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RESEARCH AND EVALUATION OF COAL MINE VENTILATION MANAGEMENT

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Abstract: *The main scientific and practical results of the study and assessment of ventilation control in coal mines using the decomposition method based on data from the analysis of aerodynamic parameters of air distribution are presented. This will lead to increased safety and reduced accident rates in mining operations at coal mines. Methods of decomposition, statistical dynamics, set theory, fundamental laws of mining aerodynamics, and discrete mathematics are described. The studies were carried out based on the experimental data of the authors using various mathematical and statistical methods. A universal technique is proposed that can be used in mine workings for analysis, assessment of ventilation processes and associated aerodynamic factors, as well as optimization of the air distribution control system under various operating modes. A methodology and application software developed on its basis have been compiled. Automated geographic information systems such as GIS K-MINE® (Krivoy Rog, Ukraine) and VENTSIM are recommended. This system has been approved by regulatory authorities in Ukraine and is utilized by specialists from industry institutes, State Mining Supervision authorities, mines, and others. They are adapted for coal mines, ensuring increased safety and efficiency of work. This will ensure increased safety, labor protection, and reduced accident rates in coal mining operations.*
Keywords: *ventilation, coal mine, mining, models and algorithms, decomposition, diagonals, air flows*

1. Introduction

Well timed delivery of the necessary amount of air to work areas at any given time, ensuring the smooth progress of the mineral extraction process, and maintaining safe working conditions for miners are pressing issues [1, 2]. One of the challenging aspects of air distribution management in mines is the development and implementation of measures under topologically and aerodynamically stable conditions [3, 4]. Additionally, operational redistribution of airflow across ventilation network workings was investigated depending on deviations of monitored parameters from technological standards mandated by safety regulations (SR) and mine operation protocols (MOP). This issue is addressed through the creation of a methodology for air distribution management in coal mines using the decomposition method [5, 6]. Therefore, the development of a universal methodology employing the decomposition method aimed at enhancing safety and reducing accident rates in mining operations, represents a crucial scientific and practical endeavor requiring prompt attention.

Objective: To investigate and evaluate the management of ventilation in coal mines using the decomposition method based on the analysis of aerodynamic air distribution parameters obtained through application software. This will lead to increased safety and reduced accident rates in mining operations at coal mines.

To achieve the stated objective, the following tasks were addressed:

1. Propose a method for the operational redistribution of airflow across ventilation network workings to ensure compliance with technological standards mandated by current mine safety regulations.

2. Develop a universal methodology for optimizing the air distribution control system under various operating conditions, considering the specifics of mine ventilation networks.

3. Compile a methodology and develop application software based on it for adaptation in coal mines.

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Methodology: Methods of decomposition, statistical dynamics, set theory, fundamental laws of mining aerodynamics, and discrete mathematics were applied. Research was also conducted using the authors' experimental data applying various mathematical and statistical methods. The methodology included compliance with and study of literature data and patent documentation during underground development of mineral resources, processing rational methods for protecting excavation areas of operating mines, and laboratory experiments. Physical modeling was conducted using additional mathematical packages of application programs. Aerodynamic parameters were experimentally measured at individual sections of mining workings of the studied air distribution scheme and summarized in specially developed forms by the authors [7, 8].

2. Discussion of research results

Ventilation management in mines implies the timely delivery of the necessary volume of air to work areas at any given time, ensuring the smooth progress of the mineral extraction process and maintaining safe working conditions for miners. Ventilation management in mines can involve both the development and implementation of measures under topologically and aerodynamically stable conditions, as well as the operational redistribution of airflow across ventilation network workings depending on deviations of monitored parameters from technological standards mandated by safety regulations and mine operation protocols [9, 10].

In general, the ventilation management system can be considered structurally composed of a control system and a controlled object. Continuous exchange and processing of information occur between the control system and the controlled object during the management process. The control system must process the information received from the ventilation objects in such a way that the control actions (measures) it generates effectively achieve the management goal under certain limiting conditions imposed by safety regulations. The management task is to ensure normal ventilation of the mineral extraction process and the state of the mine atmosphere regulated by safety regulations for mines and quarries. Quantitative characteristics of gas dynamic processes (mathematical expectation, standard deviation, etc.), minimal energy costs for ventilation, and economic indicators (minimum damage, maximum production) can be adopted as criteria for the effectiveness of mine ventilation management [11, 12].

The authors evaluated and analyzed the air supply schemes of coal mines and concluded that to improve the efficiency of its distribution, it is necessary to study the aerodynamic parameters of airflow in galleries using the decomposition method. Studies and analyses of the air supply to coal mines were conducted based on the decomposition method and were grounded on the fundamental laws of mining aerodynamics [13, 14]. For further research, the authors utilized and improved the decomposition method, which accurately determined the qualitative and quantitative indicators of ventilation schemes of the studied mining areas.

The proposed method more effectively identifies contours of varying complexity and determines the optimal approach to managing the airflow distribution of mining areas [15, 16]. At the initial stage of the research, an analysis and evaluation of the air distribution connections were conducted (Fig. 1, a).

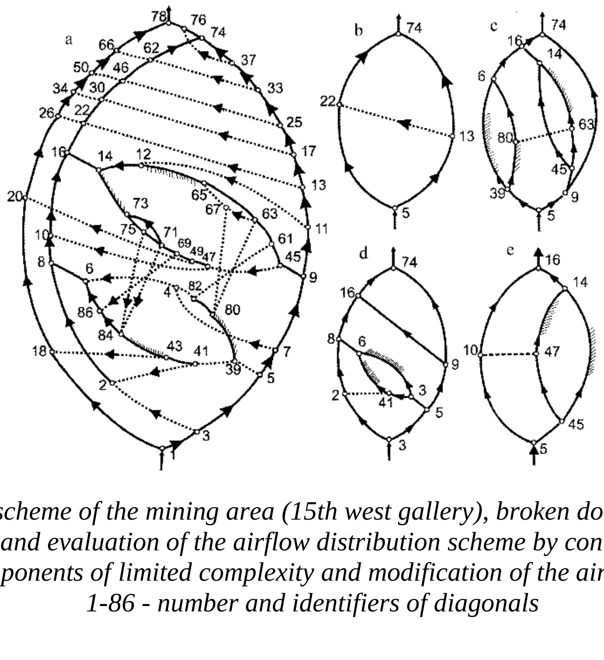

Fig. 1. Airflow distribution scheme of the mining area (15th west gallery), broken down into components of limited complexity: a- analysis and evaluation of the airflow distribution scheme by connections; b, c, d- stepwise decomposition into components of limited complexity and modification of the airflow distribution scheme; 1-86 - number and identifiers of diagonals

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The air distribution scheme (15th west gallery and 15th east gallery) was selected by the authors as the most optimal for research in coal mines. Analyzing the contour of the 15th west gallery, 86 diagonals were identified. The evaluation and analysis of diagonals were carried out using the decomposition method, i.e., by breaking them down into components of limited complexity and modifying the airflow distribution scheme, as shown in Fig. 1, b, c, d. The dependence of aerodynamic parameters on the contours broken down into components of limited complexity (for contours 1 – 3, 3 – 5, ..., 49 – 69, designations from 1 to 78 were assigned according to the number of rows) is shown in Fig. 2.

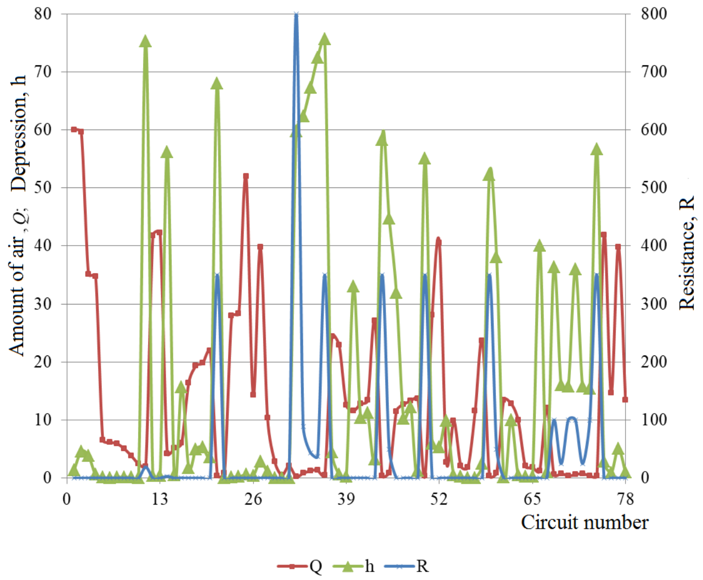

Fig. 2. Dependence of aerodynamic parameters on contours broken down into components of limited complexity

3. Research results

At the initial stage of the research, an analysis of the contours using the decomposition method and simplification of the airflow distribution scheme of the 15th west gallery revealed [17, 18]:

- 12 diagonals are active (with a large stability range);
- airflow overturning can occur in 10 diagonals;
- 54 diagonals are fictitious (with the stability range exceeding the variation range of mine air distributors' resistances);
- 5 diagonals are on the outgoing jet.

The second stage of the research was conducted based on the air distribution scheme of the 15th eastern drift (Fig. 3, a).

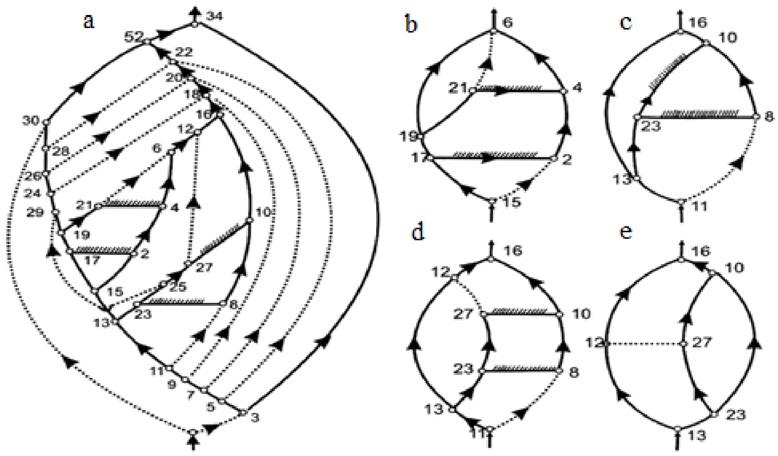

Fig. 3. Air distribution scheme of the mining area (15th eastern drift), broken down into components of limited complexity: a - analysis and evaluation of the air distribution scheme with connections; b, c, d - step-by-step breakdown into components of limited complexity and modification of the air distribution scheme; 1-86 - quantity and numbers of diagonals

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Aerodynamic parameters were experimentally measured at specific locations of the mining workings of the investigated mining area (15th eastern drift) and also compiled into a similar form for the analysis of such data (resistance, R, air quantity, Q, and depression, H). Analyzing the contour of the 15th eastern drift, 52 diagonals were identified [19, 20]. Evaluation and analysis of the diagonals were performed using the decomposition method, i.e., breaking them down into components of limited complexity and modifying the air distribution scheme, as shown in Figures 3, b, c, d. Based on the analyzed data, the dependence of aerodynamic parameters on contours broken down into components of limited complexity was plotted (for contours 1-3, 3-5,..., 20-22, denotations from 1 to 47 were assigned according to the number of rows) (Fig. 4).

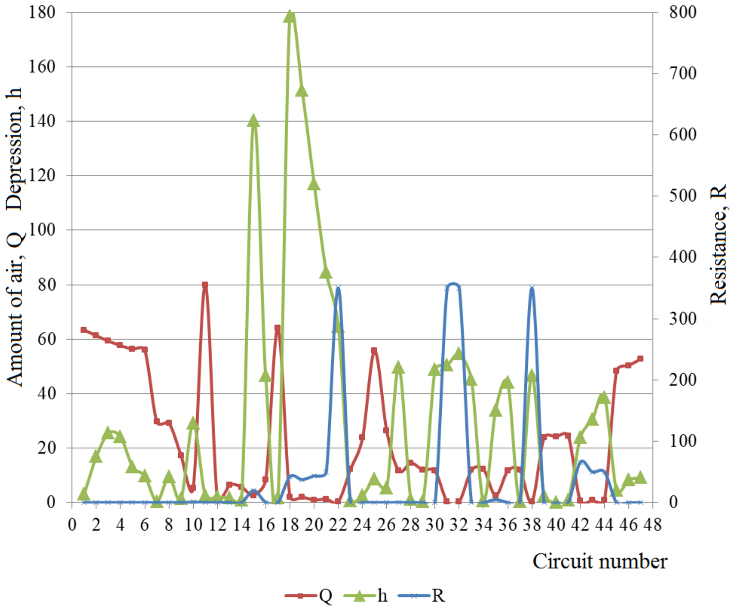

Fig 4. Dependence of aerodynamic indicators on contours broken down into components of limited complexity

Analyzing the contours of the 15th eastern drift using the decomposition method and simplifying the air distribution scheme, the following was determined [21, 22]:

- 8 diagonals are effective;
- 5 diagonals may cause air flow overturning in case of an accident;
- 32 diagonals are fictitious;
- 3 diagonals are present in the outgoing flow.

The evaluation of diagonal connections and the ventilation scheme of the technical system according to the developed methodology are presented in Figure 5.

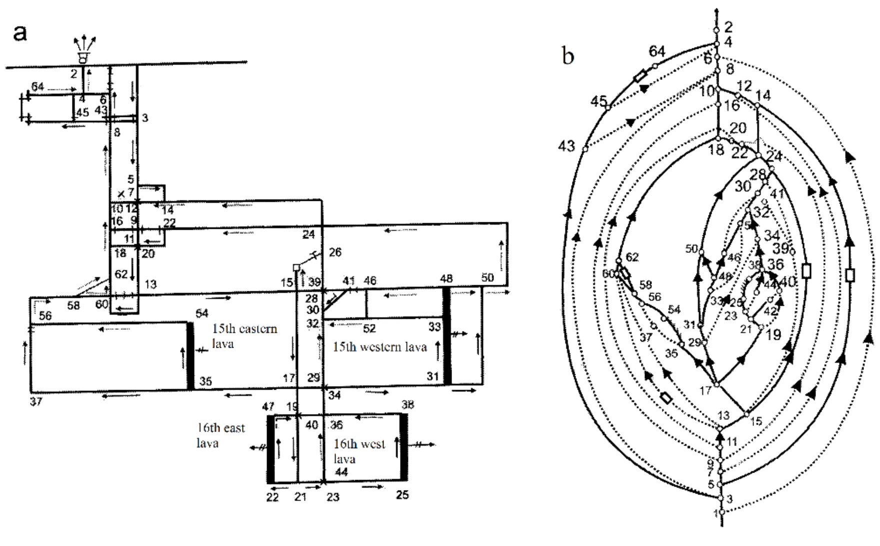

Fig. 5. Assessment of diagonal connections and ventilation system layout according to the developed methodology: a - mine ventilation scheme according to the developed methodology; b - analysis and evaluation of the air distribution scheme through connections; 1-64 - number and count of diagonals

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The stability criterion for the air distribution scheme of the 15th eastern drift (Fig. 5) was calculated based on the dynamics of the total aerodynamic resistance, while for the air distribution scheme (see Fig. 5, b), a known method of calculating diagonal connections was employed. The aerodynamic resistance of the variable contour was determined using depression, and the stability criterion was identified at the moment of jet overturning. Airflow overturns negatively impact the air distribution of mining areas, especially during emergency conditions, posing a danger. Incorrect placement of regulators poses a risk of airflow overturns. Regulators should be placed in the direction of airflow and at a certain distance from mining areas [23, 24].

4. Efficiency of the research

Based on implementation in various coal mines, an analysis and assessment of the effectiveness of the developed methodology are provided (see table 1). The economic effect is estimated to be approximately thirty-four thousand US dollars. The proposed methodology has been adapted for use in coal industry enterprises.

Table 1. Economic efficiency indicators

Company	Economic effect
LLC "Sadkinskoye Mine Management"	Increasing the efficiency of air supply organization to gallery sections by 20-23%.
State Enterprise "DONUGLEMASH"	Increase in the efficiency and quality of ventilation in stope areas by 17-20%, reduction of unplanned downtime by 10%.
AO "SUEK-Kuzbass"	The actual annual effect from the implementation of the developed methodology amounted to approximately thirty-four thousand US dollars

5. Perspective research directions

As a result, a methodology has been developed to select an efficient air distribution scheme and ensure the correct placement of regulators, thereby ensuring the stability of air supply to mining areas and coal mine galleries. The authors also suggest continuing research on adapting the methodology and applied software to other coal mines in developed countries.

The question of using mathematical modeling of technological processes and automated geographic information systems like GIS K-MINE®, Krivoy Rog, Ukraine [25, 26], becomes relevant. Today, there are international specialized programs used for modeling, solving, optimizing, and simulating complex ventilation networks, such as VENTSIM (one of the best in the world). These systems allow for more efficient geological-surveying support, including the construction of shaft ventilation workings of specified sizes and profiles, enhancing safety (see Figure 6).

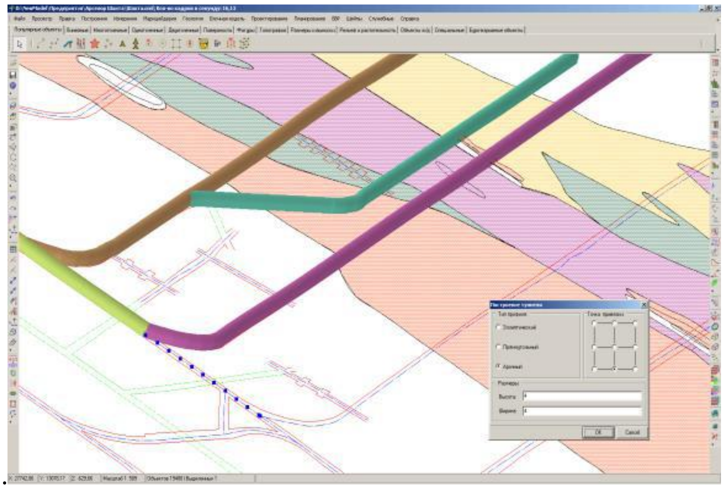

Fig. 6. Construction of shaft ventilation workings of specified sizes and profiles

It has recommendations from the State Mining Supervision and Industrial Safety Service of Ukraine, the State Commission of Ukraine on Mineral Reserves, endorsement from the State Mining Supervision and Industrial Safety Service, and a positive assessment from the National Scientific Research Institute of Industrial Safety and Occupational Health (Kyiv, Ukraine).

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Thus, based on the scientific and practical results of the research, the authors have developed a universal methodology. This methodology allows for the selection of an effective air distribution scheme and the correct placement of regulators, ensuring the stability of air distribution in the mining areas and galleries of coal mines [27, 28].

The universal methodology for analyzing and identifying diagonals is based on developed software, which enables the management and selection of air distribution schemes in mines. Additionally, with the developed methodology, it is possible to calculate aerodynamic parameters when selecting parameters for air distribution schemes. The proposed methodology and the application software developed based on it have been adapted for use in coal mines in Ukraine, the Republic of Kazakhstan, Germany, and other developed mining countries worldwide [29, 30].

6. Conclusions

Based on the scientific and practical findings of our research on ventilation control in coal mines using the decomposition method, as well as data analysis of aerodynamic parameters of air distribution through application software, the following conclusions have been drawn.

The methodologies encompass decomposition, statistical dynamics, set theory, fundamental laws of mining aerodynamics, and discrete mathematics. It is evident that the redistribution of air flow rates within the ventilation network is contingent upon deviations of controlled parameters to meet technological standards outlined in mine safety regulations. A notable increase in the efficiency of air supply organization to longwall areas has been observed, ranging between 20-23%.

A versatile technique has been devised for use in mine workings, facilitating analysis, evaluation of ventilation processes and associated aerodynamic factors, alongside optimization of air distribution control systems across various operational modes, while considering the unique characteristics of the mine ventilation network. This promises to enhance the efficiency and quality of ventilation in longwall sections by 17-20%, reduce unscheduled downtime by 10%, and contribute to safety measures, thus decreasing the accident rate in coal mining operations.

A methodology has been compiled, and application software developed based on it has been tailored for coal mines. The actual annual benefit from implementing this methodology in coal mines amounted to approximately 34 thousand US dollars.

Future studies should focus on further utilizing mathematical modeling of technological processes and automated geographic information systems like GIS K-MINE® (Krivoy Rog, Ukraine) for designing mine ventilation openings of specified sizes and profiles, thereby advancing workplace safety and labor protection in coal mines. Additionally, there are internationally recognized specialized programs for modeling, enhancing, and optimizing folding ventilation panels, such as VENTSIM, which enjoys widespread popularity. This system has been endorsed by regulatory authorities in Ukraine and is utilized by industry experts, regulatory bodies like Gospromgornadzor, mining institutes, and others.

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