Real-time air velocity monitoring in mines - a quintessential design parameter for managing major mine health and safety hazards

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REAL-TIME AIR VELOCITY MONITORING IN MINES - A QUINTESSENTIAL DESIGN PARAMETER FOR MANAGING MAJOR MINE HEALTH AND SAFETY HAZARDS

Bharath Belle

ABSTRACT: Mines should be safe places in which to work. These safe places are achieved by means of natural and mechanical means of ventilation. Air velocity is a quintessential ventilation design parameter in diagnosing and ascertaining the adequacy of ventilation for managing mine health and safety hazards. Although Australian coal mines are recognized as being the safest mines in the world using both real-time and tube bundle monitoring systems, monitoring of airflow at critical locations in real-time is glaringly deficient and poor ventilation monitoring practice. This paper discusses the needs for real-time velocity monitoring and the implementation benefits of it in mines. What is an acceptable velocity measurement error in the carbon era? Current carbon emission guidelines do not clarify the measurement challenges associated with air velocities, let alone air velocity accuracy. Historically, there are references to acceptable measurement errors ranging from ± 5 % to ± 20 %. Measured differences in monthly ventilation surveys against the real-time airflow monitoring were found to be 13.3 % resulting in annual carbon costs of A$580 000 for a CH₄ level of 0.2%. It is considered that, it is never too late to implement real-time velocity monitors in Australian mines, a safety enabler and a leading practice in the mature mining world.

INTRODUCTION

Mines should be safe places for all those who work in them. These safe places are achieved by means of natural and mechanical means of ventilation. Air velocity is a quintessential ventilation design parameter in diagnosing adequacy of ventilation for managing major mine health and safety hazards. Use of minimum air velocity as a design parameter is an integral part of various ventilation engineering planning spheres to provide assurance on regulatory requirements as well as quality of hazard controls in some form in most mining countries. Therefore, monitoring of air velocity and in turn air flow in real-time is an essential practice in assuring continuous provision of safe occupational environment.

Issues of velocity measurement in mines have been studied by various research agencies including, Thimmons and Kohler (1985), AAC (1990), Hardcastle et al. (1991, 1993), Casten (1995), Martikainen et al. (2011). A notable study is the work of Thimmons and Kohler (1985). This work noted after a review of measurement practices that flow determination is more of an art than a science. This demonstrates that during velocity compliance determination, it is possible to introduce the operator bias, i.e., novice or veteran, instrument bias, sampling location, and frequency of measurements as required by the respective safety regulations. In such instances, real-time velocity monitors provide ventilation engineers with non-emotional data for evaluating the underground conditions and effectiveness of the mine ventilation systems. This paper attempts to explore the needs, challenges and operational aspects of implementation of real-time velocity systems. Benefits derived from installing real-time air velocity monitoring installation on main fan systems at a Bowen basin coal mine are discussed.

According to McPherson (2006), prior to the invention of vane anemometers (Figure 1) in the nineteenth century, the only practicable means of measuring rates of airflow in mines was to observe the velocity of visible dust or smoke particles suspended in the air. It is still a practiced method by the ‘shift boss’ or ‘deputies’ to estimate the air movement or direction of flow in the absence of real-time velocity monitoring instruments at hand by simply throwing some float dust found in the roadways to gauge the airflow and direction at very low air velocities, i.e., non detectable instrument measurement ranges.

Recent global catastrophic events in some form can be attributed to the outcome of inadequate ventilation, lack of ventilation (air velocity) monitoring thus creation of a flammable gas mixture and absence of dedicated long term mine ventilation engineers (unlike contractors) who are responsible for airflow and gas management underground. These hazards when unmanaged would be dangerously unforgiving and are mostly managed by better mine ventilation conditions. Figures 2 and 3 show the

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alarming fatal statistical consequence due to gas and dust explosions and frictional ignition potential in both gassy and non gassy mines.

Figure 1 - Friedrichs Anemometer, Model 1400 (0.3038 m/s to 20.3 m/s), (Source: MVS Journal, 1957)

Figure 2 - Statistics on global mine explosions

Figure 2 - FI incidents in gassy and non gassy mines (PS- reference to the use of FI limit of 5.75 m³/t in PHMPs or COPs to be discouraged)

As seen above, explosion risks in coal mines are ever present because of inherent presence of methane gas. In order to minimize the risk profiles of these catastrophic events, it is timely that all interested parties in mines accept improvement opportunities in the following hierarchical control namely, air velocity (ventilation) monitoring:

- Accepting the need for continuous monitoring of hazards in the environment that is continuously changing (read gases and dust);
• Accepting the need for continuous monitoring of air velocity and ventilation that is continuously changing (read airflow) regardless of magnitude;

• Accepting that in a complex mine ventilation network, frequent manual ventilation monitoring in main returns or intakes is a cumbersome process and has practical limitations;

• Accepting the availability of Intrinsically Safe (IS) real-time monitoring tools for underground use in the current technologically advanced workplaces;

• Accepting that continuous air velocity monitoring devices can provide leading indicators of unanticipated conditions in the event of a failure or provide early warning of ventilation effectiveness or deficiencies;

• Accepting that traditional measurements aided by continuous monitoring would enhance the response time in the event of emergencies or re-entry;

• Accepting that approved IS real-time velocity monitors are available in Australia;

• Accepting that just as in other real-time gas monitoring tools, velocity monitors also need maintenance;

• Accepting that continuous velocity monitoring is a leading practice in other parts of the coal and metal mining world (UK, Canada, South Africa, and Poland);

• Accepting that improvements in velocity monitoring would assist the mines in controlling and providing improved quality of air;

• Accepting that real-time velocity monitor is a safety and production enabler.

ROLE OF AIR VELOCITY IN MINE DESIGNS AND REGULATIONS

Typical elements of occupational environment design are shown in Figure 4. These mining hazards resulting from natural and mining factors are managed by adequate mine ventilation using air velocity as a fundamental and quintessential design parameter. Air velocity expressed in metre per second (m/s) is the change of position and direction of moving air with time. Critical aspects that are considered in the design and planning of mine ventilation networks are air velocities and their direction in the working face, intake, return, tailgate, conveyor road, intake shafts, return shafts, main drifts, travel roads, haulage roads, longwall face, Last Through Road (LTR), over casts, bleeder road and regulators. These in turn with cross sectional area (m$^2$) would assist the mine ventilation engineer on the air flow rate (m$^3$/s) and in calculating the pressure differentials or calculating the efficiency of mine ventilation systems. Also, air velocity measurement along the maingate, mid-face and tailgate of a longwall enables the ventilation engineer to quantify the leakage of air into the goaf areas as well as estimate the heat loads and carry out in thermodynamic calculations.

Figure 4 - Elements of occupational environment design
Typical ruling ventilation design parameters for various mineral types are shown in Figure 5. It must be noted that based on the place of operation (read continent), the ventilation ruling parameter may change due to the provision of minimum hazard limits at different commodities and mining countries.

Figure 5 - Critical hazards in defining minimum air velocities

The methods considered for the minimum ventilation using air velocities for the working areas, viz.:

1) Ventilation for a minimum velocity (to dilute dust or gas or other identified hazards);
2) Ventilation for diesel engines to manage Diesel Particulate Matter (DPM) and gases;
3) Ventilation for heat management;
4) Ventilation for blasting re-entry time.

The normal design process is to calculate the air requirements using each of the above methods and to provide sufficient ventilation to meet the highest hazard management together with limit values prescribed in local regulations. This highest requirement is termed as the ‘ruling parameter’. In some instances, this requirement is excessive or impractical and changes must be made to the mining or equipment parameters to reduce the ventilation requirements or cause another of the three parameters to become dominant.

Table 1 summarises an example of the air quantity requirements for the face ventilation system using various design criteria for identified hazards. The correct ventilation design factor used in the estimation can be debatable and the choice of factors is based on the individual operational experiences and the understanding of ventilation inflexibility needed during the life of the mine (LOM). In this example, measuring air velocity is the only means to ascertain the sufficient air quantities are supplied to manage the hazards, thus demonstrating the importance of measuring air velocities.

Table 1 - Example of determination of ventilation air quantity requirements

<table>
<thead>
<tr>
<th>Condition</th>
<th>Design Criteria</th>
<th>Air Quantity</th>
<th>Leakage, 10%</th>
<th>Pressurisation, 15%</th>
<th>Required Air Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legal-Min Std</td>
<td>0.25 m³/s/m²</td>
<td>2.72</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Re-entry multi-blast development</td>
<td>30 min wait; 8 air changes; 60 m tunnel</td>
<td>2.90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Re-entry-Secondary blasting</td>
<td>10 min wait; 8 air changes; 30 m to face</td>
<td>4.36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dust clearance*</td>
<td>1.0 m/s</td>
<td>10.89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel Engine-DPM</td>
<td>0.0482 m³/s/kW</td>
<td>6.884</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel Engine-Avg. Heat**</td>
<td>0.065 m³/s/kW</td>
<td>9.23</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*based on type of dust and make [this example is for kimberlite dust for a block cave, incline cave and sub level cave mining methods, Belle (2005)] ** It is assumed that the average intake air WBT will not exceed 18° C

The following paragraph summarizes the example expressions of air velocity in the ventilation code of practice (COP) and legislations of mining intensive countries. These requirements illustrate that manual
and or electronic means of real-time velocity monitoring devices would enable to provide assurance needed on meeting those compliance requirements.

- The QLD mine safety legislation requires that the Principal Hazard Management Pan (PHMP) must ensure that the ventilating air provided for the mine is of sufficient volume, velocity and quality to remove atmospheric contaminants from mining operations and maintain a healthy atmosphere at the mine during working hours. Also, it must ensure that the effective working temperature requirements are met. Effective temperatures are determined using wet bulb and dry bulb temperatures and air velocity. (Coal Mining Safety and Health Regulation 2001, Regulation 343-345)

- Controlled ventilation for a working place in each standing working place that is on the intake side of a working place and in each working place in an ERZ1 must provide for a ventilation current of an average velocity of at least 0.3 m/s measured across the cross-sectional area of the roadway in the working place. (Coal Mining Safety and Health Regulation 2001, Regulation 343-345)

- Mine safety legislation requires that in areas of the mine where persons work and travel, the ventilation system provides an average air velocity of at least 0.3 m/s measured across the work or travel area (Model Work Health and Safety (Mines) Regulations 2011 Section 649).

- The prescribed Chinese ventilation regulations, viz., minimum ventilation volume per person (4 m³/min/person); decline travel airway velocity limit of 8.0 m/s; depending on location or activity a minimum ventilation velocity of 0.25-0.50 m/s and minimum diesel emission dilution factor of 0.06 m³/s/kW.

- US regulation 30 CFR 75.350(b) limits belt air velocity to 5.08 m/s; 30 CFR 75.327(b) limits air velocity in trolley haulage entries to 1.27 m/s provided the methane content can be maintained below 1%.

Typically, ventilation systems are designed, implemented and monitored to manage the gaseous and particulate hazards. The following paragraphs reinforce the importance of ‘air velocity’ in mine ventilation designs and thus the need for accurate measurement requirements. Velocity values are widely published with accepted ventilation design standards on airways, viz., men and material shaft, dedicated intake shaft, exhaust shaft, travel road, conveyor road, working faces, main intake roadways, main return roadways (Jeppe, 1946; Lambrechts, 1974; Lambrechts and Howes, 1989; MVS Databook, 1999; McPherson, 2009). These proven or unproven ‘design velocity’ values (Table 2) have significant influence during mine planning in terms of main shaft and main airway sizes, number of roadways in mains or panels to carry certain design ventilation loads, e.g., six heading mains or eight heading mains, two heading roads or three heading roads in coal mines.

**Table 2 - Typical ventilation design velocities (m/s)**

<table>
<thead>
<tr>
<th>Area</th>
<th>V1*</th>
<th>V2 (coal)**</th>
<th>V3** (metal)</th>
<th>Australian Guidelines***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working faces</td>
<td>4</td>
<td>-</td>
<td></td>
<td>0.3</td>
</tr>
<tr>
<td>Conveyor drifts</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Main haulage routes</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Smooth lined mine airways</td>
<td>8</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Ventilation Shafts</td>
<td>20</td>
<td>18-22</td>
<td>18-22</td>
<td></td>
</tr>
<tr>
<td>Decline Intakes</td>
<td>-</td>
<td>6-8</td>
<td>6-8</td>
<td>4-7</td>
</tr>
<tr>
<td>Dedicated Intake Shaft</td>
<td>-</td>
<td>18-22</td>
<td>18-22</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Downcast Shafts with hoisting</td>
<td>-</td>
<td>10-12</td>
<td>10-12</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Intake Airways</td>
<td>-</td>
<td>2-5</td>
<td>6-8</td>
<td></td>
</tr>
<tr>
<td>Return Airways</td>
<td>-</td>
<td>3-5</td>
<td>6-8</td>
<td></td>
</tr>
<tr>
<td>Overcasts</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2-5</td>
</tr>
<tr>
<td>Auxiliary ventilated headings</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.5-0.75</td>
</tr>
<tr>
<td>Limit for safe pedestrian access+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>&lt;12</td>
</tr>
</tbody>
</table>

* McPherson (1984); Mouset-Jones (1986); ** MVS Data Book (1999); ***Draft
+ If the second egress path is along the overcasts

Figure 6 show an example of a simulated ventilation model of an operating longwall coal mine with seven heading mains and an exhaust fan system and air velocities.
A summary of main airway velocities (excluding shafts) from few typical operating Australian coal mines is shown in Figure 7.

Figure 7 - Typical airway velocities in coal mines (Belle, 2012)

Amongst various air velocity design factors, another commonly quoted design air velocity is 4 m/s in conveyor road, face areas and intake airways. The basis for this value is to manage the physical discomfort of large dust particles (Figure 8) striking the skin (although not a health hazard) after McPherson (1984). The question is often less debated or questioned is if this conveyor road air velocity value still holds true based upon recent empirical data or studies based on increased daily production rates or speed of conveyor belts or if workers ever likely to be using that particular travel road (by walking) on a regular basis.

Figure 8 - Relationship between air velocity and relative dust concentrations (McPherson, 1984)

Real-time velocity monitoring leading practices

Air velocity is an indicator to monitor and control the hazards and is typically guided by design values. Traditionally, air velocity is monitored by a competent person (deputy or ventilation officer) by means of manual measurement tools such as vane anemometer by means of complete airway traverse or centerline measurements as required by the legislation or mine ventilation COP. However, in recent years, the need for electronic means of monitoring in real-time for management of hazards has become a
reality. Use of real-time velocity monitoring device and by measuring the airway size, airflow rates or gas make are readily determined.

Various studies have been done in the recent years on the use of real-time velocity monitoring in mines by research institutions or instrument suppliers. Real-time ventilation monitoring in coal and metal mines is a leading practice worldwide probably started in UK mines (vortex based velocity monitors). For example, almost all collieries in South Africa have been using the real-time air velocity monitoring devices underground over at least three decades. One of the limitations of these real-time velocity monitors for use in Australian underground coal mines is the complex process of approval certificates by the respective legislative or testing authorities for use in underground mines. However, some of these IS real-time velocity monitors are approved in other mining (coal and metal) countries such as UK, Poland, South Africa, Canada.

Summary of practical benefits from real-time air velocity monitoring are:

- Continuous monitoring of the efficiency of the mine environment system and mine safety in the prevention of mine fires, spontaneous combustion and explosion events.
- Estimation of real-time carbon monoxide, methane and other noxious gas flow rates as an indicator for Trigger Action Response Plans (TARPs) in PHMPs.
- Estimation of gas emissions during panel development and longwall retreat.
- Accurate determination of heat loads and air cooling capacity for thermal hazard management.
- Improved confidence in Ventilation Air Methane (VAM) emission data.
- Estimation and reconciliation of specific methane emissions (SME) for longwall panels and mine emissions.
- Utilisation of real-time air velocity parameter/tag in the widely used Longwall Visual Analyses (LVA) tool.

In the case of Australian mines, monitoring of airflow underground at critical locations in real-time is not an accepted practice and reasons for its non-use are not documented. Anecdotal evidence indicates that perceived maintenance systems prohibit the pursuit of air velocity monitoring systems. Another commonly expressed reason is that the ventilation systems do not change frequently. Other debate typically diverts into the choice between real-time velocity or real-time pressure differential measurement which ultimately results in neither of the systems being considered. What has become noticeable is that most explosions or fire events have occurred in a smallest ‘window’ of change that occurred to the ventilation systems.

Figure 9 show the typical locations of real-time velocity monitoring in bord and pillar sections (left), underground velocity check using Kestrel (a digital anemometer) in low seam ~ 2 m (middle) and high seam (4.5 m) seam (right) coal mines in South Africa.

Real-time air velocity monitors in conjunction with CO, CH₄ and smoke sensors are typically placed at intake and return airways. At the beginning of the shift the Kestrels are calibrated against the known air velocities on the surface and later used underground to check if there are any significant deviations from the real-time vortex real-time velocity monitors. Typically the shift boss would calls the control room operator on surface and check the real-time air velocity readings for any significant deviations. Figure 10
shows the hand held Kestrel calibration on the surface, real-time vortex type air velocity sensor and mobile real-time monitoring sensor cluster of velocity, CH$_4$, CO and smoke sensors.

![Figure 10 - Calibration of Kestrels on surface (left), vortex real-time velocity monitor (centre); CH$_4$, CO, smoke and velocity monitoring instrument cluster in section return (right) in South African collieries](image)

**ROLE OF VELOCITY MEASUREMENT - LW FACE AND MAIN FAN DUCT VELOCITY PROFILES - AN OBSERVATION**

Velocity measurement is a quintessential activity in an underground mine to monitor the hazards on a daily basis by the deputies and ventilation officers. Application of air velocity is typically expanded to understanding the ventilation system effectiveness through velocity profiles like roadways, mine fan ducts and shafts. Velocity profiles are typically carried out to establish the velocity at different points along the longwall face or main fan ducts. Traditionally longwall face velocities of between 1.8 to 2.5 m/s have been considered optimum for longwall operations at conventional height. However, these values have evolved over time. Similarly, main fan duct velocity profiles would provide the main fan operational characteristics and air turbulence profiles in the main fan ducts.

**Longwall face velocities**

Figure 11 shows the LW face air velocities measured on two consecutive days by two different operators on three different longwall faces. Similarly Figure 12 shows the longwall main gate, panel intakes and return air velocities measured at three different longwalls. It is noted that they are also influenced by the location of shearer along the longwall face or if the shearer is operating. For example (Figure 11), for LW 3 (right), shearer was operational on day one (LW3-A); shearer was standing still at main gate chock ten and tail gate chock 160 on day two and three respectively.

![Figure 11 - Influence of manual velocity measurement by different operators in different longwall faces](image)

Measured air velocities when the shearer was operational were higher than when it is standing still at TG or main gate position. However, it is not true for LW2, where the results were opposite to that of LW3. It is important to note that these measurements are typically measured using instruments such as Kestrels (not vane anemometers that are used by the ventilation engineer).

Figure 13 provides the longwall face velocity contours of measured longwall face air velocity data, viz., Chock 15 (top Left), Chock 75 (top middle), Chock 115 with shearer present (bottom Left) and Chock 135 (bottom right). As seen from these profiles based on air velocity measurements, these velocity contours can provide both a visual depiction of the air flow pattern and also a means of quantifying airflow. These
profiles are useful to understand the possible location or presence of gas as well as possible scenarios for ventilation to leak into the goaf. Furthermore, it demonstrates the need to locate the daily velocity measurements taken by deputies throughout the industry. These air velocity readings along with the wet bulb temperature (WBT) and dry bulb temperature (DBT), which would provide the longwall effective temperatures and their status in relation to the TARPs.

Figure 12 - Operator influences on measured air velocities along the longwall face

Figure 13 - Isovels along the longwall face maingate (top left), mid gate (top right), shearer (bottom left) and tailgate (bottom right) locations

These velocity profiles would enable the operator on the Frictional Ignition (FI) potential to ventilation leakage potential into the goaf area. In the prevention of FI, critical monitoring parameters of interest are methane, section or face air velocity, alarm settings of these monitors (Belle, et al., 2012). In all or most of FI incident investigation reports it is noted that there was a failure to analyse the pre-ignition gas trends or velocity trends due to limited manual gas records or unconnected real-time gas recording and data collection system or velocity measurements. Improvement in collection of this crucial information is worth the effort for improved understanding and management of FI risks in the LW or development face areas. Therefore, real-time velocity monitoring installation along the longwall face would be a step in the right direction to the mining industry.

From measurement examples (longwall), it is noticed that without major changes to the ventilation flow, the differences in air velocity readings are significant despite each observer using the similar equipment and measurement techniques. These differences translate themselves onto some other parameters such as determining the effective temperatures for thermal stress or longwall panel gas make or longwall panel CO make. The resulting outputs further translate themselves onto the TARPs or longwall Specific Methane Emission (SME) models, monthly ventilation survey reports or review of simulations models such as Ventsim, or even during accident investigations on Frictional Ignitions (FI). Therefore the need to measure the air velocity beyond the statutory measurement location and their frequencies is increasingly becoming a practical reality.
Main fan duct velocity profiles

Figures 14 and 15 show the isovels of main fan ducts measured from two different exhaust shafts (A and B) with a total seven different fans. These velocity profiles provide a graphical presentation of any issues that can be identified in main fan performance or turbulence associated with the shaft bend designs. What is valuable is that the velocity measurements derived from velocity pressure measurements provide the status of the fans or its future long term use. The isolvel plots suggest that they are definitely different to ideal velocity contours obtained in Computational Fluid Dynamic (CFD) simulations provide by main fan suppliers.

Figure 14 - Isovels measured at three different fan ducts from an exhaust shaft-A

Figure 15 - Isovels measured at four different fan ducts from an exhaust shaft-B

There are several studies on the use of correction factors (including factory correction factors and their given range of velocities) in the literatures; its application in practice is remote. For example Thimmons and Kohler (1975) have suggested that the measurement should always be made at a minimum distance of three roadway diameters upstream of an obstruction and ten roadway diameters downstream of an obstruction. In reality, presence of these ideal locations is scarce or simply they do not exist. Measurement experiences suggest that each operation or a location underground or even the velocity contour profiles of a roadway which is dynamic is different and thus development or application of these correction factors are remote.

Critical measurement aspects that are commonly faced by the ventilation surveyors underground and during surface fan performance evaluations are:

1. Art of velocity measurement (years of experience u/g and correlating monthly ventilation reports to independent surveys);
2. Practical locations of velocity readings to be taken underground (high velocity turbulent regions or sharp bends);
3. Instruments used and their calibration on surface (kestrel or vane anemometers);
4. Underground environment conditions (humid and dusty vs. comfortable conditions);
5. Time constraints and understanding of significance of ‘velocity values’ to be used after the ventilation surveys.

Above pragmatic measurement challenges offer the users the benefits of fixed real-time velocity monitoring systems to minimise various operator (human) errors identified above.

**Australian experiences of real-time velocity monitoring on main fans**

With no means of measuring emissions from the mine in real-time and without compromising current mine monitoring systems dedicated for mine safety, specifically sponcom, explosion prevention and management of thermal stress, the need for dedicated real-time airflow monitoring at strategic underground locations is quintessential. Typically, during most shifts various measurements are taken and ideally these are analysed for suitable trends. These trends at times may identify the deficiencies in controls or measurement errors. For example, analyses of recorded underground data on temperature measurements and associated air velocities suggested that LW mid face temperatures were higher than the tailgate temperatures with constant ventilation flow. Later the measurement bias was rectified through toolbox talk, whereby temperatures and air velocity were taken at the same time on each shift and at the same location on a consistent basis. These accurate data are typically used to evaluate the performance and effectiveness of the mine cooling systems.

Figure 16 shows possible location for real-time velocity monitoring system in an underground drift which is a common practice in overseas mines.

![Figure 16 - suitable location for real-time air velocity measurements to carry out performance evaluation of Bulk Air Cooler (BAC)](image)

In recent past, the introduction of a carbon price on Green House Gas (GHG) emission has further necessitated the need for accurate airflow data from mine exhaust systems. The biggest variable in the carbon emission is the airflow. Most mines have established the emission inventory using the existing manual ventilation measurement practices in accordance with the obligations of the National Greenhouse and Energy Reporting Scheme (NGERS) Act (2007). The NGERS Act underpins the Carbon Pricing Mechanism which was introduced on 1st July 2012. The mine Ventilation Air Methane (VAM) is a significant constituent (over 70%) of past, current and future underground carbon emissions.

A significant opportunity exists in Australian coal mines to build a robust, compliant, accurate and transparent VAM reporting system through improved real-time airflow monitoring systems instead of the current user of manual monthly ventilation surveys. Both internal and later external VAM compliance audits have identified the need for a paradigm shift in VAM monitoring systems in terms of resolution and frequency of measurement of key data components. The common findings from most carbon audits is that the current single monthly ventilation survey data for VAM estimation is deemed as a ‘Potential Risk of Non-Compliance’ due to the materiality of ‘Run-of-Mine Coal Extracted from Gassy Underground Mine’ emissions. Typically any changes in ventilation system (such as slowing down of fans or maintenance of a single fan or brief power failures) or errors associated with the ventilation measurement are not captured in the estimated carbon emissions. This is because the monthly ventilation surveys do not capture them. For example, 400 m$^3$/s of airflow with 0.3% methane, 10% changes in airflow alone would relate to additional carbon tax of AUD$1.4 million per annum. Similarly, a 5% error in manual measurement flow at 0.36% methane over a 5 year period would have an emission cost of AUD$10.9 million at carbon price of AUD$23. Acknowledging these significant costs, the VAM monitoring system considered by mines is typically independent of current systems which are dedicated to mine safety.
As a proactive approach, most mines are implementing the underground use of approved IS ultrasonic flow monitoring devices at the exhaust shaft fan ducts. It is also noted that a handful of coal mines are in the process of implementing these real-time monitors underground. Current installation of monitoring systems at exhaust shaft fan ducts or underground shaft bottoms incorporate independent measurement of real-time exhaust airflow, CH₄, CO₂, temperature (WBT and DBT), moisture and pressure to improve VAM measurement accuracy which is a largest variable in the VAM greenhouse gas estimates. The introduction of leading practice of real-time monitoring of airflow and low range gas measurements at fan ducts will enable mines to produce transparent emission reports and also enable immunisation from carbon tax estimation errors. Recently, these systems have been implemented at mines in NSW, Moranbah North Mine and are also proposed to the new Grosvenor mine.

Figure 17 shows the implementation of real-time ultrasonic air velocity monitoring system installed on main fan ducts. Figure 18 demonstrates the daily real-time air flows measured at individual fans (for a period of 34 d) and the average airflow measured over a period of 5 months. The average airflow measured from underground surveys over a period of five months was 253 m³/s. Similarly, the average flow recorded using real-time air velocity for a period of 32 d was 219.78 m³/s with a difference of 13.25%. Other benefits of obtaining the air velocity trends from each fans is to evaluate individual fan performance against the planned airflow in mine ventilation designs and ventilation simulation models. In this example, it is easily noticeable that Fan A is significantly different than the other two main fans. In addition, the impact of airflow measurements is significant on the estimation of greenhouse gases as well as associated annual costs in the region of $580 000 for a methane concentration level of 0.2%. Table 3 provides the carbon costs associated with variations in measured velocities and methane concentrations.

Another significant parameter that is used in determining the airflow is the area of a roadway. Typically, 5% is considered to be an acceptable error during underground airway measurement survey. Even with this low level of acceptable error the carbon cost is significant, i.e., at 0.2% methane level for a roadway area of 20.30 m², 5% accepted error in airway area (m²) would be costing around ±$200 000 per annum (Table 3).
Table 3 - Cost of carbon with variation in methane levels and various accuracy levels on measured air velocity

<table>
<thead>
<tr>
<th>Air Velocity, m/s</th>
<th>0</th>
<th>0.01</th>
<th>0.075</th>
<th>0.1</th>
<th>0.125</th>
<th>0.175</th>
<th>0.2</th>
<th>0.225</th>
<th>0.21</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH4 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>$300,000</td>
<td>$290,000</td>
<td>$280,000</td>
<td>$270,000</td>
<td>$260,000</td>
<td>$250,000</td>
<td>$240,000</td>
<td>$230,000</td>
<td>$220,000</td>
</tr>
<tr>
<td>5%</td>
<td>$325,000</td>
<td>$315,000</td>
<td>$305,000</td>
<td>$295,000</td>
<td>$285,000</td>
<td>$275,000</td>
<td>$265,000</td>
<td>$255,000</td>
<td>$245,000</td>
</tr>
<tr>
<td>10%</td>
<td>$350,000</td>
<td>$340,000</td>
<td>$330,000</td>
<td>$320,000</td>
<td>$310,000</td>
<td>$300,000</td>
<td>$290,000</td>
<td>$280,000</td>
<td>$270,000</td>
</tr>
<tr>
<td>15%</td>
<td>$375,000</td>
<td>$365,000</td>
<td>$355,000</td>
<td>$345,000</td>
<td>$335,000</td>
<td>$325,000</td>
<td>$315,000</td>
<td>$305,000</td>
<td>$295,000</td>
</tr>
<tr>
<td>20%</td>
<td>$400,000</td>
<td>$390,000</td>
<td>$380,000</td>
<td>$370,000</td>
<td>$360,000</td>
<td>$350,000</td>
<td>$340,000</td>
<td>$330,000</td>
<td>$320,000</td>
</tr>
</tbody>
</table>

What is an acceptable velocity measurement error in the carbon era? Current guidelines do not necessarily clarify the measurement challenges associated with air velocities, let alone measurement air velocity accuracy. Historically, there are few references to acceptable measurement errors. Thimmons and Kohler (1985) have expressed the definitions on accuracy requirements for mine ventilation applications. They had expressed the accuracy of ±20% is satisfactory based on the ventilation measurement practices of 1970s. Also, recently, there are suggestion of ±5% error value that is viewed as an acceptable air velocity measurement error in an underground mine (Martikainen, et al., 2011).

Considering the recent financial impacts, lack of a standard on an acceptable measureable error persists and in addition, which velocity measurement instrument to be seen as a ‘reference true velocity measurement device’ to estimate the accuracy of a velocity measurement device needs to be established by the mining industry.

ENVIRONMENTAL MONITORING SYSTEM, MAINTENANCE DILEMMA AND IMPLEMENTATION BENEFITS

Continuous on-line velocity monitoring systems will facilitate the establishment and maintenance of a safe environment underground if well installed, maintained and monitored. Such a system will give early warning of a fire, spontaneous combustion heating, abnormal methane or carbon monoxide gas concentrations and a failure or weakening of the air flow. Prompt response can then be taken to deal safely with the abnormal situation provided controls are in force and manageable. Interested parties in determining the real-time velocity monitoring strategy are the ventilation officer, mine manager assisted by the mechanical and electrical engineering manager. Most of the Australian coal mines incorporate CH4, CO, CO2, and O2, barometric pressure monitoring systems stationed at strategic locations along the intake, return and longwall face and on the surface. The monitoring of air velocity at strategic positions will indicate the status of the air distribution in the mine on a continuous basis. For example, the ventilation and heat simulation software tools like Ventsim Visual have the facility to incorporate real-time velocity tags for live simulations. The real-time velocity monitors will give early warning of a weakening in airflow or a ventilation failure. It will also indicate a weakening trend in airflow and action can therefore be taken before a gas accumulation develops. Benefits of real-time velocity monitors will provide ventilation engineers additional information on whether an increase in gas levels is due to increase in gas release rate or reduced ventilation.

Just as in real-time and tube bundle environmental monitoring systems, the maintenance of real-time velocity monitoring system is of vital importance. Confidence in the system will be lost if the system is not maintained and kept in a fully operational condition as in other real-time measurement parameters such as CH4, CO, O2 sensors. All existing real-time and tube bundle systems require adequate maintenance as per the Australian Standard (AS) 2290.3. Failure to address this will lead to misinterpretation of conditions underground and should be addressed without delay by relevant person responsible for the installation and maintenance of the monitoring systems. As in the case of existing environmental monitoring systems, the inspection should include provision for frequency of cleaning of monitors, testing of response of monitors, replacing malfunctioning monitors, a documentation system to include installation, cleaning, testing and replacement dates. As in the case of existing environmental monitoring systems, air velocity monitors must be provided with battery back-up power which must switch on automatically in the event of a power failure.

CONCLUSIONS

The monitoring of air velocity at strategic positions will indicate the status of the air distribution in the mine on a continuous basis. The velocity monitors will give early warning of a weakening in airflow or a
ventilation failure. It will also indicate a weakening trend in airflow and action can therefore be taken before a gas accumulation develops. Benefits of real-time velocity monitors will provide the ventilation engineers additional information on whether the increase in gas levels is due to increase in gas release rate or reduced ventilation.

Use of real-time air velocity monitoring technology underground can aid the ventilation engineers, longwall operators, technical services managers, safety officers and emergency response personnel for any unanticipated surprises on gas or ventilation situation and develop speedy interventions and thereby reduce production downtime. Therefore, monitoring of air flow in real-time is essential and is a leading practice in evaluating the performance of underground environment conditions and must be pursued by the Australian mining industry into the next decade.

Air velocity and area of a roadway, and wet bulb temperatures (WBT) and dry bulb temperatures (DBT), CH₄, CO₂, barometric pressure are the key parameters that will assist in understanding the key hazards (gas, dust, sponcom, thermal), associated risks and the effectiveness of controls provided at the workplace. Therefore, it is important that these parameters are accurately measured by those who are responsible for them.

It is hoped that the implementation of real-time velocity monitors that are glaringly absent in the Australian coal mines that have one of the best gas monitoring systems would consider this improvement opportunity to clear out any distractive comments or criticisms on Australian Safety and Health Systems. In author’s opinion, it is never too late to implement the real-time velocity monitors in mines, a life saving safety enabler and a leading practice that exists in the rest of the coal mining countries.

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