Cost-saving strategies in mine ventilation

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https://doi.org/10.15834/cimj.2018.9

ABSTRACT Underground operation ventilation energy requirements constitute a significant portion of mine energy consumption (40–50%) and total energy costs (25–40%). In general, mine ventilation systems are energy inefficient; the author has found several systems that operate at efficiencies below 65%. This paper presents how engineering design principles can improve the performance and efficiency of ventilation appliances, resulting in reduced power consumption and operating costs. Case studies demonstrate that, by retrofitting ventilation appliances using proper engineering concepts, systems will operate at efficiencies well above common operating efficiencies, resulting in a drastic reduction in costs and base electrical and energy loads.

KEYWORDS Mine fans, Mine ventilation, Operating costs, Power consumption, Power costs, Ventilation economics, Ventilation efficiency, Ventilation energy

RÉSUMÉ Les besoins énergétiques nécessaires à l'aérage d'une exploitation souterraine représentent une part considérable de la consommation d'énergie d'une mine (de 40 à 50 %) ainsi que des coûts totaux liés à l'énergie (de 25 à 40 %). De manière générale, les systèmes d'aérage d'une mine sont loin d'être écoénergétiques ; l'auteur a trouvé plusieurs systèmes fonctionnant à des rendements inférieurs à 65 %. Cet article présente les principes de conception technique qui peuvent améliorer la performance et l'efficacité des systèmes d'aérage, entraînant une réduction de la consommation d'électricité et des coûts d'exploitation. Des études de cas montrent qu'en les rénovant à l'aide de concepts techniques adéquats, les systèmes d'aérage fonctionneront à des rendements bien supérieurs aux rendements habituels d'une exploitation. Ces rénovations donneront lieu à une réduction considérable des coûts ainsi que des charges électriques et énergétiques de base.

MOTS CLÉS aérage de mine, aspect économique de l'aérage, consommation électrique, coûts de l'électricité, coûts d'exploitation, efficacité de l'aérage, énergie nécessaire à l'aérage, ventilateurs de mine

INTRODUCTION

Increasing electricity supply problems in North America have encouraged an industry-wide evaluation of energy consumption, resulting in a more urgent emphasis on energy-efficient design and operation for all energy-consuming systems. Electricity is the main mode of energy supply and the mining industry is affected by the increasing cost of this commodity (Natural Resources Canada, 2017). Ventilation systems normally operate 24 hours per day, 365 days per year, and account for 25–40% of the total energy costs and 40–50% of the electrical consumption of a mine operation (De Souza, 2013). Ventilation engineers are under ever-increasing pressure to reduce ventilation energy consumption and be cost effective.

Experience has indicated that a large number of ventilation systems have efficiencies (defined as measured system performance/design system performance) of 65% or lower. Ventilation efficiency values fall within a wide range, ranging from 75% down to 10% (McPherson, 1993). Two forms of efficiency are considered: mechanical efficiency and ventilation system efficiency. Mechanical efficiency is the percentage of total energy input to a machine that is consumed by useful work and not wasted as useless heat. Ventilation efficiency is the percentage of total air that reaches production and other areas requiring ventilation. Factors affecting efficiency loss include air leakage and airway and appliance (fans, doors, air locks, check curtains, seals, line brattices, bulkheads, and regulators) design, sizing, and selection. Ventilation network systems are extremely complex; they must be carefully managed and optimized because they help guarantee the health and safety of the workers. An increasing number of engineers have been assessing the efficiency of their ventilation systems along with the operating performance and costs, efficiency, energy consumption, and associated environmental impact of their fan installations.

To improve the energy efficiency of mine ventilation systems, air use, or delivery components, many researchers addressed several of areas of development and the application of energy-efficient ventilation techniques, including

- ventilation modelling software to optimize ventilation systems (von Glehn, Marx, & Bluhm, 2008);
- economic sizing of main mine airways (McPherson, 1993; Bonnington & Young, 2008; De Souza, 2009);
- on-demand–based ventilation control (Belle, 2008; Acuna, Alvarez, & Hurtado 2016);
- intelligent active ventilation system control using live modelling and online monitoring (Gillies, Wu, Tuffs, & Sartor, 2003; Wu & Gillies, 2005);
- heating on demand (Wilson & De Souza, 2015) and cooling on demand (Marx, von Glehn, & Wilson, 2006);
- main fan energy management, with reduced air flows during selected peak and off-peak periods, resulting in a substantial reduction in peak power demand (Gundersen, von Glehn, & Wilson, 2005; du Plessis & Marx, 2008);
- retrofit of main fan installations (De Souza, 2013);
- variable-pitch axial fans that can be adjusted during periods of low activity (Hudson Products Corp., 2000);
- variable-speed drives to provide speed control, reduce mechanical stress on the fan and motor, and reduce energy consumption (Smith, 1999);
- impeller upgrading or replacement with a design impeller to suit the actual ventilation requirements, resulting in increased fan efficiencies (Fourie, 2012); and
- composite materials (lighter than steel, with higher resistance to fatigue) that limit fan impeller and blade failure.

The general solutions and tactics for improving ventilation systems with minimum capital investment presented in this paper come from four ventilation audits performed by the author. They target mechanical efficiency and the systematic efficiency of subsystems. Standard survey and design methods, covered in many ventilation handbooks (Hartman, Mutmansky & Wang, 1982; Burrows, Hemp, Holding, & Stroh, 1989; McPherson, 1993; De Souza, 2013), have been used in each of the case applications. By increasing the efficiency of the ventilation system components, a reduction in energy use could be achieved. With every kilowatt offset, a mine not only reduces overall costs, but lowers overall base electrical and energy loads, helping to reduce the strain on energy infrastructure.

CASE APPLICATIONS

Four case applications associated with engineering work conducted by the author are presented in the following sections to demonstrate how, by conducting detailed ventilation efficiency audits, simple low-cost solutions can be devised to increase efficiency, reduce power consumption, and lower operating costs. The low-cost solutions include improving the discharge cone (evase) design of exhaust fans; changing fan configurations from full blade to half blade; improving the installation of auxiliary ventilation systems; and controlling air leakage.

Case application 1: Main exhaust fan cone replacement

As part of an efficiency audit of a mine ventilation system, a main exhaust fan system was inspected and surveyed (Figure 1). The system consisted of two surface exhaust fans operating in parallel configuration. The fans were 2.1 m in diameter with a 0.8 m hub diameter. They had 261 kW motors operating at 1,170 rpm. The fan assemblage was well designed, with acceptable resistance pressure losses. The fans were exhausting 189 m^3/s total; however, they were fitted with very inefficient discharge cones. The cone losses were estimated to be 0.161 kPa. The fan velocity pressure—including losses—was estimated to be

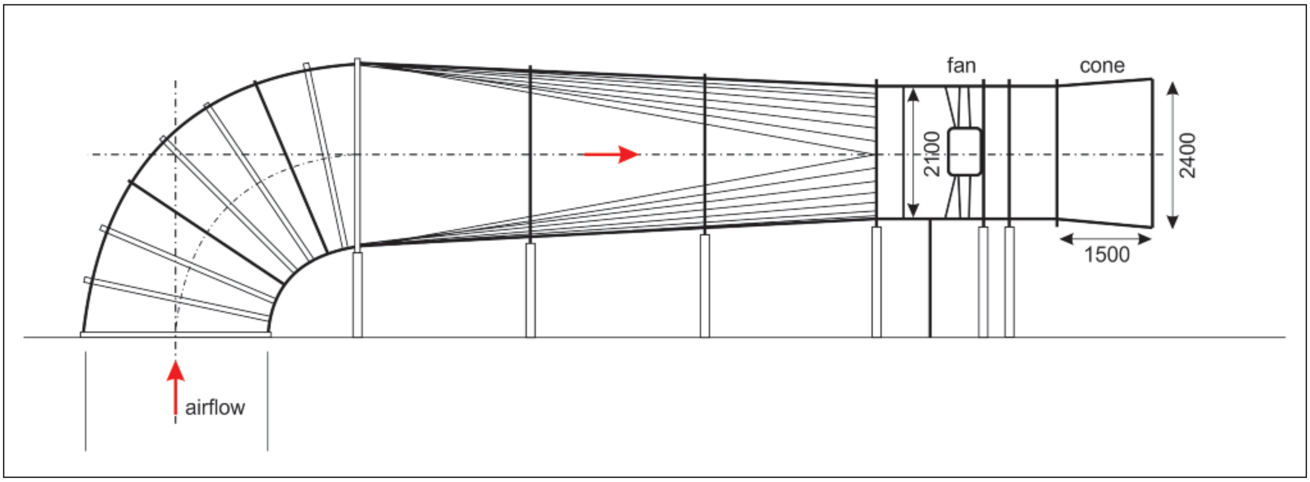

Figure 1. Simplified schematic of the main exhaust fan system

0.41 kPa and the fan total pressure was estimated to be 1.9 kPa. The operating power per fan was estimated to be 230 kW.

A simple retrofit was proposed, in which the existing exhaust discharge cones were replaced with a more efficient design. An ideal cone would provide gradual expansion of the airflow, reducing the shock loss experienced by the airstream and the exit loss. The ideal cone would also have a taper angle of approximately 6.4°. Conventional cone design methodologies, covered in many ventilation handbooks (Hartman et al., 1982; Burrows et al., 1989; McPherson, 1993; De Souza, 2013), were used to size the new cone. The existing cones were 1.5 m long with a 2.4 m outlet diameter, whereas the proposed cones were 4.3 m long with a 3.05 m outlet diameter. Using the same flow volumes for the retrofit, the cone losses were estimated to be 0.149 kPa. The fan velocity pressure—including losses—was estimated to be 0.25 kPa and the fan total pressure was estimated to be 1.74 kPa. The operating power was determined to be 211 kW per fan.

The total operating power savings are thus 38 kW and the annual operating cost savings are C$37,330, based on a power cost of $0.112/kWh. Despite only representing a 6% savings, a net present value analysis on the $60,000 investment to construct and install the new cones with a discount rate of 10% estimated a payback on year two and an internal rate of return of 57.9%. This indicated a very financially attractive project, and it was successfully implemented by the mine.

Case application 2: Booster fan blade configuration change

A ventilation survey was conducted on a set of underground fresh air booster fans installed in a bulkhead and operating in parallel in a large-opening mine. In general, large-opening mines have low system resistance and thus require relatively low static pressures. The fans were high-pressure units; however, because of the low system resistance, they operated at a relatively low efficiency of 46.5%.

The full-blade booster fans were 1.67 m in diameter with a 0.66 m hub diameter. They had 112 kW motors installed, operating at 1,200 rpm and a blade setting of 20° (Figure 2). The fans were properly fitted with screens, inlet bells, backdraft dampers, and cones. Conventional ventilation survey techniques, which are covered in many ventilation handbooks (Hartman et al., 1982; Burrows et al., 1989; McPherson, 1993; De Souza, 2013) were used to determine the fan pressure and flow. Survey results indicated a flow of 70.8 m^3/s per fan and a total pressure of 0.72 kPa. The fans operated at a brake power of 110 kW and had an annual operating cost of $150,000.

As previously indicated, the fans were high-pressure units that do not operate efficiently in relatively low resistance systems. To improve fan operating efficiency without incurring any investment costs, a half-blade configuration was proposed. By operating the fans with a half-bladed impeller and a blade setting of 22° (Figure 3), the fans would supply the same required flow with an increased efficiency of 59.5%. The brake power would be reduced to 85.9 kW per fan and the overall annual operating cost would be reduced to $117,470, representing a 22% decrease in energy operating costs.

This recommendation was successfully carried out by the mine and, following this accomplishment, additional operating fans were modified to half-blade configurations, resulting in substantial savings in ventilation operating costs. When adding new fans to the mine, lower pressure fans were properly sized to operate efficiently and conform with the lower system resistance.

Case application 3: Auxiliary ventilation installation improvement

To improve air quality conditions at production faces in an underground hard-rock mine, a quality assessment of ventilation installations was performed in all of the

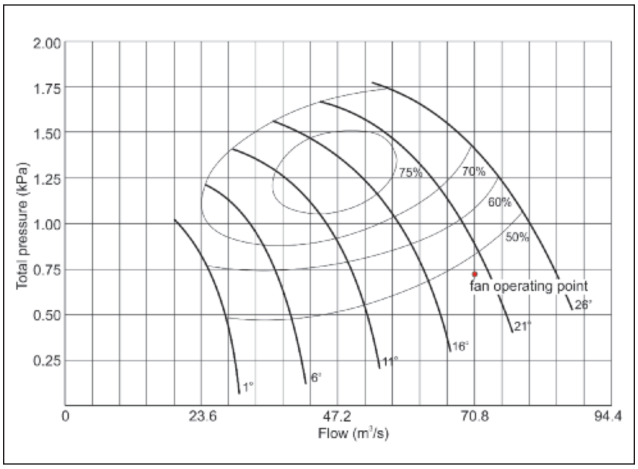

Figure 2. Fan operation in full-blade configuration

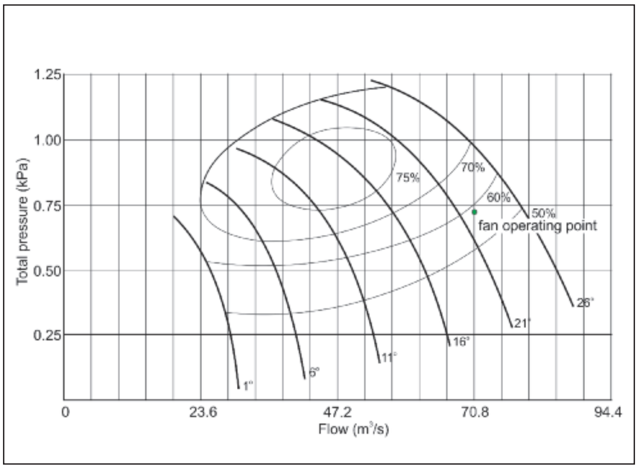

Figure 3. Fan operation in half-blade configuration

production stope access drawpoints on a mining block. Longhole stoping is used to mine the orebody and level mucking accesses are ventilated with auxiliary ventilation. Face ventilation requires a flow of 9.4 m^3/s per crosscut, based on the production equipment used and provincial regulations. Flow surveys at all active faces indicated flows ranging between 4.7 and 7.6 m^3/s, with only three faces meeting the minimum flow requirements. Typical auxiliary fans were 0.965 m in diameter with 0.686 m diameter hubs, and had 56 kW motors operating at 1,780 rpm. Lay-flat ducts with the same diameter as the fans were used.

Detailed inspections and surveys of the installations showed poor duct installation practices, with much higher than desired static pressure losses along each duct column. Fans were not properly hung and duct-to-fan connections leaked noticeably. Severely damaged duct sections were noted in most installations.

The fan operating point for one of the surveys is presented in Figure 4. The system produced 7.28 m^3/s of flow at the face with the fan operating at 17.04 m^3/s. The duct diameter was 1,219 mm and the column length was 304.8 m. Leakage was determined to be more than 57%. The fan total pressure was 1.356 kPa, the brake power was 42 kW, and the annual operating cost was $29,344.

The auxiliary system installation was improved (column straightened, connections tightened, and duct column repaired) to reduce shock losses and minimize leakage, resulting in a decrease in the amount of power needed by the fan. The fan blade setting was adjusted accordingly and the system now produced 9.53 m^3/s of flow at the face, meeting production requirements, with the fan operating at 11.64 m^3/s (Figure 4). Leakage was calculated at 18%, the fan total pressure was 0.83 kPa, and the brake power decreased to 21 kW. The annual operating cost for the single fan was reduced to $14,362, representing a 51% cost reduction.

Following this successful system improvement, the additional existing nine drawpoint duct installations on this mining block were similarly improved, with annual fan operating cost savings of approximately $180,000, representing a 52% reduction in operating costs. The mine also adopted a proposed management program with appropriate procedures for the sizing, selection, installation, inspection, and maintenance of all future, planned, and currently operating auxiliary systems.

Case application 4: Ventilation system leakage control

A detailed survey was conducted in an underground hard-rock mine to assess the economic efficiency of the mine ventilation system. The mine uses a push system with primary surface fresh air fans installed on a dedicated raise. Based on the operating diesel fleet, overall underground flow requirements were estimated to be 220 m^3/s.

The fresh air system consisted of two surface fresh air fans operating in a parallel configuration. The fans were 2.6 m in diameter, with 1.55 m hub diameters, and 448 kW motors operating at 710 rpm. Each fan was delivering 193.5 m^3/s of flow at a total pressure of 1.69 kPa. The brake power was 410 kW and the annual operating cost per fan was $287,200. The fan operating point is shown in Figure 5.

With a combined fan flow delivery of 387 m^3/s, the flow reaching the active mining area was 224 m^3/s. Leakage was calculated to be 42%. Leakage occurred at raise connections to 15 mined-out levels above the active mining levels. Extensive work was conducted to reduce leakage by sealing off and shotcreting the bulkhead raise connections to the 15 inactive levels. Where level access was required, appropriate doors were installed. Once the raise connections were sealed off, the surface fans were modified to operate at a 22° blade setting. Each fan was now delivering 125 m^3/s of flow at a total pressure of 0.83 kPa (Figure 5). Despite a

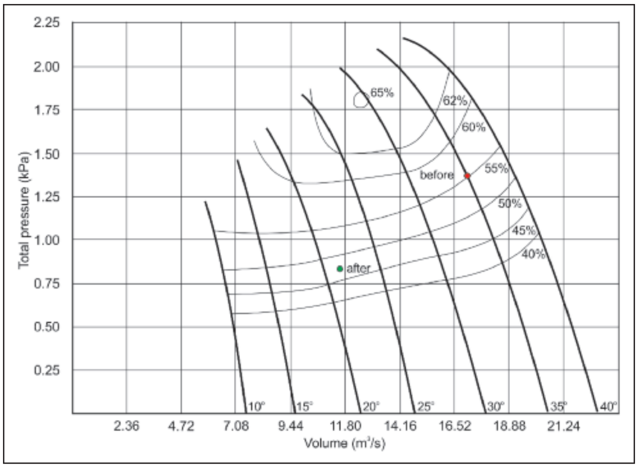

Figure 4. Fan operating points before and after system installation improvement

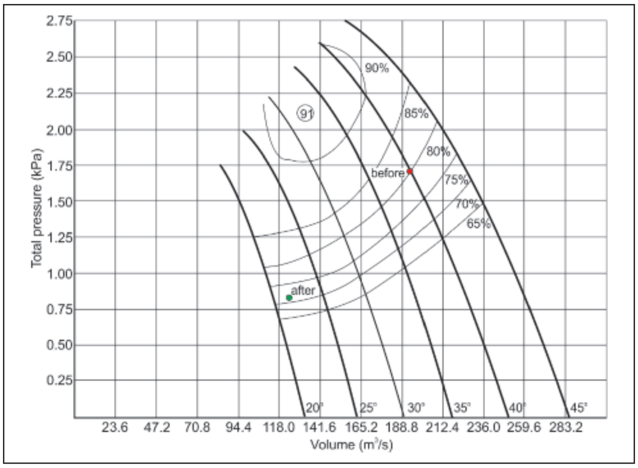

Figure 5. Fan operation before and after leakage control

drop in fan efficiency, the power requirement of the new duty point was 145.7 kW and the annual operating cost per fan decreased by 64% to $102,120.

With both fans now delivering a combined flow of 250 m^3/s, the flow reaching the active mining area was maintained at 224 m^3/s. Leakage was estimated to be 9.9%, which permitted an overall annual fan operating cost savings of $370,160, representing a 64.4% reduction in operating costs.

DISCUSSION

The continuous operation of a well-designed and managed ventilation system is vital to mine production activities and mine personnel health and safety. The mine ventilation system must be continuously and stringently managed to ensure the system meets all regulatory requirements and company policies and cares for the health and safety of mine personnel.

The mine ventilation system is a continuously changing and evolving system. Upset conditions will occasionally occur but should be promptly resolved for the system to function properly and according to design.

Those managing the mine ventilation system must have fundamental engineering training in ventilation and have good comprehension and control of the mine ventilation network. Ventilation management by untrained and inexperienced personnel can result in serious consequences when the system becomes ineffective.

It is important to have well-trained and experienced personnel managing the ventilation system to be able to properly resolve an upset condition because ventilation personnel must be able to evaluate the mine ventilation system, determine and locate any problems, understand the causes of each problem, find a solution, and promptly and efficiently correct those problems.

Four case studies have been presented to demonstrate how on-site engineering assessments identified the causes of certain issues, how solutions were derived from the investigations, and how simple, low-cost engineering solutions were implemented to successfully resolve these issues (see a summary in Table 1). The ventilation operations were returned to compliance, permitting the mines to safely resume production activities.

CONCLUSIONS

Ventilation is recognized as one of the main sources of electricity consumption within the mining industry; consequently, the optimization of ventilation systems should be a ventilation engineer's top priority. Mechanical efficiency of fans and ventilation efficiency must be considered, as discussed in this paper. Other important factors are actual air usage and considerable effort put towards demand-based ventilation. Even though ventilation systems can be very complex engineering systems, by using proper engineering concepts of fluid physics and flow, the efficiency of the individual components and the overall efficiency of the system in delivering air to the required workplaces can often be improved. Depending on the mine, this can result in moderate to appreciable reductions in overall costs and base electrical and energy loads. The four case studies conducted by the author demonstrate how simple solutions can be devised to increase efficiency, reduce power consumption, and lower operating costs. Some of the savings were simply due to the correction of inappropriate designs or system degradation caused by poor maintenance.

Table 1. Summary of case study benefits

	Before	After
Case application 1: Main exhaust fan cone replacement		
Total flow (m^3/s)	189	189
Fan total pressure (kPa)	1.9	1.74
Operating power per fan (kW)	230	211
Annual operating cost savings ($)	37,300	
Payback period (y)	2	
Case application 2: Booster fan blade configuration change		
Total flow (m^3/s)	70.8	70.8
Fan efficiency (%)	46.5	59.5
Brake power (kW)	110	85.8
Annual operating cost ($)	150,000	117,470
Increase in fan efficiency (%)	21	
Decrease in operating costs (%)	22	
Case application 3: Auxiliary ventilation installation improvement		
Fan flow (m^3/s)	17.04	11.64
Face flow (m^3/s)	7.28	9.53
Leakage (%)	57	18
Fan total pressure (kPa)	1.356	0.83
Brake power (kW)	42	21
Annual operating cost ($)	29,344	14,362
Annual cost savings ($)	180,000	
Decrease in operating costs (%)	51	
Case application 4: Ventilation system leakage control		
Flow per fan (m^3/s)	193.5	125
Fan total pressure (kPa)	1.69	0.83
Brake power (kW)	410	145.7
Flow delivered by fans (m^3/s)	387	250
Flow delivered underground (m^3/s)	224	225
Leakage (%)	42	9.9
Annual operating cost per fan ($)	287,200	102,120
Annual cost savings ($)	370,160	
Decrease in operating costs (%)	64.4	

An earlier draft of this paper was published in the Proceedings of the CIM 2015 Convention, prior to undergoing the CIM Journal *peer-review process.*

This paper was reviewed and approved for publication by the Maintenance, Engineering and Reliability Society of CIM.

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