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Development of technological schemes for open-pit mining of deposits using “mobile crushing-reloading-conveyor complexes”

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Abstract. This article analyses the use of cyclic-flow technology schemes with mobile crushing and reloading complexes in open cast mining. An analysis of the application of cyclic-flow technology schemes with mobile crushing and reloading complexes in open cast mining shows that the main directions of its radical improvement are the development, creation and implementation of fundamentally new mining transport equipment and technological schemes for its quarries, which include: “mobile excavators crushing and transhipment plants and conveyor systems". Technological schemes for the development of rocks with an end arrangement of mobile complexes using a single bucket excavator and conveyor transport, with an end arrangement of mobile complexes and an increased width of the working platform during conveyor transport, with an end arrangement of mobile complexes and the presence of a mobile interstage loading crane with sequential mining at three horizons, a methodology has been developed for determining the working time and annual productivity of mobile crushing and handling conveyor complexes and a new technological scheme for the development of overburden ledges using mobile crushing and handling conveyor complexes. To reduce the time for idling the complex and reduce the number of exit ledges, a new technological scheme for the development of overburden ledges with the use of mobile complexes is recommended. As a result of the calculations according to the developed method, when working out two benches with different block lengths, the dependence of the annual productivity of the complex on the block length was established.

1 Introduction

In the open-pit mining of carbonate rock deposits of uniform strength and diverse strengths with a content of weak differences of up to 30% in complexes with mobile equipment, mobile crushing plants, mobile interstage conveyor reloader and mobile downhole conveyors are used [1, 2].

There are 3 main schemes for organizing mining operations in the development of sedimentary, carbonate and rock, which differ in the type of machinery and installations

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used, as well as their location in the face [1 – 6]:

1) with the installation of a mobile crusher in the face (Fig. 1, *a*) in which the rock is loaded into the crusher by an excavator through a hopper feeder, which is an integral part of the crusher and mounted on the same platform with it. Crushed rock downhole conveyor is transported directly to the intermediate or main conveyor. The main disadvantages of this scheme are the need for fencing downhole conveyors during blasting and their frequent movement;

2) with the installation of a mobile conveyor-reloader or interstage conveyor-reloader between a mobile crusher and a downhole conveyor (Fig. 1, *b*). The rock is loaded into the crusher by an excavator through a hopper feeder. The rock from the crushing plant is transferred to a mobile conveyor-reloader and further to the downhole conveyor. Using a mobile conveyor reloader allows you to reduce the frequent movement of the downhole conveyor and place them at a great distance from the bottom;

3) using mobile crushers at the working site (Fig. 1, *c*). The extraction, loading and delivery of the rock mass to the crushers is carried out by single-bucket wheel loaders. With this scheme, the movement of the crusher and conveyor is less frequent compared to the first and second schemes. The distance of delivery of the rock mass from the bottom with a single-bucket loader determines the movement step. This scheme is often used in the development of building rocks.

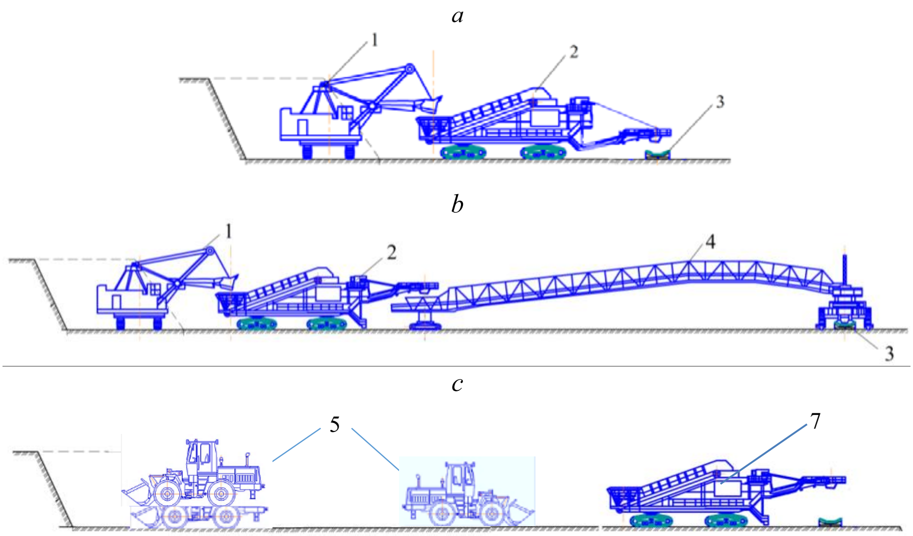


Fig. 1. Schemes of development of rock using conveyor transport: 1 – excavator; 2 – mobile crushing plant; 3 – downhole conveyor belt; 4 – mobile conveyor reloader; 5 – single bucket loaders; 7 – mobile or mobile crushing plant.

In the scientific literature, only the basic methods for developing deposits using mobile crushing complexes are given, in connection with this there is a need to find an effective technological scheme for their application. The rationality and effectiveness of the application of technological schemes using "mobile crushing-reloading-conveyor complexes" (MCRCC) depend on the specific geological and mining conditions. Also, when using mobile crushing complexes, it is necessary to predict the efficiency of mining operations, and also take into account the reliability of the equipment complex and the environmental consequences of operating crushing plants in the quarry. In this regard, when making decisions on the use of mobile crushing complexes, it is necessary to scientifically substantiate and systematize the mining schemes.

2 Methods

When choosing the optimal technological scheme for overburden mining using MCRCC is necessary [4 – 6]:

1. Choose a type of crushing plant that would ensure the maximum productivity of the excavator and the required lumpiness of rocks with various physical and mechanical properties.
2. Select the optimal mining and handling equipment taking into account the required technological parameters, such as, for example, discharge height, excavator bucket capacity, its productivity, method of loading into the crusher hopper, etc.
3. Take into account the presence and type of reloaders (horizontal or interstage).
3. Choose the type of downhole conveyor (mobile or telescopic).
4. Choose the installation method of the crushing plant during the loading, followed by the excavator and parallel to the bottom of the face.
5. Choose installation methods and moving the interstep loading crane.

The use of MCRCC is most appropriate when working out benches with longitudinal approaches. In this case, it is possible to practice the ledges from one position of the face conveyor in narrow (for one excavator approach) or wide (up to two to three excavator approach) strips.

3 Results and discussion

Consider various significant options for the application of technological schemes using MCRCC.

1-option. The technological scheme of the development of rocks with the end position of the MCRCC using a single-bucket excavator and conveyor transport. This technological scheme is used when mining long blocks or small open cast mine with no blasting development of semi-overburden rocks (Fig. 1, *a*) [2, 7].

2-option. The technological scheme of the development of rocks with the end position of the MCRCC and the increased width of the working platform with conveyor transport (Fig. 1, *b*) [2, 6].

The number of movements of the downhole conveyor is reduced by introducing into the technological scheme a telescopic mobile conveyor or a mobile belt and interstage conveyor reloader. Their sufficient length allows the downhole conveyor to be installed outside the danger zone during blasting operations.

Installation of a mobile conveyor reloader ensures a safe distance to the downhole conveyor and reduces the cost of moving the conveyor stand.

3-option. Technological scheme of working out benches by longitudinal approaches by the MCRCC complex with a lateral location of the downhole conveyor and the presence of a mobile interstart-reloader with sequential mining operations at 3 horizons (Fig. 2)

According to this technological scheme, the downhole conveyor is initially installed on the second ledge (between the first and third ledges). MCRCC sequentially fulfills the first step (Fig. 1, *a*), then the third (Fig. 1, *b*) and at the end of the second step (Fig. 2, *c*). After that, the downhole conveyor frontally moves along the width of the excavator's entry [7].

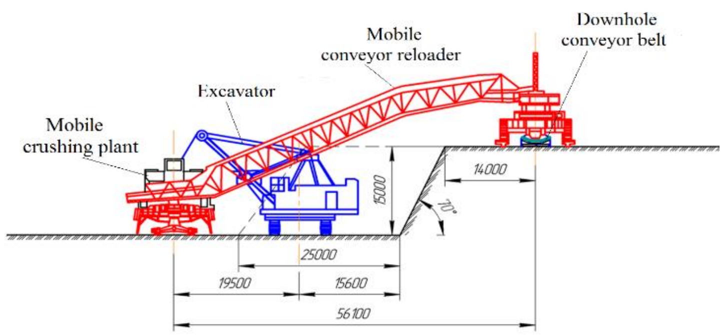
The working time of the complex during the development of one block (cycle) is:

$$T_{CYCLE}^{1} = \frac{V_{BLOCK}}{Q_{oper}^{h} K_{p}} = \frac{B_{W} L_{B} H_{L}}{Q_{O.P.} K_{p}}, \tag{1}$$

where $Q^{h}{}_{oper}$ is the operational productivity of the complex, m^3/h; K_p is coefficient of productivity reduction, taking into account the shutdown of the complex, technological and organizational factors (K_p = 0.85 – 0.95); V_{BLOCK} is the volume of the processed block, m^3; B_W is excavation trench width, m; L_B is block length, m; H_L is ledge height, m.

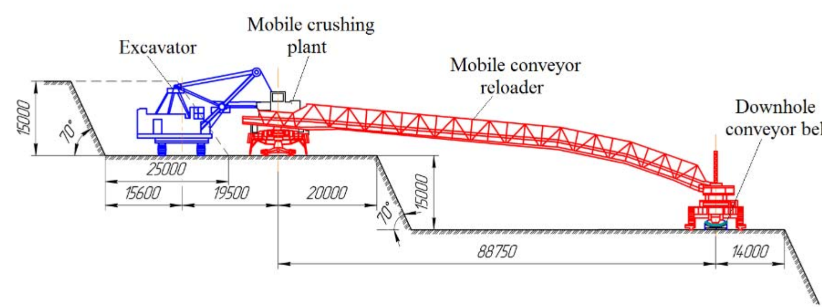
a

Bench-1, Horizon -15.0 m



b

Bench-3, Horizon +15.0 m



c

Bench-2, Horizon +0,0 m

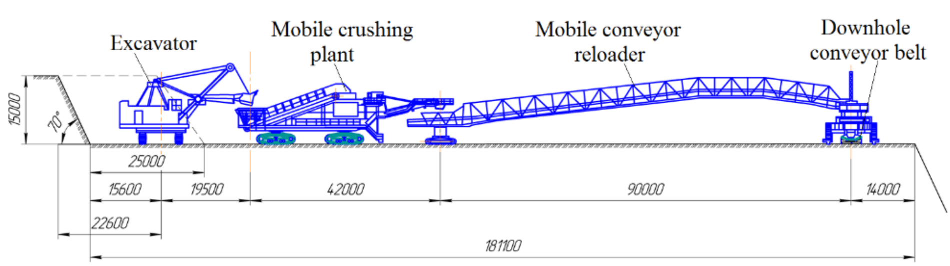


Fig. 2. The technological scheme of working out the benches with longitudinal runs by the MCRCC complex with a lateral location of the downhole conveyor and the presence of a mobile interstage loading crane with sequential mining operations at 3 horizons: *a* - the complex operates on a 1 ledge; *b* – the operation of the complex on a 3-step; *c* – operation of the complex on a 2-step.

The time of movement of the downhole conveyor is determined by the formula [8]:

$$T_{D.S.M.} = t_p + \frac{B_W L_d K_i}{K_s^t P_T} + t_f \text{, h,} \tag{2}$$

where t_p is the time for preliminary and auxiliary operations when moving the conveyor stand (t_p = 3 h according to [8]); L_d is the length of the stav downhole conveyor, m; K_i is coefficient taking into account the influence of production conditions on the implementation of the movement process (K_i = 1.2 according to [8]); K_s^t is coefficient of use of the tournode doser during the shift (K_s^t = 0.56 according to [3]); t_f is time for final operations when moving the conveyor bed (t_f = 4 hours according to [8]); P_T is technical productivity of the tournode doser:

$$P_T = v_T + B_T, \text{m}^2\text{/h}, \tag{3}$$

where v_T is operating speed of a tournode doser, m/h; B_T is step width of the stroke of the tournode doser, m.

The annual operating time of the complex, taking into account the working time of the excavator, is determined by the formula:

$$T_A = T_{SH} n_{SH} N_W K_U, \tag{4}$$

where T_{SH} is the duration of the shift, h; n_{SH} is the number of shifts per day; N_w is the number of working days of the excavator per year; K_U is utilization factor of the complex change time (is K_B = 0.73 – 0.85).

The number of cycles performed in the developed blocks of the complex per year is determined by the formula:

$$N^1_{CUCLE} = \frac{T_A}{N^1_{CUCLE} + T_{m.d.k.}}. \tag{5}$$

The annual productivity of the complex is determined by the formula:

$$Q^A_{COM} = V_{BLOCK} \cdot N^1_{CYCLE} = B_W L_B H_L \cdot N^1_{CYCLE}, \text{ m}^3\text{/year}. \tag{6}$$

Table 1 shows the results of calculations of the annual productivity of the MCRCC complex at different block lengths according to the 1st option of the technological scheme.

Table 1. Calculation results of the MCRCC complex during the development of benches according to the technological scheme for the development of rocks with the end face of the equipment using a bucket excavator and conveyor transport.

Q^A_{COM}, m³/year	Q^h_{oper}, m³/h	V_{BLOCK}, m³	T_{CYCLE}, h	L_{BLOCK}, m	$T_{D.S.M.}$, h	T_A, h	N^1_{CYCLE}
4767252.6	1478	53400	40.14	200	19.71	5344	89.3
4960630.4	1478	80100	60.21	300	26.07	5344	61.9
5063324.2	1478	106800	80.28	400	32.43	5344	47.4
5127007.1	1478	133500	100.4	500	38.79	5344	38.4
5170359.8	1478	160200	120.4	600	45.14	5344	32.3
5201777.6	1478	186900	140.5	700	51.5	5344	27.8
5225592.7	1478	213600	160.6	800	57.86	5344	24.5
5244266.9	1478	240300	180.6	900	64.21	5344	21.8
5259302.5	1478	267000	200.7	1000	70.57	5344	19.7
5271668.7	1478	293700	220.8	1100	76.93	5344	17.9
5282018.4	1478	320400	240.8	1200	83.29	5344	16.5
5290807.6	1478	347100	260.9	1300	89.64	5344	15.2
5298364.6	1478	373800	281.0	1400	96.0	5344	14.2
5304931.4	1478	400500	301.1	1500	102.4	5344	13.2

Table 2 shows the results of calculations of the annual productivity of the MCRCC complex at different block lengths according to the 2nd option of the technological scheme.

Table 2. Calculation results of the MCRCC complex when using the technological scheme for the development of rocks with the end arrangement of MCRCC with an increased width of the working platform.

$Q^A{}_{COM}$, m³/year	$Q^h{}_{oper}$, m³/h	V_{BLOCK}, m³	T_{CYCLE}, h	L_{BLOCK}, m	$T_{D.S.M.}$, h	T_A, h	$N^1{}_{CYCLE}$
4917382.9	1478	106800	83.63	200	32.43	5344	46.04
5018275.7	1478	160200	125.4	300	45.14	5344	31.33
5070290.8	1478	213600	167.3	400	57.86	5344	23.74
5102020.6	1478	267000	209.1	500	70,57	5344	19.11
5123395.4	1478	320400	250.9	600	83.29	5344	15.99
5138773.1	1478	373800	292.7	700	96.0	5344	13.75
5150367.0	1478	427200	334.5	800	108.7	5344	12.06
5159420.8	1478	480600	376.3	900	121.4	5344	10.74
5166686.8	1478	534000	418.1	1000	134.1	5344	9.68
5172646.9	1478	587400	460.0	1100	146.9	5344	8.81
5177624.2	1478	640800	501.8	1200	159.6	5344	8.08
5181843.2	1478	694200	543.6	1300	172.3	5344	7.46
5185465.0	1478	747600	585.4	1400	185.0	5344	6.94
5188608.0	1478	801000	627.2	1500	197.7	5344	6.48

Table 3 shows the results of calculations of the MCRCC complex when developing benches according to the technological scheme according to the 3-option.

Table 3. Calculation results of the MCRCC complex during the development of benches according to the technological scheme for working off the benches by longitudinal approaches by the MCRCC complex with a lateral location of the downhole conveyor and the presence of a mobile interstart loading crane with sequential mining operations at 3 horizons.

$Q^A{}_{COM}$, m³/year	$Q^h{}_{oper}$, m³/h	V_{BLOCK}, m³	T_{CYCLE}, h	L_{BLOCK}, m	$T_{D.S.M.}$, h	T_A, h	$N^1{}_{CYCLE}$
3441427.8	1478	156600	223.73	200	19.43	5344	21.98
4034255.7	1478	234900	285.50	300	25.64	5344	17.17
4414479.6	1478	313200	347.26	400	31.86	5344	14.09
4679078.2	1478	391500	409.03	500	38.07	5344	11.95
4873832.7	1478	469800	470.80	600	44.29	5344	10.37
5023173.1	1478	548100	532.56	700	50.5	5344	9.165
5141325.6	1478	626400	594.33	800	56.71	5344	8.208
5237136.4	1478	704700	656.10	900	62.93	5344	7.432
5316394.9	1478	783000	717.86	1000	69.14	5344	6.79
5383049.6	1478	861300	779.63	1100	75.36	5344	6.25
5439885.4	1478	939600	841.40	1200	81.57	5344	5.79
5488923.1	1478	1017900	903.16	1300	87.79	5344	5.392
5531664.6	1478	1096200	964.93	1400	94.0	5344	5.046
5569249.3	1478	1174500	1026.70	1500	100.2	5344	4.742

Fig. 3 shows the dependence of the annual capacity of the MCRCC complex on the length of the block when comparing three options of technological schemes:

1-option – a flow chart of the development of rocks with the end-face arrangement of the MCRCC using a single-bucket excavator and conveyor transport;

2-option – a technological scheme for the development of rocks with an end arrangement of MCRCC and an increased width of the working platform for conveyor transport;

3-option – a technological scheme for working out benches with longitudinal runs by the MCRCC complex with a lateral location of the downhole conveyor and the presence of a mobile interstart- reloader with sequential mining operations at 3 horizons.

Graphic dependence in Fig. 3 shows that in all three variants of technological schemes with an increase in the length of the block from 200 to 1800 m, the annual productivity of the system increases from 3 500 000 to 5 800 000 m^3/year. The graph shows that the system performance in the first and second variants have almost the same value. In the second version of the technological scheme, with an increase in the length of the block from 500 m, the system performance is significantly reduced compared to the first version. In the third version of the technological scheme, the system performance is even faster with a small block length, but with an increase in the length of the block from 700 m it rapidly increases. The low performance of the system with a block length of up to 700 m can be explained by the fact that in the third version of the technological scheme, the number of idle transfers of the complex is larger compared to the first and second options.

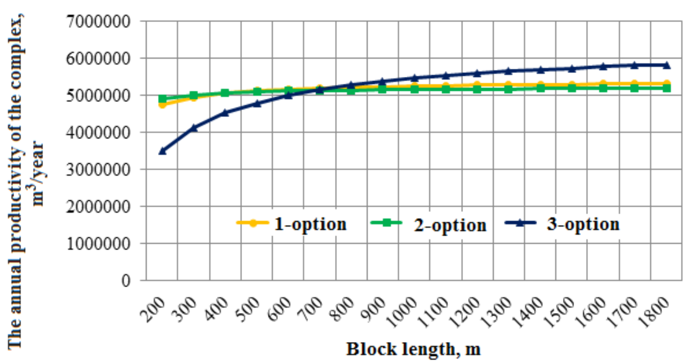


Fig. 3. Dependence of the annual productivity of the MCRCC complex on the length of the block and a comparison of three variants of technological schemes.

Thus, a methodology has been developed for determining the working time and annual productivity of the MCRCC complex by comparing three variants of technological schemes and the dependence of the annual productivity of the MCRCC complex on the block length is established.

Comparison of the three options of technological schemes, given above, showed that it is necessary to develop a fundamentally new technological scheme of central heating systems with MCRCC, which provides high system performance and low time spent on idling.

To reduce the time for idle shifting of the complex and reduce the number of exit ledges, a new technological scheme for the development of overburden ledges with the use of central heating systems with MCRCC is recommended (Fig. 4).

We have developed a new technological scheme (4-option). According to this technological scheme, the MCRCC system works on two horizons. In this case, the downhole conveyor is installed on the upper ledge. Excavator-mobile crushing-reloading-conveyor complexes first the lower ledge, and then the upper one with two runs. After that, the downhole conveyor moves along the front of the excavator [12].

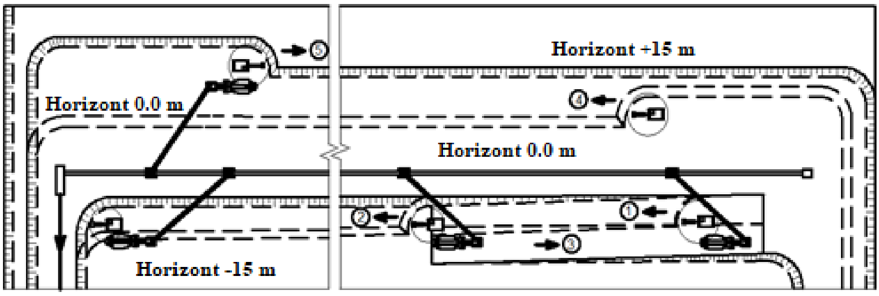


Fig. 4. The technological scheme of working out the benches with longitudinal runs by the MCRCC complex with a lateral location of the downhole conveyor and the presence of a mobile interstage reloader with sequential mining operations at two horizons.

According to this technological scheme, the MCRCC system works on two horizons. In this case, the downhole conveyor is installed on the upper ledge. Excavator-mobile crusher – an interstage reloader works first on the lower ledge, and then on the upper ledge with two runs. After that, the downhole conveyor moves along the front of the excavator. Technological processes during mining operations on the exit ledge using MCRCC are shown in Table 4.

Table 4. Technological processes of mining at the exit ledge using MCRCC.

Process number	Process name	Process brief
1	Development of the first inclined exit ledge with the descent to the lower horizon	$R_{EL(1)}$
2	Development of the left flank of the main lower ledge	$R_{ML(1L)}$
3	U-turn and reverse movement of the complex on the left flank of the lower ledge	$D_T + D_{ML(1L)}$
4	Development of a second inclined exit ledge	$R_{EL(2)}$
5	U-turn and reverse movement of the complex along the right flank of the lower ledge	$D_T + D_{ML(1R)}$
6	Moving the complex along the first inclined exit ledge to the upper horizon	$D_{EL(1)}$
7	Moving the complex to its starting position on the upper ledge	$D_{SP(2)}$
8	Development of the first entry of the upper ledge	$R_{ML(1E)}$
9	Development of the second entry of the upper ledge	$R_{ML(2E)}$
10	Movement of the complex by turning to the first starting position	$D_{SP(1)}$
11	Downhole conveyor movement	D_C

According to the Table 1, combining the relevant processes, we determine the full cycle of MCRCC in the following form [6]:

$$1CYCLE = \left[R_{EL(1)} + R_{EL(2)}\right] + \left[R_{ML(1L)} + R_{ML(1E)} + R_{ML(2E)}\right] +$$
$$+\left[D_T + D_{ML(1L)} + D_T + D_{ML(1R)} + D_{EL(1)} + D_{SP(2)} + D_{SP(1)} + D_C\right] =$$
$$= 2R_{EL} + R_{ML(1L)} + 2R_{ML(2)} + 2D_T + D_{ML(1)} + D_{EL(1)} + 2D_{SP} + D_C.$$

The time of one cycle of working out of two benches with the use of MCRCC is [6]:

$$T_{CYCLE} = 2T_{R.EL} + T_{R.ML(1L)} + 2T_{R.ML(2)} + 2T_{D.T} + T_{D.ML(1)} + T_{D.EL(1)} + 2T_{D.SP} + T_{D.C}, \text{ h.}$$

Table 5 shows the results of calculations of the MCRCC complex when developing two benches according to the recommended technological scheme for different block lengths.

Table 5. The results of calculations of the MCRCC complex when developing two benches according to the technological scheme for different block lengths.

Q^A_{COM}, m³/year	Q^h_{oper}, m³/h	V_{BLOCK}, m³	T_{CYCLE}, h	L_{BLOCK}, m	$T_{D.S.M.}$, h	T_A, h	N^1_{CYCLE}
4443906.3	1478	160200	172.9	200	19.71	5344	27.74
4938030.1	1478	240300	234.0	300	26.07	5344	20.55
5228724.6	1478	320400	295.0	400	32.43	5344	16.32
5420171.0	1478	400500	356.1	500	38.79	5344	13.53
5555785.3	1478	480600	417.1	600	45.14	5344	11.56
5656883.1	1478	560700	478.1	700	51.5	5344	10.09
5735154.5	1478	640800	539.2	800	57.86	5344	8.95
5797546.0	1478	720900	600.2	900	64.21	5344	8.042
5848445.1	1478	801000	661.3	1000	70.57	5344	7.301
5890759.4	1478	881100	722.3	1100	76.93	5344	6.686
5926492.0	1478	961200	783.4	1200	83.29	5344	6.166
5957067.5	1478	1041300	844.4	1300	89.64	5344	5.721
5983527.3	1478	1121400	905.5	1400	96.0	5344	5.336
6006650.0	1478	1201500	966.5	1500	102.4	5344	4,999

The results show that the performance of the MCRCC complex increases with increasing block length. This is due to a decrease in the number of cycles during the work period during the year.

Studies have also found that the productivity of the MCRCC complex increases with a decrease in the specific time for moving the downhole conveyor during the working cycle.

As a result of the calculations of the MCRCC complex during the development of two benches with different block lengths, the dependence of the annual capacity of the MCRCC complex on the block length was established (Fig. 5).

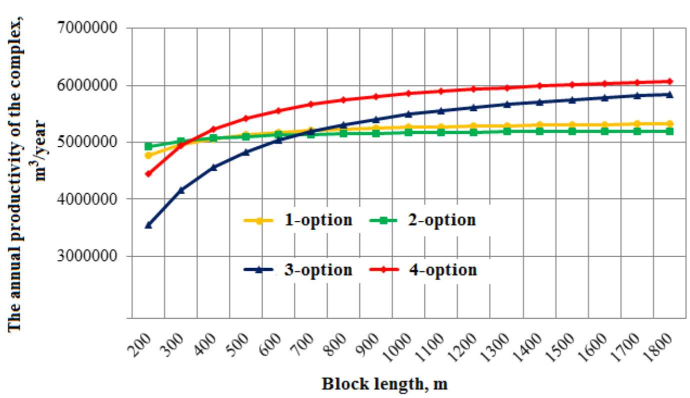


Fig. 5. The dependence of the annual productivity of the MCRCC complex on the length of the block and its comparison with the previous three variants of technological schemes.

Comparison of the new technological scheme for working out benches with longitudinal runs by the MCRCC complex with a lateral location of the downhole conveyor and the presence of a mobile interstage loading crane with sequential mining operations at two horizons showed its high productivity with an increase in the length of the block. Compared to the third technological scheme, idle shifts of the complex are reduced by 33%, travel time on the exit ledge – by 50%, and productivity of the entire complex is increased by 20%. At the same time, technological indicators are the best in comparison with the three previous technological schemes.

4 Conclusions

The novelty of this technological scheme is the movement of the complex following the movement of the excavator in the face and thereby ensuring the flexibility and mobility of the entire mining and transport system. In combination with continuously operating conveyors, a mobile crushing complex allows you to abandon the necessary for an alternative excavator-motor transport scheme and a fleet of heavy-duty dump trucks. In addition to reducing the cost of mining, the development technology based on the new fully mobile crushing system also provides a significant reduction in emissions of exhaust gases into the surrounding atmosphere.

Thus, the recommended process flow diagram for overburden development using mobile crushing plants ensures the dynamic development of mining operations along the front and depth with high technical and economic indicators of mining.

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