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CFD SIMULATION OF AIRFLOW RATE EFFECTS ON DUST DISPERSION IN A COAL MINE HEADING

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Abstract: Respirable dust generated during underground coal roadway development is one of the primary occupational hazards, directly affecting workers' health and mine operational safety. The major sources of dust generation include drilling, blasting, mucking, roof support installation, and haulage activities at the development face. This study employed Computational Fluid Dynamics (CFD) in combination with field investigation data collected from Khe Tam mining area of Duong Huy Coal Mine to analyze the spatial and temporal characteristics of dust dispersion under different ventilation airflow rates. The simulation results demonstrate that the ventilation airflow rate has a significant influence on dust dispersion and concentration distribution within the development heading. Dust concentration decreases markedly as the airflow rate increases. Specifically, increasing the airflow rate from 150 to 500 m³/min resulted in a substantial reduction in dust concentration, whereas a further increase from 500 to 700 m³/min produced a relatively smaller reduction, indicating a tendency toward stabilization. The findings provide a better understanding of the relationship between ventilation conditions and dust dispersion in underground coal mine roadways, offering a scientific basis for optimizing ventilation airflow rates to improve dust control efficiency, enhance the underground working environment, and protect the occupational health of mine workers.

Keywords: Mine dust; Computational Fluid Dynamics (CFD); Ventilation airflow rate; Coal mine heading.

1. Introduction

According to Decision No. 625/QĐ-TTg issued by the Prime Minister of Vietnam, approving the Development Strategy of the Vietnam National Coal and Mineral Industries Holding Corporation Limited (VINACOMIN) to 2030 with a vision to 2045, the projected annual commercial coal production is expected to reach 35–40 million tonnes by 2030 [Prime Minister of Vietnam, 2025]. To achieve this target, underground coal mines must expand their production capacity by increasing mining depth and driving a greater number of development roadways. During roadway excavation, particularly in drilling, blasting, mucking, and haulage operations, large quantities of respirable dust are generated. These dust emissions significantly deteriorate underground air quality, reduce working efficiency, and pose serious occupational health risks to mine workers.

At the Khe Tam mining area of Duong Huy Coal Mine (VINACOMIN), the production development plan includes the construction of numerous new roadways with different cross-sectional dimensions to support future mining activities. Consequently, dust pollution in the heading face is expected to increase substantially unless effective ventilation and dust control measures are implemented. Therefore, investigating the mechanisms of dust dispersion and quantifying the influence of ventilation parameters on dust concentration are of considerable importance for the design and optimization of underground mine ventilation systems.

In recent years, numerous studies have investigated dust control technologies for underground coal mining. Studies conducted in Vietnam and worldwide have primarily focused on dust suppression using water spray systems combined with auxiliary ventilation

[Dinh Thi Thanh Nhan et al., 2021; Nguyen Van Quang et al., 2019] and dust extraction systems to reduce dust concentrations in working areas [Dao Van Chi et al., 2022]. International studies have further investigated a variety of dust control technologies, including water spray techniques for dust suppression [Nie, W et al., 2017], ventilation methods to control dust dispersion [Guo, L et al., 2020; Toraf , J et al., 2011], and coal seam water infusion to reduce dust generation at the source [Cheng, W m et al., 2012]. However, most existing studies have focused on mechanized mining faces or specific mining conditions. Because geological characteristics, ventilation layouts, mining methods, and coal properties vary considerably among mines, the applicability of these findings to other underground coal mines remains limited without appropriate calibration and validation under site-specific conditions.

To address this research gap, the present study develops a three-dimensional (3D) numerical model of the V5 transportation roadway at the -90 m level of Duong Huy Coal Mine and employs Computational Fluid Dynamics (CFD) to simulate the transport and dispersion of blasting-generated dust. Dust concentrations were evaluated at monitoring locations situated 1, 2, 4, and 6 m from the excavation face under seven ventilation airflow rates of 150, 300, 400, 500, 600, 700 m³/min. Based on the simulation results, the study quantitatively evaluates the influence of airflow rate on the spatial and temporal distribution of dust concentration and identifies the optimum ventilation airflow range for effective dust control. The findings provide a scientific basis for optimizing auxiliary ventilation design, improving underground working conditions, and enhancing occupational health protection in underground coal mines with similar mining conditions.

2. Physical Model Development

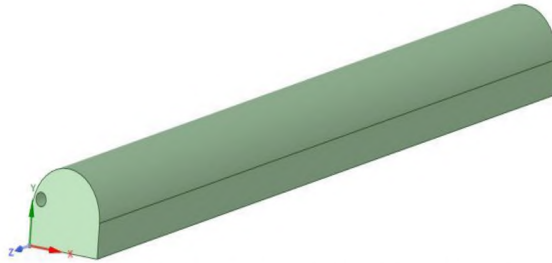


Fig. 1. Physical model of the V5 transport roadway at the -90 m level.

To investigate the influence of ventilation airflow rate on dust dispersion in a development heading, a full-scale (1:1) physical model was established based on the actual geometry of the mine roadway. The model has dimensions of 60 m in length, 4 m in width, and 3.5 m in height, accurately representing the geometric characteristics of the study area (Figure 1). Employing a full-scale model minimizes geometric scaling errors and preserves the aerodynamic characteristics of airflow as well as the transport behavior of dust particles, thereby providing simulation results that closely reflect actual underground mining conditions.

During the simulation, the dust source was assumed to emit particles at a constant rate of 0.0018 kg/s, representing dust generated during mechanized roadway excavation. The simulation duration was set to 900 s, which is sufficient to capture the complete evolution of dust generation, transport, dispersion, and the gradual stabilization of the dust concentration field throughout the roadway.

To evaluate the effect of ventilation conditions, seven airflow rates were investigated: 150, 200, 300, 400, 500, 600, and 700 m³/min. These airflow rates were selected to represent the range commonly encountered in underground coal mine development, from insufficient ventilation to enhanced ventilation conditions. For each simulation scenario, all other

boundary conditions and physical parameters were maintained constant to ensure that differences in dust distribution resulted solely from variations in airflow rate.

The simulation focused on several key performance indicators, including the temporal evolution of dust concentration, dust dispersion distance, three-dimensional spatial distribution of the dust concentration field, and the attenuation rate of dust concentration along the roadway. By comparing the simulation results under different airflow conditions, the study quantitatively evaluates the transport and dilution efficiency of ventilation airflow and identifies an appropriate airflow range for minimizing dust accumulation within the working area.

The developed physical model provides valuable insights into the interaction between ventilation airflow and dust particle transport, establishing a scientific basis for optimizing mine ventilation system design, selecting appropriate airflow rates, and improving dust control strategies in underground coal development headings. The findings also contribute to enhancing workplace air quality, reducing workers' exposure to respirable dust, mitigating the risk of occupational respiratory diseases, and improving the overall safety and sustainability of underground mining operations.

3. Mathematical Model for Airflow and Dust Transport

The continuity equation can be expressed as follows [N.A. Patankar et al., 2001; T. Ren et al., 2014]:

(1) The continuity equation for the gas phase in the gas–solid two-phase flow is given as follows:

$$\frac{\partial p}{\partial t} p_g + \frac{\partial}{\partial x_i} (p_g u_{ij}) = 0 \quad (1)$$

where t is the time; p_g is the gas density; u_{ij} is the time-averaged velocity; and i and j denote the coordinate directions in the Cartesian coordinate system.

(2) The momentum conservation equation is given as follows:

$$\frac{\partial p}{\partial t} (p_g u_i) + \frac{\partial}{\partial x_i} (p_g u_i u_j) = \frac{\partial}{\partial x_j} (\alpha_f T_{ij}) - \frac{\partial p}{\partial x_j} + F_{fs} + p_g g \quad (2)$$

(3) The turbulent kinetic energy (k) transport equation is given by:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[\mu + \frac{\mu_t}{\sigma_k} \right] + G_k - \rho \epsilon \quad (3)$$

(4) The turbulence dissipation rate (ϵ) transport equation is given by:

$$\frac{\partial(\rho \epsilon)}{\partial t} + \frac{\partial(\rho \epsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[\mu + \frac{\mu_t}{\sigma_\epsilon} \right] + c_{1\epsilon} \frac{\epsilon}{k} G_k - C_{2\epsilon} \rho \frac{\epsilon^2}{k} \quad (4)$$

where:

$$G_k = \mu_t \left[\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right] \frac{\partial u_i}{\partial x_j}, \quad \mu_t = \rho C_\mu \frac{k^2}{\epsilon}$$

Where, x_i and x_j are the Cartesian coordinates in the X , Y and Z ; u_i and u_j are the velocity components in the X , Y and Z (m/s); ρ is the air density (kg/m³); μ is the dynamic viscosity of the fluid; G_k is the production rate of turbulent kinetic energy due to the mean velocity gradients (%); μ_t is the turbulent (eddy) viscosity; k is the turbulent kinetic energy (m²/s²); ϵ is the turbulent dissipation rate (m²/s³); $C_{1\epsilon}$, $C_{2\epsilon}$, C_μ , σ_k , and σ_ϵ are empirical model constants

4. Results and Discussion

4.1. Effect of Airflow Rate on Dust Dispersion Throughout the Roadway and at the Breathing Zone (1.5 m Above the Roadway Floor)

Immediately after blasting, a large quantity of dust particles with different particle sizes was generated from the tunnel face and rapidly dispersed throughout the roadway under the influence of the ventilation airflow. The transport of dust particles was governed by several concurrent mechanisms, including airflow-induced convection, turbulent diffusion, gravitational settling, and the deposition of coarse particles. Among these factors, the

airflow rate played a dominant role in determining the transport velocity, dispersion distance, and residence time of airborne dust within the roadway.

Figures 2–7 illustrate the temporal evolution of dust dispersion distance throughout the entire roadway and at a height of 1.5 m above the roadway floor, corresponding to the workers' breathing zone. The simulation results indicate that the increase in dust dispersion distance did not follow a linear relationship but was accurately described by a second-order polynomial function, with coefficients of determination (R^2) exceeding 0.99 for all airflow conditions investigated. This behavior indicates that dust propagated rapidly during the initial stage immediately after blasting, followed by a gradual reduction in propagation rate as the airflow field approached a quasi-steady state and the effects of turbulent mixing, particle deposition, and dilution became increasingly dominant.

For all seven airflow-rate scenarios investigated ($Q = 150, 200, 300, 400, 500, 600$, and $700 \text{ m}^3/\text{min}$), the dust cloud expanded rapidly during the first few minutes after blasting, after which the rate of increase in dispersion distance gradually declined until reaching a stable value when the dust cloud had propagated throughout the entire 60 m roadway. This trend demonstrates that the interaction between airflow momentum and turbulent diffusion governs the transport dynamics of dust particles in underground mine roadways.

Specifically, at an airflow rate of $Q = 150 \text{ m}^3/\text{min}$, the dust cloud required approximately 300 s to propagate along the full 60 m length of the roadway after blasting. However, at the **worker's breathing zone (1.5 m above the roadway floor)**, complete dust coverage of the roadway was achieved only after approximately 500 s (Figure 2). This delayed response indicates that dust particles initially accumulated near the roadway floor before gradually being transported upward into the breathing zone through turbulent diffusion and momentum exchange between airflow layers. Consequently, under low-airflow conditions, workers remain exposed to elevated respirable dust concentrations for a prolonged period following blasting, thereby increasing the risk of occupational exposure and the development of dust-related respiratory diseases, such as pneumoconiosis.

These findings demonstrate that the airflow rate not only controls the rate of dust dispersion but also governs the residence time of respirable dust within the workers' breathing zone. Therefore, selecting an appropriate ventilation airflow rate is essential for reducing the post-blasting re-entry time, minimizing dust concentrations in the working area, and improving occupational health and operational safety in underground coal mining.

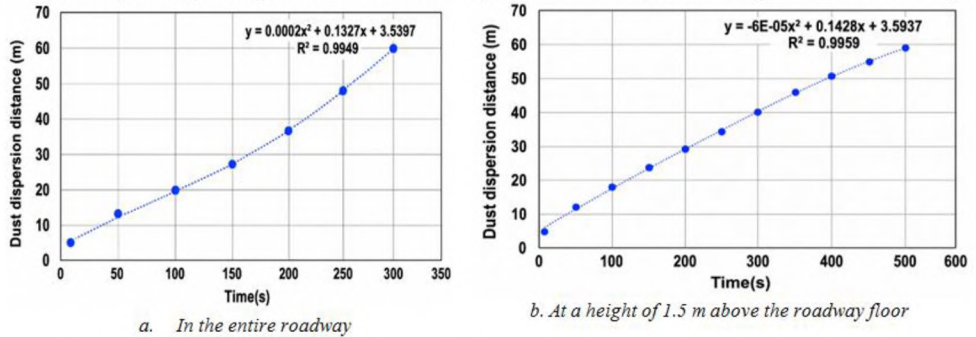


Fig. 2. Temporal and spatial dust dispersion in the roadway at an airflow rate of $150 \text{ m}^3/\text{min}$.

At an airflow rate of $Q = 300 \text{ m}^3/\text{min}$, the simulation results showed that the dust cloud propagated throughout the entire 60 m roadway within approximately 150 s. However, at a height of 1.5 m above the roadway floor, representing the workers' breathing zone, approximately 250 s was required for the dust cloud to fully disperse throughout the study area (Figure 3). The difference between these two propagation times reflects the combined effects of gravitational settling of coarse dust particles and the non-uniform vertical

dispersion of dust, resulting in a slower transport of dust within the breathing zone than in the overall roadway volume.

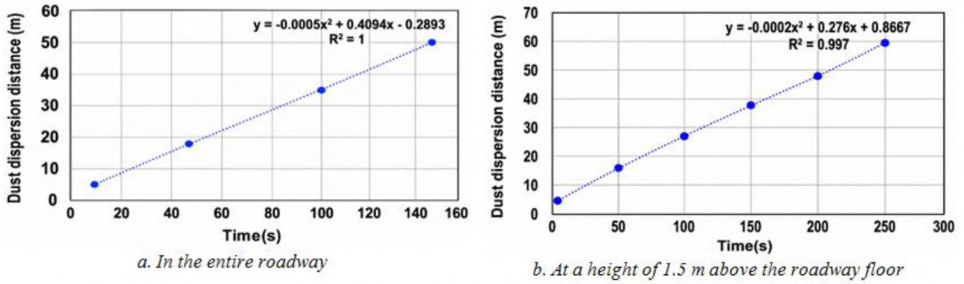


Fig. 3. Temporal and spatial dust dispersion in the roadway at an airflow rate of 300 m³/min.

When the airflow rate increased to 400 m³/min, the dust propagation time decreased significantly. Both throughout the entire roadway and within the workers' breathing zone, the dust cloud reached the full 60 m roadway length in approximately 150 s (Figure 4). This finding indicates that the airflow velocity at this ventilation rate was sufficient to generate strong convective transport, thereby reducing dust stratification and enhancing the downstream transport of dust particles along the ventilation airflow.

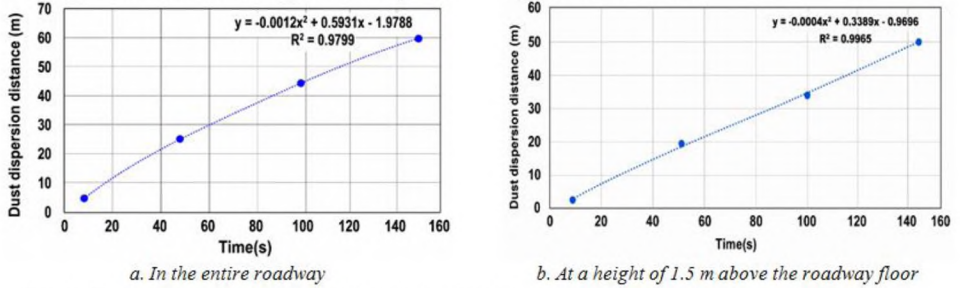


Fig. 4. Temporal and spatial dust dispersion in the roadway at an airflow rate of 400 m³/min.

For an airflow rate of Q = 500 m³/min, the dust propagation time throughout the entire roadway was further reduced to approximately 100 s, whereas the propagation time within the workers' breathing zone remained approximately 150 s (Figure 5). These results indicate that further increasing the airflow rate primarily enhanced the overall transport of the dust cloud throughout the roadway, while the improvement in dust transport within the breathing zone became less pronounced. This behavior can be attributed to the fact that dust motion in the breathing zone is governed not only by the airflow velocity but also by gravitational settling, particle deposition, and local turbulent flow structures.

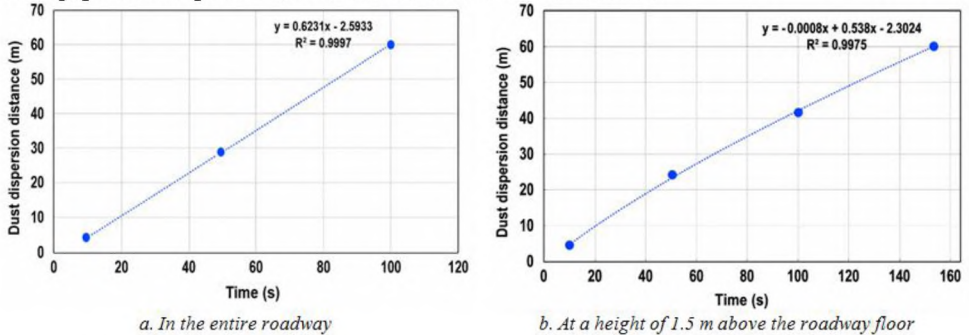


Fig. 5. Temporal and spatial dust dispersion in the roadway at an airflow rate of 500 m³/min.

A similar trend was observed at an airflow rate of $Q = 600 \text{ m}^3/\text{min}$. The dust cloud propagated throughout the entire 60 m roadway within approximately 100 s, whereas approximately 150 s was required for the dust cloud to reach the same distance within the workers' breathing zone (Figure 6). Although the higher airflow rate further enhanced convective transport, the reduction in dust propagation time within the breathing zone was negligible compared with that observed at $Q = 500 \text{ m}^3/\text{min}$. This result suggests that, beyond a certain airflow threshold, further increases in ventilation rate provide only marginal improvements in dust transport within the breathing zone, where particle motion is increasingly governed by turbulent mixing, gravitational settling, and particle deposition rather than airflow velocity alone.

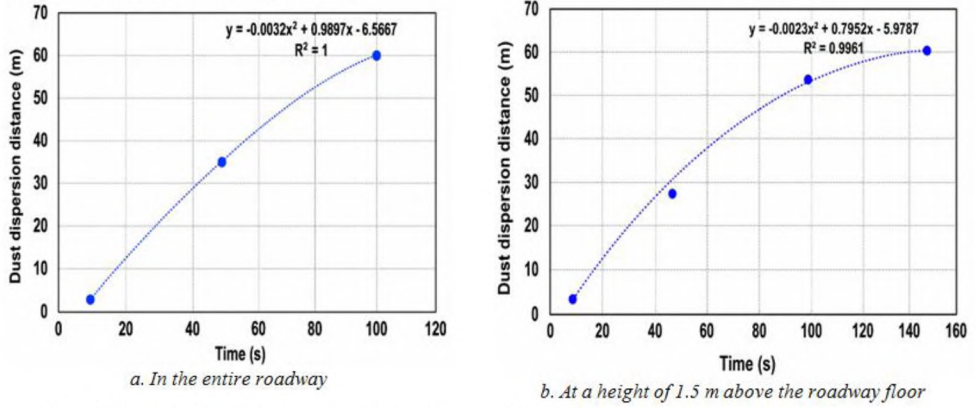


Fig. 6. Temporal and spatial dust dispersion in the roadway at an airflow rate of $600 \text{ m}^3/\text{min}$.

At an airflow rate of $Q = 700 \text{ m}^3/\text{min}$, the simulation results showed that the dust cloud propagated throughout the entire 60 m roadway within approximately 100 s, whereas approximately 150 s was required for the dust cloud to reach the same distance within the workers' breathing zone (Figure 7). Compared with the cases of $Q = 500$ and $600 \text{ m}^3/\text{min}$, the dust propagation time was reduced only slightly, indicating that the improvement in dust transport gradually diminished as the airflow rate continued to increase.

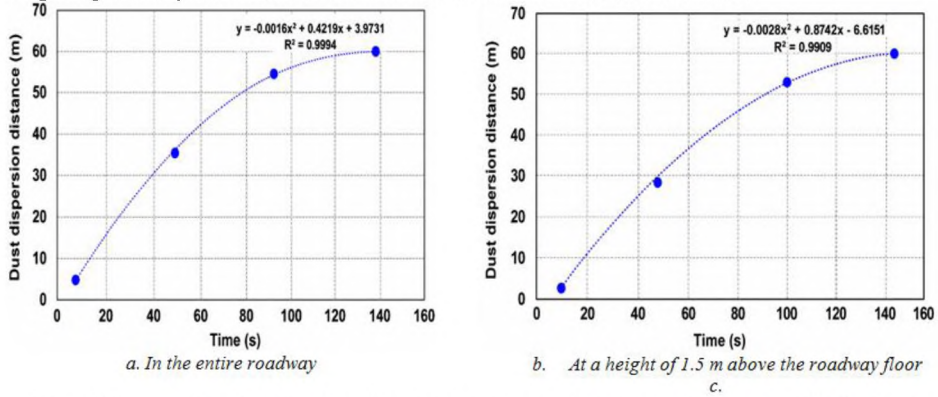


Fig. 7. Temporal and spatial dust dispersion in the roadway at an airflow rate of $700 \text{ m}^3/\text{min}$.

Overall, the simulation results demonstrate that increasing the airflow rate from 150 to $500 \text{ m}^3/\text{min}$ substantially reduced the dust propagation time, particularly throughout the entire roadway volume. However, further increasing the airflow rate to $500\text{--}700 \text{ m}^3/\text{min}$ resulted in only marginal improvements, indicating a clear phenomenon of diminishing returns. This finding suggests that the selection of an appropriate ventilation airflow rate should not be based solely on maximizing airflow capacity but should also consider the

balance between dust control performance, ventilation energy consumption, and practical operational requirements. Within the range investigated, an airflow rate of approximately 500–700 m³/min appears to represent the optimal operating range, as it significantly shortens dust propagation time while avoiding unnecessary increases in energy consumption with limited additional dust control benefits. These findings provide an important scientific basis for optimizing mine ventilation system design and developing effective dust mitigation strategies to reduce workers' exposure to respirable dust in underground coal mine development roadways.

4.2. Effect of Airflow Rate on Dust Concentration in the Working Area Near the Tunnel Face

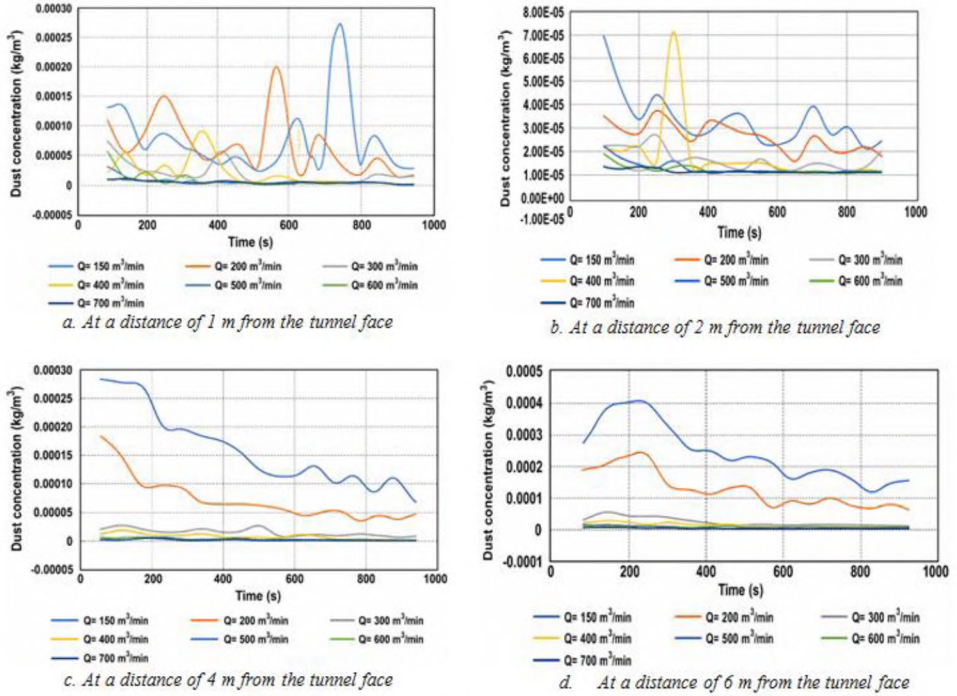


Fig. 8. Dust concentration at locations 1 m, 2 m, 4 m, and 6 m from the working face.

To evaluate the effectiveness of dust control in the working area of miners after blasting operations, four representative locations were selected at distances of 1 m, 2 m, 4 m, and 6 m from the excavation face along the roadway direction. These locations represent the breathing zone of workers during underground excavation activities. The variation in dust concentration was monitored over a period of 100–900 s after dust generation, corresponding to six ventilation flow rates of 150, 300, 400, 500, 600, and 700 m³/min.

The simulation results indicate that airflow rate has a significant influence on the maximum dust concentration at all investigated locations. At the location 1 m from the excavation face, the maximum dust concentration reached 230 mg/m³ at an airflow rate of $q = 150$ m³/min. When the airflow rate increased to 300 m³/min, the maximum concentration decreased to 54.75 mg/m³, corresponding to a reduction of approximately 76.2%. For airflow rates of 400, 500, 600, and 700 m³/min, the maximum dust concentrations were 69.5, 23.17, 46.13, and 8.07 mg/m³, respectively. Although the overall trend shows a decrease in dust concentration with increasing airflow rate, the local increases observed at 400 m³/min and 600 m³/min indicate that the airflow field was not completely stable, resulting in the formation of local recirculation zones where dust temporarily accumulated near the excavation face.

At the 2 m location, the maximum dust concentration decreased from 70 mg/m³ at 150 m³/min to 18.2, 70.4, 12.5, 8.63, and 2.63 mg/m³ corresponding to airflow rates of 300, 400, 500, 600, and 700 m³/min, respectively. The relatively high value observed at 400 m³/min further reflects the influence of turbulent mixing and dust transport processes in the near-source region.

At a distance of 4 m from the excavation face, the differences among ventilation conditions became more pronounced. The maximum dust concentration reached 280 mg/m³ at $q = 150$ m³/min, then decreased to 24.6 mg/m³ at 300 m³/min, 16.9 mg/m³ at 400 m³/min, and further decreased to only 4.88, 4.16, and 4.17 mg/m³ at airflow rates of 500, 600, and 700 m³/min, respectively. This demonstrates that when the airflow rate reaches 500 m³/min or higher, dust is transported more rapidly away from the working area, while the dilution process becomes more effective.

At the 6 m location, a continuous reduction in dust concentration was also observed. The maximum concentration decreased from 407 mg/m³ at 150 m³/min to 46.5, 24.2, 8.23, 6.45, and 8.76 mg/m³ corresponding to airflow rates of 300, 400, 500, 600, and 700 m³/min, respectively. Although the maximum concentration at 700 m³/min was slightly higher than that at 600 m³/min, the difference was insignificant. This phenomenon can be explained by the formation of turbulent vortices at the downstream end of the investigated region under excessively high airflow conditions, causing local redistribution of dust particles before they are continuously transported out of the roadway.

Overall, the results demonstrate that ventilation airflow rate is a key factor governing dust control performance in underground roadways after blasting operations. Within the airflow range of 150–400 m³/min, dust concentrations at the investigated locations remained relatively high throughout the period of 100–900 s, indicating limited dilution and transportation efficiency, which caused the workers' breathing zone to remain significantly affected by generated dust. In contrast, increasing the airflow rate to 500–700 m³/min resulted in a substantial reduction in dust concentration at all locations, with reductions exceeding 90% in many cases compared with the 150 m³/min condition. This confirms that increasing ventilation airflow not only enhances dust removal from the excavation face but also shortens the dust residence time in the working area, thereby significantly improving air quality and reducing workers' exposure risk to airborne dust.

The findings indicate that an airflow range of 500–700 m³/min represents a highly effective operating condition for the investigated roadway model. However, further increasing the airflow rate beyond this range may not provide a proportional improvement in dust reduction efficiency due to the effects of turbulent flow and dust re-entrainment phenomena. Therefore, the selection of an optimal ventilation airflow rate should consider both the airflow field characteristics and the actual geometric conditions of the roadway to achieve effective dust control while minimizing energy consumption.

5. Conclusions

This study employed a physical model combined with numerical simulation to investigate the effect of ventilation airflow rate on the dust dispersion characteristics after blasting operations in underground coal mine roadways. Based on the obtained results, the following main conclusions can be drawn:

- Dust dispersion in underground roadways is strongly influenced by the ventilation airflow rate. The spatial and temporal propagation of dust follows a nonlinear trend and can be well described by a second-order polynomial function of the form $y = ax^2 + bx + c$. Increasing the airflow rate enhances dust transportation and dilution processes, thereby significantly reducing the dust residence time in the working area.

- Dust control efficiency varies significantly with ventilation airflow rate. At airflow rates of 150–400 m³/min, dust concentrations in the miners' breathing zone remained relatively high throughout the investigated period (100–900 s), indicating limited dilution and dust removal capacity. When the airflow rate increased to 500–700 m³/min, dust

concentrations decreased significantly at all monitoring locations, satisfying the requirements for occupational environmental conditions according to current regulations.

- Increasing the airflow rate from 150 to 500 m³/min provided the most significant dust reduction effect, as demonstrated by the substantial decrease in the maximum dust concentration at locations 1 m, 2 m, 4 m, and 6 m from the excavation face. However, when the airflow rate was further increased from 500 to 700 m³/min, dust reduction efficiency continued to improve, but the rate of improvement became less pronounced, indicating that the ventilation system was approaching its optimal operating range.

- Among the investigated ventilation conditions, an airflow rate of 700 m³/min provided the highest dust control efficiency. The dust concentration in the working area in front of the excavation face was maintained below 10 mg/m³, while the dust residence time in the roadway was significantly shortened. This demonstrates that an appropriate ventilation regime can effectively improve air quality and reduce workers' exposure to airborne dust.

- The results confirm that adjusting the ventilation airflow rate is a highly effective technical solution for controlling post-blasting dust, even without the application of additional dust suppression measures such as water mist spraying, dust-binding agents, or dust filtration systems. These findings provide a scientific basis for selecting optimal ventilation conditions in the design and operation of underground coal mine roadways, contributing to improved working conditions, reduced risks of dust-related occupational diseases, and enhanced safety in underground mining operations.

- Future research should simultaneously consider the effects of airflow rate and other influencing factors, such as dust particle size distribution, ventilation duct location and diameter, local ventilation modes, and the integration of dust control technologies (high-pressure water mist systems, dust-binding additives, or dust extraction systems). This approach will contribute to the development of more comprehensive and highly efficient dust mitigation solutions under actual mining conditions.

References

1. Cheng W.-m., Nie W., Zhou G., Yu Y., Ma Y., and Xue J. (2012). Research and Practice on Fluctuation Water Injection Technology at Low Permeability Coal Seam. *Saf. Sci.* 50 (4), 851–856. doi:10.1016/j.ssci.2011.08.021
2. Dao Van Chi, Le Tien Dung, and Do Van Linh (2022). Research on the installation technology and evaluation of the dust control efficiency of wet dust collectors during roadway excavation at Vang Danh coal mine. *Mining Industry Journal*, No. 2, pp. 47–52.
3. Dinh Thi Thanh Nhan, Nguyen Van Thinh, and Le Manh Cuong (2021). Research on solutions for reducing dust concentration in the VM-L(7)-1 mechanized longwall at Mong Duong coal mine. *Journal of Mining and Earth Sciences*, Vol. 62, Issue 5a, pp. 54–61.
4. Guo L., Nie W., Yin S., Liu Q., Hua Y., Cheng L., et al. (2020). The Dust Diffusion Modeling and Determination of Optimal Airflow Rate for Removing the Dust Generated during Mine Tunneling. *Building Environ.* 178, 106846. doi:10.1016/j.buildenv.2020.106846
5. N.A. Patankar, D.D. Joseph (2001). Modeling and numerical simulation of particulate flows by the Eulerian-Lagrangian approach, *Int. J. Multiph. Flow* 27 (10) (2001) 1659–1684.
6. Nguyen Van Quang and Nguyen Van Thinh (2019). Research on solutions for reducing dust concentration and improving microclimatic conditions at excavation faces of Nui Beo coal mine. *Mining Industry Journal*, No. 2, pp. 60–64.
7. Nie W., Liu Y., Wang H., Wei W., Peng H., Cai P., et al. (2017a). The Development and Testing of a Novel External-Spraying Injection Dedusting Device for the Heading Machine in a Fully-Mechanized Excavation Face. *Process Saf. Environ. Prot.* 109, 716–731. doi:10.1016/j.psep.2017.06.002

8. Prime Minister of Vietnam (2025). Decision No. 625/QĐ-TTg dated March 17, 2025, approving the development strategy of Vietnam National Coal and Mineral Industries Holding Corporation Limited (Vinacomin) until 2030, with an orientation toward 2045. Hanoi.
 9. *Toraño J., Torno S., Menéndez M., and Gent M.* (2011). Auxiliary Ventilation in Mining Roadways Driven with Roadheaders: Validated CFD Modelling of Dust Behaviour. *Tunnelling Underground Space Technol.* 26 (1), 201–210. doi:10.1016/j.tust.2010.07.005
 10. *T. Ren, Z. Wang, G. Cooper* (2014). CFD modelling of ventilation and dust flow behavior above an underground bin and the design of an innovative dust mitigation system, *Tunn. Undergr. Space Technol.* 41 (2014) 241–254.
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