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Assessment of the ventilation system and solutions for improving the ventilation network at Khe Cham Coal Mine, Vietnam

C.H. Nguyen[1], T.T. Vu[1,2*], D.T. Le[1,2], S.A. Do[1], C.V. Dao[1,2], P.Q. Le[1,2]

[1]*Hanoi University of Mining and Geology, Hanoi, Vietnam*
[2]*Research Group: Sustainable Development of Mining Science, Technology and Environment (SDM), Hanoi University of Mining and Geology, Hanoi, Vietnam*

**Corresponding author: vutrungtien@humg.edu.vn*

Abstract. Ventilation for underground mines plays an essential role in production activities by ensuring labor safety and maintaining environmental conditions. Mine ventilation is also one of the most effective methods for preventing methane gas and coal dust explosions. Therefore, it is necessary to investigate the ventilation network annually and calculate the overall ventilation requirements for underground mines in the Quang Ninh coalfield. Based on the production plan and ventilation needs of the Khe Cham Coal Mine, the authors surveyed and evaluated the mine ventilation network, thereby proposing solutions to improve the ventilation system and calculating the ventilation parameters for 2025. To achieve the research results presented in this article, the authors used methods such as data collection, analysis and synthesis, field surveys, result analysis and evaluation, combined with numerical modeling using ventilation software to verify calculation results. To ensure ventilation for Khe Cham Coal Mine in 2025, two main fan stations – №1 at level +35 and №2 at level +112 should be operated jointly, with the following calculated working modes: fan station №1 at level +35: airflow of 193.72 m^3/s, air pressure of 448 mmH_2O, impeller angle of 40°; fan station №2 at level +112: airflow of 155.8 m^3/s, air pressure of 419.5 mmH_2O, impeller angle of 35°. Based on the analysis of data collected at the Khe Cham Coal Mine, the paper assesses the overall ventilation status of the mine. It proposes solutions to improve the ventilation network, ensuring safety during production activities. Additionally, it determines the combined working mode of the two main fan stations, providing a foundation for developing the general ventilation plan for Khe Cham Coal Mine in 2025.

Keywords: *coal mine, ventilation system, airflow, air pressure, Khe Cham Coal Mine.*

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1. Introduction

The main task of general ventilation for underground coal mines is to provide sufficient and necessary clean air for people working in the mine according to regulations [1]. Mine ventilation contributes to diluting the concentration of toxic and explosive gases to the allowable safety limit, diluting the concentration of dust generated during mine operations to the permissible limit, and removing it from the mine. At the same time, it also contributes to improving the microclimate conditions at working locations in the mine [2]. As mentioned in many studies, calculating and selecting mine ventilation methods is an essential problem. It depends on many factors, including the mine gas factor and mine class, which are among the factors that need to be considered [3]. Calculating general ventilation for mines is difficult, partly due to the extensive mine tunnel system, simultaneous exploitation of many longwalls, and different exploitation levels, which leads to complex ventilation diagrams [4, 5].

Due to changes in the tunnel system in underground coal mines, the mine output also changes annually to match the actual production. Therefore, it is necessary to periodically inspect and survey the mine ventilation network every year to ensure ventilation conditions and safety in the mine. There are many studies on mine ventilation calculation and mine ventilation network inspection. Some typical studies on ventilation inspection and solutions [6, 7], mine ventilation model [8, 9], optimal calculation of ventilation network and adjustment of mine airflow [10, 11, 12, 13], solutions to stabilize mine ventilation network, reduce airflow leakage and balance airflow in underground coal mines [14, 15, 16]. In addition, some other typical studies related to adjusting air pressure balance and ventilation for mechanized mining longwall [17, 18, 19].

In the Quang Ninh coal mine area, Vietnam, ventilation calculations and mine ventilation network inspections are carried out regularly. In recent years, several typical studies related to ventilation solutions have been conducted at Ha Lam, Quang Hanh, Duong Huy, Ha Long and Cam Thanh Coal Mines [20, 21, 22, 23, 24], studies to determine the reasonable working mode of the main fan have been conducted at Thong Nhat and Nam Mau Coal Mines [25, 26], and studies on the application of ventilation calculations using software [27, 28].

nguyenhongcuong@humg.edu.vn, vutrungtien@humg.edu.vn, t.d.le@humg.edu.vn, doanhson@humg.edu.vn, daovanchi@humg.edu.vn, lequangphuc@humg.edu.vn
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In 2024, Khe Cham Coal Mine operated with a production capacity of 1.8 million tons, with nine longwalls working simultaneously. The mine is developing tunnels and extracting coal from levels −300 to −100. Two main fan stations provide general mine ventilation: №1 at level +35 and №2 at level +112.

– fan station №1 at level +35: equipped with a 2K56-№30 fan, impeller angle of 35°;

– fan station №2 at level +112: equipped with a 2K56-№30 fan, impeller angle of 35°.

The current mine ventilation situation in 2024 shows that the general ventilation situation of the mine is facing many difficulties, and it is often necessary to maintain 3-4 auxiliary fan stations in the mine to meet the ventilation requirements, which leads to potential risks of unsafe production. The production plan in 2025 will continue to maintain exploitation with an output of 1.8 million tons. To ensure the production plan, it is necessary to dig nearly 16,000 meters of tunnel, prevent and cut thousands of meters of tunnel, and exploit 10 longwalls operating simultaneously.

The above domestic and foreign studies have all mentioned the method of calculating mine ventilation, solutions to improve mine ventilation efficiency, and solutions to balance mine air pressure. However, the research and survey of mine ventilation network, as well as ventilation calculation for Khe Cham Coal Mine in 2025 have not been carried out. Therefore, it is necessary to assess the current status and determine the working mode of fan stations for Khe Cham Coal Mine to ensure safety in production and the working environment. The research results of the paper are the basis for application in actual production at Khe Cham Coal Mine.

2. Materials and methods

2.1. Study area

The study was conducted at the Khe Cham Coal Mine, located in Mong Duong Ward, Cam Pha City, Quang Ninh Province, Vietnam. The mine is situated approximately 20 km north of the Cam Pha city center, along the left side of Route 18A from Ha Long to Mong Duong [29]. It is bordered by the Bac Huy fault to the north, Khe Cham II-IV Coal Mine to the south, Khe Cham I Coal Mine to the east, and Khe Tam Coal Mine to the west. The location of the Khe Cham Coal Mine is illustrated in Figure 1.

Figure 1. Location map of the Khe Cham Coal Mine (modified from [30])

2.2. Current status of the Khe Cham Coal Mine ventilation system diagram

In 2024, Khe Cham Coal Mine operated nine longwalls simultaneously, distributed across three seams: 14.5, 14.4, and 14.2 [31].

Coal seam 14.5 included five longwalls (14.5-33.1, 14.5-28A, 14.5-28B, 14.5-28.1, and 14.5-12.5), all exploited using drilling and blasting technology with chain support. The operating levels for these longwalls were as follows:

– 14.5-33.1: from −126 to −158;

– 14.5-28A: from −95 to −143;

– 14.5-28B: from −126 to −155;

– 14.5-28.1: from −136 to −170;

– 14.5-12.5: from −269 to −275.

Seam 14.4 included one longwall (14.4-23), exploited using drilling and blasting technology with chain support, operating from −140 to −162.

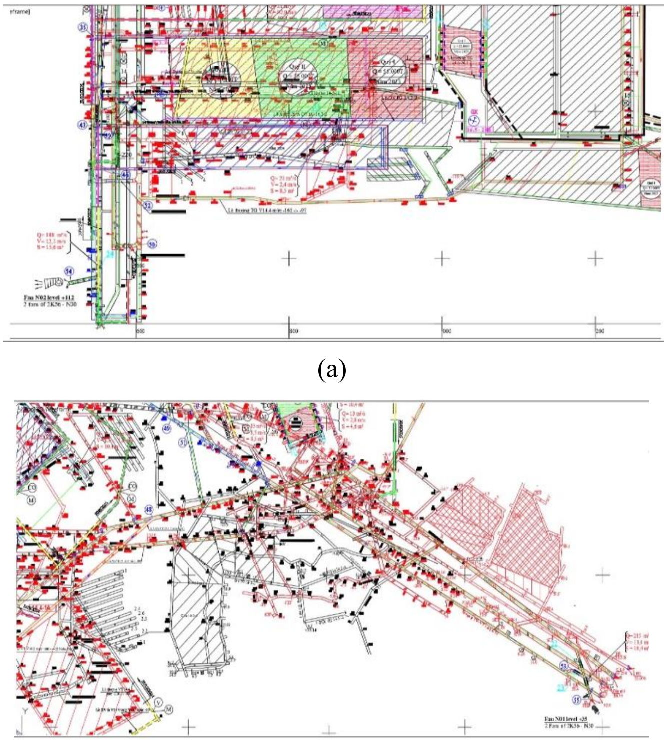
Coal seam 14.2 included three longwalls:

– 14.2-12, exploited using fully mechanized technology with shield support, from −182 to −208;

– 14.2-10, exploited using drilling and blasting technology with chain support, from −169 to −173;

– 14.2-1, exploited using drilling and blasting technology with chain support, from −182 to −213.

To ensure ventilation for the nine simultaneously operating longwalls and airflow consumption areas mentioned above, Khe Cham Coal Mine applies the exhaust ventilation method based on a side ventilation diagram, with the main fan stations located at +35 and +112 levels, as detailed below (Figure 2). Complex multi-level ventilation system is important for maintaining air quality, diluting hazardous gases, and ensuring the safety of miners across all active longwalls.



(a)

(b)

Figure 3. The ventilation system diagrams of Khe Cham Coal Mine [31]

The diagrams in Figure 2 illustrate the airflow organization, the arrangement of the main fan stations, and the ventilation pathways supplying fresh air to the working longwalls.

Fan station №1 equipped with a 2K56-№30 fan (one working fan and one standby fan), installed at the +35 level. Fresh air enters through the auxiliary inclined shaft, descends to the shaft station at the −300 level, and passes through the transport brake incline from +25 to −90. It then follows the brake inclines and haulage levels to the consumption areas of Seam 14.5 (14.5-33.1 longwall), Seam 14.4 (14.4-23 longwall), and Seam 14.2 (14.2-12 and 14.2-10 longwalls), reaches the ventilation level, and exits through the upper ventilation brake incline to the exhaust fan station at the +35 level.

Fan station №2 equipped with a 2K56-№30 fan (one working fan and one standby fan), installed at the +112 level. Fresh air enters through the auxiliary inclined shaft, descends to the shaft station at the −300 level, and passes through the transport brake incline from −168 to −145. It then follows the brake inclines and haulage levels to the consumption areas of Seam 14.5 (14.5-28A, 14.5-28B, 14.5-28.1, and 14.5-12.5 longwalls) and Seam 14.2 (14.2-1 longwall), reaches the ventilation level, and exits through the upper ventilation brake incline to the exhaust fan station at the +112 level.

2.3. Research methods

The study employed a combination of field measurements, data analysis, and numerical modeling techniques to assess the ventilation system at Khe Cham Coal Mine.

Specialized measuring equipment was utilized to collect field data, including air speed meters; Japanese Aneerroid S8 barometers; temperature and humidity meters manufactured in Japan and China; and handheld gas and air meters produced in Poland, Germany, and China. Measurements and surveys were conducted at critical locations within the mine, including the two main fan stations (№1 at +35 level and №2 at +112 level), longwall faces, preparation roadways, and large openings. A comprehensive synthesis analysis was performed based on the data collected during field surveys. The data were systematically evaluated and compared to identify ventilation characteristics, airflow distribution patterns, and potential issues within the existing ventilation network.

To supplement field observations and enhance the reliability of the analysis, two ventilation simulation software packages were employed PATH Network Diagram Software and Kazamazu Ventilation Software (Japan).

The PATH software simulated the mine ventilation network, particularly under complex conditions. Each ventilation diagram was represented as a PATH network, allowing the determination of air pressure values across all flows passing through the network nodes. The maximum air pressure within the mine ventilation system was identified based on these calculations.

Kazamazu software was applied to accurately model and analyze the working modes of the main fans. The key functionalities of the Kazamazu software included identifying the main components of the mine ventilation network; determining system limitations and critical points; editing and analysis of simulation results and analysis of standard airflow distribution across the ventilation network.

These combined research methods provided a comprehensive basis for evaluating the current ventilation status and for developing proposals to optimize the ventilation system at Khe Cham Coal Mine.

3. Results and discussion

3.1. Assessment of the current status of the ventilation system of Khe Cham Coal Mine (2024)

3.1.1. Assessment of ventilation of the longwalls

Regarding the airflow direction in the longwalls, the ventilation pattern is generally from bottom to top, which complies with safety regulations for mines with explosive gas conditions. In some longwalls where the airflow moves from top to bottom, additional fresh air is supplied to dilute methane concentrations. However, it is recommended that the dust control regime in these areas be closely monitored to ensure safe working conditions.

Regarding the airflow and airspeed through the longwalls, the results of the calculations and field measurements of the required airflow are presented in Table 1.

Table 1. Assessment of airflow and speed through the longwalls

№	Name of longwall	Airflow (m^3/s)			Speed of air, m/s			
		Field	Maximum	Assessment	Cross-section, m^2	Field	Allowing	Assessment
1	14.5-28.B	6.9	12	insufficient	4.6	1.5	0.25-4	Enough
2	14.4-12	7.82	21			1.7		
3	14.5-28.A	9.98	14			1.4		
4	14.4-15	10.12	12			2.2		
5	14.2-10.2	6.99	12			1.52		
6	14.4-16	8.28	12			1.8		
7	14.4-23	6.44	10			1.4		
8	14.2-1	7.82	11			1.7		

Analysis of the data in Table 1 shows that the airflow passing through the longwalls in all eight surveyed longwalls does not meet the required standards. Considering losses through the worked-out areas and the pre-digging brake inclines, the airflow should reach at least 70% of the calculated airflow values. In particular, the 14.4-12 longwall demonstrates a significant shortfall, lacking approximately 50% of the maximum required airflow. Regarding the composition of toxic and harmful gases in the longwalls, automatic centralized monitoring data and actual field measurements indicate that the concentrations of toxic gases (CH_4, CO_2) are within allowable limits. However, in the 14.5-28.A longwall, CO_2 emissions into the working area have been detected. In this case, it is necessary to provide additional airflow into the longwall and install a temporary ventilation door if there is insufficient space to construct a permanent crosswall.

This measure would help prevent air leakage from the exploited area, thereby reducing the ingress of CO_2 into the longwall. Regarding microclimate conditions in the longwalls, the measurement and survey results show that the air temperature generally remained within allowable limits but was close to the upper threshold. Therefore, measures such as mist spraying and increasing fresh air intake into the mine are recommended to lower the temperature and enhance airflow through the longwalls. Additionally, in 2025, longwalls with opposite airflow directions, such as 14.4-16 and 14.2-9, will require adjustments, including reducing the slope of the longwalls and adding fresh air to the polluted airflow before it mixes with the common return air.

Regarding booster fans for longwall ventilation, while this solution provides timely support for production without needing pre-digging brake inclines and rim roadways to supply and remove air, it also presents several disadvantages. Using booster fans significantly increases electricity consumption, as each longwall requires two FBD2×30 kW fans operating continuously. Moreover, reversing the airflow in the event of an incident becomes more difficult. Importantly, electric motor-driven booster fans cannot effectively prevent the ignition of methane gas in mines with explosive gas hazards. Consequently, while the current solutions are effective in the short term, they are considered temporary. They must be replaced by the proper excavation of ventilation routes and the calculation of fresh air supply for the respective longwalls.

3.1.2. Assessment of the longwalls ventilation

The measurement and survey data on the ventilation status of the preparation roadways are presented in Table 2.

Table 2. Assessment of airflow and speed through the preparation roadways

№	Name of roadways	Measurement results			Q calculation result (m³/s)	Assessment
		V, m/s	S, m²	Q, m³/s		
1	Haulage level of 14.5-29A	0.3	9.3	2.79	2.8	Enough
2	Haulage level of 14.5-24.1		9.3	2.79	2.2	Enough
4	Ventilation level of 14.2-2		7.8	2.34	2.6	Insufficient
5	Ventilation level of 14.5-35A		9.3	2.79	2.8	Enough
6	Haulage level of 14.5-10.2		9.3	2.79	2.8	Enough
7	Haulage level of 14.5-35A		9.3	2.79	2.8	Enough
8	Ventilation level of 14.2		7.8	2.34	2.6	Insufficient
9	Haulage level of 14.5-36.1		9.3	2.79	2.8	Enough
10	Ventilation level of 14.5-36.1		9.3	2.79	2.8	Enough
11	Haulage level of 14.5-33.2		9.3	2.79	2.8	Enough
12	Haulage brake incline of 14.5-37		9.3	2.79	2.8	Enough
13	Haulage level of 14.5-21.1		7.2	2.16	2.2	Enough
14	Haulage level of 14.5-24.1		7.2	2.16	2.2	Enough

Analysis of the data in Table 2 shows that most of the preparation roadways meet the ventilation requirements. However, two ventilation roadways, specifically the Ventilation level of 14.2-2 and the Ventilation level of 14.2, exhibit insufficient airflow compared to the calculated airflow requirements. These areas require additional ventilation measures to ensure compliance with safety standards and maintain suitable working conditions.

Most roadways have average ventilation lengths ranging from 100 to 500 meters, thus ventilation operations do not face significant difficulties. The fans' locations comply with the regulations, adequate ventilation capacity is sufficient, and the airflow sufficiently meets the requirements for mine excavation activities.

The installed booster fans are in good working condition. Ventilation ducts are correctly installed and maintained under the ventilation methods applied at the mine. The airflow supplied to the working faces generally meets the required levels, and the microclimate conditions at the faces are within acceptable limits as regulated. However, in some working faces, insufficient airflow has been observed. Therefore, it is necessary to inspect the pipe connection points and the overall condition of the ventilation pipes to identify and rectify any deficiencies promptly.

3.1.3. Assessment of the longwalls ventilation

The ventilation works of the mine, as identified during the survey, include the fan station houses, fan drifts, ventilation doors, ventilation doors with adjustable regulators, ventilation gates, and partitions.

The fan stations №1 and №2 are solidly and firmly constructed, providing stable support for the mine ventilation system. The quality of the fan drifts ensures effective airflow, contributing to the overall efficiency of the ventilation network. The ventilation doors throughout the mine are arranged reasonably, with a solid structure that effectively regulates airflow within the mine.

The ventilation gates, installed to prevent air leakage at the two main fan stations, are of good quality and maintain air leakage within the allowable limit of Q_r = 5 m³/s, as regulated. Additionally, these ventilation works contribute significantly to preventing air leakage into the exploited areas, thus maintaining safe and efficient ventilation conditions throughout the mine.

3.1.4. Assessment of the working capacity of fan stations

The results of calculations, measurements, and surveys of the working modes of the main fans at the two fan stations are presented in Table 3.

Table 3. Working modes of the main fans

Stations	№1	№2
Name of fans	2K56-№30	2K56-№30
Impeller angle, degree	35	30
Working mode by calculation:		
– Airflow, m³/s;	165	140
– Air pressure, mmH₂O	305	230
Working mode according to measurement and survey:		
– Airflow, m³/s;	182.04	270
– Air pressure, mmH₂O	182.04	160

Analysis of the data presented in Table 3 shows that the two main fan stations are operated in association to create air pressures of 270 mmH_2O and 160 mmH_2O for stations №1 and №2, respectively. These air pressures are within the normal operating range of the installed fans.

The measurement results indicate that when both fans are operated jointly, the total airflow reaches 265 m^3/s. However, the maximum air pressure at fan station №1, measured at 270 mmH_2O, is significantly lower than the calculated value and the rated capacity of the fan. Therefore, the actual working mode of the two fans does not fully meet the optimal performance parameters. Nevertheless, the system can be adjusted to increase the airflow into the mine, thereby improving ventilation efficiency.

3.2. Proposed solutions to improve the ventilation network to ensure safety

3.2.1. General viewpoint

In order to develop an effective solution for completing the general ventilation system of the entire mine, it is necessary to unify the overall approach and implement the following specific technical ventilation measures:

– ensure that sufficient airflow is provided to all consumption areas of the mine;

– avoid placing local fans in dirty air tunnels to ventilate the longwalls, as this could compromise air quality and ventilation efficiency;

– in longwalls with opposite airflow directions, fresh air must be introduced into the polluted airflow to improve air quality during its passage through the common return airways.

3.2.2. Proposed solutions

To address the ventilation issues identified above, the following solutions are recommended:

– excavate a brake incline in front of the 14.5-36 longwall area to provide a fresh air supply;

– excavate a rim roadway to direct polluted air from the ventilation level of 14.4-17 to the haulage brake incline between levels −145 and −268 of Seam 14.2;

– excavate a rim roadway from the ventilation level of 14.2-2 to the middle gate of Seam 14.2 to improve ventilation;

– excavate a rim roadway from the haulage brake incline between levels −83 and −150 to the haulage level of 14.2-9 of Seam 14.2 to supply fresh air to the 14.2-9 longwall;

– excavate a rim roadway from the ventilation level 14.5-29A to the haulage brake incline between levels −100 and −160 of Seam 14.4.

– perform calculations and adjustments of the ventilation network to establish a reasonable and optimized ventilation mode for the mine.

3.3. General ventilation calculation for Khe Cham Coal Mine in 2025

3.3.1. Determining of consumption places

Consumption places in Khe Cham Coal Mine include the airflow supplied to longwalls, dead-end, and large opening (power stations) calculated according to the mining and tunneling plan (Tables 4-6).

Table 4 summarizes the longwalls planned for simultaneous operation in 2025 at Khe Cham Coal Mine, including their daily production outputs. These data are essential for determining the required ventilation airflow to ensure safe mining operations.

Table 4. Longwall mining plan

№	Longwall	Output, tons/day-night
1	14.5-37.1	600
2	14.05.1932	646
3	14.04.2017	547
4	CGH 14.2-9	880
5	14.5-33.A	584
6	CGH 14.2-2	1000
7	14.5-12.5A	600
8	14.5-29.A	749
9	14.5-36.1	500
10	14.2-11.1	560

Table 5. Prepared a tunnel excavation plan

№	Tunnel/Heading	Area, m^2
1	Ventilation level of 14.5-28B	13.1
2	Haulage level of 14.5-28B	12.5
3	Ventilation level of 14.5-36.2	13.1
4	Opening heading of 14.5-36.2	12.5
5	Haulage level of 14.5-39	13.1
6	Opening heading of 14.5-39	12.5
7	Opening heading of 14.4-21	12.5
8	Ventilation level of 14.2-3	16.1
9	Opening heading of 14.2-3	16.1
10	Ventilation level of 14.2-12.1	13.1
11	Opening heading of 14.2-12.1	12.5
12	Ventilation level of 14.2-14	11.2
13	Haulage level of 14.2-14	11.2
14	Drainage roadway at −290 level	22
15	Ventilation-haulage crosscut at −280 (North side)	13.1
16	Ventilation incline from −180 to −280 levels	16.1

Table 6. Large openings requiring ventilation

№	Facility	Capacity, kW
1	Fan station at +35 level	2750
2	Pumping station at −90 level	1350
3	Pumping station at −220 level	700
4	Pumping station at −160 level	700
5	Fan station at +112 level	4650
6	Pumping station at −300 level	3750
7	Pumping station at −200 level	900

Table 5 presents the prepared tunnel headings, excavations, and their cross-sectional areas. Table 6 outlines the major large openings, such as fan and pumping stations, requiring ventilation in the mine. These facilities are critical for calculating the airflow needed to maintain appropriate microclimate and operational conditions.

3.3.2. Calculating the general airflow and air pressure for the entire mine

The general airflow requirement for Khe Cham Coal Mine is calculated using the following formula [32]:

$$Q_m = 1.1\cdot\left(1.1\cdot\sum Q_{lc} + \sum Q_{cb} + \sum Q_{ht} + \sum Q_r\right),\ \text{m}^3/\text{s}, \quad (1)$$

where: 1.1 is the coefficient referring to the possibility of uneven air distribution; $\sum Q_{lc}$ is total required airflow for ventilating the longwalls (m^3/s); $\sum Q_{cb}$ is total required airflow for ventilating the dead-end tunnels (m^3/s); $\sum Q_r$ is total required airflow for ventilating the large openings (m^3/s); $\sum Q_{ht}$ is total airflow leakage through ventilation structures (m^3/s). The results of calculating the total required airflow for consumption places are shown in Table 7.

Table 7. Table of calculation results of the required airflow of consumption places

№	Name of consumption places	Required airflow, m^3/s	№	Name of consumption places	Required airflow, m^3/s
I	Longwall, Q_{lc}		II	Dead end, Q_{cb}	
1	Longwall of 14.5-37.1	13	1	Ventilation level of 14.5-28B	3.3
2	Longwall of 14.5-32	13	2	Ventilation level of 14.5-28B	3.2
3	Longwall of 14.4-17	11	3	Ventilation level of 14.5-36.2	3.3
4	Longwall of CGH 14.2-9	18	4	Opening heading of 14.5-36.2	3.2
5	Longwall of 14.5-33.A	12	5	Haulage level of 14.5-39	3.3
6	Longwall of CGH 14.2-2	21	6	Opening heading of 14.5-39	4.9
7	Longwall of 14.5-12.5A	13	7	Opening heading of 14.4-21	3.3
8	Longwall of 14.5-29.A	16	8	Ventilation level of 14.2-3	4.1
9	Longwall of 14.5-36.1	10	9	Opening heading of 14.2-3	4.8
10	Longwall of 14.2-11.1	12	10	Ventilation level of 14.2-12.1	3.4
	$\sum Q_{lc}$	139	11	Haulage level of 14.2-12.1	3.9
III	Large opening, Q_{ht}		12	Ventilation level of 14.2-14	2.8
1	Pumping station of -90 level	9	13	Haulage level of 14.2-14	3.4
2	Pumping station of -220 level	5	14	Drainage roadway of –290 level	5.7
3	Pumping station of -160 level	5	15	Ventilation- haulage crosscut of –280 level at North side	3.4
4	Pumping station of –300 level	25	16	Ventilation incline of –180 / –280 level	4.1
5	Pumping station of –200 level	6		$\sum Q_{cb}$	61.5
	$\sum Q_{ht}$	50	IV	Airflow leakage ($\sum Q_r = 10\% \sum Q_{lc}$)	13.9

From the results presented in Table 7, substituting the values into Equation (2), the general airflow requirement for the mine is calculated as follows:

$$Q_m = 1.1 \cdot \left(1.1 \cdot 139 + 61.5 + 50 + 13.9\right) \approx 306 \text{ m}^3/\text{s}, \quad (2)$$

Based on the calculation results of airflow for the mine $Q_m = 306$ m^3/s, proceed to distribute airflow to consumption places. Based on the principle of standard airflow distribution, the airflow distribution results are shown on the ventilation diagram in Figure 3.

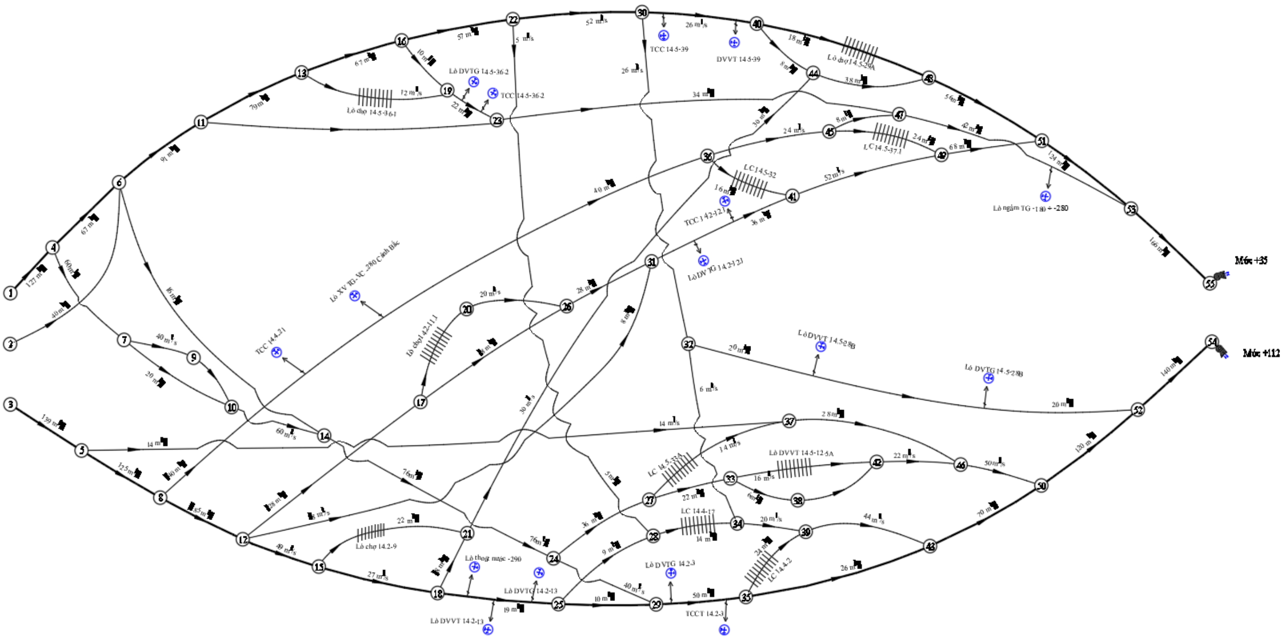


Figure 3. Ventilation diagram of Khe Cham Coal Mine in 2025

The general air pressure of the mine is calculated using the following formula [32]:

$$H = R \cdot Q^2, \text{ mmH}_2\text{O}. \quad (3)$$

where: R is aerodynamic resistance of the tunnel, $k\mu$; Q is airflow through the tunnel, m^3/s.

When designing the mine ventilation system, the general aerodynamic resistance is determined based on the flow with the maximum air pressure, while other flows are adjusted accordingly. To calculate the general air pressure of the mine, it is necessary to determine the air pressure for all flows within the ventilation network. However, identifying the flow with the maximum air pressure can be very challenging when the complex network contains multiple nodes.

The PATH network diagram software was applied in this study to address this. Based on the ventilation diagram constructed in PATH, a matrix was generated to calculate and identify the flow corresponding to the maximum air pressure using the PATH Table. According to the calculation results, the flow passing through the nodes 3-5-8-12-15-18-25-29-35-39-43-50-52-54 (as shown in the ventilation diagram in Figure 3) exhibited the highest air pressure, with a value of $H_{max} = 363.05$ mmH_2O. Therefore, the general air pressure of the mine is determined as: $H_m = H_{max} = 363.05$ mmH_2O. These results form the basis for selecting, adjusting, and operating the main fans to ensure stable and efficient ventilation throughout Khe Cham Coal Mine in 2025.

3.3.3. Determining the appropriate working mode of the main fans

The appropriate working mode of the main fans must meet several requirements: it should ensure the required airflow and air pressure, operate within the practical and stable region of the fan characteristic curves, and maintain overall stability in the mine's production process.

Based on the 2025 ventilation plan results, the total required airflow for Khe Cham Coal Mine was determined to be 306 m³/s. According to the ventilation diagram in Figure 3, the airflow requirements were distributed between the two main fan stations, with fan station №1 requiring Q_1 = 166 m³/s and fan station №2 requiring Q_2 = 140 m³/s. Similarly, the air pressure requirements were determined based on the PATH network diagram analysis results. The calculated pressures necessary to maintain proper airflow through the ventilation network were H_1 = 352.07 mmH₂O for fan station №1 and H_2 = 363.05 mmH₂O for fan station №2 [33].

The appropriate working modes of the main fans were determined based on these airflow and air pressure values. The fans must operate with parameters that satisfy the ventilation demands and ensure efficient energy use and reliable functioning throughout the mine's operations. The calculated operating parameters for the main fans are summarized in Table 8.

Table 8. Working mode of the main fan stations of Khe Cham Coal Mine in 2025

Stations	Name of fans	Airflow (Q), m³/s	Air pressure (H), mmH₂O	Engine power, KW	Impeller angle, degree
№1 level +35	2K56-№30	182	415	1250	40
№2 level +112	2K56-№30	154	408.1	1250	35

Thus, the selected operating parameters for the main fans ensure that the ventilation system will meet both the production needs and the safety requirements of Khe Cham Coal Mine in 2025.

3.3.4. Use ventilation software to verify calculation results

To re-check the operating capacity of the fan stations to meet the calculated airflow and air pressure requirements, Kazamaru ventilation calculation software must be used to check and determine the reasonable working mode of the fan stations. Based on the calculation results of the airflow, air pressure of the ventilation network, and the impeller angle of the fans, use Kazamazu ventilation software (Japan) to determine the main fans' working mode accurately. Enter the resistance parameters of the roadway adjusted according to the PATH network, the characteristics of the 2K56-№30 fan into the Kazamazu software for calculation. The airflow results are shown in Figure 4, and the fan working points in Figure 5.

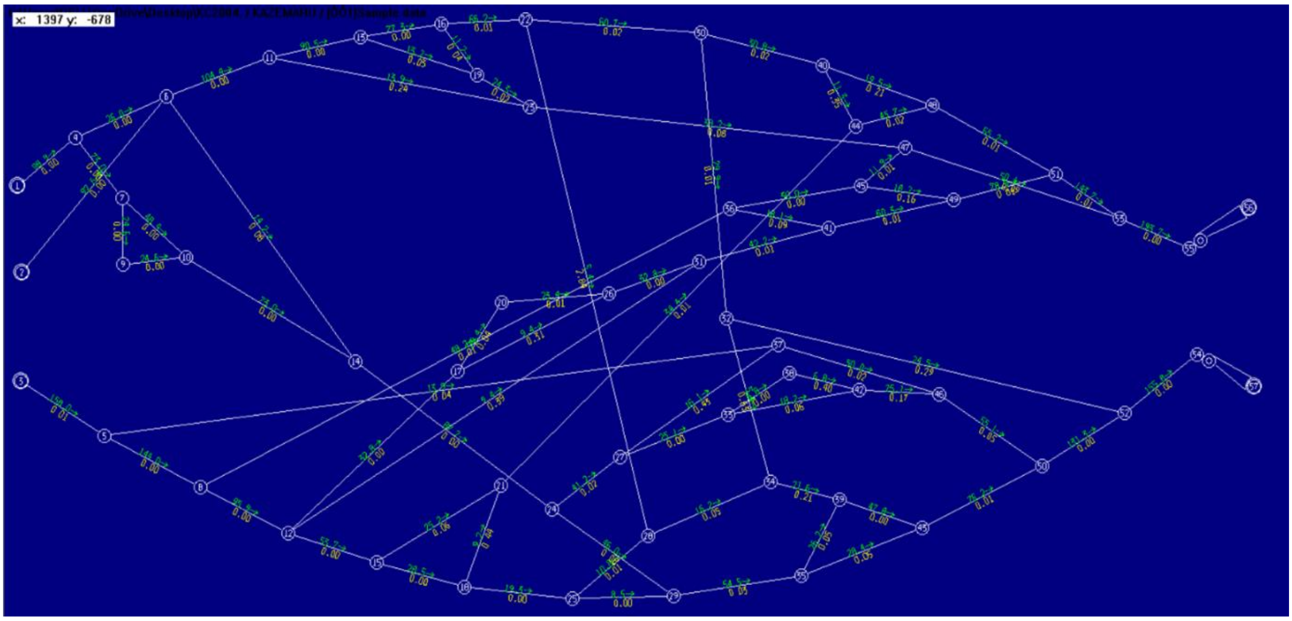
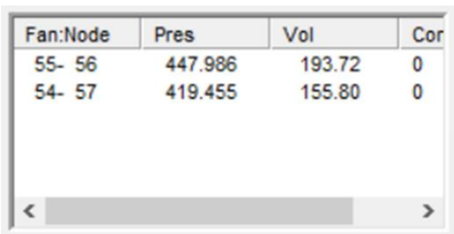


Figure 4. Diagram to determine the actual airflow of combined working fans using Kazamazu software



Fan:Node	Pres	Vol	Cor
55- 56	447.986	193.72	0
54- 57	419.455	155.80	0

Figure 5. Working parameters of fans №1 and №2 in 2025 using software

Thus, the software results demonstrate that the reasonable working points of the fans are consistent with the design calculations, as shown in Table 9.

Table 9. Table of calculation of airflow and air pressure after putting the fans into use (using calculation software)

Stations	Name of fans	Airflow (Q), m³/s	Air pressure (H), mmH₂O
№1 level +35	2K56 - №30	193.72	447.986
№2 level +112	2K56 - №30	155.8	419.455

Through checking the airflow and air pressure of the flows, it was verified that the performance of the fans meets the requirements compared to the initial calculation results. This confirms that the selected working modes for the main fan stations are adequate to ensure stable and safe ventilation at Khe Cham Coal Mine in 2025.

5. Conclusions

Khe Cham Coal Mine, one of the largest underground mines in Vietnam, is characterized by complex geological conditions and is classified as a type II mine according to methane gas risk classification. The survey results, field measurements, and ventilation calculations conducted in 2024 indicate that the general ventilation status and microclimate conditions in the mine largely meet the required standards. However, the temperature at the longwalls remains high, reaching approximately 29°C, and insufficient airflow was recorded at several longwalls, particularly at the fully mechanized longwall faces, necessitating additional airflow to ensure operational safety.

The PATH network diagram software proved suitable for calculating airflow pressure values across the ventilation network. Additionally, the application of Kazamazu ventilation software significantly enhanced the reliability of determining the combined working mode of the main fan stations. The analysis of the ventilation network in 2025 using these software tools yielded the following results: for fan station №1 at level +35, an airflow of 193.72 m^3/s, an air pressure of 448 mmH_2O, and an impeller angle of 40° were determined; for fan station №2 at level +112, an airflow of 155.8 m^3/s, an air pressure of 419.5 mmH_2O, and an impeller angle of 35° were identified.

To ensure proper ventilation and maintain fire safety concerning methane gas, it is essential to organize excavation works, including pre-digging brake inclines and rim roadways, to introduce fresh air into the longwalls and properly discharge polluted air. These measures are necessary to maintain safe ventilation patterns in the longwall areas.

Survey results also indicate that the resistance in some branches of the ventilation network has increased by 20% to 50% compared to the calculated values. This increase is attributed to the narrowing of ventilation and transportation tunnels over time. Therefore, regular inspection of the tunnels' cross-sectional areas is required to implement timely measures for improving ventilation efficiency.

Finally, during the mining process, it is necessary to continuously monitor and inspect the ventilation system, temperature, mine gas concentrations, and overall mine resistance, with particular attention to airflow distribution in the branches serving the longwalls.

Author contributions

Conceptualization: CHN, TTV; Data curation: DTL, CVD; Formal analysis: SAD, PQL; Investigation: CHN, TTV; Methodology: TTV; Project administration: CHN, TTV; Resources: DTL, SAD; Supervision: TTV; Validation: CVD, PQL; Visualization: SAD; Writing – original draft: CHN, TTV, SAD; Writing – review & editing: TTV, DTL, CVD, PQL. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interest

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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Вьетнам, Хэ-Чам көмір шахтасының желдету жүйесін бағалау және желдету желісін жақсарту бойынша ұсыныстар

К.Х. Нгуен[1], Т.Ч. Ву[1,2*], Д.Т. Ле[1,2], Ш.А. До[1], Ч.В. Дао[1,2], Ф.К. Ле[1,2]

[1]*Ханой тау-кен және геология университеті, Ханой, Вьетнам*
[2]*Ғылыми-зерттеу тобы: Тау-кен ғылымының, технологияның және қоршаған ортаның тұрақты дамуы (SDM), Ханой тау-кен және геология университеті, Ханой, Вьетнам*

**Корреспонденция үшін автор: vutrungtien@humg.edu.vn*

Аңдатпа. Жерасты игеру кезінде желдету өндірістік қызметте маңызды рөл атқарады, бұл еңбекке қауіп төндірмейді және қоршаған ортаның тиісті жағдайларын сақтайды. Сонымен қатар, желдету метан мен көмір шаңының жарылуын болдырмаудың ең тиімді әдістерінің бірі болып табылады. Осыған байланысты жыл сайын желдету желісін зерттеп, Куангнинь көмір бассейнінің жерасты шахталары үшін жалпы желдету қажеттіліктерін есептеу қажет. Хе-Чам көмір шахтасының өндірістік жоспары мен желдету қажеттілігін ескере отырып, авторлар шахтаның желдету желісін зерттеп, бағалады, желдетудің си-жүйесін жақсарту бойынша шешімдер ұсынды, сондай-ақ 2025 жылға арналған желдету параметрлерін есептеді. Осы мақалада келтірілген нәтижелерге қол жеткізу үшін деректерді жинау, талдау және синтездеу әдістері, далалық зерттеулер, нәтижелерді талдау және бағалау, сондай-ақ есептеулерді тексеру үшін мамандандырылған желдету бағдарламалық жасақтамасын қолдана отырып сандық модельдеу қолданылды. Хе-Чам көмір шахтасының желдетілуін қамтамасыз ету үшін 2025 жылы екі негізгі желдеткіш станцияның бірлескен жұмысы ұсынылады - көкжиектегі №1 +35 және гори-қолшатырдағы №2 +112. Олардың жұмысының есептік режимдері келесідей: көкжиектегі №1 желдеткіш станциясы +35-ауа шығыны 193.72 м^3/с, қысым 448 мм су. қалақтардың бұрылу бұрышы 40°; горизонттағы № 2 желдеткіш станциясы +112-ауа шығыны 155.8 м^3/с, қысым 419.5 мм су. ст., иық пышақтарының айналу бұрышы 35°. Чам шахтасында жиналған деректерді талдау негізінде мақалада желдетудің жалпы жағдайына баға беріліп, тау-кен жұмыстарын жүргізу кезінде қауіпсіздікті қамтамасыз ететін желдету желісін жетілдіру шаралары ұсынылған. Сондай-ақ, үкі-екі негізгі желдеткіш станцияның жергілікті жұмыс режимдері анықталды, бұл Хе-Чам шахтасының 2025 жылға арналған жалпы желдету жоспарын жасауға негіз болады.

Негізгі сөздер: *көмір шахтасы, желдету жүйесі, ауа ағыны, ауа қысымы, көмір шахтасы.*

Оценка вентиляционной системы и предложения по улучшению вентиляционной сети угольной шахты Кхе-Чам, Вьетнам

К.Х. Нгуен[1], Т.Ч. Ву[1,2*], Д.Т. Ле[1,2], Ш.А. До[1], Ч.В. Дао[1,2], Ф.К. Ле[1,2]

[1]*Ханойский университет горного дела и геологии, Ханой, Вьетнам*

[2]*Научно-исследовательская группа: Устойчивое развитие горной науки, технологий и окружающей среды (SDM), Ханойский университет горного дела и геологии, Ханой, Вьетнам*

**Автор для корреспонденции:* vutrungtien@humg.edu.vn

Аннотация. Вентиляция при подземной разработке играет важнейшую роль в производственной деятельности, обеспечивая безопасность труда и поддержание надлежащих условий окружающей среды. Кроме того, вентиляция является одним из наиболее эффективных методов предотвращения взрывов метана и угольной пыли. В связи с этим необходимо ежегодно исследовать вентиляционную сеть и рассчитывать общие вентиляционные потребности для подземных шахт угольного бассейна Куангнинь. Учитывая производственный план и потребности в вентиляции угольной шахты Кхе-Чам, авторы провели обследование и оценку вентиляционной сети шахты, предложили решения по улучшению системы вентиляции, а также рассчитали вентиляционные параметры на 2025 год. Для достижения результатов, представленных в данной статье, использовались методы сбора, анализа и синтеза данных, полевые обследования, анализ и оценка результатов, а также численное моделирование с применением специализированного вентиляционного программного обеспечения для верификации расчетов. Для обеспечения вентиляции угольной шахты Кхе-Чам в 2025 году рекомендуется совместная работа двух главных вентиляторных станций - №1 на горизонте +35 и №2 на горизонте +112. Расчетные режимы их работы следующие: вентиляторная станция №1 на горизонте +35 – расход воздуха 193,72 м^3/с, давление 448 мм вод. ст., угол поворота лопаток 40°; вентиляторная станция №2 на горизонте +112 – расход воздуха 155,8 м^3/с, давление 419,5 мм вод. ст., угол поворота лопаток 35°. На основании анализа данных, собранных на шахте Кхе-Чам, в статье дана оценка общего состояния вентиляции и предложены меры по совершенствованию вентиляционной сети, обеспечивающие безопасность при ведении горных работ. Также определены совместные режимы работы двух основных вентиляторных станций, что служит основой для разработки общего плана вентиляции шахты Кхе-Чам на 2025 год.

Ключевые слова: *угольная шахта, вентиляционная система, расход воздуха, давление воздуха, угольная шахта Кхе-Чам.*

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