

Ventilation Challenges Facing the Metalliferous Sector

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ABSTRACT

The underground metalliferous mining industry continues to change under the influence of many factors including, to name a few, new mining techniques and equipment, new approaches to risk management, more stringent safety and health standards, new employment practices and orebodies become deeper and often lower grade. In addition, the same technological revolution and plummeting cost of technology that has brought the GPS, smart phones and digital cameras to the general population is also working its way through the mining industry impacting on communications, automation and process control as well as introducing major efficiency and productivity dividends. However, not all factors are positive including, in particular, the issues of carbon costs and electrical power. This paper explores some of the trends affecting ventilation in hard rock mines, some of the existing and likely future challenges and some of the potential future solutions to these issues.

INTRODUCTION

'Futurologists' and 'think tanks' have a poor track record for gazing into even a scientific crystal ball, if such exists, so that predicting the future of underground hard rock mine ventilation is a risky activity for any author. However, there are four approaches that could potentially be used to do so:

- an examination of the trends in hard rock mine ventilation in recent years, on the basis that extrapolating past trends provides at least some insight into future trends
- a review of recognised current problems and weaknesses in hard rock mine ventilation on the basis that our profession must face up to known problem areas at some point
- a review of proposed changes in personal exposure levels for atmospheric contaminants on the basis that these will probably flow through into ventilation requirements in the future
- a review of global national regulators' current research priorities relating to ventilation on the basis that these must be indicators of the key concerns of (or opportunities for improvement seen by) the regulators.

Each of these is discussed in turn.

TRENDS IN HARD ROCK MINE VENTILATION IN THE PAST 15 YEARS

Brake (2013) recently summarised key changes affecting hard rock ventilation practices in Australia over the past 15 years as being:

- Larger and more powerful diesel equipment and the growth in the number and engine size of light vehicles have increased airflow requirements.
- Changes in approach to ground support have meant more development faces need to be available, and ventilated, for a development crew at any time.

- The need to ventilate multiple headings has led to the use of large auxiliary duct and fans with multiple offtakes with numerous management issues.
- The mobility of the underground mining fleet has resulted in air being reused by linking ventilated workplaces in series with many mines now being ventilated as a single 'mega' series circuit.
- In smaller mines, the surface decline is the only intake, so the total mine airflow is limited by the capacity of the decline.
- This trend away from 'one pass' (parallel) ventilation to series ventilation has reduced the ability for persons to escape past a fire, or products of combustion, by using a parallel escape route.
- The duty of care towards emergency workers has meant it is no longer acceptable to risk emergency workers lives (eg mine rescue teams) to rescue trapped workers.
- Developments in remote operation of LHDs and in blasting technology have allowed mining methods to develop in which stopes do not have any exhaust (return) but are open at top and bottom and create major short-circuits.
- The increased size of development has meant that ventilation controls need to be large and expensive and are time-consuming to install and maintain. In many cases, ventilation controls are not being installed at all where they would have in the past, resulting in short-circuiting, or are poorly installed, resulting in excessive leakage.
- Reductions in allowable personal exposure levels for respirable crystalline silica dust and a growing awareness and increased regulatory focus on the health impacts of diesel particulate matter are impacting on airflow allowances, with the design value increasing from typically 0.04 m³/s per kW rated diesel engine power in

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the late 1990s to 0.05 m³/s per kW (based on larger diesels only) to the recently recommended value of 0.10 m³/s per kW (Western Australian Department of Mines and Petroleum, 2013).

- The change from eight hour shifts to 12 hour shifts has reduced many atmospheric contaminant limits (eg time weighted averages, TWAs).
- The reduced cost of handheld electronic gas sensors and the increase in the number of gases that can be measured has changed re-entry procedures after blasting.
- The very high usage of turbo-chargers on underground diesel engines has resulted in a range of additional precautions to prevent and/or ameliorate the impact of engine fires, including use of aqueous film forming foams (AFFF) systems on all, or at least larger, diesel engines.
- The trend towards deeper mines has resulted in a substantial increase in installed mine cooling (refrigeration) capacity.
- There has also been a trend to installing underground mines beneath existing or completed open cut operations. In some cases, problems have occurred with recirculation of air between the mine exhaust and intake, or temperature inversions associated with the depth of the ventilation shaft collars within the open cut. Similar problems with recirculation are common where two portals (ultimately intake and exhaust) are established within the same box cut.
- There is substantial interest in the concept of 'ventilation on demand'.
- Developments in personal computer technology and software for solving mine ventilation problems has meant that more ventilation design options can be investigated, and this includes not only airflow engineering, but also gas analysis, re-entry calculations after blasting, temperature and cooling investigations and fire and explosion modelling.

RECOGNISED CURRENT SAFETY CONCERNS IN HARD ROCK MINE VENTILATION

A recent Western Australian Safety Bulletin (Western Australian Department of Mines and Petroleum, 2011) highlighted a number of current problems with ventilation in hard rock mines ('particularly in the lower level workings of decline mines ... associated with excessive temperatures, use of diesel equipment and dispersal of fumes after blasting').

Contributing factors were stated as being:

- *inadequate planning and scheduling resulting in the main return shafts and airways being too far behind the decline and level development*
- *electrical infrastructure not properly planned to provide an adequate power supply for multiple fans*
- *fan characteristics not properly assessed for the diameter and length of ventilation ducting required*
- *inadequate consideration of the regulatory requirements for ventilation standards at truck loading stockpiles in declines and on operating levels*
- *shift supervisors not aware of ventilation standards with regard to velocities and quantities of air*
- *lack of appropriate equipment to monitor blasting fumes and noxious gases*
- *use of single fans to ventilate multiple headings.*

The Inspectorate reminded mine operators in Western Australia of three items in particular:

- *Where the WB exceeds 25°C at any workplace, at least 0.5 m/s must be provided at that workplace (Western Australian regulation 9.15(3)(a))*
- *There must be sufficient air provided at truck loading places for both the loader and the truck, even if the truck is only 'idling' or not there for a significant duration*
- *Loaders and trucks used for loading at stockpiles have power ratings that require ventilation quantities typically between 25 m³/s and 40 m³/s at loading locations. In many cases, this means that the velocity of air required at the stockpile is greater than 1 m/s.*

The Inspectorate recommended the following steps to improve these unsatisfactory outcomes:

- *strictly adhere to the planned intervals between ventilation surveys*
- *include stockpile loading locations in ventilation survey*
- *monitor scheduling of return airway development to keep up with the general development of the mine*
- *advance electrical infrastructure in a timely manner*
- *discourage the practice of ventilating multiple ends from one fan – it may be practical to work two ore drives in opposite directions but multiple levels should not generally be ventilated with one fan*
- *carefully assess fan characteristics against the duties required*
- *make shift supervisors aware of the ventilation standards in their operating areas*
- *provide employees engaged in re-entry examinations after blasting with monitors suitable for the range of gases likely to be encountered*
- *provide shift supervisors and operators with the ventilation quantities required for the operation of diesel equipment in their operating areas.*

NON-SAFETY FACTORS CURRENTLY AFFECTING HARD ROCK MINE VENTILATION

There are many non-safety factors affecting hard rock mine ventilation in Australia at present, but two that particularly impact on ventilation costs are the carbon tax and electrical power charges. This is due to the fact that ventilation consumes up to 80 per cent of electrical power in typical underground hard rock mines that truck to surface. Industrial power charges have risen sharply from 2007. There are a number of reasons for this but the carbon tax is certainly one factor and neither Canada nor the USA has a carbon tax. The increase in diesel fuel costs has also increased power cost for mine sites relying on diesel generator sets.

One potentially important technology to assist with reducing power costs, particularly in large complex mines, is 'ventilation on demand' (VOD). A recent statement by the Canadian Centre for Excellence in Mining Innovation (2013) summarising the results from first large-scale pilot programs (conducted at large base metal operations in the Sudbury area) stated that VOD has the potential to:

- *increase production by two to three per cent by dynamically re-allocating available ventilation capacity*
- *reduction in indirect overhead costs of 8 to 20 per cent*
- *recovery of energy from waste air ventilation flow that could provide additional power savings of 5 per cent (note: this is probably heat recovery which would not be relevant in Australia)*
- *improvements to future mine design including the potential for reduced capital development, better*

placement of lateral development with respect to ventilation flow, and less dependence on operating resources to optimise ventilation flow to production needs.

Other important non-safety business factors impacting on the practice of mine ventilation include:

- the certain growth in underground uranium mining in Australia over the next few years
- the inevitable increase in depth of mining
- the continued globalisation of the mining industry.

There are also an important number of 'human factors' that are currently impacting on hard rock ventilation effectiveness including:

- FIFO rosters and the lack of ventilation staff on-site during breaks.
- The lack of mentoring opportunities for inexperienced ventilation officers.
- The strong growth in the number of overseas-trained mining engineers and ventilation officers joining Australian mines. Often these staff do not have the training or experience provided in an Australian style of mining operations.
- The significant increase in Australian mining engineers and ventilation professionals providing services for (usually) Australian or 'first world'-based (USA or Canadian) mining houses operating overseas. In some cases, there are ethical issues to consider when determining what ventilation standards should be applied at overseas operations.

POTENTIAL FUTURE CHANGES TO ALLOWABLE EXPOSURE LIMITS

History indicates that personal exposure limits for gases, dusts, fumes and radiation almost always reduce with time. This is due to a variety of factors, including longer life expectancy of workers, improved medical understanding of harmful effects of contaminants, and lower community tolerance towards damage of workers' health.

Several examples of this are:

- Radiation, where the allowable exposure was reduced from a dose of 12 'working level months' to four WLMs (20 mSv) per year in 1971, ie reduced to one third of its former value.
- Respirable crystalline silica, where the American Conference of Government Industrial Hygienists (ACGIH) time weighted average (TWA) exposure level was changed from 'millions of particles per cubic foot' prior to the early 1970s to 0.1 mg/m³ in the 1980s to 0.05 mg/m³ in 2000 and to 0.025 mg/m³ in 2005. This is a reduction to one quarter of its value in 1985 although this ACGIH limit has not yet been adopted by most statutory authorities (including Australia).
- Diesel particulate matter (DPM), where the limit in the USA for hard rock mines was reduced from 400 µg/m³ (TC) in 2001 to 160 µg/m³ (TC) in 2008². This 'final' value is 40 per cent of the value in 2001.
- Nitrogen dioxide, where in 2012 the ACGIH lowered the TLV TWA from 3 ppm to 0.2 ppm and eliminated the previous STEL of 5 ppm. The Netherlands reduced the TWA to 0.2 ppm (with a STEL of 0.5 ppm) in 2004 and the European Scientific Committee on Occupational Exposure

2. The 2001 limit was based on atmospheric concentration; the 2008 limit is based on a TWA.

Limits now recommends a TWA of 0.2 ppm with an STEL of 1 ppm. The current US NIOSH REL is a STEL of 1 ppm (Occupational Health Clinics for Ontario Workers, 2013). Compare these values to the current occupational limits of 3 ppm (TWA) and 5 ppm (STEL) in Australia.

It is therefore certain that further reductions in most exposure limits will continue to occur. Apart from the reasons mentioned above, two other concepts are important in understanding the trend towards lower exposures levels: the 'No observable adverse effects level' (NOAEL) and 'As low as reasonably achievable' concept (ALARA).

Regarding the NOAEL, the Australian Institute of Occupational Hygienists (2009) makes this statement in the context of respirable crystalline silica (quartz):

The AIOH supports the current ASCC (Australian Safety and Compensation Council) occupational exposure standard of 0.1 mg/m³ for respirable crystalline silica. The principal reason for this position is the declining reported incidence of silicosis in Australia. However it is becoming evident that there is not a substantiated 'no observable adverse effects level' (NOAEL) at which it can be categorically stated that exposure to crystalline silica has no adverse health effects. The literature is demonstrating risks to health at levels previously considered as being acceptable. The determination of such a level may also be hampered by limitations in measurement technology which do not allow the measurement of very low level exposure. There is an emerging trend within the occupational hygiene community to take a pragmatic approach to the measurement and control of exposures to toxic substances without attempting to define a dose response based exposure standard. Thus the AIOH acknowledges the importance of adhering to good control strategies so as to reduce exposures to 'as low as reasonably practicable' (ALARP).

Whilst the AIOH refers to ALARA above in the context of minimising exposures to hazardous substances, both the Western Australian and Queensland mining regulations (the two largest hard rock mining states) also provide a mandatory legal requirement for ALARA:

The Western Australian regulations state (author's emphasis)

9.5. Duties of ventilation officer – underground

A ventilation officer for an underground mining operation is responsible for –

(a) regularly inspecting and testing workplaces, travelways, and locations where persons may travel in the mine to determine whether –

(i) atmospheric contaminants in the mine are maintained at levels as low as can reasonably be achieved; and

(ii) the mine ventilation system is providing adequate ventilation flows through those areas.

The Queensland Government Mining and Quarrying Safety and Health Act 1999 (Queensland Government, 1999a) states (author's emphasis):

What is an acceptable level of risk

26.(1) *For risk to a person from operations to be at an 'acceptable level', the operations must be carried out so that the level of risk from the operations is –*

(a) within acceptable limits; and

(b) as low as reasonably achievable.

(2) To decide whether risk is within acceptable limits and as low as reasonably achievable regard must be had to –

- (a) *the likelihood of injury or illness to a person arising out of the risk; and*
- (b) *the severity of the injury or illness.*

Unfortunately this author *never* sees any reference in either ventilation plans (including major feasibility studies) or mine operating standards to this critically important legal requirement to meet the ALARA standard.

GOVERNMENT AUTHORITY RESEARCH PRIORITIES IN MINE VENTILATION

In terms of the US National Institute for Occupational Safety and Health (2013), current research programs for mining are (their priority order):

1. *Respiratory diseases: reduce respiratory diseases in miners by reducing health hazards in the workplace associated with coal worker pneumoconiosis, silicosis, and diesel emissions.*
2. *Hearing loss: reduce noise-induced hearing loss (NIHL) in the mining industry.*
3. *Cumulative injuries: reduce repetitive/cumulative musculoskeletal injuries in mine workers.*
4. *Traumatic injuries: reduce traumatic injuries in the mining workplace.*
5. *Mine disasters: reduce the risk of mine disasters (fires, explosions, and inundations); and minimise the risk to, and enhance the effectiveness of, emergency responders.*
6. *Ground control: reduce ground failure fatalities and injuries in the mining industry.*
7. *Surveillance and training: determine the impact of changing mining conditions, new and emerging technologies, training, and the changing patterns of work on worker health and safety.*

At least two of these priorities (respiratory diseases and mine disasters) are directly related to ventilation and their 'top priority' is respiratory diseases.

As unfortunately there is no equivalent to NIOSH in Australia³, Canada or South Africa, it is difficult to know what the regulators in these countries would see as the research priorities for hard rock mine ventilation. However, they are probably similar.

A LIST OF HARD ROCK VENTILATION CHALLENGES

This author has written extensively about some of the major factors currently impacting adversely on hard rock ventilation design (Brake, 2009; Brake, 2012). However, here is an updated list of challenges, with some additions.

The challenge to go beyond 'cookie cutter' ventilation designs

The dumbing-down of the industry's level of ventilation competence due to the hollowing-out of the hard rock mine ventilation profession in Australia has led to an increasingly narrow and unimaginative approach to ventilation design:

- The 'U-tube' or 'whole-of-mine' series ventilation circuit has become very popular. Whilst it does have a place in the ventilation engineer's toolbox, it is often being used where it is unsuitable or unsafe or even uneconomic in the sense that it would be reducing the net present value of the operation.

- Many in the industry see airflow requirements as being merely the sum of truck and LHD engine kW multiplied by 0.05 m³/s. This is a wholly inadequate approach but continues to persist. It implies that if a hard rock mine has no large diesels, that it would need no airflow, a ludicrous notion, given the ventilation is required to dissipate, among other things, dusts, heat and blasting fumes! A sound guideline is to achieve an airflow of 0.5 m/s in all headings needing ventilation, even if no diesel is present. For typical heading sizes in hard rock mines, this means about 12 to 15 m³/s even without diesels. It is disingenuous for those selling DPM-reduction technologies (including vehicle or engine manufacturers) to state or imply that these new technologies will reduce mine airflows. DPM is an issue in hard rock mines but it is far from being the only or even the most important issue.
- The airflow requirement in the target mine is being aggregated together for the whole mine but this is an incorrect interpretation of good practice or regulations, such as Western Australian Regulation 10.52.4 which states (author's emphasis in bold):

A sufficient volume flow of air must be maintained in each workplace in which a diesel unit is operated to dilute the engine exhaust gases to the lowest practicable levels, and this volume flow must not in any case be less than the minimum ventilation flow specified in this regulation.

The challenge to break free from persistent bad habits and ignorance

Hard rock mine ventilation has developed a combination of bad habits and ignorance, some of which are entrenched:

- Completely inadequate short to long-term ventilation planning. Many of the problems identified in the Western Australian Safety Bulletin (Western Australian Department of Mines and Petroleum, 2011) are due to inadequate attention to ventilation planning.
- Ladderways in exhaust, which in most cases should be an unacceptable practice (Figure 1).
- Excessive use of series circuits, especially these are not adequately monitored.
- Unhealthy preoccupation with minimising capital costs. This author regularly encounters main fans operating very inefficiently or incorrectly sized auxiliary fans. A 'mine standard' 180 kW auxiliary fan costs in the vicinity of \$30 000 to purchase but uses \$320 000 per year (more than ten times its capital costs) in electrical power (at \$0.20 per



FIG 1 - Installing a ladderway in a surface exhaust is very poor practice.

3. Australia does have Safe Work Australia (SWA), a successor to the National Occupational Health and Safety Commission (NOHSC). However, SWA is not a research body or broker.

kWh). The same applies for the costs of excessive circuit resistance and excessive leakage.

- In the more general case, ventilation is seen as a cost to be minimised or even just a general annoyance, and not an important health, safety, productivity and morale issue, as well as a means of adding value to the operation. This author gave a presentation years ago entitled ‘Workers are from Mars, Managers are from Venus’ due to his frequent observation that managers often believe ventilation is an unimportant issue in their mine, but underground workers in that same mine see it as one of their most important issues.
- Placing primary ventilation surface connections (intakes and exhausts) within open cuts or box cuts, which in some cases is leading to serious recirculation and in most cases is not monitored at all for recirculation.
- Failing to have a suitably comprehensive and statistically valid program of personal atmospheric exposure monitoring. In Western Australian, many operators believe that complying with the CONTAM protocols (Western Australian Department of Consumer and Employment Protection, 2008) is sufficient to discharge their duty. Other states in Australia do not even have these standards. There are many operations that either due to ignorance or wanton disregard do not properly measure atmospheric contaminants.
- There is a widespread believe that contaminant levels do not need to be measured where workers are inside an

air-conditioned cabin, without understanding that cabins provide no reduction in ambient gas levels and generally only offer a minor reduction in DPM (Griffith and Kimball, 2012).

- Poor re-entry procedures particularly given the growth in series circuits (which pushes blasting fumes into areas that were not blasted) and the loss of return air raises on individual operating levels combined with no dedicated stope exhausts.

The challenge about value creation via ventilation

There is a widespread believe that it the ‘real value’ in a mine is added by good operators. However, this is not the case. Figure 2 illustrates that getting the optimal project configuration during the design phase is the critical part of the value-creation process. Having good operators merely minimises the loss of value in the ‘value delivery’ phase of the mine after it commences production. Part of the process of good design is, of course, developing a sound ventilation design.

This concept is further reinforced in Figure 3 (Knee, 2007) which illustrates that building safety into a product (such as the ventilation circuits and strategy in a mine) is far easier early in the ‘product life cycle’ (ie while the mine is still being designed) than attempting to retrofit safety into the design after the mine commences operation (Safe Work Australia, 2006).

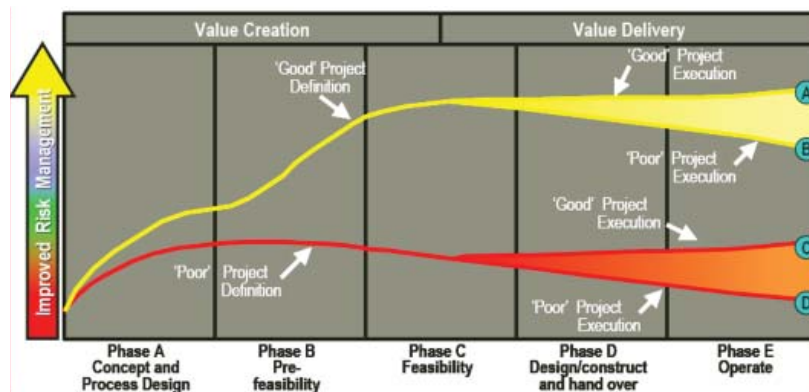


FIG 2 - Where the value is added in the mining process (source unknown).

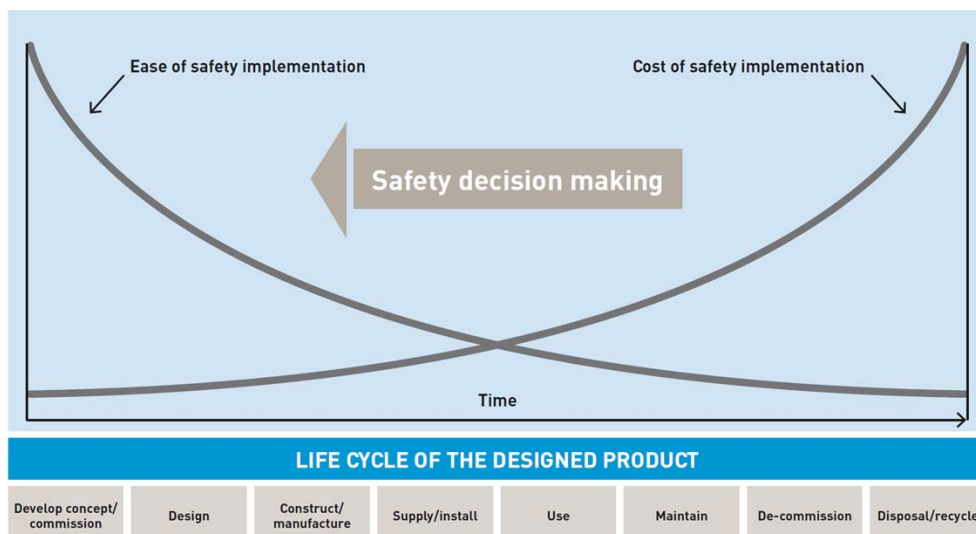


FIG 3 - Building safety into a design is far cheaper and easier early in the project life.

The challenge of new mining methods and equipment

There has been a trend towards caving methods in the past 15 years. This is likely to continue. Such mines typically need high production rates to achieve economies of scale. It is rare to truck the ore to surface, so there are likely to be somewhat more operations with underground crushers, hoisting shafts and conveyors to surface.

In the longer run, tunneling machines may start to make inroads on underground hard rock development, requiring radically different development ventilation systems to those currently employed.

The challenge of inexperienced ventilation officers and the poor standing of the ventilation profession

There has been considerable discussion within the industry and even in the public arena about the social and health issues of fly-in, fly-out (FIFO). However, from an operating point of view, it is difficult to achieve a consistently good ventilation outcome, at an operation where the ventilation officer (VO) is working a FIFO roster, unless the operation has two competent ventilation officers working back to back. This is certainly not the norm in the hard rock industry at present.

In addition, along with most other technical disciplines, there has been an explosion in the growth of knowledge within the mine ventilation profession. This is making it impractical for 'general practitioners' and even ventilation consultants to keep abreast of all the various specialties within the field of mine ventilation. The modern VO requires an extensive range of skills and increasingly sophisticated equipment to properly perform his duties (Figure 4).

The loss of ventilation engineers/supervisors in middle management in mines and the lack of group ventilation

engineers means there is certainly a pressing need in the industry to not only provide better and more practical training for mining engineers in the area of mine ventilation, but also to support them via mentoring. There is only so much that can be gained via books and assignments. A further important issue is retaining young ventilation engineers in the role so that they become the next generation of 'old, experienced' ventilation engineers.

Australia also has few post-graduate research students in any direct mine ventilation programs in recent times and given the importance of mine ventilation to underground mines, this needs to be addressed. As an aside, none of the papers published in the proceedings from this conference will count in any academic sense for young academics in Australia.

A further issue to address is the unfair but widespread perception even in the mining industry that ventilation professionals are 'nerdy' and that there are no interesting career options in ventilation so that ventilation is a 'dead end' job (Figure 5). A long-term strategy is required by the profession (and the industry) to address this perception.

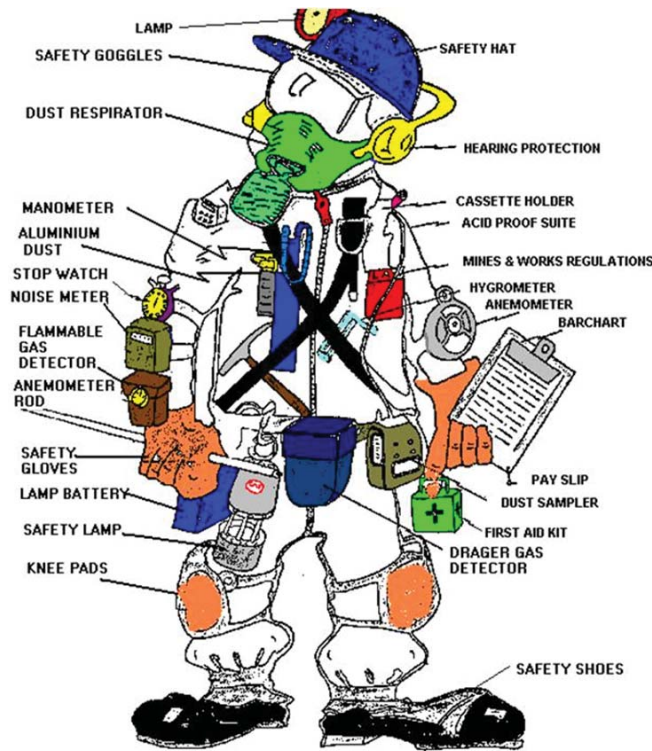


FIG 4 - The range of skills required by the 'VO' continues to increase (source: André Broodryk).

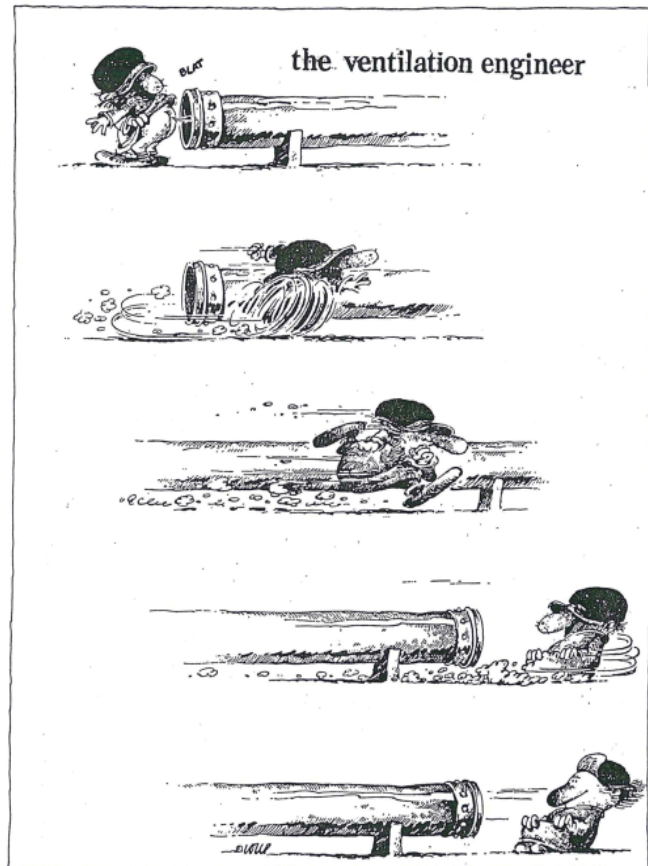


FIG 5 - The 'VO' still has a credibility problem in many mining operations (source: Chris Pritchard from a ventilation class he took in 1979).

At the same time, the new national model mining regulations will require every hard rock mine to appoint a ventilation officer (which will be a statutory position). Hard rock ventilation officers will be a 'Type 2' appointment, ie 'Safety critical positions which must be undertaken at a mine by holders of Board of Examiners' specified qualifications and competencies'.

It also needs to be recognised that there are many other stakeholders that have input into an effective ventilation system. In particular, underground supervisors often have a poor understanding of ventilation if there experience has been

in mines with poor ventilation standards. Specific training for supervisors and workers needs to be adopted (Mousset-Jones and Marks, 2001).

The challenge of mine emergencies, egress and entrapment

Hard rock mines have made substantial progress addressing emergencies such as fires and explosions. However, it is very difficult to safely and economically train underground personnel in a realistic fire scenario. It is likely that 'virtual reality' simulators can be developed that could give workers (and supervisors) a much better appreciation of the hazards and difficulties they are likely to encounter in an escape scenario (Mousset-Jones and Marks, 2001). There are many other applications for VR in underground mines that are likely to become available in the next decade.

The challenge to move into the growth area of underground civil projects

Despite its large land area and low overall population density, Australia is a highly urbanised country. There is a substantial and growing requirement for civil tunnelling in which Australian mine ventilation engineers could participate particularly during the mining and construction phase.

The challenge to understand and implement 'duty of care' legislation and self-regulation

There will always be a tension between allowing flexibility and innovation in mining design and practice (essential for continuous improvement) versus maintaining standards (essential to not repeating the mistakes of the past). Risk based ('Duty of care') legislation needs some prescription or at least a comprehensive cohort or 'companion guide' of approved codes/guidelines. It is essential for ventilation professionals to be aware of, and follow, those approved codes of practice that apply not only in their own regulatory environment, but also in other regulatory environments where these other codes are more modern or considered better practice, as this will be the benchmark against which the community will assess what constitutes a substandard design or operation. Such codes of practice include, for example, the Western Australian Approved Guideline 'Duty of Care' (Western Australian Department of Consumer and Employment Protection, 2006) and 'Underground Ventilation' (Metalliferous Mines) (Western Australian Department of Industry and Resources, 1997).

In this regard, it is this author's opinion there is a great ignorance regarding even the existence of applicable Codes of Practice combined with a (completely erroneous) perception in the industry that there is no requirement to comply with these as they are designated as 'Guidelines'. However, approved Guidelines are, in effect, legally binding in the absence of an operation adopting an alternative system that provides at least an equal level of safety. For example, the *Queensland Mining and Quarrying Safety and Health Act 1999* (Queensland Government, 1999b) states:

(section 34(3)) ... if a guideline states a way or ways of achieving an acceptable level of risk, a person discharges the person's safety and health obligation in relation to the risk only by –

- (a) adopting and following a stated way; or
- (b) adopting and following another way that achieves a level of risk that is equal to or better than the acceptable level

(section 64) A guideline is admissible in evidence in a proceeding if –

...

- (c) the guideline is about achieving an acceptable level of risk.

The Queensland WH&S legislation adds further:

Codes of practice are admissible in court proceedings under the Act and Regulations. Courts may regard a code of practice as evidence of what is known about a hazard, risk or control and may rely on the code in determining what is reasonably practicable in the circumstances to which the code relates.

Compliance with the Act and Regulation may be achieved by following another method, such as a technical or an industry standard, if it provides an equivalent or higher standard of work health and safety than the code.

An inspector may refer to an approved code of practice when issuing an improvement or prohibition notice.

Most of the other Australian states have similar legal expectations regarding the use of approved guidelines.

As noted earlier, hard rock ventilation design has been reduced by many to an over-simplified and uninformed application of the '0.05 m³/s per kW' regulation in Western Australian. At the very least, every feasibility study and every ventilation control plan should specifically refer to and discuss the ALARA concept as it applies to that design or operation. A good discussion of the application of ALARA is found in Main (2004). However, in this author's opinion, demonstrating ALARA requires meeting three criteria (Brake, 2012):

- It must show that a range of designs (options) have been considered and risk assessed, and the chosen design is not only safe in the absolute (legal) sense, but the cost to reduce the risk further to a lower-risk design, cannot be justified.
- It must demonstrate via benchmarking that its design standards and practices meet 'industry good practice' compared to its peers.
- It must show that adverse outcomes are continuing to reduce, ie a powerful way to demonstrate ALARA is to show (for example) that respirable crystalline silica dust doses to various similarly exposed groups of workers at the operation are showing a consistent downwards trend with time. In effect, that the operation is achieving a continuous improvement in all key deliverables from the ventilation system design and operation.

Finally, it has been said that 'Self regulation is to regulation what self importance is to importance'⁴. In this sense, this author does not agree with some who believe that the industry will maintain good practice safety standards if 'left to its own devices' and that regulators are either a hindrance or a waste of money (or both). In fact, this author is of the view that more inspections by more competent inspectors are required in many mines to ensure compliance with not only the applicable regulations, but also the operation's own 'ventilation standards'.

The challenge of increasing power costs

There will certainly be a growing emphasis on 'managing' (ie 'reducing') ventilation power costs. Unfortunately, often

4. Attributed to Willem Buiter, Chief Economist of Citigroup and Fellow, Centre for Economic and Policy Research in his discussion of self-regulation of the banking sector in the 'Global Financial Crisis' of 2008.

a very simplistic approach is taken in this regard, generally revolving around reducing the airflow through the mine circuits. As this is unlikely to be a viable solution in many cases, and certainly not without the complexity and expense of adopting VOD, consideration will need to be given to these areas:

- Reducing system resistance by 'paralleling' high resistance parts of the circuit or eliminating 'dog-legs'.
- Reducing system leakage so improving the 'volumetric efficiency' of the mine, ie the proportion of total airflow being usefully employed.
- Operating fans on a more efficient range of their curve.
- Operating fan motors more efficiently (ie closer to full load).
- (Potentially) using circuit fans rather than circuit regulators. Regulators destroy pressure and hence airpower. Given the cost of power (which is mostly ventilation-related) in an underground hard rock mine, more consideration needs to be given to the selective use of circuit or booster fans rather than the easy option of destroying pressure via regulators.
- (Potentially) using controlled (ie planned and carefully monitored) recirculation.

One significant issue is that most mines do not understand how much the ventilation system costs to operate, in terms of both direct and indirect costs. Few operations have adequate key performance indicators (KPIs) for ventilation.

An important challenge that will arise with the potential growth in 'ventilation on demand' and 'controlled recirculation' is the ethical issue of setting working exposure limits. For example, most mines can and do achieve TWA values for carbon monoxide far below 5 ppm. However, the legal limit in Australia is 30 ppm (15 ppm for most 12 hour rosters). If good gas monitoring is employed, should operators reduce airflow (to save fan power and capital costs) so that workers are getting a 'full dose' of 15 ppm CO on a daily basis? Surely not, but if not, what daily dose should be targetted?

The challenge of mines approaching end of life

Most farmers understand that in the 'good seasons' it is important to invest in their property, to upgrade equipment and to improve their operating practices as they understand that the lean years will eventually come. Unfortunately, there are mines that do not appear to invest in their own future during high commodity prices and face a steadily increasing operating cost, and slowly move up the cost curve. This impacts on their ability to operating the mine safely and frequently accelerates their own demise.

It is also important to understand the particular implications on the ventilation system for mines approaching their end of life. These mines are often converting to a remnant mining operation. Mining remnants imposes significant additional demands on the ventilation system due to the spread-out nature of the workings, the loss of ventilation circuits and the extra risks associated with dispersed or restricted circuits as extraction progress and entrapment.

The challenge of going deeper

There are many ventilation challenges for mines going deeper, some of which are covered in other sections of this paper. However, there does need to be a growing sophistication regarding the correct application of mine cooling in Australian mines. This author has noticed three problems in this area:

- operations adopting underground refrigeration plants without understanding the problems of maintaining and operating such plants
- operations adopting surface plants when these will be ineffective or excessively inefficient for the application
- operations employing hire plants with very high rental charges when a purpose-designed plant will rapidly repay its capital cost.

The challenge of managing and reducing exposure levels

This has been discussed above, but it will be increasingly important for ventilation professionals to have at least a working knowledge of basic occupational hygiene principles and concepts such as 'similarly exposed groups'.

In some cases, the nature of the hazard is likely to change. For example, the growth in the use of bio-diesel is changing the composition of DPM which may change its toxicity and hence allowable exposure levels.

New challenges are also likely to arise with the long-standing 'three (uranium) mines policy' abandoned and both Queensland and Western Australian changing their policy to allow uranium mining. In addition, the two current states/territories that have uranium mines (South Australia and the Northern Territory) are both looking to expand their uranium operations. There are few ventilation personnel in Australia with competence in the ventilation of underground uranium mines.

The challenge of 'first world' mining companies or staff working overseas

There is an increasing globalisation of the world's mining industry. One of the implications of this is the situation that is arising more frequently of what ventilation or atmospheric contaminant standards to adopt in non-first world countries. It would be simple to say to always adopt the higher of the local regulations or first world standards; however, the decision is not always as clear cut as this. For example, the AusIMM Safety Vision and Principles (The Australasian Institute of Mining and Metallurgy, 2012) states (author's emphasis):

Institute members have an ethical, professional, legal and personal obligation and responsibility (duty of care) to ensure that employees', contractors' and consultants' rights are protected and respected. They must ensure that workplaces under their control adopt, implement and observe best practice occupational health and safety standards.

SUMMARY, CONCLUSIONS AND (SOME) POTENTIAL SOLUTIONS

- In general, the ventilation systems in Australian hard rock mines are struggling to cope with current mining methods, large equipment and FIFO rosters within the often superficial competence of ventilation staff on-site.
- It is inadequate to design operations to the '0.05 m³/s per kW' regulation, as this is not taking the WA regulation in context and ignores other regulations and important Codes of Practice.
- There are still many poor practices or misunderstandings in widespread use, such as excessive use of series circuits, ladders in exhaust and the incorrect assumption that air-conditioned cabins keep the operator in 'fresh' air (including free of gas and DPM).

- Many of the problems would be resolved if hard rock mines adopted:
 - the study of 'safe design' from the start of the project concept through the feasibility study process
 - well-designed 'ventilation control plans' and then trained their staff and operated to those plans.
- An approved guideline is required to help mine operators (and hence ventilation staff) to understand and apply the concepts of 'ALARA' and 'Codes of Practice' in ventilation design and operations. An industry database of codes of practice would be useful.
- Duty of care legislation fails to provide consistently safe underground ventilation conditions unless backed up by sound inspection policies of the regulators.
- Allowable atmospheric exposure levels will continue to fall, in some cases dramatically.
- Ventilation studies need to be more comprehensive and need to make an explicit assessment of the impact on the ventilation design of potential reductions in exposure limits over the life of the operation.
- New diesel engine technology will help reduce DPM levels but will not provide dramatic reductions in airflow requirements as engine sizes will probably continue to increase and heat will become the limiting criteria. Allowable concentrations of other gases and dusts are also likely to reduce requiring higher flows for dilution. In addition, obtaining reasonable re-entry times also depend on having at least moderate flows. Finally, for safe egress and workplaces and equipment inspection reasons, even if a driver is in an air-conditioned cabin, temperatures outside should not be allowed to exceed 34°WB.
- The trend towards bio-diesel will have an unknown (at this point) impact on allowable DPM exposure standards.
- Most operations could achieve considerable savings by reviewing power costs in their ventilation systems and looking for reductions other than by reducing total airflows.
- Most operations have inadequate cost systems to capture both direct and indirect ventilation costs and poor or nil key performance indicators for ventilation.
- Ventilation-on-demand and/or controlled recirculation are likely to become both technologically and cost-effective in the next decade, but with most benefits accruing to large complex operations using extensive parallel circuits.
- Where dust is the main airborne contaminant in an area of the mine, filtering of the air may become more economically viable especially when using 'expensive' air such as chilled air.
- The growth in underground uranium mines will require upskilling by ventilation personnel.
- With more comprehensive atmospheric monitoring becoming available, important ethical issues will arise regarding the setting of daily doses of contaminants for workers.
- The globalisation of the mining industry will also create ethical dilemmas at times for some professionals when assigned to third world countries, depending on the safety standards policies of their employer.
- The increasing depth of Australian hard rock mines will require a more sophisticated approach to selection of the appropriate mine cooling strategies.
- There have been a number of serious re-entry safety incidents in the past five years and re-entry procedures must be rigorously risk-assessed and then consistently complied with to avoid potential fatalities.
- Many mines with both intakes and exhausts located within deep open pits, or in close proximity in a box cut, are recirculating.
- Ventilation professionals need to take a far more active involvement in atmospheric exposure monitoring rather than ignoring it or allowing it to be or become the exclusive domain of the industrial hygienist, which will be to the detriment of the profession and also to atmospheric standards underground, as the ventilation officer is best placed to use the exposure data to adjust or redesign the ventilation system.
- The new national code of practice for underground hard rock mining requires the statutory appointment of a ventilation officer at all hard rock mines. This will only apply to states that adopt the new national code.
- An industry strategy is required to address the perception that mine ventilation is for 'nerds' and has limited career options. This should also include a mechanism to encourage bright undergraduates to study post-graduate and research degrees.
- Substantial new opportunities will be created in the next decade for competent hard rock ventilation engineers to be involved in large civil tunnelling projects.
- The growing sophistication of mine ventilation software will lead to a better understanding of, and risk-based control plans for, unplanned events such as underground fires and explosions.
- The competence of hard rock mine ventilation professionals needs to be lifted by a combination of:
 - better training and mentoring of young ventilation professionals
 - a more supportive approach from mine managers
 - adoption of and adherence to ventilation control plans for every hard rock mine
 - use of 'back to back' ventilation officers at all sites, even if this role is combined with some other role
 - encouragement of those with a flair or passion for mine ventilation to continue in the role and become genuinely 'senior ventilation professionals'.
- Ventilation good practices and key principles should be provided as part of training for underground supervisors.
- It is likely that virtual reality simulators specifically for underground mines will become available and be very useful in giving workers realistic training in how to respond to underground emergencies such as fires and explosions.

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