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Research Article

Performance Analysis of an Auxiliary Fan in Underground Coal Mine Ventilation Systems

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Abstract

Mine ventilation is a critical component of underground coal mining operations, ensuring the supply of fresh air and the removal of hazardous gases, dust, and heat. This study focuses on the performance analysis of an auxiliary mine fan in a duct system to understand the relationship between airflow, pressure, and system resistance. Key performance parameters, including static pressure, velocity pressure, and air velocity, were evaluated through experimental data collected from multiple mine scenarios. The study reveals that Mine B achieved the highest airflow of 5.03 m³/s and velocity of 10.0 m/s due to optimal duct diameter and pressure. The findings emphasise that controlling airflow by adjusting fan speed is significantly more energy-efficient than traditional throttling methods.

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1. INTRODUCTION

Underground coal mining involves hazardous conditions requiring strict safety measures, with ventilation being the most critical system for miner health and productivity. Ventilation removes contaminated air containing methane (CH4), carbon monoxide (CO), and coal dust.

Modern mines rely on mechanical ventilation because natural airflow is insufficient for deep workings. Auxiliary ventilation is specifically used for development headings and blind ends where the main airflow cannot reach. The effectiveness of these systems depends on the performance of mine fans, which act as the driving force for airflow. Inefficient fan operation leads to increased costs and compromised safety.

2. LITERATURE REVIEW

The study of mine fans has evolved from basic mechanical principles to complex simulations. Historically, the analysis of flow in networks was established by Cross (1936). Fundamental principles of subsurface ventilation and airflow distribution were further detailed by McPherson (1984, 1993). Modern research has identified that ventilation can account for up to 50% of total mine energy consumption, leading to a strong advocacy for variable speed drives (Wallace et al., 2015). Recent studies by Levin and Zaitsev (2018) and Yi et al. (2022) have highlighted the state-of-the-art developments and the application of Computational Fluid Dynamics (CFD) in mineral development.

Optimising these systems often involves genetic algorithms to design efficient ventilation networks (Lowndes & Yang, 2004). Furthermore, decentralised and nonlinear control of fluid flow networks has been explored to improve stability (Hu et al., 2003; Koroleva & Krstic, 2005; Koroleva et al., 2006). However, field performance often differs from laboratory results due to installation factors and system resistance (Brake, 2013). In specific regional contexts, such as the Chasnala Mines, planning for deep and gassy mines remains a complex challenge (Kishore, 2021). Comprehensive bibliographies of these advancements have been documented to track the evolution of mine aerology problems (Hundemann, 1979; Petrov et al., 1992).

3. METHODOLOGY

3.1 Data Collection

Experimental data were procured through a series of controlled procedures designed to simulate varied operational environments. To quantify the aerodynamic properties within the duct, a Pitot-static tube coupled with a digital manometer was employed to obtain precise measurements of static and velocity pressures across designated cross-sections. Volumetric airflow and localised air velocities at the system's intake and exhaust were monitored using a calibrated anemometer. Furthermore, a digital tachometer was utilised to synchronise these pneumatic readings with the fan's rotational speed, recorded in revolutions per minute (RPM).

3.2 Performance Evaluation Parameters

The operational characteristics of the auxiliary fan were defined by a rigorous assessment of fluid dynamics parameters. These included the Airflow Rate (Q), calculated via the area-velocity method (Q = A x V), and Static Pressure (Ps), which served as a measure of the total resistance encountered by the air stream. The kinetic energy of the flow was captured as Velocity Pressure (Pv), calculated through the application of Bernoulli's theorem to facilitate the analysis of pressure-volume relationships within the experimental setup.

4. Technical Evaluation of Fan Performance

4.1 System Types

Mine fans are categorised into axial flow and centrifugal designs. Axial flow fans, as used in this study, move air parallel to the axis of rotation and are suitable for high volume at low pressure.

4.2 Experimental Data and Field Observations

Based on the surveyed mine data (A, B, and C), the following results were obtained:

Parameter	Mine A	Mine B	Mine C
Duct Diameter (m)	0.6	0.8	0.7
Static Pressure (P_S) (Pa)	180	220	200
Velocity Pressure (P v) (Pa)	45	60	50
Calculated Velocity (m/s)	8.66	10.0	9.13
Airflow Quantity (m^3/s)	2.45	5.03	3.51

4.3 Losses due to System Resistance

Resistance is caused by friction between air and duct surfaces, bends, and leakage. The study found that "more resistance results in less airflow and higher energy requirements".

5. Human Resource and Safety Implications

5.1 Role of HRM in Ventilation

Human Resource Management (HRM) ensures that skilled workers are selected and trained for managing technical systems. HRM acts as the bridge between technical operations and safety protocols.

5.2 Training and Safety Practices

Training is vital for the correct use of instruments like anemometers and pitot tubes to avoid inaccurate readings that could lead to equipment failure or accidents. Safe behaviour, including following instructions and wearing protective equipment, is essential to prevent hazards in air pressure systems.

6. RESULTS AND DISCUSSION

6.1 Analysis of Fan Curves

The fan performance curve demonstrates a non-linear (approximately quadratic) relationship between airflow and pressure. Mine B showed superior performance due to its larger duct size (0.8 m) and higher velocity pressure (60Pa). **Acuña**

and Lowndes (2014) emphasised that energy consumption can be further minimised through optimised fan placement.

6.2 Efficiency and Energy Utilisation

A critical observation was the 68% variation between anemometer and Pitot tube readings, indicating potential measurement errors or uneven distribution. Energy utilisation assessment proved that throttling (closing the duct) is inefficient, while speed reduction is the most energy-efficient control method.

7. Scope for Improvement

7.1 Engineering Optimisation

Optimisation should focus on reducing friction by smoothing internal duct surfaces and using Variable Speed Drives (VSDs) instead of dampers to save energy.

7.2 Real-Time Monitoring

Modern systems should replace manual measurement with computer-connected sensors. This allows for immediate detection of pressure drops and quick decision-making during emergencies.

8. CONCLUSION

The analysis confirms that auxiliary fan performance is highly sensitive to system resistance and duct design. Optimal performance requires a balance between airflow and pressure, with Mine B serving as the baseline for efficient operation. For sustainable mining, the industry must transition to speed-controlled fan systems and real-time automated monitoring to ensure both safety and energy efficiency.

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