Код МРНТИ 52.13.25

D.R. Akhmatnurov, *N.M. Zamaliyev, M.S. Usenbekov, R.A. Musin
NJSC «Karaganda State Technical University named after Abylkas Saginov» (Karaganda, Kazakhstan)

DEVELOPMENT OF A METHODOLOGY FOR DETERMINING THE VOLUME OF CAVITIES OF GAS ACCUMULATIONS IN WASTE AREAS AND METHANE CONTENT

Abstract. The article explores the use of degassing wells for capturing and utilizing methane at the Kirovskaya mine. The study presents results from measurements of gas pressure and flow rate at the vacuum pump station. An analysis of the parameters of the methane-air mixture and methane concentration in the mined-out space confirms the accuracy of the gas collector volume calculations. Factors affecting methane concentration, such as the volume of voids and fractures, were investigated, and methods for managing gas emission were examined. Methane concentrations in the Karaganda Basin mines can reach 90-95% after ventilation ceases. Methane flow rates through degassing wells ranged from 4.9 to 1380.6 thousand m³, with a total capture of 7547.1 thousand m³ over 21 months. The results highlight the importance of degassing wells for the safe management of gas emission.

Key words: *methane, gas mixture, degassing well, methane flow rate, methane content in the exhausted space.*

Пайдаланылған учаскелердегі газ жинақтау қуыстарының көлемін және метан құрамын анықтау әдістемесін әзірлеу

Аңдапта. Мақала «Кировская» шахтасында метанды жинау және пайдалануға арналған дегазациялық скважиналардың қолданылуын зерттейді. Жұмыста вакуумды сорғыш станциядағы қысым мен газ дебитін өлшеу нәтижелері ұсынылған. Метан-ауаның қоспаларының және шахтадағы метан концентрациясының параметрлерін талдау жүргізіліп, газ жинаушы көлемін есептеу дәлдігі расталған. Метан концентрациясына әсер ететін факторлар, мысалы, қуыс және жарықшақтардың көлемі зерттелген, және газ шығару әдістері қарастырылған. Карагандин бассейні шахталарында метан концентрациясы проветриваниені тоқтатқаннан кейін 90-95%-ға жетуі мүмкін. Дегазациялық скважиналар арқылы метан дебиті 4,9-дан 1380,6 мың м³-ке дейін өзгеріп, 21 ай ішінде 7547,1 мың м³ метан жинақталған. Нәтижелер дегазациялық скважиналардың газ шығаруын қауіпсіз басқарудағы маңызды рөлін көрсетеді.

Түйінді сөздер: *метан, газ қоспасы, газсыздандыру ұңғымасы, метан дебиті, өндірілген кеңістіктегі метан мөлшері.*

Разработка методики определения обьемов полостей газонакоплений на отработанных участках и содержания метана

Аннотация. Статья исследует применение дегазационных скважин для каптажа и утилизации метана на шахте «Кировская». В работе представлены результаты измерений давления и дебита газа в вакуум-насосной станции. Проведен анализ параметров метановоздушной смеси и концентрации метана в выработанном пространстве, что подтвердило точность расчетов объема газового коллектора. Исследованы факторы, влияющие на концентрацию метана, такие как объем пустот и трещин, и рассмотрены методы управления газовыделением. Концентрация метана в шахтах Карагандинского бассейна может достигать 90-95% после прекращения проветривания. Дебит метана через дегазационные скважины колебался от 4,9 до 1380,6 тыс. м³, с общим захватом 7547,1 тыс. м³ за 21 месяц. Результаты подчеркивают важность дегазационных скважин для безопасного управления газовыделением.

Ключевые слова: *метан, газовая смесь, дегазационная скважина, дебит метана, содержание метана в выработанном пространстве.*

Introduction

Methane is one of the primary gases released during coal mining and poses a significant threat to mine safety. In abandoned sections of the Karaganda coal basin mines, methane can accumulate in substantial quantities, creating a high risk of explosions and accidents. Methane is particularly dangerous when ventilation ceases in the mines, leading to concentrations reaching up to 90-95%. Therefore, developing methods for accurately calculating the volume of gas accumulations and determining methane concentration is a critical task for ensuring mine safety.

The aim of this research is to develop and test a method that will accurately determine the volume of voids where methane accumulates and calculate the methane concentration in the mined-out space. The research tasks include measuring pressure and gas flow parameters, as well as analyzing the dynamics of methane concentration changes based on the volume of voids and cracks in the mine. The study also focuses on developing methods for gas emission control and safe methane disposal for further use.

Research Methods

To determine the volumes of gas accumulations, a method based on measuring pressure and gas flow using a vacuum pumping station was employed. The calculations are based on the gas law known as Boyle's Law. By using the measured values of gas pressure before and after pumping a certain volume of gas mixture, the volume of gas accumulations can be calculated. This method provides accurate data even when direct measurement of void volumes is challenging. Experimental data were collected at the Kirovskaya mine, where measurements of methane-air mixture parameters were conducted. Degassing wells connected to a vacuum pumping station were used for this purpose. During the experiments, gas pressure, methane concentration in the mixture, and the volume of gas passing through the wells were measured.

Special attention was given to the impact of void and crack volumes on methane concentration. It was found that the volume of voids significantly affects the final gas concentration, as confirmed by observing gas emission dynamics in the mined-out space.

Results and Discussion

The experiments provided data on methane concentration and gas volumes in the mined-out space of the Kirovskaya mine. The methane concentration in the methane-air mixture varied depending on the operation of the vacuum pumping station. At the beginning of the experiment, methane content in the mixture reached 34%, while under vacuum, it decreased to 31%. Over 21 months of operating degassing wells, 75,471 thousand cubic meters of methane were captured, confirming the effectiveness of the proposed method.

The analysis of methane concentration in relation to void volume showed that as the volume of voids increases, so does the methane concentration. In the mines of the Karaganda basin, methane concentration in the mined-out space can reach

90-95% after ventilation ceases. This requires careful monitoring and proper gas emission management to prevent hazardous consequences.

The experimental results indicated that the proposed method for calculating gas accumulation volumes works with high accuracy. Comparison with previous studies confirmed its applicability for practical mining needs. For example, similar trends were observed in other mines in the region, making the method versatile for use in the coal industry.

Conclusions

Based on the conducted research, it can be concluded that the proposed method for determining gas accumulation volumes and methane concentration in the mined-out space is an effective tool for managing gas emissions. Using degassing wells significantly reduces methane concentration in mines and ensures safe working conditions.

The proposed method can be successfully applied in the mines of the Karaganda basin and other coal regions for methane control and safe disposal. The results of this work can be used for further research in this field and the development of automatic gas concentration monitoring systems.

Theory of the issue

When solving operational issues of managing gas release from the exhaust space and simultaneous gas production for its use, a method for determining the volume of the gas reservoir is required, based on measuring the parameters of the exhaust gas (pressure, volume).

Since there is no real opportunity to measure the volume of the gas collector in the exhaust space of the mine using instrumental instruments, to solve this problem, this work considers a method for determining this parameter, based on measuring the gas pressure in this collector before and after extracting a certain volume of the gas mixture. This problem can be solved using the equation of gas state of a certain mass of gas, which is uniquely determined by thermodynamic parameters [1-4]: temperature t, volume V and gas pressure P.

Let us imagine the voids and delamination cavities in the waste space as a single volume (Figure 1) and assume a constant temperature of the gas mixture and the volume of the gas reservoir.

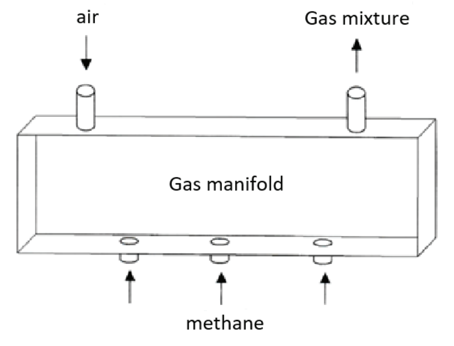


Figure 1. Scheme for determining the volume of the gas reservoir.
Сурет 1. Газ қабатының көлемін анықтау схемасы.
Рис. 1. Схема определения объема газового пласта.

To solve the problem of determining the volume of a gas reservoir, consider the following example. In a reservoir with a volume V_c (m^3), there is a gas [4] under pressure P_0 (mm Hg) and density ρ (kg/m^3).

During the time dt, a mass of gas is sucked out from a given volume or supplied into it in accordance with the formula:

$$Dm = q\rho dt, \tag{1}$$

where q – the amount of pumped gas, m^3/min;

ρ – density of the pumped gas, kg/m^3.

On the other hand, the amount of gas contained in a given volume, after pumping it out (injecting it), will change by an amount according to the formula:

$$dm = V_x,\ dp. \tag{2}$$

Then the law of conservation of mass will be written according to the formula:

$$V_k\, dp = \pm q\rho dt. \tag{3}$$

$$\frac{dp}{\rho} = \pm \frac{q\, dt}{V_k}. \tag{4}$$

We accept the sign (+) when creating pressure in the gas manifold, and the sign (-) when creating a vacuum in it.

Let's integrate the resulting expression within $P \in [P_0, P_1]$; $t, (s) \in [0, T]$ according to the formula:

$$\int_{\rho_0}^{\rho_1} \frac{dp}{\rho} = \pm \frac{q}{V_k} \int_0^T dt\,. \tag{5}$$

Solving equations (3), we obtain the formula:

$$ln\left(\frac{\rho_1}{\rho_0}\right) = \pm \frac{qT}{V_k}. \tag{6}$$

From expression (4) we obtain a formula for calculating the value V_k of the goaf volume:

$$V_k = \pm \frac{qT}{ln\frac{\rho_1}{\rho_0}}. \tag{7}$$

It is known that the equation of state of a gas is expressed by the dependence:

$$P = R_{г} t_{г} p, \tag{8}$$

where P – gas pressure, kgf/cm^2;

R_g – universal gas constant, 287 J/kg °K;

t_g – gas temperature, °K.

Since in our example R_g and t_g do not change, the solution to (5) has the form of equality:

$$V_k = \pm \frac{qT}{ln\left(\frac{P_1}{P_0}\right)}. \tag{9}$$

Based on the well-known Boyle-Mariotte law [5], the volume of the gas reservoir is determined by the formula:

$$V_k = \frac{P_0 Q}{P_0 - P_1}, \qquad (10)$$

where Q is the amount of extracted gas, m^3.

When pumping gas from a reservoir, it is necessary to take into account the simultaneous entry of methane into it from the remaining coal and air.

To solve the problem of practical determination of the volume of a gas reservoir, we introduce the following notation:

q_m, ***qв*** – respectively, the amount of methane and air entering the gas collector, m^3/min;

qcm – amount of gas mixture extracted from the gas reservoir, m^3/min;

C_m and **Cв** – content of methane and air in the gas reservoir, respectively, %;

P_0 – gas pressure in the manifold before the start of suction, mm Hg. Art.;

P_1 – gas pressure in the manifold after stopping the vacuum pump unit, mm Hg. Art.;

T – operating time of the vacuum installation, s.

The amount of methane entering the gas reservoir q_m is calculated based on the results of measurements on the gas pipeline. The amount of extracted gas mixture q_{cm} is determined by measurements during operation of the suction unit.

The values of q_m and q_b through the concentration of methane and air in the gas reservoir are related by the relation:

$$\frac{C_M}{C_e} = \frac{q_M}{q_B}. \qquad (11)$$

From equality (8) it follows that air leaks into the gas manifold can be determined by the formula:

$$\frac{C_M}{C_e} = \frac{q_M}{q_B}. \qquad (12)$$

During the suction of gas T into the collector, methane will be released in a volume of $q_m T$, air $q_b T$, and during the same time the gas mixture will be extracted in a volume of $q_{cm} T$.

Based on this, the amount of gas that influenced the change in gas pressure in the reservoir is calculated using the formula:

$$Q = (q_M + q_e - q_a) \cdot T. \qquad (13)$$

When the suction unit stops, the gas pressure in the reservoir at the wellhead is calculated using the formula:

$$P_1 = P_0 - h, \qquad (14)$$

where h is the vacuum at the wellhead, mm Hg. Art.

The flow rates of methane, air and gas mixture in formula (10) are reduced to normal conditions.

The possibility of using the established relationship (5) was verified based on the results of experimental research measurements on a section of the Kirovskaya mine field [6]. Due to the good gas production of degassing wells after the liquidation of part of the mine field along the A5 layer, the six remaining vertical wells (depth 450-509 m) with an average methane flow rate at a natural flow of 0.088 m^3/s are connected to a common gas pipeline to capture methane and use it in the boiler room of the mine.

The essence of the experiment was to measure the pressure (rarefaction) and gas flow rate in the gas pipeline at the wellhead with the vacuum pump station (VPS) turned off and running.

On the day of the experiment, at the beginning of turning on the VNS, the concentration of methane in the gas mixture was 34.0%. When creating a vacuum, the methane content in the gas mixture decreased to 32.0%. In just 5 hours and 30 minutes of work, the VNS was extracted 7194.0 m^3 gas mixture, with an average flow rate of 0.363 m^3/s. The results of measuring the parameters of the VNS operation are shown in Table 1.

Measurements showed that the pressure of the methane-air mixture in the gas reservoir (at the wellhead) before turning on the VNS was $P_0 = 740$ ***mm Hg. Art.***

Taking into account the concentration values of methane and air, as well as the value of methane flow rate using formula (10), we obtain the value of air leaks into the collector:

$$q = \frac{0.088 \times 660}{34.0} = 1.7\ m^3/s. \qquad (15)$$

Substituting into formula (11) the values of the amount of the sucked mixture, methane flow rate and air leaks, as well as

Table 1

Operating parameters of the VPS at the Kirovskaya mine

Кесте 1

«Кировская» шахтасындағы ВНС жұмыс параметрлері

Таблица 1

Рабочие параметры ВНС на шахте «Кировская»

Time, hour, min	Underpressure, mm. Hg Art.	Concentration methane, %	Quantity gas mixture, m^3/s	Quantity methane, m^3/s	Note
300	740	34	0.36	0.122	On VNS
400	743	33	0.361	0.12	
600	742	32	0.363	0.116	
830	725	31	0.365	0.113	Off VNS
1105	682	-	-	-	On VNS
1140	700	33.0	0.358	0.118	Off VNS

the operating time of the VNS, we obtain the amount of gas that influenced the change in gas pressure in the collector:

$$\boldsymbol{Q = (0.988 + 0.17 - 0.36) \times 1900 = 1516.2\ m^3.} \qquad (16)$$

Next, substituting the measured and calculated values of quantities (P0, P1 and Q) into formula (8), we find the volume of the gas reservoir:

$$\boldsymbol{V_K = \frac{740 \times 2079}{740 - 700} = 38,451.5.\ m^3.} \qquad (17)$$

This volume of the gas mixture contains (38462X34/100) = 13076.9 m^3 of methane.

To confirm the reliability of the calculation formulas, a second experiment was carried out and the following values were established: ***P_0 = 741 mm Hg. Art., P_1 = 699 mm Hg. Art., q_m = 0.085 m^3/s, qb = 0.18 m3/s, q_{cm} = 0.382 m^3/s, C_m = 31%, T = 370 min.***

Substituting these values into formulas (11) and (8), we obtain ***$V_к$ = 38493.5 m^3.*** A comparison of the results from the two experiments shows that the discrepancy between them is less than 1.0%, and therefore it can be assumed that the adopted method can be used to calculate the volume of the gas reservoir.

If it is impossible to connect the wells to a vacuum installation, you can use an autonomous compressor, with which air will be supplied to the gas reservoir. Then, instead of qcm, the compressor performance is substituted into formula (11).

To solve the issue of managing gas emissions and extracting gas from exhausted sections of a mine for the purpose of its further use, it is necessary to have data on the concentration of methane. All these indicators depend on a number of factors, the main of which are the sources of methane release and the volume of voids and cracks in which methane can accumulate.

Below we will consider the issue of the formation of methane concentration in the mined-out space of the mined area and the dynamics of its change after the cessation of ventilation.

Repeated measurements of the methane content in the mined-out spaces of active longwalls in the mines of the Karaganda basin have established that the concentration can fluctuate over a wide range: from a few percent to 90-95%. The methane content mainly depends on two factors: on the volume of gases entering the goaf from various sources (remaining pillars of coal and unexcavated packs of the developed seam, under- and overmined satellite seams, gas-bearing rocks, etc.) and air leaks during ventilation Lav. The more gas enters the goaf and the less air leaks, the higher the methane content will be and vice versa. Moreover, it should be noted that the methane content in the goaf is not a constant value and, given the constancy of the above factors (gas release, air leaks), varies over the area of the goaf. Typically, a low methane content is observed at the boundary of the mined-out space with the lava and in the area where the main flow of air leaks occurs.

From the point of view of gas extraction, it is necessary to have information about the average methane content in the goaf. In accordance with [7], with a return-flow ventilation scheme, when air leaks through the goaf are minimal [8], the average methane content (Cm) is determined by the formula:

$$\boldsymbol{C_M = \lambda I_{\text{в},n},} \qquad (18)$$

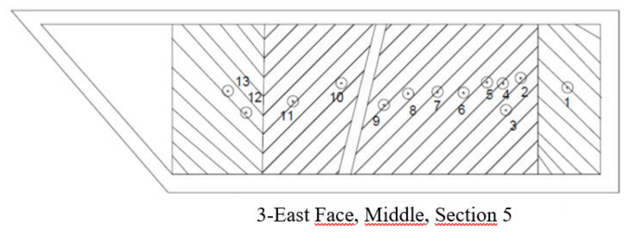
where ***ë*** is a coefficient characterizing the increase in methane concentration depending on the intensity of gas release, %C/m^3. Based on experimental data ***ë = 140%C/m^3;***

Iv.p – the amount of methane released into the goaf, m^3/min.

Gas release into the mined-out space of active longwalls usually varies widely: from 0.03-0.05 to 0.66-0.83 m^3/s. The greatest significance of gas emission occurs in longwalls where undermining (overworking) of coal seams is carried out. Under these conditions, the methane content reaches 80-90%.

After the lavas stop, the intensity of gas release from the sources of methane decreases. But at this time, the ventilation of the lava stops, which creates favorable conditions for the accumulation of a gas mixture in the exhaust space with a high methane content.

As an example, this section provides information on the former Churubay-Nurinskaya mine, where in order to reduce the gas abundance of the 3rd eastern longwall of the middle sublevel of the K13 seam by capturing gas from the undermined satellite seams K_{14}, K_{15}, K_{16}, K_{17} and the mined-out space with 13 vertical wells were drilled on the surface (Figure 2. 8).



1-13 – degassing wells

Figure 2. Layout of mine workings and degassingwells of the K_{13} formation of the Churubay-Nurinskaya mine.
Сурет 2. Чұрубай-Нұрын шахтасының K_{13} қабатының кен қазбалары мен дегазациялық ұңғымаларының орналасу жоспары.
Рис. 2. План горных выработок и дегазационных скважин пласта K_{13} шахты Чурубай-Нуринская.

The total methane flow rate from the wells ranged from 4.9 (wells No. 1-3) to 1380.6 thousand m^3, while the concentration of methane in the sucked mixture was in the range of 20-55%. During longwall mining (for 21 months) the indicated wells captured 7547.1 thousand m^3 of methane, i.e. on average it was 12,500 m^3/day. After the end of the longwall operation, gas capture from the wells was stopped, and their mouths were blocked with plugs. A year after mining the said longwall at a distance of 2-3 m from there, excavation of the 3rd eastern conveyor drift of the upper subfloor began. Since the excavation was carried out through a coal massif, which was drained due to the passage of a ventilation drift of the middle sublevel, the gas content of the 3rd eastern conveyor drift of the upper sublevel was relatively low and with a dead-end length of 300-380 m, as a rule, did not exceed 0.05-0.066 m^3/s, and the methane content in the outgoing ventilation stream was 0.5-0.8%. At the same time, it should be noted that in certain periods during mining, a sharp increase in gas emissions was repeatedly observed, reaching 0.1-0.11 m^3/s, and the concentration of methane in the air increased to 1.5-1.7%, which led to forced stoppages of excavation work.

Based on the observations, it was established that the source of increased gas emission was the mined-out space of the previously mined 3rd eastern face of the middle floor. In order to prevent increased gas release, it was decided to use vertical degassing wells to remove gas from the goaf to the day surface under natural flow. To do this, plugs were removed from each well and gas exhaust pipes («candles») of length4 m. Of the 13 wells drilled, only 5 wells turned out to be suitable for reuse (No. 1, 2, 3, 5, 9), and the rest were pinched by settling rocks, and gas did not flow through them to the surface.

Based on measurements taken at the wells, it was established that the methane flow rate in individual wells ranged from 500-700 m^3/day and in total amounted to about 3000 m^3/day. The measurement results showed that the methane flow rate in wells (No. 1, 2, 3, 5) ranged from 83 to 448 m^3/day. The total amount of methane coming through the wells to the surface was 840-980 m^3/day. The methane content in the gas mixture arriving at the surface during natural outflow was relatively high: 80-92%.

The data presented show that within 1 year after the cessation of degassing and ventilation of the longwall, despite the fact that the methane content in the goaf increased by 2-5 times, and the methane flow rate decreased from 12,500 to 3,000 m^3/day, i.e. 4 times.

Next, to analytically describe the dynamics of changes in the concentration of methane in the mined-out space over time, taking into account the entry of methane into it from various sources of gas release, we will determine the possible flow of methane from the mined-out spaces after the cessation of ventilation and mothballing of the mine.

To solve the problem, we will make the following assumption. Let's say that on the closed part of the mine field there are mined-out spaces of three mined longwalls with volumes of voids and cracks V_1, V_2, V_3 and the methane content in them is C_1, C_2, C_3. The mine has main and preparatory workings, the volume of which is Vp.v., and the average concentration in them is C$_4$.

Thus, the total volume of voids, cracks and excavations can be written as the formula:

$$\sum V = V_1 + V_2 + V_3 + V_{n.\text{B}}. \qquad (19)$$

The measurements carried out established that at the time of mine closure, the total gas release into the ventilated development workings, including gas release from mined-out spaces, was I$_i$ per unit time. Methane reserves located in mined-out longwall spaces and in main and development workings will be calculated using the following formulas:

$$I_1 = \frac{C_1 V_1}{100}. \qquad (20)$$

$$I_2 = \frac{C_2\, V_2}{100}. \qquad (21)$$

$$I_3 = \frac{C_3 V_3}{100}. \qquad (22)$$

$$I_{n.8} = \frac{C_4 V_{n.8}}{100}. \qquad (23)$$

The total amount of methane, taking into account the additional gas supplied, is calculated using the formula:

$$\sum I = I_1 + I_2 + I_3 + I_{n.\text{B.}} + \sum I_i T. \qquad (24)$$

The weighted average concentration of methane in the goaf before its closure is calculated using the formula:

$$C_{cp} = \frac{C_1V_1 + C_2V_2 + C_3V_3 + C_4V_{n.8}}{\sum V}. \qquad (25)$$

Subsequently, the process of enrichment of the gas mixture located in the waste spaces will begin, and at any point in time the average methane content can be determined using formula (2.71):

$$C_{cp} = \frac{C_1V_1 + C_2V_2 + C_3V_3 + C_nV_n}{\sum V_i + \sum I_i T} \times 100, \qquad (26)$$

where T is the time elapsed after the mine was closed.

Thus, in general terms, the average methane concentration for an unlimited number of mined-out spaces can be expressed by the formula:

$$C_{cp} = \frac{\sum\left(\frac{C_iV_i}{100}\right) + \sum(I_iT)}{\sum V_i + \sum(I_iT)} \times 100. \qquad (27)$$

It should be borne in mind that the flow of methane into the goaf is not a constant value, but will decrease over time. Therefore, when calculating the value $\sum I_i T$ it is necessary to proceed from the average gas emission value.

The amount of gas that will be released through gas exhaust pipes (wells) is calculated using the formula:

$$I_{bp} = \frac{C_4 \sum E_i}{100}. \qquad (28)$$

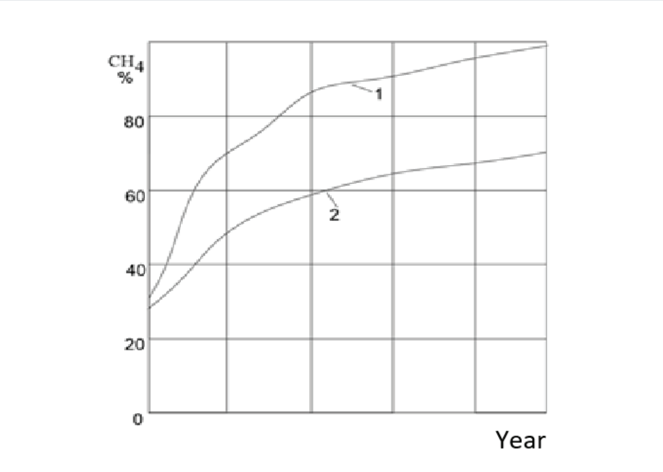


Figure 3. Change in methane content in goaf.
Сурет 3. Гофтегі метан мөлшерінің өзгеруі.
Рис. 3. Изменение содержания метана в выработанном пространстве.

$$1 - at_1\ I_i = 0.167\ m^3/s;$$
$$2 - at_1\ I_i = 0.016\ m^3/s.$$

Thus, at the Shakhtinskaya mine, after the ventilation of the mine workings ceased, the methane content in them increased to 80-90%.

Acknowledgment

The research was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan as part of program-targeted funding for the implementation of the scientific and scientific-technical program IRN No.BR24993009.

REFERENCES

1. *Kudryashov V.F. Promyshlennaya bezopasnost' i ekologicheskii monitoring pri dobyche metana v shakhtakh. // Ugol'naya promyshlennost' Rossii. 2018. №7. S. 22-27 [Kudryashov V.F. Industrial safety and environmental monitoring in methane extraction in mines. // Coal Industry of Russia. 2018. №7. P. 22-27] (in Russian)*
2. *Zaitsev V.G. Metan v ugol'nykh shakhtakh: dobycha i utilizatsiya. / V.G. Zaitsev, V.M. Minaev. // Gornye nauki. 2020. №2. S. 34-40 [Zaitsev V.G. Methane in coal mines: extraction and utilization. / Zaitsev V.G., Minaev V.M. // Mining Sciences. 2020. №2. P. 34-40] (in Russian)*
3. *Trofimov V.A. Problemy i perspektivy degazatsii ugol'nykh shakht. // Bezopasnost' v ugol'noi promyshlennosti. 2019. №5. S. 18-22 [Trofimov V.A. Problems and prospects of degassing coal mines. // Safety in Coal Mining. 2019. №5. P. 18-22] (in Russian)*
4. *Belik V.N. Degazatsiya ugol'nykh shakht i gazifikatsiya metana. / V.N. Belik, V.G. Aronov. // Gornaya promyshlennost'. 2016. №4. S. 25-30 [Belik V.N., Aronov V.G. Degassing of coal mines and methane gasification. // Mining Industry. 2016. №4. P. 25-30] (in Russian)*
5. *Zolotykh S.S., Arnautov V.S., Surin E.V. Iz nedr kuzbasskikh kladovykh – goryuchii gaz metan. Gazprom dobycha Kuznetsk: Kemerovo: Kuzbassvuzizdat, 2015, S. 247 [Zolotykh S.S., Arnautov V.S., Surin E.V. From the depths of Kuzbass storerooms – combustible gas methane. Gazprom Dobycha Kuznetsk: Kemerovo: Kuzbassvuzizdat, 2015, P. 247] (in Russian)*
6. *Issledovanie i puti sovershenstvovaniya degazatsionnykh rabot dlya kompleksnogo razvitiya ugol'noi promyshlennosti: Monografiya. / N.A. Drizhd, R.K. Kamarov, M.S. Usenbekov, D.R. Akhmatnurov. Karaganda: Izdatel'stvo KarGTU, 2017, 242 s. [Research and ways to improve degassing operations for the integrated development of the coal industry: Monograph. / Drizhd N.A., Kamarov R.K., Usenbekov M.S., Akhmatnurov D.R. Karaganda: KarSTU Publishing House, 2017, 242 p.] (in Russian)*
7. *Zolotykh S.S., Arnautov V.S., Surin E.V. Iz nedr kuzbasskikh kladovykh – goryuchii gaz metan. Gazprom dobycha Kuznetsk: Kemerovo: Kuzbassvuzizdat, 2015, S. 247 [Zolotykh S.S., Arnautov V.S., Surin E.V. From the depths of Kuzbass storerooms – combustible gas methane. Gazprom Dobycha Kuznetsk. Kemerovo: Kuzbassvuzizdat, 2015, P. 247] (in Russian)*
8. *Sun Y. CO2-ECBM in coal nanostructure: modeling and simulation. / Sun Y., Yuan L., Zhao Y. // Journal of Natural Gas Science and Engineering. 2018. Vol. 54. P. 202-215 (in English)*
9. *Jia T. Micro-nanostructure of coal and adsorption-diffusion characteristics of methane. / Jia T., Liu C., Wei G. et al. // Journal of Nanoscience and Nanotechnology. 2021. Vol. 21. Issue 1. P. 422-430 (in English)*
10. *Fu J.P. Rapid pyrolysis of pulverized coal for the preparation of nanostructured powder activated coke. / Fu J.P., Zhang Z., Zhou B.X. et al. // Materials Science Forum. 2019. Vol. 962. P. 63-69 (in English)*
11. *Hashemipour H. Direct and one-stage conversion of coal into carbon nanostructures with spherical, rod, tube, and plate geometry by chemical solid synthesis method. / Hashemipour H., Danafar F. et al. // Summer. 2020. Vol. 15. Issue 56. P. 179-194 (in English)*
12. *Reddy B.R. Preparation of carbon nanostructures from medium and high ash Indian coals via microwave-assisted pyrolysis. / Reddy B.R., Ashok I., Vinu R. // Advanced Powder Technology. 2020. Vol. 31. Issue 3. P. 1229-1240 (in English)*

ПАЙДАЛАНЫЛҒАН ӘДЕБИЕТТЕР ТІЗІМІ

1. *Кудряшов В.Ф. Өнеркәсіптік қауіпсіздік және экологиялық мониторинг метан өндірісінде. // Ресейдің көмір өнеркәсібі. 2018. №7. Б. 22-27 (орыс тілінде)*
2. *Зайцев В.Г. Көмір шахталарындағы метан: өндіру және пайдалану. / Зайцев В.Г., Минаев В.М. // Геологиялық ғылымдар. 2020. № 2. Б. 34-40 (орыс тілінде)*
3. *Трофимов В.А. Көмір шахталарын дегазациялау проблемалары мен перспективалары. // Көмір өнеркәсібіндегі қауіпсіздік. 2019. №5. Б. 18-22 (орыс тілінде)*
4. *Белик В.Н. Көмір шахталарын дегазациялау және метанды газдандыру. / Белик В.Н., Аронов В.Г. // Көмір өнеркәсібі. 2016. №4. Б. 25-30 (орыс тілінде)*
5. *Золотых С.С., Арнаутов В.С., Сурин Е.В. Кузбасс қоймаларының тереңдігінен – жанғыш метан газ. Газпром добыча Кузнецк: Кемерово: Кузбассвузиздат, 2015, Б. 247 (орыс тілінде)*

6. Дегазациялық жұмыстарды жетілдіру және көмір өнеркәсібінің кешенді дамуы: Монография. / Дрижд Н.А., Камаров Р.К., Усенбеков М.С., Ахматнуров Д.Р. Қарағанды: ҚарГТУ баспасы, 2017, 242 б. (орыс тілінде)
7. Золотых С.С., Арнаутов В.С., Сурин Е.В. Кузбасс қоймаларының тереңдігінен – жанғыш метан газ. Газпром добыча Кузнецк: Кемерово: Кузбассвузиздат, 2015, Б. 247 (орыс тілінде)
8. Sun Y. CO2-ECBM көмірдің наноструктурасында: модельдеу және симуляция. / Sun Y., Yuan L., Zhao Y. // Табиғи газдың ғылымы мен техникасы журналы. 2018. Т. 54. Б. 202-215 (ағылшын тілінде)
9. Jia T. Көмірдің микро-наноструктурасы және метанның адсорбция-диффузиялық сипаттамалары. / Jia T., Liu C., Wei G. және т.б. // Нанонаука және нанотехнологиялар журналы. 2021. Т. 21. №1. Б. 422-430 (ағылшын тілінде)
10. Fu J.P. Көмір шаңының жылдам пиролизі арқылы наноструктураланған ұнтақты белсендірілген көмір алу. / Fu J.P., Zhang Z., Zhou B.X. және т.б. // Ғылыми форум материалдары. 2019. Т. 962. Б. 63-69 (ағылшын тілінде)
11. Hashemipour H. Көмірді химиялық синтез әдісімен сфера, таяқша, түтік және пластина геометриясындағы көміртек наноструктураларына тікелей және бірқадамды конверсиялау. / Hashemipour H., Danafar F. және т.б. // Summer. 2020. Т. 15. №56. Б. 179-194 (ағылшын тілінде)
12. Reddy B.R. Үнді көмірлерінен микротолқынды пиролиз әдісімен көміртек наноструктураларын алу. / Reddy B.R., Ashok I., Vinu R. // Алдыңғы қатарлы ұнтақты технология. 2020. Т. 31.№3. Б. 1229-1240 (ағылшын тілінде)

СПИСОК ИСПОЛЬЗОВАННЫХ ИСТОЧНИКОВ

1. Кудряшов В.Ф. Промышленная безопасность и экологический мониторинг при добыче метана в шахтах. // Угольная промышленность России. 2018. №7. С. 22-27 (на русском языке)
2. Зайцев В.Г. Метан в угольных шахтах: добыча и утилизация. / В.Г. Зайцев, В.М. Минаев. // Горные науки. 2020. №2. С. 34-40 (на русском языке)
3. Трофимов В.А. Проблемы и перспективы дегазации угольных шахт. // Безопасность в угольной промышленности. 2019. №5. С. 18-22 (на русском языке)
4. Белик В.Н. Дегазация угольных шахт и газификация метана. / В.Н. Белик, В.Г. Аронов. // Горная промышленность. 2016. №4. С. 25-30 (на русском языке)
5. Золотых С.С., Арнаутов В.С., Сурин Е.В. Из недр кузбасских кладовых – горючий газ метан. Газпром добыча Кузнецк: Кемерово: Кузбассвузиздат, 2015, С. 247 (на русском языке)
6. Исследование и пути совершенствования дегазационных работ для комплексного развития угольной промышленности: Монография. / Н.А. Дрижд, Р.К. Камаров, М.С. Усенбеков, Д.Р. Ахматнуров. Караганда: Издательство КарГТУ, 2017, 242 с. (на русском языке)
7. Золотых С.С., Арнаутов В.С., Сурин Е.В. Из недр кузбасских кладовых – горючий газ метан. Газпром добыча Кузнецк: Кемерово: Кузбассвузиздат, 2015, С. 247 (на русском языке)
8. Sun Y. CO2-ECBM в наноструктуре угля: моделирование и симуляция. / Sun Y., Yuan L., Zhao Y. // Журнал науки и техники природного газа. 2018. Т. 54. С. 202-215 (на русском языке)
9. Jia T. Микро-наноструктура угля и адсорбционно-диффузионные характеристики метана. / Jia T., Liu C., Wei G. и др. // Журнал нанонауки и нанотехнологий. 2021. Т. 21. Вып. 1. С. 422-430 (на английском языке)
10. Fu J.P. Быстрая пиролиз угольной пыли для получения наноструктурированного порошкового активированного угля. / Fu J.P., Zhang Z., Zhou B.X. и др. // Материалы научного форума. 2019. Т. 962. С. 63-69 (на английском языке)
11. Hashemipour H. Прямая и одностадийная конверсия угля в углеродные наноструктуры с геометрией сфер, стержней, трубок и пластин методом химического синтеза. / Hashemipour H., Danafar F. и др. // Summer. 2020. Т. 15. Вып. 56. С. 179-194 (на английском языке)
12. Reddy B.R. Получение углеродных наноструктур из индийских углей средней и высокой зольности с помощью микроволнового пиролиза. / Reddy B.R., Ashok I., Vinu R. // Передовая порошковая технология. 2020. Т. 31. Вып. 3. С. 1229-1240 (на английском языке)

Сведения об авторах:

Ахматнуров Д.Р., доктор PhD, руководитель лаборатории, Карагандинский технический университет имени Абылкаса Сагинова (г. Караганда, Казахстан), *d.akhmatnurov@gmail.com;* https://orcid.org/0000-0001-9485-3669

Замалиев Н.М., доктор PhD, и.о. доцента, Карагандинский технический университет имени Абылкаса Сагинова (г. Караганда, Казахстан), *nailzamaliev@mail.ru;* https://orcid.org/0000-0003-0628-2654

Усенбеков М.С., кандидат технических наук, доцент, Карагандинский технический университет имени Абылкаса Сагинова (г. Караганда, Казахстан), *meirambek46@mail.ru;* https://orcid.org/0009-0003-5369-8393

Мусин Р.А., доктор PhD, и.о. доцента, Карагандинский технический университет имени Абылкаса Сагинова (г. Караганда, Казахстан), *r.a.mussin@mail.ru;* https://orcid.org/0000-0002-1206-6889

Information about the authors:
Akhmatnurov D.R., PhD, Head of the laboratory, Karaganda Technical University named after Abylkas Saginov (Karaganda, Kazakhstan)
Zamaliyev N.M., PhD, Acting Associate Professor, Karaganda Technical University named after Abylkas Saginov (Karaganda, Kazakhstan)
Usenbekov M.S., Candidate of Technical Sciences, Associate Professor, Karaganda Technical University named after Abylkas Saginov (Karaganda, Kazakhstan)
Mussin R.A., PhD, Acting Associate Professor, Karaganda Technical University named after Abylkas Saginov (Karaganda, Kazakhstan)

Авторлар туралы мәліметтер:
Ахматнуров Д.Р., PhD докторы, зертхана басшысы, Қарағанды техникалық Әбілқас Сағынов атындағы университет (Қарағанды қ., Қазақстан)
Замалиев Н.М., PhD докторы, доцент м. а., Қарағанды техникалық университеті Әбілқас Сағынов атындағы (Қарағанды қ., Қазақстан)
Усенбеков М.С., техника ғылымдарының кандидаты, доцент, Қарағанды техникалық Әбілқас Сағынов атындағы университет (Қарағанды қ., Қазақстан)
Мусин Р.А., PhD докторы, доцент м. а., Қарағанды техникалық университеті Әбілқас Сағынов (Қарағанды қ., Қазақстан)