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JUSTIFICATION OF RATIONAL METHODS FOR PROVISION OF AIR TO FACES OF OPERATING COAL MINES OF VIETNAM DURING DEEPENING OF MINING

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Based on the analysis of the mining and geological conditions for developing coal deposits in Vietnam, the existing mining safety regulations, the application of methods for calculating the air supply of working and development faces using the methane factor and modern methods of mathematical modeling of the ventilation of mines threr was developed the procedure for analyzing the efficiency of air distribution management considering the proposed indicator - energy efficiency coefficient for ventilation systems, determined by the efficiency of air use and energy consumption. Relations have been obtained that determine the relationship between the aerodynamic resistance of negative regulators, the number of simultaneously developed working and development faces, the performance of main ventilation fans and the consumed electric power.

***Key words*:** coal mine; methane; methane content; methane emission; ventilation; gas mode; methane category; methane-bearing capacity forecast

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Introduction. The development plan for Vietnamese coal industry provides for an increase in coal production in 2015 and in 2020, respectively, to 60 and 70 million tons, with 60 % of the total volume mined using the underground mining method [10]. The implementation of long-term plans for the extraction of coal in Vietnam (Fig.1) is possible only with the fullest realization of the existing potential of coal deposits and mines [4]. At the same time, the main direction of increasing production is the development of coal seams in the deeper horizons of existing mines.

The growth of depth leads to the complication of mining conditions, among which is the methane content of coal seams and, consequently, the need to increase the amount of air supplied to workplaces. As shown by the results of air surveys, the provision of air to the existing working and development faces cannot be considered satisfactory. The reasons for this are the use of main ventilation fans (MVF), the aerodynamic characteristics of which do not correspond to the aerodynamic characteristics of the ventilation networks of existing mines, a significant amount of working and development faces, which are simultaneously operated, and each of them needs a specific air flow parameters due to different values of methane-bearing capacity of coal seam.

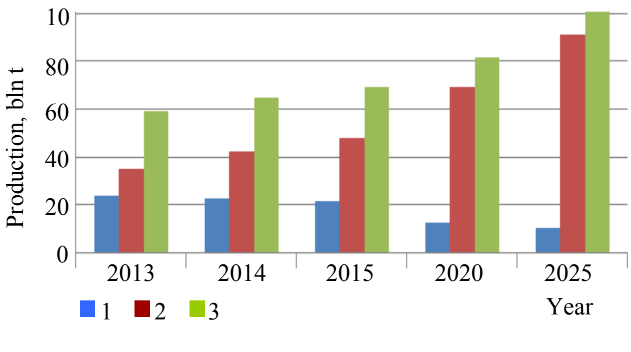

Fig.1. Planned coal mining volumes in Vietnam in 2013-2025
1 – open pit; 2 – underground; 3 – total

The required air supply to a significant number of working places, determined by the predicted values of natural methane-bearing values used in development of mining systems and working faces, while ensuring acceptable values of the efficiency of the main ventilation fans and rational use of supplied air, is possible only if it is provided according to a specified distribution pattern.

Even though the issues of air distribution control in complex ventilation networks were considered in several papers [1, 6, 7, 11-13, 15, 17-22], the subsequent analysis of the results of mathematical modeling, allowing to justify rational ways of air distribution control, characterized by an acceptable level of efficiency is not sufficiently developed. The need to address these issues and determines the relevance of this work.

Analysis and forecast of methane-bearing capacity of the Mao Khe mine with increasing depth of development. At the Mao Khe mine, coal mining has now been completed at horizons +30/–25 m and simultaneous mining continues at two horizons –80/–25 and –150/–80 m. In the future, by 2020, coal mining is planned at horizons –400 m. Horizons –230, –320, –400 m are mined by vertical shafts and crosscuts [10].

Analysis of the results of natural methane-bearing studies carried out by the Mining Safety Center (Vietnam) together with the Mao Khe mine in 2004-2013 showed that with increasing mining depth, the methane content of coal seams increases. To achieve the forecast values of methane content on the –400 horizon, which is planned to be developed in 2020, the data obtained as a result of the measurements were approximated by dependencies of various types (linear, hyperbolic, parabolic). Comparative analysis has shown that the use of dependencies of a parabolic type leads to the largest value of the correlation ratio, which is almost one (Fig.2) [5, 8, 20].

At the same time, the D7 and D9 seams [3] have the highest methane-bearing capacity, the formulas for calculating their natural methane content are:

$$H = -8.1X^2 - 8.8X + 27.4, \quad (1)$$

$$H = -3.25X^2 + 2.45X + 34.8, \quad (2)$$

where H – coal seam depth, m; X – methane bearing capacity of coal seam, m^3/t.

Determination of the necessary air flow for airing the working faces of the existing and projected horizons of the Mao Khe mine. Research data on the methane potential of coal seams were used to predict methane emission and to calculate the amount of air required for ventilation according to the methane emission texture. To compute them, software developed at St. Petersburg Mining University was used based on the guidelines for the design of ventilation of coal mines [2, 14].

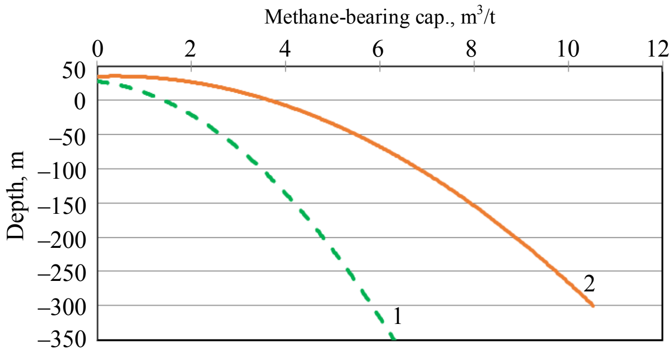

Fig.2. Results of forecast of methane-bearing capacity of seams D7 (1) and D9 (2)

The results of the calculation of the required amount of air depending on the productivity of the face and natural methane-bearing capacity are presented in Fig.3. It shows the values of the necessary quantities of air based on the value of the specific amount of air adopted in the Vietnamese standard (QCVN01-2011, Ministry of Industry and Trade of Vietnam) and equal to 1.5 m^3/min for very gassy mines.

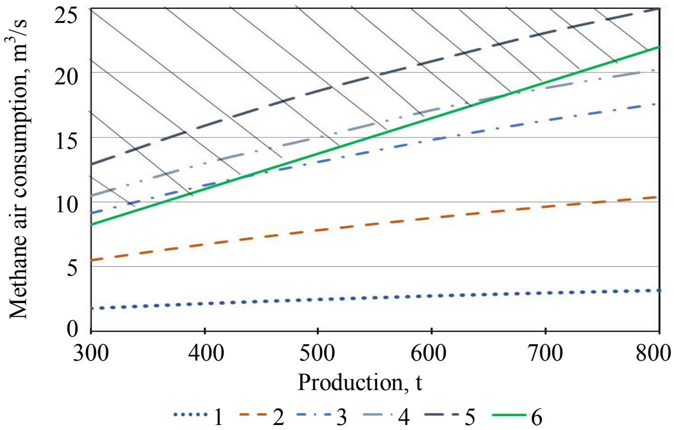

Fig.3. Dependence of the required methane air consumption on the methane-bearing capacity of coal seams and the productivity of the face
1-5 – methane-bearing capacity is qual respectively to 2; 6; 10; 12; 15 m^3/t; 6 – calculations according to existing standard

The analysis of Fig.3 shows that the use of the specific air amount of 1.5 m^3/min adopted in Vietnam can, in some cases, lead to a significant excess of the required air quantities determined with the help of the design guidelines for the ventilation of coal mines, and in others with methane-bearing capacity over 12 m^3/t, on the contrary, to lower values. This indicates the need for a differentiated approach to determining the necessary quantities of air, considering not only the performance of the working faces, but also the natural methane-bearing capacity of coal.

Mathematical modeling of air distribution in the ventilation system of the Mao Khe mine. The efficiency of ventilation of stopes largely depends on the chosen ventilation scheme, parameters of ventilation equipment, including main ventilation fans used to perform the necessary air distribution of control devices [9, 16].

To ensure the planned annual capacity of 2 million tons at the Mao Khe mine, simultaneous work of 11 working and 15 development faces is required by 2020. For a given air distribution between the stopes, it is proposed to use one of the negative control methods, which implies installing ventilation regulators with varying aerodynamic resistance in each air supplying shaft [16].

To assess the feasibility of using the proposed technical solution using the «Ventilation 2» software package [12], mathematical models of the ventilation network of the Mao Khe mine were developed for its operating conditions in 2014 and 2020.

Based on the results of mathematical modeling, the possibility of achieving a given air distribution in the stopes is shown both at the present time and for the period of 2020.

Processing the data of mathematical modeling made it possible to identify the functional links between the total air flow supplied to the mine, the power consumed by the MVF and the general aerodynamic resistance (Fig.4). The use of the obtained dependences allows the selection of rational modes of the operation of mVF, in which the efficiency of the ventilation system tends to achieve the maximum value.

The choice of rational ways to control the ventilation modes of the Mao Khe mine. Summarizing the experience of airing the coal mines of Vietnam showed that with a significant number of working and development faces and providing them with the necessary amount of air, the main ventilation fans have low efficiency, it does not exceed 0.3. These findings are confirmed by computer simulation of the mine ventilation system.

As an indicator to characterize the efficiency of the mine's ventilation system with a significant number of sources of air consumption (a large number of working and development faces) and the need to continue operating the existing main ventilation fans, a coefficient calculated as a result of summing up the energy efficiency coefficient determined by dividing the power consumed by the main ventilation fans installed power of their engines and air-use efficiency equal to the ratio of the required amount of air to the amount of air supplied to the mine by main ventilation fans.

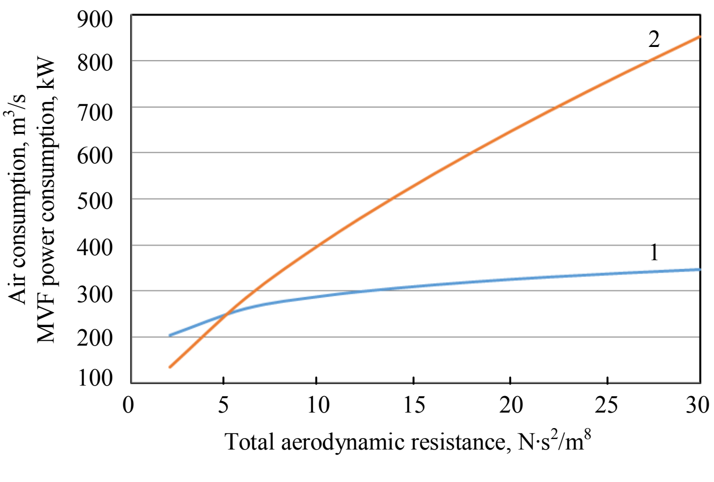

Fig.4. Dependency of air consumption (1) and MVF power consumption (2) on aerodynamic resistance of ventilation system at horizons –80/–150

With this method of controlling the ventilation mode, simultaneously with an increase in the efficiency of the fans, the flow rate of air entering the shaft increases and, starting with a certain value, it begins to exceed the required amount of air, i.e. its efficiency use is reduced.

It is proposed to evaluate the overall efficiency of the ventilation systems of coal mines where it is planned to use previously installed ventilation equipment using the efficiency coefficient of the ventilation system, the value of which is determined by the dependence

$$K_{v.s.ef} = K_{a.u} + K_{en.ef}, \qquad (3)$$

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where $K_{a.u}$ – air-use efficiency coefficient; $K_{en.ef}$ – energy efficiency coefficient;

$$K_{a.u} = Q_n / Q_{a.s}; \quad (4)$$

Q_n – air necessary for ventilation, m^3/s; $Q_{a.s}$ – air supplied to a mine with main ventilation fans, m^3/s;

$$K_{en.ef} = F(Q_{a.s}). \quad (5)$$

By plugging the dependencies (4)-(5) into (3) and calculating $K_{en.ef.}/dQ_{a.s}$, we get the equation to determine $Q_{a.s}$, at which the value of $K_{en.ef.}$ reaches the minimal value:

$$Q_n / Q^2_{a.s} + dF(Q_{a.s})/dQ_{a.s}) = 0. \quad (6)$$

The proposed sequence is used to calculate the air flow rate $Q_{a.s}$, at which $K_{en.ef.}$ has minimal value for horizons –150 and –230 m of Mao Khe mine.

Graphs of dependences $K_{en.ef}$ ($Q_{a.s}$) for ventilation systems of horizons –150 and –230 m were determined as a result of processing of the data of mathematical modelling of ventilation system of these horizons made in «Ventilation 2» software package. For horizons –150 and –230 m the dependencies for calculation of $K_{en.ef}$ can be presented as (Fig.5):

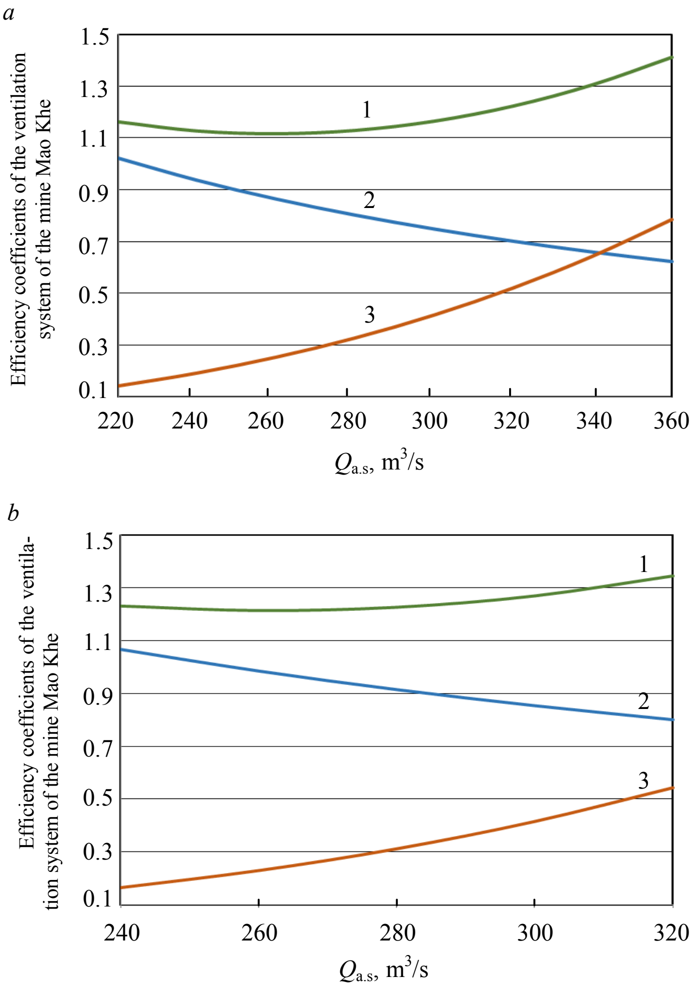

Fig.5. Ventilation system efficiency values for horizons –150 m (*a*) and –230 m (*b*) for different combination of MVF working modes
1 – $K_{v.s.ef}$; 2 – $K_{a.u}$; 3 – $K_{en.ef}$

$$K_{en.ef} = 10^{-9} \cdot Q^{3.48}{}_{a.s}; \; K_{en.ef} = 2 \cdot 10^{-11} \cdot Q^{4.17}{}_{a.s}. \quad (7)$$

The solution of equation (6) with regard to formulas (7) gives the following values for $Q_{a.s.кр}$, at which $K_{v.s.ef}$ have minimal values for horizons –150 and –230 m: $Q_{a.s.кр} = 264$ m^3/s, $Q_{a.s.кр} = 257$ m^3/s. With that the necessary air flow rates for these horizons are 225 and 256 m^3/s respectively.

Thus, from the analysis of graphs in Fig. 5 it follows that in order to increase the efficiency of the mine ventilation system at horizons –150 m and –230 m (increase of the coefficient $K_{v.s.ef}$) it is necessary to improve the performance of the main ventilation fans, i.e. to increase the amount of air supplied to the mine workings, within the technical capabilities of existing MVF.

Conclusions

1. A specific feature of underground mining in Vietnam in the near future is to increase production not by developing new mines, but as a result of increasing the depth of mining at existing plants, which leads to an increase in the number of working and development faces that are in simultaneous operation.

2. The prediction of the natural methane-bearing capacity of coal seams developed by the Mao Khe mine, with an increase in the depth of mining at a correlation ratio corresponding to 0.99, can be made based on parabolic-type dependencies.

3. The amount of air required, calculated according to the relative methane-bearing capacity adopted in the current Vietnamese standard, classifying the mine category by methane volume, should be refined considering the different natural methane-bearing capacity of coal seams being developed, the characteristics of the used development systems, the technology and the productivity of mining workings.

4. For mathematical modeling of aerodynamic processes in complex ventilation networks of the Mao Khe mine, the most suitable is the «Ventilation 2» software package recommended for use in Russian coal mines.

5. The control of air distribution in the coal mines of Vietnam with a significant number of working faces that are in simultaneous operation can be implemented by changing the operating modes of the main ventilation fans and using the negative control method carried out by installing air bridges.

6. To assess the effectiveness of the ventilation system of the Mao Khe mine, a coefficient of efficiency of the ventilation system is proposed, which is determined by summing the effectiveness of the MVF and air-use coefficient of air supplied to faces, which shows that the ventilation efficiency improved due to increased production of MVF.

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