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Soil and ecological state of reclaimed sites with the use of waste coal

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Abstract. The results of the survey of reclaimed areas with waste coal are presented. The assessment of the soil and ecological state showed that the restoration of disturbed lands in the areas of reclamation with the formation of a geological substrate from waste coal and bulk root inhabited horizons allows a stable vegetation cover on the reclaimed surface to be formed and waste coal to be used for reclamation purposes in an environmentally safe way.

1. Introduction

Kuzbass is the largest industrial center in Russia. At present, 41 mines, 52 open-pit mines operate in the region, and new enterprises are created every year. Coal production volumes in Russia for the period from 2000 to 2017 increased by 1.6 times, in Kuzbass by 2.2 times [1]. As a result of mining activities, waste is generated, the volumes of which are determined by the scale of production and the technology of mining and coal preparation. Waste volumes also depend on the mining and geological conditions of the deposits and the quality of the coal. The issue of disposal and processing of waste generated in the coal mining industry remains relevant, since out of 7 billion tonnes of waste generated annually in the country, 3 billion tonnes are overburden – waste from the mining industry [1].

All components that are not included in the commercial coal are considered to be mining waste – these are rocks of the coal-bearing seam, overburden, inclusions in coals, coal and coal-rock sludge and low-grade coals. Thus, with a high content of carbonaceous particles (more than 20%), coal waste can be classified as technogenic mineral raw materials, and their accumulations – as technogenic deposits of the coal series [2, 3].

The composition and properties of coal preparation wastes are determined by the geochemical composition of coals, properties of overburden and enclosing rocks, and the peculiarities of the beneficiation technology. The first type of waste is the so-called “cake”, in a wet state it is a pasty, plastic mass, when dried, a powdery material, consisting mainly of small particles of coal and mineral particles. The pasty, low-flowing state of “cake”, the high content of carbonaceous particles makes this material much less dense than stony waste. The density of the “cake” largely depends on moisture content, the degree of compaction during storage and on the preparation technology.

The second type of waste is large fragments of rocks from 1 to 30 cm in diameter, also with a certain admixture of carbonaceous particles. The physical properties of coal preparation wastes are determined by their state of aggregation.



In modern conditions, the volume of waste is constantly increasing, which leads to the withdrawal of significant areas of land and environmental pollution.

Currently, a wealth of experience has been accumulated in the implementation of works related to the restoration of disturbed lands and vegetation cover on dumps and tailings of the Urals, the Far East, Kuzbass, as well as abroad [4, 5, 6, 7, 8, 9, 10, 11, 12].

The purpose of the work: assessment of the soil-ecological state of the reclaimed areas where waste coal is used.

2. Experimental part

To assess the efficiency of the waste coal used, the soil-ecological studies were carried out on the reclaimed plots of 3 – 7 years old, located in the suburb of Leninsk-Kuznetskiy, Kemerovo region.

Geomorphologically, the study sites are located in the western part of Kemerovo Region, in the center of the Kuznetsk Basin. In this geomorphological area, a weakly dissected accumulative-denudation plain stands out. The climate of the study area is sharply continental with long cold winters and short hot summers. The sum of active temperatures is above 10°, on average 1800° C – 1900° C, in some years it can be even higher. The study area belongs to the first hydrothermal zone of the steppe core and forest-steppe of the Kuznetsk depression. Hydraulic series – moderately moist with aridity. The amount of precipitation per year is 300 – 350 mm per year [13].

Reclamation of disturbed lands was carried out by backfilling the worked-out pits of the former coal mine with coarse-grained material of coal preparation wastes, leveling the surface and dumping materials of potentially rich rocks (PRR) and rich soil layer (RSL) on the planned surface. As a result of the work performed on the reclaimed areas, artificial soils were formed with a dumped root layer, which, according to the profile-genetic classification of soils of technogenic landscapes, belong to humusogenic technosols (if the material of the root layer is dumped by RSL) or to lithogenic technosols (if the material of the root inhabited layer is dumped by PRR) [14].

Currently, as a result of many years of research, it has been established that non-reclaimed and reclaimed soils of technogenic landscapes, especially the first 20 years of self-development, are extremely dynamic. The structure of the soil mantle in disturbed territories, assessed by the ratio of the areas occupied by one type of soil or another, mainly embryo-soils (in non-reclaimed areas), is constantly changing. Therefore, the study of the processes of restoration of soil properties at the initial stages of disturbed lands reclamation and assessment of the soil-ecological state are very important, this allows us to identify further prospects for reclamation of disturbed areas and develop measures to increase the efficiency of reclamation works. The experience of many years of research and the application of such approach to assessing the soil-ecological state of disturbed territories made it possible to divide the conditions of soil formation in different parts of technogenic landscapes and the level of restoration of disturbed lands into five categories [15, 16]:

- unsatisfactory, in which the processes of soil formation are absent and the soils remain initial embryo-soils for a pragmatically acceptable period;
- satisfactory, in which soil-forming processes are slow and at the time indicated above do not lead to the formation of humus-accumulative embryo-soils;
- good, in which humus-accumulative embryo-soils are formed over a period of 20 or more years;
- very good, in which humus-accumulative embryo-soils are formed in 10 – 20 years;
- excellent, in which humus-accumulative embryo-soils are formed over a period of less than 10 years.

At the same time, it can be assumed that if a complex phytocoenosis is formed over 20 years and developed humus-accumulative embryo-soils are formed, then self-restoration of disturbed lands proceeds at a normal pace, and reclamation activities can be performed according to an abbreviated scheme, supporting, if necessary, only the restoration of vegetation and biodiversity on disturbed areas.

The division of disturbed lands into these categories makes it possible to assess their condition and, individually for each technogenic object, propose measures to reduce the negative consequences of soil disturbance.

In the study of the agrophysical and agrochemical properties of soils, standard methods were used, adopted in soil-ecological surveys [17, 18].

To study the soil and ecological state of the sites reclaimed with the use of waste coals, a field soil survey of the sites was carried out with the selection of soil and rock samples in the reclaimed sites, characterized by the peculiarities of the formation of the root layer: a mixture of mine rocks without the application of PRR and RSL (initial embryo-soil on technogenic eluvium – point 1); with application of PRR (undifferentiated lithogenic technosoil – point 2); with the application of RSL on the surface covered with coal preparation wastes (undifferentiated humusogenic technozem – point 3) (figure 1); layer-by-layer application of PRR and RSL (differentiated humusogenic technosoil – point 4). In this case, the PRR layer is placed directly on the rock and serves as a kind of screen and transitional horizon between the RSL and the rock. An area with natural soil – leached black humus earth (point 5) was chosen as a control.



Figure 1. Point 3. Undifferentiated humic technosoil. Leveled surface. Sowing of brome grass and alfalfa.

To characterize the agrophysical properties of the surface layers of soils and substrates, soil and rock samples were taken from the surface of the reclaimed areas.

To assess the soil-ecological state of the studied technogenic landscapes, the profile-genetic classification of soils of technogenic landscapes was used.

3. Results and discussion

The soil and ecological state (SES) of the studied areas was determined taking into account the properties of soils limiting or, conversely, stimulating the performance of their ecological functions and was calculated using the formula (1) [14]:

$$\text{SES (b. b.)} = B_p \times C_s, \quad (1)$$

B_p is the point of the bonitet of the undisturbed soil of the site;

C_s is the specificity coefficient of the properties of the studied soils in relation to the properties of the undisturbed zonal, in fractions of unity.

Soil specificity coefficient is calculated according to the main soil indicators. These are the content of physical clay (C_c p.c.), the density of the addition of the substrate (C_c s.) and the content of humus (C_c hum.). The numerical values of this coefficient characterize the degree of deviation of the soil

indicator from the control value in black humus earth. Regardless of whether the considered indicator is lower or higher, the more it differs from the optimal values of the control option, the less is C_c .

In general, the soil specificity coefficient is calculated (2) as the average value of the specificity coefficients for specific soil properties, taking into account the thickness of the horizons in which the samples were taken.

$$C_S = \frac{C_{c \text{ p.c.}} + C_{c \text{ hum.}} + C_{c \text{ s.}}}{3} \quad (2)$$

To calculate the SES, the following indicators were taken: humus content – 7.1%; physical clay – 45%; addition density – 1.2 g / cm³. The results are shown in table 3.

Table 3. Soil properties of the sites, which determine their specificity in relation to the soils of undisturbed sites.

Type of soils	Horizon (sampling depth, cm)	Content		Density, g/cm ³	pH _{wat}	C _c p.c.	C _c hum.	C _c s.	C _c	Bonitet point
		physical clay, %	humus, %							
1. Initial embryo-soil	D (0-10)	66.29	-	1.56	9.89	0.53	0.00	0.5	0.41	35
2. Lithogenic technosoil (RPP)	I (0-12)	29.65	1.59	1.38	8.19	0.61	0.11	0.51	0.39	41
	II (12-22)	17.28	2.13	1.42	8.92					
	D (22-30)	29.83	-	2.22	8.19					
3. Humusogenic undifferentiated technosoil (RSL)	A _d (0-8)	53.56	6.70	1.24	8.06	0.90	0.38	0.60	0.63	63
	A ₁ (8-16)	48.04	5.17	1.28	8.00					
	A ₂ (16-25)	51.39	4.52	1.38	8.22					
	D (25-35)	47.73	-	2.06	9.44					
4. Differentiated humusogenic technosoil (RSL + RPP)	A _d (0-8)	58.33	4.36	1.20	8.43	0.74	0.36	0.73	0.61	61
	A ₁ (8-25)	55.45	4.38	1.34	8.47					
	III (25-35)	54.65	1.87	1.39	8.80					
	D (35-50)	58.27	-	2.03	9.22					
5. Leached black humus earth	A ₁ (6-33)	45.75	7.10	1.18	6.66	0.96	0.74	0.94	0.88	88
	AB (33-44)	50.64	2.05	1.34	7.24					
	B (44-60)	47.20	1.01	1.42	7.03					

The calculations showed that all the studied areas can be divided into four groups: excellent SES (bonitet point more than 80), with good (bonitet score 60 – 80), satisfactory (bonitet score 40 – 60) and unsatisfactory (bonitet score less than 40) ecological condition. The first group includes leached chernosol (control) No. 5. The second group includes sites No. 3 and 4 with humusogenic technosols, which are characterized by very close bonitet points – 61 – 63, despite the fact that they have different thickness of the dumped root layer represented by clean RSL (section No. 3) and RSL applied to the RPP layer by layer (section No. 4). Moreover, the option with the layer-by-layer placement of RSL and RPP, despite the high thickness of the applied layer, is characterized by lower SES indices, which is due to lower indicators of humus content. These territories are characterized by a fairly developed vegetation cover, but due to the small thickness of the covered layer and the unfavorable properties of the underlying rocks, they do not reach a higher SES gradation.

Due to the low content of humic substances in the bulk horizon of lithogenic technozem (site No. 2). In this option, SES is characterized as satisfactory. Therefore, the growth of plants that are not

demanding of the nutrient and water regime is possible here, which significantly reduces the efficiency of reclamation work.

The most unfavorable properties and the weakest development of soil-forming processes are characteristic of the initial embryo-soils on site No. 1. There is practically no vegetation here and the SES of this site is characterized as unsatisfactory. It should be emphasized that this is the oldest site (7 years after backfilling) of all the options surveyed. Therefore, it can be assumed that without carrying out reclamation work to improve the agrophysical and agrochemical properties of the substrate of this site, its unfavorable SES can persist for a long time (ten or more years).

4. Conclusions

1. As a result of the conducted studies of the agrophysical and agrochemical properties of reclaimed soils, it was found that technosoils and embryo-soils are characterized by increased density, which is associated with the peculiarities of their formation and significant overcompaction during planning work with heavy equipment at the mining technical stage of reclamation. The biological stage of reclamation contributes to the improvement of agrophysical properties, and after 5 years, the indicators in the upper layers of the dumped horizon can reach the level of the control option (1.20 g/cm³). Thus, the development of vegetation contributes to the gradual improvement of the agrophysical state of the root layer.

2. The conducted studies showed that the best results of the soil and ecological state of the reclaimed areas were obtained in the options with the use of RSL for the formation of the root layer. Within 5 years, a stable vegetation cover was formed in such areas and a gradual restoration of soil properties in the surface covered layers towards the natural soils common in the adjacent territories was recorded. However, due to the small thickness of the backfilled horizon and the short recovery period, the new soils do not reach the natural level. At the same time, a negative effect of the underlying rocks (increase in pH) on the dumped RSL and RPP material is recorded, especially in the lower layers.

Thus, the studies carried out showed the possibility of using waste coal for reclamation. It was established that waste can be used to level the technogenic relief and form a stable base for the placement of substrates suitable for biological reclamation. To prevent the negative impact of waste coal on the root layer, it is necessary to form a shielding layer that would prevent phytotoxic substances from entering the root layer. To increase the efficiency of reclamation work at the biological stage, it is necessary to increase the thickness of the dumped layer from substrates suitable for reclamation.

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