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Experience of coalbed methane extraction in the Karaganda coal basin

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ABSTRACT
This article discusses the issues of ensuring the safe conduct of mining operations in coal mines. Ensuring the safety of coal industry workers is an urgent problem today. The gas content of the layers increases with the depth of their occurrence and is a deterrent factor in the extraction of minerals. Sudden methane emissions can provoke a large number of human casualties, financial losses, and other consequences. In recent years alone, such accidents have claimed more than 157 human lives in the mines of the Karaganda coal basin. However, by solving this important problem, you can get associated gas. It is not easy to reduce the gas content using existing degassing technologies. The formations have almost zero gas permeability and low gas output at the current depths of their development. That is why it is necessary to have an impact on the coal seam as early as possible in order to ensure the release of methane. This process will make it possible to obtain associated gas, which can be used for the needs of industry or the national economy. As a result, reducing the gas content of coal seams will reduce the risks of mining operations and increase labor safety.
Keywords: safety, coal mines, coal seams, methane, sudden emissions.

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Introduction

Investigating the issue of methane production, it can be concluded that the Karaganda coal basin is essentially a coal and gas deposit. Estimating methane reserves from various sources, it can be seen that they are comparable to natural gas reserves. From 1 to 4 trillion is concentrated in the Karaganda coal basin alone, m^3 of gas at a depth of up to 1800 m. At local enterprises, approximately 500 million m^3 of gas is extracted from the ground annually by means of degassing. At the same time, only 15% of this volume is used as fuel, the rest replenishes the emission indicators into the environment. Meanwhile, methane is 20-40 times more efficient than other gases. It destroys the ozone layer and absorbs infrared solar radiation. Comparing the anthropogenic increase in the concentration of greenhouse gases, it can be seen that the annual accumulation of methane in the atmosphere is 1-2% [1]. This indicator exceeds the intensity of the accumulation of other gases. However, methane is a good unconventional energy carrier. It can also be considered as a component of the fuel and energy raw material base of the country. For example, for the chemical industry, methane of coal genesis will serve as a valuable raw material in the production of ammonia, methanol, acetylene, protein mass, etc. [2].

Experimental part

Methane in coal seams is not in a free state. This is the main feature that must be considered when developing methane coal deposits. The mining technology is influenced by the heterogeneity of deposits, the complexity of geological conditions of the formation, stress state of coal rocks. Meanwhile, only a part of methane is in the free state in coal seams. A large proportion of it, up to 90%, is still in a sorbed state. In order to release at least part of it due to the pressure gradient, the formation is dried before the start of gas production [[3], [4]]. This allows you to change the pressure and promotes the flow of methane gas to the well. The efficiency of the development of methane-coal deposits depends on the filtration properties, density of coal rock, and gas content in the formation, because gas is contained even in a low-permeable coal matrix, and its movement is carried out through a system of microcracks Figure 1.

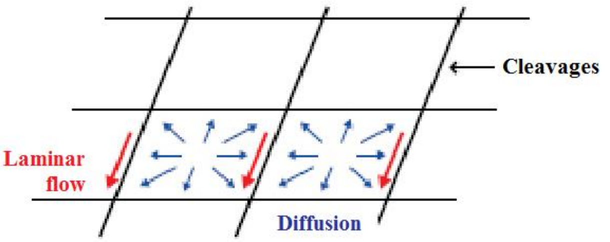

Figure 1 - Gas flow in the coal column

The amount of gas contained in the formation depends on the type of coal, reservoir pressure, and host rocks. Methane desorption is described by the Langmuir isotherm, which demonstrates the ability to contain gas with a coal matrix in accordance with reservoir pressure at a constant temperature:

$$V = V_L \frac{P}{P + P_L}, \qquad (1.1)$$

where V is the volume of the adsorbed gas at normal temperature;

Tn = 0 °C and pressure, per ton of coal;

V_L is Langmuir's volumetric constant (the limiting amount of gas that can be in an adsorbed state on a unit surface of coal at infinite pressure);

P_L is the Langmuir pressure constant (corresponds to the pressure at which half of the volume of VL is in the adsorbed state);

P is the reservoir pressure [[5], [6]].

Coal methane reserves in reservoirs are often calculated by multiplying the mass of coal by the average methane content in the counting block [7].

$$Q_m = M_{av} \cdot m, \qquad (1.2)$$

where Q_m is the initial methane reserves in the counting block, m^3;

M_{av} - average methane content per block, m^3/t of coal;

m is the mass of coal in the counting block, t [8].

When assessing and calculating methane gas reserves, certain blocks are first identified that have a stable consistency of reservoir capacity, approximately homogeneous tectonic disturbance, ash content, methane content, and permeability. The average methane content for the counting block is determined taking into account the volume of coal within the boundaries of the allocated block. In general, the calculation of coal methane reserves is a symbiosis of the method of geological blocks, which is used to calculate coal reserves and the volumetric method of calculating gas reserves. It is worth noting that the natural methane content depends on a large number of parameters. It is necessary to take into account the depth of the formation, the power of gas weathering, the degree of coal metamorphism, temperature, pressure, and many other parameters. As a result, it turns out that the natural methane content is an arithmetic mean value with its uniform increase in depth and a weighted average value with its uneven increase in the area of the calculation block [[9], [10]].

The extraction coefficient often depends on the technology of gas recovery intensification, filtration characteristics of coal seams, the grid of production wells, the cost of produced gas, and other factors. The recovery coefficient can also be a fixed value if the experience of developing this type of deposit is not great and it is not possible to determine this indicator by other methods. In this case, based on experimental studies, the value is taken from experience and by analogy with other deposits.

The calculation of methane reserves should begin with the justification of the boundaries and the definition of the objects of the calculation of reserves, to assess the quality of coal and geological and commercial characteristics of productive layers, to determine changes in methane content in depth and area, to identify the forecast of mining opportunities [[11], [12], [13]].

The counting block schematically shown in Figure 2. should have the same degree of exploration and study of parameters, a homogeneous geological structure or approximately the same degree of complexity of the structure, consistency of the conditions of occurrence of the studied block, similarity of mining and technological conditions of its development.

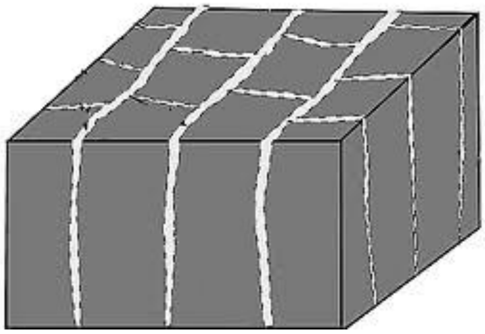

Figure 2 - Graphical model of the counting block

With the use of interpolation and extrapolation algorithms, a geometrically correct network is constructed using data from horizon plans, the points of intersection of formations with wells, and the coordinates of the points of formation exits to the surface.

The size of the cells or equilateral rectangles depends on the degree of study of the object, the heterogeneity of its structure, and the distance between the wells.

Methane production is carried out from a group of layers, which is why the calculation of the main parameters can be carried out in total for all layers within the counting block.

The distribution of properties, such as power, ash content, density, humidity, and methane content, is also an important step in building a digital model.

The depth of occurrence and the degree of metamorphism affect the indicators of methane content. That is why traditional methods of interpolation and extrapolation do not always give a positive result. According to the curvilinear law, the methane content of coal seams increases with increasing depth. Up to 300-400 m, the most intense increase in the indicator occurs. Then its growth slows down to a depth of 800-1000 m. As a result, the methane content reaches the limit values characteristic of each stage of metamorphism.

The main regularities of the natural methane content of coals in the methane gas zone can be described by the following equation:

$$M = A - \frac{B}{(C - H)}, \quad (1.3)$$

where M is the methane content, m^3/t; A is the maximum methane capacity of coal at the maximum depths of the explored area m^3/t; B and C are empirical coefficients; H is the depth of the formation, m.

The geological process of coal formation occurs together with the formation of methane. Some part of it just remains in the thickness of the coal seam until the moment of its extraction. The development of alternative energy sources allows us to consider this gas as a new mineral. If earlier it was a source of increased danger, now it has also become an energy carrier that can change the prospects for the development of the Karaganda region.

There are at least three boilers operating at the mines of the ArcelorMittal Temirtau Coal Department that produce energy by burning coal mine methane. One installation is located at the Abayskaya mine and two are at the IM mine. Lenin. About 20 years ago, gas equipment with a capacity of 10 Gcal for each boiler unit was developed and installed by the management of "Spets shakhto montazh degazatsiya". This made it possible to significantly reduce the cost of heating the premises. In addition, it has reduced harmful methane emissions into the atmosphere. When gorenje this gas practically does not form by-products. The beginning of degassing works in the Karaganda coal basin was laid back in the mid-1950s. Pilot tests took place at one of the mines in 1961 [14].

The risk of accidents increases with the development of overlying horizons and the transition to lower horizons. For more than half a century of degassing operations at the mines of the Karaganda region, a huge positive experience has been accumulated. It was possible to test more than 10 different technological methods for extracting coalbed methane. Tested: cyclic hydraulic fracturing of formations using gaseous and liquid nitrogen; hydraulic fracturing using hydrochloric acid; hydraulic pulse action using powder pressure generators; hydro-action without well development; pneumohydro-separation of formations; pneumatic action on a water-gas-saturated formation; thermal effect; impact on the formation with chemically active gases; impact on the formation in cavitation mode [15].

155 vertical wells were drilled for research and development work. This made it possible to extract more than 100 million, m^3 of methane. In general, in the basin, the average flow rate was 2045 m^3/day. The accumulated experience in advanced degassing from 1961 to 2017 showed the prospects of this method of reducing the gas content of coal seams. The gas content of the workings was then reduced from 30 to 80% [16].

Another three-stage project for the extraction of coalbed methane was implemented by KazTransGas. During the VI International Mining and Metallurgical Congress, Deputy Director of the Coal Industry Development Department of the Ministry of Energy of Kazakhstan, Council Dambarbayev, said that a methodology for methane reserves and resources in coal seams has already been developed. KSTU has even approved a professional development program for specialists in the field of geological exploration and production of coalbed methane. The work was carried out with the involvement of the companies "Zhumysstroyservice", "Taldykudukgaz", SEC "Sary-Arka" and "Kazgeologiya". Also, the joint venture "Satbayev University" and "ArcelorMittal Gas Production" was established on July 9, 2018. Its goal is the production of methane gas in the Karaganda coal basin, as part of the project on Kazakhstan's transition to a "green" economy and the development of a new energy sector for the extraction of coal methane in the Karaganda region. "Building a full–fledged methane production cluster is not a one-day task," says Chingiz Cherniyazdanov, Managing Director for Innovation at Satbayev University, a member of the Supervisory Board of the joint venture Satbayev University & ArcelorMittal Gas Production. Coal methane degassing and extraction systems are analyzed for their subsequent improvement. The world's highest gas content of coal seams in the Karaganda basin is from 15 to 35 m^3/t. According to preliminary estimates, it contains about 490 billion. m3 of methane at a depth of 1,500 m and about 500-550 billion, m^3 at a depth of 2,000 m [17].

1.4 MW gas generating plant at the mine named after Lenin covers up to 20% of the mine's electricity needs. In addition, it reduces emissions of harmful substances into the atmospheric air compared to coal-fired boilers. According to the company's official website, in 2013, the production of electricity by the methane gas generator of the mine. Lenin was 5,541 MW of methane used 4,029,609 m3. According to the data of the Ministry of Energy of Kazakhstan published in 2015, more than 290 million tons were disposed of from 1996 to 2013, m^3 of methane. This ensured a reduction in CO_2 emissions into the atmosphere by 4 million tons.

Methane is the main greenhouse gas in the activities of mines. Currently, boilers running on this gas are used to heat the air supplied to the mine. Such installations operate at the Shakhtinskaya, Abayskaya, Kostenko, Lenin mines (Figure 3.).

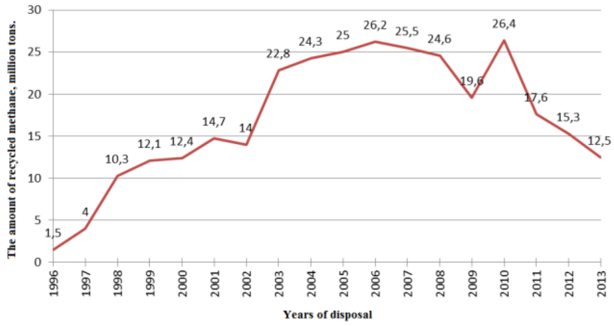

Figure 3 - Utilization of mine methane by gas-generating plants at the Shakhtinskaya, Abayskaya, Kostenko, Lenin mines

The cost of a conventional unit of methane extracted from coal seams is several times higher than natural gas. However, the leaders-gas producers are interested in the development of this industry. That is why representatives of companies from China, Germany, the USA and Poland periodically hold talks on the development of mining technologies and regularly demonstrate equipment for the extraction and processing of mine methane.

Research results and discussion

The geological and economic essence of methane as a mineral can be assessed from two fundamentally different sides. Methane extraction can be carried out by gas fishing, as an independent mineral, without coal mining. Here, the profitability of this production and the availability of a possible consumer of this gas are prioritized. By the way, the technology for controlling gas emission, according to the analysis of statistical indicators, accounts for up to 25% of the costs associated with the extraction of solid fuel.

The need to degass the layers of the Karaganda coal basin is a good factor in the profitability of methane extraction. Reducing the emission hazard and ensuring the gas safety of mining operations are an important criterion of the production process. When considering independent commercial production of methane, the profitability of this process becomes paramount, which depends on the depth of the formation, gas content, filtration properties and extraction technology.

Methane extraction can be carried out by onshore wells in areas where coal mining does not occur or in areas adjacent to existing mines. It is also possible to organize production on the explored and exploration and evaluation areas, on gas-bearing coal deposits that are not planned for production in the near future, as well as lower horizons inaccessible for coal mining [[18], [19]].

Only a comprehensive study and consideration of all geological factors, as well as the properties of coal, will allow us to determine the efficiency of extraction technology and the profitability of methane gas production as an independent mineral.

Comparing the geological characteristics of the Karaganda basin with foreign ones, it can be concluded that the development of methane extraction projects in the basin areas is promising. Analyzing the data of the geological study of the basin, the Taldykuduk site, located in the southwestern part of the Karaganda syncline, appears to be the primary object for the implementation of the pilot project.

The geological parameters of the Black Warrior basin, one of the largest in the USA, are significantly inferior to the parameters of the Karaganda coal basin. The methane gas content in the Karaganda basin is almost 2 times or higher than the average gas content in the world's largest deposits.

This choice is based on the following indicators:

- the site has the maximum coal content in the Karaganda basin — 9.5%, the total capacity of the coal seams of the Karaganda formation is about 60m;

- the main part of the coal seams is sustained in area and capacity, they have a distribution outside the selected area within the entire basin, and the maximum capacity of a separate coal seam reaches 12.4 m;

- the site has a large number of consonant surges with displacement amplitudes up to 400 meters and regional folded structures of syncline and anticline type with amplitudes up to 200 m and a length of up to 4-5 km, which can be structural traps of methane. In this regard, it can be assumed, in addition to cleavage cracks, the development of tectonic fracturing and wide crushing zones in the locks of folds and at the displacers of discontinuous faults, as well as in general in the coal-containing massif, which will serve as additional channels for methane drainage.;

- coals of the brand from QL to OS assume a high sorption and gas-generating capacity. The vitrinite content in the range of 40-91% provides intense microcracking and gas permeability of the coal pack;

- the adjacent areas of the coal basin, which do not differ much in geological structure, represent a prospect for expanding a possible large-scale project to extract coalbed methane, increasing the resource base several times. The total area possible for the development of a promising large-scale project exceeds 120 km^2 with a projected volume of coalbed methane of about 100 billion m^3.

Brown coals are characterized by low gas content and high permeability. High gas content and low permeability - anthracites. For the extraction of methane, the most promising are the coals of the middle stages of metamorphism, which have moderate gas content, are intensely fractured, and as a result, are more permeable.

As in an unconventional reservoir, fluid filtration occurs mainly through cracks in the coal seam. The capacity for methane is macro-, meso- and micropores, although their indicator is usually insignificant in the total reservoir capacity. The change in the capacitance and filtration characteristics occurs in the process of coal metamorphism from brown to anthracite. As a result, brown coals are characterized by the lowest marginal gas capacity – 5-8 m3/t. Anthracites have the opposite situation, where the maximum gas capacity can reach 45-47 m3/t. Meanwhile, the size of pores and voids varies widely in coals.

The pore indices in anthracites are not large, meanwhile, they increase in the process of metamorphism. So hard coals have average numbers, and brown coals have the greatest value. Fracturing and geomechanical conditions characterize the filtration characteristics of coal seams.

The morphology of the formation, its hypsometry, as well as the qualitative indicators of coal, methane content, and permeability, are determined at the prospecting, evaluation, and exploration stages of the preparation of a methane coal deposit. These data are obtained by drilling structural and parametric wells, as well as by laboratory examination of the coal core.

Methane content is associated with porosity. Under the same pressure conditions, a coal seam can hold much more gas than the same volume of sandstones. When water is removed, the formation matrix shrinks, which contributes to the formation of a system of orthogonal cracks – cleavage. The free pore volume is often filled with water. Its pumping leads to a decrease in reservoir pressure. As a result, methane trapped in micropores is released. This gas spreads in all directions spontaneously through the existing cleavage cracks. The basis of the mechanism of gas movement is a system of natural fracturing.

Hydraulic fracturing is used to intensify methane release. As a result, it is possible to open existing cracks and form new ones. This leads to an increase in the productivity of the well. In addition, the use of a wedging agent allows them to fill cracks and does not allow them to close. All this leads to an improvement in the permeability conditions, which allows methane to be released and penetrate the well [20]. This is clearly shown in Figure 4.

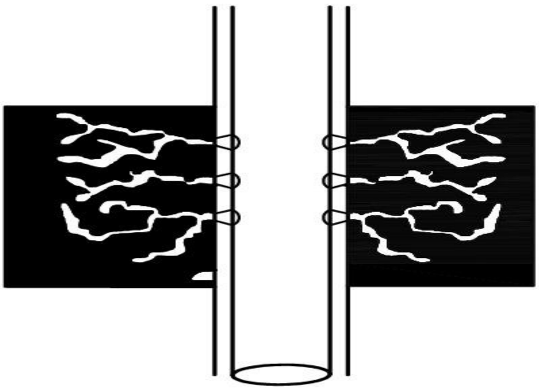

Figure 4 - Schematic representation of the process of crack formation around the borehole after applying the method of hydraulic fracturing of the coal seam

Horizontal drilling can also be a way to intensify gas recovery. The method is effective in conditions of a highly anisotropic reservoir. In this case, the hydraulic fracturing technology will be less successful. Meanwhile, cluster horizontal drilling can contribute to an increase in the flow rate of methane from the well. Important factors in this case are the direction and stability of the well. This is confirmed by the long-term experience of Australian drillers.

The intensity of gas recovery can also be enhanced by the method of pneumatic-hydrodynamic action on the formation. In this case, cavities form in the thickness around the borehole and cracks near them. This is clearly shown in Figure 5.

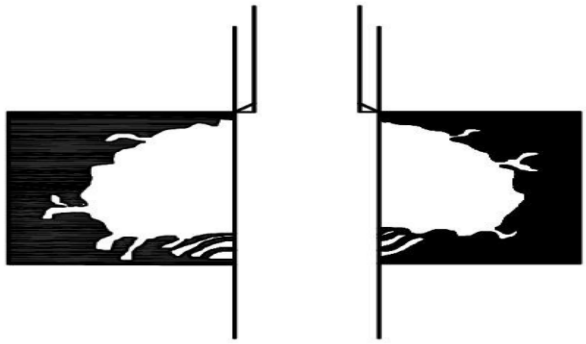

Figure 5 - Schematic representation of the process of formation of cavities and cracks after the application of the method of pneumatic-hydrodynamic action

This method consists of cyclic pulsation due to pressure when a water-air mixture is introduced into the borehole. This leads to the collapse of coal around the borehole, and the formation of cracks and cavities.

Conclusions

Kazakhstan has significant potential for the extraction and exploration of methane coal deposits. Up to a depth of 1500 meters, methane resources in the Karaganda coal basin amount to 490.47 billion m^3. This makes it possible to consider methane gas as a good alternative to traditional natural gas because its content in the Karaganda basin varies from 80 to 98%. Meanwhile, the Ekibastuz coal basin has been less studied for methane reserves, and there is no information at all on the remaining deposits, which indicates that they are poorly studied. There are deposits in Kazakhstan that occupy significant areas and concentrate coals with a high gas density. That is why it is worth carrying out a number of research works to clarify the available volumes of methane. Its extraction from coal seams is considered a more expensive process than the extraction of traditional gas. The need to create channels effects in the coal seam for the movement of methane, through hydraulic fracturing. For example, the gas contained in sandstone independently comes to the surface due to reservoir pressure.

Having analyzed the conditions of geological occurrence of methane in various countries of the world, we can conclude about the economic efficiency of extracting this gas in the Karaganda coal basin. The experience of other countries demonstrates the extraction of methane under similar conditions of occurrence of coal seams.

The prospects of the sites can be determined by the following geological and technological factors:

- the gas capacity should be more than 8-10 m3/t and grow with the deepening of the formation.

- total reservoir capacity - 8-10 m or more;

-petrographic composition of coals - vitrinite;

- the depth of assessment is limited by methods and technologies of methane extraction. At the present time, it is 300 - 1800 m. Meanwhile, 500 - 1200 m is considered the most favorable;

- the scale of resources affects the determination of the period of operation of the field for gas production. Promising can be considered with deposits of more than 50-75 MW. m^3 at a mining site or site.

- resource density evaluates the productivity of reservoir groups. A concentration of more than 150-200 million m^3/km^2 is considered favorable;

- ash content of coals up to 25-30 %;

-the degree of metamorphism – coals from the group G, W, K, OS, T.

-fracturing and fragility. Coals of the middle stage of metamorphism.

-in the tectonic plan of occurrence, the best option would be flat layers, with the angles of incidence of folds in the range of 30-40 degrees.

The fields of mines operating in the Karaganda region can be considered a source of cheap gas, which allows for the reduction of the gas content of formations and improves the safety of mining operations, provided that methane is extracted in advance.

The flow rate of wells after the application of gas recovery intensification technologies should be more than 5-10 thousand m^3/day, with an increase in this indicator in the active phase of development to 20-40 thousand m^3/day.

Industrial methane production, in areas with appropriate indicators, should be based on the desorption of gas from the surface of coal. A sharp pressure relief contributes to the flow of methane into the well through the system of cracks formed after the intensification methods.

Government support and subsidies for this process have an important impact on the development of methane production on an industrial scale, as evidenced by the experience of countries successfully producing coal methane.

The existing infrastructure has a restrictive impact on methane production in a number of countries – low throughput of gas pipelines and export terminals, technologically complex and expensive drilling, and lack of qualified personnel. [[21], [22]].

Conflict of interest. On behalf of all authors, the corresponding author states that there is no conflict of interest regarding others.

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ТҮЙІНДЕМЕ
Бұл мақалада көмір шахталарында тау-кен жұмыстарын қауіпсіз жүргізуді қамтамасыз ету мәселелері қарастырылған. Көмір өнеркәсібі жұмысшыларының қауіпсіздігін қамтамасыз ету бүгінгі таңда өзекті мәселе болып табылады. Қабаттардағы газ мөлшері тереңдеген сайын артады және бұл тау-кен өндірісінде тежегіш болып табылады. Метанның оқыс шығарындылары адамдардың құрбан болуына, қаржылық шығындарға және басқа жағымсыз әсерлерге әкелуі мүмкін. Тек соңғы жылдары мұндай апаттар Қарағанды көмір бассейнінің шахталарында 157-тан астам адамның өмірін қиды. Осы маңызды проблеманы шешу арқылы ілеспе газ алуға болады. Қолданыстағы газсыздандыру технологияларының көмегімен газдың мөлшерін азайту оңай емес. Қабаттар іс жүзінде нөлдік газ өткізгіштікке

ие және олардың мөлшері қазіргі тереңдіктерде аз болуы мүмкін. Сондықтан метанның бөлінуін қамтамасыз ету үшін көмір қабатына мүмкіндігінше ертерек әсер ету қажет. Бұл процесс өнеркәсіптің немесе халық шаруашылығының қажеттіліктері үшін пайдаланылатын ілеспе газды алуға мүмкіндік береді. Көмір қабаттарындағы газдың мөлшерін төмендету арқылы тау-кен жұмыстарын жүргізу тәуекелділіктері азаяды және еңбек қауіпсіздігі артады.

Түйін сөздер: қауіпсіздік, көмір шахталар, көмір қабаттары, метан, оқыс шығарындылар.

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Опыт добычи метана угольных пластов Карагандинского угольного бассейна

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АННОТАЦИЯ

В данной статье рассмотрены вопросы обеспечения безопасного ведения горных работ на угольных шахтах. Обеспечение безопасности работников угольной промышленности на сегодняшний день является актуальной проблемой. Газосодержание пластов увеличивается с глубиной их залегания и является сдерживающим фактором при добыче полезных ископаемых. Внезапные выбросы метана могут спровоцировать большое количество человеческих жертв, финансовых потерь и других последствий. Только за последние годы подобные аварии унесли более 157 человеческих жизней на шахтах Карагандинского угольного бассейна. Однако, решив эту важную проблему, можно получить попутный газ. Снизить показатель газосодержания с помощью существующих технологий дегазации непросто. Пласты имеют практически нулевую газопроницаемость и низкую газоотдачу на текущих глубинах их разработки. Вот почему необходимо как можно раньше оказать воздействие на угленосный пласт, чтобы обеспечить выброс метана. Этот процесс позволит получать попутный газ, который может быть использован для нужд промышленности или народного хозяйства. В результате снижение газосодержания угольных пластов снизит риски ведения горных работ и повысит безопасность труда.

Ключевые слова: безопасность, угольные шахты, угольные пласты, метан, внезапные выбросы.

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