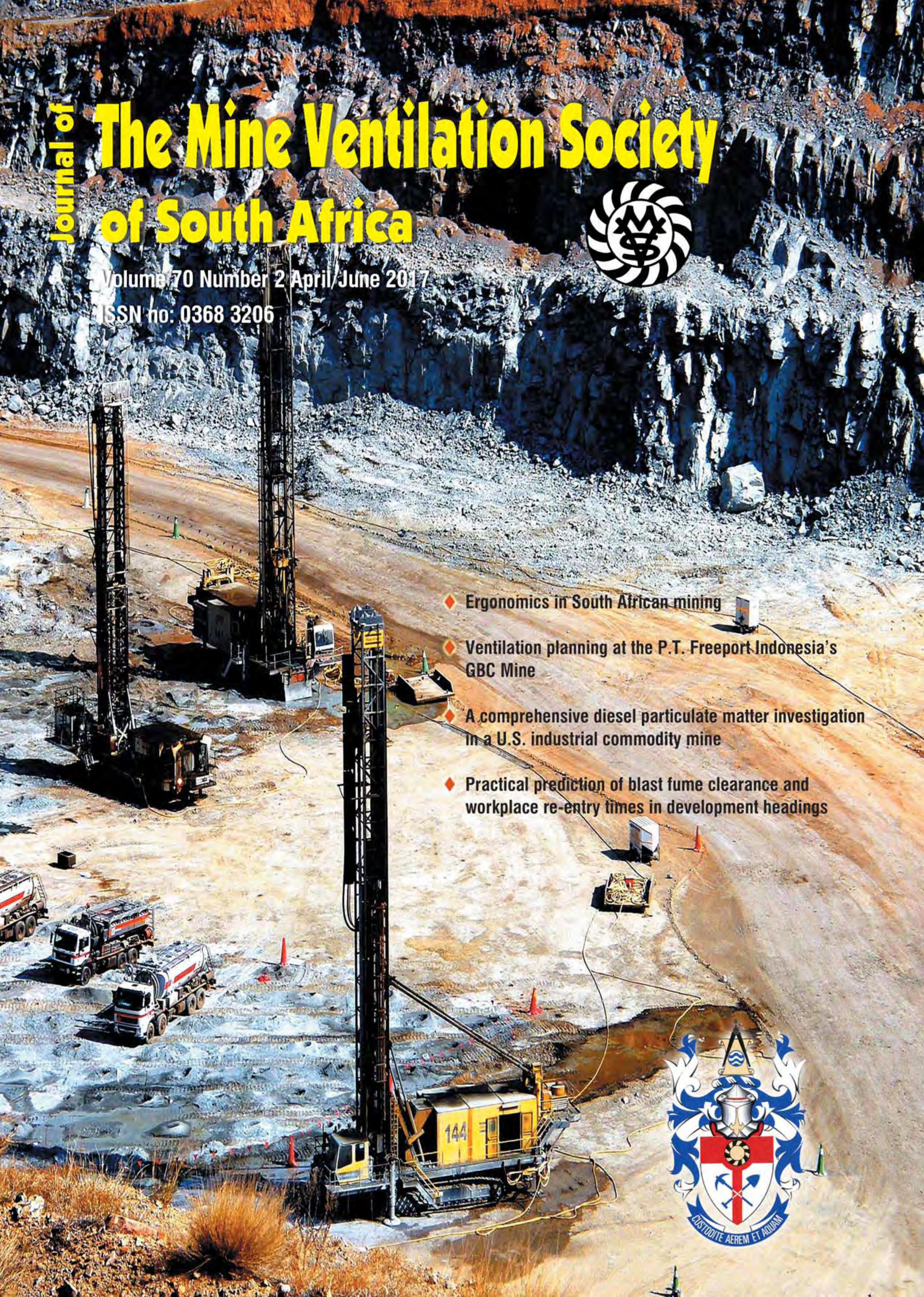

Journal of The Mine Ventilation Society of South Africa

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- Ergonomics in South African mining
- Ventilation planning at the P.T. Freeport Indonesia's GBC Mine
- A comprehensive diesel particulate matter investigation in a U.S. industrial commodity mine
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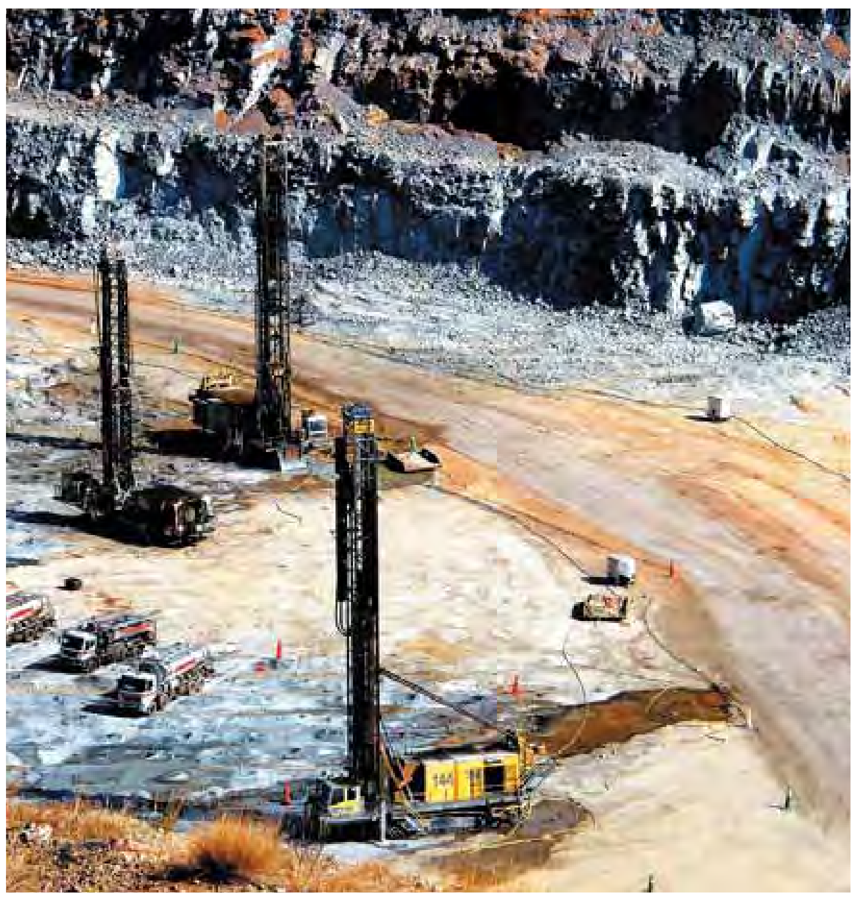

Photo taken by Julize van Niekerk

Editor's Comment

Prof Jan du Plessis
Honorary Editor

Please send your comments and opinions to info@mvssa.co.za

During a number of recent engagements, the topic of what do associations and societies do for their members was again discussed. Societies and associations of like-minded professionals should in itself be enough motivation to consider being part of. The intend of societies is to assist in the development of young and upcoming professionals. It is sad to often hear that some of the young professionals do not fully understand the value proposition of societies.

Through the years we in the MVSSA have been privileged to have some of the foremost leaders and academic members forming part of and leading our professional society. The ever changing mining landscape has brought many additional challenges to the daily tasks associated with mine ventilation. These challenges will only increase in the future as the mining industry continues to strive to improve the working conditions within and around the mines.

We have been dealing with the challenges that are associated with deep hot mines for many years. In the past decade we also have had to reconsider how we deal with this as energy costs have escalated rapidly, and at some stages we also had the risk of security of supply. These challenges have been met with new and innovative designs, use of alternative and more energy efficient systems and equipment. These challenges were solved through using sound engineering solutions. Some of the remaining challenges that have not yet been resolved are human interface with mining.

In this issue one of the papers considers the impact of ergonomic design and it clearly highlights the risk of poor design.

The exposure of workers to dust and diesel particulate matter continues to be one of the major challenges associated with mining. Recent articles published in the USA and Australia have again highlighted the risk of coal worker pneumoconiosis - more generally known as Black Lung. In South Africa we have been well regulated and mines have developed a well-guided set of good mandatory code of practices assisting us in our efforts to manage the exposure to airborne pollutants. As time has passed, it has become clear that our original agreed-to occupational exposure limits may not have been set low enough to protect mine workers over an extended mining career.

Considering this, we must ask ourselves whether the current design standards are adequate to be able to design and assist in the managing of our mines to protect workers so that they return home safely and healthy. Historically we have not been able to guarantee this and perhaps we need to start a debate on what is required to be able to ensure this in the future so that history does not repeat itself.

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It would be appreciated that the questionnaire below be completed and faxed or e-mailed to any one of the person/s listed below:·

- Prof Jan du Plessis info@mvssa.co.za, or
- MVS Office, Fax 086 660 7171, e-mail secretary@mvssa.co.za

All communications will remain confidential in terms of identification of the communicator. Should you wish to remain anonymous you are welcome to do so.

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Ergonomics in South African mining

C.J. Badenhorst, Anglo American, South Africa

ABSTRACT

In 1996 the South African Mines Health and Safety Act was promulgated. The Act was amongst the first South African legislation published to set statutory requirements relating to ergonomics. 18 years since the promulgation of the Act, there is a need to assess the current status of ergonomics in the South African mining industry and the potential risks associated with the failure to address ergonomic stressors in mining. Against this background, a load haul dumper (LHD) vehicle used underground at a South Africa platinum mine was assessed to identify the ergonomics-related hazards that could impact on the operators' ability to work safe and efficiently. The majority of vehicles used in underground platinum mines pose a certain level of risk in terms of ergonomic stressors as was found in this ergonomics assessment. In most cases these risks are not identified as part of the basic hazard identification and risk assessment processes, and for those few that are identified, the risks are not understood and limited so no steps are taken to manage risk.

Keywords: *Ergonomics, load haul dumper, platinum mine, risk management, design.*

INTRODUCTION

The International Ergonomics Association defines ergonomics as: "the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance". As a practice, ergonomics applies human-systems interface technology to the analysis, design, standardisation and control of systems to improve safety, health, comfort and productivity. From a practical point of view, ergonomics is the science and practice of designing systems to fit people. In the workplace, the application of ergonomics aims to minimise design-induced human error and to promote the health, efficiency and well-being of workers.

Derived from the Greek ergon (work) and nomos (laws) to denote the science of work, ergonomics is a systems-oriented discipline which now extends across all aspects of human activity. Practising ergonomists must have a broad understanding of the full scope of the discipline. That is, ergonomics promotes a holistic approach in which considerations of physical, cognitive, social, organisational, environmental and other relevant factors are taken into account. Ergonomists often work in particular economic sectors or application domains. Application domains are not mutually exclusive and they evolve constantly; new ones are created and old ones take on new perspectives.

There exist domains of specialisation within the discipline, which represent deeper competencies in specific human attributes or characteristics of human interaction.

Original paper presented at the the 10th International Mine Ventilation Congress 2014

Domains of specialisation within the discipline of ergonomics are broadly the following;

Physical ergonomics

Physical ergonomics is concerned with human anatomical, anthropometric, physiological and biomechanical characteristics as they relate to physical activity. (Relevant topics include working postures, materials handling, repetitive movements, work related musculoskeletal disorders, workplace layout, safety and health).

Cognitive ergonomics

Cognitive ergonomics is concerned with mental processes, such as perception, memory, reasoning, and motor response, as they affect interactions among humans and other elements of a system. (Relevant topics include mental workload, decision-making, skilled performance, human-computer interaction, human reliability, work stress and training as these may relate to human-system design).

Organisational ergonomics

Organisational ergonomics is concerned with the optimisation of sociotechnical systems, including their organisational structures, policies, and processes. (Relevant topics include communication, crew resource management, work design, design of working times, teamwork, participatory design, community ergonomics, cooperative work, new work paradigms, virtual organisations, telework, and quality management).

Local and international safety statistics indicate that ergonomic factors (mostly physical ergonomic factors) underlie many of the accidents occurring in mines, and could impact negatively on the effective and efficient operation of mining machinery and transport systems.

In an industry-wide risk assessment conducted under the auspices of the Safety in Mines Research Advisory Committee (SIMRAC) in 1997, it was indicated that poor ergonomic design and the lack of strategy for introducing ergonomics into the South African mining industry were major contributing factors to the development of work-related injury and disease. (de Koker and Schutte, 1999).

A lack of research in ergonomics in the local mining industry and a very small knowledge base was also identified as major short-comings and contributing factors. (Harper, 1997).

A large number of physical ergonomic hazards leading to the risk of musculoskeletal problems exist within the mining working environment. This is created by the man-machine interface and thus affects design of all equipment and workplaces where there is a human operator or occupant.

Assessment and management of the risks are essential from the design and purchase stages through to day-to-day operation and maintenance. Exposure to these hazards represents a critical and persistent source of injuries to miners. On an annual basis, such injuries represent a significant category of non-fatal, lost-time injuries and occupational disease, associated absence from work and a significant loss of productivity.

Despite the fact that local as well as international statistics indicate that ergonomic factors underlie many occupational accidents and work-related diseases, it is surprising that ergonomics is not an integral part of management procedures to ensure health, safety and productivity in the South African mining industry.

Although there is a growing awareness of the need for ergonomics, very little has been done about its application. (Schutte, 2005).

Against this background, a load haul dumper (LHD) vehicle used underground at a South Africa platinum mine was assessed to identify the physical ergonomics-related hazards that could impact on the operators' ability to work safe and efficiently. Cognitive and organisational ergonomic stressors were excluded from the assessment. (MHSA, 1996)

South African legislation

South Africa Mine Health and Safety Act, Act 29 of 1996.

- Section 5, Employer to maintain healthy and safe mine environment:

  "5.(1) As far as reasonably practicable, every employer must provide and maintain a working environment that is safe and without risk to the health of employees"

- Section 11, Employer to assess and respond to risk.
- Section 12, Employer to conduct occupational hygiene measurements
- Section 13, Employer to establish system of medical surveillance
- Section 21, Manufacturer's and supplier's duty for health and safety:

  "21.(1)(c) Any person who designs, manufactures, erects or installs any article for use at a mine must ensure, as far as reasonable practicable, that ergonomic principles are considered and implemented during design, manu-facture, erection or installation."

Standards

Observed occupational health and safety hazards and risks resulting from ergonomic related factors can be ascribed predominantly to workstation designs based on anthropometric data. In most instances available anthropometric data are not entirely suitable for the South African user population.

In 2000 SIMRAC commissioned a research project on the ergonomics of locomotive design in the gold and platinum mines in South Africa. (Schutte and Shaba, 2000).

A report of this study provides recommendations and a range of data that can be used to improve the ergonomics aspects and the design or selection of mining locomotives and guard cars.

This information could also, together with appropriate anthropometry, be used as a basis for the assessment of the ergonomics of underground transport vehicles in use at a mine, as was done in this assessment.

METHODS

Assessment protocols developed during SIMRAC (Schutte and Shaba, 2003) and SIMRAC (Schutte and Shaba, 2000) were used as the basis for evaluation and assessment of ergonomic stressors of the LHD.

The ergonomic assessment consisted of inspections to identify potential ergonomics-related hazards in the design and operations of the LHD. In cases where obvious ergonomics-related risks were identified, further dimensional evaluations were performed.

Operators and supervisors were also interviewed to obtain information and other data not apparent during walk-through observations.

The assessment was based on a random set of selected parameters; therefore certain ergonomic hazards may exist which have not been identified during this assessment.

Typical ergonomic aspects of the LHD assessed at the operator's workstation are shown in the figure below, and their descriptions are presented in Table 1.

Table 1.Primary ergonomics aspects at the LHD operator's workstation

Reference	Description
	Seat dimensions
A	Leg clearance (forward horizontal distance from the SRP* to the cab panel)
B	Head clearance (vertical distance from the SRP* to the cab roof line)
C	Lateral shoulder space inside the cab
D	Lateral leg room (the space around the feet)
E	Eye view above 0? Horizontal
F	Eye view below 0? Horizontal
G	Eye view to either side
H	Distance obscured in front of the vehicle

** SRP - the point of reference where the three axes intersect between the seat base and the seat backrest.*

The LHD at the mine was assessed against the following parameters:

- Climbing in or on (access)
- Operator's cab
- Operator's seat
- Working position and controls
- Instrumentation
- Climatic conditions inside the cab
- Exhaust fumes and dust
- Visibility from the cab
- Exterior and interior lighting
- Noise
- Vibration
- Operator maintenance work
- Physiological indicators.

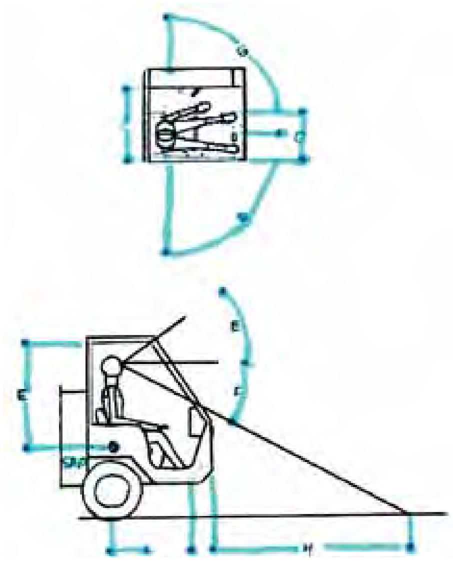


Figure 1. Typical ergonomic aspects of the LHD assessed at the operators' position

RESULTS

The ergonomics-related risks resulting from inadequate design considerations are indicated and discussed below, under the headings of the stated parameters.

Climbing on and off (access)

A convenient and safe means of access to and from the cab, with no danger of the operator being injured by slipping, etc. is especially important in jobs where the operator has to leave the cab at frequent intervals.

Furthermore, poorly designed steps, handholds, etc., may make it difficult for people to do the job. The cab design should also incorporate facilities that enable the operator to bail out quickly in an emergency, essential in the case of fire.

Cabin ingress and egress proved to be a problem. The cabins are low with a high entrance level to cab floor-line and with the restricted entrance width so that the act of mounting a LHD created strain on the operator. Further strain is added by the difference in entrance level and cab floor-line. A single handrail is provided at the roof level of the cabin. Hand clearance between the retaining surface and the inner surface of the handrail is inadequate. The light located to the right of the handrail restricts the hand clearance area surrounding the handrail to 40 mm, compared to a preferred 76 mm. The fact that the operators of the LHDs on average do not climb in and out of the cabins more than 5 per shift (climbing on and off, count as one), lower the criticality of this parameter for the successful execution of operator's task.

Parameter	Range of values	Preferred	Measured
ACCESS			
Surface to entrance-level height	380 mm - 500 mm (max)	380 mm	580 mm
Entrance level to cab floor-line	0 mm - 200 mm	0 mm	210 mm
Entrance width	500 mm - 760 mm	760 mm	*
Entrance level to roof line	1300 mm (min)	870 mm	
Handrails:			
Length	150 mm - 300 mm	200 mm	N/A
Diameter	25 mm - 32 mm	32 mm	N/A
Hand clearance between the retaining surface and the inner surface of the handrail		76 mm	55 mm*
Hand clearance area surrounding the handrail		76 mm	40 mm
Centre of hand-rail to ground	1000 mm - 1470 mm	1250 mm	1400 mm

			Importance		
Point to assess	**Yes**	**No**	**High**	**Low**	**N/A**
Is the access to and from the cab convenient based on measurements taken (gap between steps, the design, location and function of handles, hand-holds, door and steps)?		X	X		
Can the operator climb in and out with no danger of slipping (type of materials used, design and location of steps, etc.)?		X	X		
Can the operator climb in and out with no risk of injury from other causes (sharp edges, pointed corners, etc.)?		X	X		
Is it easy to reach the operating position?		X	X		
Is an emergency exit, other than the door, provided?		N/A			N/A
Are the steps designed or positioned in such a way that they are unlikely to be damaged during operations?		N/A			N/A

OVERALL ASSESSMENT OF DESIGN

Extremely unaccept -able	Unacceptable	Barely unacceptable	Barely acceptable	Acceptable	Extremely Acceptable
-5	-3	-1	+1	+3	+5

OVERALL ASSESSMENT OF ERGONOMIC IMPORTANCE

1	2	3	4	5	6	7	8	9	10

Operator's cab

The operator's cab should be large enough for the operator to be able to adopt a comfortable working position. In the case of both

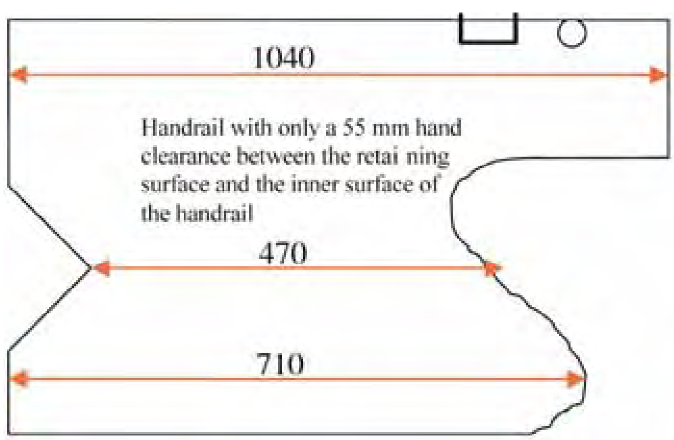


Figure 2. Figure indicating the dimensions of the entrance to the drivers' cab

Figure 3. Driver position inside the cab

Parameter	Range of values	Preferred	Measured
OPERATOR'S WORKSTATION			
Leg clearance (forward horizontal distance from SRP to cab panel)	910 mm - 1000 mm	1000 mm	1000 mm
Head clearance (vertical distance from SRP to roof line)	Erect seated stature of the 9th percentile male South African + 100 mm	1100 mm	930 mm
Shoulder clearance (dynamic elbow/ abducted arm space, the minimum width of the cab)	875 mm - 1000 mm (minimum)	910 mm	600 mm
Leg room (lateral space around the feet on the cab floor-line)	690 mm - 900 mm	880 mm	570 mm

forward and reverse operations a larger cab must be provided for. It should be remembered that if the cab is unnecessarily large there will be a reduction in visibility. There should not be any protruding parts that could injure the operator.

Inadequate cabin space, controls in the wrong location and information displays that are difficult to read resulted in operators adopting awkward postures.

The awkward postures, particularly if they are adopted repeatedly or over long periods, may cause discomfort and fatigue, and increase the risk of musculoskeletal disorders. Shoulder clearance and available leg room (i.e. lateral space around the feet on the cab floor-line) is of concern.

With the cab being confined and the limited cabin space, upper body size of operators should be considered as a selection criteria for future employment (part of the man-job specification).

Operator's seat

The seat should provide firm support and enable the operator to work comfortably. Discomfort due to poor support often develops

			Importance		
Point to assess	**Yes**	**No**	**High**	**Low**	**N/A**
Is the cab large enough based on the measurements taken?		X		X	
Is the cab free from protrusions that could injure the operator?	X			X	
Is the floor free of obstacles?	X			X	
Are the working areas free of obstacles?		X	X		
Is the cab floor fitted with non-skid material?	X			X	
Is the cab floor fitted with isolating material?		X			X
Is the cab easy to keep clean?		X		X	
Are windows fitted?		X			X
Are windows made of safety class?		X			X
Are protective screens fitted over cab openings?		X		X	
Are the locking mechanisms for the doors easy to reach and operational?		X			X
Are the locking mechanisms for windows easy to reach and operational?		X			X
Are pipes and hoses guarded inside the cab?	X			X	
Is there a fire extinguisher?	X		X		
Is the fire extinguisher easily accessible?	X		X		
Does the cab have an operator protection structure (ROPS and FOPS)?	X		X		

OVERALL ASSESSMENT OF DESIGN

Extremely unaccept -able	Unacceptable	Barely unacceptable	Barely acceptable	Acceptable	Extremely Acceptable
-5	-3	-1	+1	+3	+5

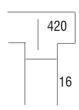
ASSESSMENT OF ERGONOMIC IMPORTANCE

1	2	3	4	5	6	7	8	9	10

over long periods of time and the effect of poor posture is not immediately evident.

The operator's seat should be securely anchored. The height and the fore and aft position of the seat should be easy to adjust, so that the seat position can be altered to suit the build of the majority of operators. The reference values given below refer to operators who are between 158 and 190 cm tall. It should also be

Figure 4. Seat design and condition

Parameter	Range of values	Preferred	Measured
SEATING			
Type	Cushioned seat with backrest that can accommodate the personal protective equipment, no sharp edges	T-shaped backrest	T-shaped backrest
Vertical adjustment range from recommended mid-range	0 mm - 40 mm up and down	80 mm	60 mm
Horizontal adjustment to the fore and aft positions	150 mm - 200 mm	180 mm	0
Seat base:			
Cushion thickness	25 - 50 mm	38 mm	70 mm
Width	485 mm - 510 mm		400 mm
Depth	420 mm - 445 mm		100 mm
Height (SRP to cab floor-line)	300 mm - 550 mm	350 mm	320 mm
Slope towards the SRP	5º - 8º		<10º
Seat backrest:			
Height (from SRP)	300 mm - 650 mm	600 mm	440 mm
Width	480 mm - 510 mm; 200 mm minimum only in area where provision for personal protective equipment at waist level is required for T-shaped backrest	485 mm	
Angle from vertical plane	6.5º - 30º		30º
Arm rest:			
SRP to top surface of the armrest		235 mm	N/A
width	50 mm - 120 mm	75 mm	N/A
length	210 mm - 300 mm	220 mm	N/A
Spacing (inside dimensions)	480 mm - 510 mm	500 mm	N/A

possible to adjust the seat and back-rest independently. The suspension and damping of the seat should effectively reduce shaking and jolting and should be adjustable to suit different body weights.

For evaluation, a reference point called the seat reference point (SRP) is used. It is defined as being the point where the backrest surface, seat surface and midline of the seat intersect.

The seats in LHDs assessed were in a poor, and in some instances in an unserviceable, condition.

Seats have limited (only in a horizontal plane) seat-adjustment controls. These controls were found either not to be used by the operators or not to be in working order.

The dimensions of the seats fitted in the LHDs were found to be acceptable, except for the depth of the seats (100 mm vs. a preferred depth of 420 - 445 mm).

			Importance		
Point to assess	**Yes**	**No**	**High**	**Low**	**N/A**
Is the position of the seat in the cab acceptable?		X	X		
Does the backrest provide acceptable lower back and side-to-side support?		X	X		
Does the seat provide acceptable side-to-side support and prevent the operator from sliding forward?		X	X		
Is the seat securely anchored?	X		X		
Can the seat be easily adjusted?		X	X		
Can the seat be adjusted for different body weights?		X	X		
Once rotated can the seat be locked in position?					X
During driving operations can the operator work without having to twist the body or having to adopt uncomfortable positions?		X	X		
During stationary operations can the operator work without having to twist the body or having to adopt uncomfortable positions?		X	X		
Are there conveniently located arm rests?		X		X	
Is there an adequate restraint system for the operator (seat belts)?		X		X	
Can the restraint system be positioned for operator comfort?					X

OVERALL ASSESSMENT OF DESIGN

Extremely unaccept -able	Unacceptable	Barely unacceptable	Barely acceptable	Acceptable	Extremely Acceptable
-5	-3	-1	+1	+3	+5

OVERALL ASSESSMENT OF ERGONOMIC IMPORTANCE

1	2	3	4	5	6	7	8	9	10

Body worn self-contained self-rescuers and cap lamp battery packs hinder quick exit out of the cabins. Furthermore, these damage the backrest of the seats, as can be seen on the photos in figure 4.

Seats have no shock absorbing mechanism. This results in whole body vibration exposure of operators and continuous shock impacts on the back, especially lower back areas, of operators.

Optimum seat design should provide adequate support for the operator while he or she is working or driving. The seat should not place any unnecessary stress on any part of the body and should encourage optimum posture, allowing for comfort, efficiency and minimal muscle fatigue.

People vary markedly in size and this range must be allowed for in the dimensional specifications of seats.

In order to accommodate 95% of the target user population, some adjustability can be incorporated into design, for example, seat height, backrest angle, and fore and aft adjustments. Adjustments should be easy to achieve for any user in the seated position.

OPERATOR'S WORKING POSITION AND CONTROLS

To avoid undue strain on the operator, the design of the cab must allow the operator to work in a comfortable position, i.e. the use of limbs should not give rise out any immediate discomfort or to potential long-term effects. Accordingly, positions such as where the operator has to twist around, must be avoided. Moreover, the operator should be able to alter posture and position from time to time.

It must be possible for a comfortable working position to be adopted by operators of varying physique. Thus, arrangements must be met in respect of the relative positioning of the seat, controls and pedals.

Controls which are frequently used, or which have a bearing on safety, should be positioned well within the primary reach area. No part of the range of lever movement should fall outside the area of convenient hand movement. Actuating forces should not make controls difficult to operate nor make them subject to accidental activation.

The type of control provided should be suitable for the function in question. Switches or push buttons should be used for start/stop or on/off functions. Levers are generally provided when continuous and infinitely variable control is required. Hand-operated controls are best when precision or speed is required. Foot-operated controls should be used when considerable force or continuous activation not requiring precision is necessary, and to keep the number of hand-operated functions at a reasonable level.

Control functions should be logical and the number of functions performed by a given control reasonable. Controls should conform to established customs within a type of machine. For example:

- Forward lever movement should mean increased throttle power, or downward movement of a working unit (blade, boom, etc.). Rearward lever movement should mean the opposite. Right or left control movements should correspond to the right or left movement of the working unit.
- Knobs should normally turn clockwise for increased electrical current or fluid flow, and counter-clockwise for the reverse.
- Red colour is associated with stop or danger.

The design of the controls should be such that the operator can obtain a secure grip on them. Their arrangement and coding should eliminate the risk of confusion and of the controls being involuntary activated. Coding refers to any of the means of identifying the functions of a control: e.g. symbols, colour, shape, etc.).

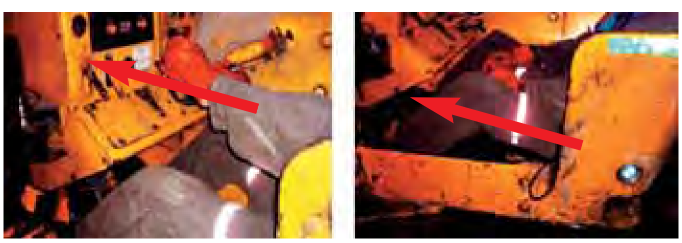


Figure 5. Position of the operator in relationship to the displays

Typical shortcomings observed with regard to displays include poor positioning of displays, incorrect labelling, no labelling, or if

Parameter	Range of values	Preferred	Measured
CONTROLS			
Forward reach distance (from SRP to hand controls in the most forward seat position for the 5th percentile person and in the most rear seat position for the 95th percentile South African male	Forward seat position: 180 mm - 330 mm Rear seat position: 350 mm - 500 mm		680 mm 720 mm
Vertical distance from SRP to the hand controls	300 mm - 380 mm	320 mm	580 mm
Hand Levers:			
Clearance area around the control	76 mm	76 mm	140 mm
Clearance - front		75 mm	N/A
Minimum length of hand control portion	115 mm - 150 mm	150 mm	210 mm
Hand control diameter	25 mm - 32 mm	32 mm	
Diameter of push-button controls	13 mm - 19 mm	19 mm	
Start / Stop button			40 mm
Screen controls			28 mm
Horn			15 mm
Foot pedals:			
Distance from SRP to bottom of foot pedals	690 mm - 860 mm	700 mm	830 mm
Angle of foot pedals	< 30	20	15°
Width and depth of foot pedals	75 mm - 100 mm		Petrol 120 x 300 Brake 70 x 290
Clearance between pedals (must allow sufficient space to avoid inadvertent application or sufficient space to pass a boot inbetween the pedals)	50 mm or 150 mm	50 mm	70 mm

present, the labels were damaged, dirty and illegible. As far as controls are concerned, the positioning and configuration are not optimal in terms of ergonomics requirements.

The arrangement and dimension of foot pedals, i.e. in terms of distance from SRP to the bottom of the foot pedals, angle of the foot pedals, width and depth of the foot pedals and clearance between the pedals, are within preferred specifications.

Vertical distance from SRP to the hand controls in the observed LHDs is of concern, 580 mm vs. a preferred distance of 320 mm, resulting in operators having to reach for certain of the controls or adopting unnatural body positions.

The arrangement and dimension of foot pedals, i.e. in terms of distance from SRP to the bottom of the foot pedals, angle of the foot pedals, width and depth of the foot pedals and clearance between the pedals, are within preferred specifications.

Typical shortcomings observed with regard to displays include poor positioning of displays, incorrect labelling, no labelling, or if present, the labels were damaged, dirty and illegible. As far as

			Importance		
Point to assess	**Yes**	**No**	**High**	**Low**	**N/A**
Is the working position generally comfortable?	X	X			
Are the pedals conveniently located during driving operations?	X		X		
Are the controls within easy reach of the operator during driving operations?		X	X		
Do employees need to reach in a horizontal plane?		X		X	
Do employees need to reach in a vertical plane?	X		X		
Are the pedals and controls conveniently located during stationary operations?	X			X	
Are controls within easy reach of the operator during stationary operations?		X	X		
Are frequently used controls within the primary reaching area?		X	X		
Are frequently used controls easy to use?		X		X	
Is the operator unable to accidentally activate or confuse controls?		X	X		
Are controls grouped according to function?		X	X		
Are control actions grouped in order of sequence?		X	X		
Are employees required to sit for long periods?		X		X	
Are employees required to stand for long periods?		X	X		

OVERALL ASSESSMENT OF DESIGN

Extremely unaccept -able	Unacceptable	Barely unacceptable	Barely acceptable	Acceptable	Extremely Acceptable
-5	-3	-1	+1	+3	+5

OVERALL ASSESSMENT OF ERGONOMIC IMPORTANCE

1	2	3	4	5	6	7	8	9	10

Figure 6. The foot pedals of the LHD

controls are concerned, the positioning and configuration are not optimal in terms of ergonomics requirements.

Instrumentation

The instrumentation and acoustic signals should provide the operator with all necessary information.

The instrument used should be appropriate for the information to be conveyed, the position of the recipient and the receiving conditions.

Acoustic signals are best when short warnings are to be given (critical information). Signal lamps are suitable to indicate one of two states, e.g. empty/not empty, charging/not charging, etc. Instruments with dials are suitable in many other cases.

Digital display is generally suitable when exact values of fairly constant or only slowly changing variables are required.

The design and arrangement of the instruments should enable all important instruments to be monitored at a glance. The size, scales, dials, colours, etc., of the instruments should be such that the instruments are readily legible and comprehensible. Dials should have light figures against a dark background if they are to

Parameter	Range of values	Preferred	Measured
INSTRUMENTS			
Label placement	Above or below the controls	Above the controls	Below
Label type		Symbols	Symbols
Alphanumeric characters and displays			
Width	70% of the height		N/A
Height	5 mm (minimum)	5 mm	N/A
Viewing distance from eye reference point	330 mm - 630 mm	400 mm	700 mm
Viewing angle from centre axis	0 - 65	0 - 45º	0

			Importance		
Point to assess	**Yes**	**No**	**High**	**Low**	**N/A**
Are all essential instruments and signals for safe and efficient operations provided?	X		X		
Are warning indicators visible or audible under operating conditions?	X		X		
Can the operator warn others of danger (hooter, etc.)?	X		X		
Are the most important and most frequently used instruments placed in the central field of view?		X		X	
Are instruments legible					
- during the day		X	X		
- at night					X
Are instruments comprehensible					
- during the day		X	X		
- at night					X
Is there no/minimal glare from the instrumentation?		X		X	
Remarks					
Instrumentation illuminated by means of cap lamp.					

OVERALL ASSESSMENT OF DESIGN

Extremely unaccept -able	Unacceptable	Barely unacceptable	Barely acceptable	Acceptable	Extremely Acceptable
-5	-3	-1	+1	+3	+5

OVERALL ASSESSMENT OF ERGONOMIC IMPORTANCE

1	2	3	4	5	6	7	8	9	10

be monitored under varying light conditions. Scales should run clockwise and be graduated into divisions of two of five or multiples thereof.

Climatic conditions inside the cab

The influence of cab climate on the operator depends on temperature, humidity, air velocity the operator's clothing and the degree of physical activity.

Studies on the effects of heat stress on performance have shown that excessive heat reduces efficiency.

For a rough assessment of the climate inside the cab, the air temperature can be taken as an indicator. In an assessment of the climatic conditions, the performance and effectiveness of fresh air

Guideline Values	Optimum	Maximum Value	Measured
Temperature	22 - 26°C	32°C	WB=24.5 DB=27.2
Temperature difference between head and floor levels	0 - 5°C		Not measured

Note: Open cab

Point to assess	Yes	No	Importance: High	Importance: Low	N/A
Is the machine comfortable in					
- summer	X				X
- winter	X				X
Is the cab equipped with an adequate air conditioner?		X			X
Is the cab equipped with adequate fans?		X			X
Is the cab equipped with adequate heating facilities?		X			X
Is it necessary to open the windows?		X			X
Can the temperature be easily regulated within the recommended range?	X			X	
Is protection provided from thermal radiation (exhaust, engine)?	X			X	
Is protection provided against the sun?		X			X
Remarks					
Dependent on environmental conditions of the specific workplace					

OVERALL ASSESSMENT OF DESIGN

Extremely unaccept-able	Unacceptable	Barely unacceptable	Barely acceptable	Acceptable	Extremely Acceptable
-5	-3	-1	+1	**+3**	+5

OVERALL ASSESSMENT OF ERGONOMIC IMPORTANCE

1	2	3	**4**	5	6	7	8	9	10

fans, air coolers and the like should be taken into account. Unless a machine is to be instrumented for long-term testing, cab climate can only be assessed by questioning the operator. Guideline values are only given for your information and need not be measured.

Exhaust emissions and inhalable hazards

Foreign gases should not be present in dangerous amounts and the cab should be free from exhaust gases and dust. Exhaust fumes,

Point to assess	Yes	No	Importance: High	Importance: Low	N/A
Is the cab free from any smell of toxic fumes (e.g. exhaust gases)?		X	X		
Is the operator protected against excessive dust?		X	X		
Has the supplier of the machine consented that fume levels are within acceptable limits?		X	X		
Remarks					
Occupational hygiene measurements to be used as reference. DPM's might pose a potential risk					

OVERALL ASSESSMENT OF DESIGN

Extremely unaccept-able	Unacceptable	Barely unacceptable	Barely acceptable	Acceptable	Extremely Acceptable
-5	**-3**	-1	+1	+3	+5

OVERALL ASSESSMENT OF ERGONOMIC IMPORTANCE

1	2	3	4	5	6	**7**	8	9	10

containing such gases as carbon monoxide, formaldehyde and nitrogen dioxide, and dust may be present in the cab due to the location of the exhaust pipe or the fresh-air in-take, or poor sealing around the various cab openings. The presence of exhaust fumes and dust can often be detected without apparatus.

Employee exposure to exhaust emissions (fumes, gases and particulate matter) will vary from day to day (even hourly variation might be observed). Exposure is dependent of machine engine condition, exhaust cleaning systems (filters), fuel quality, machine work rate, air flow patterns and quantity around the machine, just to mention a few. Employees should make use of approved respiratory protection should the occupational health risk assessment on the LHDs indicate a need thereof. Occupational exposure monitoring should be used to establish exposure trend and to define the risk posed to the LHD operators by exhaust emissions.

Visibility from the cab

Poor visibility increases the likelihood of accidents occurring and forces the operator to adopt uncomfortable and tiring positions.

Visibility should be judged from the point of view of the operator when seated comfortably in the seat. The operator's field of vision should be assessed in relation to the operations to be carried out. Visibility requirements vary according to the travelling speed of the machine, the operating area of the boom, etc.

Drivers are assisted by state-of-the-art camera technology. Screens located inside the cabin provide operators with an all-round view.

Exterior and interior lighting

Sufficient lighting should be provided for the operator as the machine is intended to be operated in poorly-lit conditions. In other words the appropriate lighting should provide sufficient and relatively uniform luminance throughout the field of vision. This can generally be achieved through the provision of illumination that is sufficiently powerful and evenly distributed over the operating area.

Point to assess	Yes	No	Importance: High	Low	N/A
Is there sufficient illumination provided?	X		X		
Is the lighted area large enough?	X		X		
Is the distribution of light in the field of vision satisfactory?	X		X		
Is the lighting equipment protected to prevent it being damaged?	X		X		
Is there interior lighting in the cab?	X		X		
Can this lighting be regulated?		X		X	
Does the vehicle comply with the Road Traffic Act and Regulations regarding exterior lighting and visibility?		N/A			
Remarks					
92 lux on instrument panel - cap lamp					

OVERALL ASSESSMENT OF DESIGN

Extremely unaccept -able	Unacceptable	Barely unacceptable	Barely acceptable	Acceptable	Extremely Acceptable
-5	-3	-1	+1	**+3**	+5

OVERALL ASSESSMENT OF ERGONOMIC IMPORTANCE

1	2	3	4	5	6	7	**8**	9	10

For driving	A clear all-round view of the ground, starting no further than 5 m from the cab.
For stationary operation	A clear view of the ground within the operating area (e.g. boom operating area). Clear view of the operating area above the ground (forwards and backwards, sideways, up and down).

Point to assess	Yes	No	Importance: High	Low	N/A
Can the operator see the working area?	X		X		
Does the operator have sufficient upwards visibility?	X		X		
Can the operator see to drive forwards?	X		X		
Can the operator see to drive backwards?	X		X		
Are the cab windows equipped with appropriate wipers, washers, demisters, etc.?		-			
Is the operator's view free from distracting reflections or obstacles?		X		X	
Is the machine equipped with suitable rear-view mirrors?		X			
Remarks					
Driver assist by state of the art camera screen technology to assist in visibility from the cab					

OVERALL ASSESSMENT OF DESIGN

Extremely unaccept -able	Unacceptable	Barely unacceptable	Barely acceptable	Acceptable	Extremely Acceptable
-5	-3	-1	+1	**+3**	+5

OVERALL ASSESSMENT OF ERGONOMIC IMPORTANCE

1	2	3	4	5	6	7	**8**	9	10

Too little illumination results in poor visual acuity and poor colour detection. Illumination that is distributed unevenly over an area can give rise to glare and consequently, to a substantial reduction on visual performance.

There are types of glare: simultaneous glare and successive glare. Simultaneous glare may be caused by the presence of excessive contrast (highlights and shadows) in the field of vision.

Successive glare may be caused by the eyes moving from one part of the field of vision to another with one part being illuminated more brightly than the other. Glare can often be avoided if care is taken in the arrangement of the lighting equipment and in setting the beam directions.

To prevent dazzling reflections, illuminated machine components in the field of vision should have a matte finish.

Illumination deemed to be in order. A movable spotlight can be useful in helping the operator to familiarise himself with the terrain.

Lighting equipment should be simple and safe to maintain. The equipment should also be protected to prevent it from being damaged when the machine is being operated.

Noise

It is widely recognised that chronic exposure to high levels of noise represents a risk of hearing loss.

The level of risk depends on exposure time, sound level and frequency. The sound level is generally expressed in dB (A), which is a frequency related value.

If the sound level at the operator's ear exceeds 85 dB (A), the risk of hearing damage is deemed present. In the case of continuous noise in excess of 85 dB (A), a special frequency analysis should be

Point to assess	Yes	No	Importance: High	Low	N/A
Is the noise level in the cab, as specified by the manufacturer lower than 85 dB (A)?		X	X		
Is the noise level in the cab acceptable?		X	X		
Have measures been taken to isolate the noise (cab, covers, etc.)?		X	X		
Is suitable hearing protection available for the machine operator (if required)?	X		X		
Is the noise level acceptable to someone outside the cab?		X	X		
Is suitable hearing protection available to workers outside the cab (if required)?	X		X		
Remarks					
89,5 dB (A)					

OVERALL ASSESSMENT OF DESIGN

Extremely unaccept -able	Unacceptable	Barely unacceptable	Barely acceptable	Acceptable	Extremely Acceptable
-5	**-3**	-1	+1	+3	+5

OVERALL ASSESSMENT OF ERGONOMIC IMPORTANCE

1	2	3	4	5	6	7	**8**	9	10

carried out to examine the risk of hearing damage more precisely. As regards intermittent noise (varying levels), an assessment should be made of the recorded dB (A) values in relation to the relative exposure time, so that the equivalent sound level can be determined.

Even when noise is not injurious as such, it can be very disturbing and often results in reduced job satisfaction, lower productivity and communication difficulties.

LHD operators are exposed to noise levels in excess of 85 dB (A). The risk of hearing damage is deemed present. With regards to the intermittent noise (varying levels) to which LHD operators are exposed to, an assessment should be made of the recorded dB (A) values in relation to the relative exposure time (i.e. personal exposure over an 8 hour shift by means of personal dosimetri), so that the equivalent sound level can be determined. These assessments should be conducted continuously to establish exposure histories.

Vibration

Research has shown that exposure to whole body vibration and shaking has a tiring effect on the operator and can have adverse effects on both health and work capacity.

Three factors have to be considered in an assessment of the influence of whole body vibration: the intensity and frequency of the vibration, and the exposure time. The intensity of the vibration is dependent on the nature of the ground, the design of the machine (suspension system, location of cab and design of cab seat) and travelling speed.

			Importance		
Point to assess	Yes	No	High	Low	N/A
Is the operator subjected to severe whole body vibration?	X		X		
Is the operator subjected to severe shocks?	X		X		
Does the seat have good shock absorbing properties?	X	X			
Is the cushioning of the seat firm and durable?		X	X		
Remarks					
Seats are generally damaged and in a poor condition. Damage by cap lamp battery a SCSR					

OVERALL ASSESSMENT OF DESIGN

Extremely unaccept-able	Unacceptable	Barely unacceptable	Barely acceptable	Acceptable	Extremely Acceptable
-5	**-3**	-1	+1	+3	+5

OVERALL ASSESSMENT OF ERGONOMIC IMPORTANCE

1	2	3	4	5	6	**7**	8	9	10

Vehicles must be designed to control the transmission of whole body vibration to levels that will permit safe operation.

During operation, LHD operators are exposed to severe whole body vibration and shocks. Current seats have little, if any, shock absorbing properties. The cussing of seats is damaged by the cap lamp battery pack and the self contained self rescuer (SCSR). Alternative seats with better shock absorbing properties should be investigated.

Operator maintenance work

LHD operators do not do any maintenance. All maintenance is carried out by qualified technicians. The design of the LHD does present several ergonomic hazards to these technicians but falls outside the scope of this assessment.

Physiological indicators

			Importance		
Point to assess	Yes	No	High	Low	N/A
Excessive physical demands					
Are work conducted at a high intensity?		X		X	
Are work conducted over excessive periods of time?	X		X		
Are employees conducting repetitive actions?	X		X		
Are employees conducting a single task activity?	X		X		
Are employees required to lift heavy objects?		X		X	
Are material manually handled?		X		X	
Are employees required to crouch for excessive periods of time?		X		X	
Are employees required to spend time in fixed work posture?	X		X		
Are force needed to operate any equipment, levers, valves, hand tools, etc.?		X		X	
Any complaints of back pain?	X		X		
Any complaints of muscle cramps / pain?	X		X		
Any complaints about stiffness?	X		X		
Increased mental demand					
Can the employee in the area be classified as "poor general education"?		X		X	
Are there any signs of lack of job related understanding?		X		X	
Are there any signs of low self-confidence?		X		X	
Are there any signs of lack of motivation?		X		X	
Are the employees in the area easily distracted?		X		X	
Are there any signs of lacking overall organisation?		X		X	
Awkward posture					
Are any of the listed awkward postures present:					
Hand / wrist?		X		X	
Arm / elbow?		X		X	
Shoulders?		X		X	
Back?		X		X	
Head / neck?	X		X		
Knee / ankle?	X		X		
Shift and night work	X		X		
Is shift work performed in this are?	X		X		
Does this include night shift?	X		X		
On average, how much overtime do employees in this section work?	2 hours max				
On average, how many double shifts do employees in this section work?	None				
Remarks					
Operators are required to concentrate for extensive periods of time					

OVERALL ASSESSMENT OF DESIGN

Extremely unaccept -able	Unacceptable	Barely unacceptable	Barely acceptable	Acceptable	Extremely Acceptable
-5	-3	**-1**	+1	+3	+5

OVERALL ASSESSMENT OF ERGONOMIC IMPORTANCE

1	2	3	4	5	6	7	**8**	9	10

A LHD operator is classified as a sedentary type of work. This task in general does not require high levels of physical work capacity for tasks such as materials handling and repetitive movements. Working postures and workplace layout may contribute to work related musculoskeletal disorders. It does however require a high psychomotor function which involves high reaction speed, attentiveness, concentration ability, eye, hand and foot coordination and time movement anticipation that entails the ability of speed estimation, which is based on visual speed sensation. The mental load and stress resulting from an 8-12 hour shift as a LHD operator due to the high levels of concentration, i.e. cognitive ergonomic stressors, needs to be assessed. This could include the assessment of recognised physiological indicators of stress such as heart rate and blood pressure.

Summary

In order to summarise the findings the following summary table has been included:

Assessment area	Design of machine						Ergonomic importance
	-5	-3	-1	+1	+3	+5	Value
Climbing on and off				X			6
Operator's cab				X			7
Operator's seat				X			7
Operator's working position and controls			X				5
Instrumentation					X		3
Cab climatic conditions					X		4
Exhaust emissions and inhalable hazards		X					7
Visibility from cab					X		8
External and internal lighting					X		8
Noise		X					8
Vibration		X					7
Physiological indicators				X			5

OVERALL ASSESSMENT OF DESIGN

Extremely unaccept -able	Unacceptable	Barely unacceptable	Barely acceptable	Acceptable	Extremely Acceptable
-5	-3	-1	**+1**	+3	+5

OVERALL ASSESSMENT OF ERGONOMIC IMPORTANCE

1	2	3	4	**5**	6	7	8	9	10

The ergonomics-related risks resulting from inadequate design considerations are indicated and discussed below, under the headings of the stated parameters.

Climbing on and off (access)

Cabin ingress and egress proved to be a problem. Mounting of most underground vehicles create strain on the operator. Further strain is added by the difference in entrance level and cab floor-line. No handgrips are provided. The fact that the operators on average do not climb in and out of the cabins more than 50 times per shift (climbing on and off, count as one), lower the criticality of this parameter for the successful execution of operator's task.

Seating

Current seatings are not only of a poor design type (narrow, not adjustable metal seat base with no back or arm supports) but have little, if any, shock absorbing properties. Seat heights were either too high or too low for stable, comfortable sitting posture. In all three of the assessed vehicles, the operators are facing sideways. This induces a sustained twisted neck posture when facing towards the direction of the vehicle movement.

Inadequate seating arrangement, restricted visual field and limited cabin space resulted in operators adopting awkward postures. The awkward postures, particularly if they are adopted repeatedly or over long periods, may cause discomfort and fatigue, and increase the risk of musculoskeletal disorders.

Controls and displays

All controls are within the reach envelope of the standard South African male. All controls and displays are within the visual field. Controls may be outside the reach environment of the standard South African female, which may up the criticality of this parameter in the case of female operators.

Noise

Vehicle operators are potentially exposed to noise levels in excess of 85 dB (A). The risk of noise induced hearing loss is deemed present. With regards to the intermittent noise (varying levels) to which these employees are potentially exposed to, an assessment should be made of the recorded dB (A) values in relation to the relative exposure time (i.e. personal exposure over an 8 hour shift by means of personal dosimetri), so that the equivalent sound level can be determined. These assessments should be conducted continuously to establish exposure histories.

Vibration

During operation, vehicle operators are exposed to severe whole body vibration and shocks. Current seats have little, if any, shock absorbing properties. Seats are mounted directly onto the vehicle body, resulting in a direct transfer of vehicle and road related vibration and shocks to the seat (and to the operator). Alternative seats with better shock absorbing properties should be investigated.

Physiological indicators

Although the majority of the tasks of vehicle operators can be classified as sedentary type tasks, some tasks do require physical and functional work capacity. Furthermore these operators require a high psychomotor function which involves high reaction speed, attentiveness, concentration ability, eye, hand and foot coordination and time movement anticipation that entails the ability of speed estimation, which is based on visual speed sensation. The awkward body position adopted by operators as a result of the seating arrangement is especially of concern. The adopted position may result in excessive strain on the neck and back which, on its own or in the presence of vibration, could pose a serious risk.

DISCUSSION

The LHD studied in this assessment poses a certain level of risk in terms of ergonomic stressors. In most cases these risks are not identified as part of the hazard identification and risk assessment process, and for those few that are identified, the risks are not understood and thus not comprehensively assessed. Inadequate legislative framework for ergonomics and a lack of enforcement to protect employees contribute to the overall risk posed by the problematic ergonomics of mine vehicles such as this LHD. Most mines have limited access (if any) to an ergonomist to assist in the development of on-mine ergonomic programmes, as has government, in order to develop national policies and a legislative framework for ergonomics.

CONCLUSION

The absence of a national policy and a legislative framework on ergonomics should not be reasons to ignore the potential risks associated with mining vehicles in which ergonomic principles were neglected, not considered or not implemented during the design or manufacturing of these vehicles. Companies should develop in-house ergonomic policies and give expression to these policies in comprehensive ergonomic programmes. The application of sound ergonomic principles in mining has the potential to enhance the effectiveness and efficiency with which human tasks are carried out, and also to eliminate significant occupational health and safety risks.

REFERENCES

De Koker, T.H., and Schutte, P.C. (1999). *A comprehensive strategy for the South African mining industry*. SIMRAC Final Project Report: GEN 603. Pretoria: Department of Minerals and Energy.

Schutte, S., and Shaba, M.N. (2003). *Ergonomics of mining machinery and transport in the South Africa mining industry*. SIMRAC 02 05 04. www.simrac.co.za.

Haper, G.S. (1997). *Current and future risks and casual issues relating to engineering-related issues in South African mines.*

SIMRAC Final Project Report: SIMRISK 401. Pretoria. (1997). Department of Minerals and Energy.

Schutte, S., and Shaba, M.N. (2000). *The ergonomics of locomotive design in the gold and platinum mines in South Africa*. SIMRAC GAP 704. www.simrac.co.za.

Mine Health and Safetuy Act, Act 29 of 1996.

Schutte, S. (2005). Personal Communications

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Ventilation planning at the P.T. Freeport Indonesia's GBC Mine

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ABSTRACT

This paper describes the ventilation planning that was performed for the P.T. Freeport Indonesia's Grasberg Block Cave (GBC) deposit located in the province of Irian Jaya, Indonesia. The mine is located at an elevation of around 3,000 m in the Puncak Jayawijaya Mountains and about 90 km from the coast. The GBC mine will be one of the largest underground block cave mines in the world with projected production at 160,000 tons per day. Primary personnel and supply access to the mine will be via a 6.0 km tunnel called the AB Adits.

From the AB Adits, a shaft will convey personnel and supplies up to the main workings in the GBC. Primary ventilation is through 2.6 km tunnels with four as intake and three as exhaust. A fourth exhaust is in parallel with the conveyor system. A series of network simulations were conducted to evaluate ventilation raise locations, size and number of airways, and the duties of the primary exhaust fans.

Analyses also investigated fixed facility ventilation systems and dust control strategies for three 60,000 tpd crusher stations. This paper describes the challenges with the design due to limitations in the intake and exhaust airway tunnels, distribution of airflow over a large area, and the requirement to have a ventilation management system to control regulators and other infrastructure.

Keywords: *Ventilation design, ventilation planning, massive mining, diesel particulate, heat load.*

INTRODUCTION

P.T. Freeport Indonesia, 90.64% owned by Freeport-McMoRan Copper & Gold and 9.36% owned by the Indonesian government, operates the largest gold mine and the third largest copper mine in the world at its mine operation in Papua, Indonesia. Presently, the mine complex consists of the Grasberg open pit mine and two underground mines, DOZ and Big Gossan. Total production from the mining complex is approximately 240,000 tpd. Figure 1 shows the location of the mine in Indonesia.

The future of the mine will be to develop one of the largest block caves in the world below the current Grasberg open pit. In addition to this expansion, the company is planning a deeper block cave mine below the current DOZ mine. The production goal from the Grasberg Block Cave (GBC) mine is 160,000 tpd with an additional 80,000 tpd from the new DMLZ block cave mine and 7,000 tpd from the high grade Big Gossan stope mine. This production would make this complex the largest tonnage underground mine in the world.

Original paper presented at the the 10th International Mine Ventilation Congress 2014

The basic design of the GBC block cave mine consists of an undercut level, production level, ventilation level, haulage level, and drainage level. Access to the mine will be through an access tunnel below the mine horizon called the AB tunnels. This tunnel system will be used to bring in all supplies and personnel to the mine. A hoisting shaft from the AB tunnel to the various levels in the mine will be the primary means to bring personnel and supplies to the mine. The mine also includes numerous fixed facilities including three primary crushers, conveyor systems, offices, fuel bays, maintenance bays, and rail shops.

Ventilation to the mine will primarily be through multiple ventilation drives. Four intake drives connect to surface at the side of a mountain and slope downwards to the ventilation sublevel. The tunnels, termed Grasberg Ventilation Drives (GVD) are approximately 6.8 m wide by 9 m high for a length of 2.6 km. The design also includes three primary exhaust drives of the same dimensions with fans located in the tunnels near the exhaust portals. Twin conveyor drives with a service drift (GVD 8) are also on exhaust to surface. The conveyor systems tie into an existing conveyor that feeds the current stock pile in front of the processing plant.

On large projects such as this one, there are challenges coordinating the mine planning work with the ventilation design. The ventilation design follows the planning design and once ventilation modelling is performed, it is often the case where the design iterates to change airway dimensions and/or add ventilation infrastructure such as doors, raises, etc. The design described in this paper represents a snapshot of the mine layout at the time of this paper was prepared. The final design may differ from what is presented here.

DESIGN CRITERIA

The primary design criteria for this project was to provide a minimum velocity of 1 m/s per drive with diesel equipment, providing at least 0.06 $m^3/s/kW$ of diesel power, and a design philosophy of placing strategic return airways near dust generation points and to exhaust air from maintenance bays and fuel bays. For certain fixed facilities the airflow was based on air changes per hour. Velocity limits on primary intake and exhaust airflows of 10 m/s were included in the design.

GENERAL VENTILATION DESIGN LAYOUT

The primary personnel and supply access to the mine will be through the AB tunnels. These tunnels are located below the mining horizon and connect not only to GBC but also to the Big Gossan and DMLZ mines. In consideration of controlling any adverse fire event in any of these mines on this level, the AB

Figure 1. Location of P.T. Freeport's mines in Indonesia

tunnels are designed to exhaust air from each mine to the portal. Access from the AB level to the primary GBC levels will be through a hoisting shaft and ramp system. The hoisting shaft is expected to be the primary access for most personnel and supplies.

In 2021 (when the infrastructure is expected to be developed to achieve the first full 160,000 tpd production goal) the ventilation system is expected to consist of 4 primary intake adits, GVD 1 through 4, and three exhaust adits from the service level of the mine, GVD 5, 6, and 7. Twin conveyors exhaust air in parallel with a fourth exhaust drive GVD 8 (also considered a service drive). In addition to the GVD intakes and returns, the GBC mine intakes a limited quantity of air through an existing mine connection at CI3. Figure 2 represents the entire mine in 2023.

Although excavated at a large dimension, the long GVD intake and exhaust drives limit the total airflow capacity in the mine because of velocity constraints and significant increases in fan pressure for marginal increases in total mine airflow. The total flow for the GBC mine is predicted to be 3,070 m^3/s. This quantity of air appears low when compared to other block cave mines. Calculating flow based on mining tons per day, shows the GBC mine to be approximately 0.019 $m^3/s/tpd$. Other block cave mines have ratios from 0.017 to 0.04 $m^3/s/tpd$ (Wallace, 2001). The low ratio infers that the GBC mine does not have excess air

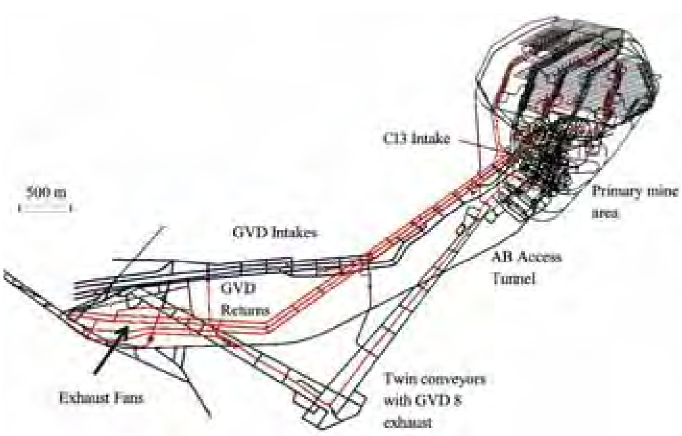

Figure 2. Isometric of GBC mine in 2023

and that a ventilation management system will be required to maintain adequate airflows in all areas where personnel and equipment operate. The flow also reflects that GBC will use electric rail haulage systems which significantly reduce the flow requirements over a truck haulage system.

The primary fans for this project were specified by preliminary analyses conducted by Freeport engineers. These analyses were based on initial ventilation modelling. The fan duties were verified in later modelling that took into consideration the airflow computed to achieve a full flow balance while maintaining 10 m/s in the GVD drives. The fans specified for this project are Howden MF107/0.91/38.5/19 mixed flow fans each with 4,100 kW motors. Each fan is predicted to operate at approximately 720 m^3/s at a total fan pressure of 4.5 kPa.

Production areas

The primary production areas of the mine are the undercut, production, haulage, and drainage levels. These areas account for the majority of the airflow allocated in the mine. Each of these levels connects to the ventilation level with raises. The ventilation level intake and exhaust drives are on the same horizon.

Undercut level

The undercut will be initiated in two cave zones. This will require two separate areas to be ventilated. There are only two or three entrances into the undercut level which will allow for the intake airflow to be closely controlled. The air will be exhausted through a series of raises located on the perimeter of the level close to the development areas. Approximately 180 m^3/s will be required for the undercut level based on the equipment load projected for the level. This value is likely to increase in the final design in addition to the way air will be delivered and exhausted from this level.

Production level

The production level in 2023 is shown on Figure 3. Also shown on this figure is the ventilation level that is below the production level. The airflow for a single extraction drift segment is based on achieving a minimum airflow velocity of 1 m/s required for dust dilution. For a nominal airway cross-sectional of 17.6 m^2 this results in a value of 17.6 m^3/s. This value was rounded up to 18 m^3/s for modelling purposes. If the airflow requirement was

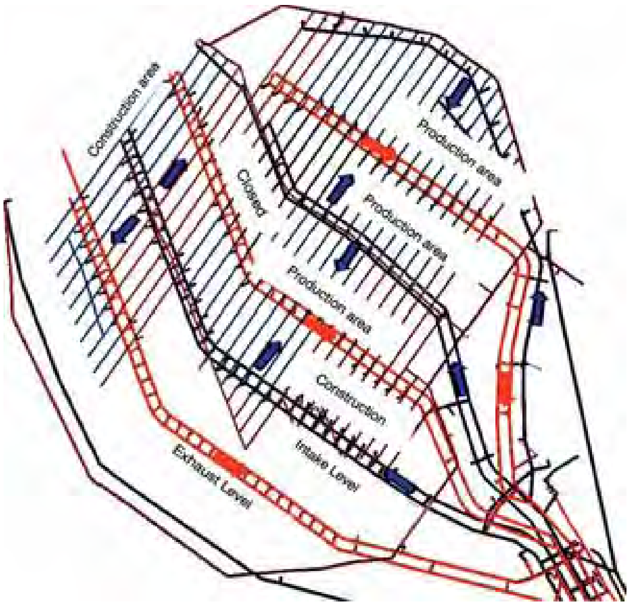

Figure 3. Production Level in 2023

based on diesel dilution then the one operating R1700G LHD (231 kW) would require a minimum of 13.6 m^3/s.

Airflow is drawn from the perimeter fresh air raises to the central exhaust raise located near or adjacent to the ore pass. Only one LHD will be operated in a single extraction drive segment. The GBC extraction level will actively ventilate up to 44 segments to support the 44 LHDs in the production area. An additional 290 m^3/s is supplied to achieve this airflow. Air doors will be required at each end of a fully developed extraction drive to limit airflow when not in use. If the doors are not used then airflow cannot be limited to a single side of an extraction drive. Regulators will be required for each exhaust and intake raise leading to the extraction level. The regulators will be located on the service level to avoid equipment, blasting, and local non-permitted adjustment. Ventilation controls are required in the extraction drives to maintain an even airflow distribution (louvres, partially opened doors, or doors with removable panels).

Trying to achieve an even airflow distribution across the extraction level in a block cave is always an onerous and difficult task. One of the best ways to achieve an even airflow distribution is to provide a dedicated fresh air raise for each extraction drive segment, however, with larger mining footprints this results in a significant quantity of vertical development. Isolation or low resistance doors can be placed along the perimeter drives to further separate the extraction drifts if fresh air raises are developed for multiple extraction drives but this often results in operational concerns dealing with traffic flow. Small booster fans are another option on the fresh air and exhaust raises to apply the required pressure to achieve an even distribution. This system can work, but can also have unintended consequences of creating recirculation loops if not closely monitored. In addition, the system will result in significant electrical power requirements. Without these controls, the even distribution of flow is not attainable.

For the GBC production level, a single fresh air raise is developed for every three extraction drives. A small resistance is applied at the entrance to each extraction drive segment in the form of an open door to slightly restrict flow (by 5 to 15 Pa). This allows the airflow to be more evenly achieved across the panel. Panels not in production were modelled with closed doors. Panels no longer drawing ore are assumed to be sealed from the ventilation system (no access). Because of the large number of controls required, the system needs to be designed such that the controls can be remotely operated. These controls will need to be part of a ventilation management system that can be controlled from a central underground location and tied to daily production plans.

Haulage level

The airflow on the haulage level enters the level through raises located on the north side of the rail fixed facilities and is drawn both towards the north (active ore chutes) and the south (through the rail fixed facilities and rail loop). The airflow exhausts the level at the outer perimeter of the level both on the north side (after the chutes) and through the ore dump bins (on the south side). The haulage fleet consists of electrified rail haulage with only intermittent diesel equipment, or construction equipment at the perimeter. A flow of 520 m^3/s is allocated for this level which will provide an air velocity of between 0.3 m/s and 1 m/s in each of the parallel haulage loops.

Drainage level

The drainage level will be ventilated by air exhausting from the north end of the haulage level. Because of the limited use of diesel equipment on the haulage level this airflow will remain reasonably fresh and can provide adequate ventilation for the equipment used intermittently on the drainage level. It is anticipated that the equipment will primarily consist of development equipment. An air velocity of about 1.3 m/s was used to estimate a total flow per heading of 38.6 m^3/s. This will be sufficient to support the limited diesel equipment on this level.

Non-production mine areas

Because of the significant cost of providing additional airways into and out of the mine, every airflow allocation not directly supporting production activities requires specific justification to ensure that the air is used in the most efficient manner. These areas include crushers, fixed facilities (e.g. shops, fuel bays, offices, etc.), conveyors, and pump stations.

The general design of each of these areas is presented along with the basic design rationale. These areas account for approximately 385 m^3/s which is not used to directly support production activities.

Crusher ventilation

The crusher areas in block cave mining operations traditionally are generally poorly ventilated with air circulating from the haulage level bin dumps often flowing back into the haulage level areas. This has the effect of causing elevated dust levels on the haulage level. A system like this relies totally on the ancillary dust suppression (sprays) and sometimes localised extraction (filtration) systems. These systems are often found to be clogged, ineffective, or inoperable.

The ventilation system surrounding the GBC crushers and haulage level can best be described as a central exhaust system as shown in Figure 4. All of the air that flows through an area of significant dust generation will be directed to an exhaust raise. This allows any residual dust not controlled by the ancillary systems to be directly exhausted.

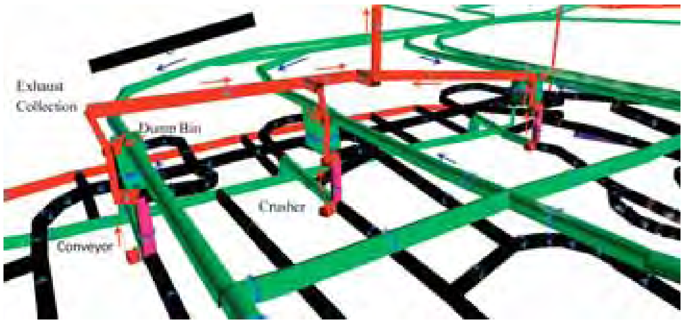

Figure 4. GBC crusher ventilation

Highlights of the system are shown on Figure 4 and are described below:

- 60 m^3/s will be directed to the exhaust at each haulage level bin dump, this relates to all of the airflow on the haulage level leading to the bin dump.
- 25 m^3/s will be directed to the exhaust at each crusher mid-level (apron feeder).
- The lower conveyor drift will have an airflow of 20 m^3/s of which 3 m^3/s will be directed to exhaust through the dust extraction system.

The ventilation system does not remove the need for the ancillary dust control systems, rather, the combination of both the ancillary control systems and the exhausting ventilation system should provide for good control of dust in the surrounding areas. This system does have the drawback of requiring additional airflow that could be used in other areas as it is not laden with diesel exhaust gases, but in order to minimise the dust contamination 88 m^3/s per crusher was considered to be an acceptable cost.

Fixed facility ventilation

Fixed facilities for large block cave mining operations are very extensive. These facilities include fuel bays, maintenance shops, warehouses, locker rooms, lunch rooms, mosques, and churches. For GBC the facility is over 600 m in length and approximately 300 m in width (not including fuel bays or facilities on other levels). The facility is on the production level with one end connecting to access drives to production panels. Ventilation of these facilities is through intake raises near the production panel and exhaust raises at the other end of the facility. Figure 5 shows the fixed facilities at the time this study was performed. Since this time, numerous changes have occurred that reoriented the fuel bay and other facilities. There is a strong desire by operation personnel to not have doors between the facility and the production level drives. From a ventilation perspective this is not ideal as the best design is to isolate the facility from the mine and provide a separate split of air through the fixed facilities to the exhaust raises.

At the GBC mine, the current design uses a hybrid case where airflow enters the fixed facility about one third of the way from the production level drives and splits some air through the facility to the production level and the balance to the exhaust raises. In this design, all higher fire risk areas, such as maintenance bays, are in the split of air going to exhaust. The only higher risk facility that is on the mine side of the facility is the equipment parking area. Automatic fire or isolation doors are planned for each access to the production panel.

Table 1. GBC fixed facility airflow calculation

Location	Airflow per area (m^3/s)	No.	Total airflow (m^3/s)	Reuse air?
Office on fringe drive	3	4	12	Y
Parking and bus loading area*	15	3	45	Y
Office/Elect/bus area	10	1	10	Y
Primary lunch area	5	1	5	N
Toilet	2	1	2	N
Main mosque	6	1	6	Y
Mine warehouse and office	30	1	30	Y
Shop warehouse and office	30	1	30	Y
Second lunch area and toilet	7	1	7	N
Second mosque and chapel	8	1	8	Y
Service bays	7	12	84	N
Offices/training elec on acc.	5	6	30	Y
Welding bay	15	1	15	N
Crane bay (vel of 0.5m/w min)	60	1	60	Y
TOTAL AIRFLOW			**344**	
Reuse warehouse/office air			168	
Minimum airflow required			176	

*Air from parking bus loading area goes onto fringe drift

The airflow requirement for the fixed facilities was computed using ASHRAE standards for air changes required for machine/auto shops and offices. These calculations resulted in Table 1 that shows the flow requirements to be approximately 175 m^3/s. For design, the flow through the exhaust raises was modelled at 180 m^3/s. These raises are located on the bottom right of Figure 5.

Rail haulage shop

The rail haulage shop is ventilated with an intake raise located near the north end of the facility and an exhaust raise near the southern end. Normal operation is for 20 m^3/s to exhaust through the return raise. This air is exhaust air from welding and mechanical areas of the shop. Normal ventilation is for intake air to exhaust both ends of the shop.

Airflow exhausting the south entries courses to the crusher dump bins and provides a portion of that airflow.

Conveyors

The GBC oreflow system consists of parallel conveyor drives separated by an exhaust/service drift. The service drive is maintained as an exhaust to minimise the differential pressure between the service drive and the conveyors in an effort to decrease leakage between the two systems.

Air is drawn from the crusher area through the two conveyor drives and courses toward portals. Because the main ventilation system is driven by exhaust fans (located in close proximity to the conveyors) air will also enter the conveyor system through the portal.

A connection midway down the second conveyor will draw the conveyor air into the exhaust system. At this point fresh air will be drawn from the portals and air will be drawn for the mine.

Airflow from the portals will be controlled by a series of conveyor

Figure 5. Layout of GBC fixed facilities

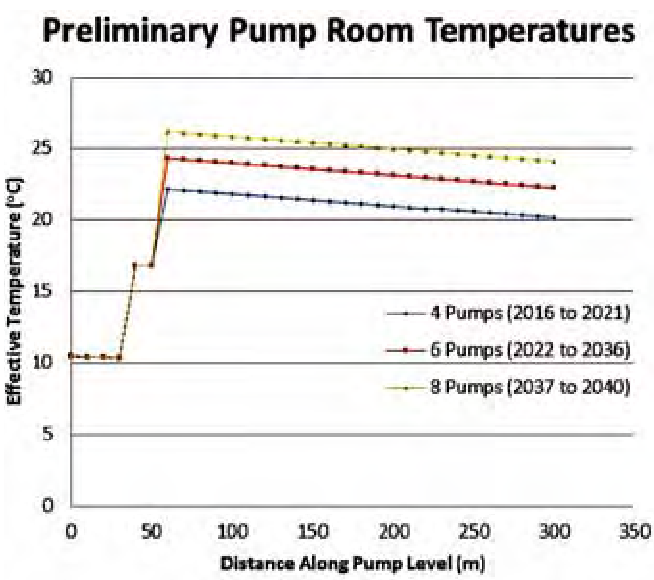

Figure 6. Predicted heat load in pump room

regulators/belt checks. A minimum of 25 m^3/s of airflow is required in each conveyor drive based on a minimum air velocity of 0.75 m/s. The air velocity will increase due to leakage.

Pump station

The GBC Mine will be located under the extensive Grasberg Open Pit Mine. There is a concern that excessive water inflow may occur. This has resulted in the design and incorporation of a significant pump room at the perimeter of the mining footprint just below the drainage level.

The design incorporates up to 8 operating 420 kW pump motors. The size of the pump motors and the limited airflow available for ventilation means that the pump room could experience a significant heat load.

A series of climatic simulations were undertaken to predict the temperature in the pump chamber for different airflow quantities. It was determined that an airflow of 30 m^3/s through the pump chamber would maintain the effective temperature at approximately 26°C with a maximum wet bulb temperature of less than 22.5°C.

Figure 6 shows the predicted pump room temperatures.

Batch plant

The batch plant, shown in Figure 7, requires a closed ventilation system to isolate and reduce dust emissions into the ventilation system, however, because of the significant quantity of shotcrete produced and degree of vehicle traffic isolation through the use of doors will be difficult to put into effect.

The airflow around the plant is reduced through a by-pass raise in the main access ramp. This allows for the differential pressure across the plant to be significantly reduced (to 4 to 5 Pa).

By reducing this pressure difference the flow through the facility is much lower.

An air mover (small jet fan) can be installed in the batch plant perimeter drive to reduce the quantity of airflow moving across the plant and exhausting through the southern ventilation raise.

This allows for the removal of all doors in the haulage route through the batch plant and provides for a reasonable capture area for the 20 m^3/s exhaust from the batch plant.

SUMMARY

The GBC block cave mine will be one of the largest producing underground mines in the world. The ventilation system designed for the mine consists of 4 primary intake drives and 4 primary exhaust drives, each approximately 2.6 km in length.

Access to the mine is through a 7.5 km tunnel, called the AB tunnel that is located well below the mining horizon.

A hoisting shaft at the access tunnel will bring personnel and supplies to the various levels in the mine.

The airflow to the mine is approximately 3,070 m^3/s. The total

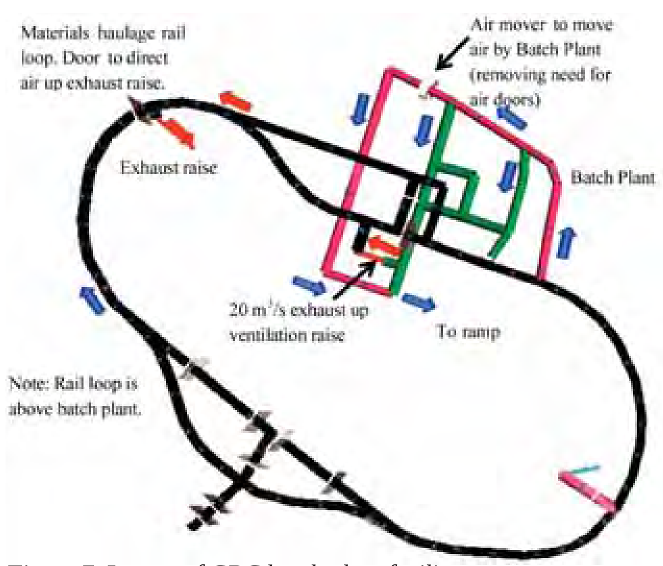

Figure 7. Layout of GBC batch plant facility

flow is limited by the number of intake and exhaust drives, velocity limits of 10 m/s in these drives and maintaining primary fan pressures of below 4.5 kPa. Because of these limitations, the ventilation design needs to be carefully controlled. Each ventilation raise from the ventilation sublevel will be controlled with regulators.

On the production level, controls within the production drives will be necessary. These controls will consist of doors to either close the unused panel drive or a partially opened door to limit the flow entering the drive. These controls are possible because the LHD operation is completely within the panel (from the draw point to the ore pass).

In order to ensure doors and regulators are configured correctly, a ventilation management system will be required.

Currently the system envisioned will provide indication of the door and/or regulator position with the control room operator being able to remotely control the regulator settings. The system envisioned at this time is not reliant on sensors to determine the regulator settings.

The ventilation system described in this paper is based on the mine plan when the study was performed.

The mine plan is very likely to be modified and the ventilation system presented may not represent the final design that will be constructed.

Mine planners are currently considering changes to the number of GVD drives, increased flow to the AB tunnel ventilation system, and modifications to the block cave sequence plan (which impacts the under-cut and production levels).

In addition, the fixed facilities, such as fuel bays, etc. will also likely be altered.

None the less, the ventilation philosophy of airflow requirements, primary fan duties, and airflow distribution considerations, developed at this stage of the study is valid for any future possible mine planning modifications.

REFERENCES

Wallace, K.G. (2001). *General Operational Characteristics and Industry Practices of Mine Ventilation Systems*. Proceedings of the 7th International Mine Ventilation Congress, Krakow, Poland.

Peer reviewed for Journal publication

A comprehensive diesel particulate matter investigation in a U.S. industrial commodity mine

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ABSTRACT

Diesel Particulate Matter (DPM) measurements were undertaken at FMC's Trona mine in Wyoming using both shift average and real time monitoring methods. The DPM survey was conducted in two periods. In a primary survey, the mine was divided into several sections. Each included two stations that covered all the entries including belt drifts. Two Airtecanalyzers were used for real time measurement by placement upstream and downstream of sources. Thirteen Elf pumps were employed taking Total Weighted Average concentrations. The stations covered mains, submains, development and Longwall (LW). DPM concentration was measured in the main exhaust shaft. A vehicle monitoring log was constructed consisting of vehicle type, direction of travel and time. The log was then used in analysis to determine the DPM spread rate in the different entries up and down stream with respect to the vehicle location. Airflow measurements at the stations were taken during the survey. The survey results also identified the vehicles with higher emission rates that were due to be taken to the DPM maintenance workshop for service. The secondary survey was conducted during a LW move where intense activities were taking place in both recovery and installation set-up face movement operations. The surveys were done for several cycles. It started at the beginning of the recovery cycle with supports, loaded on haulers, leaving the recovery face, travelling in the headgate and approaching the set-up room before returning, unloaded, to the recovery face. The stationary measurements were taken by using the Airtec devices along the recovery and set-up faces by placement upstream and downstream of DPM sources. The equipment measurements were taken by putting the MAHA analyser on the shield haulers. The results were analysed to understand the DPM spread during the move while the machines were under load hauling the supports to the set-up face and travelling back under normal conditions. Local ventilation changes were recommended to improve the ventilation during the move. The mine's underground transportation fleet consists of over 250 diesel vehicles. ECOM gas and MAHA DPM analysers, located in the mine's underground emission shop were used to obtain various vehicle emission rates. The measurements were taken under various conditions such as stall, idle and running conditions. The correlation of workshop and field measurements were investigated with regard to the machine activity, fuel usage and atmospheric conditions. The results were used to calibrate and validate the DPM surveys and improve the preventive maintenance programme.

Keywords: *DPM, sampling, compliance, real time, air requirement, field measurements.*

Original paper presented at the the 10th International Mine Ventilation Congress 2014

INTRODUCTION

DPM has been classified as a potential occupational carcinogen by the National Institute for Occupational Safety and Health (NIOSH).The Mine Safety and Health Administration (MSHA) rule governing DPM exposures in metal and nonmetal mines cites total carbon (TC), a summation of elemental carbon (EC) and organic carbon (OC) obtained by NIOSH Method 5040, as a surrogate for determining DPM exposures (Noll, et. al., 2006). MSHA personnel use the 1973 sampling criteria outlined by the American Conference of Government Industrial Hygienists (ACGIH) for collecting compliance-based respirable and inhalation samples in metal/nonmetal mines. Instrumentation developments are allowing improved real time monitoring of ventilation parameters particularly DPM.

DPM is within the aerodynamic particle size range of the samplers used for respirable and inhalable dust measurements. Therefore, if a sampler used by MSHA to collect inhalable or respirable dust samples in underground metal/nonmetal mines was used to collect DPM, both the DPM and mine ore dust would accumulate on the sample filter (Noll, et. al., 2006).

Therefore, U.S. Bureau of Mines (BOM) researchers developed a size-selective sampler that allowed only particulate matter with an aerodynamic diameter less than 0.8 µm to pass through the device and be collected on a downstream filter. (Cantrell and Watts, 1997). Since the aerodynamic diameter of most ore dust is typically greater than 0.8 µm, and the aero-dynamic diameter of most DPM is less than 0.8 µm, (Cantrell and Rubow, 1991) the impactor segregates most of the DPM from the ore dust and permits only DPM to be collected. Research results show that the classification efficacy, in preventing dust to pass through this impactor, is greater than 90%. To comply with the requirement and lower the DPM exposure, mines are implementing a variety of control technologies such as emission based maintenance programmes where adjustments or repairs are performed on the vehicles (McGinn, 2000).

MEASURING METHODS

Several methods were used to measure DPM. The survey was focused on area sampling throughout the mine. The DPM sampling requirement as stated §57.5071, MSHA compliance sampling procedures were followed during the survey.

An initiative in some mines has been to limit the number of vehicles in the mining section or panel by the use of a tag board or traffic controller at the panel travel road entrance to manage exhaust DPM and gases. Diesel tags or tokens are used to control the number of vehicles entering a section or panel and so limit level of pollution. Summation of DPM levels from points monitored throughout a panel demonstrates increasing DPM levels from influence of additional equipment in series within the ventilation circuit (Gillies, 2012). An alternative approach is to invest in underground continuous real-time monitoring of exhaust gases; DPM and section air quantity and integrate this information to determine whether an additional vehicle can enter without exceeding the diesel target limit. This optimises the access of diesel vehicles and replaces the existing manual tag board system. Real-time DPM monitoring allows the industry to pin-point high exposure zones such as those encountered where various vehicles work in areas of constrained or difficult ventilation. Identification of high DPM zones allows efficient modification of mine ventilation, operator positioning and other work practices to reduce underground miners' exposures.

NIOSH 5040

The NIOSH 5040 method is an established technique for measuring both organic and elemental carbon. The process involves drawing sampling air through a DPM cassette at a flow rate of 1.7 litres per minute to collect soot onto quartz filters inside the cassette. After sampling, punches of these filters are placed inside a 5040 oven for analysis. The oven first measures organic carbon (OC) by progressively increasing its temperature up to 870°C in four steps in a pure helium environment. The lack of oxygen prevents EC from reacting. OC is oxidised to carbon dioxide and is reduced to methane. The methane is measured using a flame ionization detector (FID). EC is then measured by reducing the oven temperature and then raising it back up to 900°C in a helium/oxygen atmosphere (Janisko and Noll, 2008). EC reacts with oxygen to form carbon dioxide. Once again, the carbon dioxide is reduced to methane and the methane is measured with an FID.

Because a suitable reference material is not available for determining the organic and elemental carbon content of a complex carbonaceous aerosol, only the accuracy of the method in the determination of total carbon (TC) could be examined (NIOSH Manual). During the survey, 13 Elf pumps were at the stations. The cassettes were then sent to the laboratory and the results were adjusted to calculate the concentration for the period of 8 hours.

Real time monitoring

Several monitoring devices were used to measure DPM concentration. The FLIR Airtec only became commercially available in 2011 subsequent to NIOSH development (Noll et al., 2007). It measures the Elemental Carbon (EC) component of DPM by a laser scattering approach. Results from the Airtec can be compared directly with SKC system DPM evaluations. Both new instruments have been evaluated underground in robustness and reliability testing in coal and metal/non-metal mines. Two Airtec units were used in this study, up and down stream and the results were compared against the NIOSH method.

Tailpipe monitoring

The MSHA tailpipe particulate method, which is similar to the American Society for Testing and Materials (ASTM) approach, requires dilution of the exhaust prior to collecting a sample (MSHA 2009; ASTM 2002). This method, as well as the required laboratory instruments can be time-consuming and the logistical requirements made it unfeasible in many areas of an underground mine (Noll et al., 2013). Several studies have published data evaluating the use of different instruments.

The Emission Shop at FMC Trona Mine is equipped with a MAHA MPM-4M DPM and ECOM Gas analyser. The study was undertaken to investigate the correlation of the results from emission shop data and actual field measurement. For this purpose the MAHA MPM-4M unit was installed on a Fletcher Prime Mover, Shield Hauler during a LW move. The results were then compared against the Airtec readings. The MPM-4M is a rugged, practical and easily operated diesel particulate measuring instrument specifically designed for measuring particle concentrations in the exhaust of mining engines. Using advanced laser light-scattering technology coupled with integrated sample preconditioning, the MPM-4M can accurately and instantly measure diesel particulate concentrations in the exhaust from all engine types, including exhaust which has passed through water scrubbers. Table 1 is an example of the emission shop tailpipe DPM measurements emitted from LHD.

Table 1. DPM concentration on a LHD mg/m^3

	Pre-scrubber	Post-scrubber
Stall test Result	14.4	13.1
Average Conc (Idle)	8.2	9.2
Average Conc (Power)	26.8	20.9
Min Reading	2.1	2.8
Max Reading	113	75.3

TEST DESCRIPTION (CASE STUDY)

The DPM test was conducted in two stages. The primary survey covered the south of the mine where a majority of diesel equipment commutes on a regular basis. For this reason, the mine was divided into four sections. The secondary survey was done during the LW move where the support haulers were moving the shields from recovery room to the set up face. Moving the LW is considered the most concentrated diesel activity in the mine.

Primary test (Regular mining)

The four divided sections were chosen in a way to cover the main developments. Each station consisted of the main roads, back road and belt drifts. At each station, a real time Airtec was placed at the main drift that mostly is used as a transportation drift. The Elf pumps were placed in the main roadway as well as the other drifts to measure the TWA concentration of DPM. Figure 1 shows the instrument placement pattern at each station. 9 Shaft is one of the mine's exhaust shaft for the south part of the mine. Therefore two Elf pumps were placed to monitor the DPM concentration at 9 Shaft. The Elf pumps also were placed outby the main shop regulators. Currently the shop is ventilated by approximately 50 m^3/s. The air is considered fresh air and the sampling results show that the DPM concentration is lower at the main development. The station's layout is shown in Figure 1.

The leapfrogging approach was used to measure the DPM concentration up and downstream. A vehicle monitoring log was constructed consisting of vehicle type, direction of travel and time.

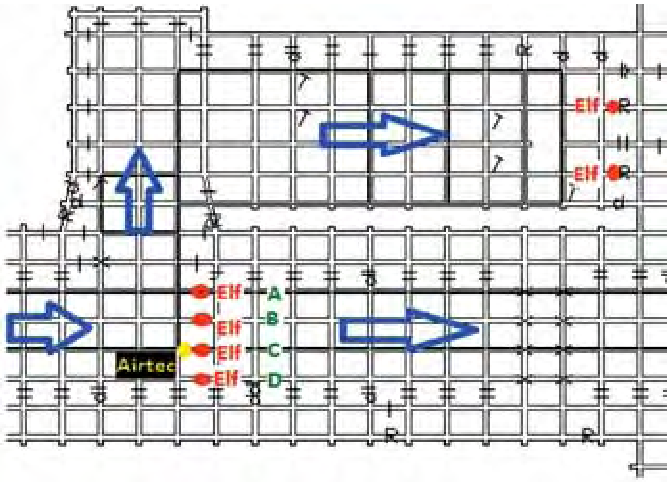

Figure 1. Instrument placement pattern at each station

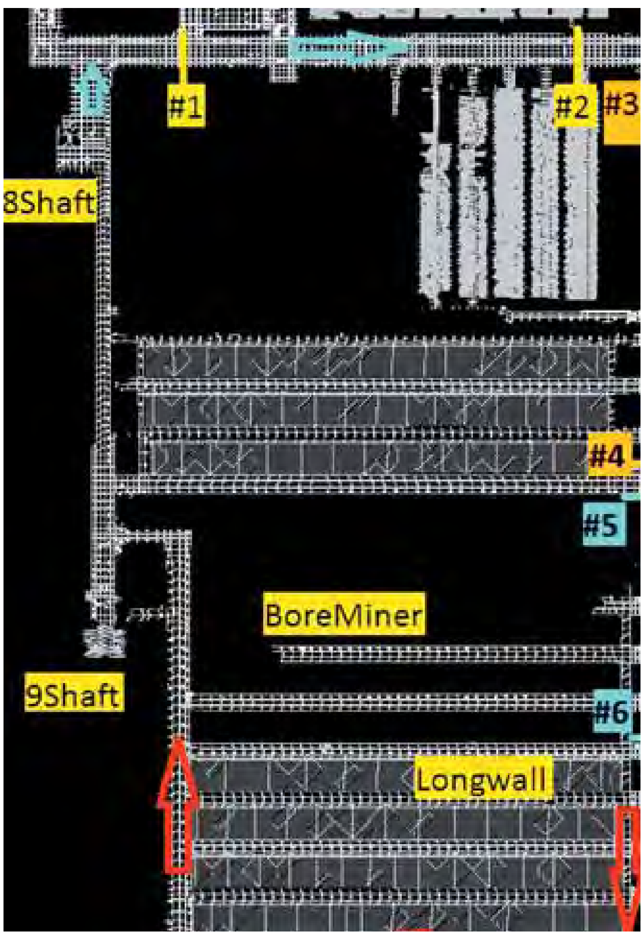

Figure 2. Station layout throughout the mine

The logged data was then used to analyse the DPM concentration graphs. Furthermore, the data used to identify which equipment emitted DPM at higher rates.

Leapfrogging station #1 and #2

Station # 1 was chosen inby the main shop split as shown in Figure 2. About 110 m^3/s of air enters the split. Approximately 50 m^3/s enters the shop and the rest flows inby the station #1. Station #2 was chosen about 2.7 km inby the first station.

A total of 9 Elf pumps were placed in both station and shop south regulator. Figure 6 shows the pumps that were hung from the top.

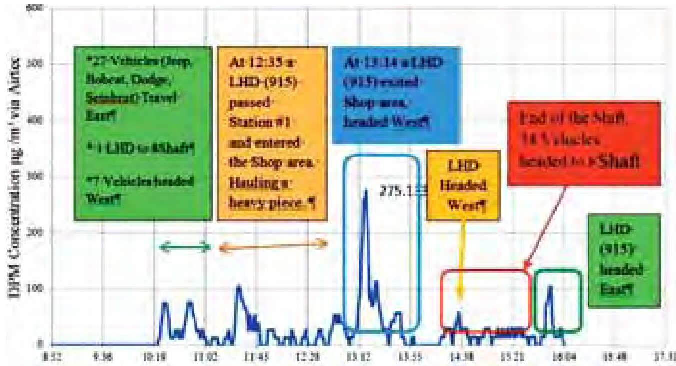

Figure 3. EC concentration via Airtec at station 1

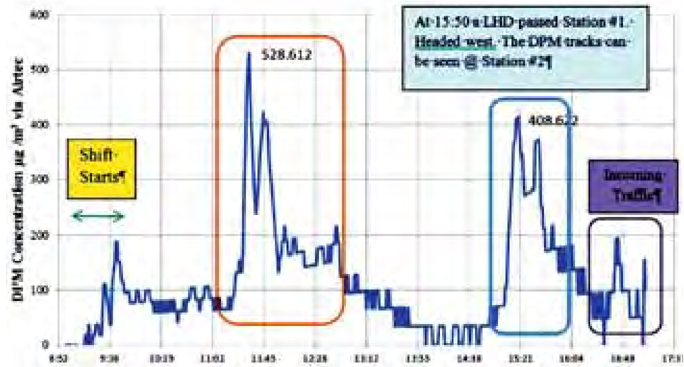

Figure 4. EC concentration via Airtec at station 2

Results from the Airtecs are presented in Figure 3 and Figure 4. The vehicle log data shows that 140 pieces of diesel equipment travelled inby or outby of Station #1. The direction of travel can be used to explain the peak points.

It was observed that LHD units are the main contamination sources.

The intake air from 8 Shaft dilutes the air after the shop split. The DPM concentration increases inby the first station.

In part due to air leakages through the stoppings and the rock (these are old working areas where the floor is cracked due to excessive floor heave).

Table 2. NIOSH 5040 via Elf and Airtec TWA results

Station #	Organic μg/m³	Elemental μg/m³		Total μg/m³	
	NIOSH 5040	NIOSH 5040	Airtec	NIOSH 5040	Airtec
#1 A	38	21		59.5	
#1 B	33	34		75	
#1 C	30	30	26	69	65
#1 D	25	11		41	
Shop	57	25		81	
#2 A	40	57		105	
#2 B	30.4	31.5		68.9	
#2 C	46.7	99.2	93	151.8	14
#2 D	44	83		148	
9Shaft	38	19		66	

The vehicles emit considerable levels of DPM especially when they are under load.

The Elf results were compared against the Airtecs as shown in Table 2. The results show that DPM concentration at shop area is significantly lower than the reading in the main developments. The Airtec and NIOSH 5040 cassettes results are in the acceptable range.

The leapfrogging was conducted in between all the stations. It was observed that LHDs are the main DPM source.

Entire mine sampling

Further DPM sampling was conducted across the entire mine. The purpose of this sampling was to understand the DPM spread throughout the mine and dilution rate (required fresh air to reduce the concentration). Thirteen Elf pumps were distributed in all of the main developments, bore miner panels, LW headgate and tailgate, diesel shop regulator and 9 Shaft. The concentration was adjusted according to running time period on each pump.

Two Airtec monitors were placed at the same station for a period of about three hours. The results show readings differed by approximately 3%. One of the Airtec monitors was then moved down to station #6. Figure 5 shows the DPM concentration for the entire mine as measured by Elf pumps (NIOSH 5040) and the real time Airtec units.

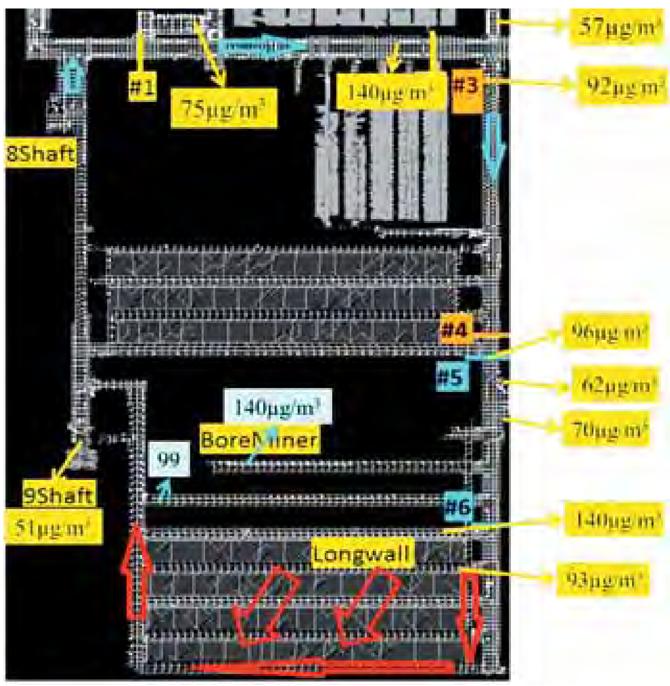

Figure 5. EC concentration via Airtec at station 2

The results from the Elf pumps are shown in Figure 5. The concentration at station #1 (3ME 55 1/2 XC) is relatively high (140 $\mu g/m^3$). Approximately 60 m^3/s of intake air (57 $\mu g/m^3$) from 5 Shaft enters the intersection. This air reduced the concentration to 92 $\mu g/m^3$. The survey results show that the DPM concentration slightly increases between station #3 and #4. The fresh air enters the split at station #4 (592 S, station #5) which reduced the DPM concentration to 62 $\mu g/m^3$. The air then enters the production faces at 299 East Development. The DPM concentration significantly increased to 140 $\mu g/m^3$ at 9HG development as the result of higher than usual traffic at this active face.

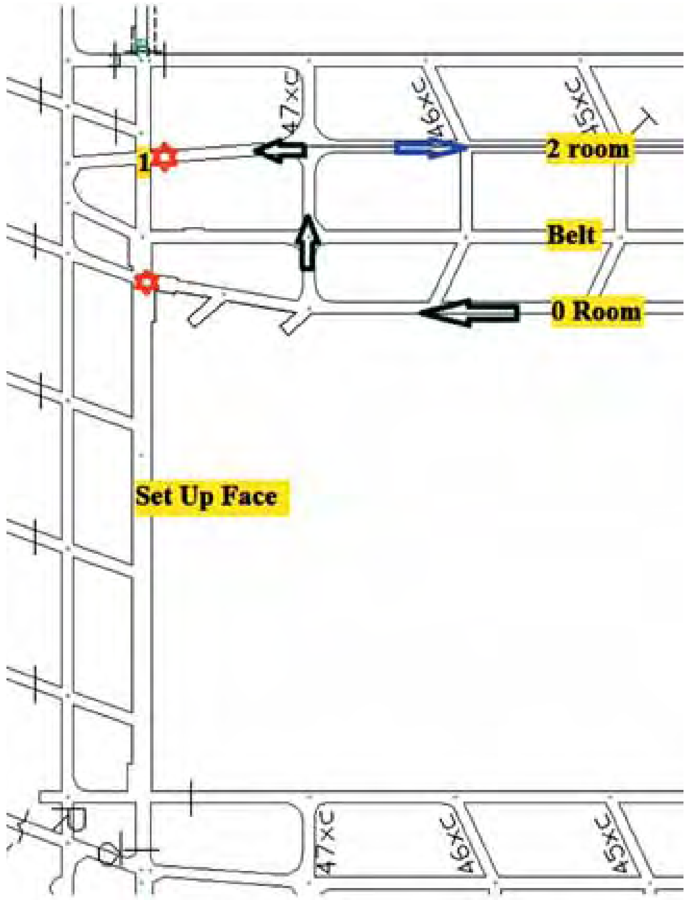

Figure 6. Airtec station and haulers pattern at the face

The vehicle log was analysed. A total of 78 pieces of diesel equipment passed by the log station (at station #5) The LHD activities matched the Airtec readings as shown in Figure 6. The LHD activities are shown in Table 4.

Table 4. Vehicle log at station #5

Equipment type	Time	Direction of Travel
LHD (913)	9:46	In
LHD (915)	10:22	Out
LHD (915)	10:38	Out
LHD (915) X 2	112:00 @ station 3	In
LHD (915)	14:05	Out
LHD (913)	15:04	In

Secondary test (Longwall move)

More DPM sampling was conducted during the LW move. Two Airtec units were placed at the LW set-up face at 0 room and 2 room as shown in Figure 6. The sampling was conducted when there were several shields stacked up, ready to transport in the recovery room. The Fletcher Prime Mover shield haulers loaded the shields at the recovery face, moving in 0 room towards the set up face. As each hauler neared the set-up face, they needed to move to 2 room to get properly oriented to unload the shields. After the shields were unloaded, the empty haulers headed back to the recovery face. The complete loop travel lasted approximately 50 minutes. Figure 6 shows the Airtec monitors locations. The Airtec stations are marked as the red star. The shield haulers move from 0 room to 2 room. The support was unloaded at 2 room. The 30X machine was used to pick and haul it back to the face. The shield haulers then travelled back to the set up room.

Direct tailpipe sampling

Direct tailpipe sampling was conducted on one of the shield haulers. The MAHA MPM-4M instrument was installed directly on the machine. An inverter was used to power the MAHA. The unit measured real time DPM concentration. The unit was hooked directly to the Fletcher's main exhaust tailpipe to measure the DPM amount emitted to the mine atmosphere. Figure 7 shows the MAHA unit placed on the shield hauler. The MAHA is designed for operation in harsh conditions with an advanced micro-processor that monitors the test and auto-zeroes the unit before every test.

Per §57.5071 if exposure exceeds PEL, corrective action must be initiated by the next work shift. In order to determine the air required to dilute the DPM, the exhaust gas emitted by the mine's operating diesel engines must be estimated. In order to do this, estimates of each vehicle running time must be made.

MSHA evaluates diesel engines and provides data for determining the air required to dilute diesel exhaust gases and diesel particulate matter concentrations to suggested levels (MSHA, 2001). For each engine tested by MSHA, the approval number, engine specifications and model number, engine rating (kW and rpm) and ventilation and diesel particulate indices are available. The results of the tests provide two indices, a gas index and a particulate index. The diesel particulate index is the estimated air flow needed to dilute the weighted average DPM emitted during the MSHA test to a concentration of 1000 µg/m^3.

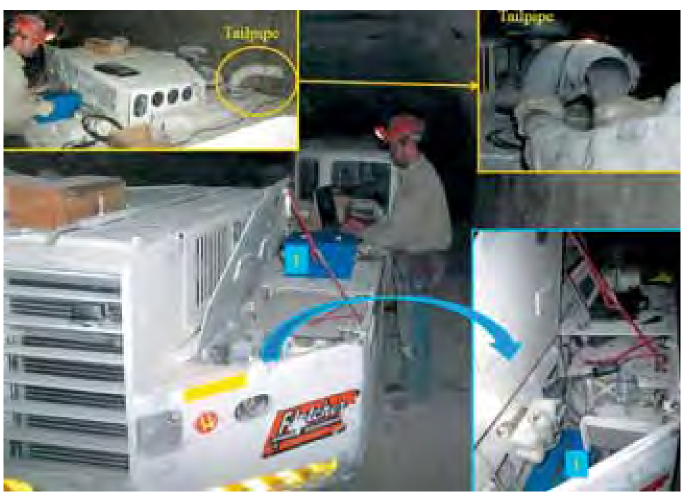

Figure 7. MAHA set up on the Fletcher Shield Hauler

Results and discussion

During the test the number of vehicles in the block were monitored and 28 vehicles travelled in and out of the block. This number excluded the forklift, shield haulers and 30X machine. The monitoring started at 15:40 by placing the Airtec in 0 room at the LW set-up face. Figure 8 show the EC concentrations measured by one of the Airtec units.

The shield hauler activities were logged. Table 4 shows the vehicle activity log for 65DT (Fletcher Shield Hauler). The shield haulers

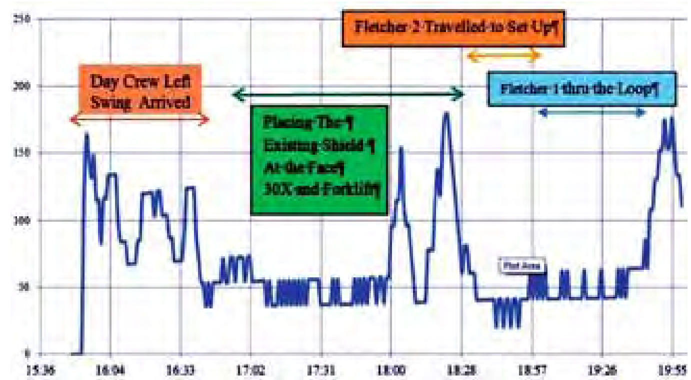

Figure 8. EC DPM concentration readings via Airtec µg/m^3

are equipped with SintAC Diesel Particulate Filters (DPF) with an active regeneration system. The SintAC is an active DPF system for diesel applications in the lower to middle performance range. The SintAC system is comprised of a sintered metal diesel particle filter and a fully automatic regeneration unit. It is capable of regenerating the soot accumulated in the filter at any engine operating state without any support from the engine management system and without intervention by the operator. When sufficient soot has accumulated in the filter the control unit automatically triggers a regeneration. Figure 9 shows the MAHA's logged data.

Table 4. Vehicle log at station #5

Location	From	To	Activity
Set Up	18:00	18:08	Preshift and Idling
2 Room	18:08	18:29	Idling, Waiting
2 Room	18:29	18:52	Back up to Set up and Unload
2 Room	18:52	19:18	Fuel and Traveling to Recovery
Recovery	19:18	19:24	Loading
0 Room	19:24	19:48	Travelling to Set Up

In order to reach the operating temperature necessary for a regeneration, the computer activates the heater integrated in the filter system by means of a relay as necessary. In order for all the soot to burn off in a short time leaving practically no residue, an additive is added automatically to the diesel fuel by the dosing system. This additive lowers the ignition temperature of the soot and increases the burn off speed.

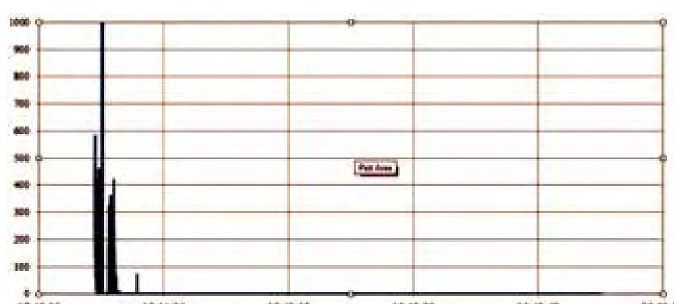

Figure 9. EC DPM concentration readings via Airtec µg/m^3

The results show that the hauler emits a considerable amount of DPM right after the engine is started.

However this heavy emission declines rapidly as the engine reaches a stable operating condition after about 5 minutes.

No significant emission was recorded throughout the test. According to the Fletcher User's Manual, regeneration may have automatically occurred after the operator started the engine. The regeneration may activate several times a day during longer operation. Regeneration starts automatically if the soot deposit in the filter exceeds a certain value.

A maximum PEL (Permissible Exposure Limit) of 37 µg/m^3 was recorded at the set up face. This number was measured for a period of approximately 5 hours. It can be concluded that the shield haulers do not increase the DPM concentration.

The 30X and 25X machines as well as the forklift are the main emission contributors during the move. Other transportation diesel equipment contributes significantly as well.

DIESEL PARTICULATE FILTERS

A variety of DPFs were considered and some tested to reduce the emission rate on LHDs. As part of this improvement, the Diesel Shop installed a Puritech DPF on a LHD. The machine was recently rebuilt with an Airflow Catalyst DPF and Caterpillar 3304 turbo-charged engine. The emission test was conducted and DPM was reduced from 50-80 mg/m^3 to less than 0.1 mg/m^3 proving the filter was over 99% efficient. Figure 10 and 11 show the MAHA DPM test before and after Puritech installation. The NO_x concentration was also reduced by 10%. Figure 12 shows the filter installed on a LHD.

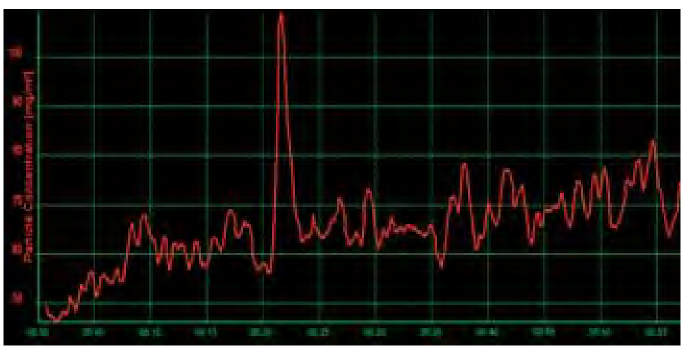

Figure 10. DPM concentration, pre-filter

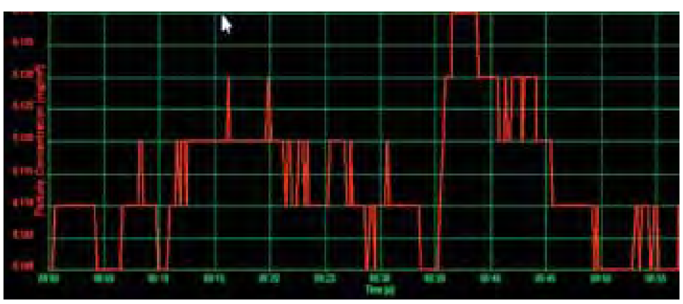

Figure 11. DPM concentration, post filter

The filter was found to be plugged after one day of usage. It was determined that fuel was not being injected into the exhaust stream. This prevented the expected increase in the exhaust temperature required to initiate regeneration. Further investigation showed that the filter, as delivered from the manufacturer, will only work on Tier 3 or higher engines.

A TF Hudgins HJS SMF-AR DPF will be installed on the machine in the next phase. It is similar technology to Mann &

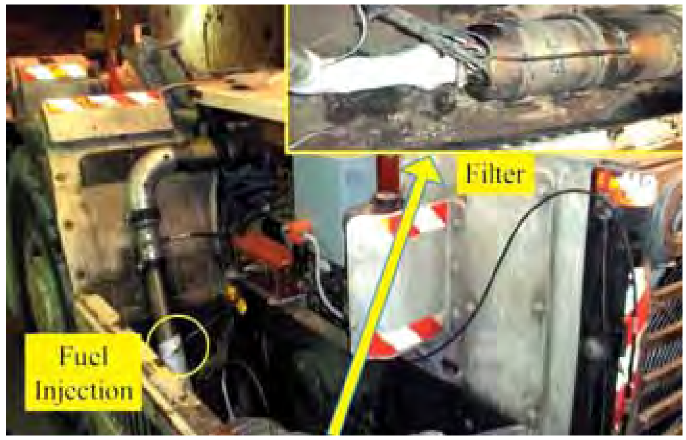

Figure 12. Puritech installation on a LHD

Hummel. Currently there are two Mann & Hummel filters being used at the Mine. These filters perform well and require minimal maintenance.

DETERMINATION OF MINE AIR REQUIREMENT

The air quantity required for a mine can be determined using a cookbook approach. A list of operating engines should be created in tabular form. The list should contain important information about each vehicle such as the equipment, and engine type (new direct, old direct or indirect injection), year of manufacturer, model, age, size, percent operating time, catalytic efficiency, filter efficiency and finally, the engine emission. The suggested air quantity from any engine nameplate should not be used as the only metric as this value is for diesel exhaust gases and it is generally lower than airflow needed for DPM dilution. Once this information is compiled, the estimated total mine air is the sum of the engine air quantity requirements operating in the mine. This technique assumes that all of the mine air will be efficiently used to dilute the DPM and that the air exiting the mine will be at the regulatory limit (Grau et. al., 2008).

CONCLUSIONS

The following is a review of the results and observations:

• The DPM survey throughout the mine proves that the LHDs (915 and 913) are the main emission sources. High DPM concentrations were measured at the main development (station #1), bore miner panel face as a result of high traffic and lower air quantity.

- The real time Airtec monitor readings and Elf NIOSH 5040 readings were overlapped. The MAHA MPM-4M results were also compared against the Airtec monitors.
- It was observed that Fletcher Prime Mover shield haulers are extremely clean and do not emit a considerable amount of DPM. The older Wagner 30X and 25X and other diesel equipment are the main DPM sources during the LW move.
- Man trips (Jeeps, Dodges and Bobcats) contribute a considerable amount of DPM to the atmosphere. The yearly preventative maintenance programme could determine the exhaust DPM rate for each vehicle. This result would help us to calculate the required air quantity to dilute the contaminant.
- 8 Shaft Diesel Shop: The results from all the surveys show that

the DPM level at the shop regulators are lower than 3ME readings. Therefore the execution of a ventilation project to reroute approximately 20 m^3/s air may reduce the DPM concentration at station #1 (station #2).

- The DPF filters with active regeneration system seem to capture at least 99% of DPM and require minimal maintenance.

ACKNOWLEDGMENT

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REFERENCES

ASTM Standard, 2002, BS ISO 16183. *Heavy duty engines: Measurements of gaseous emissions from raw exhaust gas and of particulate emissions using partial flow dilution systems under transient test conditions.* New York: American National Standards Institute.

Cantrell, B.K., and Rubow, K.L. (1991). *Development of personal diesel aerosol sampler design and performance criteria*. Min. Eng. 43:232-236.

Cantrell, B.K., and Watts, W. F., Jr. (1997). *Diesel exhaust aerosol: Review of occupational exposure.* Appl. Occup. Environ. Hyg. 12:1019-1027.

Gillies, A.D.S., and Wu, H.W. (2012). *Some approaches and Methods for Real-Time DPM Ambient Monitoring in Underground Mines.* SME Annual Meeting, Feb 19-22 Seattle, Washington.

Grau, R.H., III, Robertson, S.B., Mucho, T., Garcia, F., and Smith, A.C. (2008). *Practical techniques to improve the air quality in underground mines.* NIOSH, Pittsburg Research Laboratory, Pittsburg, PA, USA.

Janisko, S., and Noll, J.D. (2008). *Near Real Time Monitoring of Diesel Particulate matter in Underground Mines*.12th North American Mine Ventilation Symposium, Wallace (ed), ISBN: 978-0-615-20009-5.

McGinn, S. (2000). *The relationship between Diesel Engine Maintenance and Exhaust Emissions*. Final Report: DEEP, http://www.camiro.org/DEEP/Project_Reports/mtce_report.pdf

Mine Safety and Health Administration (MSHA), U.S. Department of Labor. (2001). Final Rule 3 0 CF R Part 57, January.

MSHA, Mine Safety and Health Administration. (2009), 30 CFR part 7. Testing by applicant or third part. Code of Federal Regulations, Washington, DC: U.S. Government Printing Office, Office of Federal Register.

NIOSH Manual of Analytical Methods (NMAM), Elemental Carbon, Method 5040, Issue 3, 15 March 2003.

Noll, J.D., and Janisko, S. (2007). *Using Laser Absorption Techniques to Monitor Diesel Particulate Matter Exposure in Underground Stone Mines*. In: Cullum, B., Porterfield, D., ed. Proceedings for SPIE: Smart Biomedical and Physiological Sensor Technology V. Vol. 6759 Boston, Massachusetts: SPIE, pp. 67590P-1 67590P-11.

Noll, J.D., Timko, R.J., Schnakenberg, G.H., and Bugarski, A. (2006). *Sampling Results of Improved SKC Diesel Particulate Matter Cassette*. Journal of Occupational and Environmental Hygiene, Volume 2, pp.29-37. ISSN: 1545-9624 print / 1545-9632 online.

Operator's Manual, 5th Wheel Prime Mover, J.H Fletcher & Co, pp 151.

Peer reviewed for Journal publication

Practical prediction of blast fume clearance and workplace re-entry times in development headings

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ABSTRACT

Re-entry into blast fume affected underground areas is a safety and productivity concern for most mines. Lengthy re-entry times may improve clearance of noxious gases, but can result in production delays and decreased overall productivity. Re-entry times into development headings are often standardised based on worst case scenarios, resulting in unnecessary delays. Fume clearance from blast areas can be mathematically estimated using a number of different methods however a complicating factor of fume clearance is considering the volume, efficiency and discharge location of fresh air ducts required to clear development blast areas. This paper proposes a modification to an existing well know method of fume clearance calculation to account for vent duct flow clearance and dilution efficiency. Finally, the paper considers how such an algorithm may be incorporated into modelling software.

Keywords: *Explosions, re-entry periods, dilution, blast fumes explosion gases.*

INTRODUCTION

Mine development and blasting

Blasting with explosives is an essential activity for developing tunnels in most underground hard rock mines, however the process introduces a number of hazards that must be controlled to ensure a safe work environment. A major consideration is the release and removal of noxious gases from the mine before the re-entry of workers to areas that may be affected by blasting fumes.

Traditional methods of estimating blast fume dispersal can provide accurate indications of clearance times if carefully calibrated to mine conditions; however these tools are rarely used systematically with blasting activities due to the wide range of variations in ventilation and blasting conditions.

In addition, the traditional calculation methods provide a limited platform for calculating mine wide fume dispersal, where mixing of airflows and dilution limit the use of fume concentration calculations.

Explosive quantities

Unless specialised properties are required, ANFO (Ammonium Nitrate Fuel Oil) is the predominant explosive used for development blasting due to price and performance characteristics.

Original paper presented at the the 10th International Mine Ventilation Congress 2014

Typical explosive quantities used in development headings vary according to rock type and blast practices however powder factors in development rounds typical from 0.6 kg to 1.2 kg ANFO per tonne of rock blasted.

Larger headings tend to have lower powder factors due to the smaller relative proportion of the high intensity blast in the initial confined centre of the development face.

Table 1. ANFO Properties

Ammonium Nitrate	94%
Fuel Oil	6%
Density (unpacked)	820 kg/m^3
Gas Volume	1.08 m^3/kg (at 25^{0}C)

A typical heading size of 5 m wide x 5 m high, 3.5 m deep and with a rock density of 2700 kg/m^3, would therefore be expected to use approximately 150 kg to 250 kg of explosives, depending on rock type and fragmentation required.

ANFO explosive gas composition can vary significantly based on moisture content and fuel oil percentage. In addition to complete combustion gases of Nitrogen (N_2), Carbon Dioxide (CO_2) and water (H_2O), ANFO (Ammonium Nitrate with 6.0% fuel oil) will produce the following additional noxious gases on detonation.

Fuel oil percentages less than 6% will produce less Carbon Monoxide (CO) but higher Oxides of Nitrogen (NO_x), while higher fuel oil percentages will increase CO yield and decrease NO_x yield.

Atmospheric mixed gas compositions will be substantially less than shown in table 2, due to the phenomenon of 'throwback', where the detonation of explosives will cause a discharge of blasted material and gases into the atmosphere well back from the blasted face.

Table 2. ANFO Explosive Noxious Gas Composition

Noxious Gases	Gas Yield 1 kg ANFO	Conc. ppm	Gas Density kg/m^3
NO_2	1.8	1667	2.62
NO_x (inc. NO_2)	3.5	3241	< 2.62
CO	16.0	14815	1.15
NH_3	0.4	370	0.73

Explosive gas exposure limits

Many documented cases exist of mine worker injuries or fatalities from exposure to explosive fumes. In the Revenue-Virginius mine in Colorado in November 2013, 20 miners were exposed to what is believed to be carbon monoxide from recent blasting, resulting in two fatalities.

Re-entry into work areas too soon after blasting, or inadequate ventilation can lead to fatal exposure to poisonous gases. The three main gases of immediate concern to human life are the oxides of Nitrogen (NO_x/NO_2), Carbon Monoxide (CO), and Ammonia (NH_3).

At typical explosive gas yields rates, NO_2 theoretically has the greatest danger to life. Exposure to high levels of NO_2 causes blistering in lungs and ultimately potentially fatal pulmonary oedema can develop from fluid buildup in the lungs. However NO_2 is an irritant asphyxiant gas which causes intense irritation to the eyes and respiratory passages, and is normally easily detectable at up to 40 times lower than exposure standards, reducing the chance of accidental exposure (although higher concentrations >4 ppm can anesthetise the nose making detection more difficult). NO_2 is also a dense gas and brown in colour. In the absence of ventilation it will often accumulate near the floor or in low hollows.

Carbon Monoxide is a colourless, odourless gas that, while having lower toxic explosive yield emission than NO_2 from blasting, is arguably a greater threat to life due to the increased chance of accidental exposure, particularly in poorly ventilated areas.

It mixes better with the atmosphere at normal exposure heights, and can be retained within broken muck piles long after the blast. Most injuries and fatalities from exposure to explosive gases cite carbon monoxide as the prime cause of poisoning.

Ammonia can also cause harm through over-exposure, however the yield of this gas is much lower than both NO_2 and CO and is easily identified and normally avoided through smell.

Table 3. Explosive Gas Exposure Limits

Noxious Gases	TWA* ppm	STEL* ppm	IDLH* ppm
NO_2	3	5	20
CO	25-35	100	1200
NH_3	25	35	300

* TWA - Time Weighted Average
STEL - Short Term Exposure Limit
IDLH - Immediate Danger to Life and Health.

GAS CLEARANCE TIME ESTIMATION

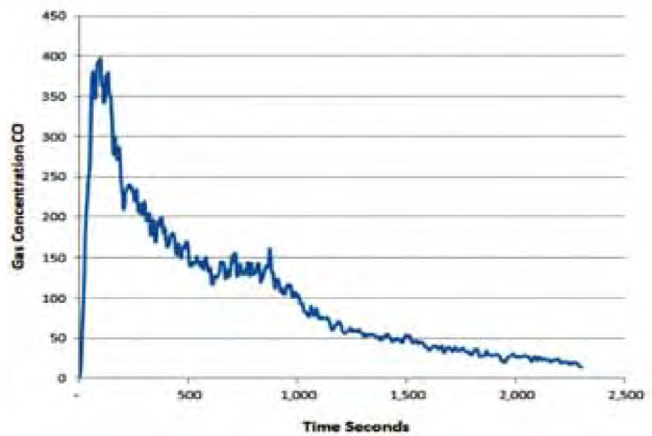
Methodology of gas data recording

A number of development headings at the host mine (15 in total) were measured for gas during and after blasting to help understand the potential variance in gas concentrations and clearance times.

The gas data logging handheld monitors (2 Dräger XAM 7000 and 3 Industrial Scientific iBrid MX6 units) were left at a safe distance of 50 m - 100 m from the face, and collected after the blast.

Carbon Monoxide was the measured gas and was used in the analysis of the estimation method, however other gases such as NO_2 or NO_x could also have been used.

The measured results showed a wide range of maximum concentrations and clearance times, highlighting the problem of estimating theoretical clearance times.



Graph 1. A typical gas monitor data log. Results varied widely between faces due to vent duct placement, air-flow quantity and duct discharge velocity and direction

The main observed variation factor was the position and velocity of fresh air from the duct. There was also considerable variation when the fans were resumed after blasting (to protect duct). See Graph 1.

Due to the limited number of gas recordings available, no attempt was made to quantify and statistically validate the cause of the variations.

Methods of calculating theoretical clearance time

A number of methods are available to estimate concentration and clearance times from underground blasting. In most cases a variation of a mathematical logarithmic decay series is the basis behind estimations. The data collected from gas sampling strongly supports this methodology.

De Souza et al., (1991) proposed a logarithmic decay method incorporating dispersion factors for distance away from the face. Gillies, Wu and Shires (2004) proposed modified logarithmic constants to improve correlation. Agasty et al., (2013) proposed computational fluid dynamics (CFD) to solve and analyse the problem.

All methods have significant merit and can closely represent the dilution behaviour of blast gases, but can be difficult for the site engineer to calibrate to local mine conditions. This paper will focus on the use of one of the more traditional approaches using a blast throwback approach.

Figure 1. Initiation of an underground development blast video (nonel tubes sending blast signals to detonators)

Figure 2. Subsequent throwback of gases and rock material during the underground development blast

Throwback method

A simple and well-documented method appearing in many texts is to calculate the theoretical blast throwback distance from the development face, and then use a log natural decay series to estimate the reduction in gas concentration over time. The blast throwback is the distance the blast material and gas expands (throws back) and contaminates the atmosphere immediately after the blast.

A number of simplified assumptions are made for the throwback method.

- The throwback volume is assumed to be uniformly mixed with blast gases.
- A flow rate of fresh air is then assumed to mix evenly with the contaminated volume, diluting the gas uniformly over time. Fume throwback length *L* can be estimated from the equation;

$$L = \frac{KM}{FaD\sqrt{A}} \qquad (1)$$

Where: L = Length of fume throw back (m), K = Constant (usually 25), M = Mass of explosives used (kg), Fa = Face advance (m), D = Density of rock (t/m^3) and A = Area of face (m^2)

The time *t* taken for gas to disperse to a defined level can be defined using;

$$t = \frac{V}{Q} \ln\left(\frac{Gc}{Gt}\right) \qquad (2)$$

Where: t = Time to achieve target concentration (s), V = Volume of gas filled space (m^3), Q = Flow rate of fresh air (m3/s), Gc = Initial gas concentration (ppm), Gt = Gas concentration at time t (ppm)

If the initial gas concentration (Gc) of the throwback region is unknown it can be calculated from the diluted theoretical gas yield of the explosive product as follows;

$$Go = \frac{1000 y_{gas}}{y_{anfo}} \qquad (3)$$

Where: Go = Initial undiluted (no throwback) gas concentration, y_{gas} = yield rate of noxious gas (l/kg explosive), y_{anfo} =total gas yield of explosive (m^3/kg)

$$Gc = \frac{M \times y_{anfo}}{V} \times Go \qquad (4)$$

To estimate gas concentration *Gt* at any specific time after the blast, equation (2) can be rearranged as;

$$Gt = \frac{Gc}{Exp\left(\frac{tQ}{V}\right)} \qquad (5)$$

Estimation errors

The application of theoretical formulas to estimate gas concentration and clearance time often shows a poor correlation to actual gas readings.

In many cases the main source of correlation error is the efficiency of the fresh air from the duct in penetrating the full throwback blast zone. Coupled with the potential lack of uniformity in the concentration of the throwback gas cloud (with higher concentrations more likely at the face), the potential for estimation error increases.

If the duct is discharging some distance from the face (even if the duct discharge is within the throwback zone), only a portion of the supplied fresh air will reach into the region close to the face, resulting in lesser amounts of cleared gas, and longer clearance times.

A CALIBRATED APPROACH

Defining a calibration factor

To improve correlation with recorded results, it is advantageous to consider the delivery flow of fresh air from a duct into the heading (which can be easily measured) separate to the portion of the flow that effectively clears the gas (which cannot be easily measured). Assuming we treat flow Q as the full discharge flow from the duct, the equations in section 2 can be modified to account for observed differences by applying a calibration or 'dilution efficiency factor'.

Goals for a calibrated method

To achieve improved correlation with actual results, and to provide a useful tool for mine wide simulation, some key requirements must be met:

- Easy calibration to actual blast conditions measured in a mine, to account for the dilution efficiency of duct air at the face.
- Volumetric and mass balance of explosive gas products released into the mine atmosphere must be preserved.
- The ability to incorporate into mine ventilation simulation software using dynamic (transient) simulation methods.

A factored solution

Clearance times and concentrations will change significantly based on the proximity of the fresh air duct from the blast face and how this duct is directed into the heading. The fresh airflow must penetrate the explosive gas region and 'scavenge' the blast gases at the face, carrying the gases in the return air stream.

This scavenging behaviour is a complex 3D flow dynamics problem depending on many factors and prediction would require complex computational fluid dynamics (CFD) methods or extensive empirical data. However the aim in this case is to only calibrate this behaviour to produce a reasonable basis for predicting future blast activities with similar ventilation configurations at the mine. A dilution efficiency factor (f_d) can be considered by modifying equation 2, 4and 5 as follows;

$$t = \frac{V}{Q \times f_d} \ln\left(\frac{Gc}{Gt}\right) \quad (2a)$$

$$Gc = \frac{M \times y_{anfo}}{V} \times Go \times f_d \quad (4a)$$

$$Gt = \frac{Gc}{Exp\left(\frac{t \times Q \times f_d}{V}\right)} \quad (5a)$$

Where: f_d = dilution efficiency factor

If the initial gas concentration (Gc) and any future concentration (Gt) at time (t) are known, equation (2a) can be rearranged such that any point along the data logged curve can be used to calculate the dilution efficiency factor;

$$f_d = \frac{V \times \ln\left(\frac{Gc}{Gt}\right)}{t \times Q} \quad (6)$$

The best estimate of the dilution efficiency factor will occur if a point is near the centre of the curve (where concentration is 50% of maximum).

Worked data example

An example blast was selected for calibration. Approximately 220 kg of explosives was fired at 5 m x 5 m x 3.5 m deep development heading.

Gas data collection

The gas monitor was placed near a junction approximately 60 m from the face. A 1070 mm duct supplied approximately 20 m^3/s of air to within 35 m of the face. Large tears were observed at several locations along the vent duct between the monitor and the face.

This location was chosen due to consistent data collection quality that was not affected by blasting in other nearby headings. Some other locations measured were found to be contaminated with gases from upstream blasts. On other occasions there were lengthy delays in turning the ventilating fans on which affected data quality.

Measured results

Shortly after firing, the data logging gas detector quickly rose to a maximum of 448 ppm from the face, reducing to 110 ppm after 500 seconds.

Calculations

The throwback length L can be calculated from equation 1;

$$L = \frac{25 \times 220}{3.5 \times 2.7 \times \sqrt{25}} = 112.2\ m$$

The throwback volume V = 116 x 25 = 2806 m^3.

The dilution efficiency factorf_d can be calculated from equation 6;

$$f_d = \frac{2806 \times \ln\left(\frac{448}{83.73}\right)}{600 \times 20} = 0.392\ or\ 39\%$$

A corrected concentration graph can now be calculated from equation 5a.

Figure 3 shows a graph of the actual measured data, the uncalibrated curve, and the calibrated result using the dilution efficiency factor. As expected, the calibrated curve closely matches the actual results.

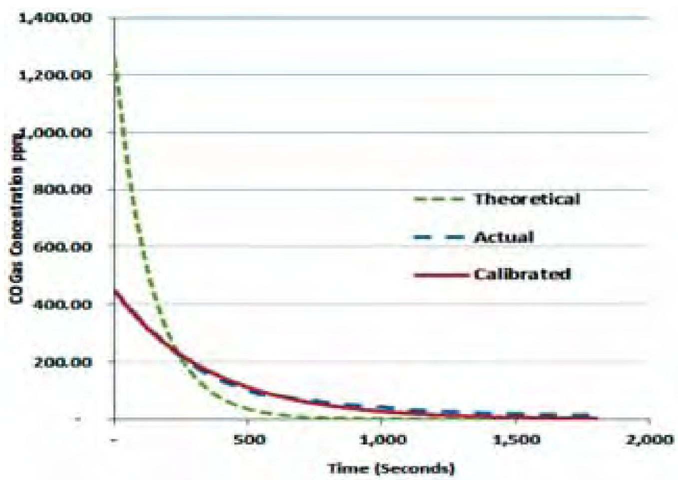


Figure 3. CO Gas comparison of measured concentrations, uncalibrated calculations, and calibrated calculations

Summary of example results

The calculated results were compared again to actual data. The calculated gas concentration at 5 minutes from equation 5a is calculated;

$$Gt = \frac{448}{Exp\left(\frac{300 \times 20 \times 0.392}{2806}\right)} = 181\ ppm\ CO$$

- The five minute concentration compares well at 181 pm calculated versus 185 ppm measured.
- The 15 minute sample shows some variation with 29 ppm calculated versus 39 ppm measured, however this is accounted by a background mine concentration of 10 ppm CO.

The calculated line shows that while the theoretical estimation based on the unfactored throwback formula is not accurate, the calibrated curve using the dilution efficiency factor shows a very close match to the measured data.

If contaminants are already part of the fresh air stream (from upstream blasting for example), then the new concentration Gt can be added to existing fresh air contaminant levels in the airflow providing the relative portions of the contaminant gas are small compared to the overall airflow.

As a final check, total CO gas volumes were calculated using actual data, estimated CO gas volume from ANFO mass (@16l/kg), and theoretical calculation from the above equations.

- Measured CO gas volume = 3900 litres
- Theoretical explosive volume = 3520 litres
- Calibrate calculated volume = 3480 litres

Given limited accuracy in airflow estimations and ANFO mass, the differences are negligible and support the factored method of gas clearance estimation. The difference between measured and theoretical can be attributed to background levels of approximately 10 pmm from other areas of the mine (approximately 540 litres over the measured time intervals).

Practical gas concentration prediction

Provided basic parameters such as explosive mass and the quantity of ventilating fresh air are known, the only factor required to predict gas levels is the dilution efficiency factor.

Estimating the dilution efficiency factor

Since this factor is an indication of the efficiency of the airflow in clearing the gas from the area we must consider the configuration and location of the air-flow into the heading.

From a practical perspective, a factor of 100% indicates the duct airflow will initially push the maximum concentration contained in the throwback volume, while lesser amounts indicate penetration of the fresh air flow into the gas zone is less efficient, and hence will result in decreased clearing efficiency and longer clearance times.

It is important to note that the dilution efficiency factor is independent of the amount of airflow quantity from the duct. It is the efficiency of whatever air is available to clear the gas. On several tests where the fan was not turned on, the clearance factor was still recorded at over 90% due to slow but efficient natural diffusion of air.

It is just as important to note however that while the dilution factor may not change, the actual clearance times are still dependent on the quantity of clearing airflow. In the measured examples the blast headings without ventilating flow took many hours to clear.

It is proposed that mines could develop their own set of dilution efficiency factors based on observed differences in measured data. While the amount of airflow from the duct does not theoretically impact the estimation of a dilution efficiency factor, the amount of air leaking from the duct between the detector and the face is important. Duct leakage lowers the dilution efficiency factor because a portion of the duct air is no longer available to clear the fumes.

An example demonstrating one approach to dilution efficiency factor estimation could be as simple as shown in table 4 which sets different factors based on the distance of the duct from the face. Other factors such as velocity of air from the duct may also need to be empirically considered if gas testing at the mine indicates it is important.

Unfortunately there was not enough quality data in this study to offer further recommendation on factors to use, however it is expected most mines could fairly easily establish factors to suit their ventilation practices. The measured data set gathered for this study, showed clearance factors typically ranging from 30-40% for headings with duct 35 m from the face in fair condition.

*Table 4. Example Dilution Efficiency Factors **

Vent Duct Distance	Dilution Efficiency Factor Duct Condition		
To Face	Good	Average	Poor
10 m	85%	75%	65%
15 m	78%	70%	58%
20 m	70%	62%	50%
30 m	50%	42%	34%
40 m	34%	26%	20%
50 m	25%	18%	15%

*Example only - do not use. These figures are highly dependent on mine ventilation and duct practices. This table shows one approach to utilising empirical data results to predicting future clearance times.

One heading measured with duct much closer to the face showed over 80% efficiency. In fact in theory, if the duct was placed at the face with even distribution of air pushing back the fumes as a 'plug', or the blast occurred in a flow through ventilated area, an efficiency of 100% could be assumed.

Using different factors

To calculate a concentration versus time curse based at a (for example) 50% dilution efficiency factor, the following process can be used.

Assuming the same physicals as the previous example, equation 4a can be used to estimate the initial gas concentration before throw-back dilution;

$$Go = \frac{1000 \times 16}{1.08} \quad = \quad 14814 \ ppm \ CO$$

From the undiluted concentration, the throwback concentration (and hence the initial clearing concentration from the heading) can be calculated;

$$Gc = \frac{220 \times 1.08}{2806} \times 14814 \times 0.5 \quad = 627 \ ppm \ CO$$

Now that the initial blast clearance concentration is calculated, the concentration of gas from the face any time after the blast can be calculated from equation 5a. For example, the gas concentration from the face at time = 10 minutes (600 seconds) is;

$$Gt = \frac{627}{Exp\left(\frac{600 \times 20 \times 0.5}{2806}\right)} \quad = 74 \ ppm \ CO$$

The time for gases to dilute to a safe level of 25 ppm* at the face;

$$t = \frac{2806}{20 \times 0.5} \ \ln\left(\frac{627}{25}\right) = 904s \quad or \quad 15 \text{ min}$$

*Note: CO gas at 25 ppm may not be the limiting re-entry consideration as NO_x may have a higher TWA risk.

APPLICATION TO MINE NETWORK SIMULATION

Blasting gas concentration estimation methods in mine wide ventilation network simulation is potentially very useful. By combining the results of one or more blast locations, the concentration and travel time of fumes through an entire mine can be predicted, and re-entry times can be estimated, not only for individual headings, but for mine regions.

Mine wide re-entry times

The complex interactions between multiple headings in the same ventilation stream and the dilution of gases through the remainder of the mine is an important consideration for re-entry time.

While the re-entry time for a specific heading (for example) may only be 15 minutes, if the same gases from the cleared heading travel through other travel-ways in the mine, the actual re-entry time to access the area may be much greater.

Gas transport and mixing

The movement of gas throughout a mine can be a complex predictive process. The physical processes of gas diffusion, layering, imperfect mixing at junctions, and boundary drag can all have an impact on accurate prediction of gas movement. De Souza et.al., (1991) suggests using a diffusion factor to spread and dilute gas concentrations over distance travelled. However, for large mine wide network models such factors add significant complexity to a simulation, and may not necessarily add significant value in terms of providing a tool to improve ventilation.

Therefore, for large scale mine wide prediction of gas transport can be simplified by assuming linear gas movement at average flow velocities, no diffusion of gas once it has left the blast area, and complete homogenous mixing at junctions of airflow. The time to travel along any airway in the mine assuming constant cross sectional area is;

$$t = \frac{L}{v} \quad or \quad t = \frac{L \times A}{Q} \tag{10}$$

Where: t = time to travel the length of airway (s), L = length of airway (m), v = velocity of airflow (m/s), A = cross sectional area of airway (m^2), Q = airflow quantity of air (m^3/s)

Where two airways meet at a junction or 'node', the gas compositions of the two airflows can be mixed homogeneously as a weighted average and (assuming perfect mixing) the newly calculated mixture can be predicted downstream from the junction as follows;

$$Gm = \frac{\sum (G_{1..n} \times Q_{1..n})}{\sum Q_{1..n}} \tag{11}$$

Where: Gm= mixed airflow gas concentration, Q1..n = Flows into junction from connecting airways, G1..n = Concentrations of gas into junction from connecting airways

A mine network simulation method

To calculate changing gas concentrations within a ventilation simulation network, a transient or dynamic form of simulation method is needed to transport gas and predict concentrations in all parts of the model at any time.

Gas movements can be calculated assuming the network simulator has first correctly balanced the ventilation network such that:

- All airflows are calculated and balanced so that the airflows into each junction are equal to the airflows from the junction.

and

- Average airflow velocities are available or can be derived from airflow and airway size.

Discrete cell transport

A method (used by Ventsim Visual™) is discrete cell transport. This method divides each airway up into multiple cells containing individual information about the gas concentrations at that point in the airway. Fresh airflow into blind headings is carried by ducts modelled as separate small airways. The throwback volume of blast fume is assumed to be a point source of gas fumes that is fed at the calculated concentrations into the returning fresh air flow. The method works as follows:

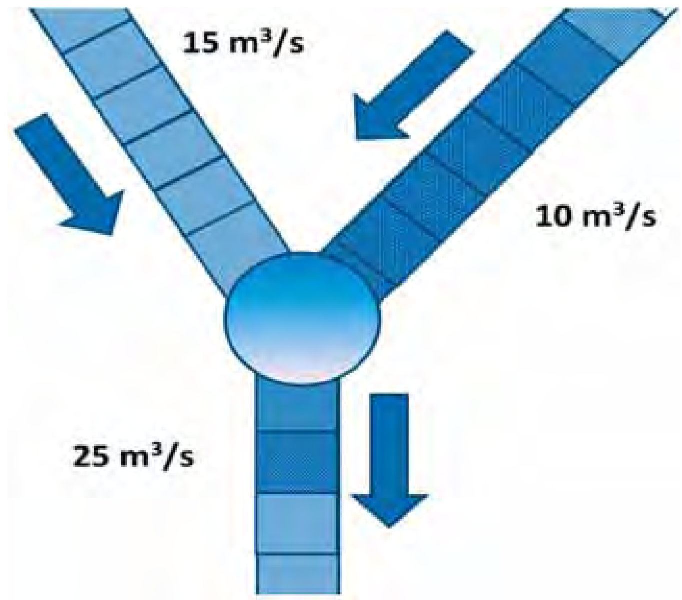


Figure 5. Discrete cell method of flow transport and mixing

- The cells are shuffled in position along the airway at a time based on the average airflow velocity described in equation (10).
- As cells exit the airway, the junction node collects the cell concentration and flow rate information.
- New cells enter the airway from the entry end. The concentration contained in the new cells is based on the volume weighted average concentration entering the junction from other airway cells (as per equation 11).
- The cells which travel through the explosive clearance area has gas added using concentrations defined by equation 5(a). This can be done using simple addition assuming relatively small concentrations; a mass balance method may need to be used for higher concentrations.
- The simulation continues until the explosive clearing concentration has fallen below threshold levels and gas levels in the remainder of the mine have decreased to acceptable levels.
- Data can be recorded over time at specified locations in the model, to display after the simulation completion as a graph.
- If gas diffusion needs to be considered, a portion of the gas can be withheld between each cell movement based on length travelled.

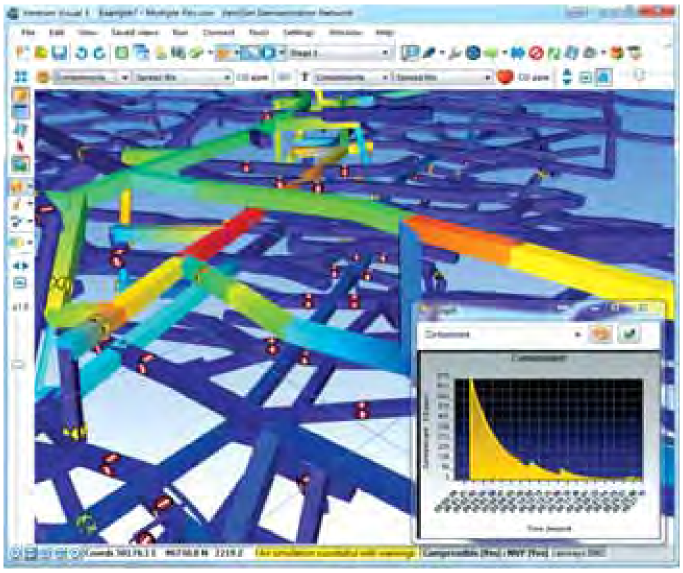


Figure 6. Complex interactions of different simultaneous blast locations and clearance time modelled in Ventsim Visual

Improving clearance times using simulation

It is not suggested that simulation methods be used for all blasting in a mine. Nor is it reasonable to suggest that simulation alone should be used to predict safe re-entry times. Re-entry formulas and simulation models can never replace safe work practices and measurement of gas in risky atmospheres.

Much of the blast gas dispersion and clearance time results will be an inevitable consequence of the mine ventilation design. Therefore, it is valuable to use ventilation network simulation as a tool to improve ventilation design, so that gas clearance and re-entry times can be improved. A good simulation model can also demonstrate the presence of recirculation which is a common factor in mines that experience lengthy blast fume clearance times.

Increasing airflows, preventing recirculation, diverting gases away from re-entry pathways and sequencing blasting activities to limit higher gas buildups are all valid design approaches to removing blasting fumes and improving re-entry times.

By simulating design vent circuits and testing a variety of possible blasting scenarios, a benchmark of clearance times can be established and other design options can be considered which may reduce clearance times or improve access into the areas. In addition, temporary solutions such as short-term changing of ventilation controls like regulators can also be examined for effectiveness.

CONCLUSION

The wide variation observed in blast fume monitoring results precludes the recommendation of fume clearance formulas as a single tool to calculate safe and accurate re-entry times. There are too many variables to consider and too great a chance of unforeseen changes occurring with the blasting process and the ventilation circuit.

Standard re-entry procedures and gas detection and monitoring will remain important parts of safe blast fume management. However calibration and prediction of typical blast fume clearance from typical headings can give greater certainty to re-entry time procedures and can help build confidence in the performance of the ventilation circuit. It can also assist in identifying poor ventilation or blasting practices occurring at the mine which may result in longer clearance times.

Of most practical use however, is the ability to use calibrated blast fume clearance formulas in mine wide simulation, where fumes concentration in many areas can be simultaneously observed over time. Even if the clearance rates fail to accurately describe every blast, the relative merits of different ventilation designs can be assessed against each other.

The simulation results can be used to benchmark and improve ventilation design, and potentially reduce the downtime and lost productivity that occurs when blast fumes are poorly ventilated from the mine.

REFERENCES

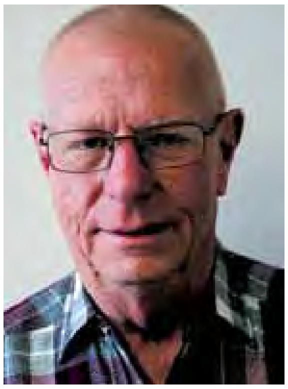
De Souza, E., Katsabanis, P.D., Roberts, W., andHeidrich, H. (1991). *Blasting Fume Prediction and Control as a Means of Reducing Ventilation Costs.*

Agasty, A., Clausen, E., Kellner, M., and Langefeld, O. (2013). *After Blast Re-Entry Time for a Room and Pillar Operation.*

Gillies, A.D.S., Wu, H.S., and Shires, D. (2004). *Development of an Assessment Tool to Minimize Safe After Blast Re-Entry Time to Improve the Mining Cycle.*

50 years in mining -
Boet van der Vyver

by Neil Roman



The Mine Ventilation Society of South Africa would like to pay tribute to a long-standing member of our discipline. Cornelius Marthinus van der Vyver, better known to us as Boet, has spent an incredible 50 years in the mining industry, most of it in mine ventilation.

Boet grew up in Johannesburg and attended the Marist Brothers College in Observatory. On leaving school, he signed on with Gold Fields (GFSA) as a learner official in January 1967, posted at Venterspost Mine. He did his second year of training at West Driefontein, where he was involved in the infamous flooding incident in October 1968. He dealt with stores and procurement, and was responsible as the scribe of the 'War Diary'. He gained great experience in the field of emergency management, which would stand him in good stead in the future. He was also involved in early rock-cutting research at West Drie.

In 1969, Boet was transferred to Doornfontein Mine and after his training period was finished, transferred into mine ventilation and was again posted to West Driefontein under Tom Burger.

He spent the next four years learning the trade and completing his qualifications - he obtained his Certificate in Mine Environmental Control in 1973 and was again transferred, this time as second-in-charge at Libanon Mine under Jan Scholz. He (not so) fondly remembers spending six months doing the ventilation planning for 4 Shaft on HP calculators!

Boet's skills and talents were recognised, and he became the 'go-to guy' in Gold Fields for new mines, expansions, and commodities.

In 1979 he was appointed as the Ventilation Engineer for the new Black Mountain Mine in the Northern Cape. For anyone used to the ordered ventilation systems at South African gold mines, the ventilation layout of a deep base metal mine resembles a Rube Goldberg invention! Following a very steep learning curve, the Black Mountain Mine was successfully established (and ventilated).

Boet transferred to Doornfontein in 1983 to establish a new expansion, including the new 3 Shaft vertical and sub-shaft complex.

In 1988, Boet was sent to the new Northam Platinum Zondereinde Mine, to set up Gold Fields' first foray into platinum. This hot, deep platinum mine was planned with several innovations such as hydropower.

After 26 years in the industry, his bosses probably thought he was tired, and in 1993, Boet was appointed as Gold Fields' Group Firemaster, traditionally a job one quietly retires from. Not our Boet! - he was heavily involved in every subsequent fire at Gold Fields' mines, and established the use in South Africa of the GAG jet engine for fighting fires. He wrote all of the procedures and guidelines for its use, sometimes based on disconcerting incidents. He remembers one event where the cooling jacket at the engine exit failed and crumpled from the heat, and the engine threatened to take flight in the opposite direction!

With some reluctance, Boet was approached to re-enter the mine ventilation field at Kloof Mine in 1996, to design and implement ventilation for the new 4 Shaft complex.

Following the Gold Fields / Gencor merger in 1998, Boet was offered early retirement. He accepted, but after six months 'gardening leave', Boet decided that he missed the rough-and-tumble of mining.

He entered the consulting business with Turgis and spent four years there working on numerous mine studies.

Boet then took another short sabbatical during 2002, travelling and working in China. He helped to set up a new college in Changchun and served as an advisor to Chinese students seeking to study abroad.

Boet returned to Turgis in 2003 for six months, until one of his clients, BCL Nickel, offered him a five-year contract to run the ventilation department there. Part of his responsibility was to train a local understudy to be able to take over the running of the department, which was successful. During his tenure at BCL, Boet somehow found the time to successfully complete a Certificate in occupational hygiene at the TshwaneUniversity of Technology (Pretoria).

After the completion of his BCL contract in 2008, Boet joined BBE Consulting and spent five years there until 2013, before accepting a thirty-month contract to train ventilation engineers at the Loulo mining complex in Mali. After this was completed, Boet returned to BBE, where he remains as a Senior Ventilation Consultant.

Boet plans to retire in 2018 to his property on the Chinese mainland near Hong Kong, but suspects that he will take on some English teaching in order to keep busy.

Those of us who know Boet would not be at all surprised to see him pop up in mining again!

On a personal note, having known Boet for over 30 years, I would like to express my personal congratulations on an exceptional 50-year career, and to thank him for sharing his wisdom and knowledge.

On behalf of the MVSSA Council and members, I wish him a happy and healthy retirement.

Obituary

Des Wrigley

It is with Deep regret that the Society records the passing of Des Wrigley of cancer at the age of 64 on 29 April 2017.

Des started his career with Anglo American (now AngloGold Ashanti) as a Learner Official and soon afterwards joined the Ventilation Department at President Brand Mine 1972/73.

Other positions included:

1976 - Sectional ventilation officer at Pres Brand Mine, Welkom

1979 - Sectional ventilation officer at Saaiplaas Mine, Virginia

1982 - Ventilation Superintendent at Free State Geduld Mine, Welkom

1994 - Senior Divisional Ventilation Manager, Vaal Reefs

1996 - Regional Ventilation Manager, Vaal Reefs

1998 - Group Ventilation Manager

Des made his mark within AngloGold Ashanti and the whole of the industry. He went through the ranks quickly and served on many committees and working groups within the industry and occupied many leadership roles. He also served as President of the Mine Ventilation Society of South Africa during 1995-1996.

Des was a level-headed person, hard-working, honest, a good mentor and fair towards all who crossed his path. He was the kind of boss who would not look over your shoulder, and would show his trust and express his gratitude for work well done. He could also be trusted with any private issues and would have gone out of his way to help wherever he could.

Des was Chairman of the MVSSA Free State branch from 1989 - 1998.

After his retirement Des spent some time working at the Chamber of Mines with the MIOSH (Mining Industry Occupational Health and Safety) noise team after which he spent the last two years of his career assisting AngloGold Ashanti with the preparation of litigation in regards to Silicosis and Occupational Lung Disease.

Des was loved and respected in society and as a Christian in his church. Des lived by John 13: 34-35: "A new commandment that I give you, that you love one another; as I loved you, that you also love one another. By this all will know that you are my disciples, if you have love for one another".

Des was a loving husband to his wife Sheila and a wonderful father to his daughters Kayleen and Ashlyn. He will be dearly missed by family friends and ex-colleagues.

At the end, when he was very ill, he maintained his special witticism and still made people smile. Sheila chose the following to remember him by, which is truly how Des would have wanted it: *I'd like the memory of me to be a happy one. I'd like to leave an after-glow of smiles when life is done. I'd like to leave an echo whispering softly down the ways, of happy times and laughing times and bright and sunny days. I'd like the tears of those who grieve, to dry before the sun: of happy memories that I leave when life is done.*

2017 annual Conference of the Mine Ventilation Society of South Africa

Meeting the challenges of 21st Century mining

DATES: 27 and 28 July 2017 VENUE: Emperors Palace, Ekurhuleni

CONTACT: The Mine Ventilation Society of South Africa Tel: +27 11 482-7957 Email: secretary@mvssa.co.za WEBSITE: www.mvssa.co.za

Programme

Thursday 27 July 2017

		Session theme	Presenter
07:00	08:00	Registration	
08:00	08:15	Welcome	MVS President
08:15	08:45	Key Note Speaker	Dr L. Ndelu
08:45	09:10	Fatigue Management Technology: Putting a Cap on Miner Fatigue	J. van Niekerk
09:10	09:35	Trackless mining machinery: Is it Noise Induced Hearing Loss [NHL] or Nerve Injury [NI]?	I. Sibisi, M. Barnard
09:35	10:00	The effectiveness of process plant ventilation to reduce exposure to harmful airborne pollutants	J. Snyman
10:00	10:25	Local Exhaust Ventilation (LEV)	M. Morrison
10:25	11:00	Tea	
11:00	11:25	Ventilating shallow platinum mine shafts in a more energy efficient manner	A. Viljoen, J.J.L. du Plessis
11:25	11:50	Shallow depth diurnal variations of rock to air heat transfer in an intake incline	A. Pandey, B.S. Sastry
11:50	12:15	Closing the gap between mine ventilation planning and implementation	R. Funnell
12:15	12:40	Operational advantages of mobile refrigeration using a closed loop heat rejection configuration	R. Potgieter
12:40	13:05	Education feedback	M. Beukes
13:05	14:00	Lunch	
14:00	14:25	*Junior Session:* Effectiveness of fail-safe mechanisms on continuous miner dust control	I. Mahlangu, J.J.L. du Plessis
14:25	14:50	*Junior Session*: Challenges of junior ventilation and occupational hygiene practitioners. A perspective from a junior MVS member	T.F. Ngobeni
14:50	15:15	*Junior Session*: Real time continuous miner dust monitoring and preventing methane ignitions around continuous miners	A. Lenonyana
15:15	15:35	Tea	
15:35	16:00	Emergency analytical testing: Things to consider	C.J. Pretorius
16:00	16:25	Advancing the technology and effectiveness of methane monitoring on a continuous miner	C.F. Meyer
16:25	16:50	Challenges around reporting and taxation for coal mining fugitive greenhouse gas emissions	A.P. Cook
16:50		Cocktail	

Friday 28 July 2017

07:00	08:00	Registration	
08:00	08:25	Fire engineering principles: Reducing the risk of underground conveyor belt fires	D. Senekal
08:25	08:50	Assessing support packs from an occupational hygiene perspective	C.J. Pretorius, R. Teleka
08:50	09:15	Equipment review: A historic view of published literature on personal dust sampling instrumentation used in coal mining	J. van Niekerk
09:15	09:40	Confined spaces	H. Thiel
09:40	10:05	The use of a compact cyclone separator to effectively remove bulk dust - CFD Study	D. Bibby
10:05	10:35	Tea	
10:35	11:00	Junior Session: Effective cooling at Mponeng	P. Mokgosi
11:00	11:25	Junior Session: Reducing mine ventilation air – the unintended consequences	D. Setshwaro, W. van der Merwe D. Labuschagne
11:25	11:50	Junior Session: History behind the MVSSA Coat of arms and what it symbolises	J. Pienaar
11:50	12:15	Closure	MVS President
12:15	12:40		
12:40	13:00		
13:00		Lunch	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