Mining of Mineral Deposits
Volume 16 (2022), Issue 4, 103-114

MMD JOURNAL / MINING.IN.UA

https://doi.org/10.33271/mining16.04.103

Research into the coal quality with a new selective mining technology of the waste rock accumulation in the mined-out area

Dmytro Malashkevych[1], Mykhailo Petlovanyi[1*], Kateryna Sai[1], Serhii Zubko[1]

[1] *Dnipro University of Technology, Dnipro, Ukraine*

**Corresponding author: e-mail petlyovanyi1986@gmail.com*

Abstract

Purpose. The research purpose is to study the formation of quantitative-qualitative indicators of mined coal under conditions of dynamic changes in space and time with a new stope mining technology with waste rock accumulation in the underground mined-out area.

Methods. The contours are formed for mining low-thickness coal reserves and extracting thicknesses, undercut rock volumes in the stoping and preparatory faces in the conditions of the Heroiiv Kosmosu mine. The average density values of coal, rock layers and wall rocks in the seam within the boundaries of mining contours are determined based on the geological data of wells and mining operations. The graphic basis is executed in the AutoCAD program. A digital spatial model of the C_{10}^{t} seam contours is used, according to the schedule for organizing stope and preparatory operations. The volumes of waste rocks and minerals involved in the formation of quantitative-qualitative rock mass indicators in a given time period are calculated.

Findings. It has been determined that during mining of coal reserves from the studied mining area (equal to extraction site), the volume of production and the operational coal ash content in the mining technology with waste rock accumulation averages 376.5 thousand tons and 15.2%, while with traditional technology – 621.3 thousand tons and 46.7%. Nevertheless, it has been proven that in terms of energy equivalent, the value of mined coal using the mining technology with waste rock accumulation is higher by 7.4% than the traditional technology (9.6 TJ versus 8.9 TJ).

Originality. For the first time, a mechanism for the formation of operational ash content and energy value of coal has been revealed when combining the processes of drifting operations to prepare reserves from new extraction pillars with associated stope operations into a new selective mining technology with waste rock accumulation in the mined-out area.

Practical implications. An algorithm for predicting the operational ash content and quality of coal when using selective mining technology with waste rock accumulation in the mined-out area has been developed, which is important for the technical and economic indicators of coal mines.

Keywords: *waste rocks, accumulation, operational ash content, stoping face, drifting face, selective mining*

1. Introduction

Given the rapidly evolving trends in the development of the decarbonization and green energy strategies, in recent years, the global hard coal market has seen a significant increase in demand and prices for it (almost by 2 times in 2021), which is caused by the need to ensure the necessary volume of electricity production in a number of powerful industrial countries [1], [2]. A significant role in the current situation was also played by the closure of large-scale coal-mining enterprises in a number of countries. However, the pace of implementation of “green” technologies in the world does not keep pace with the global economy, which today needs fossil fuel energy carriers in significant volumes [3]-[5]. Therefore, the importance of hard coal as a decisive source of energy for many countries, including Ukraine, is currently a priority.

As a result of minerals mined from the bowels, underground cavities are formed, contributing to subsidence and destructive deformations of the earth’s surface [6], [7]. At the same time, the technological mining processes are characterized by significant waste generation, the consequences of which are the alienation of significant land areas of the daylight surface for stockpiling of mine waste rocks and beneficiation waste [8], [9]. In order to reduce the negative phenomena of underground mining, the methods of mining minerals with the use of backfilling the mined-out area have become widespread in the global mining practice. The purpose of this technology is to preserve the integrity of the earth’s surface and infrastructure facilities, as well as to utilize large-tonnage industrial waste accumulations [10], [11]. For example, in the mining of ore deposits, paste and uncemented rockfilling has become widespread [12]-[14], and in coal deposits – mechanical rock and paste backfilling has become widespread [15]-[17]. However, in the conditions of coal deposits in Ukraine, the backfilling of mined-out area has not become widespread, which has led to a deterioration in the environmental situation in the mining regions.

In Ukraine, the main hard coal reserves (> 70%) are concentrated in seams with a geological thickness of less than

Received: 15 June 2022. Accepted: 5 December 2022. Available online: 30 December 2022

Mining of Mineral Deposits. ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print)

1.0 m, which gradually causes significant economic difficulties in their mining, and leads to the gradual involvement of thinner seams in mining [18]-[20]. These seams today can be mined using the following technologies: the traditional method using mechanized complexes [21], [22], underground gasification [23]-[25] or augering method [26], [27].

In the Western Donbass, the most important coal-mining region of Ukraine, thin coal seams with a thickness of 0.75-1.0 m are currently mined by complex-mechanized longwall faces with undercutting of the wall rocks, which leads to a significant deterioration in the mined coal quality, an increase in the ash content level of the mined coal up to 40-50% [28]. As a result, there is a need for a technological beneficiation cycle. In addition, the coal industry is characterized by significant waste generation in the form of stockpiling of millions of tons of waste rock and beneficiation tailings on the daylight surface, which causes significant environmental damage.

To date, the existing technologies for mining thin coal seam in the conditions of Ukrainian mines need to be radically improved and transformed from the standpoint of global efficiency and environmental friendliness of thermal coal mining in order to achieve the quality of the mined coal products and complete waste rock accumulation in the mined-out area. Reducing the cost of coal production by creating a low-waste mining cycle, eliminating the need for coal beneficiation and substantially improving its quality will create conditions for increasing the coal industry's importance for the Ukrainian economy. This will make it economically more profitable to mine our own Ukrainian coal and eliminate the need for its import supplies from the USA, South Africa and other countries. Recent scientific and technological developments aimed at reducing the generation of waste by leaving it in the underground space have not yet been widely used due to the complexity of technological processes or the low level of waste rock utilization [29]-[32].

Thus, for the conditions of coal mines in the Western Donbass, the development of a new technology for mining coal seams with waste rock accumulation in the mined-out area is very relevant today, as it will exclude the delivery of waste rocks to the daylight surface and improve the mined coal quality. Given the significant relevance, for the first time a new coal-mining technology with waste rock accumulation in the mined-out area for the conditions of coal mining from thin seams has been developed, but the final quality of the mined coal is still unknown. The most important quality indicator of the mined thermal coal is its operational ash content and energy value, which determines the consumer and commodity price [33]-[35].

In this regard, using the example of one of the Western Donbass coal mines, an analytical research on the quality formation of coal mined from stoping and preparatory faces has been conducted for comparing two technologies – the traditional one used at the enterprise and the technology with waste rock accumulation in the mined-out area.

2. Elements of compared technologies for thin coal seam mining

To perform analytical research, it is necessary to form an idea about the research objects – different technologies of coal seam mining to determine the mined coal quality.

Traditional mining technology. In the conditions of the Western Donbass mines, the longwall mining technology with the following elements is used [36], [37]. The planned mine field extraction site is preliminarily delineated by extraction workings – a ventilation (boundary) drift, conveyor (prefabricated) drift and a mounting chamber where the mechanized complex will be located. Mining is performed by removing the mining strip from one drift to another using a shearer. The coal broken off from the mass, together with the bottom rocks (bulk mining), is transported by a scraper conveyor to the conveyor drift, where it is reloaded onto a belt conveyor and then fully conveyed to the surface. Usually, the geological seam thickness is less than the extracting thickness, and therefore, the rocks of the coal seam bottom are undercut using a shearer-loader. The roof in the stoping face is controlled by the complete caving of rocks. One of the extraction drifts is reused for mining a new mine field. With the start of stope operations in the longwall face, according to the conditions for timely planning of the preparation of an adjacent new extraction site, drifting operations begin with the extraction drift and the mounting chamber.

During the functioning of the above-mentioned technology, mine waste rocks from mine workings and stope operations (coal dilution with rocks from the bottom undercutting) are transported together with coal through a single transport line to the daylight surface and are stockpiled in dumps. Panel layout of existing traditional mining technology is illustrated in Figure 1.

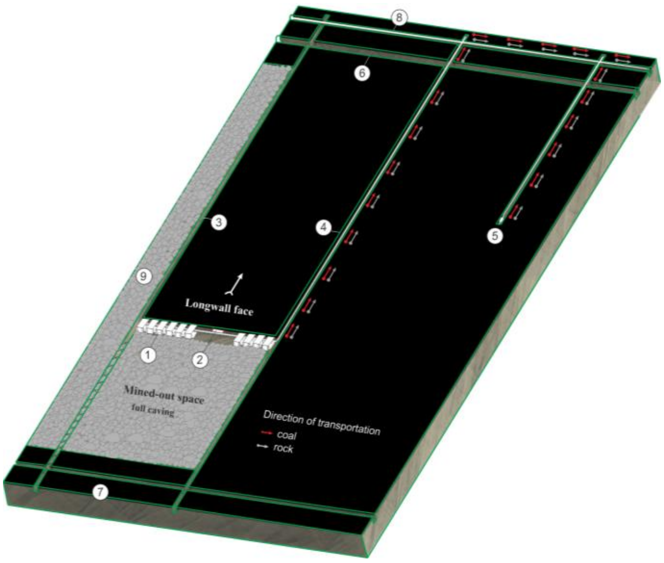

Figure 1. Panel layout of existing traditional mining technology: 1 – mechanized roof support; 2 – shearer; 3 – ventilation drift; 4 – conveyor drift; 5 – drivage of conveyor drift; 6 – main haulage drift; 7 – main drainage drift; 8 – main conveyor drift

A new selective mining technology with accumulation of mine waste rocks. The mining technology with waste rock accumulation is based on the principle of selective mining of minerals from stoping and drifting faces, when the coal seam is mined first, and then the waste rock is removed [38], [39].

The new technology includes the preparation of an extraction site of paired longwall faces with selective mining of coal and rocks. In this case, the waste rock accumulation is performed by backfilling it in the mined-out area of the longwall faces and abandoned mine working, taking into account the rock volume from preparatory mine workings and undercut rocks from the longwall face. In the process of preparing the extraction site, paired longwall faces are formed with a central accumulating rock drift and two conveyor (prefabricated) drifts. The longwall faces are mined simultaneously with a straight-line front. At the same time, in one of the paired longwall faces, selective mining of coal with transportation to the conveyor drift is conducted, and in the adjacent one, selective mining of undercut rocks with transportation to the central accumulating drift is conducted, followed by sequential backfilling of the mined-out area. When mining coal in the first longwall face, the mined-out area is simultaneously backfilled with rock supplied from the adjacent longwall face. Then, in the adjacent longwall face, coal is mined with backfilling, using the rock coming from the first longwall face in one continuous technological process, and then the formation of subsequent paired longwall faces with complete backfilling of the mined-out area. With the start of stope operations in paired longwall faces, according to the conditions for timely planning of the preparation of an adjacent new extraction site, drifting operations begin with two conveyor drifts, and then two mounting chambers.

The peculiarity and difference of the new technology is the combination of the processes of drifting operations for preparing the reserves from new extraction sites with adjacent stope operations in paired longwall faces through an innovative rock-transport and rock-backfill chain. The latter is able to place all formed mine waste rocks of the system in the mined-out area of longwall faces and mine workings, thereby preventing their delivery and stockpiling on the daylight surface.

During the functioning of the above-mentioned technology, mine waste rocks from mine workings and stope operations are accumulated in the mined-out area without their delivery to the daylight surface. Panel layout of a new selective mining technology with accumulation of mine waste rocks is illustrated in Figure 2.

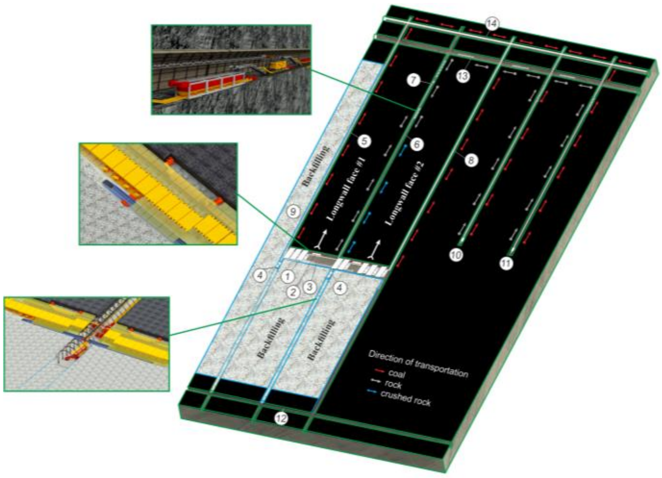

Figure 2. Panel layout of a new selective mining technology with accumulation of mine waste rocks: 1 – machanized backfilling support; 2 – shearer; 3 – backfilling modular conveyor; 4, 5, 8 – transportation drift; 6 – central accumulation rock drift; 7 – rock crushed equipment; 9 – rock backfilling massif; 10 – drivage of a central accumulating rock drift; 11 – drivage of a transportation drift; 12 – drainage drift; 13 – main haulage drift; 14 – main conveyor drift

3. Research methods

3.1. Initial data for conducting research

An analysis of information on the planning and production activities of the Western Donbass mines shows that the highest operational ash content among coal mining enterprises in the region is observed at the Heroiiv Kosmosu mine of PJSC "DTEK Pavlohradvuhillia", which, according to the results of 2021, amounted to 52.4%. At the same time, it should be noted that at present the mine is mining 4 coal seams C_5, C_9, C_{10}^t and C_{11}, the parent ash content of which does not exceed 14%, and the geological thickness within the contours of the extraction pillars of active longwall faces varies within 0.61-0.98 m. In addition, mining operations are characterized by a high level of concentration of stope and preparatory operations, which is of particular interest for this research. Then, the mined coal quality is studied in the conditions of the specified Heroiiv Kosmosu mine with different mining technologies – existing traditional and new ones.

The C_{10}^t seam mining site, selected for research and located in the western wing of the mine field at the Heroiiv Kosmosu mine, is shown on a excerpt from the plan of mining operations (Fig. 3). The 1070 and 1072 extraction pillars of the longwall face are studied in the research. As initial parameters in the development of a perspective calendar schedule for the organization of mining and preparing of extraction sites, the thickness, length of the longwall face and extraction pillar are taken. The research takes into account the actual situation of mining operations on the specified extraction pillars for the calendar year.

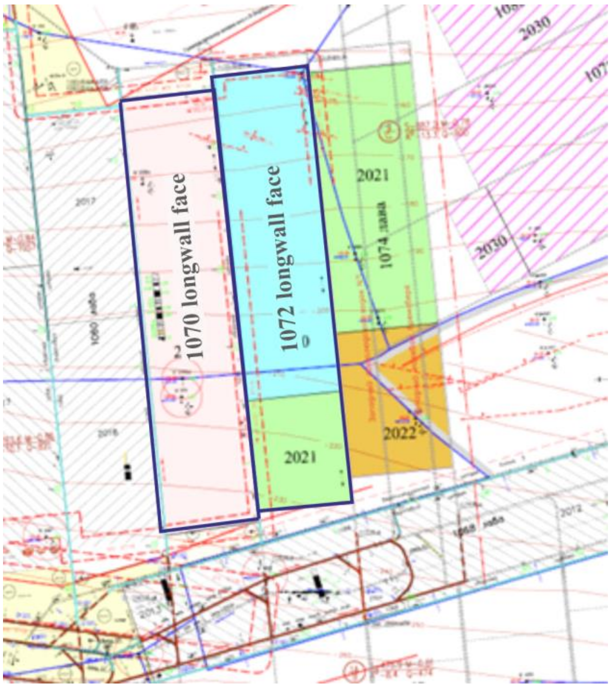

Figure 3. Mine field area selected for research on the plan of mining operations

For traditional technology, the longwall face length l_{lon} is taken as 250 m, and with selective technology of waste rock accumulation, the length of each paired longwall face is taken as 125 m. Thus, the total length of the front of stope operations in the area of paired longwall faces is equivalent to the length of the longwall face with traditional technology, which is more convenient for a qualitative comparison of these technologies. The extraction pillar length L_{pill} for both options is taken as 1200 m. Extracting seam thickness m_{exth} in the longwall faces for compared technologies is 1.05 m.

According to data of mining operations, within the boundaries of the contours, the C_{10}^t coal seam has a relatively consistent geological thickness, which varies within the range of 0.78-0.82 m. The cutting resistance of coal is A_r = 420 kN/m.

The seam inclination angle is 3-4º. The summary lithological column of the C_{10}^t coal seam is presented in Figure 4.

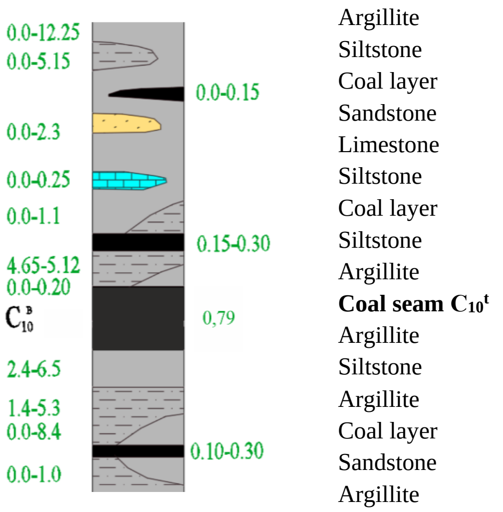

Figure 4. Structural column of the C_{10}^t coal seam within the boundaries of the studied mined-out contour of the extraction sites

The composition and structure of rocks on the area of the studied contour of the C_{10}^t seam distribution is as follows. Within the boundaries of the mined pillars, the immediate roof is represented by siltstone up to 5.12 m thick. The ultimate compressive strength of siltstone is σ_{compr} – 24.0 MPa. The main roof is composed of argillites and siltstones, less often – sandstone. In terms of load-bearing properties, it can be easily collapsed. A friable roof has a thickness of up to 0.2-0.35 m and caves over the entire thickness. Argillites and siltstones of "curly" texture up to 1.0 m thick with an ultimate compressive strength of 5.2-6.6 MPa occur in the seam bottom. Siltstones up to 6.5 m thick occur below the rocks with a "curly" texture, and argillites up to 5.3 m thick occur even lower.

Qualitative indicators of the mined C_{10}^t coal seam at the Heroiiv Kosmosu mine are presented in Table 1.

Table 1. Coal seam C_{10}^t characteristics

Analytical humidity W_a, %	2.3
Maximum humidity W_{max}, %	8.0
Parent ash content A_{seam}, %	8.3
Total sulphur S_t^d, %	1.5
Unit specific gravity of coal, γ, t/m^3	1.2

3.2. Algorithm for performing the research

To conduct the relevant research, the site for mining the C_{10}^t seam, located in the western wing of the mine field at the Heroiiv Kosmosu mine, has been selected for research. The rationale for choosing this mining field is confirmed by the presence of complete comprehensive mining-geological and mining-technical information, as well as the acute problem of deterioration in the planned rock mass qualitative indicators. This takes place during the mining of the rock mass by the enterprise by driving the longwall faces with a significant undercutting of wall rocks, especially when mining the C_{10}^t seam.

Based on the available digital database of geological information, the research provides for the implementation of a computational experiment of qualitative-quantitative indicators of mined coal in stoping and preparatory faces and the mine as a whole by forming the contours of mined-out reserves and extracting thicknesses in stoping faces. In addition, it is planned to develop a perspective calendar schedule for organizing the seam mining using the waste rock accumulation technology.

The first stage of the research involves the development of a perspective calendar schedule for organizing the mining and preparing of extraction sites of the C_{10}^t seam for the two compared technologies by determining the rational ratio between the stope and preparatory operations, with the observance of the appropriate conditions for the duration of mining the extraction pillars and the time for their preparation using the Expression:

$$T_{prep} + t_{res} \le T_{st},$$

where:

T_{prep} – total time spent on preparing a longwall face pillar, months;

t_{res} – a reserve of time to compensate for unforeseen delays in preparing the pillar, months (1.0-2.0 months);

T_{st} – total time spent on stope operations a longwall face pillar.

At the second stage, the contours for mining the reserves and extracting thicknesses, undercut rock volumes in the stoping and preparatory faces are formed The average density values of coal, rock layers and wall rocks through the C_{10}^t seam within the boundaries of mining contours are determined based on the geological data of wells and mining operations. The graphic basis is executed in the AutoCAD program.

At the third stage of research, using a digital spatial model of the C_{10}^t seam contours, according to the schedule for organizing mining and preparing of extraction sites, for these technology options, the volumes are calculated of waste rocks and minerals involved in the formation of quantitative-qualitative indicators of the rock mass, mined over a certain period of time.

4. Research results

The characteristics of mine workings conducted with traditional technology and technology with waste rock accumulation during mining the C_{10}^t seam are summarized in Tables 2 and 3, respectively.

Thus, as a result of the performed calculations, with the observance of the appropriate conditions for the duration of mining the extraction pillars and the time for their preparation, perspective calendar schedules of movement and preparation of extraction sites for the traditional technology (Table 4) and technology with waste rock accumulation (Table 5) have been developed.

Table 2. Characteristics of mine workings conducted using the traditional technology of C_{10}^t seam mining

Indicators	Name of mine workings		
	1070 longwall face	1072 prefabricated drift	1072 mounting chamber
Design length, m	1200	1300	250
Type of support	KShPP 11.7	KShPP 11.7	KShPP 11.7
Rock driving section, m^2	13.2	13.2	13.2
Roadheader	KSP	KSP	KSP

Table 3. Characteristics of mine workings conducted using the technology with waste rock accumulation during the C_{10}^t seam mining

Indicators	Name of mine workings			
	Central accumulating rock drift (CARD)	Longwall face mounting chamber 1	Longwall face prefabricated drift 2	Longwall face mounting chamber 2
Design length, m	1290	125	1300	125
Type of support	KShPP 15.0	KShPP 11.7	KShPP 11.7	KShPP 11.7
Rock driving section, m²	17.1	13.2	13.2	13.2
Roadheader	P110	P110	P110	P110

Table 4. Perspective calendar schedule of movement and preparation of the longwall face extraction sites with the traditional technology of mining the C_{10}^t seam

Name of mine workings	Advance by months, m								
	I	II	III	IV	V	VI	VII	VIII	IX
1070 longwall face	80	140	140	140	140	140	140	140	140
1072 prefabricated drift	100	200	200	200	200	200			
1072 mounting chamber							125	125	

Table 5. Perspective calendar schedule of movement and preparation of the longwall face extraction sites using the technology with waste rock accumulation during the C_{10}^t seam mining

Name of mine workings		Advance by months, m									
		I	II	III	IV	V	VI	VII	VIII	IX	X
Extraction site 1	Longwall face 1	75	125	125	125	125	125	125	125	125	125
	Longwall face 2	75	125	125	125	125	125	125	125	125	125
Extraction site 2	CARD	90	150	150	150	150	150	150	150	150	
	Longwall face mounting chamber 1									125	
	Longwall face prefabricated drift 2	100	200	200	200	200	200	200			
	Longwall face mounting chamber 2								125		

Formation of contours for mining the reserves. The process of forming the contours for mining the reserves consists in the construction of a network of mine workings according to two options for mining the C_{10}^t coal seam, followed by contouring of the stoping and preparatory faces accepted for mining. The geological information of the coal seam test (structured by blocks), uploaded into the digital model, contains data on such indicators as average thickness, ash content, unit specific gravity of minerals and rocks, the presence of a friable roof and its size within the model calculation block. Thus, the pillar mining system allows, prior to putting the longwall face into operation, to perform a detailed exploration of the deposit area due to the preparatory workings that have been previously driven in the seam, delineating the extraction pillar reserves.

Therefore, mining data are taken as reliable data in determining the geological thickness of the seam. Using the advantages of this mining system, the Geological Service has surveyed the actual thickness of the C_{10}^t coal seam while mining the 1070 longwall face. The survey methodology consisted in measuring the actual thickness of the exposed coal seam along the contour of the preparatory workings, which delineate the extraction pillar. The data is used to refine the coal seam geological model.

Figure 5 shows a spatial model of the location of mine workings delineating the reserves of the C_{10}^t seam using traditional technology in accordance with the calendar schedule of the seam mining.

Table 6 presents data on the changes in the geological seam thickness, the volume of undercutting, as well as the characteristics of minerals and rocks during the planned period of the longwall face mining using traditional technology.

Thus, within the contour boundaries of the seam mined using traditional technology, the geological seam thickness varies within 0.78-0.82 m and averages 0.79 m. The unit specific gravity of coal averages 1.26 t/m³, while rocks and roofs are 2.31 and 2.36 t/m³, respectively. The seam ash content varies from 8.0 to 8.2%, and the ash content of the bottom and roof rocks in the delineated area of the C_{10}^t seam distribution is 90.8 and 91.3%, respectively.

For preparatory faces, the results of calculating the areas occupied by a coal band, the roof rocks that are exposed to dinting, and bottom rocks in the section of the conducted mine working, as well as the characteristics of the mined coal and rocks by the stages of the extraction sites, are given. As an example, the results of driving the 1072 prefabricated drift are presented, summarized in Table 7.

In the same sequence for the option of selective mining of the C_{10}^t coal seam with waste rock accumulation, a network of mine workings and a block model of the coal seam, containing information about the extracting thickness structure and characteristics of the minerals and rocks, have been constructed. Figure 6 shows a spatial model of the location of mine workings when mining the C_{10}^t seam using selective technology with waste rock accumulation.

Unlike traditional technology, reserves are mined with an extraction site from paired longwall faces with a central accumulating rock drift (CARD), which are mined out simultaneously with a straight-line front. Thus, the total length of the stope face line is 250 m. Due to the peculiarities of the technological scheme for selective mining with complete waste rock accumulation in the mined-out area of the longwall face, the total duration of the extraction pillar mining increases and amounts to 10 months.

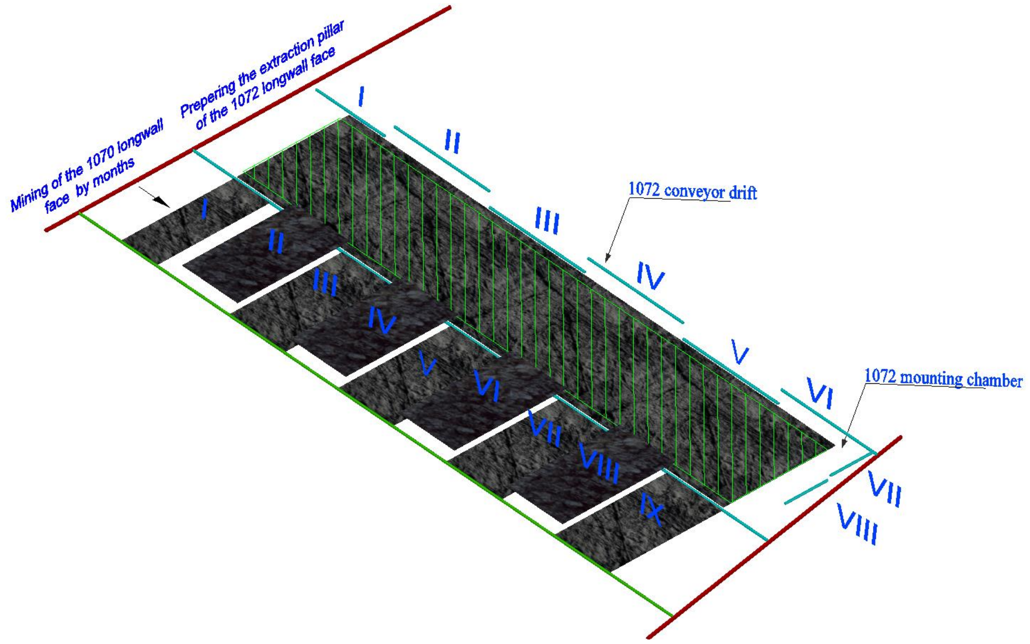

Figure 5. Spatial model of the location of mine workings when mining the C_{10}^t seam using traditional technology

Table 6. Change in the geological thickness, value of undercutting, characteristics of minerals and rocks when mining the C_{10}^t seam using traditional technology

Months of operation	Extracting thickness structure in the longwall face, m			Unit specific gravity, t/m³			Ash content A_d, %		
	Seam m_{geol}	Undercutting m_{uncutt}	Roof caving m_{cav}	γ_{coal}	$\gamma_{bott\ rock}$	$\gamma_{roof\ rock}$	Seam A^d_{seam}	Bottom rocks A^d_{bott}	Roof rocks A^d_{roof}
I	0.79	0.26	0.062	1.27	2.31	2.36	8.1	90.8	91.3
II	0.78	0.27	0.062	1.28	2.31	2.36	8.0	90.8	91.3
III	0.78	0.27	0.062	1.28	2.31	2.36	8.2	90.8	91.3
IV	0.79	0.26	0.062	1.27	2.31	2.36	8.1	90.8	91.3
V	0.78	0.27	0.062	1.26	2.31	2.36	8.1	90.8	91.3
VI	0.82	0.23	0.062	1.25	2.31	2.36	8.0	90.8	91.3
VII	082	0.23	0.062	1.27	2.31	2.36	8.2	90.8	91.3
VIII	0.78	0.27	0.062	1.27	2.31	2.36	7.9	90.8	91.3
IX	0.79	0.26	0.062	1.25	2.31	2.36	8.0	90.8	91.3

Table 7. Changes in the area of the coal band and undercutting, the characteristics of minerals and rocks when mining the 1072 prefabricated drift of the C_{10}^t seam

Months of operation	Plan of the area in draft, m²				Coal face width, m	Coal band thickness, m	Unit specific gravity, t/m³			Ash content of the seam A^d, %
	Project area in draft S_{pr}^d	Seam S_{seam}^d	Bottom dinting S_{bott}^d	Roof dinting S_{roof}^d			γ_{coal}	$\gamma_{bott\ rock}$	$\gamma_{roof\ rock}$	
I	13.2	4.1	8.3	3.6	5.2	0.79	1.26	2.67	2.54	8.0
II	13.2	4.1	8.3	3.6	5.2	0.78	1.27	2.67	2.54	8.0
III	13.2	4.1	8.3	3.6	5.2	0.78	1.28	2.67	2.54	8.1
IV	13.2	4.1	8.3	3.6	5.2	0.79	1.27	2.67	2.54	8.1
V	13.2	4.2	8.3	3.5	5.2	0.8	1.26	2.67	2.54	8.0
VI	13.2	4.2	8.3	3.5	5.2	0.8	1.26	2.67	2.54	8.0

Table 8 presents data on the changes in the geological thickness, the characteristics of minerals and rocks when mining the C_{10}^t seam using selective mining technology with waste rock accumulation.

From the data presented in Table 9, it follows that when driving the central accumulating rock drift, the average area of coal mined from the mass is 3.6 m², which is 21% of the mine working area during drifting, the remaining 89% are caused by dinting of the bottom and roof rocks in the seam. Thus, the models constructed in this way make it possible to analyze the extracting thickness structure in stoping and preparatory faces, as well as to calculate the formation of qualitative-quantitative indicators of coal mined in different time intervals.

Analysis of mined coal quantitative-qualitative indicators. Firstly, it is necessary to analyze the formation of coal quality within the extraction site. Figure 7 shows the graphs of the change in the geological seam thickness m_{geol} within the extraction pillar contours, the change in the volume of undercut rocks h_{uncutt}, as well as the predicted operational ash content in the stope face A_e. The value of undercut rocks h_{uncutt} is determined as the difference between the minimum extracting thickness m_{extr}, taken for the mechanized complex operation, and the actual geological seam thickness m_{geol}. The predicted operational coal ash content A_e is calculated according to the known expression using the methodology [40], taking into account the parent ash content of the seam A_{seam} and the volume of rocks involved in the mined coal dilution over a certain period of time.

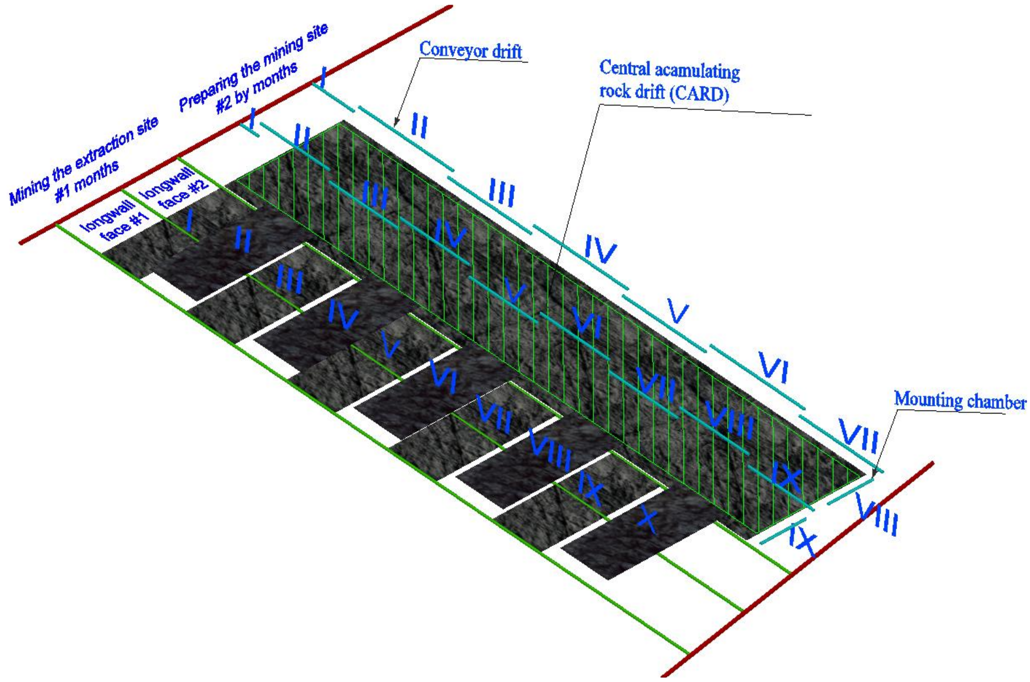

Figure 6. Spatial model of the location of mine workings when mining the $C_{10}{}^t$ seam using selective technology with waste rock accumulation

Table 8. Changes in the geological thickness, the characteristics of minerals and rocks when mining the $C_{10}{}^t$ seam using selective mining technology with waste rock accumulation

Months of operation	Extracting thickness structure in the longwall face, m		Unit specific gravity, t/m^3			Ash content A_d, %		
	Seam m_{geol}	Roof caving m_{cav}	γ_{coal}	$\gamma_{bott\ rock}$	$\gamma_{roof\ rock}$	Seam A^d_{seam}	Bottom rocks A^d_{bott}	Roof rocks A^d_{roof}
I	0.79	0.04	1.27	2.31	2.36	8.1	90.8	91.3
II	0.78	0.04	1.28	2.31	2.36	8.0	90.8	91.3
III	0.78	0.04	1.28	2.31	2.36	8.2	90.8	91.3
IV	0.79	0.04	1.27	2.31	2.36	8.1	90.8	91.3
V	0.78	0.04	1.26	2.31	2.36	8.1	90.8	91.3
VI	0.82	0.04	1.25	2.31	2.36	8.0	90.8	91.3
VII	0.82	0.04	1.27	2.31	2.36	8.2	90.8	91.3
VIII	0.78	0.04	1.27	2.31	2.36	7.9	90.8	91.3
IX	0.79	0.04	1.25	2.31	2.36	8.0	90.8	91.3
X	0.77	0.04	1.25	2.31	2.31	8.0	90.8	91.3

Table 9. Changes in the area of the coal band and undercutting, the characteristics of minerals and rocks when driving the central accumulating rock drift

Months of operation	Plan of the area in draft, m^2				Coal face width, m	Coal band thickness, m	Unit specific gravity, t/m^3			Ash content A^d, %		
	Project area in draft $S_{pr}{}^d$	Seam $S_{seam}{}^d$	Bottom dinting $S_{bott}{}^d$	Roof dinting $S_{roof}{}^d$			γ_{coal}	$\gamma_{bott\ rock}$	$\gamma_{roof\ rock}$	Seam A^d_{seam}	Bottom rocks A^d_{bott}	Roof rocks A^d_{roof}
I	17.1	3.6	13.5	–	4.54	0.80	1.27	2.63	2.48	8.1	93.5	92.5
II	17.1	3.5	13.6	–	4.54	0.78	1.26	2.63	2.48	8.0	93.5	92.5
III	17.1	3.6	13.5	–	4.54	0.79	1.27	2.63	2.48	8.2	93.5	92.5
IV	17.1	3.6	13.5	–	4.54	0.79	1.27	2.63	2.48	8.1	93.5	92.5
V	17.1	3.7	13.4	–	4.54	0.81	1.26	2.63	2.48	8.1	93.5	92.5
VI	17.1	3.6	13.5	–	4.54	0.80	1.26	2.63	2.48	8.0	93.5	92.5
VII	17.1	3.7	13.4	–	4.54	0.82	1.28	2.63	2.48	8.2	93.5	92.5
VIII	17.1	3.6	13.5	–	4.54	0.80	1.27	2.63	2.48	7.9	93.5	92.5
IX	171	3.7	13.4	–	4.54	0.82	1.26	2.63	2.48	8.0	93.5	92.5

From the presented graphs, it is obvious that the operational ash content of the mined coal averages 15.3% with the mining technology of waste rock accumulation during mining the extraction pillar (Fig. 7b), reaching the highest value of 15.4% at the final stage of mining the extraction pillar, in the area of PK-92 – PK-98, that is, for the 10th calendar month of operation. At the same time, the analysis results of the quality indicators of coal mined from the longwall face using traditional technology (Fig. 6a) show that the rock mass ash content varies in the range of 40.8-44.5%, averaging 43.3%. Thus, by comparing the obtained results, it can be stated that when using mining technology with waste rock accumulation, the ash content of coal mined from longwall face is 2.5-2.8 times lower than when using traditional technology.

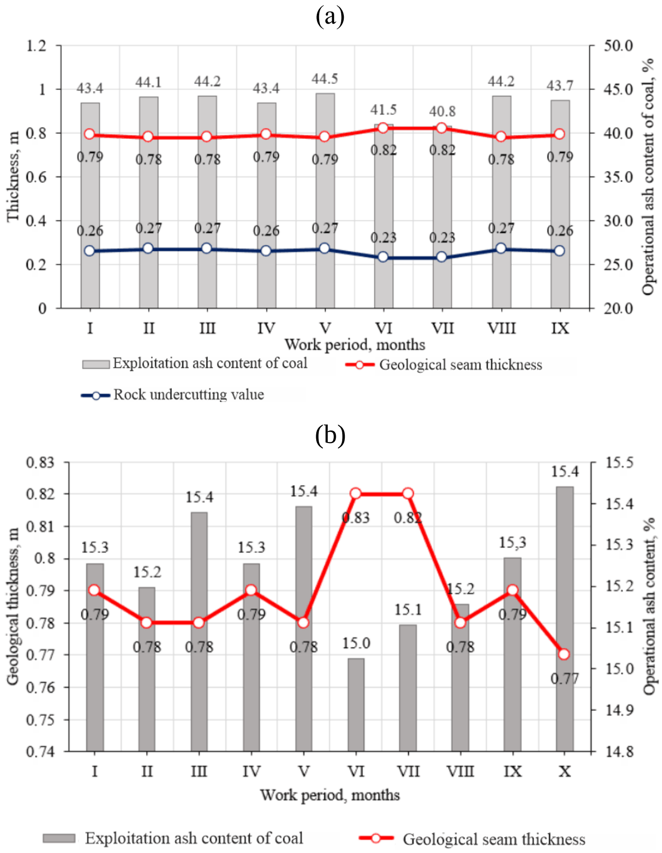

Figure 7. Changes in the geological thickness, the value of rock undercutting and operational ash content within the extraction pillars of the extraction sites: (a) with traditional technology; (b) with mining technology of waste rock accumulation

It should also be noted that with selective mining technology of waste rock accumulation, due to the absence of mined coal dilution with the rocks from bottom undercutting, the operational ash content value is affected by the volume of caved roof rocks, the presence of interlayers in the coal seam, as well as the natural ash content, the density of the coal seam and wall rocks. In the overall balance, these indicators increase the operational ash content by 7.3-7.5% for the given conditions of technology application. Therefore, in the mining technology of waste rock accumulation, the change in the thickness and seam hypsometry practically does not affect the operational ash content and to a greater extent depends on the performance of the executive bodies of the longwall face stope equipment.

Figure 8 shows the dynamics of rock mass mining in stoping faces depending on the period of mining the extraction pillar reserves. With the traditional technology of mining the C_{10}^t seam, in the first month of longwall face operation, the volume of coal mined reaches 38.0 thousand tons/month, and the following months it stabilizes at the level of 65.9-67.2 thousand tons/month (Fig. 8a).

The predicted total volume of rock mass mined from the extraction pillar is 568.5 thousand tons, with 43.3% of operational ash content. Thus, the output of waste rocks during extraction pillar mining will be 241.5 thousand tons, or 29.8% of the total longwall face production, which, together with coal, will be delivered to the daylight surface for further beneficiation through the mine's transport lines.

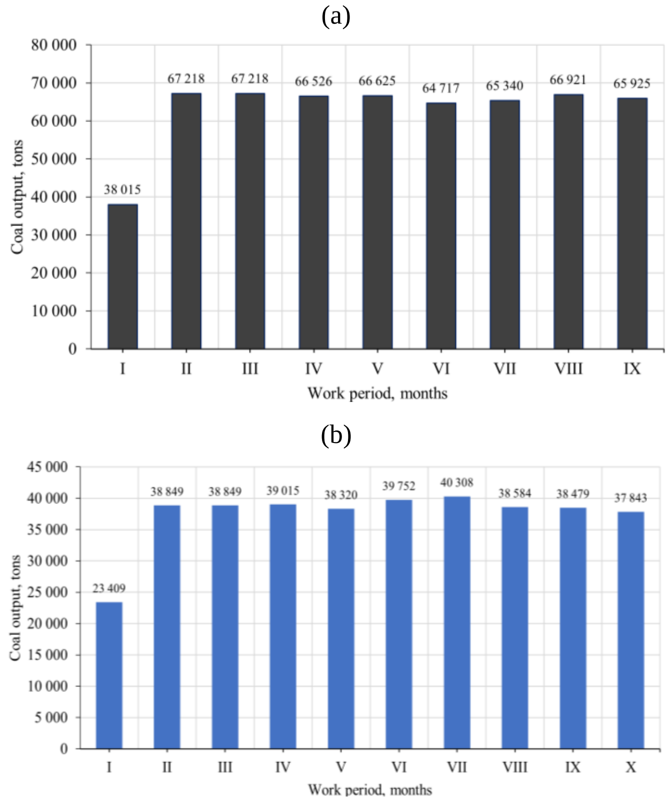

Figure 8. Dynamics of coal production in stoping faces: (a) with traditional technology; (b) with mining technology of waste rock accumulation

It follows from the data analysis in Figure 8b that when implementing a selective mining technology with waste rock accumulation, up to 373.4 thousand tons of coal can be mined from the extraction pillar, the ash content of which is 15.3%. Depending on the time period of mining the extraction pillar, output varies from 23.4 to 40.3 thousand tons/month, which averages 31.8 thousand tons. When the extraction site reaches a stable production capacity, the average predicted output will be 38.9 thousand tons/month.

Further, an analysis is conducted of the coal quality formation during the joint rock mass transportation from stoping and preparatory faces using traditional technology (Table 10).

The data of Table 10 show that with the traditional technology of mining the C_{10}^t seam, for the planned period of longwall face operation, one preparatory face is in operation, from which the rock mass is transported to the main conveyor. According to the presented data, the operational ash content of the rock mass produced during the bulk mining of coal and rock in the preparatory faces and the joint rock mass transportation averages: 1072 prefabricated drift – 83.8%; 1072 mounting chamber – 84.3%. Thus, in the overall structure of the volume of rock mass mined from the seam, output from drifting faces is 8.5%. At the same time, the rock mass delivered from the preparatory workings consists of 90% waste rocks, which increase the total operational ash content.

Then, dynamics of changes is analyzed in the total output and operational ash content of the C_{10}^t seam with traditional mining technology (Fig. 9). As is evident from the data presented in Figure 9, the total operational ash content in the C_{10}^r seam during the joint rock mass transportation from stoping and preparatory faces using traditional technology varies within 46.2-48.1%, averaging 46.7%.

Table 10. Production indicators and operational ash content in the stoping and preparatory faces with traditional seam mining technology

Months of operation	Output, tons			Ash content, %			Total ash content in the seam, %
	1070 longwall face	1072 prefabricated drift	1072 mounting chamber	1070 longwall face	1072 prefabricated drift	1072 mounting chamber	
I	38014.8	3379.9	–	43.4	83.7	–	46.6
II	67217.6	6770.6	–	44.1	83.9	–	47.3
III	67217.6	6770.6	–	44.2	83.9	–	47.4
IV	66525.9	6759.8	–	43.4	83.7	–	46.7
V	66624.7	6749.0	–	44.5	83.6	–	47.6
VI	64716.6	6749.0	–	41.0	83.6	–	44.5
VII	65340.0	–	4332.2	40.8	84.2	–	44.4
VIII	66921.2	–	4345.8	44.2	–	84.2	47.5
IX	65925.3	–	–	43.7	–	84.4	46.7

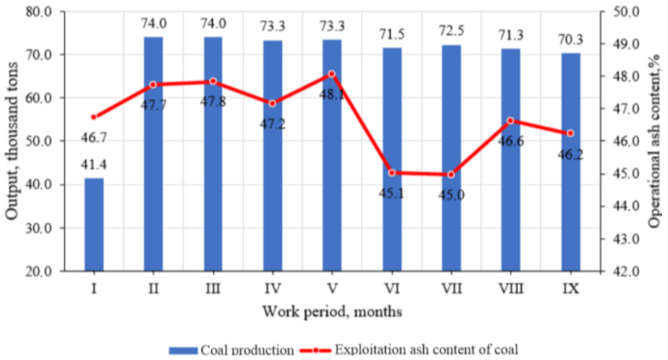

Figure 9. ***Dynamics of changes in total output and operational ash content in the C_{10}^{t} seam with traditional mining technology***

From this it can be drawn a disappointing conclusion that the rock mass delivered from the drifting faces increases the total operational ash content by 3.4%. The total output for the period of mining the extraction pillar is 621.3 thousand tons, of which 568.5 thousand tons are accounted for stoping mining and 52.8 thousand tons are accounted for mining from drifting faces or, in percentage terms, 91.5 and 8.5%, respectively.

In addition, as the research results show, with the same parent ash content and density of coal and rock, a decrease in the geological seam thickness by 0.01 m leads to an additional dilution of the rock mass mined in the stoping face by 0.1%.

At the same time, with the constant thickness and characteristics of the coal seam, an increase in the unit specific gravity of wall rocks involved in dilution leads to an increase in the rock mass operational ash content averaging 1.5-2.0%.

Table 11 summarizes data on production indicators and operational ash content in stoping and preparatory faces using selective mining technology with waste rock accumulation.

The analysis of the systematized data in Table 11 and the dynamics of changes in the total output and operational ash content in the C_{10}^{t} seam (Fig. 10) based on these data show that the average monthly output varies within 23.7-40.9 thousand tons. The total volume of the rock mass mined during the period of mining the extraction pillar with the extraction site of paired longwall faces is 376.5 thousand tons, which at first glance is 39.4% less than with traditional technology. At the same time, in the overall production balance, stope operations account for 94.9% versus 91.5% – with traditional technology, which is mainly due to the share of dinting rocks that are mined by the bulk method in preparatory faces and their high unit specific gravity relative to the mined coal.

It has been determined that within the mined-out area of the C_{10}^{t} seam reserves, the total operational ash content of coal mined from the stoping and drifting faces is practically unchanged during the time of mining the extraction pillar, averaging 15.2% (with an average parent ash content A_{seam}^{d} = 8.1%).

Comparing these indicators with those obtained with traditional technology, it can be argued that the transition to selective technology with waste rock accumulation, under these conditions, provides a decrease in operational ash content by 3 times – to 15.2%. At the same time, comparing the obtained values of the total operational ash content of coal in the selective mining technology with waste rock accumulation, the increase in the value of undercutting has practically no effect on the increase in the ash content of coal mined in the stoping face.

Table 11. Production indicators and operational ash content in stoping and preparatory faces using selective mining technology with waste rock accumulation

Months of operation	Output, tons				Ash content, %				Total ash content in the seam, %
	Longwall face 1	Longwall face 2	Central accumulating rock drift	Prefabricated drift	Longwall face 1	Longwall face 2	Central accumulating rock drift	Prefabricated drift	
I	11176.0	11176.0	806.1	545.8	15.3	15.3	15.3	15.3	15.3
II	18543.5	18543.5	1318.8	1081.9	15.2	15.2	15.0	15.2	15.2
III	18543.5	18543.5	1331.2	1101.3	15.4	15.4	15.4	15.4	15.4
IV	18626.6	18626.6	1331.2	1110.8	15.3	15.3	15.2	15.2	15.3
V	18278.7	18278.7	1355.7	1091.6	15.4	15.4	15.3	15.3	15.4
VI	18994.8	18994.8	1343.5	1081.9	15.0	15.0	15.2	15.2	15.0
VII	19273.1	19273.1	1367.8	1072.1	15.1	15.1	15.4	15.4	15.1
VIII	18411.1	18411.1	1343.5	682.3	15.2	15.2	15.3	15.3	15.2
IX	18358.5	18358.5	1367.8	676.2	15.3	15.3	15.2	15.2	15.3
X	17934.3	18146.4	–	–	15.4	15.4	15.3	15.3	15.4

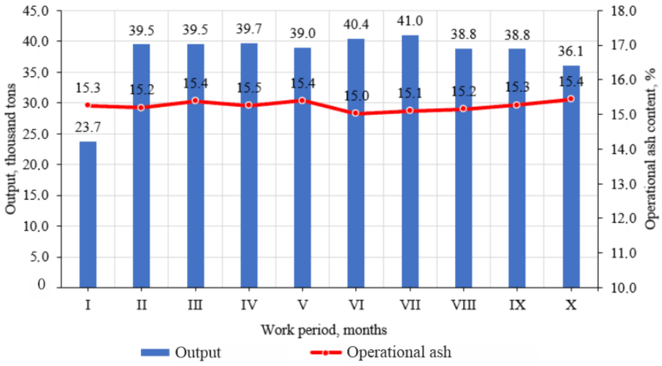

Figure 10. Dynamics of changes in the total output and operational ash content in the C_{10}^t seam using selective mining technology with waste rock accumulation

However, the caving friable roof rocks, which are involved in coal dilution, contribute to an increase in operational ash content. Thus, research has shown that an increase in the rock layer thickness by 0.01 m contributes to an increase in operational ash content by an average of 1.0-1.5%. Figure 11 shows the share of coal and rock in the rock mass, for the compared technologies of the C_{10}^t seam mining.

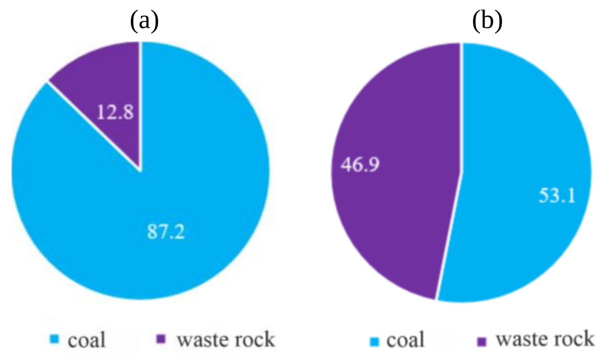

Figure 11. Share of coal and waste rock in the rock mass: (a) with selective mining technology of waste rock accumulation; (b) with traditional technology

An analysis of mined coal quality indicators makes it possible to determine that in the structure of the rock mass cargo flow formation, when mining the extraction site with the selective technology of waste rock accumulation, 87.2% is coal with parent ash content and 12.8% is waste rock. With the traditional mining technology, the rock mass cargo flow consists of coal – 46.9% and rock – 53.1%. It follows from the data that when the mining technology with waste rock accumulation is implemented in the conditions of the C_{10}^t seam at the Heroiiv Kosmosu mine, not only an increase in the qualitative-quantitative indicators of coal production is achieved, but also the transportation of ballast rocks to the daylight surface is reduced by 4 times.

It should be noted that, at first glance, when changing to selective mining technology with waste rock accumulation, the volume of mined minerals decreases. In this regard, it is necessary to determine the mined coal energy value in terms of energy thermal equivalent. Given the specifics of exploiting the reserves, based on the available information on the composition and characteristics of coal-bearing rocks for the conditions of mining the selected C_{10}^t coal seam contour, an assessment of the specific heat of the rock mass combustion in the traditional and selective coal mining technologies is conducted.

Figure 12 presents data on the volume of heat generated from the mined coal according to the options for the C_{10}^t coal seam mining technologies.

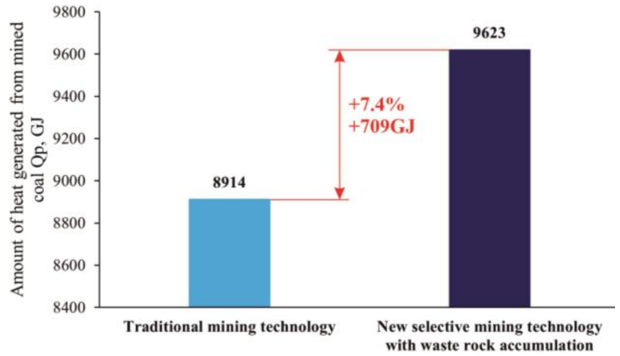

Figure 12. Histograms of the distributed amount of heat generated from the mined coal according to the options for the C_{10}^t coal seam mining technologies

Based on the results of the assessment, it can be seen that the total amount of thermal energy generated from the rock mass produced from mining the extraction site according to the traditional bulk technology has a technically achievable potential of 8.9 TJ. At the same time, when changing to progressive selective mining technology, the total thermal energy potential that can be generated from the mined fossil fuels increases by 709 GJ or by 7.4% and reaches 9.6 TJ. Comparison of the obtained indicators confirms that it is possible to significantly increase the produced fuel energy potential due to the use of a new selective mining technology at the Western Donbass coal enterprises.

Thus, to mine more coal does not mean to obtain more commercial fuel. It is important to obtain energy calories, and the higher the mined energy fuel caloric content, the more resources will be released in the future from technological chains, covering the transportation of multitone “ballast” rocks, their processing and beneficiation, as well as stockpiling in landfills and sludge storage facilities. This will increase the efficiency of coal mining, coal beneficiation and energy-generating enterprises, as well as reduce the impact on our environment.

The obtained research results can be used to substantiate the rational parameters of mining technology with waste rock accumulation, aimed at improving the mined coal quality, increasing the degree of mining the reserves from the bowels, the efficiency and environmental friendliness of mining.

5. Conclusions

In the presented research, the peculiarities of the formation of mined coal quantitative-qualitative indicators in the conditions of their dynamic change in space and time with a new mining technology of waste rock accumulation in the underground mined-out area, as well as their comparison with traditional mining technology are determined.

1. A comprehensive methodical research algorithm has been developed, which consists in determining the average density values of coal, rock layers and wall rocks in the seam within the mining contours according to the geological data of wells and mining operations, as well as constructing a digital spatial model of the C_{10}^t seam contours based on the schedule for organizing stope and preparatory operations. The volumes of waste rocks and minerals involved in the formation of quantitative-qualitative indicators of the rock

mass mined in a specific period of time have been analytically determined. The graphic basis is executed in the AutoCAD program.

2. It has been determined that during mining of coal reserves from the studied mining area (equal to extraction site), the volume of production and the operational coal ash content in the mining technology with waste rock accumulation averages 376.5 thousand tons and 15.2%, and with traditional technology – 621.3 thousand tons and 46.7%.

3. It has been determined that the total amount of thermal energy generated from the rock mass produced from mining the extraction site according to the traditional bulk technology has a technically achievable potential of 8.9 TJ. At the same time, when using progressive selective mining technology, the total thermal energy potential that can be generated from the mined fossil fuels increases by 709 GJ or by 7.4% and reaches 9.6 TJ. Comparison of the obtained indicators confirms that it is possible to significantly increase the produced fuel energy potential due to the use of a new selective mining technology at the Western Donbass coal enterprises.

4. It has been revealed that with the recommended mining technology of waste rock accumulation, the total production volume decreases and the costs for conducting an additional third mine working increase. However, the mentioned negative aspects are leveled by the following priority advantages: a significant increase in the energy value of coal, eliminating the need for its beneficiation, eliminating the cost of transporting rock, preventing the formation of waste rock dumps on the surface, reducing the waste disposal fees, reducing timber to support mine workings, as well as favorable conditions for maintaining an accumulating rock drift and reusable transport extraction drift.

Acknowledgements

The research results have been obtained within the framework of the scientific-research project “Development of advanced technologies for the complete mining of steam coal with the accumulation of waste rocks in the underground space” (No. 0120U101099).

References

[1] Shah, Y.T. (2021). Hybrid energy systems – strategy for decarbonization. *Hybrid Energy Systems*, 1-18. https://doi.org/10.1201/9781003159421-1

[2] Debiagi, P., Rocha, R.C., Scholtissek, A., Janicka, J., & Hasse, C. (2022). Iron as a sustainable chemical carrier of renewable energy: Analysis of opportunities and challenges for retrofitting coal-fired power plants. *Renewable and Sustainable Energy Reviews*, (165), 112579. https://doi.org/10.1016/j.rser.2022.112579

[3] Wang, Q., Song, X., & Liu, Y. (2020). China’s coal consumption in a globalizing world: Insights from multi-regional input-output and structural decomposition analysis. *Science of the Total Environment*, (711), 134790. https://doi.org/10.1016/j.scitotenv.2019.134790

[4] Spencer, D. (2019). BP statistical review of world energy statistical review of world. *World Energy*, (68), 1-69.

[5] Khorolskyi, A., Hrinov, V., Mamaikin, O., & Fomychova, L. (2020). Research into optimization model for balancing the technological flows at mining enterprises. *E3S Web of Conferences*, (201), 01030. https://doi.org/10.1051/e3sconf/202020101030

[6] Zhou, B., Yan, Y., Dai, H., Kang, J., Xie, X., & Pei, Z. (2022). Mining subsidence prediction model and parameters inversion in mountainous areas. *Sustainability*, *14*(15), 9445. https://doi.org/10.3390/su14159445

[7] Koshka, O., Yavors’kyy, A., & Malashkevych, D. (2014). Evaluation of surface subsidence during mining thin and very thin coal seams. *Progressive Technologies of Coal, Coalbed Methane, and Ores Mining*, 229-233. https://doi:10.1201/b17547-41

[8] Bini, C., Maleci, L., & Wahsha, M. (2017). Mine waste: Assessment of environmental contamination and restoration. *Assessment, Restoration and Reclamation of Mining Influenced Soils*, 89-134. https://doi.org/10.1016/b978-0-12-809588-1.00004-9

[9] Aznar-Sánchez, J., García-Gómez, J., Velasco-Muñoz, J., & Carretero-Gómez, A. (2018). Mining waste and its sustainable management: Advances in worldwide research. *Minerals*, *8*(7), 284. https://doi.org/10.3390/min8070284

[10] Zhu, W., Xu, J., Xu, J., Chen, D., & Shi, J. (2017). Pier-column backfill mining technology for con-trolling surface subsidence. *International Journal of Rock Mechanics and Mining Sciences*, (96), 58-65. https://doi.org/10.1016/j.ijrmms.2017.04.014

[11] Behera, S.K., Mishra, D.P., Singh, P., Mishra, K., Mandal, S.K., Ghosh, C.N., Kumar, R., & Mandal, P.K. (2021). Utilization of mill tailings, fly ash and slag as mine paste backfill material: Review and future perspective. *Construction and Building Materials*, (309), 125120. https://doi.org/10.1016/j.conbuildmat.2021.125120

[12] Ghirian, A., & Fall, M. (2017). Properties of cemented paste backfill. *Paste Tailings Management*, 59-109. https://doi.org/10.1007/978-3-319-39682-8_4

[13] Petlovanyi, M.V., Zubko, S.A., Popovych, V.V., & Sai, K.S. (2020) Physicochemical mechanism of structure formation and strengthening in the backfill massif when filling underground cavities. *Voprosy Khimii i Khimicheskoi Tekhnologii*, (6), 142-150. https://doi.org/10.32434/0321-4095-2020-133-6-142-150

[14] Petlovanyi, M., & Mamaikin, O. (2019). Assessment of an expediency of binder material mechanical activation in cemented rockfill. *ARPN Journal of Engineering and Applied Sciences*, *14*(20), 3492-3503.

[15] Zhang, J., Yang, K., He, X., Wei, Z., Zhao, X., & Fang, J. (2022). Experimental study on strength development and engineering performance of coal-based solid waste paste filling material. *Metals*, *12*(7), 1155. https://doi.org/10.3390/met12071155

[16] Zhou, N., Zhang, J., Ouyang, S., Deng, X., Dong, C., & Du, E. (2020). Feasibility study and performance optimization of sand-based cemented paste backfill materials. *Journal of Cleaner Production*, (259), 120798. https://doi.org/10.1016/j.jclepro.2020.120798

[17] Wang, J., Zhang, J., Li, M., Sartaj, M., & Wang, Y. (2022). A numerical simulation of the interaction of aggregate and rockfill in a gangue fluidized filling method. *Sustainability*, *14*(19), 12838. https://doi.org/10.3390/su141912838

[18] Malashkevych, D., Sotskov, V., Medyanyk, V., & Prykhodchenko, D. (2018). Integrated evaluation of the worked-out area partial backfill effect of stress-strain state of coal-bearing rock mass. *Solid State Phenomena*, (277), 213-220. https://doi.org/10.4028/www.scientific.net/ssp.277.213

[19] Nehrii, S., Nehrii, T., Zolotarova, O., & Volkov, S. (2021). Investigation of the geomechanical state of soft adjoining rocks under protective constructions. *Rudarsko-Geološko-Naftni Zbornik*, *36*(4), 61-71. https://doi.org/10.17794/rgn.2021.4.6

[20] Bondarenko, V.I., Kovalevska, I.A., Biletskyi, V.S., & Desna, N.A. (2022). Optimization principles implementation in the innovative technologies for re-used extraction workings maintenance. *Petroleum and Coal*, *64*(2), 424-435. https://doi.org/10.1016/j.tust.2021.104182

[21] Wang, G., Ren, H., Zhao, G., Zhang, D., Wen, Z., Meng, L., & Gong, S. (2022). Research and practice of intelligent coal mine technology systems in China. *International Journal of Coal Science & Technology*, *9*(1), 24. https://doi.org/10.1007/s40789-022-00491-3

[22] Yilmaz, E., & Erkayaoglu, M. (2021). A discrete event simulation and data-based framework for equipment performance evaluation in underground coal mining. *Mining, Metallurgy & Exploration*, *38*(5), 1877-1891. https://doi.org/10.1007/s42461-021-00455-2

[23] Jiang, L., Chen, S., Chen, Y., Chen, Z., Sun, F., Dong, X., & Wu, K. (2023). Underground coal gasification modelling in deep coal seams and its implications to carbon storage in a climate-conscious world. *Fuel*, (332), 126016. https://doi.org/10.1016/j.fuel.2022.126016

[24] Dychkovskyi, R., Shavarskyi, J., Cabana, E.C., & Smoliński, A. (2019). Characteristic of possible obtained products during the well underground coal gasification. *Solid State Phenomena*, (291), 52-62. https://doi.org/10.4028/www.scientific.net/ssp.291.52

[25] Petlovanyi, M., Lozynskyi, V., Saik, P., & Sai, K. (2019). Predicting the producing well stability in the place of its curving at the underground coal seams gasification. *E3S Web of Conferences*, (123), 01019. https://doi.org/10.1051/e3sconf/201912301019

[26] Yuan, Y., Chen, Z., Yuan, C., Zhu, C., Wei, H., & Zhang, X. (2019). Numerical simulation analysis of the permeability enhancement and pressure relief of auger mining. *Natural Resources Research*, *29*(2), 931-948. https://doi.org/10.1007/s11053-019-09501-9

[27] Petlovanyi, M, Medianyk, V., Sai, K., Malashkevych, D., & Popovych, V. (2021). Geomechanical substantiation of the parameters for coal auger mining in the protecting pillars of mine workings during thin seams development. *ARPN Journal of Engineering and Applied Sciences*, *16*(15), 1572-1582.

[28] Malashkevych, D., Poimanov, S., Shypunov, S., & Yerisov, M. (2020). Comprehensive assessment of the mined coal quality and mining conditions in the Western Donbas mines. *E3S Web of Conferences*, (201), 01013. https://doi.org/10.1051/e3sconf/202020101013
[29] Buzilo, V.I., Sulaev, V.I., Koshka, A.G., & Yavorskiy, A.V. (2013). *Tekhnologiya otrabotki tonkikh plastov s zakladkoy vyrabotannogo prostranstva*. Dnepropetrovsk, Ukraina: NGU, 124 s.
[30] Petlovanyi, M.V., Malashkevych, D.S., & Sai, K.S. (2020). The new approach to creating progressive and low-waste mining technology for thin coal seams. *Journal of Geology, Geography and Geoecology*, *29*(4), 765-775. https://doi.org/10.15421/112069
[31] Kovalenko, V.V., & Garkusha, V.S. (2015). Issledovanie vliyaniya PVA-emul'sii na reologicheskie svoystva tamponazhnykh rastvorov na osnove pustykh porod. *Forum Hirnykiv*, (2), 110-114.
[32] Byzylo, V., Koshka, O., Poymanov, S., & Malashkevych, D. (2015). Resource-saving technology of selective mining with gob backfilling. *New Developments in Mining Engineering 2015: Theoretical and Practical Solutions of Mineral Resources Mining*, 485-491. https://doi.org/10.1201/b19901-84
[33] Hindistan, M.A., Tercan, A.E., & Ünver, B. (2010). Geostatistical coal quality control in longwall mining. *International Journal of Coal Geology*, *81*(3), 139-150. https://doi.org/10.1016/j.coal.2009.12.014
[34] Petlovanyi, M., Ruskykh, V., Zubko, S., & Medianyk, V. (2020). Dependence of the mined ores quality on the geological structure and properties of the hanging wall rocks. *E3S Web of Conferences*, (201), 01027. https://doi.org/10.1051/e3sconf/202020101027
[35] Qi, H., Gai, K., Ma, D., Liang, X., & Sun, N. (2020). Study on coal quality development and application in Hetaoyu coal mine. *IOP Conference Series: Earth and Environmental Science*, *514*(2), 022027. https://doi.org/10.1088/1755-1315/514/2/022027
[36] Busylo, V., Savelieva, T., Serdyuk, V., Koshka, A., & Morozova, T. (2015). Substantiating parameters of process design of contiguous seam mining in the Western Donbas mines. *New Developments in Mining Engineering 2015: Theoretical and Practical Solutions of Mineral Resources Mining*, 17-25. https://doi.org/10.1201/b19901-5
[37] Sdvizhkova, Ye.A., Babets, D.V., & Smirnov, A.V. (2014). Support loading of assembly chamber in terms of Western Donbas plough longwall. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (5), 26-32.
[38] Smoliński, A., Malashkevych, D., Petlovanyi, M., Rysbekov, K., Lozynskyi, V., & Sai, K. (2022). Research into impact of leaving waste rocks in the mined-out space on the geomechanical state of the rock mass surrounding the longwall face. *Energies*, *15*(24), 9522. https://doi.org/10.3390/en15249522
[39] Sotskov, V.O., Podvyhina, O.O., Dereviahina, N.I., & Malashkevych, D.S. (2018). Substantiating the criteria for applying selective excavation of coal deposits in the Western Donbass. *Journal of Geology, Geography and Geoecology*, *26*(1), 158-164. https://doi.org/10.15421/111817
[40] SOU 10.1.00185755.001-2004. (2004). *Vuhillia bure, kamiane ta antratsyt. Metodyka rozrakhunku pokaznykiv yakosti*. Kyiv, Ukraina: Minpalyvenerho Ukrainy.

Дослідження якості видобутого вугілля при новій технології селективного видобування з акумуляцією пустих порід у виробленому просторі

Д. Малашкевич, М. Петльований, К. Сай, С. Зубко

Мета. Дослідження формування кількісно-якісних показників видобутого вугілля в умовах динамічної зміни у просторі та часі при новій очисній технології видобування з акумуляцією пустих шахтних порід у підземному виробленому просторі.

Методика. Виконано формування контурів відпрацювання малопотужних запасів вугілля і виїмкових потужностей, величин присікання порід в очисних та підготовчих вибоях в умовах шахти «Ім. Героїв Космосу». Визначалися середні значення щільності вугілля, породних прошарків і бічних порід по пласту у межах контурів відпрацювання за геологічними даними свердловин та гірничих робіт. Графічна основа виконана у програмі AutoCAD. Використано цифрову просторову модель контурів запасів пласта $C_{10}^{в}$, згідно графіка організації очисних та підготовчих робіт. Розраховувалися обсяги пустих порід і корисних копалин, що беруть участь у формуванні кількісних та якісних показників гірничої маси у конкретний проміжок часу.

Результати. Встановлено, що при відпрацюванні запасів вугілля з розглянутої виїмкової дільниці (рівна площа виїмки) обсяг видобутку та експлуатаційна зольність вугілля при технології видобування з акумуляцією пустих порід становить в середньому 376,5 тис. т та 15,2%, а при традиційній технології – 621,3 тис. тис. т та 46,7%. Проте, доведено, що в енергетичному еквіваленті цінність видобутого вугілля за технологією видобування з акумуляцією пустих порід вища на 7,4% у порівнянні з традиційною технологією (9,6 ТДж проти 8,9 ТДж).

Наукова новизна. Вперше виявлено механізм формування експлуатаційної зольності та енергетичної цінності вугілля при поєднанні процесів прохідницьких робіт для підготовки запасів нових виїмкових стовпів з суміжними очисними роботами у нову селективну технологію видобування з акумуляцією порід у виробленому просторі.

Практична значимість. Розроблено алгоритм прогнозування експлуатаційної зольності та якості вугілля при використанні селективної технології видобування з акумуляцією порід у виробленому просторі, що має важливе значення для техніко-економічних показників вугільних шахт.

Ключові слова: *пусті породи, акумуляція, експлуатаційна зольність, очисний вибій, прохідницький вибій, селективне виймання*