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TECHNIQUE FOR REDUCING METHANE CONCENTRATION IN THE STOPE OF THE EXTRACTION SITE OF A COAL MINE

[1]Cheberiachko Yu.I., [1]Stolbchenko O.V., [1]Yurchenko A.A., [1]Luts I.O., [1]Mukha O.A.

[1] National Technical University "Dnipro Polytecnic"

СПОСІБ ЗМЕНШЕННЯ КОНЦЕНТРАЦІЇ МЕТАНУ В ОЧИСНІЙ ВИРОБЦІ ВИЇМКОВОЇ ДІЛЬНИЦІ ВУГІЛЬНОЇ ШАХТИ

[1]Чеберячко Ю.І., [1]Столбченко О.В., [1]Юрченко А.А., [1]Лутс І.О., [1]Муха О.А.

[1]Національний технічний університет «Дніпровська політехніка»

СПОСОБ СНИЖЕНИЯ КОНЦЕНТРАЦИИ МЕТАНА В ОЧИСТНОЙ ВЫРАБОТКЕ ВЫЕМОЧНОГО УЧАСТКА УГОЛЬНОЙ ШАХТЫ

[1]Чеберячко Ю.И., [1]Столбченко Е.В., [1]Юрченко А.А., [1]Лутс И.О., [1]Муха О.А.

[1]Национальный технический университет «Днепровская политехника»

Abstract. The article presents the results of research on means and techniques for increasing load on mining face of a coal mine which is constrained by a considerable methane emission from gas-bearing coal seams being developed, by the specified value of methane concentration in the outgoing longwall jet and air speed at mine working. Based on the analysis of the distribution of air flow masses in the longwall, it is established that there is a reserve for using air masses which move to the working face.

It has been substantiated that, apart from preliminary degassing of the developed seam and improvement of ventilation schemes for mining areas, it is possible to increase the load on the longwall through using special pipelines. One of the pipelines (pressure line) is attached to the elements of the powered support directly at the bottom and cleans the atmospheric air in the longwall through the system of nozzles, whereas the other one (suction line), which is fixed on the side of the mined-out space, removes the polluted air with the help of the nozzles. Both pipelines are equipped with an individual air draft source.

The technique has been developed to reduce the methane concentration in the extraction space by changing the turbulent characteristics of the ventilation flow by means of a pressure air pipe with dispersed fresh air supply and a suction air pipe with dispersed suction of outlet air, which are mounted along the longwall. This allows one to optimally distribute the air masses fed into the extraction space in cross section, and thereby increase the amount of air in the longwall, which, in turn, will significantly increase the load on the working face

The efficiency of the proposed technique is confirmed by the results of studies on 3D models in CAD systems in the CDF software package.

The developed technique for ventilation of the working face of the excavation area of a coal mine will allow maintaining the methane concentration and air velocity in the longwall within sanitary norms using the most powerful mechanized systems currently used in coal mining internationally.

Keywords: working face, load, ventilation scheme, methane concentration, air velocity, pipeline, modelling in CAD-systems.

Introduction. Currently, a rapid increase is evidenced in the volume of gas in coal mines as a result of their increasing depth and stimulation of coal production. At the same time, the ventilation capabilities of the extraction sites often appear to be exhausted, which is a deterrent to increase the load on the mining faces.

The maximum relative methane-bearing capacity of the site is the value of methane content at which the productivity of the mining face does not result in exceeding the norms of methane concentration at stoping of the extraction site. In the literature, this indicator is also called a "gas barrier". The value of this indicator is determined by the throughput capacity of the ventilation network of the site and the load on the working face.

The limit of load on the mining face by the ventilation factor is directly dependent on the amount of air flow, i.e. the greater the air flow (its velocity) in the longwall face is, the higher the limit of load on the working face becomes.

Since the throughput capacity of the face by the air flow rate depends on its distribution along the cross section of the working face, the value of the "gas barrier" will vary depending on the air distribution along the face cross section.

To reduce the methane concentration in the outcoming jet of the extraction site to sanitary standards, special measures are taken: choosing of rational ventilation schemes; preliminary degassing of the coal seam; degassing of rocks containing a coal seam; degassing of the mined-out space.

All ventilation schemes provide for the removal of methane from all stoppings of the extraction site. As early as on the haulage gate, methane comes to the intake air from the transported coal and the side walls of the mine. The most intensive flow of methane into the ventilation jet occurs in the working space of the longwall face. Apart from the release of methane from the seam and the broken-down coal, methane from the mined-out space is carried here methane flows to here from the mined-out space, sometimes in significant quantities. Further pollution of the ventilation jet coming out of the longwall face occurs on the return airway, achieving the maximum permissible concentrations.

To reduce the methane concentration in the return air of the extraction site, ventilation schemes have been developed with separate dilution, with the with directing of the outcoming jet from the site to the coal massif the outcoming jet of the site on the coal massif, with independent ventilation of sections, with downward movement of fresh air through the mining face, with direct flow movement of intake air and outcoming jet. Currently, more than two hundred schemes of ventilation of extraction sites have been developed; however, none of them solves the problem of methane dilution in the longwall face through increasing the supply of fresh air while stabilizing the cross section of the longwall face and the average speed of its movement within sanitary standards.

Therefore, the development of techniques and means for enhancing the efficiency of ventilation of extraction sites of mines still remains an urgent task.

Theoretical part. Let us calculate the maximum possible relative gas content of the site at which the concentration of methane does not exceed the maximum permissible standards. Upon that, we accept that methane from the made-out space in the bottomhole region is not appropriate.

The required amount of air to dilute the gas to permissible standards is determined according to the known formula [1] when calculating the ventilation of mine workings

$$Q_l = \frac{1{,}7 \cdot I \ k_v}{C - C_0}, \text{ m}^3\text{/s},$$

where I - is average expected gas emission in the stope, m^3/min; it is determined when forecasting methane emissions by the natural methane content of the seam; C - is permissible methane concentration, according to safety regulations, in the ventilating jet coming out from the stope,%, with the equipment available for automatic control of methane C = 1.3%; C_0 - is the gas concentration in the jet entering the extraction site , %; k_v - is a coefficient of variation of methane emissions, unit fraction.

The value of the coefficient of variation of methane emissions can be determined according to the formula [1]

$$K_v = 1.94\, I^{-0.14} \tag{1}$$

Taking $C_0 = 0$ and considering (1), we obtain

$$Q_l = \frac{3.23 \cdot I^{0.86}}{C}, \text{ m}^3/\text{s} \tag{2}$$

Let us determine the absolute gas emission I through the relative gas content

$$I = \frac{qA}{864}, \text{ m}^3/\text{s} \tag{3}$$

where A - is output per face per day , t/day.

Substituting (3) into (2), and expressing the air flow Q_l through the cross-sectional area of the workpiece S and the air flow rate υ, we convert the obtained expression to determine q

$$q = \frac{211.84 \cdot (S\upsilon C)^{1.163}}{A}, \text{ m}^3/\text{t}$$

If degassing of the seam and seam satellites is not performed, the maximum possible relative gas content for ventilation schemes with serial dilution and removal of harmful impurities in the direct and reverse methods for working out the extraction column is found according to the expression [2]

$$q_{site.\max} = \frac{211.84 \cdot (S_l \upsilon_l C)^{1.163}}{A_{\max}} k_{al}, \text{ m}^3/\text{t} \tag{4}$$

where k_{al} - is air leakage factor at a site; for Heroiv Kosmosu mine, we take k_{al} = 1.5; S_l - is a cross-sectional area of the air flow with the thickness of the seam extracted, m = 1.2 m, we can take S_l = 3.4 m^2; υ_l - is permissible air velocity in the longwall, m/s; according to safety regulations for coal mines υ_l = 4 m/s;

Based on (4), the maximum load on the working face is determined according to the expression

$$A_{\max} = \frac{211.84 \cdot (S_l \upsilon_l C)^{1.163}}{q_{site.\max}} k_{al} \quad (5)$$

For calculation purposes, we assume the relative methane content of extraction sites to be at the level of 15 m^3/t, which is typical for most coal mines in the Western Donbas.

Therefore, substituting the known values of the parameters in (5) we obtain

$$A_{\max} = \frac{211.84 \cdot (3.4 \cdot 4 \cdot 1.3)^{1.163}}{15} \cdot 1.5 \cong 600 \text{ t}$$

Currently, the average daily capacity of the longwall in the coal mines of the Western Donbas is 2,000 tons, which is provided by measures on degassing, whose efficiency is 0.7, whereas the relative gas capacity has decreased to 4.5 m^3/t due to degassing.

The results of the research [3] indicate that throughout the bottomhole region the ventilation flow is distributed very unevenly. The air velocity on the first track along the seam exceeds the permissible velocity by 1.2 ... 1.8 times, whereas on the second track it is 2 ... 3 times as low. This allows one to increase the throughput ability of the working face by up to 1.5 times when observing the air flow velocity on the second track within the requirements of the safety regulations.

The ventilation flow in the longwall area of the combined machine partially flows from the bottomhole space into the mined-out space, which is evidenced by the shift of the flow isolines [4] (Fig. 1).

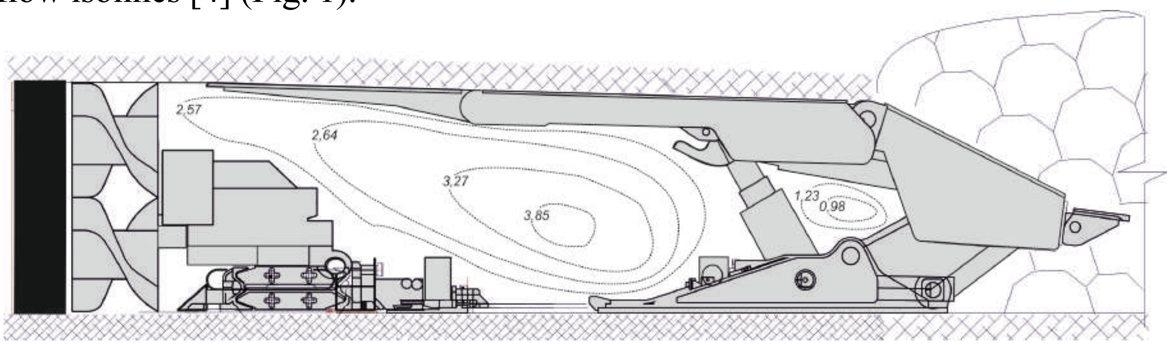


Figure 1 – Distribution of ventilation flows in the extraction space of the longwall near the combined machine

After the section is mined with a combined machine, the air is again directed to the bottomhole part and is distributed there along the technological tracks according to their aerodynamic resistances (Fig. 2).

The volume flow on the first technological track reaches 84% of the total flow on the bottomhole region. This distribution is positive, as it contributes to a more intense dilution of impurities released from the main sources – face and broken-down coal.

With increasing aerodynamic resistance of the working face from its “wall face” to the mined-out space, as well as with increasing uneven flow of air masses, their distribution in this direction is of destructive non-optimal nature.

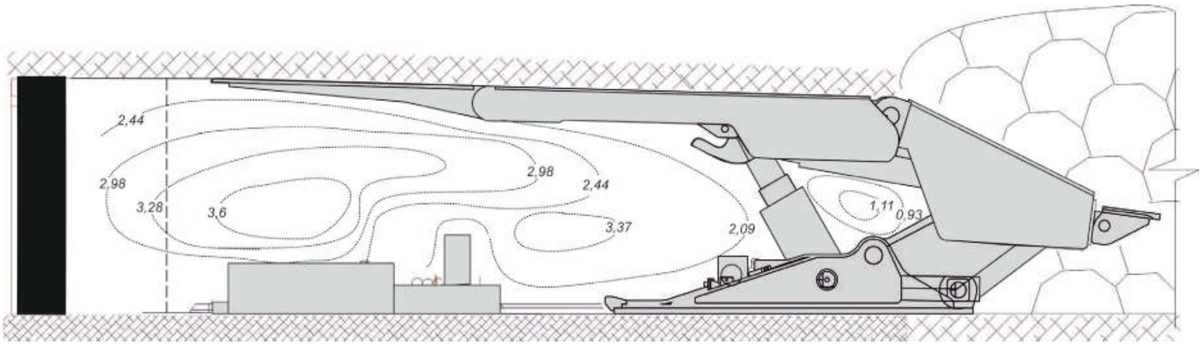


Figure 2 – Distribution of ventilation flows in the extraction space of the longwall after the combined machine

Uneven distribution of the air flow velocity is associated with the manifestation of friction forces caused by air viscosity. The friction force acts both between the layers of ventilation flows and at its boundaries during the friction of the flow on the surface of the structural reinforcing elements. According to the literature, the friction force of the ventilation flow on the surface of the mine workings is 50 ... 75% of the total resistance of the mine ventilation network; front resistance is 10 ... 20%; and local resistance is 15 ... 30% [5, 6].

To obtain the given efficient flow distribution, it is necessary to redistribute the aerodynamic resistance of different zones of the working face accordingly. It is obvious that the total resistance of the working face will increase significantly. That is, any given distribution of air in the channel results in increased resistance and requires additional energy consumption.

In the area of combined machine operation, the direction of the ventilation flow in relation to the direction of movement of the cutting machine has a significant effect on the gas situation. The experiments showed that simultaneous aeration is the most rational for reducing the maximum value of the impurity concentration [4] and allows increasing the load on the face by the gas factor by 1.3 ... 5 times compared to adverse ventilation. This is a significant reserve for production under restrictions of the gas barrier. In the case of the same maximum concentration during the shuttle operation of the combined machine, the speed of the latter with simultaneous ventilation can be 2 ... 5 times higher than during the adverse ventilation.

The thickness of the extracted seam affects the methane flow. The methane flow rate increases in proportion to the capacity of the seam developed, and its removal intensity remains almost unchanged. This explains the increase in the value of the maximum concentration of the impurity. It is established that the thickening of the seam does not affect the displacement of the maximum methane concentration, but has a significant effect on its value, and, consequently, on the gas situation in the bottomhole region [7]. The value of the maximum methane concentration largely depends on the direction of ventilation flow in relation to the direction of movement of the cutting machine. With simultaneous ventilation, the value of the maximum methane concentration is lower than that with the adverse ventilation, which is due to changes in the aerodynamics of the area where cutting machines operate.

The studies [8], which were conducted applying combined machines of different geometric shapes, showed the possibility of reducing the content of impurities in the cleavage face due to the design change in the body of extracting machines. However, the maximum methane concentration in the reverse direction of the ventilation flow, even in a streamlined form increases along with the dilation of the combined machine body; moreover, with increasing capacity of the seam, the value of the maximum concentration of impurities intensifies. The latter necessitates the search for other techniques for influencing the shadow area at the site of destruction of the coal seam. These techniques should make it possible to change the aerodynamics of the zone of location of the maximum concentration of impurities in the direction of intensification of gas leaching. One such technique is the installation of reflective surfaces.

The analysis of the mass distribution of air flow in the longwall indicates that there is a reserve for the use of air masses moving to the working face. The use of this reserve is possible on the basis of measures and means that have a significant impact on the magnitude of the transverse velocity fluctuation of the ventilation flow rate and the density of the gas-emission source. This effect can be exerted by artificial flow turbulizers which are installed in the flow itself and, thus, provide for the transverse methane transfer, reducing its concentration in the bottomhole region.

As turbulizers, additional air jets directed perpendicular to the main ventilation flow can be used.

Research results and discussion. The study on aerodynamic parameters of mine workings is one of the key tasks when designing mine ventilation. Rational aerodynamic parameters of the face allow not only providing the face with a sufficient amount of air, but also significantly improving the ventilation stability of the face [9, 10, 11].

The development of transverse ventilation flows in the extraction space will significantly increase the supply of air to the longwall, without exceeding the air velocity, which is provided by safety regulations.

The speed of ventilation flow along the longwall depends on the amount of fresh air supply and the cross section of the extraction space, which is set by the design of the powered support.

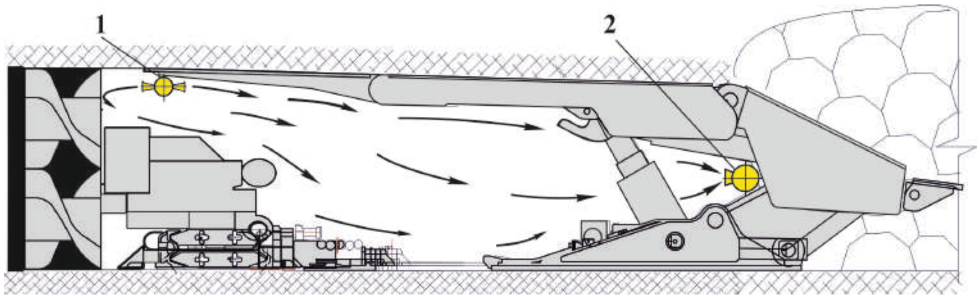
When the ventilation flow moves from the outcropping coal seam (bottom) to the mined-out space, the amount of fresh air will be limited by the longitudinal section of the extraction space, which with a longwall length of 200 m exceeds the cross-sectional area of the face by about 50 times. Moreover, the greater the length of the longwall is, the greater the supply limit of fresh air into the extraction space is. That is, changing the direction of fresh air supply to the extraction space virtually removes its restrictions on the amount of its supply to the longwall, and, consequently, the load on the working face when implementing this proposal is limited only by technological and technical capabilities of gas-saturated coal seam.

The maximum load on the working face, which is found according to the expression (5) with the predicted relative gas capacity of the extraction site of 15 m^3/t will be only 600 t/day, whereas the intended load in the new longwall is 2,000 t/day.

When implementing the recommendations, the maximum load on the working face with a longwall length of 200 m will be almost 85,000 tons/day, which is much higher than the productivity of the most powerful mechanized complexes currently used in coal mining internationally.

This proposal can be implemented by applying the known popular technical means used nowadays.

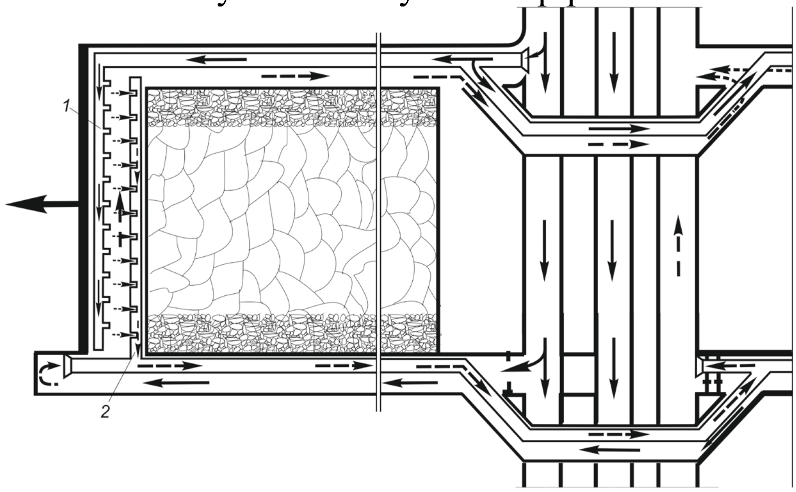
To create transverse flows in the working face of the mined-out space along the length of the longwall a suction pipeline is run with holes scattered along its length for air suction (Fig. 3), and on the opposite side, in the upper part (under the roof), a discharge line is run with distribution of air lengthwise. Fresh air is supplied through the discharge line, which dilutes methane when coming out of the side holes. Some part of the diluted methane is removed from the extraction space due to the general shaft depression, whereas the other part enters the vacuum zone created by the suction pipeline. Therefore, there is a process of efficient mixing and removal of methane from the working space due to the interaction of various-directional ventilation flows.



1 – corrugated flexible pipeline with fresh air dispersed along the length of the longwall; 2 – corrugated flexible pipe with dispersed suction of outlet air

Figure 3 – Combined air exchange in the working space of the longwall section

Sufficiently high efficiency of methane dilution is achieved due to the turbulence of the main ventilation flow (directed along the extraction space) by transverse air flows created by an additionally mounted system of pipelines in the longwall (Fig. 4).



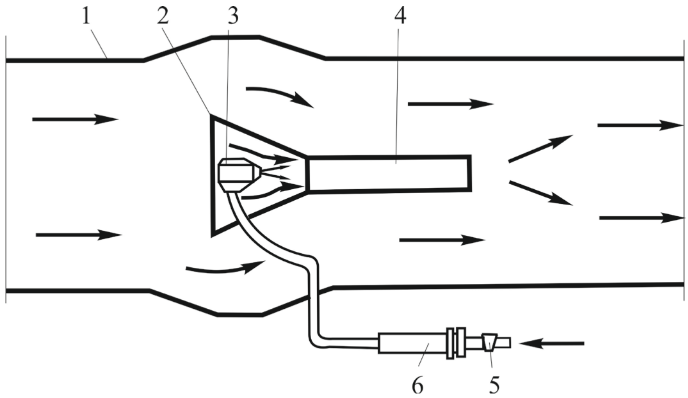
1 – pressure pipeline with dispersed fresh air supply; 2 – suction line with dispersed exhaust air suction

Figure 4 – Scheme of the ventilation system of the extraction site

Fans or injectors that are installed at the inlet and outlet ends of the pipeline and work at injection or suction are used as traction agents in pipelines.

If the outcoming jet is diverted through the pipeline by a fan, it is placed in a special chamber, which is ventilated by a fresh jet due to the general shaft depression or by a fan for local ventilation. The location of the fan is chosen so as to eliminate the need for reassembly throughout the life of the longwall.

The capacity of the fan unit is to ensure the dilution of methane in the pipeline to the permissible concentration. If an injector is a draft source, it is placed directly in the pipeline (Fig. 5).



1 – pipeline; 2 – nozzle chamber of the injector; 3 – nozzle; 4 – stabilization chamber; 5 – plug-type valve; 6 – filter

Figure 5 – Placement of the injector for refreshing or removing the outcoming jet of the extraction site

The place for the mixing chamber is selected taking into account the unhindered passage of people through the stope (in accordance with the requirements of safety regulations) and the amount of air moving through this stope, which should be sufficient to dilute methane to permissible levels.

As a source of draft when supplying a refreshing jet through the pipeline, all types of mine fans for local ventilation which provide the required capacity can be used. When diverting the outcoming jet only centrifugal fans VMP- (fan for local ventilation) (VCO-06, VC 0-1,0) (turbine fan), VCPD-8, (dust fan) can be used. EDD injectors can be used in both cases.

Evaluation of the proposed scheme of ventilation of the working face is performed through modelling in CAD-systems. For this purpose, a 3D model of the extraction site of a coal mine in CDF-packages was created [11]. As a result of modelling, distribution of the fields of air flow velocity and atmospheric pressure differences is obtained.

Fig. 6 presents the results of simulation of ventilation of the longwall according to the traditional scheme without flow and suction pipelines.

Air flow $Q = 8$ m^3/s, cross-sectional area of the longwall $S = 3$ m^2, average air velocity $V = 2.7$ m/s.

Diagram of estimating the vortex formation in an air stream on the longwall width to Fig. 6.

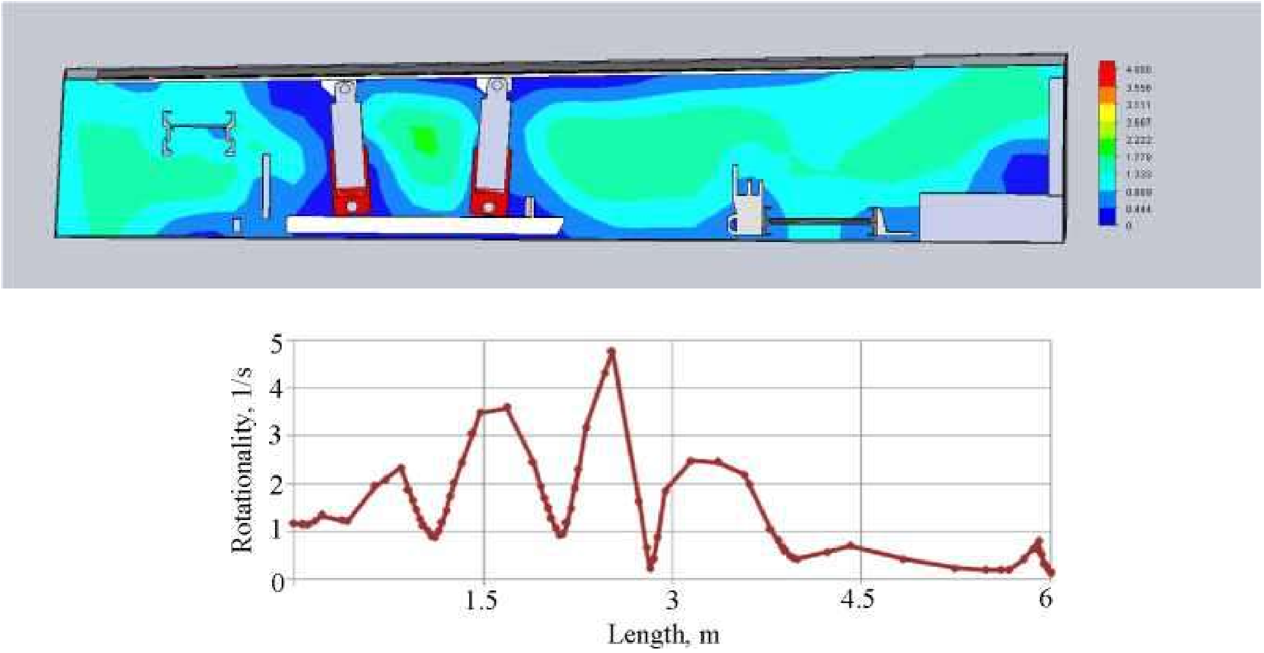


Figure 6 – Distribution of air velocity by the longwall cross section with mechanized complex MKD90

The analysis of the obtained modelling results showed that with the given parameters of the longwall cross section, longwall ventilation does not exceed the sanitary norms.

Fig. 7 shows the results of simulation of longwall ventilation according to the proposed scheme with flow and suction pipelines.

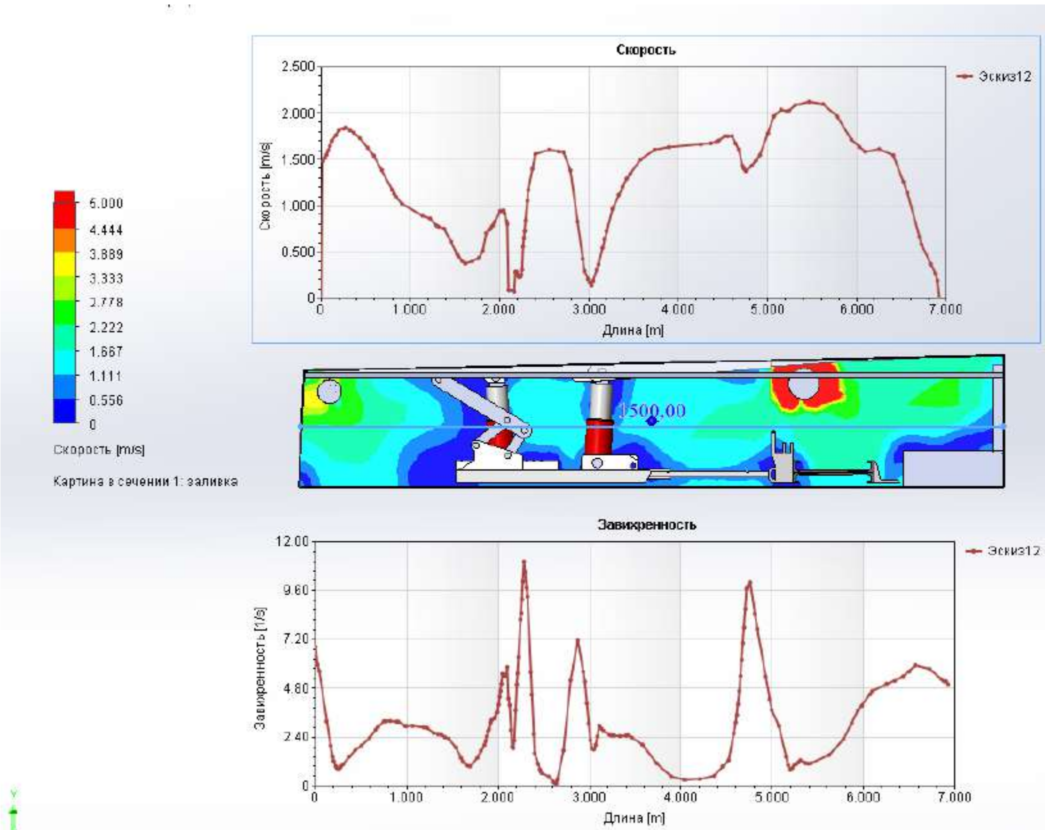


Figure 7 – Distribution of air velocity by the longwall cross section with mechanised complex MKD90 using pressure (left) and suction (right) air pipelines

At the same time, 8 m^3/s was fed into the longwall via the flow pipeline and the same amount was discharged through the suction pipeline.

The figures presented show that in the extraction sites, the air velocity does not exceed the maximum permissible values and only behind the mounting racks and near the suction duct, vortices form.

Therefore, to dilute the methane released during the coal-face operation, in addition to the air supplied by the general shaft depression, the proposed ventilation scheme can supply the required amount of air to implement the specified load on the longwall.

Conclusions.

1. Based on the analysis of the distribution of air flow masses in the longwall, it is established that there is a reserve for using air masses which move to the working face. The use of this reserve is possible on the basis of measures and means that have a significant effect on the value of the transverse pulsation of the ventilation flow rate and the density of the gas-emission source.

2. The technique has been developed to reduce the methane concentration in the extraction space by changing the turbulent characteristics of the ventilation flow by means of a pressure air pipe with dispersed fresh air supply and a suction air pipe with dispersed suction of outlet air, which are mounted along the longwall. This allows one to optimally distribute the air masses fed into the extraction space in cross section, and thereby increase the amount of air in the longwall, which, in turn, will significantly increase the load on the working face.

3. The developed technique for ventilation of the working face of the excavation area of a coal mine will allow maintaining the methane concentration and air velocity in the longwall within sanitary norms using the most powerful mechanized systems currently used in coal mining internationally.

4. Analysis of modelling in CAD-systems showed the efficiency of the proposed scheme of ventilation of the longwall, which provides the required amount of fresh air to ensure the implementation of the specified load on the longwall.

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About the authors

Cheberiachko Yurii Ivanovych, Doctor of Technical Sciences (D.Sc.), Professor, Professor of the Department of Labor Protection and Civil Safety, National Technical University "Dnipro Polytechnic" (NTU "DP"), Dnipro, Ukraine, cheberiachkoyi@ukr.net

Stolbchenko Olena Volodymyrivna, Candidate of Technical Sciences (Ph.D.), Associate Professor, Associate Professor of the Department of Labor Protection and Civil Safety, National Technical University "Dnipro Polytechnic" (NTU "DP"), Dnipro, Ukraine, elena_aot@ukr.net

Yurchenko Anneta Anatoliivna, Candidate of Technical Sciences (Ph.D.), Associate Professor, Associate Professor of the Department of Ecology and Environmental Protection Technologies, National Technical University "Dnipro Polytechnic" (NTU "DP"), Dnipro, Ukraine, anneta2904@ukr.net

Luts Ihor Olehovych, Candidate of Technical Sciences (Ph.D.), Associate Professor, Associate Professor of the Department of the Department of Labor Protection and Civil Safety, National Technical University "Dnipro Polytechnic" (NTU "DP"), Dnipro, Ukraine, i.luts.aot@gmail.com

Mukha Oleh Anatoliovych, Candidate of Technical Sciences (Ph.D.), Associate Professor, Associate Professor of the Department of Labor Protection and Civil Safety, National Technical University "Dnipro Polytechnic" (NTU "DP"), Dnipro, Ukraine mukha.o.a@nmu.one

Про авторів

Чеберячко Юрій Іванович, доктор технічних наук, професор, професор кафедри охорони праці та цивільної безпеки Національного технічного університету «Дніпровська політехніка» МОН України (НТУ «ДП»), Дніпро, Україна, cheberiachkoyi@ukr.net

Столбченко Олена Володимирівна, кандидат технічних наук, доцент, доцент кафедри охорони праці та цивільної безпеки Національного технічного університету «Дніпровська політехніка» МОН України (НТУ «ДП»), Дніпро, Україна, elena_aot@ukr.net

Юрченко Аннета Анатоліївна, кандидат технічних наук, доцент, доцент кафедри екології та технологій захисту навколишнього середовища Національного технічного університету «Дніпровська політехніка» МОН України (НТУ «ДП»), Дніпро, Україна, anneta2904@ukr.net

Лутс Ігор Олегович, кандидат технічних наук, доцент кафедри охорони праці та цивільної безпеки Національного технічного університету «Дніпровська політехніка» МОН України (НТУ «ДП»), Дніпро, Україна, i.luts.aot@gmail.com

Муха Олег Анатолійович, кандидат технічних наук, доцент, доцент кафедри охорони праці та цивільної безпеки Національного технічного університету «Дніпровська політехніка» МОН України (НТУ «ДП»), Дніпро, Україна, mukha.o.a@nmu.one

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Анотація. У статті наведено результати досліджень засобів та способів підвищення навантаження на очисний вибій вугільної шахти, яке стримується значним виділенням метану з газоносних вугільних пластів при їх відпрацюванні, нормованим значенням концентрації метану у вихідному струмені лави і швидкістю руху повітря на робочих місцях. На підставі аналізу розподілу мас повітряного потоку в лаві встановлено, що є резерв використання повітряних мас, що рухаються до вибою.

Обґрунтовано, що крім попередньої дегазації розроблюваного пласта і удосконалення схем вентиляції виїмкових дільниць, підвищити навантаження на лаву можна шляхом застосування спеціальних трубопроводів. Один з трубопроводів (нагнітальний) прикріплений до елементів механізованого кріплення безпосередньо у вибої і через систему насадок підсвіжує повітря в лаві, а інший (всмоктуючий), який закріплений з боку виробленого простору, видаляє за допомогою насадок забруднене повітря. Обидва трубопроводи обладнані індивідуальним джерелом тяги. Розроблено методику зниження концентрації метану у витяжному просторі за рахунок зміни турбулентних характеристик вентиляційного потоку за допомогою напірного повітроводу з розосередженою подачею свіжого повітря та відсмоктуючого повітроводу з розосередженим відсмоктуванням відпрацьованого повітря, що монтуються вздовж лави. Це дозволяє оптимально розподілити повітряні маси, що подаються в виїмковий простір, по перерізу і тим самим збільшити кількість повітря в лаві, що, у свою чергу, значно збільшить навантаження на забій.

Працездатність запропонованого способу підтверджена результатами досліджень на 3Д моделях в САД системах в програмному пакеті SolidWorks.

Розроблений спосіб провітрювання вибою виїмкового простору вугільної шахти дозволить підтримувати концентрацію метану та швидкість руху повітря в лаві в межах санітарних норм з застосовуванням найпотужніших механізованих комплексів, що використовуються в даний час у вуглевидобутку у світі.

Ключові слова: очисний вибій, навантаження, схема провітрювання, концентрація метану, швидкість руху повітря, трубопровід, моделювання в САД - системах.

Аннотация. В статье приведены результаты исследований средств и способов повышения нагрузки на очистной забой угольной шахты, которая сдерживается значительным выделением метана из газоносных угольных пластов при их отработке, нормированным значением концентрации метана в исходящей струе лавы и скоростью движения воздуха в горных выработках. На основании анализа распределения масс воздушного потока в лаве установлено, что имеется резерв использования воздушных масс, движущихся к забою

Обосновано, что кроме предварительной дегазации разрабатываемого пласта и усовершенствования схем вентиляции выемочных участков, повысить нагрузку на лаву можно путём применения специальных трубопроводов. Один из трубопроводов (нагнетательный) прикреплён к элементам механизированной крепи непосредственно у забоя и через систему насадок подсвежает атмосферный воздух в лаве, а другой (всасывающий), который закреплён со стороны выработанного пространства, удаляет с помощью насадок загрязнённый воздух. Оба трубопровода оборудованы индивидуальным источником тяги. Разработана методика снижения концентрации метана в вытяжном пространстве за счет изменения турбулентных характеристик вентиляционного потока с помощью напорного воздуховода с рассредоточенной подачей свежего воздуха и отсасывающего воздуховода с рассредоточенным отсосом отработанного воздуха, который монтируются вдоль лавы. Это позволяет оптимально распределить подаваемые в выемочное пространство воздушные массы по сечению и тем самым увеличить количество воздуха в лаве, что, в свою очередь, значительно увеличит нагрузку на забой.

Работоспособность предложенного способа подтверждена результатами исследований на 3D моделях в CAD-системах в CDF-пакетах.

Разработанный способ проветривания забоя выемочного пространства угольной шахты позволит поддерживать концентрацию метана и скорость движения воздуха в лаве в пределах санитарных норм с использованием самых мощных механизированных комплексов, применяемых в настоящее время в угледобыче в мире

Ключевые слова: очистной забой, нагрузка, схема проветривания, концентрация метана, скорость движения воздуха, трубопровод, моделирование в CAD-системах.

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