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ADVANCED EXPERIENCE IN GAS SITUATION MANAGEMENT AT THE COAL MINES OF THE KARAGANDA BASIN

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This article presents the main methods of implementing degassing control systems, which allow for a radical reduction in the likelihood of accidents and achieving the most effective production results. The article discusses measures to prevent explosive gas concentrations during degassing operations, proposes optimal diameters and distances between degassing wells. Additionally, parameters influencing the volume of pumped methane are identified. A technology for sealing underground wells to maintain methane gas concentration is proposed. A modern mobile degassing unit is presented for methane extraction followed by utilization for electricity generation.

Keywords: degassing, methane, methane content, sealing, depression, methane utilization.

ГАЗ ЖАҒДАЙЫН БАСҚАРУДЫҢ ОЗЫҚ ТӘЖІРИБЕСІ ҚАРАҒАНДЫ БАССЕЙНІНІҢ КӨМІР ШАХТАЛАРЫНДА

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Мақалада жазатайым оқиғалардың ықтималдығын түбегейлі төмендетуге және ең тиімді өндірістік нәтижелерге қол жеткізуге мүмкіндік беретін газсыздандыруды басқару жүйелерін іске асырудың негізгі әдістері келтірілген.

Мақалада газсыздандыру жұмыстарын жүргізу кезінде газдардың жарылғыш концентрациясының алдын алу шаралары қарастырылған, газсыздандыру ұңғымаларының оңтайлы диаметрі мен арақашықтығы ұсынылған. Сондай-ақ, айдалатын метан көлеміне әсер ететін параметрлер анықталған. Метан газының концентрациясын сақтау үшін жерасты ұңғымаларын тығыздау технологиясы ұсынылған. Метанды соруға арналған заманауи жылжымалы газсыздандыру қондырғысы, содан кейін электр энергиясын өндіру үшін кәдеге жарату ұсынылған.

Түйін сөздер: газсыздандыру, ұңғыма, метан, тығыздау, депрессия, метанды жою.

ПЕРЕДОВОЙ ОПЫТ УПРАВЛЕНИЯ ГАЗОВОЙ СИТУАЦИЕЙ НА УГОЛЬНЫХ ШАХТАХ КАРАГАНДИНСКОГО БАСЕЙНА

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В статье представлены основные способы реализации систем управления дегазацией, которые позволяют радикально снизить вероятность возникновения несчастных случаев и достичь наиболее эффективных производственных результатов.

В статье рассмотрены меры по предотвращению взрывоопасных концентраций газов при ведении дегазационных работ, предложен оптимальный диаметр и расстояния между дегазационными скважинами. Также определены параметры, влияющие на объем откачиваемого метана. Предложена технология герметизации подземных скважин для сохранения концентрации газа метана. Представлена современная мобильная дегазационная установка для откачки метана с последующей утилизацией для выработки электроэнергии.

Ключевые слова: дегазация, метан, метаноносность, герметизация, депрессия, утилизация метана.

Introduction. The development of underground coal mining is inseparably linked to increasing concentration and intensification of mining operations. Transitioning to greater depths is accompanied by an increase in the gas content of mine workings due to the growth of gas-bearing strata [1]. Modern coal deposits are essentially coalbed methane deposits, as the methane reserves in them are comparable to natural gas reserves. Global coalbed methane resources are estimated at 260 trillion cubic meters, with significant resources concentrated in developing countries (Fig. 1).

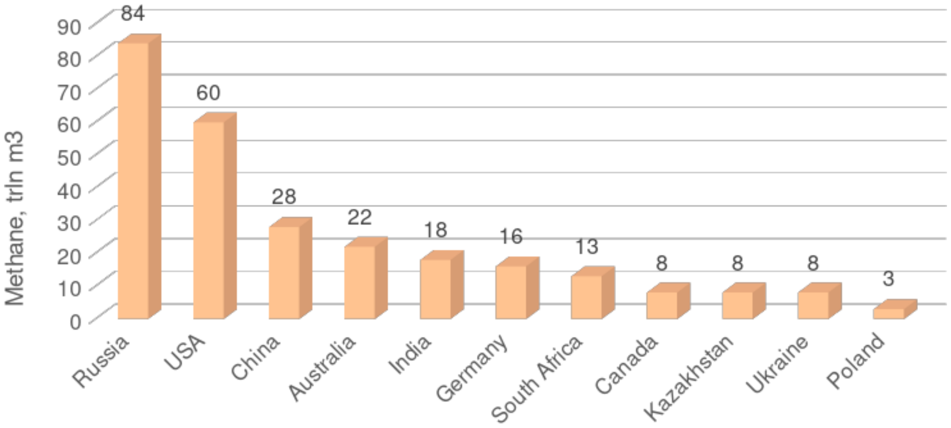


Figure 1 - Estimate of global coalbed methane reserves, trillion cubic meters

Most mines in the Karaganda coal basin at depths exceeding 500 meters are classified as hazardous due to sudden outbursts of coal and gas [2]. Thus, the development of advanced technological solutions for working high-gas coal seams, considering the specific manifestations of gas dynamic processes in coal mines, makes a significant contribution to accelerating scientific and technical progress in the industry and forms the basis of an important scientific problem [3].

The release of methane from the seam occurs continuously and depends on the strength, thickness, and gas content of the seam being mined. The release of methane from coal extracted by a shearer primarily depends on the speed of its movement along the face. The volume of methane (adsorbed gas) released from the cut and transported coal by a scraper conveyor is an order of magnitude less than the volume of methane released during coal extraction by a shearer and does not significantly affect the overall methane concentration in the ventilation heading. Methane emissions from the goaf vary randomly and are difficult to predict [4-5].

During the development of coal seams in the Karaganda basin, approximately 1 billion cubic meters of methane are emitted annually, of which around 200 million cubic meters are extracted through degassing methods. However, despite the recent development of methane capture and utilization initiatives in the basin, the utilization rate remains at approximately 10%, resulting in significant environmental damage [6].

To prevent explosive gas concentrations of CH_4/O_2 during degassing operations, measures have been considered, including: an operational system for sealing degassing wells during seam degassing, proper layout of degassing pipelines, adequate cross-section and tightness of collection and trunk gas pipelines, and a high-performance degassing unit with an integrated gas monitoring system and safety observation system. To identify existing problems, various methods of implementing degassing control systems have been presented, which significantly reduce the likelihood of accidents and achieve the most efficient production results (Fig. 1) [7-8].

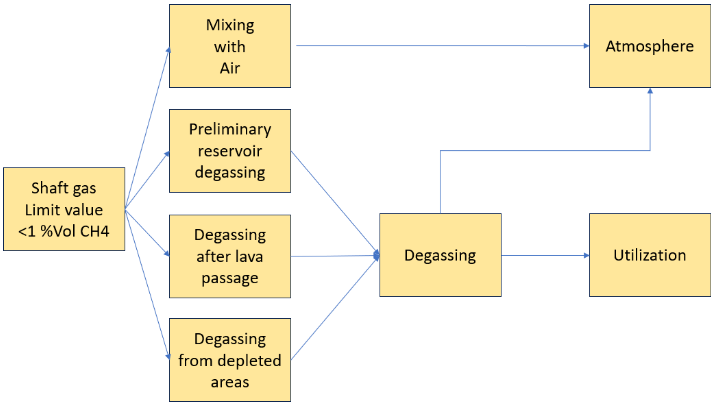


Figure 2 - Methane-air environment management scheme

The analysis of the aero-gas control problem in mine atmospheres indicates that methane gas explosions occur when the concentration of CH_4 significantly exceeds safe limits. Figure 2 illustrates a diagram of the explosive range for CH_4 and oxygen. Concentrations of methane-air mixtures within the triangle are explosive, rendering operations within this range impermissible. It is also essential to adhere to regulations regarding maximum and minimum permissible concentrations of CH_4 and oxygen [9-13].

One of the primary factors determining the spacing between wells is the gas permeability of the coal seam. The greater the gas permeability, the greater the possibility of gas extraction from the well, allowing for larger spacing between wells [14].

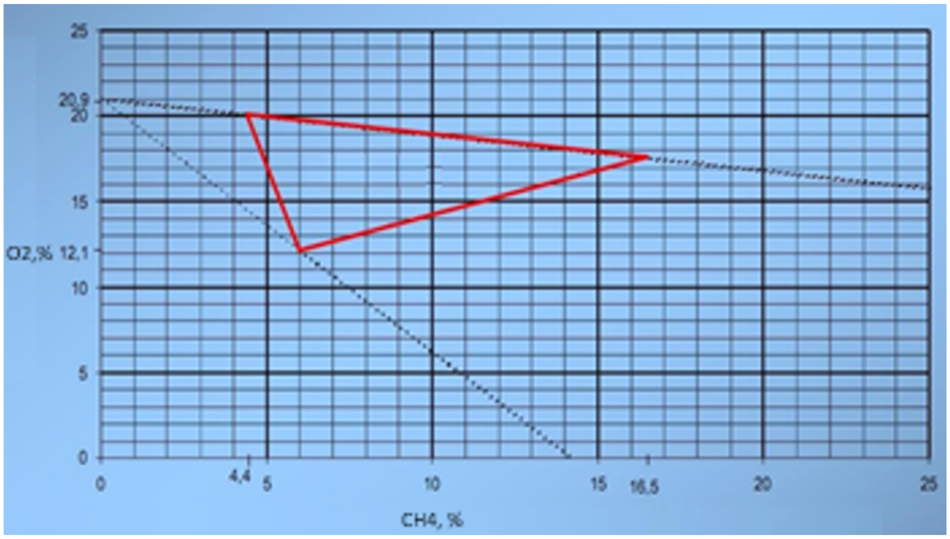


Figure 3 - Diagram of the explosive range for CH_4 and Oxygen

The gas permeability depends not only on the seam but also on whether the seam has been undermined or overmined. There is a certain accumulated experience in determining degassing parameters, but each seam has its own characteristics regarding gas emission. Therefore, conducting research on each seam is the only reliable method for determining the volumes of emitted gas [15].

The distance between wells typically ranges from 8 to 15 meters. The diameter of the well practically does not affect the amount of gas extracted, so drilling wells with a large diameter may not be necessary.

Materials and Methodology. From the experience of foreign coal mining countries, mines employ a system of sealing seam degassing wells using Flexrohr polymer pipes (Fig. 4). A guiding pipe, 2 meters in length, is inserted into the reinforced Flexrohr pipe to a length of approximately 10 cm. The guiding pipe facilitates the simplified insertion of pipes into the well.

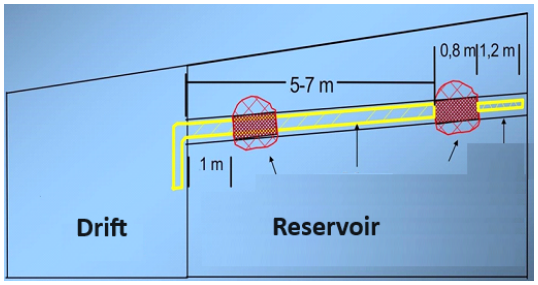
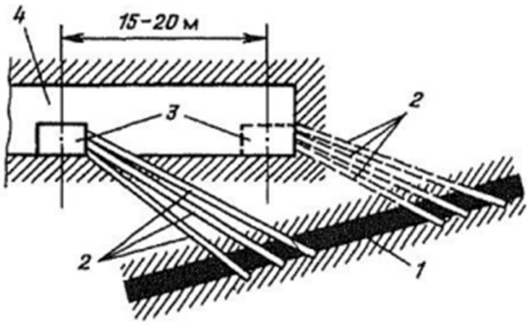


Figure 4 - Scheme of casing for seam degassing wells



1- The seam-undermining process;

2- The drilling of wells;

3- The creation of niches;

4- The development drift.

Figure 5 - Scheme of preliminary degassing of an inclined coal seam

The length of the casing for the well should be 6 - 9 meters (2 meters for the guiding pipe plus 5 - 7 meters). A foam rubber sleeve (0.8 meters in length) is placed onto the guiding pipe and secured with wire. Another sleeve is attached to the pipe at a distance of 1 meter from the wellhead, thus providing a sealing length of 1 meter. Before inserting the pipe into the well, the sleeve is soaked in water (first component) and then coated with the second component.

The pipe is inserted into the well, and a reaction between the two components occurs. After 1 - 2 minutes, polyurethane foam forms in the well. The foam fully solidifies after 5 minutes. The foam not only seals the pipe joints but also spreads throughout the well's cross-section, filling cracks. Degassing wells should be drilled at an angle to allow water drainage (Fig.5).

Water separators should operate automatically and be located at the lowest point of the collection or main gas pipeline. Measurement sections should be equipped with a control opening to allow for methane concentration and flow volume measurements.

For sealing the well and pipes, PGM-Vielflex 80 with a modified sealing package PGM-Dichtpaket can be used. This facilitates the insertion of degassing pipes into the wells and allows for sealing the well to a greater depth without the use of auxiliary equipment, enabling the extraction of gas with high concentration. To prevent vacuum loss, it is necessary to calculate the diameter of the main and sectional gas pipelines. It is important during pipeline installation to ensure and verify the pipeline's tightness each time after its modification or reinstallation. The control is carried out by fully sealing the pipeline, supplying compressed air into it, and connecting a pressure gauge. If the pressure gauge does not show any pressure changes within 30 minutes, the pipeline is considered sealed [16].

Water separators should operate automatically and be located at the lowest point of the

PGM mobile degassing units (Fig. 6) are currently the most advanced and straightforward solution for methane extraction. The units come in different performance modifications: 2-90, 2-150, and 2-229 m3/min. The units consist of a pumping module, control module, and mobile flare with a control system. Modular design ensures quick equipment reassembly. Rotary vacuum pumps operate without water in any climate conditions. The moisture content of the extracted gas is low, facilitating its further utilization. The volume of extracted gas is automatically regulated by a frequency converter and adapted to the degassing network conditions. The unit is equipped with a gas analysis system and monitors CH4, O2, and CO2. In case of unacceptable values, an alarm signal is sent, the unit is shut down, and the valves are closed off from the underground gas pipeline. Additionally, automatic control of pressure, flow volume, temperature, and other parameters is performed. All unit operation data can be transmitted via a modem to a remote control panel. Remote control of the unit is also possible from the control panel.

Figure 6 - Mobile methane utilization units PGM-ETW 1360 MG

Mobile methane utilization units like the PGM-ETW 1360 MG operate with methane concentrations ranging from 30 to 100% CH_4. These units are equipped with four-stroke gas engines manufactured by DEUTZ, capable of producing up to 1364 kW of electricity. The generator stabilizes the voltage constantly to 400 V/50 Hz. When multiple units are in operation, automatic phase synchronization is performed. With optimal utilization of heat from cooling water and exhaust gases, the overall efficiency of the unit can reach 85.8%, meeting the highest standards [17-18].

Results and Discussion. Sudden outbursts of coal and gas in the mine workings of the Karaganda basin have been occurring since 1959. In total, 58 sudden outbursts of coal and gas have occurred in the basin. These outbursts are distributed across the coal mining areas and districts of the basin as follows: there were 19 sudden outbursts in the Industrial area mines, 19 in the Saransk area, 3 in the Sherubay-Nurinsky district, and 17 in the Tenteke district.

The analysis of the first 38 sudden outbursts of coal and gas that occurred in the Karaganda basin mines is presented in the study, while information about all 54 sudden outbursts of coal and gas in the basin is provided in a catalog.

The first sudden outburst of coal and gas in the basin occurred on September 12, 1959, in shaft 3-bis of the Industrial area during the driving of a powerful K12 seam ”Upper Mariana” stope in the area of a disruptive geological fault at a depth of 381 meters from the surface. About 100 tons of coal were ejected during the blasting of borehole charges. On September 16, in the same stope and also during the blasting of borehole charges, the second sudden outburst of coal and gas occurred. About 120 tons of coal were ejected, and approximately 9000 m3 of methane were released during this outburst. Two hours after the outburst, the methane content in the outgoing air stream from the stope was 6%.

Sudden outbursts of coal and gas in the basin occurred during preparatory workings on coal seams and during the opening of seams with headings and vertical shafts. No outbursts were observed in the development workings.

The strength of sudden outbursts, measured by the mass of ejected coal, varies in the basin from 4 to 5 tons to 2000 tons. The strength of outbursts during the opening of coal seams with headings is approximately 3.5 times greater than that during preparatory workings conducted on the seam.

Sudden outbursts of coal and gas are accompanied by intense methane emissions. The volume of additionally released methane during these outbursts ranges from 660 m3 to 1,300,000 m3. The methane concentration in the workings after the outburst and for a prolonged period (1 to 3 hours or more) typically exceeds 5 to 6%, reaching 60% or more in some cases.

During sudden outbursts of coal and gas, a shockwave of the gas-air jet is felt. Outbursts where more than 350 tons of coal were ejected and additionally over 26,000 m3 of methane was released were accompanied by the overturning of the fresh ventilation air stream.

The ejected coal during sudden outbursts is primarily fine coal particles with sizes less than 10 mm. Severe coal pulverization is one of the main characteristics of sudden outbursts, distinguishing them from other gas dynamic phenomena.

In the last meters from the face of the workings, the ejected coal is usually positioned at an angle less than the natural angle of repose, typically ranging from 7 to 10 degrees. On the face, the upper layer of ejected coal, up to 20-30 cm thick, consists of finely dispersed dust, known as ”furious flour.” The more powerful the outburst, the finer the coal pulverization and the greater the amount of finely dispersed dust in the ejected coal mass. There were also cases of this dust being present on equipment, supports, and walls of the workings. During severe outbursts, instances of drilling rigs and loading machines being thrown up to 50 meters from the face of the workings were observed.

A characteristic example of sudden coal and gas outbursts in the basin can be the first outburst that occurred at the V.I. Lenin mine on December 28, 1976, in the personnel roadway of the D6 seam at a depth of 410 meters from the surface. The workings were conducted on the lower layer of the D6 seam using jackhammers. Immediately before the outburst, temporary support work was being carried out. As a result of the outburst, 50 meters of the personnel roadway were filled with fine coal, with nearly 40 meters almost completely across the section of the workings. In the upper part of the workings, between the ejected coal and the roof supports, there remained a gap 20-40 cm high. In the last 10-15 meters, the coal was positioned at an angle of 8 to 10 degrees. On the face, the layer of ejected coal, 10-15 cm thick, consisted of finely dispersed dust (”furious flour”).

In total, 550 tons of coal were ejected, and approximately 36,000 m3 of methane was released. After the outburst, the overturning of the fresh air stream in the personnel roadway was observed. The methane concentration in the blind end of the personnel roadway 1.5 hours after the outburst reached 62.5%, while in the outgoing air stream, in air duct No. 8, through which 1150 m3/min of air passed, it was 9%.

The ejected coal consisted of fine coal with particle sizes less than 10 mm. The content of the finest coal fractions, less than 1 mm, was 20-30%. After the ejected coal was removed, it was established that the face of the personnel roadway had entered the zone of geological disturbance - a thrust fault with the full thickness of the seam. The outburst occurred from the lower, most disturbed layer of the thrust part of the seam.

Before the outburst in the personnel roadway, the following warning signs were observed: a sharp increase in methane concentration in the roadway up to 2%, cracking in the massif, bouncing of coal pieces, appearance of cracks, and coal squeezing from the face, increased pressure on the supports. The outburst did not lead to serious consequences because the miners working in the personnel roadway were aware of the increased outburst risk of the D6 seam in the mining area, were well acquainted with the warning signs of outbursts, carefully monitored them, and timely left the face.

A characteristic feature of sudden coal and gas outbursts is their predominant association with zones of tectonic disturbances. All outbursts occur as workings approach major tectonic disturbances or in zones of minor disturbances associated with these major ones, as well as in areas where the seam thickness changes (dips or bulges) and where coal beds are intensely folded.

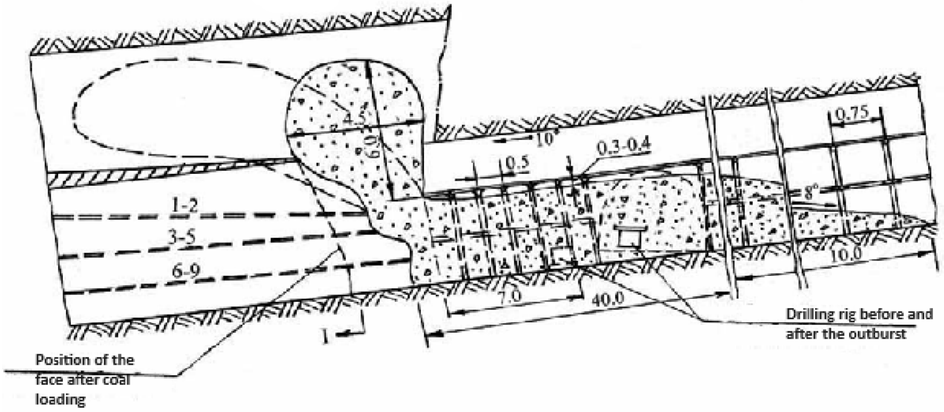
Depending on the complexity of the tectonic structure of the coal mining areas (sections), the depth at which sudden coal and gas outbursts occur varies. Thus, in the most tectonically complex Saransk section, the minimum depth at which outbursts are noted is 200 meters from the surface. In the Industrial section, characterized by a calmer coal seam deposition, the minimum depth of outburst occurrence is 350 meters.

The locations of sudden coal and gas outbursts are often associated with zones of increased stress caused by the influence of coal pillars left on overlying coal seams. In the conditions of the Karaganda basin, approximately half of all outbursts occurred in the zone influenced by coal pillars.

Sudden coal and gas outbursts in preparatory workings mainly occur in thick coal seams. Of all sudden outbursts that occurred in preparatory workings, 91% occurred in seams with thicknesses of 3.5 meters or more. When opening coal seams with entry headings, outbursts occurred both when opening thick and thin coal seams.

In terms of the amount of coal and gas ejected, the most hazardous seam is the D6 seam in the Tentek district mines. This seam lacks protective layers. The thickness of the seam varies from 5 to 7 meters, and the dip angle ranges from 7 to 24 degrees. The upper layer of the seam consists of medium-strength coal, while the lower layer consists of soft coal. In the lower part of the seam, there is a heavily disturbed and folded coal bed with a thickness of 0.4-0.6 meters, and in certain local zones, its thickness reaches 1.8 meters.

Confirmation of the high hazard of the D6 seam is a unique coal and gas outburst that occurred when crossing this seam with the eastern flank ventilation shaft of the V.I. Lenin mine at a depth of 435 meters from the surface.



1-9 – Preceding boreholes

Figure 7 - Sudden Outburst of Coal and Gas on December 28, 1976, in the Main Drift of Seam D6 at the V.I. Lenin Mine

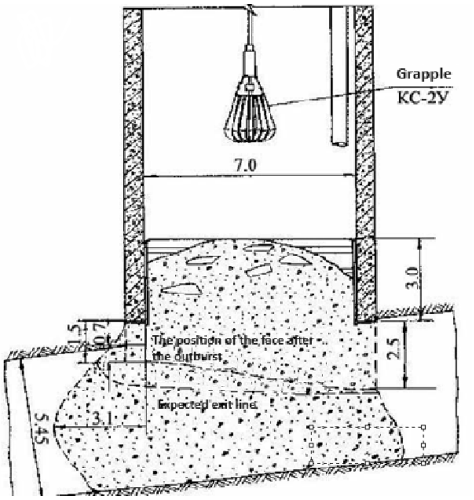


Figure 8 - Sudden Outburst of Coal and Gas when intersecting Seam D6 with a Vertical Shaft, occurring on December 22, 1978, at the V.I. Lenin Mine

To prevent sudden coal and gas outbursts when exposing the D6 seam and crossing it with a vertical shaft, a frame protective support was used. Under the protection of the protective support, the D6 seam was exposed over the entire face area. To even out the face plane of the shaft in the sector where the seam dips, 33 boreholes with depths of 0.6-1.0 meters were drilled, and charges were detonated. During their detonation, a sudden outburst of 380 tons of fine coal occurred, releasing 27,900 m3 of methane (73 m3 of methane per ton of ejected coal). Measurements of methane concentration with the SHI-3 device on the zero platform of the mine's cutting machine, taken a few minutes after the explosion, showed a methane content of over 6%. The increased gas release continued for 32 hours.

The borehole was filled with ejected coal up to a height of 5.5 meters from the expected borehole line (see Figure 8). On top of the coal, as well as on the lower and upper floors of the suspended shelf located 11 meters from the borehole, there was a layer of fine dust with a thickness of 50-60 mm. The lining of the borehole was significantly damaged during the outburst, with cracks up to 5-6 mm wide observed in the concrete lining of the borehole's bottom part. The lower layer of the seam, with a thickness of 3-4 meters, was destroyed down to its base.

The most severe sudden outburst of methane and rock mass in the Karaganda Basin also occurred at the V.I. Lenin Mine, originating from Seam D6 during its excavation with a shearer. This outburst took place on March 23, 1998, in the face of Shearer No. 2 of Seam D6, at a depth of 580 meters from the surface (see Figure 1.3).

The development of the kershlag was carried out using the drilling and blasting method in the interlayered rocks of sandstone, aleurolites, and argillites. The sudden outburst of coal and gas occurred as the face approached the kershlag at a distance of 7 meters from the seam along the normal line, in the zone of weakened rock due to the bed's soil and a sharp change in the topography of the seam. After the blasting operations, the loading of the broken rock mass by a loading machine was carried out in the kershlag face. Approximately 4 hours after the blasting, during the unloading of the rock mass, a sudden outburst of coal and gas occurred. The entire length of the kershlag face (106 meters) and the second eastern heading of the seam D6 -100 meters over almost 150 meters were filled with ejected rock mass. The total amount of ejected rock mass was 3250 tons, including 2000 tons of coal and 1250 tons of rock. The additional methane released during the sudden outburst amounted to 1300 thousand cubic meters. This sudden outburst of coal, rock, and gas led to the overturning of the ventilation airflow in three preparatory headings and one clean heading.

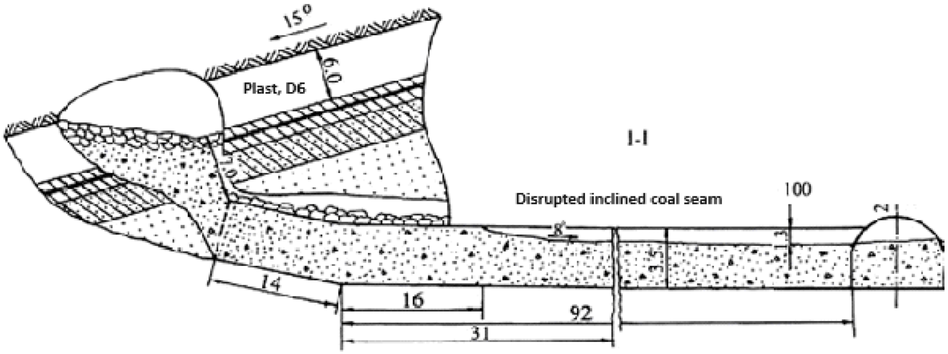


Figure 9 - Sudden Outburst of Coal and Gas Occurred in Faulty Kershlag No. 2 During the Extraction of Seam D6 at the V.I. Lenin Mine

The majority of hazardous seams in the basin do not have separate, intensively folded (hazardous) coal benches. During sudden outbursts of coal, it is usually ejected from several benches of the seam. However, there have been several outbursts from a single intensely folded coal bench of the seam.

Coal in zones of sudden coal and gas outbursts differs in reduced mechanical strength and the absence of cleavage. The coal strength coefficient in these zones ranges from 0.6 to 0.1. In places of sudden coal and gas outbursts, coal is characterized by an increased initial gas release rate. The initial gas release rate values for coal samples taken from sites of sudden coal and gas outbursts range from 12 to 28 units. The initial gas release rate for coal from heavily disrupted, intensely folded hazardous seam benches reaches 28-30 units.

The coals of hazardous seams have volatile matter content ranging from 17 to 32%. Most of the coal and gas outbursts in the basin (96%) occurred in coal seams with volatile matter content ranging from 24 to 32%. Coal in areas of coal and gas outbursts is usually dry, and its moisture content does not exceed 3% in most cases.

The natural gas content in coal at the depth of occurrence of sudden coal and gas outbursts in the basin ranges from 10.7 to 22.1 m3/ton, and the gas pressure in coal seams ranges from 1.25 to 4.1 MPa. The minimum gas pressure (1.25 MPa) at which a sudden coal and gas outburst occurred was recorded in the K7 seam ”Remarkable” of the Dubovskaya mine at a depth of 200 meters from the surface.

There is no direct connection between the natural gas pressure in a coal seam and the natural gas content in coal, on one hand, and the risk of sudden coal and gas outbursts, on the other. All other conditions being equal, with an increase in gas pressure and gas content in coal, the risk of coal and gas outbursts increases. With the increase in the depth of coal seam mining, there is an increase in the number of outbursts, especially in the depth interval of 200-400 meters from the surface. Additionally, there is a trend of increasing the amount of ejected coal and the volume of additionally released gas.

Most of the sudden coal and gas outbursts are associated with direct impacts on the coal mass. Approximately 70% of sudden coal and gas outbursts occurred during coal cutting by mining machines, using percussion drills, through explosive works, and during drilling operations.

Sudden coal and gas outbursts are typically preceded by warning signs. According to modern understanding, coal and gas outbursts occur in several stages, and the preparation for a hazardous situation can last for several tens of minutes. This preparatory stage manifests as warning signs of sudden coal and gas outbursts, which can be observed several minutes, hours, or even a day before the event.

The most characteristic warning signs of sudden coal and gas outbursts include a sudden increase in gas emission into the workings, an increase in ground pressure manifested by coal squeezing (extrusion) from the seam, coal spilling, coal particles bouncing off the seam surface, and increased pressure on the ground support (deformation and cracking of support), as well as the appearance of a dust cloud. In some cases, dull impacts and cracks of varying intensity and frequency in the rock mass, shaking of the mass, sometimes felt at distances of tens to hundreds of meters, were observed before a sudden outburst. A significant warning sign of the entry of the workings into a hazardous zone is the reduction in coal strength and the appearance of intensely fractured coal benches in the seam.

Warning signs of sudden coal and gas outbursts during drilling operations or spudding include the jamming of the drilling tool, ejection of the drill rod, coal fines, and gas from the borehole or spud.

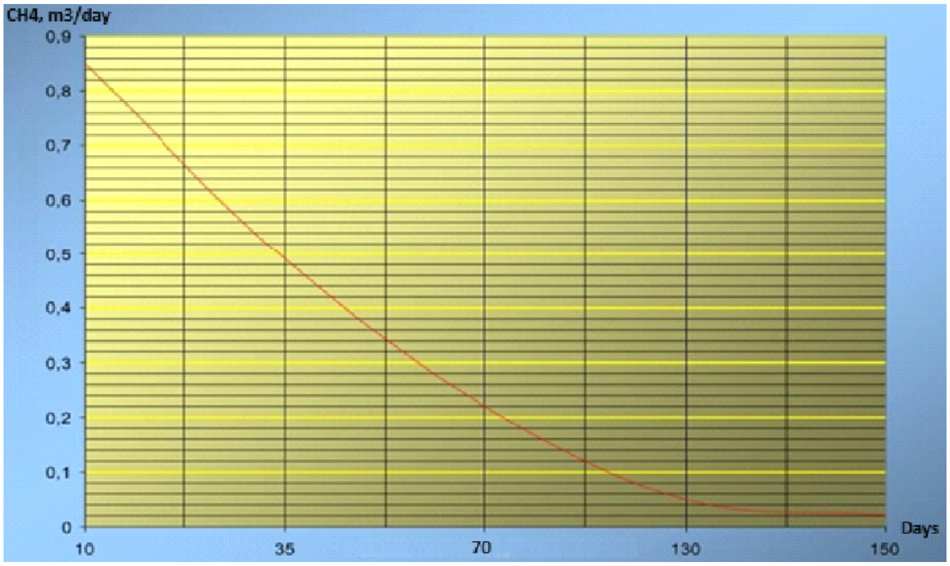


Figure 10 - Methane Volume Over Time

To study the influence of depression on degassing outcomes, let's consider an example where the gas pressure in the seam is approximately 10,000 mbar. If we create a depression of 100 mbar at the well, it represents only 1% of the gas pressure. The volume of the mixture, i.e., the absolute volume pumped out of the well, increases with an increase in depression. The methane concentration decreases with increasing depression.

Only after several months of degassing does the methane concentration increase with increasing depression, and as depression increases, the volume of pumped mixture increases, but the gas concentration decreases. Identical reservoirs do not exist, so preliminary tests are necessary.

With the help of an automatically regulated degassing installation, it is possible to set the optimal depression. Water ring pumps do not meet these requirements. Under normal operating conditions, depression at wells should be maintained in the range of 50 to 100 mbar.

Conclusions. In addition to the reservoir properties and its methane content, the temporal factor plays a significant role in degassing results. Experience has shown that degassing of the reservoir should commence at least 6 months before its exploitation begins. In some cases, the degassing period may need to be extended, but the influence of neighboring reservoirs, which can also affect the outcomes, must not be overlooked. With a well-designed degassing system, it is possible to extract at least 50% of methane from the reservoir. Ensuring the sealing of wells and optimally regulating the installed depression are crucial. High depression levels do not necessarily yield the expected results in the long run.

Based on the analysis conducted, it has been established that the distance between reservoir wells and their sealing is a key factor in the effectiveness of coal reservoir degassing. Additionally, the optimal depression under normal operating conditions for wells should be maintained within the range of 50 to 100 mbar. Degassing of the reservoir should commence at least 6 months before exploitation begins, utilizing mobile degassing units optimized for the conditions of the Karaganda Coal Basin.

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