Heavy accumulation of fertile soil layer in the mined-out space of opencast using geothermal energy

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Abstract
The theoretical evaluation of accumulation of fertile soil layer is conducted on the basis of rate of increase of the organic matter of higher aquatic plants with the use of technique of intensive recovery of the biodiversity in the mined-out space of opencast using geothermal energy. It is established that the suggested technique allows increasing the accumulation rate of fertile soil layer, which is material

and energy basis for biodiversity recovery in the mined-out space of the opencasts.
Key words: MINED-OUT SPACE OF OPENCAST, GEOTHERMAL ENERGY, HYDROBIONTS, BIODIVERSITY, CLAY-GRAPHITE COMPOUND, FERTILE SOIL LAYER

Relevance

The open-cut mining leads to formation of dead areas without fertile soil layer in the mined-out spaces. The mined-out spaces after extraction of raw materials like refractory clay, fluxes, chalk-stone or chalky clay have the form of "lunar" dead landscapes; they are cavities without any fertile soil layer with edges subjected to erosion damage. Thus, the high level of environmental threat is developed [1]. The self-existing recovery of flora and fauna within such areas takes hundreds of years and in some cases leads to further environment deterioration.

The method of the biodiversity initial state recovery in the areas after mining of mineral products is necessary. This method must meet the requirements of cost characteristics and at least partial payback as far as possible.

Some researchers propose to restore the mined-out opencasts by applying the filling operation of the mined-out spaces with subsurface rocks. However, such recultivation is reasonable only for small-area and shallow opencasts with the availability of sufficient amount of worked-out rocks and fertile soil layer, as well as for the opencasts with high level of ground water depth.

The problem of recreation of mined-out spaces is often solved by filling of mined-out spaces of the opencasts with water making an artificial reservoir. However, it is often impossible to make an artificial reservoir because of relief complexity, structure fracturing of soil layer or other factors.

One of the advanced way of problem solving is the intensive creation of fertile soil layer on the pit floor.

State of problem

In order to speed up the recovery of biodiversity in the mined-out opencast spaces and polluted water purification, the authors have suggested using the method of the biological purification of quarry water by plants with increasing the path length and purification time by terms of making the labyrinth configuration to the water flow [2]. Hereafter, for the year-round control of water flows, it is suggested to improve the method of the bacterial purification of the quarry water by plants with the increasing the path length and purification time through temperature regulation, flowed through water streams regarding geothermal energy [2].

In this regard, it is required to drill boreholes 50…100 *m* in depth along the water track right and left from the auxiliary dams and arrange the geothermal heat transfer device in these boreholes; this device is transverse borehole collector "pipe-in-pipe" (Fig. 1). In this case, the plastic tube (32-50 *mm* in diameter) paths along the axis of steel one (100-120 *mm* in diameter) which is welded at the bottom.

The quarry water runs into the tube space through the convergent tube and moves downwards through the tube by impact pressure. As the quarry water runs, there is a heat exchange between the metal tube wall with the temperature of enclosing rocks and water flow, as a result of which the temperature of water is raised. At the bottom of tube, the water flow changes the direction by 180° and rises to the surface through the inner plastic tube by dynamic impact and density difference between heated and cold water. The interval between wells should not be less than 10…15 *m*. Such construction resists successfully soil movement and provides a good heat transmission.

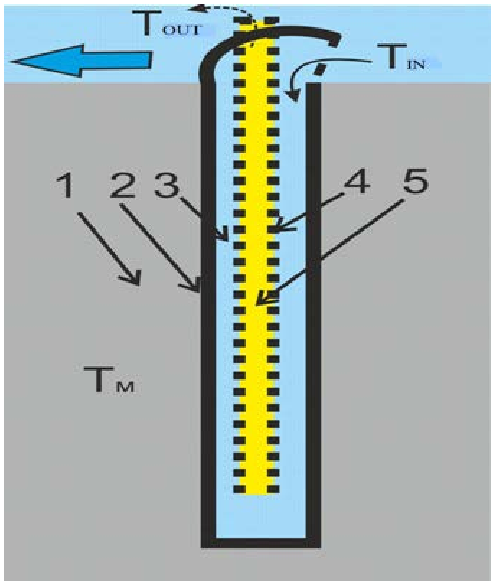

Figure 1. The operation scheme of transverse borehole collector "pipe-in-pipe":
a – vertical section; 1 – rock mass; 2 – metal pipe; 3 – stream of cold supply water; 4 - inner plastic tube; 5 – the stream of heated water; T_m, T_{in}, T_{out} – temperature of rock mass, running into and dropping out of the collector water respectively

As a result of year-round control of the quarry water streams by using of geothermal energy, the stable temperature conditions will be achieved.

On the basis of chemical analysis of water specimen, it has been concluded that it is necessary to remove suspended materials from water and take measures to reduce rigidity and salt content. It is reasonable to use such plants as bulrush, rush, reed mace, and water hyacinth because those particular plants purify water properly and they are of low-cost.

It is necessary to maintain the water temperature within 10…12 ^{0}C in the purification plant in order to prevent reduction of water purification efficiency in winter period. The water does not freeze over with such temperature; however, its temperature falls off significantly under the ice crust of the plant. At a temperature of waste water less than 7 ^{0}C, the living abilities of hydrobionts and their activity are reduced sharply. At temperature more than 28 ^{0}C, the nitrification rate decreases due to reduction of dissolved oxygen quantity in the water. Thus, the optimum temperature is 10…12 ^{0}C in winter period and no more than 25…28 ^{0}C in summer period.

The analysis of temperature conditions on the surface and in depth of earth cover under conditions of Donets Basin showed that the temperature on the surface could have both negative and positive values. The temperature at depths of 5…10 *m* has only positive values within 4…12 ^{0}C. The deepness of the neutral zone for Donets Basin is 10-15 *m* that determines the necessity of partial thermal protection of steel shell of the borehole collector.

The thermal calculation was conducted, and the water temperature in depth of borehole equation was obtained in order to determine the critical parameters of the technology [3].

$$T = T_{g0} + \frac{\mathrm{grad}T_g}{A}(Az-1) + \left(T_1 - T_{g0}\frac{\mathrm{grad}T_g}{A}(Az_1-1)\right)e^{-A(z_1-z)} \quad (1)$$

where: $T=T(z)$ – current temperature of water, *K*;
T_{g0} – temperature of land surface, *K*;
$\mathrm{grad}T_g$ – thermal gradient of ground, *K/m*;
z – ground clearance, *m*;
$z>z_1$ – ground deepness before which the temperature of the ground is constant (for Donets Basin conditions, z_1=15 *m*; $T_g=T_{g0}$).

$$A = \frac{\pi Dk}{Ms} \quad (2)$$

where: k – coefficient of heat transfer, *W/(m²·K)*;
M – water expenditure, *kg/s*;
s – water specific heat, *J/(kg·K)*;
D – borehole diameter, *m*.

Taking into account the heating temperature of water $T=T_2$, it is determined the necessary length of inner pipe z_2 by solving the equation:

$$T_2 = T_{g0} + \frac{\mathrm{grad}Tg}{A}(Az_2-1) + \left(T_1 - T_{g0}\frac{\mathrm{grad}T_g}{A}(Az_1-1)\right)e^{-A(z_1-z_2)}. \quad (3)$$

At a section $0<z\le z_1$ where $T_1>T_g$ for preventing of heat loss and a temperature drop of water, it is necessary to provide the thermal protection in the borehole.

The calculation data has demonstrated that 26 *m* deep borehole provides the change of 1 ^{0}C in temperature in the geothermal heating system. For increasing of water temperature from T_1 = 7°*C* to T_2 = 12°*C*, 130 *m* deep borehole is required.

For providing the best heat transmission from the depth of solid to borehole collector, it is necessary to minimize the negative impact of rock fracturing nearby the surface of geothermal heat transfer pipes. To achieve this purpose, the authors propose to fill these holes with solidifying compound based on inexpensive material, for example, clay with addition of heat-conducting filler, in the function of which it is reasonably to use graphite powder [3].

The experimental investigation of heat-conducting properties of the clay-graphite mixture demonstrated that in case of increase of graphite powder in the mixture up to 50 % (mass), the increase of heat conducting coefficient of damped mixture is 157.12 % in comparison with heat conducting of dry bentonite; it is equal to 15.89 *W/(m·°C)*.

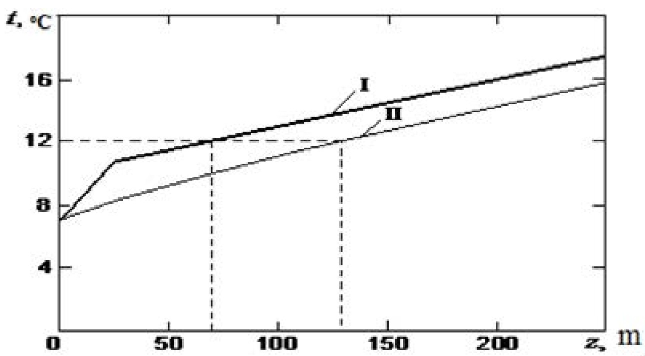

Figure 2. The temperature change of water in depth of borehole using clay-graphite mixture (I) and without it (II)

The thermal analysis with consideretion of clay-graphite mixture use allows determining that for heating of water to the same temperature, using a clay-graphite filler of space between tubes, it is required a borehole which is 1.7 times smaller than in the case of steel shell direct contact with enclosing rocks (Fig. 2).

The established regularity of heat transfer between the rock mass and aquatic medium in case of use of geothermal heat exchange units in the biological-purification installations will allow determining its key parameters (number of boreholes and their deepness) for temperature +10^{0}C maintenance in winter period.

The example of implementation of making fertile soil layer technology in the mined-out space of the opencast, which is 300x200 *m* in size (Fig. 3), with the use of geothermal energy, includes the following processes [3].

By means of earth movers and blade graders, the rebuilding of opencast bottom for 3.5° sloping is carried out. There is the main dam 5, which is 200 *m* in length, 3 *m* in width and 1 *m* high, in the center of mined-out space built from the materials unapt to slaking; they are pieces of sand rock and limestone.

The auxiliary dams are built to increase the time of water passing through the opencast, thereby increase the degree of water purification. The dams are arranged in chessboard order in 4 lines and each line includes 4 dams. The embankments of rocks unapt to slaking and covered with black soil bed will be basis for the dam. The distance between the auxiliary dams is 50 *m*. In order to minimize erosion and soil washing, surfaces of the dams are planted by bulrush, rush and reed mace.

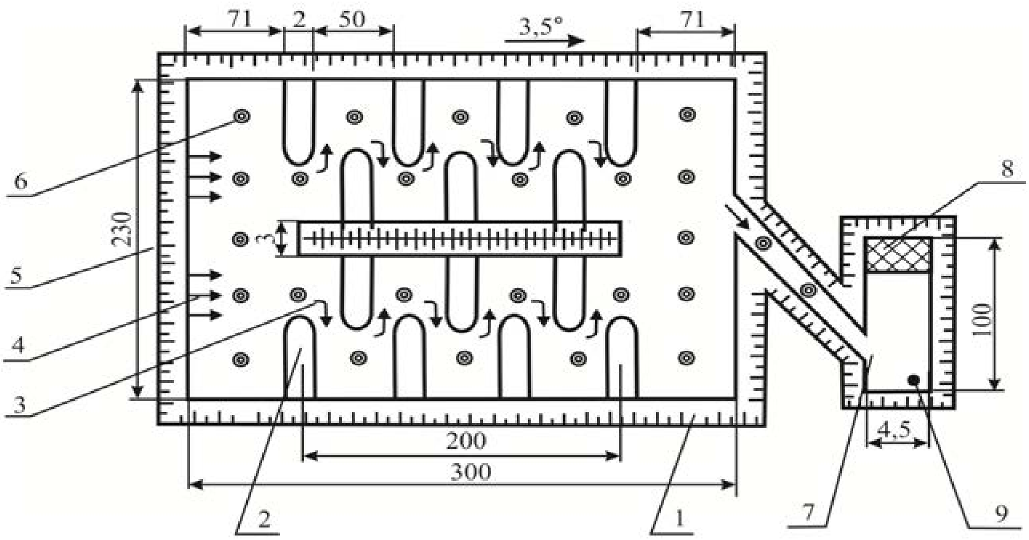

Figure 3. The installation for water purifying in opencast with the use of geothermal energy:
1 – opencast edge; 2 – auxiliary dams; 3 – bed; 4 – water inflow; 5 – main dam; 6 – transverse borehole collector "pipe-in-pipe"; 7 – water-collector; 8 – higher aquatic plants; 9 – pump

It is necessary to drill 24 geothermal boreholes (6) with diameter 200 *mm* and length 76 *m* along the stream bed to maintain required temperature water conditions (10…12 ^{0}C in period and up to 28 ^{0}C in summer period). The boreholes are arranged in 4 lines 6 items in each line; the distance between them is 50 *m*.

The heat exchangers are arranged in the drilled boreholes. The heat exchangers are cylindrical shell made of steel 4*X*13 with 20 *mm* thickness of wall, it is shut off from the bottom. The plastic pipe, which is 50 *mm* in diameter and 75 *m* in length, is located concentric in them. The space between shell and massif in the site from 10 to 75 *m* is filled with clay-graphite compound with 50 % graphite mass content. The heat exchangers are equiped with thermal isolation from cellular glass 20 *mm* thick at a depth of 15 *m* from the ground surface. The self-purification from suspended matter will be conducted by turbulent mode of water movement in the bottom-hole area of the heat exchanger.

In order to prevent erosion, the edges and benches of the opencast are planted with sloe as this plant has extremely bushy roots and it also grows quickly within a short period of time.

The water-collector 7, from which renovated water is fed by pump 9 for watering or other technical needs, is built at the bottom of opencast. The water-collector is designed for additional water purification, so the part of that will be planted with higher aquatic plants. The water hyacinth 8 is planted for biological water purification in the water-collector.

The maintenance of thermal water conditions in the biological purifier will allow creating comfortable conditions for living abilities of hydrobionts all year round; preventing freezing of shallow stream flows and death of water grass and shellfish in winter period. The living conditions of hydrobionts will also be improved due to water cooling in the shallow-water space of opencast in summer period. The water resource in the water purifier will perform year-around function of purification by way of carbon dioxide and other gasses dissolving with subsequent taking them by plants for cell composition and nourishing. Moreover, it will allow using nonfreezing water like a place for wintering of swimming birds.

As biodiversity recovery is directly connected with the formation of fertile soil layer, it is necessary to analyze the speed of its formation.

The paper objective is to evaluate theoretically the rate of fertile soil layer accumulation using geothermal energy for reduction of biodiversity of mined-out space of opencasts.

Researches results

The scale change of geographical situation, landscape influenced by natural disasters and human activity lead to gradual changes of local biocoenose state. The influences of forces, which change quality and quantity characteristics of circulation of elements and energy, usually affect biocenosis changes or destroy it. The new living organisms gradually appear in the place of previous biocenosis.

The elementary biocenosis arises and functions at the first stage. It includes restricted quantity of types of plants and animals. The elementary biocenosis changes into more complex ones gradually. It occurs when enough energy and material resources are accumulated, providing the emergence of new ecological niches, and proceeds until there appears the biocenosis, in which the biotic and abiotic relations meet requirements of the community of living organisms.

In the case of the mined-out spaces of opencasts, the biodiversity recovery is possible only with the sufficient amount of accumulated fertile soil layer, which contains material resources to create ecological niches.

The fertile soil layer is the upper humus layer of soil possessing chemical, physical and biological properties favorable to plant growth. Humus is complex dynamical composite of organic compounds formed at the mineralization of organic remains. The humus content of soils is determined by the terms and character of the soil-building process. It ranges from 1-2 to 12-15% in the surface soil layers and sharply or gradually falls with depth.

The organic part of the soil contains undergrad and semi-decomposed vegetable remains, soil organisms, and humus. The remains of plant and animal bodies rebuild and refresh humus stocks in the soils with gradual decompounding. The process is under way of active involvement of microorganisms and animals (earthworms, maggots). These complex biochemical decay and synthetic processes are simultaneous. Thus, the more biomass is produced in the ecosystem, the higher humus level is in the soil. Soil humusification can be implicitly inferred by the producing of plants biomass.

The process of fertile soil layer formation at the bottom of the opencast may be presented in the following way (Fig. 4). The labyrinthine drainage channel of the water purifier is a kind of plain catch basin. Precipitation of suspended materials gathering in mass at the bottom of the draining channel takes place. The plants, which grown along the shores, at the bottom and water surface, sorb suspended materials on the stems, leafs, and roots. Thus, the finely divided nonorganic phase of the layer is accumulated. The roots of the water and foreshore plants penetrate into the pores and fissures of roaches laying down the bottom of the opencast, and distract them by wedging. It is especially common for sedimentary rocks of the massive. Thereby, the second part of fertile soil layer inorganic component is formed.

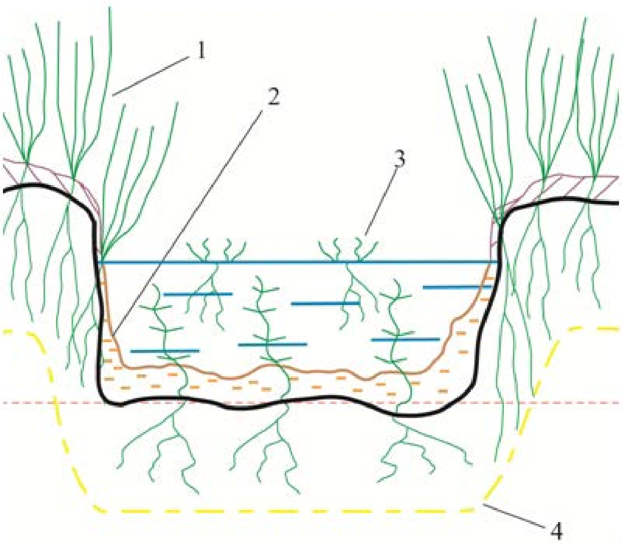

Figure 4. Diagram of formation of fertile soil layer in the drainage channel of water purifier: 1,3 – foreshore and water plants; 2,4 – upper and lower bounds of the fertile soil layer respectively

The plants absorb the salts from water as well as the carbon dioxide and other materials from the air by their roots, stems, and leaf. The root, underwater and surficial cell mass increases, and then it forms soil humus layer in the process of further cells die-away and decomposition.

It is possible to point out the upper fertile soil layer bound formed with alluvial deposits, and lower one formed with broken rocks. The productivity of the fertile soil layer is determined by its thickness and organic substance richness. The organic substance richness is proportional to formed and laid down cell mass of the plants.

The biomass of foreshore-water plants is estimated by three criteria, namely, weight of fresh just cropped mass, air-dry and oven-dry mass.

Depending on experimental tasks, the three ways of aquatic vegetation registering are used; however, the last one is the most advantageous as allowing the results of different authors to be compared.

The biomass of aquatic vegetation is expressed as a unit of weight per unit of area (*g/m²*, *kg/m²*, *c/ha²*) with the including (or exception of) underground organs. Knowing the square of certain associations and their biomass, it is possible to calculate the storage of biomass vegetation for the whole water reservoir.

It is more complicated to select the quantitative samples of the underground organs of plants as many of them reach significant depth. For example, the reed reaches 1 *m,* equisetum – 80 *cm*, water arum and bean trefoil – 70 *cm*, sedge – 60 *cm*.

The analysis of root system is important for determination of biomass as the underground organs of many plants (reed mace, bulrush, cow lily, pond lily) can exceed above-ground ones by several times by biomass. According to the literature data, the ratio of the underground parts with the above-ground parts is 2.5:1 in narrowed-leaved catoptric, 1:1 in mace reed and reed, and 9:1 in bulrush. In the formed systems, underground organs (roots, rootstocks) are 50-100% of plant biomass. However, it is necessary to notice that they are being accumulated for a number of years, so they cannot be a great part of general annual production. According to another data, about a half of underground mass grows in a growing season.

For prior assessment of the rate of increase of organic mass, it is possible to use known facts of the foreshore-water plants rise rate. According to the paper [5] data, the annual productivity of water hyacinth is only 150-440 *g/m²* of dry weight, but its gain for the period from June to August is 14.6 *g/m²* of dry mass per day. During the short period of time, the higher rate of growth that is 30 *g/m²* of dry mass per day [6] is possible for the plant system; it in turn signifies the high nitrogen and phosphorous demand [6].

The data on biomass yield and growth rate of different water-plants are presented in Table 1.

Table 1. The maximum weight of growing crop and seasonal gain of some aquatic microphyte [5]

Type of microphyte	Maximum weight of the growing crop, *g/m²* of dry mass	Seasonal gain per day, *g/m²* of dry mass
Marsh grass (*Spartina Alterniflora*)	4200	10.0
Great bulrush (*Scirpus lacustri*ne) and giant bulrush (*Arundo donax*)	10000	28.0
Radicle of roots (*Ceratophyllum Demersum*)	710	2.5
Water parsnip (*Berula Species*) and buttercup (*Ranunculus species*)	500	4.2
Delta Arrowhead (*Sagittaria Latifolia*)	810	7.5
Water hyacinth (*Eichhornia crassipes*)	1500	7.4-22.0

The yield of dry mass for such crops as mace reed (*Typha latifolia*) and swamp lily (*Saururus census*) is 1500 and 800 *g/m²* respectively [6]. The investigation results of an annual productivity (output) of the seven plants of salt lakes in Louisiana are presented in Table 2.

Table 2. The investigation results of an annual productivity (output) of the seven plants of salt lakes in Louisiana

Type of plant	Biomass gain, *g/m²* of dry mass
Alkali grass (*Distkhlis spicata*)	3237
Rush (*Juncus roemerianus*)	3416
Bur reed (*Phragmites communis*)	2318
Arrowhead (*Sagittaria falcata*)	1501

Marsh grass (*Spartina altemiflora*)	2658
Prairie Grass (*S. cynosuroides*)	1355
Marsh grass of salt pratum (*S. patens*)	6043

Consideration of underwater part of plants can affect significantly the values their productivity. For example, when studying the emergent microphytes of Wisconsin fresh-water marshes, it was established [6] that the primary annual output is in range from 1181 *g/m²* of dry mass for ling (*Cazex lacustris*) to 3200 *g/m²* of dry mass for mace reed (*Typha latifolia*); while an annual increasing of mace reed in Oklahoma was only 800 *g/m²* of dry mass [9].

For the opencast under consideration (Fig. 3), the following basic data are accepted. The parameters of auxiliary dam are the following: 2 *m* in width, 1 *m* in high, and 32 *m* in length. In total, 14 auxiliary dams were equipped; the area of each dam is 2*32 = 64 *m²*. The total area of auxiliary dams is S_{tot}=14*64 = 896 *m²*. The main dam is 200 m in length, 3 m in width, 1 m in high and 200*3=600 *m²* in area. Thus, the total area of dams planted with bulrush is 896+600=1496 *m²*.

On average, the growth cycle of bulrush is 7.5 months (233 days) under the conditions of Ukraine. In this period, the growth of bulrush dry mass is 6.35 *g/m²* per day. The growth of dry mass is 2.21 t per year for the total area of dams planted with a bulrush.

The use of geothermal energy for temperature conditions controlling in the opencast will allow providing the bulrush growth during the year. Consequently, the annual gain of bulrush dry mass will be 233*6,35= 1479,55 *g/m²*. For the total area of dams planted with bulrush, the dry mass gain reaches 3.47 *t* per year, it is 1.57 time higher than without using of underground heat.

The water-collector is arranged at the bottom of the open-cast, where water undergoes additional purification by water hyacinth (*Eichhornia crassipes*). The area of the water-collector is 450 m², 200 *m²* of which is planted with water hyacinth. On average, under the conditions of Ukraine, the growth cycle of water hyacinth is 5 months (153 days). In this period, the growth of water hyacinth dry mass is 7.4 *g/m²* per day. In such case, the annual gain of water hyacinth dry mass is 153*7.4= 1132.2 *g/m²*. For the total area of water-collector planted with water hyacinth, the dry mass gain reaches 0.226 *t* per year.

The annual gain of water hyacinth dry mass will be 365*7.4 = 2701 *g/m²* of dry mass when using geothermal energy. For the total area of water-collector planted with water hyacinth, the dry mass gain reaches 0.54 *t* per year, it is 2.4 times higher than without using of underground heat.

Conclusion

The theoretical assessment of accumulation of fertile soil layer on the basis of evaluation of gain rates of the organic matter of higher aquatic plants using the technique of intensive recovery of the biodiversity in the mined-out space of the opencast with the use of geothermal energy was conducted. The annual gain of bulrush dry mass will be 3.47 t, which is 1.57 time higher than without using of underground heat. This figure for water hyacinth is 0.54 *t*, which is 2.4 times higher than without using of underground heat.

As can be seen from the above, the suggested technology, which provides the use of heating energy of subsurface resources, will allow increasing the rates of accumulation of the fertile soil layer by 1.5…2 times. This layer is material and energy basis for biodiversity recovery in the mined-out space of the opencasts.

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