Application of ventilation management programs for improved mine safety

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ABSTRACT

The purpose of ventilation management systems is to ensure the health and safety of underground workers by creating and incorporating structured plans, procedures and processes on the day-to-day operations of the mine ventilation system. The application of ventilation management programs consists of audit, verification, and corrective action procedures to: (1) ensure adherence to regulatory standards, or to (2) return to compliance and safety standards when an upset condition arises. This paper describes how a ventilation management program can be developed and implemented to ensure regulation compliance, to increase safety, to improve operational efficiency and to reduce the operating costs of an operating mine. Two case applications are presented in this paper. The first case is presented to demonstrate use of a ventilation management program in response to a site inspection and audit, with follow-up application of corrective actions. The second case application describes how air quality conditions has been substantially improved with the development and implementation of a ventilation management program for an operating underground hard rock mine.

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1. Introduction

Mine ventilation systems must not only provide for the health and safety of underground personnel but also operate in compliance with regulatory bodies. Studious day-to-day management of the mine ventilation system is crucial to meet all the objectives of the ventilation system. A ventilation management system is used to provide, measure, and control the quantity and quality of airflow throughout the mine ventilation network. Ventilation management programs consist of an iterative framework, through which the mine ventilation department maintains the ventilation system in compliance with regulatory bodies and company policies. It consists of structured documents forming standardized procedures and guidelines for auditing the system and providing corrective actions when an upset condition arises, such that a safer and more efficient system is maintained. Proper implementation of a ventilation management program will result in significant benefits including increased operational effectiveness, increased safety, improved engineering efficiency, reduced appliance (fans, doors, regulators, ducting, etc.) maintenance costs and reduced energy costs. Quality management will allow mining operations to proactively apply mitigation techniques before environmental conditions underground become unsafe, thus shifting away from undesirable reactive practices. The case studies presented in this paper will demonstrate the direct benefits of a ventilation management program.

2. Ventilation management program structure

A quality management program is defined as a tool for organizations to meet performance expectations through the provision of quality assurance and control, and to offer a means to optimize performance though improved control of system processes [1,2]. A quality management program is supported by seven fundamental requirements, used to assess the company's ability to meet regulatory requirements as well as its internal policies: purpose, policy, planning, implementation, measurement, review and improvement. The ventilation management system consists of a series of documents which describe means of auditing and controlling the mine ventilation system in order to ensure the system meets all regulatory and safety requirements [1].

Five main document types form the structure of a ventilation management system: standards and guidelines, code of practice, procedures, work instructions and directives (Fig. 1). These documents provide guidelines for applying audit, verification and correction processes used to ensure the mine ventilation system operates within compliance standards.
The ISO 9000 Quality Systems Handbook defines work instruction, procedures and codes of practice [1]. Work instruction is defined as instructions that inform people what task to complete and when the completion of the task is needed. Procedures are defined as instructions that inform people how to do a certain task. Codes of practice are defined as constraints on how the processes in a business should be carried out in order for the result to be within the boundaries of regulating bodies.

The author has developed the framework of management programs for a specific for mine ventilation system [3]. The standards and guidelines constitute the foundation of the management program. This support documentation is a handbook providing a detailed description of the ventilation system, including all design and operational aspects of the ventilation network. The code of practice is a documentation that defines the minimum operating standards and action levels based on regulatory bodies and provides appropriate corrective and emergency action plans when an upset condition exists. Procedures are documentation that explains inter-departmental activities and each department's or individual's role in specific work procedures. Work instructions are documentation describing the process of a specific procedure and task, including who is involved, how to do the task, and what materials or supporting documentation is needed. Directives are documentation issued for any changes to the ventilation that will ensure the correct installation or change to any design, equipment, or condition. The author has implemented ventilation management programs in several mining operations, and notable mentions include system implementations in a potash mine and a uranium mine [4,5].

3. Execution of ventilation management program

The execution of a ventilation management program follows an iterative process, illustrated in Fig. 2. Management plans, which are carried out daily, is an audit of the state of the entire mine ventilation system. It includes detailed inspections of all components and appliances, pressure and flow surveys of the network and air quality surveys. Verification programs are used to assess the information collected from the management plans in order to verify if the ventilation system is in compliance and if it meets all defined objectives of the program. If the verification process indicates the system not to be in compliance, then action plans and ventilation directives are initiated to restore the system to compliance. Action plans and corresponding directives can also be directly launched in response to upset ventilation conditions or when problems are encountered during an inspection.

4. Opportunities and benefits

The easy to implement iterative framework of a ventilation management program (Fig. 2) allows mining operations to efficiently and consistently audit the mine ventilation system. Significant benefits can be gained from day-to-day management of the mine ventilation system. It ensures that: (1) the ventilation system performs according to design; (2) all ventilation appliances operate efficiently and economically; (3) an adequate air supply to all active workings is provided; (4) the mine atmosphere meets quality conditions; (5) compliance with all regulatory requirements is met; (6) safety is improved; (7) and improved system economics is achieved.

5. Case application 1

This case application is used to demonstrate routine use of the ventilation management program in an operating mine. In a work shift, an upset condition (inadequate flow supply) is encountered and actions are prepared and used to restore the ventilation system back into compliance. The application follows the steps presented in Fig. 2. A flowchart for the specific case is presented in Fig. 3. In preparation for a flow survey on a primary airway with an anemometer, the procedure and work instructions for anemometer operation, maintenance and calibration, are followed. Procedure and work instructions for traverse drift surveys are then observed during the flow survey (management plan). The results of the survey are audited (verification program) and found that the survey...
airflow volume does not meet the design requirement (code of practice). The deficiency in airflow constitutes an upset condition which needs to be addressed to permit a safe mine operation. Action plans are prepared and a ventilation design analysis, supported by network modeling, indicates the need for a fan to be installed in the primary airway. The fan is sized, with aid of work instructions for ventilation modelling. Check is made on the fan inventory list to verify if the fan model is available (standards and guidelines). The fan is prepared for installation using procedure and work instructions, including, fan blade pitch change and half-blading fans, if appropriate. A ventilation directive is issued for installation of the fan, with the following supporting documents (procedure and work instructions): fan transportation, bulkhead fan installation, and fan installation. Levels of responsibility, establishing individual roles for the required work, are listed in the ventilation directive. After installation, the fan operation is checked using procedure and work instructions for fan inspection, supported by a fan inspection sheet and fan survey. Verification of completion is then conducted using appropriate procedure and work Instructions. A flow survey on the primary airway is repeated after installation to verify if the airflow meets the design requirements.

Updates to the fan inventory list and to the fan accessories inventory list are made. A total of 10 procedure and work instructions were used to complete the particular task described in this case application. Decisions were also made with support from the company’s standard and guidelines and code of practice documents. The process enabled the mine to promptly and consistently return to compliance by restoring the airflow to design requirements.

6. Case application 2

A case application is presented in which air quality conditions have been substantially improved with the development and implementation of a ventilation management program for an operating underground hard rock mine.

A two-phase integration approach of the management program was successfully completed for the mine, the first phase involved regional leakage control, resulting in an increase in airflow volume in the main production blocks by 28% and the second phase involved improvements in local ventilation installations in the main production levels, resulting in substantial improvements in underground environment conditions (air quality, dust and heat). This permitted uninterrupted production with much improved safety, reduced re-entry times and lower costs. The underground mine employs sublevel stoping with backfill to mine a gold deposit. Stope blasting and mucking cycles due to excess concentrations of NO₂ (well above the limit of 3 × 10⁻⁶) limited the production rate and mobile diesel fleet. The mine utilizes a push ventilation system with a primary surface air fan installed on a dedicated fresh air raise. Fig. 4a presents the distribution of airflow through the dedicated fresh air raise prior to application of the management program. A detailed ventilation audit was conducted to assess the primary fresh air system prior to implementation of the first phase ventilation management program.

Over the years, prior to application of the ventilation management program, the mine had to limit the use of its available diesel fleet and also had to curtail development and production activities due to limitations in fresh air supply to the active levels (available 94 m³/s versus required of 118 m³/s). The mine also had to limit stope blasting and mucking cycles due to excess concentrations of NO₂ (well above the limit of 3 × 10⁻⁶). The fresh air system consisted of a surface fresh air fan of 2.13 m casing diameter and 1.27 m hub diameter. It had a 597 kW motor installed, operating at 1200 r/min. The fan was delivering 142 m³/s at a static pressure of 1.84 kPa. The brake power is 539 kW and the annual operating cost was $377,650. The fan operating point is shown in Fig. 5. With the fan delivering 142 m³/s, the flow reaching the active mining area was 94 m³/s; leakage was estimated at 33.6% (Fig. 4b). As previously mentioned, leakage occurred at raise connections to 7 mined-out levels, above the active mining levels.

As part of the ventilation management program execution, extensive work was conducted to reduce leakage by sealing off and shortcircuiting all bulkheaded raise connections to the 7 upper inactive levels. Leakage was reduced to 7.2% from 33.6% (Fig. 4b). Where level access was required, appropriate door locks were installed. With sealing off the raise connections, the surface fan delivered 130 m³/s at a static pressure of 2.38 kPa (Fig. 5). The brake horsepower was 502 kW and the annual operating cost per fan was $352,018. With the fan delivering 130 m³/s, the airflow reaching the active mining area was maintained at 121 m³/s, above the production based requirement of 118 m³/s. Leakage was estimated at 7.2%.

The reduction in air leakage to 7.2% from 33.6% permitted an overall annual savings in fan operating cost of $25,630 or a 7% reduction in operating costs. Even though the reduction in fan operating costs is relatively small, the operation now meets the airflow requirements at all active levels, being able to safely achieve and maintain full production activities. Having successfully improved the mine overall airflow conditions, the second phase of system implementation was initiated. This phase aimed at improving safety and air quality conditions in all production faces. First, a quality assessment of ventilation installations and airflows in all production stope access draw points was performed. To meet production requirements, 10 active faces must be ventilated at the mine. All access crosscuts to the sublevel stopes are ventilated with auxiliary ventilation. Face ventilation requires a flow of 9 m³/s per cross-cut, based on the production equipment utilized. Airflow surveys at all active faces indicated flow rates ranging between 5 and 7.4 m³/s, with 3 faces meeting the minimum flow requirements. The auxiliary fans are 1.22 m in diameter with 0.69 m hubs, operating with 22.4 kW motors and running at 880 r/min. Lay-flat ducts of same diameter are utilized.

Detailed inspections and surveys of the 10 duct installations classified the installation practices as ‘poor’, with much higher than desired static pressure losses along each duct column. Some fans were not correctly hung and duct-to-fan connections were very leaky. Several of the duct columns were not installed straight and had severely damaged sections. The fan operating point for one of the surveys is presented in Fig. 6. The system produced 7.4 m³/s at the face with the fan operating at 17 m³/s. Leakage was estimated at 57%. The fan total pressure was 0.72 kPa and the brake horsepower of 15.4 kW. The fan annual operating cost was $11,943. High diesel exhaust gas concentrations were measured at the faces due to insufficient dilution ventilation air volumes.

The auxiliary system installation was improved (duct column repaired, column straightened, connections tightened, etc.) to reduce resistance pressures and minimize leakage. The fan blade pitch angle was changed from 30° to 20°. The system produced 9.44 m³/s at the face with the fan operating at 12.75 m³/s (Fig. 6). Leakage was estimated at 26%, a reduction of more than half the original leakage. The fan total pressure was 0.52 kPa and the brake horsepower decreased to 8.77 kW. The annual operating cost for the single fan was reduced to $6,822, representing a reduction in cost by 43%. Having now achieved the required flow at the production face the mine could operate safely and in regulatory compliance.

Following this successful application of the ventilation management program, all other 9 draw point auxiliary fan installations
were similarly investigated and improved, resulting in annual savings in fan operating costs of approximately $93,000, which represents 58% reduction in operating costs. The successful application of the 2-phase ventilation management program resulted in overall annual cost savings of $118,650. More importantly, the mine is now operating safely and in compliance with regulations. The mine continues to incorporate the management program in its day-to-day production operations, resulting in increased safety, improved air quality, reduced post blast re-entry times, regulatory compliance and cost savings.

7. Conclusions

A ventilation management program provides mining operations an iterative process in which it can standardize day-to-day ventilation practices, audit the ventilation system and ensure compliance with regulatory bodies and company policies. It provides effective means for proper control and management of complex ventilation networks, resulting in significant safety, efficiency and economic benefits to the mining operation. In this paper, the structure and process implementation of a ventilation management program are presented. Day-to-day application of the ventilation management program ensures the mine operation meets all regulatory requirements and cares for the health and safety of all personnel working underground. Two case applications are presented to demonstrate the functionality of the management program and the safety, efficiency and economic benefits that can be realized by mining operations.

References


