment; materials for discussing the object of SEER in the format of public hearings. These studies must be carried out in compliance with all existing standards and norms in accordance with the customer's technical assignment. The competence of the work is confirmed by the accreditation certificate of the test room and the tolerance for conducting these works [54].

Materials and Methods

Within the framework of the study, due to supporting the laboratory and experimental base of the accredited Center for Collective Use of High-Tech Equipment of the St. Petersburg Mining University, the following tasks were implemented:

- assessment of the composition and properties of these wastes;
- bench-scale and full-scale experiments on growing heavy metal accumulator plants based on soil mixtures using ash, weeding soils from heavy metals (HM) by phytoremediation using brown coal crop; using an organomineral filler based on phosphogypsum and lignin sludge to increase the efficiency of the grass mixture growth and ensure the tolerable release of HM and rare earth metals (REM) to plants;
- developing the formulation for organomineral mixtures, as well as evaluating the possibility of their use during reclamation works.

Organomineral soil mixture based on ash from the sewage sludge incineration

For the soil mixture production, the ash from the incineration of SIMS is pre-assayed for toxicity, according to the results of the assay, the waste is uniformly mixed in the proportion (10–14)%:(90–86)% with turf-sand mixture and seeds of perennial frost-resistant plants with the following component ratio, %: ash from the incineration of SIMS 10–14; turf 43–81; sand 8.6–45.0; seeds of perennial frost-resistant plants - the rest. Trifolium pratense (Meadow clover) and lawn grass Loliumperenne (red darnel) are used as heavy metal accumulator plants. In calculating the composition of the mixture, the chemical composition of the waste is taken into account; the area of the reclamated surface; the required mass of the mixture; the components ratio of the turf-sand mixture in the proportion (50–90)%:(10–50)%. SIMS ash is a brown finely dispersed powder (particle size 1–50 microns), Heavy metals are concentrated in the smallest fraction. The waste has a class of hazard IV and can be used as a component of a fertilizer of group II. Promising areas of use of the resulting fertilizer are reclamation of disturbed lands and improvement of road slopes according to GOST R 54651-2011, provided that the content of pollutants in the soil when applying waste does not exceed 0.8 MPC in accordance with GOST R 17.4.3.07-2001.

Artificial soil based on brown coal crop

The use of soil based on brown coal crop will speed up the germination of the grass mixture and increase the volume of HM extraction from the soil. The result is achieved by the pre-application of the brown coal crop into the soil with an application rate of 200–220 kg/ha, then its distribution, land grading of the surface and plowing to a depth of 15–20 cm are carried out. As a grass mixture (with a seed application rate of 15–20 kg/ha), the following composition is used: meadow catmint – 30%; tall oat grass – 10%; yellow melilot – 20%, meadow fescue – 30%; medick – 10%. Sowing is carried out in the spring, since this time of year provides an optimal water regime for the release of HM from the plants' root system to their top. The main requirement for the used brown coal is the absence of excess concentrations of phytotoxic compounds in the soil water extract in comparison with the LOC indicators specified in the hygienic standard HS 2.1.5.1315-03. The proposed soil has a number of distinctive qualities. Fescue accumulates HM well, in particular Ni and Cu, meadow catmint contributes reaching the maximum biomass by the grass mixture, tall oat grass is able to immobilize Pb, reducing the phytotoxicity of the soil, and yellow melilot and medick will enrich the soil with nitrogen. The brown coal crop filler improves the grass mixture growth, which leads to an increase in the mass of the HM extracted from the soil.

Organomineral filler based on lignin and phosphogypsum sludge

As a mineral component of the organomineral mixture, providing an increased content of nutrients – N, K and P, the waste of the extraction phosphoric acid production—phosphogypsum is used, and as an organic component, which is a source of organic compounds and nutrients, the dehydrated SIMS of the sulfite cellulose production, lignin sludge is used. Despite this, the occurrence of traces of HM and REM in the organomineral mixture of phosphogypsum and lignin sludge necessitates the application of the components into the soil by weight ratio: phosphogypsum – 20–25%, lignin sludge – 75–80% at the ratio of organomineral fillers and soil 1:1. Mixing of the components and their simultaneous one-time application into the soil of the sod-podzolic type is carried out using fertilizer spreading equipment with subsequent filler plowing to a depth of 15–20 cm and further tilling of the soil stratum. The result is a complex textural fertilizer with the formation of hardly soluble lime humate. It concretes the structure of

aggregates and ensures the resistance of HM and REM to enleaching from the soil and releasing into plants. The application of Ca into the soil with both phosphogypsum and lignin sludge causes the involvement of excess calcium in the biochemical mechanisms of HM and Sr substitution in plants. The product provides a way to increase the growth efficiency of the grass mixture, as well as to ensure the release of HM and REM into plants in a tolerable amount.

Results and Discussion

In 2018, the volume of accumulation of industrial and municipal waste in the Russian Federation exceeded 7 billion. The main share of waste is generated by industry – 97.5%. In January 2018, the "Strategy for the development of the industry for the processing, disposal and neutralization of production and consumption waste for the period up to 2030" was approved. At the same time, the federal budget provides funds for the concessional lending to waste disposal activities. Currently, the issue of ensuring an integrated approach to the best available technologies implementation (BAT) as a part of both environmental and industrial policy, including the waste management, is extremely relevant in the Russian Federation. According to the information and technical reference (ITR) 10-2019 "Communal waste water treatment using urban centralized systems", the production of soils based on SIMS and its processed products is a valid method that guarantees complete waste disposal and allows for the reclamation of disturbed lands. According to ITR 15-2016 "Recycling and disposal of waste (except for thermal disposal of waste (waste incineration)", bioremediation is an effective method of reducing the content of mineral oils and HM in contaminated soils. The use of organomineral fillers based on lignin and phosphogypsum sludge in combination with phytoremediation improves the growth parameters of the grass mixture and increase the percentage of extracted HM from the soil. The use of brown coal crop has also proved its effectiveness in reducing the phytotoxicity of the soil. Artificial soils can be successfully sold to interested developers, road facilities, companies engaged in planting and landscaping.

Research on the development of the technology for the use of SIMS ash from the incineration is carried out under contract with the SUE "Vodokanal of St. Petersburg". As a result of the activities of three sludge incineration plants (SIP), SUE "Vodokanal of St. Petersburg" annually produces about 50,000 tons of ash, which is fully landfilled. The shortage of free space for waste storage and the organization of landfills near residential areas is an urgent environmental problem. The estimated economic feasibility when using ash as a fertilizer of group II will be about 20%. By using the proposed ash-based soil for the improvement of road slopes on an area of 237.75 hectares, the need of the St. Petersburg Improvement Committee will be 6,783 tons of ash. At the same time, the volume of ash formation at one of the SIP is 4964 tons per year. The economic effect will be 5.23 million rubles due to the implementation of ash and savings on payments for waste disposal. By the stop of waste storage, total losses of the prevented environmental damage are indicated 380.61 million rubles with a payback period of less than 1 year.

Waste storage facilities are an environmental problem of coal mining enterprises [55, 56]. On the example of reclamation of a tailing dump using an innovative product based on brown coal crop, the economic impact of the implementation of measures will consist of two indicators: exempting the enterprise from the payment of rent for the maintenance of the tailing dump and the sale of harvested hay to third parties for the production of all-mash and animal feedstuff. The final economic impact will be 195 thousand rubles per year and the payback period will be 10 years.

The proposed solution for the joint disposal of phosphogypsum waste and lignin sludge implies the sale of a mixture for its use to increase the crop-producing power of disturbed lands without purchasing more expensive fertilizers. During the first five years, the annual profit of production facilities will vary from 56 to 1.33 million rubles. The prevented economic damage for the first five years will amount to 14.48 million rubles per year, for subsequent years – 345 thousand rubles per year.

Conclusions

An integrated approach to the development of artificial soils based on available production waste meet the following challenges: efficient waste disposal; reclamation of disturbed lands and landfills, landscaping and planting of territories; economically and environmentally sound restoration of productivity of reclaimed and urban soils. Artificial soils can be successfully sold to developers, road facilities, companies engaged in landscaping and improvement, as well as to individuals as a recultivator. Based on the research results, recommendations were prepared for the implementation of the author's method to restore the disturbed lands productivity at various urban construction sites to the Committee for the Improvement of St. Petersburg and the Ministry of Construction and Housing and Communal Services of Russia. Three patents for the invention of the Russian Federation were obtained (No. 2711925 of 03.04.2019, No. 2712542 of 29.07.2019 and No. 2723401 of 05.08.2019), which confirms the scientific novelty of the research area under consideration.

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