A FRAMEWORK FOR INTEGRATING MINE VENTILATION OPTIMIZATION (MVO) WITH VENTILATION ON DEMAND (VOD)

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ABSTRACT

Air quality in underground mining operations can fluctuate significantly during the working day, but until recently the only way to ensure a mine had sufficient air quality was to over-ventilate and, with significant delay in adjusting the volume or direction of the airflow, working conditions were tolerable but rarely ideal. Underground ventilation management systems have been considered to achieve improved energy efficiency since at least 1995 in Canada. However, Mine Ventilation Optimization, (MVO) and integrating it with Ventilation on Demand (VOD) is only becoming more of a reality in the last seven (7) years. A systems approach to MVO takes into account all the elements from the point the power is distributed into the ventilation fans through to the actual quality and quantity of fresh air to the working face. Opportunities exist throughout the system for energy savings but not all of them are cost-effective. Depending on the application, these opportunities can be easily realized by properly sizing, streamlining, maintaining and operating the ventilation system using premium mine proven energy efficient components throughout.

Implementation of VOD is a key step in achieving the MVO objective. However, VOD is a concept, and it requires various tools, procedures, and strategies for cost-effective and operationally viable implementations. This paper provides a historical background in the development of VOD and provides a framework for proper and cost effective implementation. In addition, an optimized ventilation system will also allow increased airflow by reducing resistances and shock losses. This turn in would allow production target improvement, which could be an attractive objective compared to energy savings. Mine ventilation is the life support system of an underground mine, and contributes to sustainable development and corporate social responsibility goals assuring health and safety aspects of strategic planning. The proposed framework addresses implementing mine ventilation optimization integrating ventilation on demand as a vehicle for energy, health and safety improvement and overall productivity gains in the mining cycle efficiency while significantly reducing carbon footprint of a mine.

KEYWORDS

Mine ventilation optimization, Ventilation on demand, Systems approach, Energy efficiency, Sustainable development, Corporate social responsibility

INTRODUCTION

Without a total optimized ventilation system designed, installed, maintained, monitored and controlled, the incremental application of individual technologies on their own will only produce partial, possibly incremental and potentially non-optimal results. The primary objective of mine ventilation optimization (MVO) is three fold:

1. Reducing energy usage (or waste) and making a mine ventilation system energy efficient.
2. Improving mine air quality to meet regulatory standards and Duty of Care requirements
3. Improving productivity through better utilization of air flow and also improved workplace health and safety and subsequent return on investment (ROI)

An (MVO system would include the following strategic and inseparable design and engineering components:

1. Proper ventilation system design including proper location/ sizing of shafts, raises, doors which can lead to unnecessary flow and power requirements
2. Energy efficient primary and secondary fan system design and installation (primarily by reducing shock losses)
3. 3Minimizing leakage in ventilation ducts and control devices, such as mine doors and regulators (i.e., installation and ongoing system maintenance programs)
4. Integrated and efficient data collection and transmission systems
5. Innovative and intelligent instrumentation/measurement devices for control and real time monitoring
6. Effective tagging and tracking system for locating equipment and personnel at working faces
7. Ventilation System Simulation software with advanced visualization and integration of field data from survey or continuous and real time monitoring systems

From the basic concept (on-off control of local ventilation), VOD evolves to a series of strategically-sited monitoring stations equipped with sampling instruments, continuously monitoring and measuring air flow volume and velocity, temperature, oxygen levels, gases, particulates, humidity and, if it should occur, fire. This information is transmitted to a central control which analyses the data in real time and adjusts the fans, boosters, extractors and ventilation doors as per set objectives to achieve optimum health and safety along with environmental control for the whole mine. This could be extremely dangerous without any knowledge of where people are and the consequence of any such changes. With this level of monitoring only local VOD i.e., auxiliaries may be warranted

Although this simpler set-up has worked in Sweden, their ventilation systems can be considered modular and able to work independently – In Canada where up to 13 large fans work in parallel and series and interact throughout the system, control is far more complex. In subsequent VOD systems tagging and tracking of men and equipment has been added to environmental monitoring to further enable control of fans and louvers to provide the optimum fresh air based on equipment activity matched with air quality monitoring. The final component of complete VOD is the addition of ventilation modeling to validate ventilation changes

BACKGROUND AND OVERVIEW OF WORK TO DATE

Mine ventilation is a complex process and a systems approach must be applied for studying, designing and implementing relevant ventilation equipment, network, and controls. Mine ventilation combines surface and underground installations and the system varies from site to site depending on the orebody structure, geological conditions, climatic conditions and mining methods. Moreover, although stringent health and safety regulations determine the ventilation requirements and provide guidelines for strategic and operational planning, they can vary within and by country. An optimum mine ventilation system is critical for maintaining safe working conditions, producing optimum energy savings and optimum mine operational efficiencies in underground coal and metal mines.

Therefore, proper and efficient design, installations, maintenance and operations of the key hardware elements of a ventilation system including the ventilation ducting used to deliver fresh air from intake airways to the working face, energy efficient fans and properly designed and placed mine ventilation seals, doors and louvers (regulators) are key elements for achieving the desired overall mine operational efficiency.

One example of where poor practices impact systems efficiency would be auxiliary ventilation ducts at a local level. In general, an estimate of 20% leakage factor over extended distances in ventilation ducting has been observed by industry practitioners. This problem leads to the following operational conditions:

- The airflow must be increased by a 20% minimum to get prescribed fresh air to the working face
- The frictional resistance to the higher airflow increases by 44%
- The fan work/energy costs for the higher flow increase by 73% based on the Fan cube law

Similarly, primary fan design and installation problems could lead to additional shock losses, and proper remediation of this problem could be looked into while implementing an optimized mine ventilation solution. Energy management is a key component for achieving the overall operational efficiency. Ednie (2004) summarized the recent embracement by the mining and minerals industry of energy management towards greater efficiency. The Mining association of Canada (MAC) has identified energy management as one of the focuses of their drive towards Sustainable Development initiative.

Implementing energy-efficient airflow management in a mine ventilation system is the first step in energy management for an underground mining operation or a new underground mine design. Therefore, any achievement in energy efficiency for underground mine ventilation system will contribute to the overall goals of the mining industry.

Another example of a large complex underground mine ventilation system is the Grasberg block cave mine, owned and operated by P.T. Freeport Indonesia (PTFI). Duckworth et al (2004) presented a preliminary ventilation design for this mine. The annual estimated operating cost at the early stage for the main exhaust and the booster installation was $2,835,000 and for the matured stage the estimated operating cost is $3,411,000. These estimates used an assumed fan and motor efficiency of 75%. In comparison, LKAB operation mentioned earlier was operating over 88% efficiency. Therefore, any savings in the fan and motor efficiency for the Grasberg mine would lead to a significant savings. Some major Canadian operations (e.g., Creighton Mine, Vale) have significantly higher operating costs for auxiliary and primary fans.

With rapidly rising energy costs and universal concerns over health and safety, a low-grade air distribution system is no longer acceptable and the focus must be to achieve efficient low-friction, leak-free air delivery to the furthest points of the excavation while containing capital expenditure and energy consumption. Incorporating this approach in the MVO is a critical item. The many design considerations include:

- Surface and underground temperatures and humidity;
- blast fumes, air
- borne particulates, methane, carbon monoxide, hydrogen sulphide and other toxic gases such as diesel engine emissions.
- The complexity and permeability of the workings, the nature and number of the mobile plant such as drilling equipment, LHDs, etc., and the number and dispersal of mine personnel.

Since ventilation can account for 35–45% of a mine's energy consumption, the source and cost of the energy required to power the system is an important consideration. The designer may well invest in one of several software packages that perform the many calculations, layout planning and equipment selection. He may also call on experts in geophysics, mechanical and electrical engineering and other core disciplines. Before placing orders, references, ISO certifications and, fully-documented independent test results should be requested. Efficient ventilation relies on matching fans to duties and a reliable management system. The choice of fans will depend on the efficiency and reliability of the ventilation system installation and ongoing maintenance of the complete mine ventilation system.

Anisdah (2008) provided an example relating to auxiliary ventilation systems presenting a justification for low-leakage, low-friction ventilation ducting and direct impact in reducing power requirements. A well-installed duct line and fan equipment reduces associated shock losses and contributes to overall energy efficiency. The need for energy savings prompted research and practice in implementing VOD, which was first applied in tunnel ventilation projects in Europe which is evidenced in the subsequent section (Milestones). The section below lists key milestones on MVO and VOD.

Major Milestones

This section below provides a general timeline of development of ideas in VOD, and it is not an exhaustive review of progress-to-date in the area of VOD research, development, and implementation. Authors recognize that a considerable amount of work has been done, and more being pursued. A detailed review is beyond the scope of this paper.

1998–2006: VOD, known in Europe as ITV (Intelligent Tunnel Ventilation), was introduced and applied in many highway and train tunnels including Norway, Switzerland, France, Spain and Italy from 1998. The concept developed there was based on the same parameters which is driving the program in mining today. The drivers are:

4. Health and Safety optimization contributing to Corporate Social Responsibility (CSR)
5. Energy Savings optimization contributing to environmental and economic aspects of sustainable development
6. Productivity optimization contributing to economic aspect of sustainable development

In 2002 interest into VOD for Canadian mines re-emerged with a feasibility study. Creighton study – 11th US – initial base line was 2003 – study probably pre-dated that baseline, In 2005, two major Canadian mining companies visited several job sites in Norway and Sweden where the proven ITV systems were installed. As a result of these visits an ITV Pilot system was installed in a Canadian mine. There were complexities and difficulties in direct application of an ITV system, which is primarily a single level system, to a multiple level and more dynamic condition in the case of a mine wide dynamic ventilation on demand implementation. Subsequent R&D and industrial application gradually overcame these difficulties.

2002–Present: Understanding that further development work was required for industry level implementation of VOD, initiatives were created through several Canadian Government programs and agencies and other non-government research entities, all supported by industry: funded through Canada's Action Plan 2000 on Climate Change, the SDTC (Sustainable Development Technology Canada), and managed by CEMI (the Centre for Excellence in Mining Innovation) in Sudbury and other private and public sector partners to facilitate additional research and development for evaluating pilot applications, and expanding or enhancing existing VOD systems into reliable mine wide dynamic VOD (DVOD) integrated with an optimized MVO.

A preliminary study of VOD implementation in a Gold mine in Australia was reported by Tuck et al. Holden (2006). It was based on the simple concept of controlling air flow quantity (Q; m^3/s) as required rather than continuous supply of air to meet peak requirement. However, to achieve the objectives of this simple concept, a very complex level of real time monitoring and control system needs to be developed. Most of the current activities in VOD are limited to this level. Further applications in Australia is detailed in "Ventilation on demand at Gwalia Gold Mine by Cambridge & Kuruppa from the 9th International Mine Ventilation Congress, India 2009.

Another study reported by Hardcastle et al. (2006) into the feasibility and benefits of VOD addresses the early level implementation of VOD in a Canadian Mine. The next level of development in control and instrumentation hardware for real time monitoring were reported by Tonnos and Allen (2008), O'Connor (2008), and Allen and Keen (2008). In general, VOD was synonymous to the development of reliable control equipment and measuring devices for real time monitoring of air flow. A system level architecture approach was later presented by Bartsch et al. (2010) and Allen and Tonnes at the 13th US Symposium describing an attempt in VOD implementation at a system level, integrating to mine ventilation optimization.

Here, the top level goal of integrating ventilation modeling and simulation was proposed to be incorporated in real time with the mine-wide data collection for monitoring and control of air flow purposes. Detailed discussion of the process is beyond the scope of this paper. This proposed architecture has its merits, but its implementation requires a framework and the following section addresses this framework for integrating ventilation simulation with real time monitoring of various components of a mine ventilation system.

CONCEPT AND FRAMEWORK

Energy management is the key element in achieving overall operational efficiency for underground mines, and energy-efficient ventilation design is critical for maintaining safe working conditions in an underground coal or metal mines. Implementation of a number of design innovations for minimizing turbulence and flow separation ensuring streamlining of airflow and uniform loading on fan blades will minimize shock losses. However, the backbone of an efficient and optimized ventilation system depends on reliable and precise monitoring and control of mine ventilation parameters, which are air quality, quantity, and pressure. An optimized mine ventilation system is expected to provide a total solution for energy savings, for achieving safe, energy-efficient and a smaller environmental footprint through Intelligent Air Management.

It is a well understood and demonstrated fact that ventilation cost (30-40%), as documented by most mines, of total mine operating electrical cost where mines supplied by power grids and up to 70% where electrical costs are higher due to the use of diesel-powered generators, for example, Barrick Gold Mine in W. Australia and the Raglan Nickel Mine in N. Quebec. Power is also equal to the product of pressure loss (p in Pa) and air flow (Q in m^3/s):

$$P = \frac{p\,,Q}{1000} kW \tag{1}$$

Therefore, effective control of Q as needed (demand) will deliver the expected goal of optimized ventilation. This control is primarily achieved by variable frequency drives connected to fan motors for controlling motor speed (N rpm), which is directly to air flow (Q m^3/s). In addition, all areas of potential shock losses need to be investigated for minimizing the pressure loss through the use of advanced fluid flow modeling tools, such as Computational Fluid Dynamics (CFD).

This paper proposes the following framework as shown in Figure 1, in which emphasis is on for having a heuristics based module for linking to any existing ventilation simulation tool for producing an optimized solution. Moreover, an interface (MVO-VOD) is recommended for processing the acquired data and generating the heuristics required for inputs to the simulation model and the equipment control algorithm.

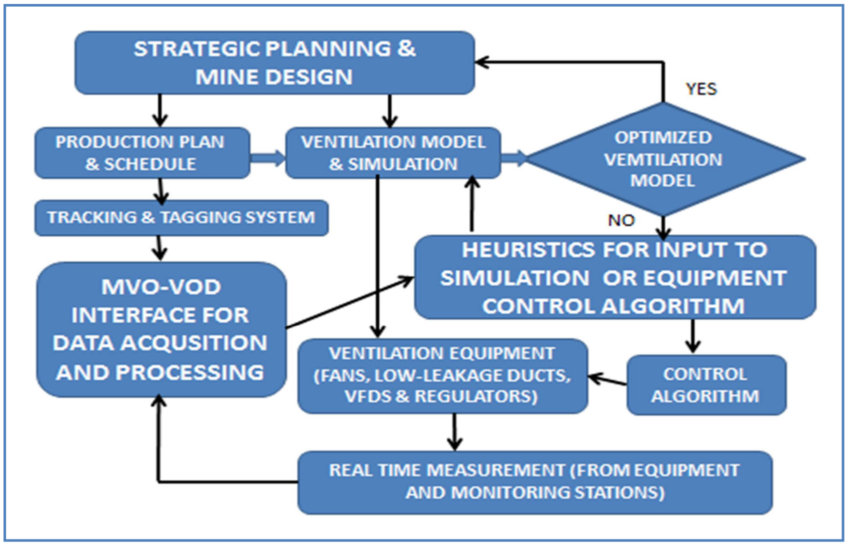

Figure 1 – A proposed framework for integrating MVO and VOD or known as DVOD (Dynamic Ventilation on Demand).

The framework's primary contribution is the heuristics module as addressed. This is where the engineering design and operational knowledge will be utilized to update the model and subsequent simulation to optimize a network. In case of a sub-optimal solution, relevant rules will fire the appropriate control algorithm for updating the operating points of the fans as necessary. The primary control mechanism is the control of airflow as required, as that is directly proportional (equation 1) to the power consumed. The most typical control mechanism is adjusting motor and fan speed by VFD drives, and these could be automated and remote application is also implemented in practice. This level of control and automation and implementation of Human Machine Interface is well established and reported by various researchers (Meyer, 2008). The success of the proposed heuristic module depends on the robustness of the MVO-VOD interface. Most of the current developments are focused in this area. The following section covers examples of current state-of-the-art in implementing this concept and the challenges to meet the global objective "Mine Ventilation Optimization integrating Ventilation On Demand"

IMPLEMENTATION EXAMPLE AND CHALLENGES

This section focuses on an example of a MVO-VOD interface. This area is most active by various players working with VOD implementations. Authors are working on utilizing the information collected to develop the intelligence required for a predictive model (work in progress). As mentioned earlier, a robust interface is the key for building the necessary intelligence for the heuristic module and the control algorithm. VOD as a concept is simple. However, it complexity increases with the nature and structure of a ventilation network and associated production objectives.

In order to provide an accurate, reliable, and effective VOD system, there needs to be an appropriate data transmission system to ensure that system parameters are reliably communicated to the master control system. There are many different data communication systems that can be used to provide this critical communications infrastructure. Depending on the existing communications infrastructure, a system can be devised using one of the following data transfer (or communication) systems:

Compatible Data Systems

1. Proprietary wired data system
2. Ethernet based data system
3. UHF/VHF Leaky Feeder communications system

4. Fiber Optic data system
5. Proprietary 900MHz mesh system
6. RS-232/RS-485 data system

Any of the above stated data systems can be used to report data back to MineBoss™ so that the system can make the necessary assessments needed to ensure proper ventilation control. In addition to providing the necessary data transmission systems, it is critical that the system provide diagnostics and notifications in case of component failures or damage. The MineBoss™ system provides warnings/alarms in cases of data failure and can be configured to provide warning/alarm notifications dependent on numerous system parameters such as: high gas concentrations, low air flow, low gas concentrations, high amperage, high temperatures, etc. As ventilation systems continue to advance, system diagnostics becomes more critical.

The primary challenge in integrating the condition monitoring results from the interface to design practice is the knowledge required for interpreting the data collected to develop heuristics for design modifications or fan system control. At present, it is done by the available experts, but there are no automated systems for knowledge extraction from the data collection for developing the necessary intelligence. Therefore, the authors recommend further research and development towards a "SMART" system.

CONCLUSIONS

This paper is primarily an overview of progress on VOD and integrating it with MVO, and presenting a framework for the proposed integration. The current driver for all the activities in this area is achieving energy efficiency, which can be obtained from two areas:

1. MVO with selection of high efficiency fans and motors, VFDs, and low-leakage and low-friction ductwork and with innovative design to minimize shock losses
2. VOD through intelligent and rugged measurement and monitoring instrumentation interfacing with control equipment.

However, the objective of a total system integration could be achieved through the heuristic module (as proposed in Figure 1) with emphasis on strategic planning, design, and engineering linking the interface and ventilation model and simulation tools for smart control of the energy-efficient ventilation equipment.

Mine ventilation is also a key health and safety component and is "life-support" to underground mine ventilation. Meeting this requirement satisfies achievement of sustainable development goals and meeting CSR objectives (Basu, 2012). A fully integrated and intelligent MVO-VOD system will not only help in engineering design and production management, it would also be of immense help in the case of a fire or other emergency management to direct the rescue operation and control the emergency by providing real time advice on mitigating the hazards.

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