Article

Parameters of Transition from Deepening Longitudinal to Continuous Lateral Surface Mining Methods to Decrease Environmental Damage in Coal Clusters

Alexey Selyukov [1], Sergey Zhironkin [1,2,3,*] and Magerram Gasanov [3]

[1] T.F. Gorbachev Kuzbass State Technical University, 28 Vesennya st., Kemerovo, Russia, sav.ormpi@kuzstu.ru; zhironkinsa@kuzstu.ru

[2] Siberian Federal University, Institute of Trade and Economy, 79 Svobodny av., Krasnoyarsk, Russia, szhironkin@sfu-kras.ru

[3] National Research Tomsk Polytechnic University, School of Core Engineering Education, 30 Lenina st., Tomsk, Russia, zhironkin@tpu.ru, maq@tpu.ru

* Correspondence: zhironkinsa@kuzstu.ru

Received: date; Accepted: date; Published: date

Abstract: The presented paper deals with an original way to reduce the environmental damage caused to land and air resources by surface coal mines with external dumping, due to transition to internal dumping with filling the worked out space of surface mine with overburden. The basic principle of the proposed idea is the transition from deepening longitudinal mining method for development of inclined and steep coal seam strata to lateral ones. This article substantiates the choice of technology for a block-and-layer continuous lateral mining method, including the construction of a first-stage pit, the use of a combined transport and direct dumping technology for moving overburden to an internal dump when mining blocks using draglines. The advantage of the presented technology, along with filling the internal capacity of the surface mine field with overburden, is the possibility of leveling the relief within the boundaries of the pit allotment and the implementation of reclamation as the mining front moves forward, without waiting for the dump to be completely filled in the boundary contours. Attention is also paid to economic benefits of block-layer technology of continuous lateral mining method, in transition to which the overburden transporting costs can be significantly reduced, while limitations of proposed method's implementation concern specific coal deposits that make up a small part of the fields being developed today by surface mining.

Keywords: direct dumping; surface coal mining; lateral mining method; land saving

1. Introduction

Coal mining is important globally for the development of modern industry and the information society, since it provides a cheap highly efficient and low-cost energy resource, easily transported to anywhere in the world. At the same time, the use of coal as an energy resource in the coming decades will be constrained by the environmental problems of its mining, mostly by surface mines – the high land consumption of surface mines and the irrevocable disturbance of a significant part of the used land.

The reduction of environmental damage in coal clusters with a predominance of surface mining is to expand the use of the lateral surface mining method – for both low-dipping and inclined (as well as steep) dipping strata. For this method, it is typical to place the overburden in the worked out space, in contrast to deepening longitudinal mining method, in which the overburden is transported to external dumps, and the surface mine field is constantly deepened and expanded [1].

Therefore, the main environmental advantage of the lateral mining method is its low land consumption – as a result of maintaining a constant size of the surface mine field and gradually filling it with overburden. As a result, the areas occupied by external dumps and open pits ("lunar landscape"), as well as dust emissions are reduced. Using draglines to move the overburden from the face zone to the dump zone (internal dump) allows reducing harmful gas emissions from the dump trucks and diesel fuel costs [2-3]. Barden et al., Beutner et al., Rodenberg et al. associate lateral surface mining method with cross-pit spreaders or cross-pit conveyors, moving the overburden to external (for inclined dipping strata) or internal (for low-dipping strata) dumps [4-6].

It is widely believed that the lateral mining method is applicable only for horizontal and low-dipping strata (0-30^0), since its main feature is the final pit depth equal to the depth of the seams [7-10]. Zhengao et al., Mishra et al. distinguish a narrower purpose of the lateral mining method – for low-dipping strata of high thickness. [11-12]

In turn, for surface mining of inclined and steeply dipping strata, deepening longitudinal mining method is recognized as basic, with the expansion of the boundaries of the surface mine field as coal seams are extracted and overburden is placed in external dumps occupying significant land areas [13-14].

Wide-spread but incomplete technological solution for reducing high land consumption of deepening longitudinal method of mining for steeply dipping strata is the adaptation of relief when filling external dumps in natural hollows, shallows, on slopes [15-16]. This makes it possible to partially smooth out disturbance to the relief and to some extent restore disturbed agricultural land, but it does not solve the problem of dust emissions from external dumps and disturbance of the water drains when they are located in lower relief zones.

The dominant opinion regarding the scope of lateral surface mining method with overburden moving by draglines to the internal dump is the development of low-dipping seams with the fip angle of strata less 30^0. However, the use of the deepening longitudinal mining method is dictated primarily by the desire to extract inclined and steeply dipping coal seams to the maximum possible depth [17]. This makes sense with high coal prices on the one hand, and a low concentration of surface mining in the cluster on the other. On the contrary, in conditions of low coal prices and the presence of closely located surface mine fields and dumps, it is necessary to provide for a transition from deepening longitudinal to continuous lateral surface mining methods, with the replacement of overburden external dumping with dump trucks by moving it to the internal dump with draglines, saving fuel component of transporting costs and reducing occupied land areas and dust emissions.

According to the official reporting, at present surface coal mines in Kuzbass (Western Siberia, Russia) amount to sixty, with annual capacity of 194 million tons. Of these, 65% carry out mining operations on inclined and steep coal deposits (strata) 18]. The continuous deepening mining method used in this case is characterized by maximum land intensity – a consequence of the constant expansion of the surface area of the pitas mining operations deepen, and the need to fill the external dumps, which also occupy significant land plots and are sources of dust. In 2019 in Kuzbass the land area occupied by external dumps of surface coal mines counted to 1500 million m^2 (up to 10% of the region's territory [19], the sample of spoiled land by overburden dumps is shown on Figure 1).

Figure 1. The view of external dumps of surface coal mines in Kuzbass.

At the same time, the majority of Kuzbass surface coal mines operate on the basis of project documentation, which contains outdated technological solutions dating back to the mid-half of the 20th century that did not consider the need to reduce land intensity, air and water pollution [20-22]. Therefore, at most existing Kuzbass surface mines, overburden is not dumped in the worked out space of the surface mine field. Meanwhile, the dumping of internal dumps will allow, on the one hand, to reduce the land area occupied by overburden, on the other hand, to reduce terrain disturbances and dust emission.

Technologically, the transition to the placement of dumps inside the surface mine field means the transition from deepening longitudinal to lateral continuous mining method, which is accompanied by the refinement of a number of spatial planning solutions that form the organizational mechanism for the mining method transformation [23-25].

It should be noted that the surface mining of inclined and steep coal seams strata within the lateral mining method is complicated with the inevitable establishment of a finite depth of the pit [26]. Therefore, a thorough technological justification for the transition from longitudinal deepening to lateral surface mining method is necessary, with the development of an approach to determining the possibilities and boundaries of its application.

2. Methods

The use of lateral mining method has its own specific features, which include the presence of strata of complex coal seams with strong enclosing rocks that require drilling and blasting to excavate them. The thickness of the coal-bearing strata of inclined and steep seams in the Kuzbass fields ranges from 200-2000 m, which makes it possible to use direct dumping technology at the lower horizons of the quarries [27]. Taking into account that with a lateral mining method, the length of the working front on the benches is much less, than with a traditional longitudinal mining method, the problem arises in ensuring the safety of surface mining in a limited space of the working zone of the surface mine. This requires an accurate calculation of the parameters of the first-stage pit, mining blocks and the internal dump.

With a small length of the working front on the benches of working area of the pit, there is a need for frequent driving of the excavator from bench to bench. Therefore, to reduce this negative factor, it is advisable to use maneuverable surface mining equipment. For the implementation of direct dumping technology in a limited space of lower horizon of the pit, a variant is possible in which the bench is worked out by a hydraulic backhoe, which carries out advance excavation of the coal seams, and overburden is excavated by a dragline located in the dump zone.

Taking into account the current provisions for the use of deepening longitudinal and continuous lateral mining methods, we have identified the following options for switching to the lateral mining method for the development of inclined and steep coal deposits:

1. Storage of overburden in a low-profile external dump at various stages of preparing the internal dump. This technological solution is aimed at positive transformation of mining allotment (creation of a horizontal site) into a useful landscape unit.
2. Designing "flexible" and combined surface mining methods with the identification of the stages and the procedure for working out the coal seams within the surface mine field with the interchangeability and sequence of application of longitudinal and lateral mining methods [28-29].
3. Adaptation of internal dumping technology to surface coal mining in the sites of closed mine on the basis of combined transport and direct dumping technology and a continuous lateral single-sided mining method.
4. The development of promising deposits with the division of the surface mine field into blocks with the extraction of a mining layer within each of them. In each layer, overburden removing is carried out according to transport technology with their delivery to the boundary between the face and dump sides, and further transshipment to the dump using direct dumping technology.

Each of these options is characterized by a certain amount of overburden placed in the internal dump and the possibility of using direct dumping technology at the lower horizons of the pit. These important indicators provide a significant increase in the efficiency of opencast mining. In general, to increase the efficiency of developing complex structural deposits with inclined and steep bedding of coal seams is possible with the use of new resource-saving development systems with lateral movement of the front of mining operations.

The following varieties of the surface coal mining system with lateral mining front movement are known: with the construction of the first-stage pit immediately to the design depth of the pit [30]; with phased immersion of mining operations to the design depth of the pit [31]; shuttle-layer mining of the surface mine field [32]; developing a surface mine field with longitudinal-and-lateral movement of the working front [33].

Taking into account the four above options, the general approach to the transition from a longitudinal mining method with external dumping to continuous lateral one with internal dumps and block-layer technology can be presented in the following form.

Firstly, the transition of the surface mine to a single-sided lateral mining method is designed with the creation of wide excavation stopes (panels) without the use of elements of the longitudinal system. In the process of developing promising solutions, it is necessary to provide for the minimization of the size of the first-stage pit and the accelerated formation of an internal multi-tier dump to the full depth of the pit according to the peripheral scheme with a minimum distance from the working side. A prerequisite for the transition to a lateral mining method is to give the slopes to the lateral working front on the benches – from the entrance to the pit to the opposite spoil side, which has horizontal berm for the delivery of overburden by the dump trucks to the internal dump. In the general case, the tiers of the dump may have a slope to provide access to the underlying benches of the working side through the horizontal transport berms of another spoil side.

Secondly, during the construction of the first-stage pit to the full depth of coal seam strata mining, overburden should be placed into an external dump, with the surface mine field divided into the bottom and dump parts. Subsequently, during the following development of the deposit, overburden is placed into the internal dump, while the face part of the surface mine field is worked out by inclined working ledges, the dump part of the field is formed by inclined dumping tiers. At the same time, the inclination of the working benches and dump tiers is performed in opposite directions, and the cargo transport connection between the working benches and the dump tiers is carried out along horizontal transport berms made in the direction along the deposit strike.

Thirdly, in the face part of the surface mine field, the working side is worked out by inclined benches. The mining front is developed across the strike of the coal seam, while the inclined working benches are cut at an angle so that the beginning and end of the working bench are located on adjacent horizons. This provides transport communication between them. At the same time, there is no need for the construction and constant transfer of sliding exits, and the dump tiers are formed in the dump part of the surface mine field at an angle. To create a transportation connection along the strike of a field between horizons of the same level, horizontal transport berms are being built. This minimizes the distance of overburden transportation from the face to the dump zone, since transportation is carried out along the shortest path.

Fourthly, it is necessary to maintain the working space of the pit unchanged throughout the life of the field. The movement of the face and dump zones of the surface mine should occur synchronously, since the overburden from the face side is laid in the dump part on the same horizon. With such organization of the lateral mining method, the need to divide the surface mine field into stages disappears, there is no fluctuation in the volumes of overburden and coal extraction over time from the moment the construction of the first-stage pit is completed until the end of mining operations and reclamation of the surface mine.

To substantiate the above-described approach, this article presents the author's concept of changing the surface mining method for inclined and steep coal seams.

The use of a block-and-layer continuous lateral mining method with combined transport and direct dumping technology consists in preliminary dividing the surface mine field into separate blocks that are developed sequentially. Morever, the development of the priority block is carried out according to a deepening longitudinal mining method with transport technology and moving its overburden volume to an external dump. Then the next block is worked out according to the same technology as the first one, but the overburden is transported to the worked out space from the first block. This variant of block technology is characterized by most of the drawbacks of traditional technology, in particular, the entire rock volume is placed in an internal dump using transport technology.

To modernize the block technolohy of surface mining, a block-and-layer technology of continuous mining method is proposed, characterized in that the construction of the first-stage pit, mining of the block and its horizontal layers is carried out according to the layered-areal technology, which ensures the extraction of all seams of the strata from its hanging side.

One of the most important elements of the lateral mining method is the first-stage pit, which creates the conditions for internal dumping. The first-stage pit is constructed according to the layered-areal transport technology, which consists in sequential field development in the boundary contours of the first-stage pit in horizontal layers (Figure 2).

It should be noted that if for the construction of the first-stage pit, as well as for excavation of coal, hydraulic backhoes are used, and then draglines are used for the direct dumping part of the formation of internal dumps.

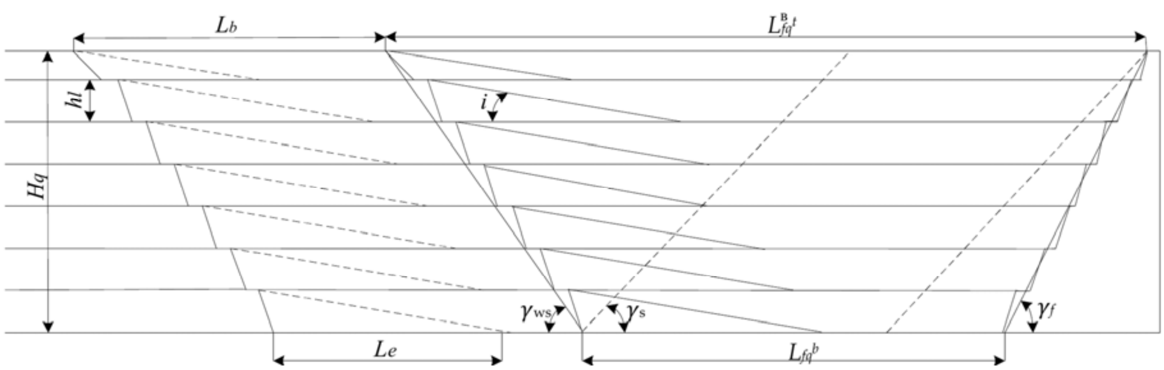

Figure 2. Scheme for calculating the parameters of the first-stage pitwith a block-and-layer continuous lateral mining method.

The parameters of the first-stage pit are determined in conjunction with the parameters of mining blocks. To display this relationship in Figure 2 the following notation is used:

L_{fq}^{b} – length of the first-stage pit along the bottom, m:

$$L_{fq}^{b} = L_{\mathrm{b}} - 0.5H_{\mathrm{q}} \times (ctg\gamma_{\mathrm{g}} - ctg\gamma_{\mathrm{f}}) = \frac{1000 \cdot h_{\mathrm{l}\times} K_{rd}}{i} - 0.5H_{\mathrm{q}} \times (ctg\gamma_{\mathrm{g}} - ctg\gamma_{\mathrm{f}}) \quad (1)$$

where: L_b - the length of the excavation block (determined by the height of the horizontal layer along the bedrock (h_l) and the elevation angle of the road (i, ‰):

$$L_{\mathrm{b}} = \frac{1000h_l \times K_{\mathrm{rd}}}{i} \quad (2)$$

K_{rd} – road development coefficient (1.2-1.3, depending on the width of the read);
H_q – designed pit depth, m;
γ_{w} – general slope angle of the working side of the internal dump, degrees
γ_f – the angle of finalization of the side of the pit, degrees.

L_e – exit length, m:

$$L_e = \frac{1000h_l}{i} \quad (3)$$

where: L_{fq}^{t} – length of the first-stage pit on top, m:

$$L_{\mathrm{fq}}^{\mathrm{t}} = L_{fq}^{p} + H_{\mathrm{q}}(ctg\gamma_{\mathrm{s}} - ctg\gamma_{ws}) \quad (4)$$

where: γ_{s} – slope angle of the side of the pit from the soil of the strata, degrees;
γ_{ws} – slope angle of the working side of the pit, degrees;

The layers are worked out in the block by a mining and transport complex, consisting of hydraulic backhoes and rope shovels in combination with the dump trucks. When switching to internal dumping, the block is mined using combined transport and direct dumping technologies. The rock from the worked layer moves under the slope of the block into the zone of dragline operation, which forms the tier of the internal dump with placing of the rock above the level of its standing, as well as part of the overburden that did not fit the capacity of the first tier is re-excavated to the upper dump tier by the dragline (Figure 3).

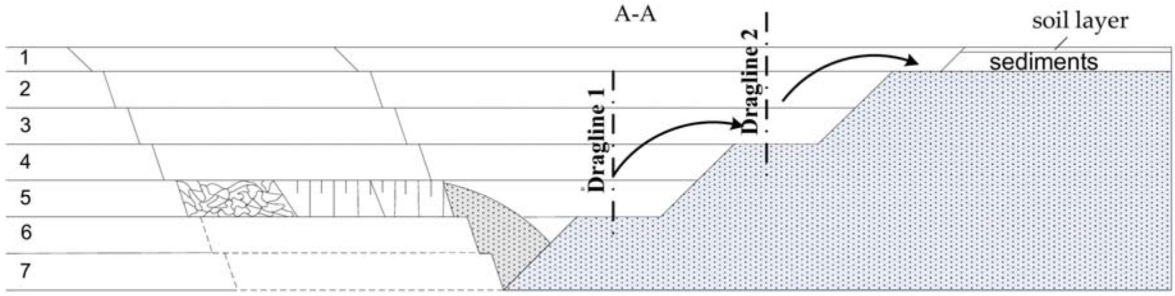

Figure 3. The longitudinal profile of the working area of the pit.

The numbers in Figure 3 are the layers' numbers in the blocks to be serially excavated. In this case, the cross section of the pit's working zone will be characterized by the width of the pit along the bottom and top, as well as the finalizing angles of the open pit sides (Figure 4).

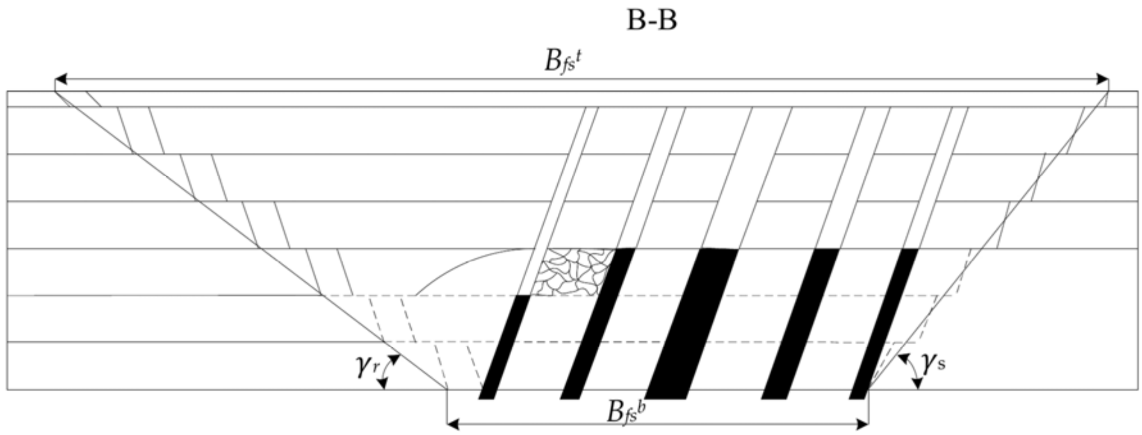

Figure 4. Cross section of the surface mine field.

Sections A-A and B-B in Figure 3 and 4 relate to the mining development plan (Figure 5) for the construction of the first-stage pit and the further development of the strata of steep coal seams according to a block-and-layer continuous lateral mining method (with filling of the worked out space by dumping internal dumps). The parameters of the mining method in the cross section include the following:

B_{fs}^b – the width of the first-stage pit along the bottom, m. Its maximum value is:

$$B_{fs}^b = \frac{M_{st}}{sin\alpha_{st}} \tag{5}$$

M_{st} – thickness of the coal seam strata;
α_{st} –average dip angle of the coal seam strata.

The working formula for calculating the width of the first-stage pit on top B_{fs}^t, m:

$$B_{fs}^t = B_{fs}^b + H_q(ctg\gamma_s - ctg\gamma_r) \tag{6}$$

where: γ_s – slope angle of the side of the pit from the soil of the strata, degrees;
γ_r – slope angle of the side of pit from the roof of the strata, degrees;

Taking into account that with a lateral mining method, the length of the front of work on benches is much less than for traditional longitudinal mining method, the problem arises in ensuring the safety and organization of mining in a limited space of the working zone of the section. Under these conditions, the use of direct dumping technology when working out the lower horizon of a surface mine field becomes difficult. To implement this possibility, it is necessary to fulfill the condition:

$$L_{front} = L_{\mathrm{s}}^{\mathrm{dbw}} + 2\mathrm{WP}_{\mathrm{dr}} + L_{\mathrm{bb}} + 2B_{\mathrm{tr}} \tag{7}$$

L_{front} – length of the working front on the lower horizon, m;
L^{s}_{dbw} – safe distance according to the conditions of drilling and blasting (minimum 300 m), m;
WP_{dr} – width of the platform for dragline, m;
B_{tr} – width of transport berm, m;
L_{bb} – blasted block length, m.

The length of mining front on the lower horizon depends on the capacity of thickness of coal seams strata, the boundary stripping ratio, the coal content of strata, the balance reserves of seams, the number of seams accepted for mining with the formation of a single common horizon.

When mining a coal seams strata of complex structure and occurrence, the length of working front on the lower horizon becomes equal to the maximum width of the first-stage pit along the bottom (B_{fs}^{b}) (5).

When mining part of the strata, the length of the pit at the lower horizon decreases. Thus, the possibility of direct dumping technology is excluded with $L_{front} \leq (L_{\mathrm{s}}^{\mathrm{dbw}} + 2\mathrm{WP}_{\mathrm{dr}} + L_{\mathrm{bb}} + 2B_{\mathrm{tr}})$. So when using dragline ESh 11.75 (made in Russia, bucket capacity – 11 m^3, boom length – 75 m), the minimum length of working front on the lower horizon will be 620 m. The thickness of the coal-bearing strata of inclined and steep deposits in Kuzbass surface mine fields exceeds 250 m, which makes it possible to use direct dumping technology at the lower horizons of the section.

The development of layers of the first-stage pit is carried out by hydraulic backhoes in complex in dump trucks. Fertile and potentially fertile layers (sediments) are separately stored on board the first-stage pit. Then they proceed to the development of bedrock (after drilling and blasting) with the extraction of coal in the first-stage pit (which is shown on Figure 5). Subsequently, the fertile and potentially fertile soil layer is restored on the dump part of the pit (internal dumps in the lower part of Figure 5). As the working front progresses, the opening of the benches is carried out by sliding exits in the barren of coal zone (left side of Figure 5).

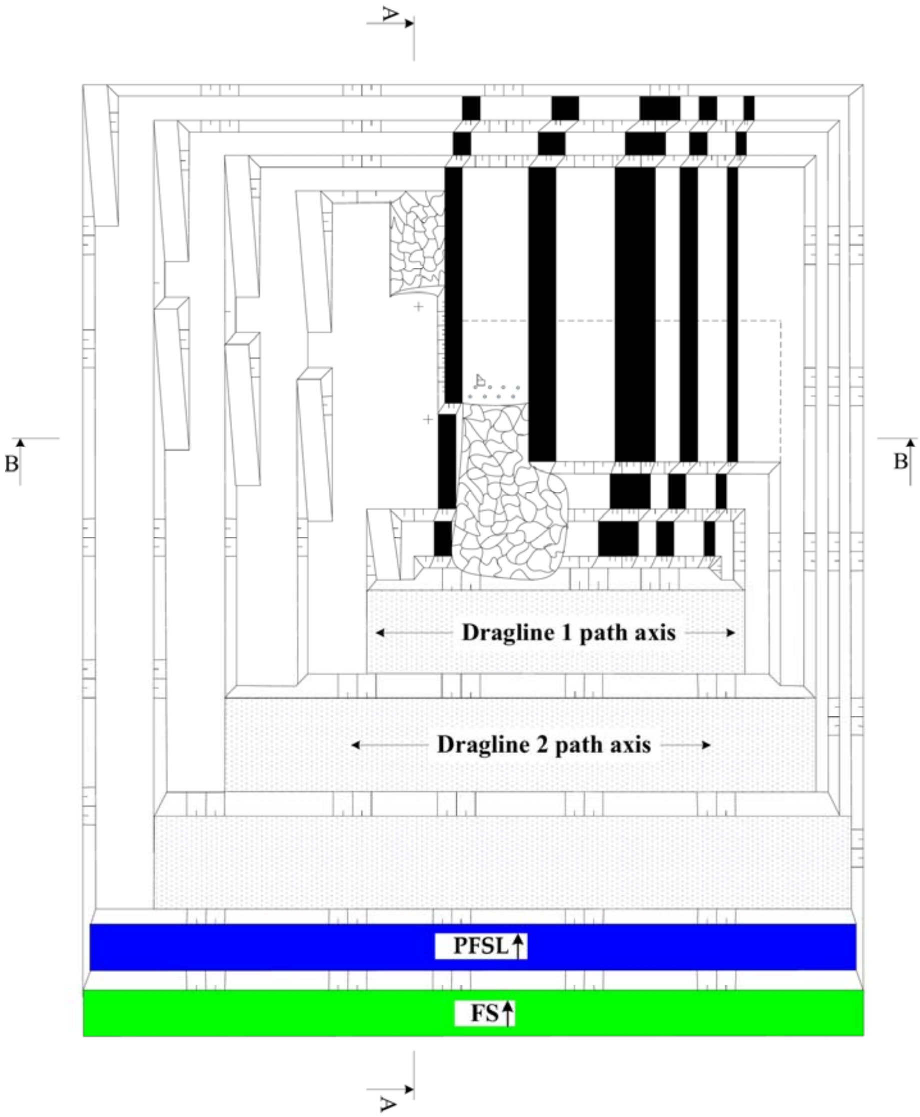

Figure 5. The scheme of a block-and-layer mining method with layered-areal combined transport and direct dumping technology (PFSL – potentially fertile layer; SL – soil layer).

Hydraulic backhoe moves from the exposed flank of the stope to the opposite one, across the strike of the coal seam strata [34]. The overburden is transported to temporary external dump formed on the pit side through a trench worked through the sediments, and the coal is delivered in a similar way to the places of its processing and storage. After working one stope over its entire length, equal to the cross section of the coal seam strata, surface mining is deepened while the mining cycle is repeated. Thus, work is ongoing to the final depth of the surface mine.

After completion of the construction of the first stage-pit, the remaining part of the surface mine field is mined in blocks along the lateral continuous mining method. Following the advancement of the working front, reclamation is being carried out.

The advantages of presented in Figures 3-5 technological scheme of a block-and-layer lateral mining method are that it does not have operational losses of coal, since exits do not cross the seams, so the additional losses can be avoided. Also, when stripping the surface mine field with sliding exits, there are no additional violations of the earth's surface, since the exits are initiated taking into account the fact that the working front approaches from the hanging side of the coal seams strata.

The use of lateral mining method in the conditions of Kuzbass has its own specific features, which include the presence of strata of complex coal seams with strong enclosing rocks that require drilling and blasting to prepare them for excavation.

A feature of the technology in the lateral development of working front during mining of coal deposits is the presence of horizontal base of the dump and lateral planes from undisturbed array. Moreover, the width of the base of dump is equal to the width of the bottom of pit, and the width of dump at the level of surface corresponds to the width of pit on top. Thus, the internal dump is formed in a clamped environment. The filling of the dump is done in tiers, i.e. dumping is carried out by draglines on all tiers of internal dump (Figure 6).

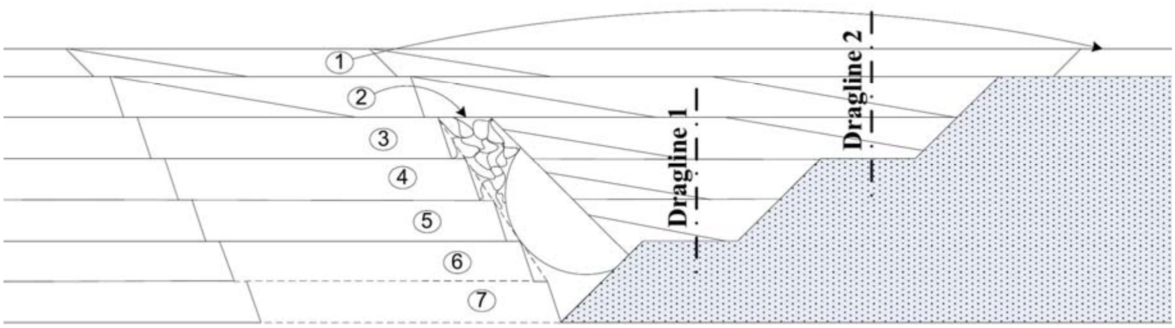

Figure 6. The scheme of excavation of overburden from the layer to the internal dump.

To determine the parameters of the internal dump, a rigid relationship should be adopted between the volume of overburden rock in the face zone and the capacity of internal dump, i.e. the capacity of internal dragline-made dump is equal to the product of the volume of overburden rocks in the face side of the surface mine field and the rock loosening coefficient. In this case, the volume of overburden and coal in the face zone (*V*) is, m^3:

$$V = H_{\mathrm{q}} \times \left[B_{fs}^{b} + 0.5(ctg\gamma_{\mathrm{s}} - ctg\gamma_{r})\right] \times L_{front} \quad (8)$$

Hq – face zone height (design pit depth), m.

The volume of coal (*Vc*) in the face zone (m^3), is equal to:

$$V_{\mathrm{c}} = H_{\mathrm{q}} \times B_{fs}^{b} \times K_{\mathrm{cb}\times}L_{front} \quad (9)$$

K_{cb} –coal-bearing coefficient (the ratio of the total normal thicknesses of coal seams to the normal thickness of the strata).

The volume of overburden, taking into account technological coal losses, transferred to the internal dump, is equal to:

$$V_o = V - V_c(1 - K_l) \tag{10}$$

where: K_l – coal losses coefficient (at the Kuzbass surface coal mines, for inclined and steep seams with a thickness of individual seams of 5-25 m: K_l = 0.03-0.05).

Direct dumping of an internal dump with a continuous lateral mining method also has its own characteristics. The base of the dump is a horizontal plane, which provides it with good stability. The analysis of geological and mining conditions of surface coal mining of inclined and steep seams in Kuzbass showed a relatively small length of the internal dump along the bottom of the pit – within 100-900 m. Therefore, the internal dump is formed in the worked out space, limited on the flanks by the sides of the pit, which with a short dumping front contributes to its stability (Figure 7).

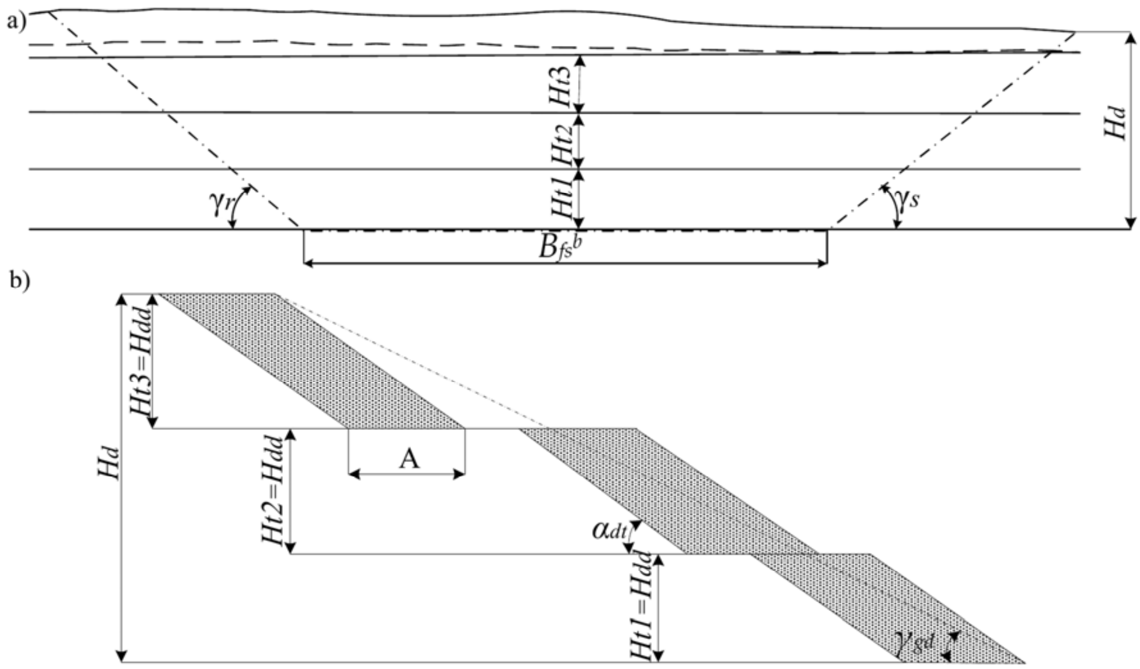

Figure 7. Schemes of the internal dragline-made dump: a - front view, b - cross section.

In Figure 7 the following designations are accepted: H_d – the height of the dragline-made dump; H_t1, H_t2, H_t3 – heights of dragline-made dump stages; *A* is the width of the dump stope; H_{dd} – dragline discharge height; γ_{gd} – general slope angle of the dump; α_{dt} – the slop angle of the dump tire. Applying the methodology of mining and geometric analysis of internal dumps, developed by Kuzbass researchers in international cooperation [25, 27], we get:

$$H_o = \frac{\sqrt{{B_{fs}^{b}}^{2} + 4R \times K_{loos}(H_q^2 \times R + H_q \times B_{fs}^{b} \times T} - B_{fs}^{b})}{2R} \tag{11}$$

To reduce the volume of formula (12), we take:

$$R = 0.5(tg\gamma_s + ctg\gamma_r) \text{ and } T = [1 - K_l \cdot (1 - K_l)] \tag{12}$$

where: K_{loos} – loosening rate of overburden in the dump.

Along with internal dumping with filling up the worked out space, the block lateral mining method presented in this article allows reclamation of internal dumps as they are being dumped.

Reclamation technology is carried out in the following sequence. Potentially fertile layer is poured after moving the dumping front to the surface of bedrock in the dumping tier, and the soil layer is laid on top of it and their addition is carried out in the following order.

The bulldozer moves the surface layer to the bulk, thereby forming it along the working front, which then develops a wheel loader for trucks with transportation to the surface of the internal dump (shown in figure by the arrow). At the same time, a potentially fertile layer is developed at its full thickness by a shovel with transportation by trucks to the surface of bedrock. Storing this layers on the surface is carried out similarly and in the following sequence. The dump truck is unloaded perpendicularly to the edge line of the slope of dump, forming a series of small rock piles, which are then moved and dumped under the slope by a bulldozer.

Reclamation is carried out after the advancement of the overburden and mining front works. After mining the surface mine field, the residual pit is filled with rocks of the external dump formed during the construction of the first-stage pit with the subsequent application of a potentially fertile layer of rocks and a fertile layer.

3. Results

As it was mentioned above, the use of a block-layer technology in lateral surface mining method for the development of an inclined and steeply dipping coal seams, proposed by the authors, can significantly reduce the land area occupied by a surface mine field and overburden dumps, change the more expensive rock transporting by dump trucks to its rehandling by draglines. In the present paper, the main parameters of mining methods (dimensions of blocks and mine workings, linear dimensions of the surface mine field, areas occupied by surface workings and an external dump, volumes of rock mass and overburden) are evaluated. The results obtained made it possible to compare the impact of the application of deepening longitudinal and continuous lateral surface mining methods on the environment – by the area of land occupied by the external dump, its height and dust emission. A comparison was also made of the deepening longitudinal and continuous lateral mining methods for inclined and steeply dipping coal seams in terms of overburden transporting costs.

3.1 Results of block parameters calculation.

The essential elements of the block-layer technology of continuous lateral surface method of mining of inclined and steeply dipping coal seams are the length and height of developed block L_b, length of the exit L_e.

Based on the calculations according to formulas (1-4), the nomogram that allows determining the block length, based on the parameters of the coal seam strata (dip angle, coal-bearing capacity, thickness), pit depth and annual capacity of the pit was built. The nomogram is shown in Figure 7, built on the basis of author's calculations.

The nomogram in Figure 8 is intended to choose the length of block L_b depending on the annual production capacity of the pit, the average dip angle of strata, the coal-bearing coefficient K_{cb} (the ratio of the total normal thickness of coal seams to the normal thickness of strata), the design depth of pit.

To determine the length of block L_b, the following procedure is used:

A) The value of the annual capacity of surface mine on the corresponding axis is projected onto one of the lines of the series of average dip angle of strata (the left part of the figure);

B) The obtained value is projected onto a line from the series of coal-bearing coefficient of strata (the left part of the figure);

C) The obtained value is projected onto a line from the series of thickness of coal seam strata (right side of the figure);

D) The obtained value is projected onto a line from the series of designed pit depth, and then is projected onto the axis of length of the block (right side of the figure).

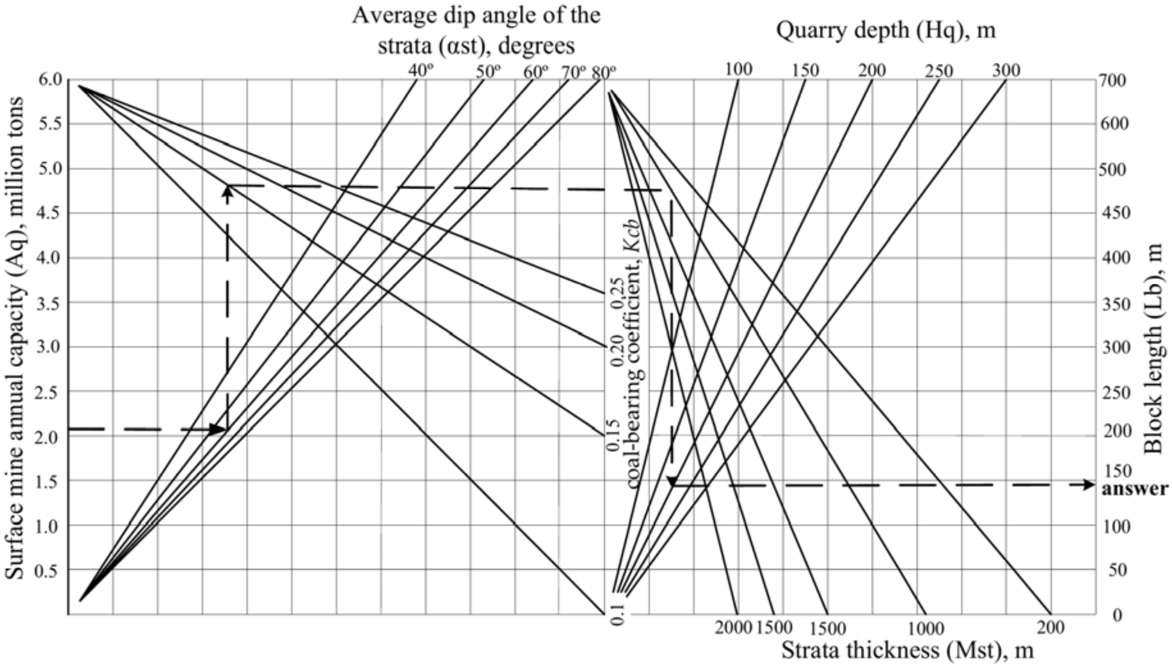

Figure 8. A nomogram of the interdependence of block and pit parameters.

As an example the Figure 8 shows the projection diagram for a surface mine with annual capacity of 2.0 million tons, which, with an average dip angle of the coal seams strata of 60%, coal-bearing coefficient of 0.15, a total thickness of the strata of 1000 m and the pit depth of 200 m, corresponds to a block length of 150 m.

To calculate the length of the exit L_e using formula (3) the layer's height h_l was defined in relation to the digging parameters of backhoes. For backhoes with bucket volume of 5-8 m^3 (Hitachi EX-1200, Caterpillar 6015, etc.) the layer's height is 5 m, for 10-12 m^3 (Komatsu PC-2000, Hitachi EX-1900, Liebherr R 9150, etc.) – 10 m, for 15-18 m^3 (Komatsu PC-3000, Hitachi EX-2600, Liebherr R 9350, etc.) – 15 m, for backhoes with bucket of 18-20 m^3 (Liebherr R 9400/R 9400 E, etc.) – 20 m. The results of the length of the exit calculation are shown in Table 1.

Table 1. Length of the exit L_e for different layer's height h_l and backhoe's bucket volume

L_e [m]	h_l [m]	Backhoe bucket volume [m^3]
80	5	5-8
100	10	10-12
120	15	15-18
140	20	18-20

3.2 Results of the calculation of the first-stage pit *parameters.*

The values of the parameters of the first-stage pit – linear (length of the bottom L_{fq}^b and of the top L_{fq}^t in relation with the block length L_b, width along the bottom B_{fs}^b and along the top B_{fs}^t) were obtained using formulas (1, 4, 5, 6) for different the dip angle of the coal seams strata a_{st}. The value of coal-bearing coefficient is 0.25 – the common feature of Kuzbass coal seams strata.

The results of calculations of the linear parameters are shown on Figures 9-10.

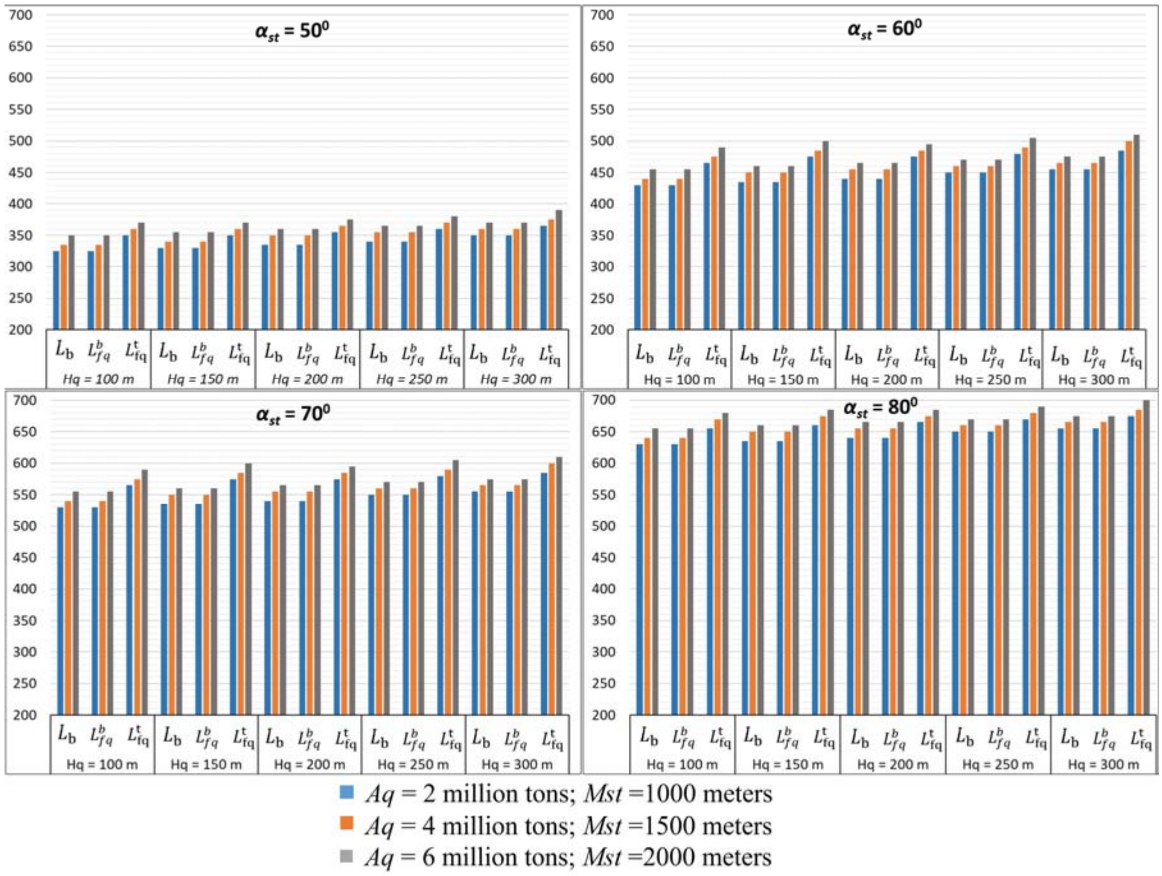

Figure 9. A family of diagrams of first-stage pit length L_{fq}^{b} (bottom) and L_{fq}^{t} (top) in accordance with strata dip angle a_{st}.

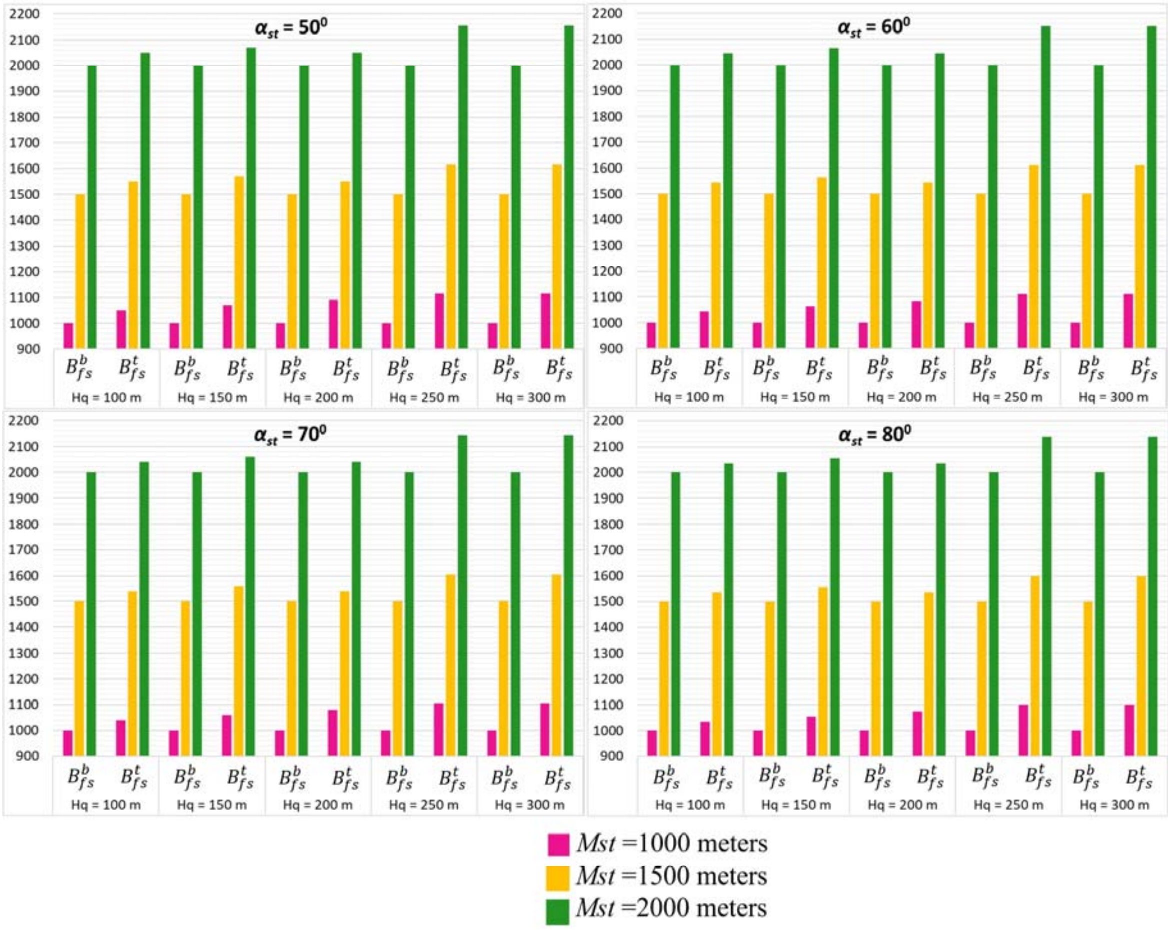

Figure 10. A family of diagrams of first-stage pit width B_{fs}^{b} (bottom) and B_{fs}^{t} (top) in accordance with strata dip angle a_{st}.

The values of the volumes of the whole rock mass in the surface mine field (V), coal (V_c) and overburden (V_o) separately are defined by formulas (8-10) according to the pit depth (H_q) and internal dump height (H_d). The results of calculations are shown in Table 2.

Table 2. The volume of the rock mass in the surface mine V, coal (V_c) and overburden placed in internal dump V_o, according to the pit depth H_q and dump height H_d

H_q [m]	H_d [m]	V [thousand m³]	V_c [thousand m³]	V_o [thousand m³]
100	100	126280	23820	102460
150	150	162640	40830	121810
200	200	207480	61360	146120
250	250	243260	82470	160790
300	300	288360	104620	183740

3.3 Results of comparison of the external dumping parameters and its influence on the environment for different mining methods.

For calculating the external dumping parameters, the following provisions were applied:

1. When comparing surface coal mining methods, it was assumed that the main source of disturbance to the terrain is external dumps, which also damages the environment by emitting large amounts of dust.

2. For the deepening longitudinal surface mining method, the entire overburden volume is moved to the external dump by dump trucks. The continuous lateral mining method, only part of the

overburden, usually the uppermost block, is moved to the external dump, which subsequently allows overburden storage in the internal dump.

3. To calculate the annual values of emissions of the rock dust from external dumps, the following indicators were taken: specific dust emissions taking into account the wind speed on the surface of the dump and the natural water cut of the field – 10-6 g / m^2 · sec; the number of dry windy days without snow in the year (in Kuzbass) – 96.

The results of comparing the parameters of external dumping and its environmental impact for deepening longitudinal and continuous lateral mining methods are shown in Figure 11.

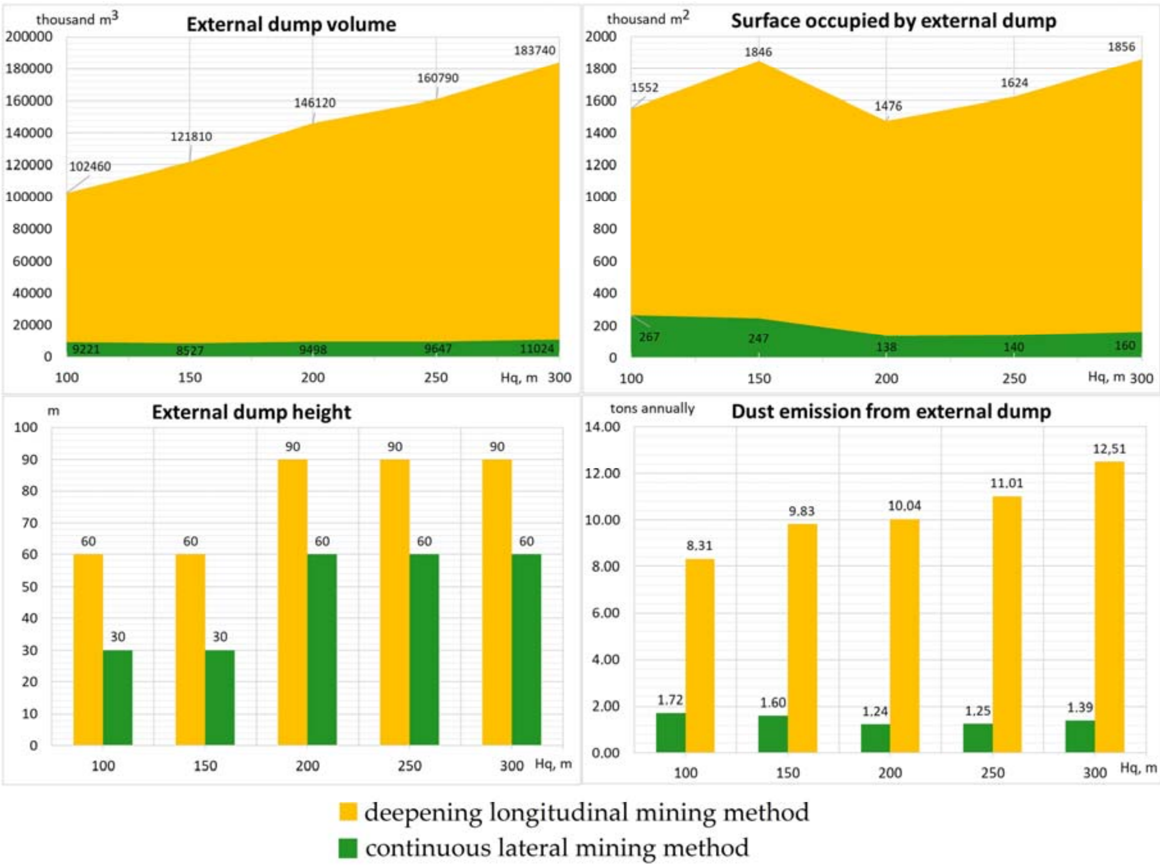

Figure 11. *Comparison of the external dumping parameters and its influence on the environment for deepening longitudinal and continuous lateral mining methods.*

3.4 Results of business indicators comparison for different mining methods.

To compare the influence of transition from deepening longitudinal to continuous lateral surface mining methods on such business indicators, as the expenses of overburden transporting, , the following intermediate parameters for the organization of surface mining were determined.

Firstly, the amount of equipment for moving overburden to the external dump (dump trucks) and internal dump (draglines), based on the volume of overburden depending on the annual coal production, the average stripping ratio at Kuzbass surface mines (depending on the depth of the pit) and equipment productivity. For the calculations, we used the following models of equipment that are widely used in the Kuzbass surface mines:

1. Dump trucks (for both deepening longitudinal and continuous lateral mining methods):

a) for annual surface mine capacity of 2 million tons of coal – Komatsu HD1500-8 (carrying capacity – 172 tons or 92 m^3, annual productivity – 2643280 m^3, fuel consumption rate – 1070 liters per 12 hours shift);

b) for annual surface mine capacity of 4 million tons – Komatsu 730E-8 (carrying capacity – 186 tons or 111 m^3, annual productivity – 3445935 m^3, fuel consumption rate – 1330 liters per shift);

c) for annual surface mine capacity of 6 million tons – Komatsu 830E-AC (carrying capacity – 221 tons or 147 m^3, annual productivity – 4045782 m3, fuel consumption rate – 1521 liters per shift).

2. Draglines (continuous lateral mining method):

a) for annual surface mine capacity of 2 million tons of coal – ESH-11.75 (made in Russia, bucket volume – 11 m^3, boom length – 75 m, annual productivity – 2741324 m^3, specific power consumption – 1.8 kWh/m^3;

b) for annual surface mine capacity of 4 million tons – ESH-20.90 (bucket volume – 20 m^3, boom length – 90 m, annual productivity – 4087065 m^3, specific power consumption – 2.2 kWh/m^3);

c) for annual surface mine capacity of 6 million tons – ESH-25.90 (bucket volume – 25 m^3, boom length – 90 m, annual productivity – 5108832 m^3, specific power consumption – 2.4 kWh/m^3).

Comparison of equipment number for deepening longitudinal and continuous lateral mining methods is shown in Table 3.

Table 3. The number of draglines (DRG) and dump trucks (DT) used for overburden transporting, in accordance with selected mining method, pit depth (H_q) and annual capacity (A_q, thousand tons)

A_q [thous. t]	H_q = 100 [m]		H_q = 150 [m]		H_q = 200 [m]		H_q = 250 [m]		H_q = 300 [m]	
	DRG	DT	DRG	DT	DRG	DT	DRG	DT	DRG	DT
Deepening longitudinal mining method										
2000	0	5	0	5	0	6	0	6	0	7
4000	0	6	0	8	0	9	0	10	0	10
6000	0	8	0	10	0	12	0	12	0	13
Continuous lateral mining method										
2000	3	1	3	1	4	1	5	1	5	1
4000	4	1	5	1	6	1	6	1	7	1
6000	5	1	6	1	7	1	8	1	11	1

To define diesel fuel consumption, the average distance to external dump was taken as 3.5 km. Comparison of diesel fuel and electricity power consumption for overburden transportation for deepening longitudinal and continuous lateral mining methods is shown in Table 4.

Table 4. Diesel fuel (DF) and electricity power (EP) consumption for overburden transporting by dump trucks and draglines respectively, in accordance with selected mining method, pit depth (H_q) and annual capacity (A_q, thousand tons)

A_q	H_q = 100 [m]		H_q = 150 [m]		H_q = 200 [m]		H_q = 250 [m]		H_q = 300 [m]	
	DF [t]	EP [kW]	DF [t]	EP [kW]	DF [t]	EP [kW]	DF [t]	EP [kW]	DF [t]	EP [kW]
Deepening longitudinal mining method										
2000	3 852	0	3 905	0	4 546	0	4 896	0	5 129	0
4000	6 113	0	7 447	0	8 670	0	9 337	0	9 781	0
6000	8 932	0	10 881	0	12 66	0	13 642	0	14 29	0
Continuous lateral mining method										

2000	770	13 910	770	16 891	770	20 534	770	23 184	770	26 164
4000	957	34 372	957	41 738	957	50 740	957	57 288	957	64 653
6000	1 095	54 482	1 095	66 157	1 095	80 426	1 095	90 804	1 095	102 478

Comparison of the costs of diesel fuel and electricity power consumption for overburden transportation for deepening longitudinal and continuous lateral mining methods is shown in Table 5. The price of 1 ton of diesel fuel was taken as 307 USD, 1 kW of electricity power – 0.013 USD.

Table 5. Costs on overburden transporting (thousand USD): diesel fuel (DF) and electricity power (EP) consumption, in accordance with selected mining method, pit depth (H_q) and annual capacity (A_q, thousand tons)

A_q [thous. t]	**H_q = 100 [m]**		**H_q = 150 [m]**		**H_q = 200 [m]**		**H_q = 250 [m]**		**H_q = 300 [m]**	
	DF	**EP**	**DF**	**EP**	**DF**	**EP**	**DF**	**EP**	**DF**	**EP**
Deepening longitudinal mining method										
2000	1 172	0	1 189	0	1 384	0	1 490	0	1 561	0
4000	1 861	0	2 267	0	2 639	0	2 842	0	2 977	0
6000	2 719	0	3 312	0	3 855	0	4 152	0	4 350	0
Continuous lateral mining method										
2000	234	200	234	242	234	295	234	333	234	375
4000	291	493	291	599	291	728	291	822	291	928
6000	333	782	333	949	333	1 154	333	1 303	333	1 470

Comparison of the total costs of overburden transporting for deepening longitudinal and continuous lateral mining methods, depending of surface mine annual capacity, is shown on Figure 12.

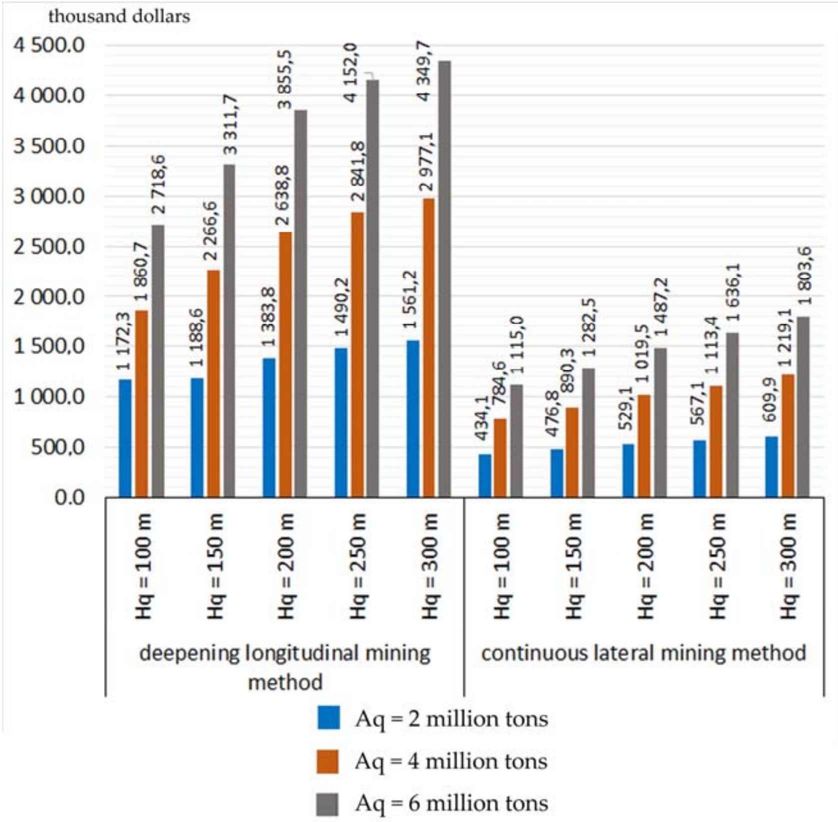

Figure 12. C*omparison of the total costs of overburden transporting for deepening longitudinal and continuous lateral mining methods.*

4. Discussion

When analyzing the first-stage pit parameters, the volumes of overburden placed in the dumps, the area of the land plots occupied by external dumps, it is obvious that continuous lateral mining method has many advantages of deepening longitudinal method in creating conditions of reducing environmental damage and transporting costs.

First, the linear dimensions of the surface mine field for the continuous lateral surface mining method are smaller than for the deepening longitudinal method. Therefore, the length of the first-stage pit along the bottom and top is almost equal to the length of the block being removed (Figure 9), while for the deepening longitudinal mining method it is in 2.5-3 times higher. Very important is a slower increase in the length of the surface mine field as the dip angle of strata increases. If for the continuous lateral surface mining method, the length of the pit for strata with the dip angle of 80% is 1.8 times higher than for strata with an angle of 50% (Figure 9), then for the deepening longitudinal method this difference is 3-3.5 times, based on mining geometric features.

The key difference between the linear dimensions of the surface mine field in the continuous lateral surface mining method from the deepening longitudinal one is a slight increase in its length and width depending on the increase in the pit depth (Figures 9 and 10). If, as the depth of the pit increases with the deepening longitudinal mining method, its length and width increase in 1.8-2.5 times, then for the lateral mining method, as follows from Figures 9 and 10, the increase does not exceed 10%.

As a result, the smaller size of the surface mine field in the continuous lateral surface mining method leads, firstly, to a smaller area of the land occupied by it, and secondly to a smaller amount of overburden placed in the dump. From the data presented in Table 2, it follows that with a three-fold increase in the depth of the pit (from 100 to 300 m), the overburden volume with the deepening longitudinal mining method increases by 1.8 times, whereas with the deepening longitudinal method this increase would be twice as much.

Secondly, along with smaller overburden volumes in the deepening longitudinal mining method, its placement is carried out mainly in the internal dump, the height of which can be equal to the depth of the pit (Table 2). In this case, only part of the overburden of the first blocks is placed in the external dump. Therefore, despite the inevitable dumping of the external dump, with the lateral mining method, its volumes are less than with the deepening longitudinal one, more than 10 times (Figure 11). Consequently, the land area occupied by the external dump with the continuous lateral surface mining method is 6–11 times less than with a longitudinal one. Along with this, the height of the external dump, determined by the dump slop stability conditions, is also 1.5-2 times less for the continuous lateral surface mining method than for the continuous lateral one – as a result of a smaller overburden volume laid in 1 or 2 tiers of 30 m in height.

It was found that the influence of the horizontal thickness of the strata (the width of pit bottom) on the height of internal dump is not significant. So, with an increase in the horizontal thickness of the strata by 100 m, the height of dump increases by 0.8%, moreover, for any values of the height of the face zone and the coal-bearing capacity of strata. On the contrary, the coal-bearing capacity of strata, characterized by respective coefficient, significantly affects the height of internal dump. An increase in coal-bearing capacity of strata by 10% leads to a decrease in the height of dump by 8%. For practical calculations when designing the technology, it is proposed to use the dependences of the dump height on the depth of pit and the coal-bearing coefficient, which determines the dumping of multi-tier dumps (up to 5 tiers) with a total height of not more than 200 m.

As a result, the smaller surface area of the external dump in the continuous lateral mining method leads to significantly less dust emission, in comparison with the deepening longitudinal method. The data in Figure 11 shows dust emission from an external dump with the lateral mining method in 5–9 times less than with the deepening longitudinal one. Moreover, as the pit depth increases from 100 to 300 m in the first case, dust emission remains almost constant, in the second case it increases by 1.4 times, reaching 12.5 tons per year for a surface mine with annual capacity of 6 million tons and an strata's dip angle of 80%.

Thus, the calculation results clearly indicate in favor of reducing environmental damage during the transition to the continuous lateral surface method of mining of coal seams of inclined and steeply dipping.

Thirdly, an economically continuous lateral mining method is also more advantageous than deepening longitudinal one, since its main technological difference is the movement of overburden by draglines into the internal dump. This means replacement the dump trucks with draglines, while the number of dump trucks with the deepening longitudinal mining method (5-13, depending on the annual capacity and depth of pit) is higher than the number of draglines with the continuous lateral mining method (3-11), due to the higher the productivity of the latter (Table 3). At the same time, despite the higher cost of selected draglines than dump trucks (in 2.5-3.5 times), the costs of their maintenance are much lower than dump trucks, and the service life (30 years or more) is significantly higher compared with dump trucks (7-9 years at maximum load).

Comparison of diesel fuel costs for dump trucks and electricity for draglines when moving overburden (Table 4 – physical measures, Table 5 – monetary estimates) indicates the advantage of the latter by 2.5-2.7 times, depending on the depth of the pit and its annual capacity. It is important to note that it is impossible to completely refuse the use of dump trucks in the continuous lateral method, since the removal of the overburden of the first blocks to an external dump is required. However, at the same time, one dump truck with the smallest carrying capacity (in our case, Komatsu HD1500-8, 172 t) is enough; the range of transportation of overburden to an external dump will also be minimal (less than 3.5 lm in our case).

As a result, the cost of overburden transporting with the continuous lateral surface mining method is 2.4-2.7 times lower than with the deepening longitudinal one (depending on the depth and annual capacity of the surface mine), as shown in the data in Figure 12.

Thus, there are environmental and economic advantages of the transition from deepening longitudinal to continuous lateral surface mining method, with the characteristic use of block extraction of rock mass for inclined and steeply dipping strata. The use of block-layer technology avoids the main limitation of the lateral mining method – applicability only for low-dipping strata.

At the same time, a number of limitations of the application of mining method presented in the article should be highlighted, connected with the special deposits for which the transition from deepening longitudinal to continuous lateral mining method is impractical:

1. Deposits of low-quality coal (high ash content and low calorific value), especially with seams of low average thickness (less than 5 m). It is highly probable that a change of the mining method for such deposits from deepening longitudinal to continuous lateral will critically decrease investment efficiency in replacement of dump trucks with draglines.

2. Coal deposits with a high density of tectonic disturbances leading to the presence of large zones barren of coal. In this case, a significant number of blocks in several layers will contain only overburden, the extraction of which will not be accompanied by coal mining. This will greatly complicate the placement of the internal dump in the worked out space.

3. Deposits of coal, before the completion of the development of which is less than 10 years. This is due to the need to build a first-stage pit for a continuous lateral mining method, which, together with reaching the maximum volume of coal production using block technology, can take up to 2/3 of this period.

4. Coal deposits in seismically active zones (more than 2 earthquakes with magnitudes more than 4 points on the Richter scale per year). This is due to the danger of violations of the tracks for the passage of draglines inside the surface mine field.

At the same time, these restrictions are associated with specific deposits, which make up a small part of the currently developed coal deposits by surface mining in the world.

4. Conclusions

When developing promising coal deposits in Kuzbass, tendencies were observed in increasing the share participation of the block order for mining surface mine fields, based on the use of a high-cost transport method of rock moving – both when preparing a container for an internal dump, and when working out a surface mine field with overburden storage in the worked out space. To reduce costs and improve the environmental efficiency of internal dumping, this article proposed a modernized solution based on combined transport and direct dumping technology and a block-layered mining procedure.

The construction of the first stage pit and its subsequent deepening in layers allows not expanding the surface mine field during the development of inclined and steeply deepening seams, but carrying out coal mining across their strike along the blocks, with overburden placement in the internal dump located at the place of extracted blocks. In this case, as coal is extracted, the first stage pit is transferred along the strike of the strata. This allows solving the main problem of the lateral mining method – the restrictions on the use of horizontal and inclined seams.

The transition from the deepening longitudinal to the continuous lateral surface mining method using block-layer technology can reduce the length of the surface mine field by 2.5-3 times, and significantly reduce the expansion in its area with increasing depth of the pit. The maximum effect is achieved by reducing the area of land occupied by external dumps (in 6–11 times, depending on the depth of the pit) and dust emissions (in 5–9 times). Along with this, the replacement of dump trucks with draglines for overburden moving during the transition to the continuous lateral surface mining method allows reducing the transporting costs up to 2.6 times. At the same time, the limitations of the method considered in the article affect a small part of the coal deposits mined today by the open way – mainly of low quality and high tectonic disturbance, as well as depleted and located in seismically active zones.

Author Contributions: Conceptualization, Selyukov A.; methodology, Zhironkin S.; validation, Gasanov M.; writing—original draft preparation, Zhironkin S.; writing—review and editing, Selyukov A. and Zhironkin S.; visualization, Gasanov M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Miliy, S.M. Evaluation of technology for development of inclined and steep coal deposits in Kuzbass. *Journal of Mining and Geotechnical Engineering* **2020**, 1, pp. 45-73 doi: 10.26730/2618-7434-2020-1-45-73
2. Tatiya, R.R. Surface and underground excavations: methods, techniques and equipment. CRC Press / Balkema. London. 2013. 904 p.
3. Czaplicki, J.M. Mining equipment and systems: theory and practice of exploitation and reliability. CRC Press. London. 2010. 285 p.
4. Barden, K.L., Files, T.I., Gilewicz, P.J. Cross-pit conveyor and end-around-conveyor continuous mining systems. *Mining Congress Journal* **1981**, 67(9), pp. 98-112
5. Beutner, D.H., Files, T.I., Surface mining method. Patent No. US 4290651. Dresser Industries Inc. 1981.
6. Rodenberg, J.E., Winzer, S.R., Nordin, D.J. Direct dumping mining systems – Application and economics. *International Journal of Surface Mining, Reclamation and Environment* **1988**, 2(4), pp. 41-54 DOI: 10.1080/09208118808944154
7. Mitra, R., Saydam, S. Surface Coal Mining Methods in Australia. In: Mining Methods, ed. by T. Onargan. InTech. Rijeka. 2012. pp. 3-22. DOI: 10.5772/39172

8. Kose, H., Pamukcu, C., Yalcin, E. Project design of an open pit colliery in Terkidag, Turkey. *Acta Montanistica Slovaca* **2010**, 15(2), pp. 109-120.
9. Cehlár, M., Cehlárová, I. Cut winnings methods of an open-pit mine development. *Acta Montanistica Slovaca* **2007**, 12(3), pp. 174-181
10. Kennedy, B.A. (Ed.) Surface Mining. 2nd Edition. Society for Mining, Metallurgy, and Exploration Inc. Littleton, Colorado. 2009. 1207 p.
11. Zhengao, Z.M., Li, L., Kemin, D., Xiaohua, X. Comparative study of mining methods for reserves beneath end slope in flat surface mines with ultra-thick coal seams. *International Journal of Mining Science and Technology* **2017**, 27, pp. 1065–1071
12. Mishra, P.C., Mohanty, M.K. System sequence of surface mining operation. *International Journal of Applied Systemic Studies* **2019**, 8(4), pp. 68-82. DOI: 10.1504/IJASS.2018.103768
13. Bullivant, D.A. Current Surface Mining Techniques. *Journal for the Transportation of Materials in Bulk: Bulk Solids Handling* **1987**, 7(6), pp. 827-833.
14. Harraz, H.Z. Mining Methods. Part I- Surface Mining. Tanta University, Tanta. 2011. 76 p. DOI: 10.13140/RG.2.1.1603.1600
15. Rowe, J.E. Coal Surface Mining. Impacts of Reclamation. New York. Routledge. 1980. 502 p.
16. Changsheng, J. Surface Coal Mining Methods in China. In: Mining Methods, ed. by T. Onargan. InTech. Rijeka. 2012. pp. 23-30. DOI: 10.5772/35061
17. Katsubin, A.V., Makridin E.V. Systematization of the technological schemes of excavator faces at the central Kuzbass open pit mines. *Journal of Mining and Geotechnical Engineering* **2018**, 1, pp. 81-88 doi: 10.26730/2618-7434-2018-1-81-88
18. Zhironkin, V., Janocko, J. Revitalization of coal brownfields in solving environmental problems and structural development of Kuzbass economy. *E3S Web of Conferences* **2019**, 134, 02002.
19. Lokhanov, B.N., Zakharov, Y.A., Bereznyak, M.M., Kalinin, A.V. Open-cut mines in the Kuzbass: pro-gress and prospects. *Soviet Mining* **1967**. 3(5), pp. 523–527.
20. Bereznyak, M.M., Kalinin, A.V., Pronoza, V.G. A method of calculating the width of the caved rubble in the transportless system of working a series of sloping beds. *Soviet Mining* **1970**, 6(6), pp. 638–643.
21. Belyakov, Yu.I., Boguslavskii, V.E., Skachkov, S.A. Evaluating the performance of mine power shovels with composite indicators. *Soviet Mining* **1985**, 21(2), pp. 165–167.
22. Scott, B., Ranjith, P.G., Choi, S.K., Manoj, K. A review on existing opencast coal mining methods with-in Australia. *Journal of Mining Science* **2010**, 46(3), pp. 280–297.
23. Prakash, A., Mallika, V., Murthy, S.R., Singh, K.B. Rock excavation using surface miners: an overview of some design and operational aspects. *International Journal of Mining Science and Technology* **2013**, 23(1), pp. 33–40.
24. Cheskidov, V.I., Norri, V.K., Sakantsev, G.G. Diversification of open pit coal mining with draglining. *Journal of Mining Science* **2014**, 50(4), pp. 690–695.
25. Gvozdkova, T., Markov, S., Demirel, N., Anyona, S. Modeling of Three Flat Coal Seams Strata Developing at Open Pit Miming. *E3S Web of Conferences* **2017**, 21, 010242.
26. Karpuz, C., Hindistan, M.A., Bozdag, T.A. New method for determining the depth of cut using power shovel monitoring. *Journal of Mining Science* **2001**, 37(1), pp. 85–94.
27. Tyulenev, M., Markov, S., Cehlar, M., Zhironkin, S., Gasanov, M. The model of direct dumping tech-nology implementation for open pit coal mining by high benches. *Acta Montanistica Slovaca* **2018**, 23(4), pp. 368-377.

28. Hummel, M. Comparison of existing open coal mining methods in some countries over the world and in Europe. *Journal of Mining Science* **2012**, 48(1), pp.146–153.
29. Lesin, Y.V., Luk'yanova, S.Y., Tyulenev, M.A. Formation of the composition and properties of dumps on the open-pit mines of Kuzbass. *IOP Conference Series: Materials Science and Engineering* **2015**, 91(1), 012093.
30. Kulakov, V.N. Geomechanical conditions of mining steep coal beds. *Journal of Mining Science* **1995**, 31(2), pp. 136–142.
31. Tanaino, A.S., Cheskidov, V.I. Substantiation of the sequence for opencast mining of a series of flat and inclined strata using the mined-out space for internal dumps. *Journal of Mining Science* **1999**, 35(3), pp. 304–313.
32. Kuznetsov, V.I., Mattis, A.R., Tashkinov, A.S., Vasil'ev, E.I., Zaytsev, G.D. Efficiency of excavation of overburden rock at quarries with the use of blast-free technology. *Journal of Mining Science* **1997**, 33(5), pp. 471–477.
33. Nazarov, I.V. Numerical modeling of overburden rehandling with draglines. *Journal of Mining Science* **2011**, 48(1), pp. 55–61.
34. Tyulenev, M., Litvin, O., Cehlár, M., Zhironkin, S., Gasanov, M. Estimation of hydraulic backhoes productivity for overburden removing at Kuzbass open pits. *Acta Montanistica Slovaca* **2017**, 22(3), pp. 296-302.