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# High productive longwall mining of multiple gassy seams: best practice and recommendations

*Oleg KAZANIN[1], Andrey SIDORENKO[2]*, Sergey SIDORENKO[3], Vladimir IVANOV[4] and Helmut MISCHO[5]*

**Authors' affiliations and addresses:**
[1] Saint-Petersburg Mining University, Saint Petersburg, Russia
e-mail: kazanin@spmi.ru

[2] Saint-Petersburg Mining University, Saint Petersburg, Russia
e-mail: sidorenko_aa@pers.spmi.ru

[3] Saint-Petersburg Mining University, Saint Petersburg, Russia
e-mail: sidorenko_sa@pers.spmi.ru

[4] Saint-Petersburg Mining University, Saint Petersburg, Russia
e-mail: ivanov_vv@pers.spmi.ru

[5] Bergakademie Freiberg, Freiberg, Germany
e-mail: helmut.mischo@mabb.tu-freiberg.de

***Correspondence:**
Andrey Sidorenko, Saint-Petersburg Mining University, 2, 21st Line, St Petersburg 199106, Russia
e-mail: sidorenko_aa@pers.spmi.ru

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**Abstract**
The article discusses the experience of reaching longwall's record coal production levels at the mine named after V. D. Yalevsky in the Kuznetsk Basin (Russia). The features of the geological and mining conditions at the mine being discussed. Several aspects and parameters were analyzed in the course of the study, including the technological solutions that made it possible to reach high production levels when mining multiple coal seams that demonstrate spontaneous combustion propensity, the methane emission control and ground control methods used at the mine, and changes in the output rate and methane emissions from the panel being mined. It is demonstrated that it is possible to increase the output rate for longwall up to 1.5 million tonnes per month when mining thick coal seams with methane contents that do not exceed 7 $m^3/t$. With an increase in methane contents up to 10 $m^3/t$, the output rate has to be slowed down due to the limited methane control capabilities. It is shown that preliminary degasification is required, with relevant options being proposed. The article also discusses the necessity of conducting development operations in a timely manner when coal output rates are high, and solutions are proposed as to how it can be achieved. In the course of the study, it was found out that longwall move operations at the Yalevsky mine could be improved. As a result, measures were developed, such as selecting the best location for the recovery room, and other recommendations were given to make longwall move operations more efficient. Numerical simulations were made to analyze the methane emission process at the longwall panel, the results of which made it possible to develop recommendations for adjusting the degasification parameters and changing the distance between ventilation crosscuts to improve methane control at the longwall panels. Also, recommendations were given to achieve the highest coal production levels possible.

**Keywords**
underground mining, coal, multiple seam mining, high gas contents, longwall mining, highly productive mining operations, methane control, mining equipment

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## Introduction

In 2017 and 2018, several coal output records were set at the Yalevsky mine that extracts coal seams located in the Kuznetsk Basin (Russia) using the longwall mining method. In May 2017, 1.4 million tonnes of coal were extracted from seam No. 50 in longwall panel No. 5003 (Meshkov et al., 2018), and in July 2017, coal production amounted to 1.567 million tonnes (Artemyev & McInally, 2018). The next record-1.627 million tonnes of coal-was set in July 2018. It became possible by using state-of-the-art high-performance mining equipment: the Eickhoff SL-500 shearer, the DBT 2550/5500 shield (Caterpillar), and the Cat AFC PF6 armoured face conveyor (Caterpillar). It should be noted that this equipment also made it possible to increase the panel width to 400 m, which is the biggest panel width in Russia (Meshkov et al., 2018).

It should be noted that the longwall mining operations are characterized by high methane emission at longwall panel, massive water inflows, and a high risk of spontaneous combustion. These challenges had to be tackled for the mine to achieve high production levels. A combined ventilation system for longwall panel and vertical gob degassing boreholes was used to solve the issues associated with methane emission. The parameters of the entries and the methane drainage schemes were optimized, taking into account the experience that mining engineers had accumulated in dealing with risks and factors complicating mining operations (Okolnishnikov et al., 2018), (Cherdantsev, 2018), (Okolnishnikov et al., 2019).

It is of particular interest to analyze the experience gained in achieving record production levels when mining multiple coal seams prone to spontaneous combustion. It can help identify both the main factors that hinder longwall mining operations and the best solutions that can mitigate the influence of these factors. Thus, the experience of the Yalevsky mine not only demonstrated that it is possible to set records in productivity but also made it possible to identify issues associated with using high-performance mining equipment in the context of complicating factors and find ways that indicate how highly productive mining techniques should develop in the future.

The aim of the study is to analyze the operations in the longwall faces with the highest production levels at the Yalevsky mine and to develop recommendations on how to improve longwall operations when mining multiple coal seams with high gas contents.

## Geological and mining conditions

The coal seams at Yalevsky mine belong to the Sokolovskoye deposit of the Kuznetsk Basin. The mine acquired its name in 2016 after the merger of the Kotinskaya mine and Mine No. 7. The seams being developed have thicknesses ranging from 1.3 to 6.5 m (Fig. 1).

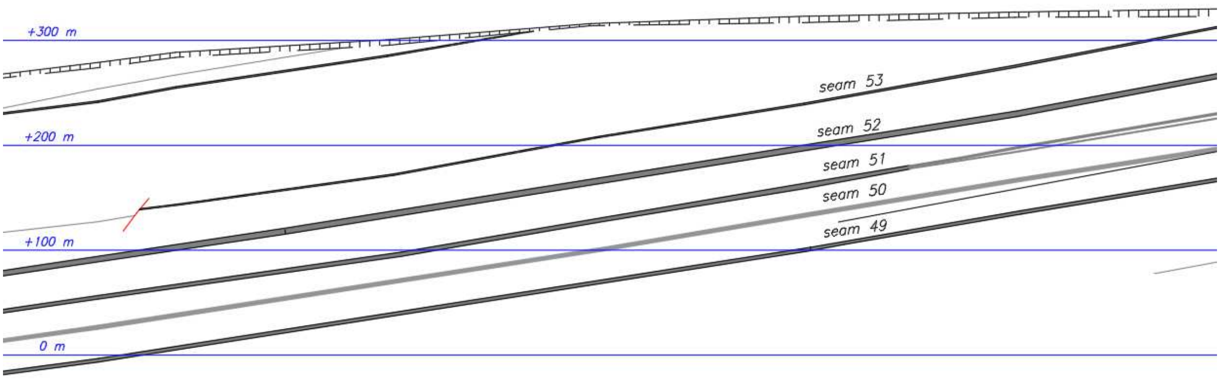


*Figure 1. Geological cross-section (the Yalevsky mine)*

The distances between the seams range from 27 to 86 m. The angle of dip varies from 0 to 15 degrees. All seams are characterized by high gas contents. Methane contents start growing at a depth of 130 m and reach a maximum of 15 $m^3$/t at a depth of 500 m. The seams are prone to spontaneous combustion. The incubation period ranges from 48 to 56 days. The block being mined is not prone to rock bursts. Massive water inflows negatively affect mining operations, with inflow rates ranging from 400 to 900 $m^3$/h.

Currently, two longwall panels are being mined, in which coal is extracted from seam No. 50 and seam No. 52. The distance between them ranges from 62 to 90 m. Mining operations in seam No. 50 are being conducted below the mined-out areas of seam No. 52, which reduces methane emissions from the overlying coal seams. However, the coal pillars that were left between the longwall panels when developing seam No. 52 form high-pressure zones in seam No. 50 (Kovalsky et al.,2018).

**Longwall operations with record coal output: a case study**

The Yalevsky mine started developing seam No. 50 in 2016 with extracting panel No. 5003 (Fig. 2). To solve the problem of massive water inflows, the longwall panels in seam No. 50 were designed to be located at an angle of about 10 degrees to the strike of the seam and to the longwall panels in seam No. 52 (Fig. 2). This enables the longwall face to advance up the dip and prevents it from flooding. To prevent the hydrodynamic connection to underground mining operations from the surface, the mining of longwall panel No. 5001 was postponed.

When starting to develop longwall panel No. 5002, its width was 300 m, which made it necessary to reverse the cutting direction quite often as well as shearer operations near the T-junctions to start cutting new strip were used, which led to a decrease in the production capacity of the shearer. In addition, the output rate was limited by the inadequate capacity of the armoured face conveyor and the stage loader. As a result, longwall panel No. 5002 reached its maximum output rate of one million tonnes of coal per month.

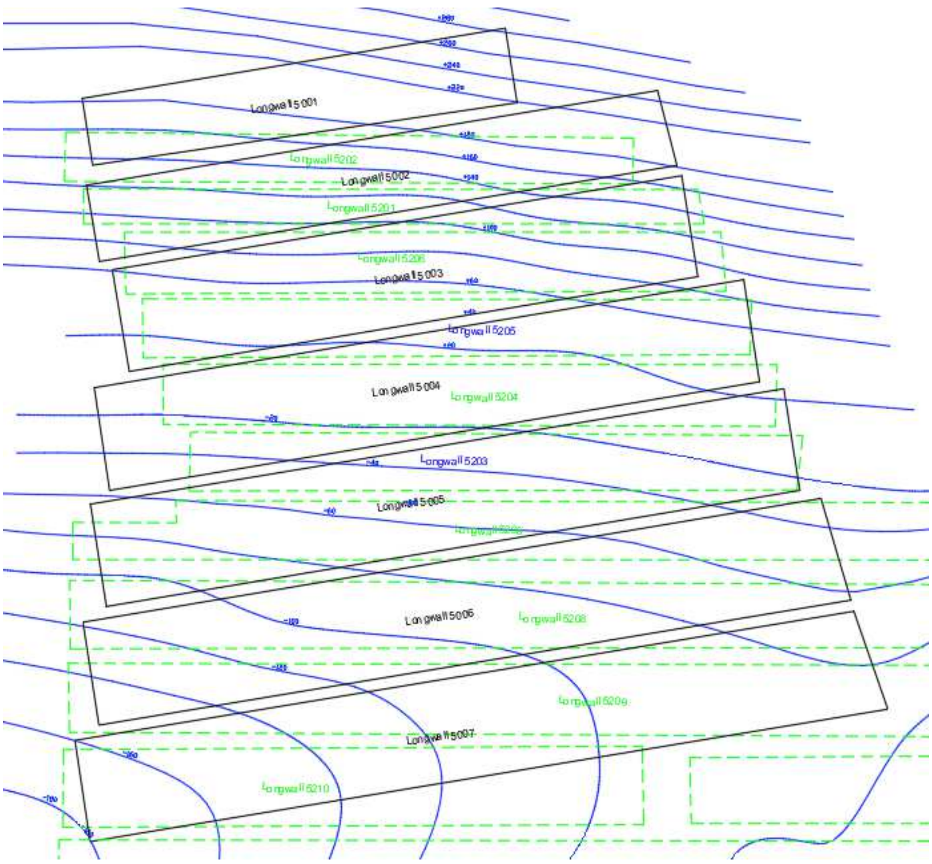


*Figure 2. Panel layout (seam No. 50 and seam No. 52)*

Taking into account the experience gained in mining longwall panel No. 5002, the panel width was increased to 400 m when the development of longwall panel No. 5003 started (Fig. 2). Also, an armoured face conveyor and a stage loader with higher capacities were procured. An increase in the panel width and the performance of the equipment, along with the fact that the depth of mining was relatively small and methane emissions were low, making it possible to achieve output rates ranging from 50,000 to 53,000 tonnes per day (Fig. 3) and produce 1.4 million tonnes of coal in May 2017. To find and achieve the highest possible output rate, mining operations were conducted under scrupulous supervision in July 2017, which made it possible to achieve a stable output rate of 50,000 tonnes of coal per day (Fig. 3) and to produce 1.567 million tonnes of coal in a month.

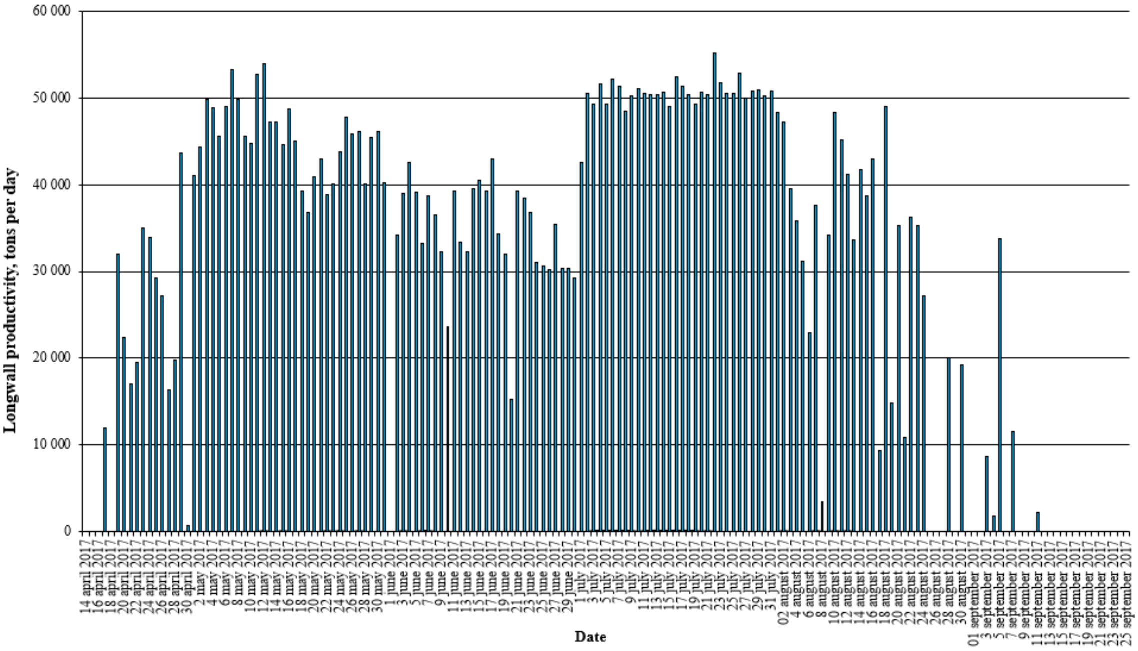


*Figure 3. Changes in the daily output rates of longwall panel No. 5003*

Despite the fact that the depth of mining ranged from only 160 to 240 m and methane contents ranged from 5 to 7 $m^3/t$, extracting huge amounts of coal in the presence of overlying and underlying seams with high methane contents resulted in massive methane emissions ranging from 80 to 118 $m^3/min$ (Fig. 4). About 90% of methane was released from adjacent coal seams and accumulated in the gob, from where it was removed using methane drainage techniques.

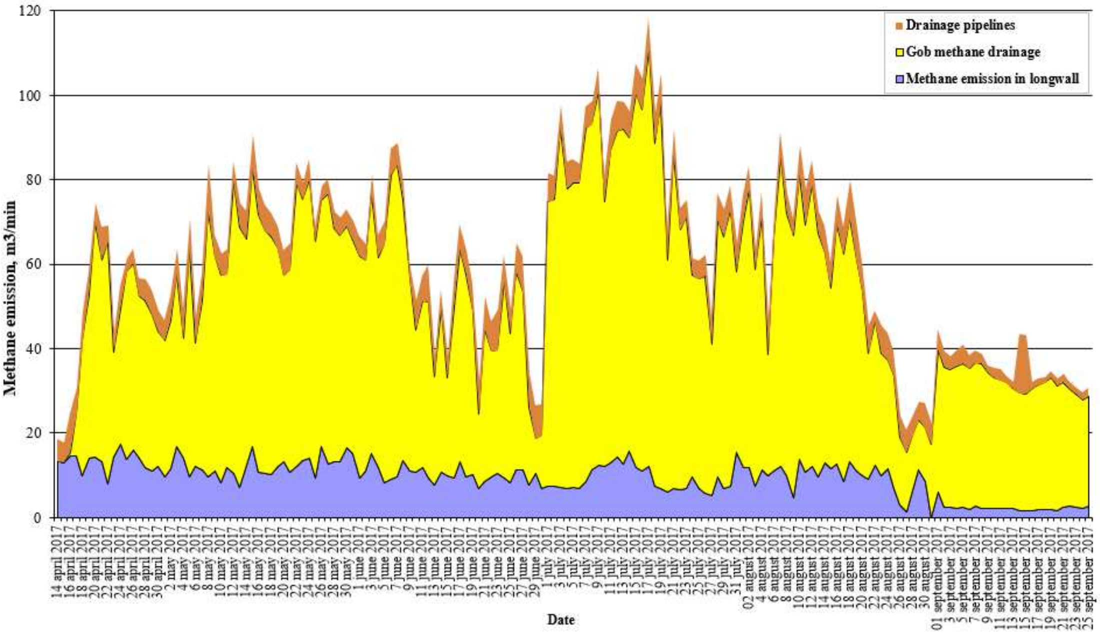


*Figure 4. Changes in methane emissions removed from longwall panel No. 5003*

The use of an efficient ventilation system with an airflow rate of up to 3,000 $m^3/min$, drilling vertical gob degassing boreholes, and the use of bleeder gas suction fans (Fig. 5) to remove methane from the gob through the stopping behind the longwall face made it possible to eliminate methane accumulation in the longwall face. To prevent the coal in the gob from spontaneous combustion, only four boreholes closest to the longwall face and the closest crosscut were used to remove methane. It should be noted that the main volumes of methane emissions (up to 100 $m^3/min$) were removed from the gob through surface boreholes (Figs. 4 and 5), and the bleeder fans that remove methane through the crosscuts were used to ventilate the ends of the longwall face better and prevent methane from moving to the face from the gob. This technique prevented spontaneous combustion but required a lot of drilling. The distance between boreholes No. 1 and No. 2 was 40 m, and that between boreholes No. 3 and No. 4 was 70 m. The boreholes were drilled in advance of coal extraction and connected to vacuum units located on the surface after the face advanced. In total, 55 surface boreholes with a diameter of 220 mm were drilled to remove methane from longwall panel No. 5003.

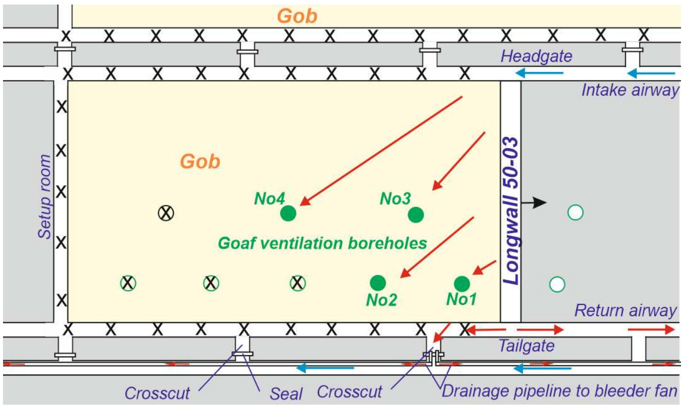


*Figure 5. The ventilation and methane drainage system in longwall panel No. 5003*

In longwall coal mining, methane sensors are used to monitor methane content in such key locations as the ends of the longwall face, the dead-end entry, the drainage pipeline, and the boreholes. By analyzing sensor data, a conclusion was made that the methane factor does not hinder a possible increase in coal output as even at the highest output rate, methane concentrations at the ends of the longwall face did not exceed 0.8% (with a permissible value of 1%). Fig. 6 shows fluctuations in methane concentrations at the control points over two days (July 15 and 16, 2017). The bleeder fans also provide for an increase in coal production since methane concentrations in the drainage pipeline ranged from 0.7 to 1.2% (with a permissible value of 3%).

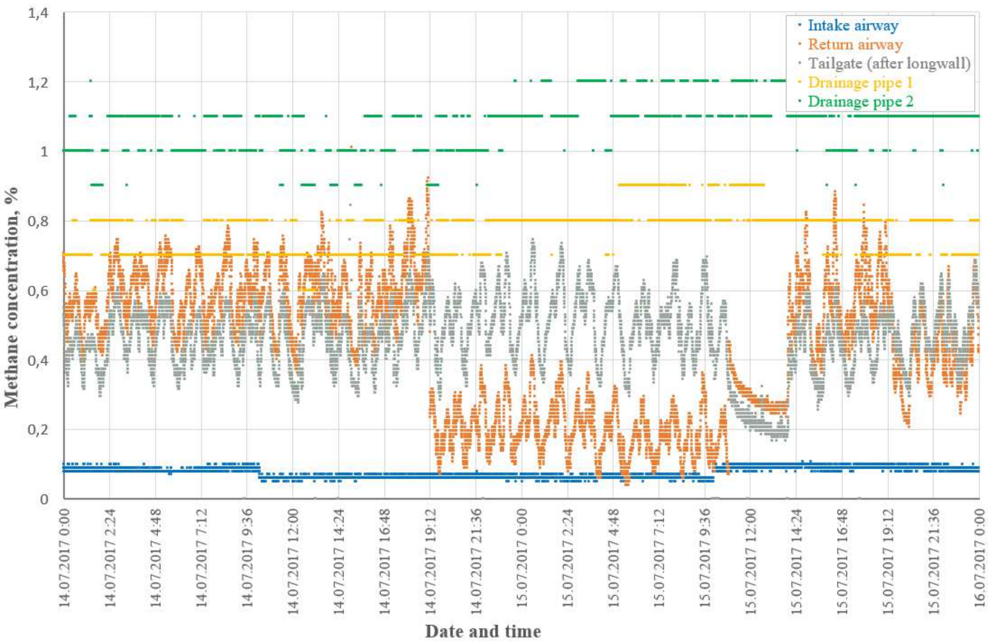


*Figure 6. Methane concentrations in the key locations*

The experience of extracting longwall panel No. 5003 showed that under favourable geological and mining conditions, the use of reliable, high-performance equipment and the best available methane emission control techniques makes it possible to achieve record production levels (more than 1.5 million tonnes of coal per month) without compromising safety (Rudakov, 2016), (Gendler et al., 2020), (Kabanov et al., 2019). However, an increase in the output rate brought about a new problem associated with development operations. Higher output rates mean that the face advances faster, and development operations did not keep up with such rates. This delay resulted in six months of longwall equipment downtime (Fig. 7).

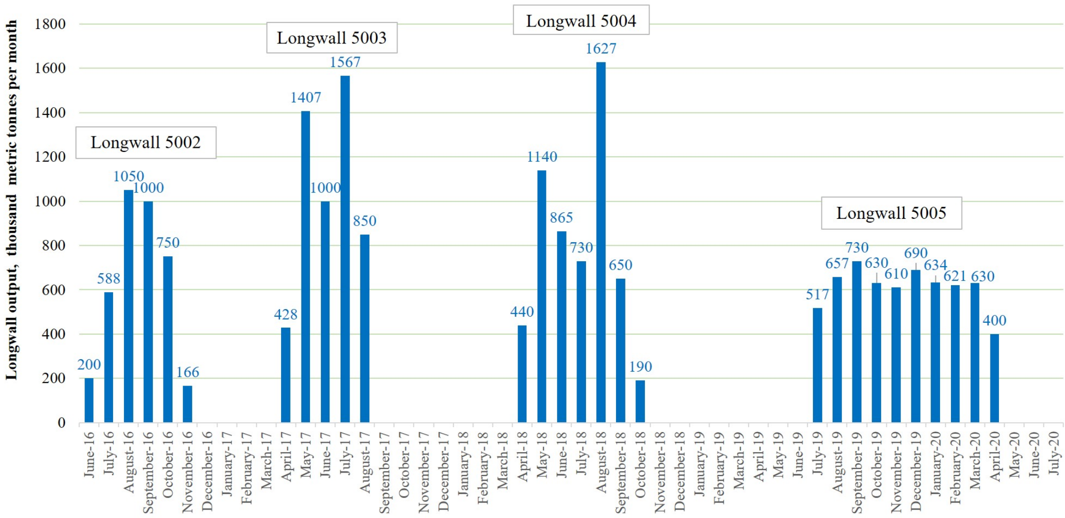


*Figure 7. Fluctuations in monthly output rates*

A new record was set when extracting longwall panel No. 5004: more than 1.627 million tonnes of coal were produced in August 2018 (Fig. 7). However, after the panel was rapidly mined out, production operations in the next panel (5005) were delayed due to development operations lagging behind, which again resulted in a lot of downtimes. Thus, periods of record-high production levels alternated with periods of downtime that were comparable in length, which led to a significant decrease in annual coal production.

It should be noted that longwall move operations also made a contribution to such long periods of downtime. They became more time-consuming due to an increase in the volume of work and the weight of the equipment as a result of an increase in the panel width and because of imperfect transportation equipment and management.

As production operations advanced, the depth of mining increased from 200 to 400 m, and methane contents in coal seams exceeded 10 $m^3/t$, resulting in great methane emissions. Consequently, the planned output rate was reduced to 800 thousand tonnes of coal per month (Fig. 7).

**Substantiation of methane control parameters using gas release process modelling**

To substantiate methane control parameters at the Yalevsky mine, a model of the gas release process was developed. The three-dimensional model of the panel being mined out (Fig. 8) includes the longwall face, the gob, the headgate and the tailgate, gob drainage boreholes, and the crosscut for removing the methane-air mixture using bleeder fans. When developing the model, methane emissions from the seam being mined out as well as from the overlying and underlying coal seams were taken into account (Fig. 8).

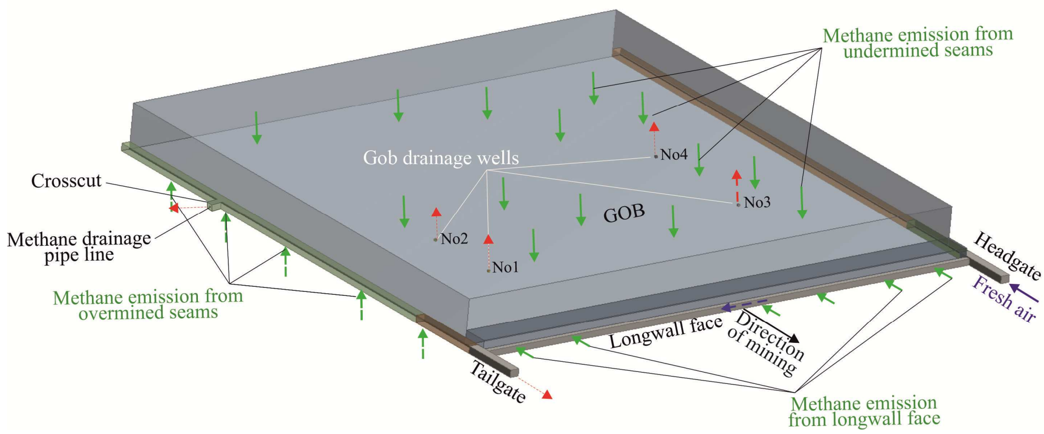


*Figure 8. The gas release process model*

In the model, the permeability of the part of the gob behind the longwall face reached $5x10^{-6}$ $m^2$ and decreased to $3x10^{-8}$ $m^2$ in the rest of the gob. The permeability of the gob right immediately after the longwall face has a significant effect on the efficiency of degasification and ventilation as it influences the volume of air leaks. Observations at the Yalevsky mine showed that the residual cross-section of the working behind the longwall face was enough to let air pass through, which has a significant effect on aerodynamic processes.

At the first stage of modelling, the adequacy of the model was tested by comparing the results it produced with on-site observations. At the next stages, the efficiency of using various borehole layouts was assessed, and the distance was measured to the ventilation crosscut through which the methane-air mixture is diverted.

As an example of the results that were obtained, Figure 9 shows the distribution of methane concentrations in the panel being mined at a distance of 2 m from the floor (A – high concentration in the gob; B – low concentration in the longwall and in the entries).

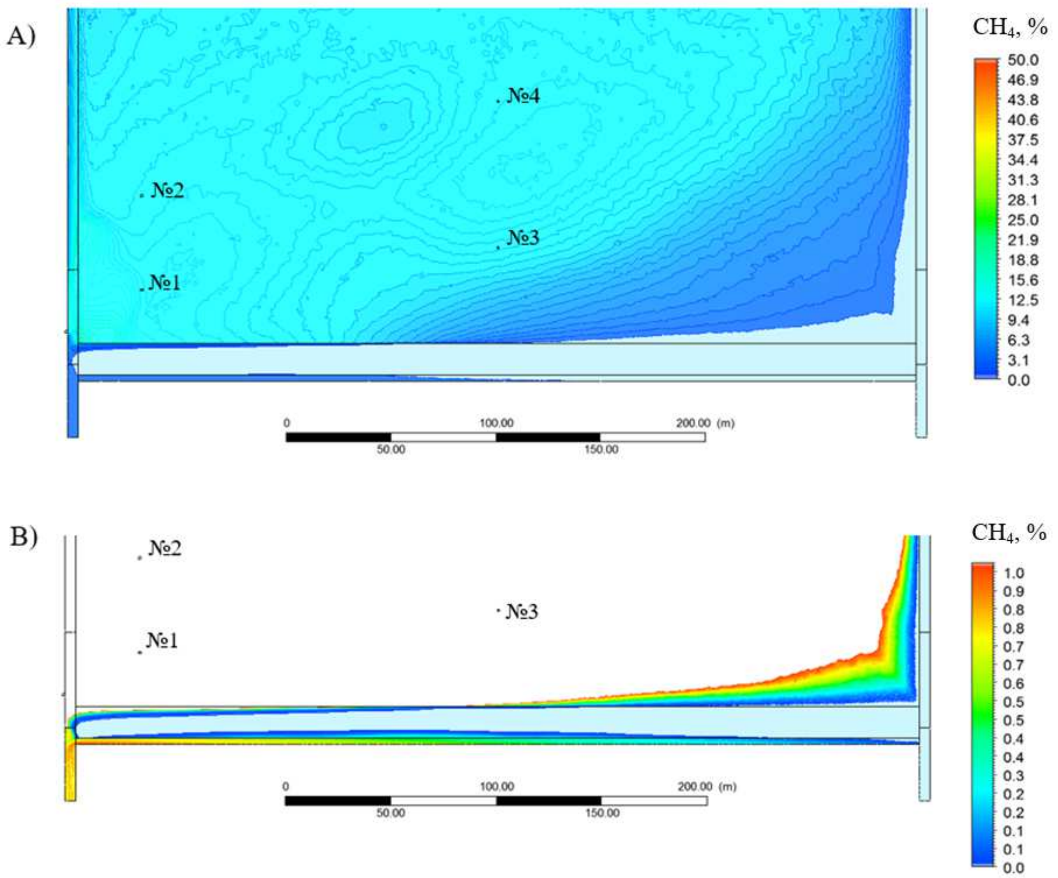


*Figure 9. Methane concentrations in the gob (longwall panel No. 5003)*

The results of the tests made it possible to conclude that it was necessary to increase the distance between the boreholes in the second row and to drill them closer to the ventilation crosscut since the central section located immediately behind the longwall face demonstrated a decrease in methane concentration and a decrease in the efficiency of the boreholes. It is recommended that the distance between the boreholes in the second row should be twice as large as the distance between the boreholes in the first row, which is taken equal to the caving step. The distance from the boreholes in the second row and the ventilation crosscut should range from 120 to 150 m (at a panel width of 400 m).

By analyzing the effect of different distances to the ventilation crosscut, a conclusion was made that it was necessary to reduce the distance between the crosscuts to 100 m because with an increase in the distance from the longwall face, the volume of methane removed by the bleeder fan decreases and methane concentrations grow, which is also associated with a gradual decrease in the residual cross-section of the working behind the longwall face.

The results of numerical modelling are confirmed by the data collected in the mine on how much methane is removed by the bleeder fans. Figure 10 shows that as the longwall face moves away from the crosscut and volumes of methane removed through the bleeder road increased.


*Figure 10. Changes in methane emissions removed through the bleeder road with an increase in the distance from the longwall face to the crosscut*

## Discussion

The example of the Yalevsky mine shows that it is possible to reach record-high production levels but also revealed several serious obstacles to maintaining high output rates:

- roadway development rates lag behind output rates;
- growth in output rates is hindered by imperfect methane emission control techniques;
- time-consuming longwall move operations result in longwall equipment downtime.

It should be noted that low roadway development rates have been seen to hinder production operations and negatively affect output rates in most top coal-producing countries (Peng, 2019), (Best Practice Guidance for Effective Methane Drainage and Use in Coal Mines, 2020). As a solution, it is proposed to use a conveyor train, which can increase development rates up to 90 m per day. However, this solution can only be applied in favourable geological and mining conditions (Peng, 2019). Another solution is to increase the panel width, which means that the shearer will have to extract a bigger volume of coal, and the rate of advance will decrease. However, at present, the maximum panel width is 482 m (Peng, 2019), (Longwall lead the way underground, 2020), (Trackemas, 2013), and its further increase implies a sharp growth in the capital and operating costs associated with the use of the armoured face conveyor as a result of a significant increase in chain weight (Trackemas, 2013). The complexity of the problem has become the reason why some mines limit their advance rates by operating their shearers only five days a week. We believe that to reduce downtime, it is important to factor in enough float time when planning mining operations.

At the Yalevsky mine, output rates were limited when mining seam No. 50 primarily due to an increase in methane emissions in the longwall panels as a result of an increase in gas contents of the formation. At the same time, methane drainage from the gob, which accounts for more than 90% of all methane removed, is carried out quite efficiently. To solve the problem of high methane concentrations at the longwall face, it can be recommended to use preliminary degasification by means of surface boreholes (Best Practice Guidance for Effective Methane Drainage and Use in Coal Mines, 2020), (Balusu et al., 2010) or roadways (Slastunov & Yutyaev, 2017), (Slastunov et al., 2016), (Yutyaev, 2017). However, the experience of degassing seam No. 52 shows that the efficiency of such measures is not high due to the low permeability of the seam. Another possible way to reduce gas contents in the seam being mined is degasification by means of overmining or undermining. At the Yalevsky mine, a decrease in the gas content of seam No. 50 can be achieved by mining seam No. 51, which is located above seam No. 50 at a distance of about 30 m. However, it is important to note that the efficiency of overmining in terms of degasification is low because its effects (stress relief and an increase in permeability) can only be felt at a distance that does not exceed 35 m.

Longwall move operations can be improved and conducted within a period of 12 to 20 days, which is the best possible result (Peng, 2019), only through the efficient organization and management of transportation and disassembly operations. As a way to increase the speed of disassembly, it is recommended to excavate several blind entries in advance towards the longwall face where the recovery room will be located. The recovery room should be formed by the longwall face to prevent the impact of its abutment pressure, which can be achieved if all the necessary operations are conducted in advance (Zhu et al., 2017), (Klimov, 2019). The location of the recovery room should be determined, taking into account the caving step (Zubov, 2018), (Zuev et al., 2019). To ensure the efficiency of transportation operations, wheeled transport should be used as it provides for a high transportation speed (Peng, 2019).

As a promising way to improve methane emission control and transportation operations in the panel being mined, it is recommended to use three-entry developments. As a rule, two-entry layouts are currently used in Russia (Peng et al., 2019), (Kazanin et al., 2019). Multi-entry developments make it possible to separate transportation, ventilation, and auxiliary operations and get rid of the restrictions that are associated with conducting several types of operations in the same work. The disadvantage of using three-entry developments is that they result in greater development costs. It should be noted that this layout is obligatory to use in the USA, and almost 90% of all longwall mining operations in the country use this method (Zubov, 2018), (Longwall lead the way underground, 2020).

## Conclusions

The experience of extracting seam No. 50 at the Yalevsky mine shows that high daily and monthly output rates do not guarantee efficient operation and may be accompanied by extended longwall downtime periods. A study of downtime reasons and effective organizational and technological solutions are required to solve the issue of equipment under-utilization, resulting in higher productivity and efficiency.

The main factor limiting the output rate is high methane emissions when methane contents in coal seams exceed 10 $m^3$/t. The main ways to solve this issue include preliminary degasification by means of surface boreholes, roadways, undermining, or overmining. In multiple seam mining, the mined-out areas become artificial methane reservoirs that accumulate about 90% of methane emissions in the panel being mined. Efficient gob degasification when mining coal seams at depths of up to 600 m can be ensured by using surface boreholes that are connected to vacuum units.

Low roadway development rates remain the main reason that hinders production growth and results in excessive longwall downtime. An increase in the panel width is an effective way to reduce the advance rate without compromising the output rate. However, today's panel widths do not exceed 500 m (Rudakov, 2016), (Gendler et al., 2020)) as they are limited by armoured face conveyor capacity (Kabanov et al., 2019). In our opinion, as the maximum panel widths have been reached and downtime can be reduced only by conducting roadway development operations in advance, which will result in sufficient float time that is required taking into account the panel advance rates that have been achieved.

Thus, there are several conditions that should be met to ensure efficient longwall operations and stable output rates:

- favourable geological and mining conditions that are characterized by a minimum number and low intensity of factors that have a negative impact on output rates and occupational safety and health (Kazanin et al., 2019);
- using powerful state-of-the-art equipment (Linh et al., 2019), (Gantry et al., 2013), (Stebnev et al., 2017), (Palyanova et al. 2017);
- using mine layouts with big panel dimensions (i.e. the panel width ranging from 400 to 500 m and the panel length ranging from 4 to 8 km) will reduce the number of planned breaks due to operations associated with reversing the cutting direction assembly and disassembly.
- using the best available ground control techniques such as leaving wide pillars between longwall panels, using rock bolts, rational mine layouts factoring in high-pressure zones, and a rational mining sequence when extracting multiple coal seams with high gas contents;
- using the best available methane control techniques (ventilation and degasification), which should provide for efficient preliminary degasification by means of drilling surface boreholes or mining out adjacent seams;
- using two- or three-entry developments and ensuring high development rates by using more productive development machines or carrying out development operations in advance to provide for sufficient float time.

If these conditions are met, mining flat-lying coal seams at depths of up to 600 m using the longwall method can result in output rates equal to those at the most productive mines and make underground coal mining highly competitive.

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