Journal of The Mine Ventilation Society of South Africa

Volume 69 Number 3 July/September 2016 ISSN no: 0368 3206

- Convergence – Heat and diesel mechanisation
- Underground fires: Prevention is better than cure
- Screening of various diesel particulate matter samples from various commodity mines
- Block cave mine ventilation optimisation techniques
- Methods to suppress dust on open pit drill rigs

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Cover Picture:

Beatrix 3# during the development and equipping phase of the settlers on 26 level in 2002. Photographer: Marthinus van der Bank.

Editor's Comment

Determining safe occupational exposure levels of combined pollutants

Prof Jan du Plessis
Honorary Editor

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

During the recent Annual MVSSA Conference a large number of papers dealing with Airborne Pollutants were prepared and presented. South Africa has had a rich history of researching dust and the illnesses due to its exposure.

For the first time at a conference, the Occupational Hygiene focus outstripped the classical Mine Ventilation Engineering papers.

The question we need to ask ourselves is whether this is the pressing issue that our members face on a daily basis? Is this the question that we as a profession struggle with routinely? I for one continuously ask myself if we actually understand what workers really are exposed to during a normal shift and if we then fully understand the effect of the combined exposure? When a worker enters a mine there are numerous airborne particles that they may be exposed to. These include dust, diesel particulates, organic matter, radon daughters, gases, mists, etc.

Originally the Air quality Index (AQI) was developed to deal with this, but was it scientifically based and justified? How widely is this even practised, at least as an indicator today?

The problem with studies dealing with exposure is the long latency associated with occupational illnesses. The lower the exposure, often the longer the latency period. It is quite easy to present the impact that new engineering controls do have on for example diesel particulate emissions. In the conference a number of papers dealing with this were presented. We can thus easily show the impact of additional controls, however, the impact on the human interface or of the potential harm is not that easy as epidemiological studies take many years. These scientific studies often only deal with a single variable, meaning a single pollutant. The combined exposure and the impact of the combined "cocktail" of pollutants are not fully understood, nor is the toxicity of various combined airborne pollutants quantified.

This will not be a quick win type of research project, but will require a long-term programme of accurate exposure measurements combined with a large enough cohort.

A further complicating factor is that Nano technologies are the so-called technologies of the future. These particles have different pathways to what we normally associate particle behaviour. Thus the impact on humans is not well defined. However, we have seen a severe impact on the environment, and many Universities have started programmes looking at Nano particle risk management. These focus mainly on environmental impact at present, but going forward, will also include medical studies.

The continuous advancements and improvements in exposure measurement of the individual worker will further enhance our understanding of airborne particulate behaviour into the future.

The trick will lie in the accurate determination of what is a "safe" occupational exposure limit.

Is the practice of setting individual OELs adequate protection? The question remains whether a combined method of determining exposure should lead to a different level of OEL when exposed to more than one pollutant, and if so, how best to determine this in the future.

The recent class action around Silicosis, where earlier set occupational exposure levels did not adequately protect workers, is but a very strong reminder that we still have a lot of detailed work to do within this area. This is true both within the exposure as well as in the control of exposure areas.

MVS Public Relations Committee - Communication Facility

The MVS Public Relations Committee would appreciate any feedback on any matter relating to the operation of this society. This facility has been initiated in order to ensure that any matter that is raised is given due attention.

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.

Name: ______________________________

Telephone number: ____________________ Fax number: ____________________

E-mail address: ______________________________

Nature of communication (please mark with an X)

Complaint Compliment Other

Details of communication:

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Senior Vice President:
Mr Kobus Dekker
Junior Vice President:
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72nd Annual General Meeting of the Mine Ventilation Society of South Africa

Friday 24th June 2016 at 10h00, EnGedi Guesthouse & Conference Venue, Kromdraai

The 72nd Annual General Meeting opened with the welcome from the President Mr Len de Villiers to the executive, council, members, guests, DMR representatives and suppliers / supporters of the society. A special welcome was tended to past presidents, retired and new members of the society, Vice President of AMMSA, Mr Philip Coetzer and SAIOH representative, Ms Claudina Nogueira.

The president confirmed the minutes of the 71st Annual General Meeting held at EnGeni conference venue, Plot 22, Protea Ridge Road / Honingklip Road, Kromdraai on Friday 19th June 2015 which were published in the Journal, Volume 67 Number 3 of 2015.

Obituaries

Council recorded the death of the following members of the Society with a minute of silence in their memory:

Mr Stoffel Allers - Colliery Branch

Mr André de Beer - Northern Branch

Mr Billy Gore - Northern Branch

Mr Mike Howes - International Branch.

Standing up for a minute of silence in respect of members who had passed away

(Right) Mr Michael Minges collects The Society Prize

(Left) Mr Dries Labuschagne collects the Gold Medal Award

Presentation of prizes and awards 2015/2016

In order to recognise special achievements and to encourage the submission of papers for publication in the Journal to enhance its quality, the society awards annual prizes.

The Prizes and Awards Committee recommended the following awards:

Gold Medal - Mr Morné Beukes & Mr Dries Labuschagne "*The effect of automated mining on the occupational environment*" (Q1 2015 - Volume 68)

Society Prize - Mr Michael Schildhauer & Mr Michael Minges "*Development of an efficient axial flow fan*" (Q4 2015 - Volume 68)

AMM Award - Not awarded

SACMA Award - Not awarded

Associate Prize - Not awarded

Best Technical Note - Not awarded

JP Rees Award - Not awarded

Best Student Awards

Mr Gert C Lindeque - University of Pretoria 2014

Mr Msawenkosi S Mathe - University of Witwatersrand 2015

AFROX Trophy Best MEC student

This award was presented by Mr Peter Rowland from Afrox to Ms Janetta H Reynecke.

(Right) Ms Janetta H Reynecke collecting her AFROX Trophy Best MEC student from Mr Peter Rowland of Afrox

(Above) Best student awards:
(Left) Mr Gert C Lindeque - University of Pretoria
(Right) Mr Msawenkosi S Mathe - University of Witwatersrand

Certificate in Mine Environmental Control (MEC)

There were thirteen successful MEC candidates who achieved the highest marks for each paper (papers 1 to 6) and received the Presidential Award which includes the new text book and a cash prize of R3,000.00.

Certificates of Achievement are awarded to those who have received their Certificate in MEC for the last two examinations:

Intermediate Papers 1 and 2 - Ms Florence Magampa (achieved 93% for Paper 1 and 94% for Paper 2)

Advanced Paper 1 - Mr Arnoldus de Wet - Anglo Gold Ashanti

Advanced Paper 2 & 5 - Mr Eugene O Mafatshe - Anglo Platinum

Advanced Paper 3 - Mr Phuti L Mphago - Samancor - ECM

Advanced Paper 4 - Mr Onalena Dickson - BCL

Advanced Paper 6 - Ms Zoe Selenati-Dreyer - Sishen Iron Ore.

Name	Certificate Number
Onalena Dickson – BCL	1061
Malefo A Morua – Swartklip	1062
Baboloki Seamorakeng – BCL	1063
Fidelis Mufara - Harmony	1064
Eugene O Mafatshe – Angloplat	1065
Janetta H Reynecke – Tau Tona	1066
George M Mapele – Sibanyegold	1067
Ema T Kemp – Anglogoldashanti	1068
Phuti L Mphago – Samancor - ECM	1069
Stephanus A le Roux – Hotazel Manganese	1070
Zoe Selenati – Dreyer - Sishen	1071
Khanani Moruti - DMR	1072
Vongai N Chindedza - International	1073

Ms Florence Magampa - 93% for Paper 1 and 94% for Paper 2

Mr Eugene O Mafatshe - Anglo Platinum, Advanced Paper 2 & 5

Mr Phuti L Mphago - Samancor - ECM, Advanced Paper 3

Ms Zoe Selenati-Dreyer - Sishen Iron Ore, Advanced Paper 6

The President's trophy

This trophy is awarded to a branch of the President's choice. This year the President's Trophy is awarded to the Western Branch

Mr Selvin Subban, past chairman and Mrs Glenda van der Westhuizen, chairman, accepted the trophy on behalf of the Western Branch.

Mr Selvin Subban, past chairman and Mrs Glenda van der Westhuizen, chairman, accepting the President's Trophy on behalf of the Western Branch

Honorary fellows

No nominees were received.

ANNUAL REPORT OF COUNCIL FOR THE YEAR ENDING 31/03/2016

Copies of the report containing information on the following highlights of the Society for the 2015/2016 year were distributed:

1. National Mine Ventilation Congress
2. Presidential Banquet - "Night with the Stars"
3. New MVSSA website
4. Madelein Terre'Blanche joined the office
5. Extraordinary Meeting on "The Way Forward"
6. Success of committees
7. Good financial performance
8. Increase in membership
9. Office activities.

FINANCIAL STATEMENTS AND BALANCE SHEET FOR 2015/2016

Mr André van der Linde presented the Financial Statements on behalf of Mr Wynand Marx.

The financial feedback is based on the audited statements by Genesis Chartered accountants.

The auditor's opinion is unqualified, meaning they found no fault and that financial management of the Society is in line with the "Generally Accepted Accounting Practice". They complimented the Society on:

- A budget that was well considered and accurate
- Good financial discipline

- Good financial administration - the secretary had kept accurate records of all transactions of the MVSSA office.

Details of the income statement were presented to the members.

APPOINTMENT OF AUDITORS FOR THE YEAR

The President announced that, in terms of Section 18.8 of the Constitution, the Council agreed to re-engage Genesis Chartered Accountants to audit the 2016/2017 accounts.

BRANCHES

The full annual reports of the branches are included in the 2016 Annual Report.

DECLARATION OF ELECTION OF OFFICE BEARERS & COUNCIL MEMBERS FOR 2016/2017

In terms of the Constitution, the outgoing Council has elected the Office Bearers for the year 2016/2017 as follows:

President - Mr Neil Roman

Senior Vice President - Mr Kobus Dekker

Junior Vice President - Mr Marthinus van der Bank

Honorary Editor - Prof Jan du Plessis

Honorary Treasurer - Mr André van der Linde

Honorary Chairperson Education - Mr Morné Beukes

Members of Council elected by ballot are:

Mr Frans Cloete

Mr Inus Labuschagne

Mr Johan Maass

Mr Wynand Marx

Mr Ronald Motlhamme

Mr Selvin Subban

Mr Albert Viljoen

These newly elected Council Members were congratulated and welcomed in the customary manner with sincere wishes for an enjoyable and fruitful year on Council.

The newly elected members of Council (Left to Right) Mr Johan Maass, Mr Inus Labuschagne, Mr Frans Cloete, Mr Ronald Motlhamme, Mr Albert Viljoen, Mr Selvin Subban

Past Presidents who have agreed to serve on Council are:

Mr Marco Biffi

Mr Henry Moorcroft

Mr Dirk van Greuning

The Branch Representatives who will serve on Council are:

The Collieries Branch - Mrs Julize van Niekerk

The Eastern Branch - Mr Tsietsi Letanta

The Free State Branch - Mr Barry Nel

The Northern Branch - Mr Billy Letlape

The Western Branch - Mrs Glenda van der Westhuizen

The International Branch - Mr Frank von Glehn

INDUCTION OF THE NEW PRESIDENT

Outgoing President Mr Len de Villiers introduced incoming President Mr Neil Roman and called him to the podium to present the pledge of honour on behalf of all Council Members.

"I William Neil Roman accept and undertake to faithfully execute the duties of the Mine Ventilation Society of South Africa, to the best of my ability, preserve, protect and defend the Constitution of the Mine Ventilation Society of South Africa."

The chain of office was then handed over to the new President.

Mr Len de Villiers invited the Senior Vice President, Mr Kobus Dekker to take the podium.

Mr Kobus Dekker then invited the new President to deliver the presidential address.

Mr Kobus Dekker invited the new President to deliver the presidential address

PRESIDENTIAL ADDRESS

Mr Neil Roman delivered his Presidential Address entitled "*Diesel Heat in Mind Ventilation Engineering*" which is published in this Journal.

Mr Neil Roman delivers his Presidential Address

VOTE OF THANKS

Mr André van der Linde proposed a vote of thanks to the President on behalf of members on his presidential address.

Mr Neil Roman thanked the outgoing President and presented him with the presidential gift and the presidential certificate.

Flowers were then presented to Mrs Marie Ackermann the secretary of the MVSSA and Mrs Madeleine Terre'Blanche the office assistant.

Mrs Marie Ackermann

Mrs Madeleine Terre'Blanche

GENERAL

The new President asked if there were any matters for general discussion.

CLOSURE

The meeting was closed and everyone was invited for lunch and refreshments.

Council 2016 / 2017; Back row (L to R) Mr Tsietsi Letanta, Mr Frans Cloete, Mr Albert Viljoen, Mrs Julize van Niekerk, Mrs Glenda van der Westhuizen, Mr Frank von Glehn, Mr Henry Moorcroft, Mr Marco Biffi, Mr Billy Letlape
Front row (L to R) Mr Ronald Motlhamme, Mr Len de Villiers, Mr Kobus Dekker, Mr Neil Roman, Mr Marthinus van der Bank, Mr André van der Linde

Convergence – Heat and diesel mechanisation

Mr Neil Roman

While all underground mines need a properly defined ventilation system, it is useful to analyse the amount of effort that should go into the design of such system. In order to determine whether a mine needs a properly-designed ventilation system, there are normally two issues that must be considered:

- The presence of toxic or flammable substances (dust and/or gases),
- The expected thermal environment in the mine.

The determinants of whether a mine will have an acceptable thermal environment or not will include:

- Depth (affects the mine heat load through auto-compression and strata heat),
- Surface climate (high ambient wet-bulb temperature), and
- Heat loads introduced as part of the mining process (diesels, electrical, other).

High values of any of these may result in an unacceptable thermal environment and may indicate the need for a sophisticated ventilation system that may include refrigeration and cooling.

Outside of South Africa, shallow ore bodies are becoming rarer and underground mines are progressing deeper. In most established mining areas, excluding South Africa, the use of mechanisation (usually diesel-powered) in underground mines has been non-negotiable for decades. South Africa has relatively few mechanised underground mines, mostly confined to the base metal, diamond, and manganese sectors.

Within the South African gold and platinum mining sectors, against their background of highly labour-intensive mining methods, labour legislation and cost are becoming unsustainable. Added to this is the rapidly increasing cost of energy - the least efficient power sources, such as mine-wide compressed air, are becoming untenable.

There is a convergence within global mining with regard to heat - most of the rest of the world has always been mechanised and now they are mining deeper. South African mines have always been deep, and they are now being prompted towards mechanisation. Both have an increased need for sophisticated ventilation systems, often including refrigeration and cooling.

Within the South African gold and platinum mining sector, other than the temperature increase encountered as air flows into a deep shaft, the progression and rate of temperature increase is 'slow and steady' (largely from strata). The wet-bulb temperature increase of air down a vertical shaft is typically 4.5°C per km, while horizontal temperature increase is often less than 1.0°C per km.

The use of diesel machinery, however, is responsible for a significant and nearly instantaneous increase in wet-bulb temperature. A typical increase in temperature due to a diesel machine can be compared to a sudden depth increase of 0.5 to 3.0 km. Part of the large and rapid increase in temperature is of course due to the often immense power of diesel mining machines, but a significant amount is due to the inefficiency of diesel engines. It is sometimes stated that heat from a diesel machine has a 'Heat Factor' of 0.8 or 1.5 times the kW rating of the machine. Where does this come from?

It is a combination of two factors:

- Engine efficiency (typically 30 - 40%),
- A 'Duty Cycle', which is essentially the average percentage of full rated power that the engine outputs during the shift (typically ranges from 10 - 60%).

The 'Heat Factor' is determined as in the following example:

- An engine rated at 100 kW divided by 40% efficiency results in total heat output (from fuel) of 250 kW (100 / 0.4),
- The duty cycle is then applied to the total heat – say 60%, thus the average heat output is 60% of 250 kW, or 150 kW,
- The resultant effective heat output of 150 kW is then related back to the engine kW (100), thus the Heat Factor is 1.5 (150 / 100),
- This would imply a duty cycle of 60% and efficiency of 40%,
- Note that it would also represent a duty cycle of 45% and efficiency of 30% or any other combination of duty cycle divided by efficiency that is equal to 1.5,
- For design work, we should clearly identify the individual assumptions made,
- In some ventilation software, the input data required is the effective diesel engine output. In this case, it would be 100 kW x 60%, or 60 kW. The software would then apply a global engine efficiency (60 kW / 40% = 150 kW of heat).

Although information can be difficult to obtain, actual figures should be obtained for engine efficiency and duty cycle where possible. The actual engine efficiency can be determined from calculations relating fuel flow at rated power, and a duty cycle can be obtained by measuring fuel consumed and engine running hours. It is important to determine these on a per-machine basis and not for a mine-wide fleet.

The heat output by a diesel machine is in the form of both sensible and latent heat. Sensible heat is responsible for an increase in air temperature. The latent heat portion goes into the creation of water vapour, both directly and indirectly. The engine directly releases about 1.4 kg of steam through the exhaust for every kilogram of fuel burned. The vehicle, as a heat source, also causes evaporation of additional water from the cooling system, machine body, wet ore, and the tunnel walls and floor.

Typically a total of 5.0 - 8.0 kg of water vapour is produced per kg of fuel burned. The energy required for water evaporation comes from the fuel, thus reducing the sensible heat contribution (and immediate temperature increase). Provided that the intake air is relatively dry, a higher latent heat contribution (from wetter surroundings) can result in in a lower wet-bulb temperature, however at the cost of increased humidity. Latent heat is typically 25 - 50% of total heat, depending on the wetness of surroundings. The concept of 'wetness' can also be described using an Enthalpy-Moisture Ratio, familiar to many South African mine ventilation practitioners as the little 'protractor' on Barenbrug's psychrometric charts.

The following chart (see Figure 1) can be used to determine the expected wet-bulb temperature increase from a diesel machine, depending on the amount of dilution air supplied (so-called Ventilation Factor) and the 'Duty Cycle' of the machine (effectively the average percentage of rated power used by the machine). In order to simplify the chart, only two 'Duty Cycles' are shown - at 40% and 60%. The former is typical of a haul truck and the latter a loader or LHD.

Note that the vertical scale is logarithmic to base 2, in order to view a larger range whilst providing some detail.

The vertical line on the chart marked '100 cfm/hp' is a ventilation factor that has been in use in North America for decades - no one is quite sure where it came from, but because it was a lovely round number, it gained traction and has become the primary and sometimes only source of ventilation planning on many North American mines. You can see that it is fairly close to 0.06 m^3/s per kW, which has gained similar traction in parts of the world who use the metric system.

You can see that if you ventilate a diesel machine with this amount of air, you can expect an increase in wet-bulb temperature of between 3 and 5°C, depending on how hard the machine is

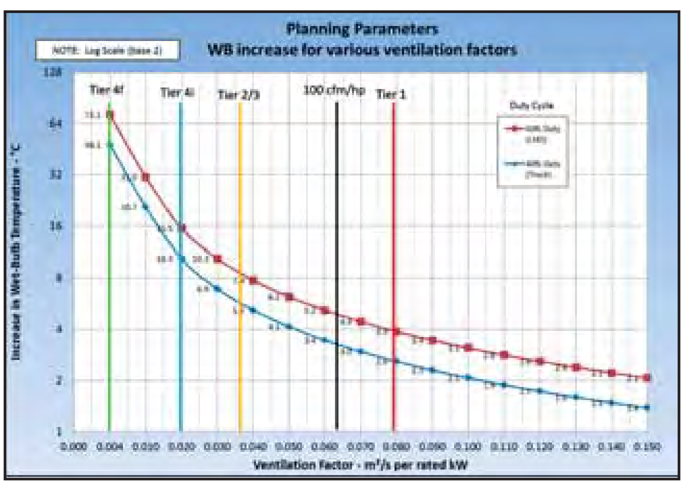

Figure 1. *Increase in wet-bulb temperature*

working. In most mines, this is an acceptable increase in temperature.

In the early 1990s, several regulatory bodies including the Environmental Protection Agency (EPA) in the USA decided that internal combustion engines may be bad for your health and the environment, and established certification and testing protocols for engines. In North America, these are known as Tiers, (or Stages in Europe) and they change the rules periodically. For mining, a system of certifying engines and requiring mines to provide a specific amount of ventilation where the engines operated was then established.

The remaining vertical lines on the chart are for a specific mining vehicle, a 17 ton Sandvik loader, and illustrate how its legislated ventilation rate has changed as the different Tier requirements have come in. I have used the Canadian CANMET requirements, which include sufficient ventilation to dilute diesel particulate matter (DPM) as well as gases. The USA standards are slightly more complex and separate the ventilation rates for gas and particulate dilution.

The first legislated value for this vehicle, for a so-called Tier 1 engine, which was legislated from 1996. This dilution rate became stricter, and if with this ventilation factor, the temperature would increase by a lower value, between about 2.6 to 3.9°C.

As legislators do, they changed the rules in about 2001 to Tier 2. They now demanded that a cleaner engine be used for this vehicle, and they rewarded the mines that used them by establishing a new lower ventilation rate. The shallow and cool mines were pleased, as they could now ventilate with less than half the amount of air - their shafts, tunnels and fans could all be smaller. The hot and deep mines complained, because if they ventilated with this new amount, their wet-bulb temperatures now increased by 6 - 9°C. Some of the hot mines could not live with this, so they went back to ventilating for the good old 100 cfm/hp or 0.06 m^3/s per kW standard. When the time came to buy new machines, they had to spend extra money to get the cleaner and more sophisticated engines, but couldn't get the benefit from them.

Everything was fairly quiet for about 10 years - a new Tier 3 was put in place in 2006, but there was very little change from Tier 2 and most suppliers found that their Tier 2 machines already met Tier 3 standards. Then in 2011, a new Tier was announced, Tier 4i (4 initial). This time, even the shallow mines were complaining, unless they were in Alaska - a wet-bulb temperature increase of 10 to 16°C is quite onerous.

Many of the shallow mines decided to remain with the Tier 2 standard. The deep and hot mines were still forced to use the 100 cfm/hp (0.06 m^3/s per kW) standard. Mine operators were forced to spend extra capital for very sophisticated machines, often with diesel particulate filters and NOx scrubbers. Three years later in 2014, the rules changed again, to Tier 4f (4 final). Resultant wet-bulb increases were so high that miners would presumably need to use liquid nitrogen for cooling.

This chart shows that ventilating for Tier ratings has now become irrelevant for mines where people work - perhaps for a fully automated mine, but that will have to be a subject for later. Most deep or hot mines are effectively trapped forever around the

0.04 - 0.06 m^3/s per kW area. Shallow or cool mines might be able to ventilate for the Tier 4i requirements, but will never be able to take advantage of the potential saving on power and infrastructure of the Tier 4f level, at least until fully autonomous mining becomes a reality.

There are many different mechanised mining methods (almost certainly more methods than mines). When carrying out computer simulation work, one must recognise that modelling software cannot cater for this wide variation in methods. Ore production areas (stopes) of some mechanised mining methods can be approximated (modelled) as development ends - others use through ventilation.

Intake airways to production areas are often ramps or declines carrying diesel traffic - it is important to maintain a substantial air-flow in ramps (typically two or three times the ventilation rate of the largest vehicle). In some cases, using ramps as exhaust airways is useful, as exhaust air from production areas can still have capacity to absorb more heat. Whether the ramp is intake or exhaust, it is often necessary to bleed off or add in air when required to maintain acceptable temperatures.

'Reject' or maximum wet-bulb temperatures below 30°C are often very difficult to achieve in highly mechanised mines - where possible in production areas, design the ventilation system so that people do not work downstream of operating diesel machines. In extreme situations, many companies or jurisdictions have rules for work-rest cycles where heat is problematic.

Consider usage of environmental cabs (air-conditioned), although this does not give licence to allow extreme temperatures. Supervisors, maintenance personnel, and mine services staff are often present in working places and their heat exposure must be considered.

To account for heat from diesel machines, the following is suggested:

- Account for stope loaders (LHDs) - use a duty cycle of 40 - 60% unless accurate data is available,
- Generally ignore additional diesel machines (i.e. trucks), when they are in production stopes. When trucks are present, they are idling while being loaded. As they arrive and pull away, the loader is idling. Some jurisdictions may require higher airflows to cater for both vehicles. While onerous for ventilation systems, this is often beneficial for heat (higher ventilation factor),
- Account for the electrical power-pack load of drill rigs only. Apply an appropriate duty cycle,
- Account for large diesel machines (trucks) as point sources in ramps. The duty cycle of trucks is lower than loaders, typically 20 - 40%,
- Non-production machinery is usually assumed to have a low duty cycle (10 - 20%). Add up the heat load of this machinery and distribute it in ramps and tunnels as kW per metre or similar.

Heat loads in stopes and development ends are often dominated by diesel heat, although heat from broken rock can be significant with some mining methods. Modelling software often caters for broken rock by using an advance rate, however this is not always practical to use for some mining methods. Where required, the following method may be useful to allow for heat from broken rock:

- Convert the monthly tonnage mined in the stope to kg/s and use Q = m x Cp x Δt,
- Δt is the difference between the virgin rock temperature (VRT) and dry-bulb temperature of the air.

Broken rock example: Stope produces 10 000 tpm
Assuming 24/7/365 operation, this is 3.86 kg/s of broken rock
Cp of mine rocks is typically 900 J/kg°C
Assume VRT is 45°C and Tdb is 30°C

Q = m x Cp x Dt
Q = 3.86 kg/s x 900 J/kg°C x 15°C
Q = 52083 J/s
Q = 52 kW
Place this heat load as point or distributed in the stope
This may overestimate the heat load, as some of the heat would be dissipated during blasting re-entry and some heat may remain in the rock after loading

In hot climates, refrigeration and cooling are often required at very shallow depths in highly mechanised mines (many Queensland collieries use cooling at 300 metres depth).

In South Africa, we tend to flood the mine with intake air and gather and collect exhaust air into specific routes. This can result in a multitude of leakage paths and is counter-intuitive - 'expensive' air is allowed to freely roam, and 'worthless' air is controlled.

The use of 'cold holes' (dedicated intake air raise systems carrying very cold air) is relatively common, but is often used to transport air only to intermediate levels, below which the air is routed through conventional intake airways (ramps or sub-vertical shafts) along with diesel, personnel or hoisting traffic.

Some very successful primary ventilation systems tightly control intake air in dedicated routes, cooling and re-cooling where necessary. In some cases, ramps and even working levels are effectively part of the exhaust system (face ventilation is provided via fan and duct from behind wall). These systems aim to provide the absolute minimum air quantity to stopes at the coldest temperature possible (minimise ventilation factor - maximise Δt).

One large mine uses Tier 4i equipment, and is legally allowed to ventilate for diesels using 0.02 m^3/s per kW. With this ventilation rate, at a 60% duty cycle, they can expect an increase in wet-bulb temperature of about 15°C. They would like to limit their maximum temperature to 30°C, so their challenge is to provide intake air at 15°C. The mine is over 3 km deep and produces over 200 000 tons per month.

Due to difficulties in establishing additional surface connections, the air quantity is limited to approximately 700 m^3/s (800 kg/s). The overall heat load exceeds 90 MW and they will need over 40 MW of cooling. They have a diesel fleet of 25 MW. Their design summer surface wet-bulb temperature is 19°C, which must be catered for. They limit the amount of air flowing down hoisting shafts and bring intake air into the mine via dedicated large diameter cold holes. They cool the air on surface, and at four more vertical intervals down the mine. In an isolated intake air circuit, they cool air aggressively once it reaches about 24°C. The final cooling stage chills air from about 24 to 9°C, so that it can reach the face at 15°C or less. Air is extracted from the intake air circuit on each working level through walls by force fans, which deliver it quickly to the stope faces via ducting. Exhaust air is returned by a combination of ramps and dedicated exhaust boreholes. Leakage is very strictly controlled, and at least 75% of the total airflow is delivered directly to stope and development faces.

The system was developed over time, largely due to limited shaft sizes and environmental objections to establishing additional surface connections, but is quite successful.

To summarise, it is inevitable that mechanisation will increase on South African mines, just as mines outside South Africa will get deeper - both will need sophisticated ventilation systems incorporating substantial amounts of cooling. The use of ventilation criteria for diesel exhaust is becoming irrelevant. Significantly more air is required for heat than for exhaust dilution of modern engines.

The design factors for diesel heat need to be fully understood and specified for any project. A target for maximum (or reject) temperatures below about 30°C is probably not attainable. Mine management must accept that there will be areas on highly mechanised mines that are hot - the key is to design the ventilation system and mining layout so that personnel are not required to work or travel in these areas.

There are as many mechanised mining methods as there are mines - traditional design tools and software cannot cater for all of them. Training, expertise, and knowledge of the science of heat is required in order to develop designs that are effective and optimal. Innovative designs for mines, ventilation, and cooling systems may be necessary to deal with the challenges of increasing depth and mechanisation. Detailed knowledge of the mathematics and science behind heat may help to adopt a 'first principles' approach to the challenges of heat in highly mechanised mines.

South African-trained mine ventilation practitioners, most of whom were and are members of the Mine Ventilation Society of South Africa, wrote the book (several, in fact) on dealing with heat in mines. They have gained, through acquiring their qualifications and work experience, skills and in-depth knowledge of psychrometry, thermodynamics, and heat transfer that are rare elsewhere. Many of the challenges faced by the global mining industry to deal with heat are being successfully addressed by mine ventilation experts who received their training in South Africa.

Peer reviewed for Journal publication

Underground fires: Prevention is better than cure

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ABSTRACT

The occurrence of any fire in working environments where fresh air is scarce always represents a heightened risk for the safety of workers. Aircraft, and naval vessels come to mind as examples of where such an occurrence has had dire consequences as the opportunities for escaping are limited. Fires in underground mines are just as insidious.

The introduction of mechanised mining and ore transport equipment in South African hard rock mining operations, is changing the risk profile posed by incipient fires arising from these diversified sources.

This paper analyses the requirements for a new, risk-based approach to the prevention of underground fires as separate from the protection against fires. It is argued that all too often, protection is preferred to prevention to counter fire hazards but that such strategies bring about unintended and unexpected outcomes.

Keywords: fires, risk assessment, regulations, prevention, control.

INTRODUCTION

There is no doubt that fire prevention and fire protection measures are often deemed to be "grudge purchases" as any measure designed to counter the occurrence of imponderable consequences of an unwanted event that does not add to the bottom line of any business.

What makes the introduction and strict observation of preventative measures so compelling is that they are key in achieving the objective of ZERO HARM, an ambition being fostered by the South African Mining Industry.

Legislated requirements

Under the current Mine Health and Safety Act Regulations, the Mine Ventilation Profession has definite responsibilities relating to fire-fighting and escape and rescue procedures. Through the years, the mine ventilation officer has been assigned additional "vicarious" responsibilities to provide protection and interventions in the event of fire incidents. It is argued in this paper that the knowledge base of the Profession should best be used in the design and implementation of preventative measures that are all too often included as an afterthought and without much consultation with this knowledgeable group of specialists.

Equally so, it would be a mistake to qualify this bold statement by saying that the choice is driven by the need to comply with "legal requirements". Legal requirements in the context of mining operations should be seen as minimum obligations which, in terms of the South African mining legislation, are not sufficient in providing the levels of protection and prevention necessary to ensure safe and profitable operations.

Another, more beneficial approach, from a business case perspective, is to consider fire preventative and corrective measures as interventions that will minimise the risk to workers' safety, damage to the infrastructures and disruption to production and hence protect the viability of the operations.

The South African Mine Health and Safety Act (MHSA), 1996, promulgated in 1998 provides a framework within which the risk posed by a number of hazards is well defined and more importantly, it outlines the way in which the process of hazard recognition and risk management shall be carried out:

- Section 2.(1)(a) of the Act requires that he owner of every mine must ensure that the mine is designed, constructed and equipped to provide conditions for safe operation and a healthy working environment,
- Section 2.(1)(b) requires that the owner of every mine must ensure that the mine is commissioned, operated, maintained and decommissioned without endangering the health and safety of workers or of any other person,
- Section 11 requires that mine management identify hazards, assess the potential risks to workers' health and safety associated with them and record the relevant details. In particular, Section 11.(2) requires management to implement a hierarchy of controls when managing the recognised risks.

More pertinent to fire risks in mines, Regulations under the MHSA stipulate additional and specific requirements:

- Reg.5.1(1): The employer must appoint a competent person who will report at regular intervals on aspects related to the effectiveness of the precautionary measures and on the adequacy of measures for the prevention, detection and combating of start and spread of fires,
- Reg.16.1(1): The employer must employ a competent person who will report at regular intervals on the adequacy of procedures implemented for escape and rescue at the mine relating to explosions, fires and flooding,
- Reg. 22.15(5)(a): The competent person contemplated in the abovementioned regulations for underground mines is deemed to be the holder of a Certificate in Mine Environmental Control, issued by the Chamber of Mines of South Africa as a minimum requirement.

It is argued later in the paper that the observance of these regulations read in conjunction with the abovementioned sections of the MHSA requires greater levels of technical preparation than currently provided by the Chamber of Mines qualification for adequate management of fire hazards.

Fire incident statistics

Fire incident data from the Mines Rescue Services was analysed and summarised to obtain a feel for the causal nature of incidents so as to provide directions for the preventative nature of the risk management process.

Figure 1 summarises fire causal data for a period of thirty five years and includes a number of incidents ascribed to unknown causes and arson. The latter occurred mostly in the first ten to fifteen years in this period. In more recent times, the increasing number of fire incidents caused by illegal miners in abandoned mines or sections of working mines, has also skewed analyses.

In addition, the use of less stable nitro-gel based explosives before the turn of the century in particular, would have increased the risk of fires in abandoned or worked-out areas. These occurrences also tend to mask any technical causes of fire incidents in abandoned areas.

In addition, in the same period, extensive use was made of timber pack supports in reef horizons of narrow reef mining operations. Often support timber was treated with fire-retardant chemicals and there have been claims that the leaching chemicals, over time would have been the cause of "ghost" fires making it difficult if not impossible to establish the real cause of fires breaking out in abandoned stopes.

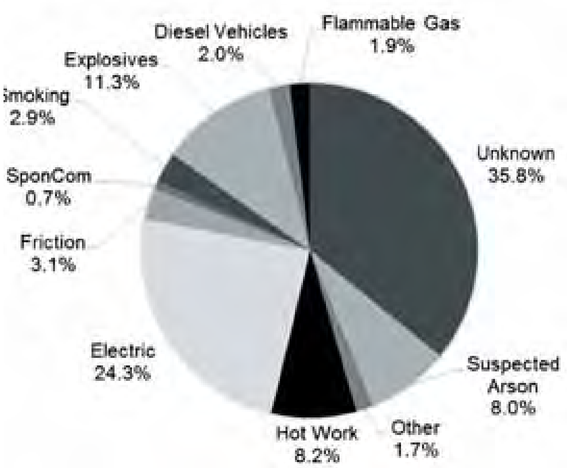

Figure 1. *Causes of underground fires in South African mines 1981 to 2015 (Mines Rescue Services, 2016)*

In an attempt to remove this bias, the original data set was filtered to remove unknown cause incidents and those ascribed to arson. The resulting data is summarised in Figure 2.

The data summarised in Figure 2 shows that the majority of fire incidents may be ascribed to electrical sources and the performance of hot work contributing to almost 58% of the revised data. If one were to add the contribution of diesel vehicle fires, this total increases to 62% which means that almost two-thirds of fire incidents may be ascribed to the operation of "machinery" in mines in one form or other.

Although not stated in the data made available it is conceivable that a fair proportion of "friction" incidents may be traced to the operation of conveyor belts.

The conclusion made by this analysis is that, not surprisingly perhaps, the use of mechanised equipment is known to cause the majority of fire incidents.

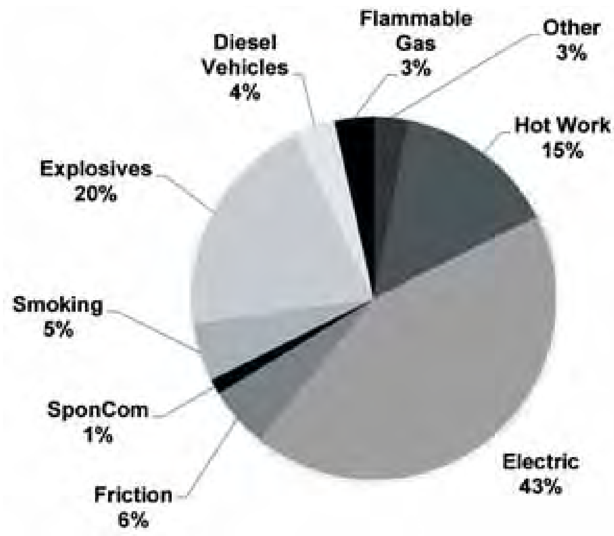

Figure 2. *Causes of underground fires in South African mines 1981 to 2015 – Filtered Data (Mines Rescue Services, 2016)*

Fire incidents and hazards

The hazard posed by mechanised machinery and equipment is ascribable to their presence in the underground environment where the supply of uncontaminated, fresh air is at a premium. In addition, machinery, by its very nature concentrates large quantities of stored energy, be this potential, electrical or chemical, in relatively confined spaces. Whenever this energy is released uncontrollably, heat is generated which, through pyrolysis, will release vapours, gases and smoke that will impact seriously on the quality of the air in circulation contaminating the integrity of the mine's ventilation system.

These emissions consist mainly of oxides of carbon and nitrogen as well as complex organic compounds in the form of gases and vapours. The toxic nature of these substances poses a serious risk to the health and safety of workers in the path of the smoke-affected atmosphere.

The presence of an agent that has a low probability of occurring but that has the potential to cause multiple fatalities and injuries particularly when a considerable and lethal energy is realised in a relatively short period of time, defines a "principal hazard".

The issue at hand is therefore the ability to prevent or at least to control such an unwanted event. Therefore, it is important to realise that all fire incidents, no matter how insignificant at face value, are potentially disastrous.

Once initiated a fire may become self-sustaining drawing oxygen and fuel from the immediate surroundings and generating increasing quantities of heat energy.

In analysing further the data provided by the South African Mines Rescue Services (MRS) as depicted in Figure 3 it is encouraging to see that the number of fire incidents reported to the MRS or at which MRS teams have attended has reduced steadily over the last thirty-five years.

Assuming that reported fires data is a true reflection of the number of incidents actually occurring, this indicates that controls are effective and that fires are prevented.

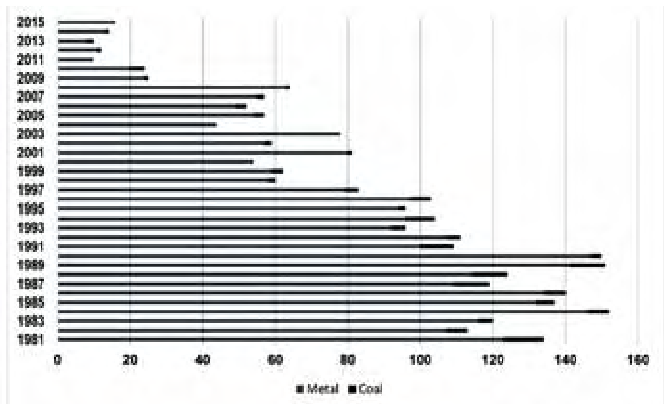

Figure 3. *Underground fire incidents in South African mines 1981 to 2015 (Mines Rescue Services, 2016)*

However, despite this achievement the industry is reminded from time to time that, despite the decreasing number of incidents, fires still occur and that sadly and tragically lives are still lost in these "few" incidents. It may therefore be argued that the severity of fires is on the increase. In reality fires are extremely serious occurrences and that therefore there are no minor fires.

This is indicated in Figure 4 where the severity of the incidents logged in Figure 3 is shown for the same time period. Figure 4 clearly shows that despite the numbers decreasing, there is no similar decreasing trend for the severity of fire incidents, based on the number of fatalities, stressing the fact that every fire incident may be potentially disastrous.

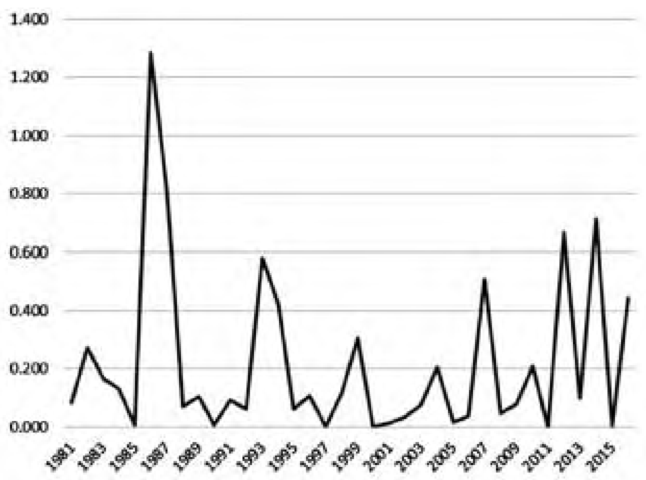

Figure 4. *Relative severity of underground fire incidents in South African mines 1981 to 2015 (Mines Rescue Services, 2016)*

FIRE HAZARD MANAGEMENT

The design, implementation and operation of systems and equipment aimed at preventing fires and protecting the mine against the hazard posed by fire outbreaks is dependent on an assessment of the risk and associated response processes, whether these be designed to prevent the outbreak altogether or are intended as a response to such an incident.

Fire hazard management is a multi-disciplinary effort under the umbrella activities of "fire prevention" and "fire protection" requiring awareness, technical knowledge, direction and motivation to maximise the effectiveness of these efforts.

The measures contemplated as part of any fire hazard management plan are risk-based and should follow a disciplined and rigorous approach requiring:

- Hazard anticipation, identification and recognition,
- Assessment and analysis of the risk, and,
- Introduction of controls to manage the hazard effectively thus eliminating or minimising the risk.

The abovementioned approach is best embodied in a series of interlinked and co-ordinated actions that constitute the fire hazard management plan.

Figure 5 shows schematically the process that may be followed in structuring a Fire Hazard Management Plan.

Figure 5. *Fire Hazard Management Plan*

Fire hazard identification

Identification of a hazard or a condition that has the potential to cause harm requires the ability to *anticipate* the presence or occurrence of such a condition, to *identify* its presence and *define* of its magnitude and potential impact.

As part of a formal fire hazard management plan, this requires identification of sites in intake airways where combustible materials are present in large quantities. In hard rock mines the use of timber support or cribbing in shafts, declines or haulages could be an example of this.

The presence of, for example, oil-filled transformers and/or conveyor belts at these sites adjacent to or in an intake airway should be indicated as a significant hazard for any working place further downstream.

The use of mobile diesel-powered, trackless vehicles provides essentially a set of "mobile" fuel sources that could be activated anywhere in the mine.

Equally important is the identification of ignition sources located in airways that may interact with other sources or with other combustible materials, be these fixed or mobile in nature. For example, the location of a 1MVA oil-cooled transformer next to a conveyor belt in a main decline system used as an intake airway may constitute a major risk for the whole mine. In coal mines where the infrastructure is excavated mainly in coal, the risk is heightened further.

The presence of identifiable, distinct major sources of fuel such as those described above should be logged in a major fire hazard register for the purpose of assigning and revising customised fire preventative and protective measures.

Fire risk analysis

Fire risk analysis is aimed at establishing the likelihood that a fire may break-out (at a certain site) and the consequence this will have on the health and safety of workers and on the integrity of the mine's infrastructure.

The ability to manage the fire risk therefore depends on the ability to eliminate or minimise the likelihood of an occurrence and the consequence thereof, or of both, by the introduction of adequate controls.

The analysis of fire risks is a multi-disciplinary effort best undertaken with the participation of and in consultation with workers and frontline supervisors who have to deal with fire hazards first hand. The correct application of adequate mitigating controls as soon as an incipient fire is detected, for example, may prevent its escalation into a major conflagration. In most occurrences it will be the frontline individuals who will be required to provide the primary intervention.

These aspects are addressed usually in formal baseline or issue-based risk assessments. However, through adequate training and awareness campaigns, these should form part of on-the-job assessment procedures, e.g. stop, look, assess and manage (SLAM) exercise.

Worker involvement in the risk analysis process is therefore essential in harnessing their practical knowledge and in promoting awareness borne from direct participation in the analysis and solution process.

Fire risk management: Controls

Risk management is enabled by implementing a series of controls defined by the risk analysis. Controls are aimed at either eliminating or mitigating the risk.

Preventative controls are interventions that will predominantly prevent the occurrence of a fire. On the other hand, protective controls are aimed at limiting the development and/or impact of any incipient fire. Protective controls are therefore deemed to be lower order interventions in the hierarchy of controls as their failure may lead to the unwanted event. In some cases however, they may be the last or only line of defence.

Risk elimination measures are a subset of the preventative controls and therefore are deemed to be most effective. Usually, the selection of preventative controls is best done with the assistance of technical content experts.

Risk mitigation measures include engineering, process or activity interventions which may prove to be effective preventative controls.

Mitigating interventions that require physical separation or shielding or the use of protective equipment are deemed secondary in terms of effectiveness for fires.

Controls should be identifiable and associated with measurable parameters that trigger them partially or totally depending on the nature and design of the control.

Workers who are expected to activate controls through the application of response actions must be adequately trained in the correct assessment of response parameters and in the activation of the respective controls based on approved response procedures. Any changes to the response actions or parameters triggering controls must be communicated clearly and timely. A typical example is the training of vehicle drivers in the use of on-board fire extinguishers to combat a fire in the vehicle's engine bay or in the activation of that vehicle fire suppression system.

Critical controls

The International Council on Mining and Metals (ICMM) defines a critical control as: "A control that is crucial (decisive) to preventing the event (fire) or mitigating the consequences of the event (fire)".

The ICMM (ICMM, 2015) further states that "The absence or failure of a critical control would significantly increase the risk despite the existence of the other controls. In addition, a control that prevents more than one unwanted event or mitigates more than one consequence is normally classified as critical".

Based on this therefore, critical controls are interventions that:

- Are clearly identifiable and measurable,
- Are independent,
- May be the only barrier between the event and the unwanted outcome,
- Either block event initiation or alternatively prevent or detect event escalation,
- Are otherwise effective in controlling multiple risks.

Therefore, the definition and introduction of critical controls should be seen as an essential component of a fire hazard management intervention. Identification of critical controls will assist in the prioritisation and selection of adequate risk management interventions.

Identified critical controls and related relevant information should be listed in the critical control register which, for fire risk management should make reference to the major fire hazard register.

REVIEW PROCESSES

The complexity of the systems described in this paper and the importance that they bear on the safety of workers and on the integrity of the mine's infrastructure, relies on the implementation of numerous procedures and operational standards.

These measures are derived from a risk-based approach and require implementation of both preventative and protective controls through adequate planning and assignment of resources that will meet effectively the assessed levels of risk.

The incorporation of these measures into routine of mining operations should consist of a seamless, co-ordinated network of actions and interventions requiring the presence of integrated controls that operate independently or across interlinked systems.

Operational standards and procedures should be reviewed at regular intervals to accommodate any changes in mining operations or methodologies or before the introduction of new technologies or equipment or as the result of lessons learned from incidents.

The effectiveness of controls governing operational standards and procedures related to the management of fire risks should be evaluated at more frequent intervals.

Of particular importance is the review of the status and effectiveness of identified critical controls based on selected, measurable parameters. Furthermore, these reviews should take into account the hierarchy of controls to establish whether higher order controls may be employed to replace possible, ineffective, lower order ones.

A framework of control monitoring should span across the mine's organisational structure. An example of such a framework is as follows:

- Inspections: These will provide condition oversight of work-place controls to ensure that the right controls are in place, are available, and are operational and that workers assigned to exercise such controls are adequately competent. Inspections should be performed by line supervisors,
- Verifications: These are performed by management to ensure that controls' inspections are planned, scheduled and verified. These activities are used to address any deviations found during inspections,
- Performance Measurements: These are are high level over-sights of controls verification based on defined action thresholds and improvement plans. Verifications will be executed to anticipate any further deterioration when deviations are detected.

In conjunction with the above controls review, parameter levels used to trigger pre-defined responses should be also revised and adapted to changes where necessary. These changes should be discussed with the relevant operators and workers, ratified by responsible managers and communicated timely to workers. Where necessary such changes should also be introduced in revisions of relevant training material.

Procedures associated with first responses to fire incidents should also be assessed by means of fire drills and mock evacuations that should be analysed to ensure adequate observance of procedures, correct use of assigned and alternative escape routes.

The outcomes from all of these reviews should be summarised in reports that include clear assessment of the controls' performance and their effectiveness together with relevant recommendations to the mine's management team.

Review processes should assist in ensuring that a healthy "fire safety culture" is fostered and managed, particularly where repeated breaches of critical safety controls occur through either or both errors or violations.

SKILLS BASE REQUIREMENTS

As mentioned initially, regulations under the Mines Health and Safety Act define clearly the responsibilities of "competent" persons, who will ensure that effectiveness of precautionary measures and adequacy of preventative measures related to the management of fire risks are reported to management at regular intervals. Such competency is embodied in the Certificate in Mine Environmental Control.

The course syllabus for the various Mine Environmental Control qualifications currently cover the theory of fires and provides material on fire prevention and protection, inclusive of basic fire-fighting methodologies.

This knowledge base is supplemented by the continual acquisition of information relating to commercially available equipment, systems and technologies that are part of routine work undertaken by ventilation professionals at mines - sometimes self-initiated or motivated by or through others. In these cases the ventilation professional uses the theoretical basis to form an educated opinion on the effectiveness of these systems and equipment in the field.

The question is whether this approach is adequate in view of technical and legal demands placed on modern mines and of increasing demands for effecting zero harm. Are the current education and training curricula to which mine ventilation professionals are exposed sufficient and adequate for the effective management of fire risks? More importantly, are ventilation professional adequately competent beyond the requirements of the law? Should they be?

It is the duty of management to ensure that proper and effective control of fire risk is exercised at a mine at all times from the design phase onwards. This requirement should be backed by the adequate engineering knowledge.

These skills and knowledge as presently provided by the mine ventilation profession are possibly the only ones residing in most mines. They may be viewed to be basic and certainly do not match those of fire engineering specialists, but it is safe to say that ventilation professionals have, as part of their responsibility under the law, an all-round understanding of the requirements for an effective fire risk management programme.

It is a good starting point and by adding a little more to the knowledge base in terms of fire chemistry and fire dynamics, fire engineering (structures) and fire-fighting (detection systems and equipment), these professionals will not necessarily be experts but will be able to provide direction as to what additional specialist competencies are required to complement theirs - which may be obtained from external sources.

Ultimately it is recognised that as with many other activities on mines, fire risk management is a multidisciplinary activity which requires co-ordination and organisation. It is suggested that possibly the time is now to re-introduce formally in the industry the role of the erstwhile fire master to fill this gap.

CONCLUSIONS

The occurrence of fire incidents has shown an encouraging decrease particularly in the last decade. This indicates that the effectiveness of preventative and protective measures is improving and that these interventions are being applied successfully.

However, recent incidents have also reminded us that the potentially lethal effect of rampant fires is still there when they take hold.

To counter this, some organisations are adopting defined critical controls. This includes consideration of preventative interventions. However, given the difficulty encountered in measuring the effectiveness of controls that manage low-probability, high-consequence incidents such as underground fires (Clough 2015), mine management opts more often than not to dedicate funds and resources for protective measures - sometimes disproportionately so.

The question remains whether prevention is better than cure. Since it is accepted that the use of critical controls alone will not enhance the effectiveness of poor controls, be these preventative or protective, it is concluded that efforts would be best focussed on preventing an occurrence.

In this paper the need to develop further the ventilation professional's skills-base to meet increasing challenges and professional requirements for improved proficiency in the eyes of the law has been voiced. This would improve the quality of fire risk management activities while protecting ventilation professionals against possible legal action.

It seems anomalous that in an industry that firmly believes that zero harm is attainable, the same conviction is not extended to the prevention of fire incidents. The question is whether zero harm may ever be achieved if we are willing to accept that fire incidents are inevitable.

Zero harm is not possible so long as zero tolerance is not achieved in respect of fire hazards. This requires improved vigilance and strict application of monitoring and control measures aimed primarily at prevention rather than protection.

We are often reminded that "eternal vigilance is the price for safety". In more modern times, for fire hazards in particular, we should say that effective prevention is the cost of "Zero Harm".

ACKNOWLEDGEMENTS

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REFERENCES

The Mines Health and Safety Act, Act 29 of 1996. South African Department of Mineral Resources.

De Klerk, C., *Mines Rescue Services.* Personal Communication.

Clough, A.J., August 2015. *Ensuring an effective Principal Hazard Management Plan*. Keynote Address, Proceedings of the Australian Mine Ventilation Conference, 2015, Sydney. AusIMM, B.K. Belle, Editor.

International Council on Mining and Metals, Health and safety critical control management. ICMM 2015. *Good practice guide*.

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Screening of various diesel particulate matter samples from various commodity mines

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ABSTRACT

This paper presents qualitative analysis results of diesel particulate matter (DPM) from various mining commodities in South Africa. The objective of this work was to determine the concentrations of elements in DPM samples. For this screening exercise, inductively coupled plasma (ICP) spectrometry was used to identify trace elements and other metal elements in the DPM samples. Most of the trace elements did not give a sufficient instrument response to warrant further evaluation. However, the concentrations of calcium (Ca), nickel (Ni), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), sodium (Na), and chromium (Cr) for most samples were detectable.

Keywords: diesel particulate matter, concentrations, spectometry, toxicity, exposure.

INTRODUCTION

Diesel exhaust emissions consist of a mixture of gases, vapours and particulate matter and were classified as carcinogenic to humans by the International Agency for Research on Cancer (IARC) in 2012 (IARC 2012). Diesel particulate matter (DPM) is the ultra-fine carbon-based particulate fraction (< 1 µm) of diesel engine exhaust. Due to their particle size they remain airborne in the atmosphere for extended periods of time and can be inhaled by humans long after they were formed as a result of incomplete combustion. These particulates pose a serious health hazard to humans because of their toxicity (Choi and Mochida, 1990), (Sydbom et al., 2001).

Diesel engine exhaust is a complex mixture and studies have been conducted to determine the composition thereof (Watson, Chow and Chen, 2005). Polyaromatic hydrocarbons (PAHs), soot particulate matter, non-organic compounds such as sulphates and metal ash were discovered in samples investigated during these studies (Liati et al., 2013), (Forbes et al., 2013).

This paper aims to investigate the inorganic composition of DPM within the context of the South African mining industry.

BACKGROUND

Diesel exhaust emission is the result of combusted diesel fuel and has a complex composition. The composition depends on a number of factors such as the engine technology, the type of fuel used, condition of the engine etc. (Birch, 2003).

DPM consists mainly of elemental carbon (EC) and organic carbon (OC) and for this reason EC was chosen as a marker (Birch, 2003). The employee exposure monitoring for DPM is carried out against the EC marker using the National Institute of Occupational Safety and Health's (NIOSH) analytical method, NIOSH 5040.

A comprehensive study was carried out in three South African Platinum mines to determine the health outcomes of mine employees that were exposed to DPM (Pretorius et al., 2014). One part of the project aimed to characterise the OC fraction of DPM. It was found that heavier PAHs, such as pyrene and fluoranthene were associated with DPM (Forbes et al., 2013), (Geldenhuys et al., 2015). These compounds have been linked to environmental cancers (Dybing et al., 2013) and pyrene in particular, is considered to be a co-carcinogen with other PAH carcinogens such as benzo[a]pyrene (Baturay and Kennedy, 1986).

DPM forms as a result of incomplete combustion of diesel fuel in diesel engines. In the ideal process, it is expected that there are very little or no metal elements associated with DPM since the source of diesel emissions is from the combustion of diesel fuel. However, in reality other particulates that form during diesel combustion are metal ash (Liati et al., 2013). When metal elements are detected from the exhaust samples, it is an indication that a different, unwanted process was taking place during the combustion of the diesel fuel. In some cases the fuel or combustion chamber could also be contaminated.

The health effects of metal ash have not been comprehensively studied (Liati et al., 2013) even though metals bound to particulate matter in ambient air have been associated with respiratory and cardiovascular diseases (Betha and Balasubramanian, 2013). The ash may contain metal oxides, sulphates or phosphate compounds that originate from the combustion of lubrication oil or contaminated diesel. Alternatively, metals present in ash may originate as a result of wear and corrosion of the engine parts (Liati et al., 2013).

Proper maintenance of diesel powered engines has been found to be the most effective control measure for DPM (Stachulak, 2003). In a pilot study that was carried out in South African platinum mines, a positive correlation was found between the wear metals in engine oil and the DPM concentrations that mine employees are exposed to (Pretorius, 2015). Although oil and diesel fuel are often analysed and tested, there is the potential to analyse DPM samples for wear metals.

This paper shows the results that were obtained from the metal screening of DPM filters.

METHODOLOGY

Ten DPM samples were randomly chosen for the screening exercise. These samples were taken from storage after they were submitted to the laboratory for DPM analysis. Nine samples were collected in an underground mining environment from different commodity mines. It was not known to the laboratory whether these samples were personal monitoring or exhaust emission samples. One sample was collected in a controlled environment directly from the diesel exhaust. A blank tissue quartz filter was included in the analysis to take trace elements in the filter media into account.

The DPM was sampled onto a 37 mm tissue quartz filter as per the NIOSH 5040 method. Samples with different DPM concentrations were chosen for the elemental screening. Table 1 lists the different samples and the source mines where they originated from.

Table 1. *Sample numbers and commodity mine source*

Sample no.	Commodity
Blank	Blank filter
V01	Platinum mine A
V02	Platinum mine B
V03	Platinum mine B
V04	Copper
V05	Coal
V06	Gold mine A
V07	Gold mine B
V08	Gold mine B
V09	Controlled environment
V10	Chrome

The samples were first analysed for DPM using method NIOSH 5040. A 1.5 cm^2 specimen was taken from the sampled filter and analysed on a thermo-optical DPM analyser. A blank filter was also analysed to record the trace EC and OC for the filter media. Another 1.5 cm^2 specimen from each filter was chemically digested in a mixture of hydrochloric (HCl) and nitric acid (HNO_3). The elemental screening was carried out using ICP optical emission spectrometry (ICP-OES) and ICP mass spectrometry (ICP-MS) to cover a range of the trace metal concentrations.

The samples were qualitatively analysed for 43 elements and the results were reported in mg/L. The results from the 1.5 cm^2 specimen were converted back to the filter deposition area (8.04 cm^2) as an even distribution was assumed based on the findings of previous studies.

RESULTS AND DISCUSSION

The results relate only to the samples that were qualitatively analysed and cannot be extrapolated to the broader population of an individual mine, or the broader mining industry. The analysis results from the blank filter are also only representative of the individual filter that was analysed and is not necessarily representative of all tissue quartz filters.

Table 2 shows the results obtained from the DPM analysis. The EC concentrations ranged from 0.001 to 4.93 mg (median 0.24) and the OC concentrations from 0.04 to 0.66 mg (median 0.16 mg). When sample V04 is excluded, all the samples have DPM concentrations below 2 mg (Figure 1).

Table 2. *Comparison of the OC, EC and TC concentrations on selected samples*

Sample	OC (mg)	EC (mg)	TC (mg)
Blank	0.046	0.000	0.046
V01	0.040	0.010	0.050
V02	0.080	0.010	0.090
V03	0.350	0.890	1.240
V04	0.660	4.930	5.590
V05	0.210	1.260	1.470
V06	0.240	0.240	0.480
V07	0.130	0.090	0.220
V08	0.090	0.050	0.130
V09	0.160	0.390	0.540
V10	0.447	0.719	1.166

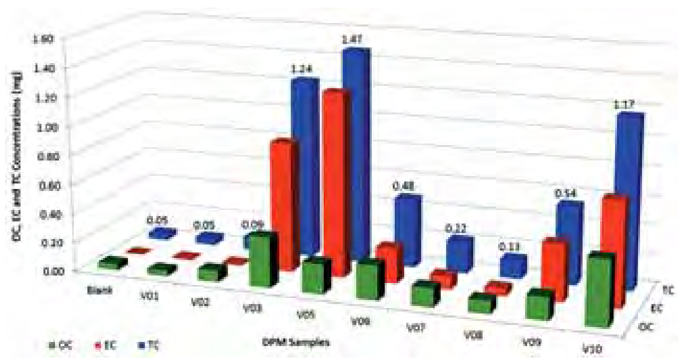

Figure 1. *OC, EC and TC concentrations excluding sample V04*

The samples were qualitatively analysed for 43 elements. Since this was a screening exercise the analytical detection limit for each element was not determined. The exclusion of some elements was made as a result of the low qualitative response from the instrumentation. For this reason only 16 elements were selected for further evaluation. Figure 2 summarises the ICP results (in mg/L) for the 16 elements on all the DPM samples.

Sample V10 stands out as having significantly higher concentrations of chrome (Cr), iron (Fe) and nickel (Ni) when compared to the other samples. The Cr may be attributed to the presence of some ore dust on the filter as the sample originates from chrome mine. The Ni may be attributed to the combustion of diesel fuel and engine oil but the presence of Ni from mineral ore dust may not be excluded. Fe may be attributed to wear metals.

Sample V04 had significant concentrations of aluminium (Al), calcium (Ca), copper (Cu), iron (Fe), potassium (K), sodium (Na), and zinc (Zn) present. Fe may be as a result of engine wear but then it would be expected that the presence of other wear metals would have been higher. Although the other elements may be from additives in the engine oil, the presence of ore dust was not excluded.

It is not clear if the Cr in the blank filter sample originates from the filter media itself or if it was a contamination. Other notable

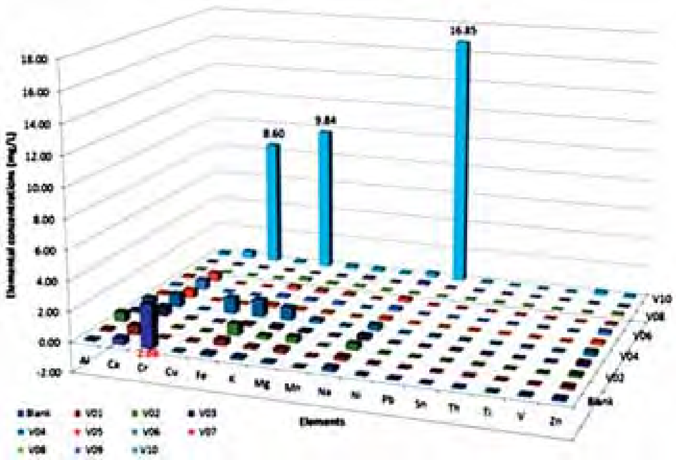

Figure 2. *Comparison of the ICP results (mg/L) for the DPM filters*

elements in the filter media were Al, Fe, K, magnesium (Mg), Na, vanadium (V) and Zn.

For the sake of clarity the samples Blank filter, V04 and V10 were excluded from the graph and Figure 3 shows the comparison of metal elements in the remaining samples. All the samples contain substantial concentrations of Al, Ca, Fe, K, magnesium (Mg), Na, and Zn. The Al, Ca, Mg, K and Zn may originate from some additives that are found in engine oil (Liati et al., 2013). Fe may be as a result of engine wear but then it would have been expected that the concentrations of elements such as Cr, nickel (Ni) and Pb would have been higher.

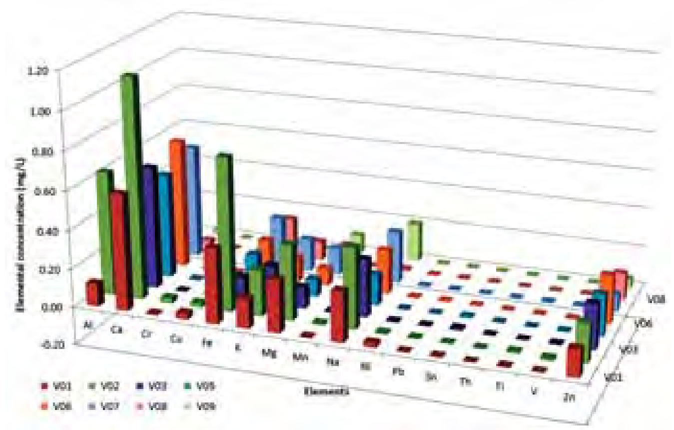

Figure 3. *Comparison of the ICP results (mg/L) when the Blank, V04 and V10 were excluded*

CONCLUSION

DPM filters were qualitatively analysed for 43 inorganic elements to determine the presence and estimated concentrations of metals. Only 16 elements were selected for further evaluation since the qualitative response from the instrumentation were sufficient enough for this screening exercise.

Two samples stood out because of the significantly higher concentrations of some elements when compared to the other samples: Sample V04 from the copper mine (Al, Ca, Cu, Fe, K, Na, and Zn) and sample V10 from the chrome mine (Cr, Fe and Ni). The other filters had substantial concentrations of Al, Ca, Fe, K, Mg, Na and Zn present. These elements can be attributed to engine oil or wear of engine components.

On some of the samples (e.g. V10), there may have been interference from mineral ore dust. The blank filter also contained substantial concentrations of certain elements. For further method development, corrections should be made for the trace elemental content of the blank and the mineral ore dust.

Further characterisation of the inorganic components of DPM is planned with the use of scanning electron microscopy (particle size and element concentration) and laser light-scattering (particle size).

The qualitative analysis of DPM samples for metal elements may be used as part of the occupational hygiene risk assessment and/or diesel engine conditions monitoring programmes.

The conditions under which the samples were taken were not known (i.e. volume of personal exposure sample). But it should be noted that some of the DPM and elemental concentrations may be above regulated limits for personal occupational exposure to airborne pollutants.

REFERENCES

Baturay, N. and Kennedy, A.R., 1986. P*yrene acts as a cocarcinogen with the carcinogens benzo(a)pyrene, beta-propiolactone and radiation in the induction of malignant transformation in cultured mouse fibroblasts; soybean extract containing the Bowman-Birk inhibitor acts as an anticarcinogen*. Volume 2, Nr. 1, Cell Biology and Toxicology.

Betha, R. and Balasubramanian, R., 2013. *Emissions of particulate-bound elements from biodiesel and ultra-low sulfur diesel: Size distribution and risk assessment*. Chemosphere, vol. 90, no. 3, pp. 1005-1015.

Birch, M.E., 2003. *Monitoring of diesel particulate exhaust in the workplace.* NIOSH Manual of Analytical Methods (NMAM). pp. 2003-2154.

Choi, K. and Mochida, I., 1990. *Characterization of particulate matter emitted from diesel engine*. Thermochimica Acta, vol. 166, pp. 267.

Dybing, E., Schwarze, P.E., Nafstad, P., Victorin, K. and Penning, T.M., 2013. *Polycyclic aromatic hydrocarbons in ambient air and cancer. Air Pollution and Cancer*. pp. 75.

Forbes, P.B., Karg, E.W., Geldenhuys, G., Nsibande, S.A., Zimmermann, R. and Rohwer, E.R., 2013. *Characterisation of atmospheric semi-volatile organic compounds*. Clean Air Journal, vol. 23, no. 1, pp. 3.

Geldenhuys, G., Rohwer, E., Naudé, Y. and Forbes, P., 2015. *Monitoring of atmospheric gaseous and particulate polycyclic aromatic hydrocarbons in South African platinum mines utilising portable denuder sampling with analysis by thermal desorption–comprehensive gas chromatography–mass spectrometry*. Journal of Chromatography A, vol. 1380, pp. 17-28.

IARC 2012. *Diesel engine exhaust carcinogenic*. Press release no. 213. International Agency for Research on Cancer (IARC).

Liati, A., Schreiber, D., Dimopoulos Eggenschwiler, P. and

Arroyo, R.D., 2013. *Metal particle emissions in the exhaust stream of diesel engines: an electron microscope study, Environmental science and technology.* Vol. 47, no. 24, pp. 14495-14501.

Pretorius, CJ and Grove, T., 2011. *The evaluation of diesel particulate matter sampling methods*. Occupational Health Southern Africa. ISSN 1024 6274. Volume 17, Number 5, September/October 2011, pp 4-13.

Pretorius, C.J., Grove, T., Schinkel, J., Pronk, A., Nelson, G. and Murray, J., 2014. *Diesel particulate matter exposure in South African platinum mines: an overview*. Proceedings of the Tenth International Mine Ventilation Congress, Sun City, Northwest Province, South Africa, 2-8 August 2014, , pp. 305-313.

Pretorius, C., 2015. *Diesel engine emission deterioration – a preliminary study*. Proceedings of the MVSSA Annual Conference 2015.

Stachulak, J., 2003. *Diesel emissions control strategy at Inco.*

Sydbom, A., Blomberg, A., Parnia, S., Stenfors, N., Sandström, T. and Dahlén, S.E., 2001. *Health effects of diesel exhaust emissions*. The European Respiratory Journal, vol. 17, no. 4, pp. 733-746.

Watson, J.G., Chow, J.C. and Chen, L.A., 2005. *Summary of organic and elemental carbon/black carbon analysis methods and intercomparisons*. Aerosol Air Qual.Res, vol. 5, no. 1, pp. 65-102.

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Block cave mine ventilation optimisation techniques

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ABSTRACT

Block cave mining operations are widely used for the extraction of steep to vertical orebodies typically found in diamond and base metal deposits. Block caving permits large volumes of ore to be extracted relatively cheaply, increasing production and making lower grade ore bodies economical to mine. These mines are constructed in two main phases, i.e. capital development phase and full production phase. When considering ventilation engineering planning, it is essential that the mine layout and plan are correctly understood for both phases. Depending on mining schedule and design, ventilation engineering challenges include airflow profiles that typically have peaks during capital development when the apex and/or undercut, extraction, haulage and ore transport levels require many development ends to be ventilated simultaneously. Various mines were investigated for similarities and differences in mining layout, ore handling and ventilation engineering. The paper summarises ventilation and cooling techniques that were identified that can be employed to optimise block cave mines to ensure fit-for-purpose mine ventilation designs.

INTRODUCTION

Block caving is generally considered when open pit mines become exhausted and extension of the mining operations is required. Block caving is a well-established underground hard rock mining method that can be utilised for near-vertical orebodies. A block cave is established a few hundred meters below the open pit operation and progressively collapses under its own weight and gravity (See Figure 1).

Block caving ensures extraction of large volumes of ore at a reasonable cost and with the increased production rates; low-grade orebodies can now be more economical to mine.

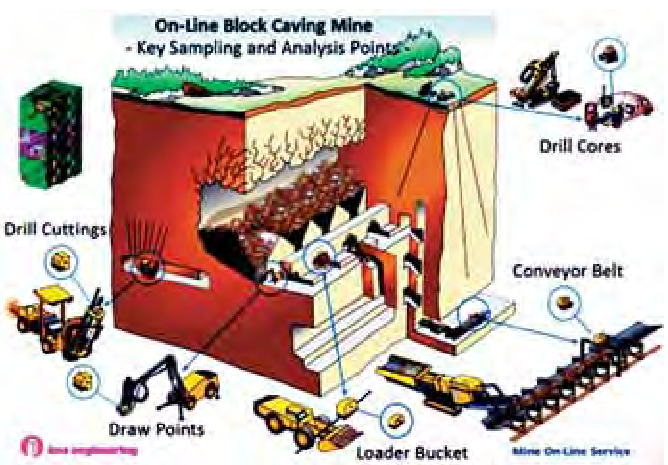

Figure 1. *Block cave mining method*

This mining method is more efficient than any other underground mining method and is being considered more frequently world-wide. Figure 2 shows major operating and planned block cave mines across the globe (some information from Hem and Caldwell, (2012)).

Figure 2*. Planned and operating block cave mines*

The objective of this paper is to demonstrate the role that the ventilation fraternity plays in mine planning when employing optimisation techniques that will lead to a LEAN, fit-for-purpose mine design. The LEAN business principle relates to practices that aim to create more value with fewer resources just-in-time.

BLOCK CAVING INFRASTRUCTURE

Block caving initially involves a significant amount of capital development as the selected production footprint needs to be accessed from shafts and/or declines from surface. Thereafter horizontal development starts on a number of levels that generally include an apex level, undercut level, production/extraction level, ore handling/haulage level and ventilation levels (Calizaya and Mutama, 2004).

BLOCK CAVING PROCESS

During the capital development phase, the apex level is mainly utilised for inspection to ensure the 'w' shaped funnels between the undercut and apex level are connected (Figure 3). On the undercut level parallel drifts/crosscuts are developed where drilling and blasting takes place to de-stress the cave. On the extraction level parallel crosscuts are developed from which draw-points and draw-bells are drilled and blasted. Another level is typically developed below the extraction level for ore transport, water pumping and return-ventilation (Duckworth et al., 2005). Haulage level and ventilation level airways are initially utilised to ensure that through-ventilation between the levels is achieved during the capital development phase.

During the capital development phase first production tons will be mined and a slow production ramp-up rate will be achieved. It is however only after the above horizontal infrastructure is established that production rates can ramp-up to steady state operations. The orebody will then be ready for blasting to start a continuous

Figure 3. *Block caving levels*

caving process. The cave will progressively collapse upward through the orebody and may in the long term cause areas on the surface to subside.

Figure 4 shows a typical block caving operation process where horizontal levels are developed and long-holes between the undercut and extraction levels are blasted which in turn enables the orebody to cave naturally (Mattox et al., 2014). Ore handling is by loaders at the extraction level that tip large rocks into crushers. Crushed rock is then tipped onto conveyor belts and is then either conveyed to surface or conveyed to production skips that hoist rock to surface. Some operations do not make use of crushers or conveyors but utilise trucks to transport rock to surface.

Secondary blasting at the draw-points is intermittently required to blast large rocks that interfere with the caving process. The frequency of secondary blasting depends on the orebody fracturing capabilities and rock strength to ensure the cave keeps on fracturing naturally.

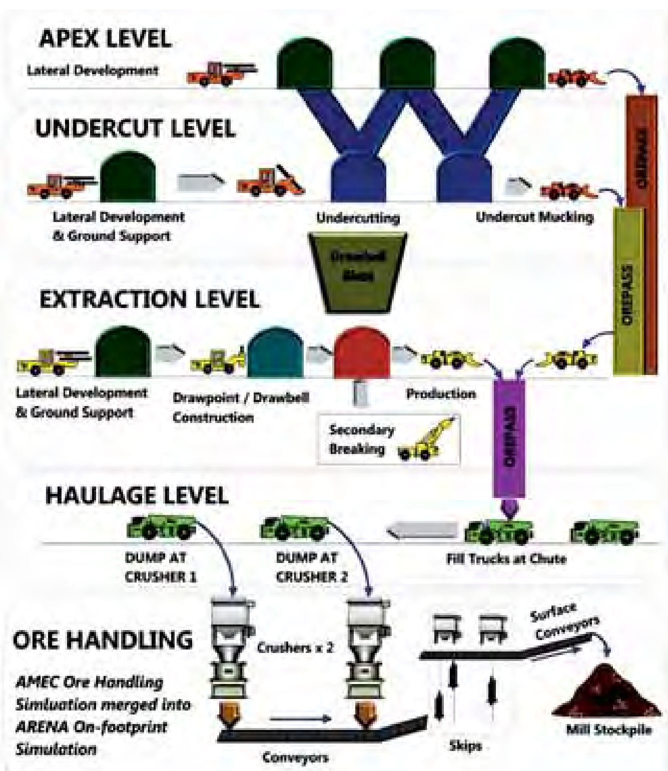

Figure 4. *Block caving process*

VENTILATION OPTIMISATION TECHNIQUES DURING CAPITAL DEVELOPMENT PHASE

During ventilation engineering planning, it is essential that the mine layout and plan are correctly understood for both the capital development and steady state production phases. Depending on the mining schedule and design, ventilation engineering challenges include high temperatures and airflow profiles that typically have peaks during capital development when the apex and/or undercut, production, ventilation and ore transport levels require many development ends to be ventilated simultaneously. There are a number of aspects that need to be included in the planning and these are discussed below.

Develop critical path to achieve through-ventilation

The critical path is the shortest path that can be mined to ensure that through-ventilation is achieved on the extraction level. Through-ventilation will enable the mine to achieve multi-end development and even multi-blast or fixed-time multi-blasting opportunities.

During this phase, the mine planning team, development schedule team and ventilation planning team need to be perfectly aligned to ensure that each department's key milestones are met. It is only when through-ventilation is established that adequate development can commence.

Capital development ventilation-on-demand

Ventilation-on-demand is an engineering control system that stops or reduces air supply to an inactive end and redirects this air to another active mining location. This reduces the overall air flow that needs to be delivered from surface. Ventilation-on-demand during the development phase can only be achieved when the mining and ventilation operations teams plan mining activities together.

In practice, this is typically achieved using force-ventilation tubing in development ends that will be tied with ropes to control the air distribution.

Alternatively, the system can be automated with open / close ventilation valves by either activating a local on / off switch or with the use of Programmable Logic Controllers (PLCs) via a Supervisory Control and Data Acquisition (SCADA) system. In some cases automated valves are used when multiple crosscuts on the undercut and extraction levels are in development and production to ensure loading crosscuts are ventilated appropriately.

Capital development cooling

Development ends are typically hot environments. The heat load is mainly caused by fresh hot broken rock, diesel loaders and / or trucks, ground water and fan heat. The overall mine cooling system needs to be carefully planned to ensure that cooling is available during all critical phases of the life-of-mine.

During the capital development phase an opportunity exists to cool the ends using localised cooling coil cars served by small temporary refrigeration machines providing chilled water. Spot cooling is an ideal solution for short-term use while larger permanent refrigeration machines with long lead-times are procured. However, spot cooling systems are inefficient and difficult to maintain over prolonged periods, and if the temporary refrigeration machines are located underground, they require access to return airways to enable heat from the refrigeration machine to be rejected.

Figure 5. *Bank of cooling coils*

Thermal design criteria

Thermal design criteria are specified to ensure acceptable working conditions and efficient operation during the life-of-mine. Capital development is the worst period in a block cave mine's life in terms of pressures on the thermal environment. During this period extensive development and production ramp-up take place but the required infrastructure (such as refrigeration equipment and main fans) has not yet been fully established. To assist with the setting up of the mine's infrastructure and to enable steady state production to be established sooner, owners/operators can consider a temporary relaxation of underground reject temperature criteria.

Application and risk management procedures have to be drafted and presented to the regulatory authorities for approval. The risks associated with any temporary relaxation need to be acknowledged and can include heat stress and heat stroke incidents. These risks need to be included in a heat stress management plan.

Heat stress management (HSM)

HSM involves heat tolerance screening, work-rest cycles, nutrition and hydration regimes, medical surveillance, acclimatisation, etc. Heat stress management (HSM) is generally a feature in hot deep mines where auto-compression, high rock geothermal properties, high production rates, etc. are encountered. HSM enables the mining operation to operate in high reject wet bulb temperatures (typically above 27.5^{o}C) and needs to be carefully monitored, measured and recorded. As part of a HSM plan, shift cycles should also be assessed to ensure that safe and healthy practices are employed for both short and long-term operations (Kielblock, 1992). Functional work assessment could be implemented in addition to the above to ensure overall physical work fitness.

Economic airway and vertical hole design

Capital development includes the development of vertical fresh air and return air passes between surface and the mining footprint. These vertical holes are then connected to the block cave by means of horizontal airways. Economic velocities of the vertical holes and the horizontal airways need be determined to ensure that capital / development costs and operating cost provide a positive net present value.

VENTILATION OPTIMISATION TECHNIQUES DURING STEADY STATE PRODUCTION

During steady state production all capital development activities are completed and the cave naturally yields under gravity. In some instances secondary breaking is required to blast large rocks to enhance the natural caving process. This section investigates various approaches that can be followed in ventilation engineering, ore handling and mining layout.

Vent distribution

Figure indicated that a block cave mine typically consists of five levels; apex, undercut, extraction, haulage and ore handling levels. Apex and undercut levels are caved during steady state production and thus three main levels remain that need to be ventilated continuously. In some instances the apex and undercut levels will be ventilated for longer with some air to ensure that mining personnel can inspect holings from the extraction level. The main ventilated levels are complimented with a ventilation level that is dedicated to warm dusty exhaust air. The haulage level is sometimes constructed adjacent to the extraction level and both these levels are generally in fresh air.

Ventilation of the cave is generally from one side of the mining footprint to the other side of the mine through parallel crosscut airways. Air can either be directed to a ventilation level below the extraction level (Figure 6 (A)) or the ventilation level can be situated on the same level if the mining footprint allows (Figure 6 (B)). The latter will result in reduced development and no vertical return air passes will be constructed.

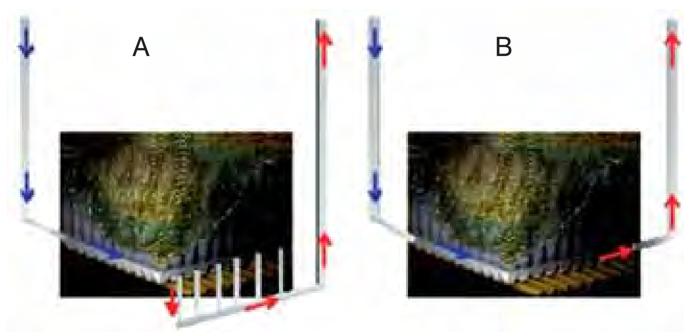

Figure 6. *Ventilation level vent layout*

Another ventilation distribution concept that needs to be considered is whether the mine will be ventilated towards the crushers (i.e. in series with the crosscuts, Figure 7) or away from the crushers (i.e. in parallel with the crosscuts, Figure 8).

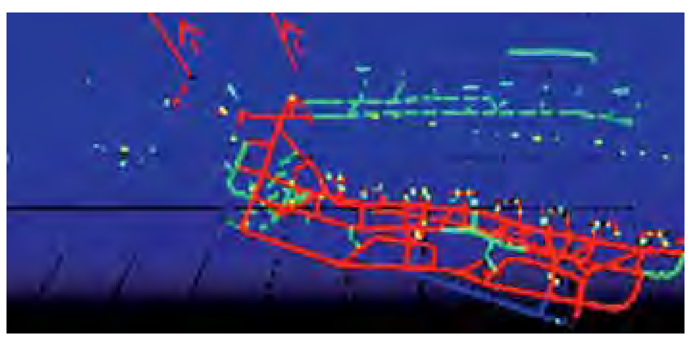

Figure 7. *Crushers and crosscuts ventilated in series*

Ventilation of the crushers in series with the crosscuts will result in reduced total required air quantity and lower power consumption at the main fans. The main disadvantage of this system is that personnel will work in warm dusty exhaust air and crusher equipment life is reduced.

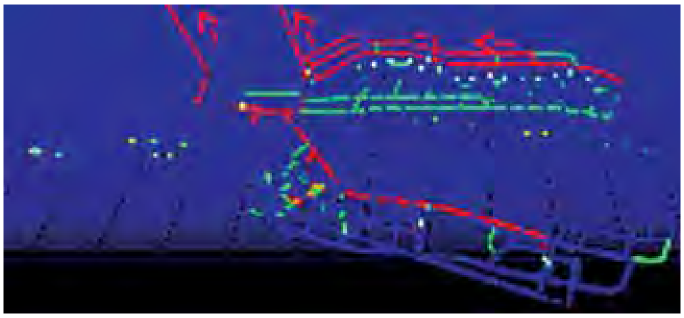

Figure 8. *Crushers and crosscuts ventilated in parallel*

Ventilation of the crushers in parallel with the crosscuts will result in increased air quantity and power consumption at the main fans as the crushers will be ventilated as a separate ventilation district that is directly connected to the return airway.

Regulators

When directing fresh air through parallel crosscuts, air control and balancing may be more difficult than anticipated as the fresh air want to take the shortest route through the first few crosscuts. To balance airflow quantities to each loading crosscut, regulators need to be carefully planned and placed. These can be managed by positioning and regulating crosscut airflow at Return Air Passes (RAPs). This can be achieved by using see-through strip brattices at the return ends of crosscuts.

Some mine designs include one RAP per crosscut and other mines have one RAP for a number of crosscuts which reduces capital cost but results in more challenging control systems. Strategic placement of RAPs can reduce worker exposure to pollutants and improve ventilation control. This reduces health and safety risks and ensures maximum productivity.

Re-use ventilation system

Re-use air systems underground facilitates constant air quantity drawn from surface. When air is re-used it is generally re-cooled and re-conditioned in horizontal bulk air cooling spray chambers. Adequate filtering of dusty re-used air is vital in the control of dust concentrations in these schemes (Booth-Jones et al., 1984).

Block cave mine layouts have the opportunity for re-conditioning and re-use of ventilation air (Marx et al., 2010). A re-use system is fairly easily possible with the re-use of air from the conveyor belt and crushers. Filtering of the dust can be achieved in water spray chamber scrubber that re-conditions air for re-use on the extraction level.

Installing re-use systems not only reduces the overall air quantity but also provides an opportunity for cooling at the re-use scrubbers. Lastly, the overall power consumption will be reduced at the main fans.

Crusher ventilation system

Crushers are used to break large rocks from the cave into smaller manageable sizes that are conveyed or hoisted from underground to surface. Crusher layout and designs need to ensure uninterrupted tipping and minimal pollutant exposure to personnel and equipment reducing health risk and maintenance requirements (Wallace et al., 2014). As discussed above, in many mines crushers are ventilated with fresh air that in turn is ventilated directly to return.

More recently mines are considering LEAN approaches for the overall mine designs and crushers are ventilated with used air from the extraction level. In these cases air at the main fans and operating costs are reduced. Visibility may however be a concern but filtering engineering controls can be considered in these cases.

Crusher ventilation systems are further improved by engineering control systems. Control systems typically include bratticing, air curtains, auxiliary fans and ducts, etc. A properly designed crusher ventilation system ensures effective capturing of dust generated by tipping and crushing operations and removes pollutants, including heat, directly to a return airway. Figure 9 shows a crusher dust extraction system.

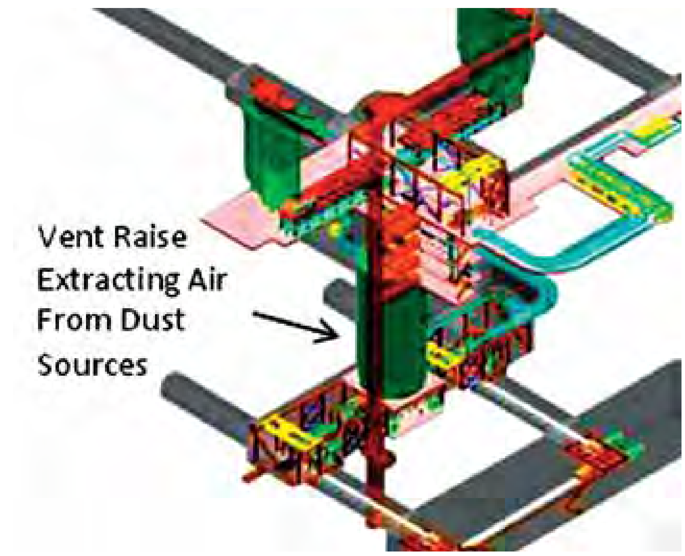

Figure 9. *Crusher dust extraction system (Wallace et al., 2012)*

Steady state cooling

Refrigeration systems are generally required for block cave operations due to their depth below surface, heat load contributed by mechanised vehicles and large volumes of broken rock. Correct positioning of cooling equipment is essential to ensure efficient, practical cooling with minimal capital and operating cost.

Block cave layouts generally create the opportunity for underground refrigeration systems to be positioned such that short pumping distances are required for both evaporator and condenser circuits. This is achieved due to the unique layout of block caves where the main intake and return airways are located near to each other. Air cooler locations need to be carefully considered to avoid over-cooling of intakes and to deliver the desired air quality near the intake to the extraction level (Marx et al., 2012).

Services ventilation

Due to the layout typical of block cave mines, crushers, workshops, pump stations and other services can be ventilated direct to return. This opportunity reduces the risk of exposure to pollutants, including smoke in the case of a fire. It does, however, increase the overall air requirement of the mine.

Ventilation-on-demand (VOD)

VOD strategies are possible in block cave mines due to the parallel layout of loading crosscuts and that not all crosscuts are operational all the time. VOD systems consist of crosscut regulators (typically doors), variable speed fans, vehicle tracking, etc. coupled with monitoring and control equipment. The equipment ensures that the minimum required airflow for heat and pollutant dilution is achieved in 'closed' cross-cuts and the required high flow is achieved for diesel and heat pollution in 'open' cross-cuts. VOD can reduce the overall air requirement of the mine and with well-managed systems could be of great value.

Some mines install VOD regulators on the fresh air side of the cave and others on the return air side or both. The location of these regulators depends on which side loaders access the cave and then tip into crushers.

When VOD regulators are installed on the return airway side, frequent maintenance of the control system will be required due to pollutants such as dust, diesel exhaust, heat and blast fumes from secondary blasting.

Well-managed VOD systems are beneficial in that they reduce the total air quantity required from surface since only the loading and serviced crosscuts are ventilated and the rest remain closed. The consequence of less air is reduced power consumption at the main fans.

However, these systems can only work when underground daily planning and cave draw control is effective and the work force applies the operational procedures to VOD regulators (i.e. open for loaders and closed for other work).

Loader equipment selection

Diesel load haul dumpers (LHDs) not only generate exhaust gas but produce up to three times the amount of heat generated by electrical LHDs for the same work output. Although electrical LHDs have the challenge of trailing cables to be considered, there is a saving in overall air quantity and cooling required. Battery operated LHDs could also be considered.

CONCLUSION

The ventilation department can be very valuable during mine planning when the mining method, sequence of mining and mining process is understood. The ventilation planners need to identify critical phases over the life-of-mine to ensure that short and long-term ventilation requirements are met.

Optimisation techniques that can be employed at block cave mines include optimal appropriate selection of design criteria and accurate application of ventilation-on-demand and heat stress management plans. The ventilation distribution and ventilation layout are key in determining the direction in which air will flow and to determine the total air quantity. The best optimised selection can have a major impact on the business case.

Re-use ventilation is an important ventilation technique that reduces the total air requirement at the main fans. Re-use systems are often combined with horizontal bulk air spray chambers that provide scrubbing and cooling capabilities. When refrigeration is mandatory to achieve thermal design conditions, careful consideration is required when deciding on a surface and / or underground refrigeration system. Constructing air coolers near the localised source of heat i.e. the block cave will ensure best positional efficiency.

The paper has summarised ventilation techniques that were identified to optimise block cave mines for fit-for-purpose LEAN designs when an already economical mining method is selected. The ventilation techniques are safe, use state-of-the-art technologies and result in favourable economies of scale. It can therefore be concluded that the ventilation fraternity is and will continue to play a relevant part in mine design planning.

REFERENCES

Booth-Jones, P.A., Annergan, H.J. and Bluhm, S.J., 1984. *Filtration of underground ventilation air by wet dust-scrubbing*. The Institution of Mining and Metallurgy / The Institution of Mining Engineers, Third International Mine Ventilation Congress, Harrogate, England, 1984.

Calizaya, F., and Mutama, K.R., 2004. *Comparative evaluation of block-cave ventilation systems*. Proceedings of the 10th US/North American Mine Ventilation Symposium, Anchorage, Alaska, USA, 16-19 May 2004. Bandopadhyay, S. Ganguli, R. (eds) Taylor and Francis Group, London.

Duckworth, I.J., Karmawan, K., and Chmura, C., 2005. *Expansion of the DOZ Mine Ventilation System*. Proceedings of the SME Annual Meeting, 28 February to 2 March 2005, Salt Lake City, UT.

Hem, P. and Caldwell, J., 2012. *Block Caving*. TechnoMine Mining Technology. Date revised: April 2012.

Kielblock, J., 1992. *Heat stress management: An Industrial perspective*. Proceedings of the fifth international conference on environmental ergonomics.

Mattox, A., Coil, D., Hoagland, N. and Hitman, B. 2012. *Block Caving*. Groundtruthtrekking. Date revised: October 2014.

Marx, W., Hooman, M., Botha, P., and Meredith, G., 2010. *Cooling system design for a block-cave mine*. Proceedings of the 2010 Mine Ventilation Society of South Africa Conference, Emperors Palace, Kempton Park, Gauteng, South Africa, 13-14 May 2010.

Marx, W., Bezuidenhout, M., van den Berg, L., Botha, P., and Meredith, G., 2012. *Block-cave refrigeration and cooling system*. ACG's 6th International Seminar on Deep and High Stress Mining, Perth, Australia, 28-30 March 2012.

Wallace, K.G., Prosser, B.S., Donoso, J.R., Guerrero, A.F. and Acevedo, J.C., 2012. *Ventilation system design for the CODELCO New Level Project*. 14th United States/North American Mine Ventilation Symposium, 2012 – Calizaya and Nelson, University of Utah, Dept. of Mining Engineering, 2012.

Wallace, K.G., Prosser, B.S., Sani, R., and Semestario, T., 2014. *Ventilation planning at the P.T. Freeport Indonesia's GBC mine*. Proceedings of the 10th International Mine Ventilation Congress, IMVC, South Africa, 2014.

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Methods to suppress dust on open pit drill rigs

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ABSTRACT

Spotters and samplers working around surface drill rigs can be exposed to high dust concentrations. In this study it was found that individuals were exposed to as much as 14.2 mg/m^3, which exceeds the Occupational Exposure Level of 10 mg/m^3. The work on which this paper is based included an extensive literature study, as well as field investigations on a surface mine in Namibia. A number of additional dust suppression interventions were identified. These improvements, listed below, will assist in reducing dust concentrations around the drill rigs:

- Increase maintenance frequency on the shroud, sealing ring, suction pipes and filters of the drill rigs,
- Design and install new overlapping rubber belts on the shroud of the DM45,
- Install an air-blocking shelf on the inside perimeter of the shroud of the DM45,
- Install an airflow meter to ensure that the QC: QB ratio never drops below 3:1,
- Only allow wet drilling,
- Flush the dust collector system more regularly with compressed air to ensure that it does not become blocked,
- Introduce stricter supervision to ensure that the suction pipes are always connected to the shroud,
- Give drill rig operators more advanced training to ensure more effective drilling in order to reduce dust levels.

It can be concluded that the implementation of the recommended improvements in engineering controls, better maintenance practices and better operating practices will assist in preventing any potential respiratory diseases and the degradation of the surrounding environment.

Keywords: dust, suppression, open pit drill rigs, exposure, control.

INTRODUCTION

The study was conducted on a mine mine that uses drilling and blasting mining operations to break the rock. Loading and hauling then follows with a monthly production of 1.6 million tonnes (Mt). The pit is currently 160 m deep, 1200 m long and 900 m wide and will eventually reach a final depth of 310 m. A bench height of 10 m is being utilised.

The mine's target is to drill 147 holes per day, which equates to a total of 1613 m per day. This target is achieved by employing the following drilling fleet:

• Three Atlas CopCo Roc-L8 with down-the-hole hammers, and

• One DM45 drill rig with a rotary tri-cone drill bit.

Excessive amounts of dust in or around the pit were reported by the blasting, geology, surveying and maintenance crews that work next to the blocks being drilled. The drill spotters and grade control operators working in the vicinity of the drilling area are, however, the most susceptible to the dust exposure, leading to potential respiratory diseases.

Although the drill rigs have dust suppression systems in place, the correct utilisation and maintenance of these systems are often under-utilised due to production pressures.

An additional four drill rigs will arrive in the near future to the mine. The introduction of the new drill rigs will contribute to even higher dust levels in or around the open pit. To improve conditions around the drill rigs and reduce the potential exposure of workers it is important to determine the deficiencies of the dust suppression systems currently installed on the drill rigs. It is also important to determine the shortcomings in maintenance and operating procedures.

DUST FORMATION MECHANISM

The drilling process is achieved by a combination of rotation, thrust, indexing and percussion of the drill bit (Kahraman, Bilginand and Feridunoglu, 2003). All these forces allow the rock to be chipped and grinded at the contact between the drill bit and the rock. This is the site where dust is created and the bailing air carries these drill chippings and dust particles out of the hole and into the atmosphere. It is of vital importance to control the dust that escapes the drill collar to reduce the amount of dust escaping into the atmosphere.

SUPPRESSION OF DRILLING DUST

If not properly controlled, drilling operations may expose drill operators, drill helpers / spotters, and grade control operators to large amounts of respirable dust. Controlling dust at the drill rigs can be achieved using a wet suppression system and / or a dry suppression system.

WET DRILLING DUST SUPPRESSION

The wet suppression system works by introducing water into the bailing air that is send down the drill stem. The water then mixes with the dust and drill chippings at the bottom of the drill hole where the dust is liberated. This allows the dust particles and drill chippings to stick to each other, making them less airborne as they are bailed out of the drill collar. Other than dust suppression, the advantage of using water in percussion drilling is an improvement in the penetration rate of drilling (Cecala et al., 2012).

According to Page (1987) (in Cecala et al., 2012), tests have shown that wet drilling can reduce dust levels up to 96%. It is, however, critical that the drill operator ensure that the water flow rate entering the bailing air is correct. Cecala (2012) stated that the flow rate can range from 3.8 to 7.6 L/min depending on the type of drill rig, the geology and the moisture content of the rock being drilled. At some sites it was found that the dust suppression efficiency could be increased by increasing the water flow rate from 0.8 to 2.3 L/min. However, when a flow rate of 3.8 L/min was reached, operational problems were encountered. This was due to the drill chippings becoming too heavy to be removed by the bailing air; they started to plug the drill bit and bind the drill stem (Cecala et al., 2012). It is therefore required that the drill operator adjust the water flow rate until the maximum amount of dust is being suppressed without encountering operational problems with too much water.

There are, however, disadvantages to using water with rotary drilling. According to Cecala (Cecala et al., 2012), water can reduce the life of tri-cone roller bits by 50% or more. This deterioration of the drill bits can be prevented by using a water separator sub. The sub is connected between the drill bit and the following drill stem, and separates the water from the bailing air. This is achieved by forcing the bailing air through sharp turns where the water separates from the air due to the inertia of the water being higher than that of the air. The compressed air then continues to the drill bit without containing water. When the water has built up to a certain level in the water reservoir, it escapes the water separator sub through the weep holes directly into the annulus above the drill bit. The water then mixes with the drill chippings and dust particles as it moves up the annulus. This prevents the water from moving through the drill bit and over the surface where the actual drilling action takes place. This is illustrated in Figure 1. It was noted that (Cecala et al., 2012) that dust reduction was improved from 96 to 98% when a water separator sub was introduced.

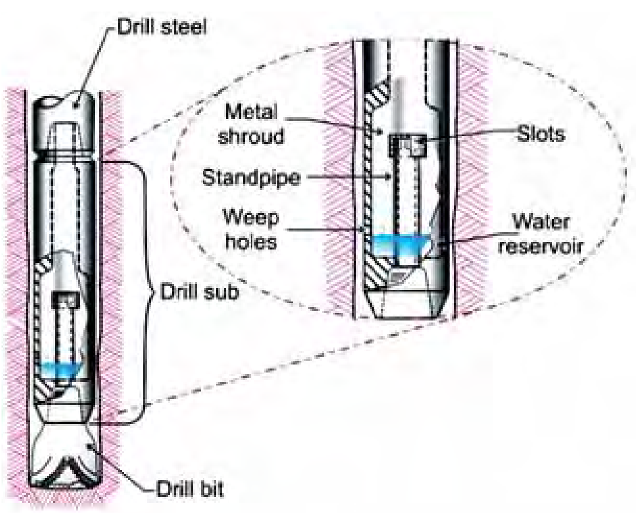

Figure 1. *Water separator sub (Cecala et al., 2012)*

DRY DRILLING DUST SUPPRESSION

Dry drilling dust control systems can be up to 99% efficient if properly maintained (Cecala et al., 2012). Dust particles and drill chippings escape from the drill collar with the aid of the bailing air and are contained within the drill deck and shroud. The dust collector system establishes a negative pressure within the shroud and draws the dust particles into the dust collector system. The dust collector system is composed of the fan exhaust, which creates the negative pressure, and the filters, which separate the dust from the air. Most filtering systems are self-cleaning. They use regular pulses of compressed air to remove the dust from the filter surface, and allow the dust to drop through the bottom of the collector and onto the ground. An additional cyclone may also be installed between the drill deck and the filters.

In order to maintain an adequate negative pressure inside the shroud it is important to have the correct drill deck and shroud design. Most shrouds are rectangular in design with four separate rubber belts suspended from the drill deck. Leakages often occur at these corners. It is therefore necessary to install angle-shaped corner flaps at these corners to create an overlap with the suspended rubber belts. Another solution is to make use of a single rubber belt installed along the perimeter of the drill deck.

A modification that can be made to the shroud design is to introduce an air-blocking shelf. This is composed of a 150 mm wide shelf installed along the inside perimeter of the shroud. An air-blocking shelf is shown in Figure 2.

Figure 2. *Air-blocking shelf installed along the inside perimeter of the shroud (Cecala et al., 2012)*

According to Potts and Reed (2008) and Reed and Pots (2009) (in Cecala et al., 2012), the bailing air containing the dust particles moves out of the drill collar along the drill stem until it hits the drill deck and disperses sideways due to the Coanda effect. The air then moves down the shroud walls and eventually strikes the ground, where the dust can escape to the atmosphere through the shroud gap. By installing an air-blocking shelf, the flow of air within the shroud is circulated within the top half of the shroud, giving the exhaust fan enough time to extract the dust. This reduces the possibility of the dust escaping through the gap below the shroud. The flow of air in the shroud and the effect of the air-blocking shelf can be seen in Figure 3. It was reported by Potts and Reed (2010) (in Cecala et al,, 2012) that dust levels were reduced to between 66 and 81% after an airblocking shelf had been installed. It should be noted that the air-blocking shelf becomes less effective when there is very little dust emission in the first place before the shelf is installed.

An additional indicator to determine the performance of the dust collector system is the ratio of its collector to the bailing airflow

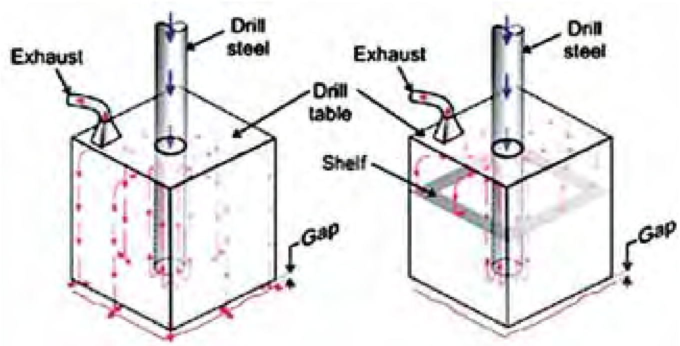

Figure 3. Airflow model within the shroud without and with the air-blocking shelf (Cecala et al., 2012)

(Cecala et al., 2012). This can be expressed as QC:QB, where QC is the volumetric flow rate of the dust collector fan and QB is the volumetric flow rate of the bailing air that escapes out of the drill collar. Normal operating drills usually have ratios of 2:1 and this can be even as high as 3:1. In some instances, due to poor maintenance, incorrect compressor settings, etc., the ratio may even drop below 1:1, rendering the dust collector system completely ineffective. It can be seen from Figure 4 that an increase in this ratio reduces the dust concentration, making the dust collector system more effective.

It should also be noted from Figure 4 that a decrease in the gap between the bottom of the shroud and the ground will also reduce the dust concentration, thereby increasing the effectiveness of the dust collector system.

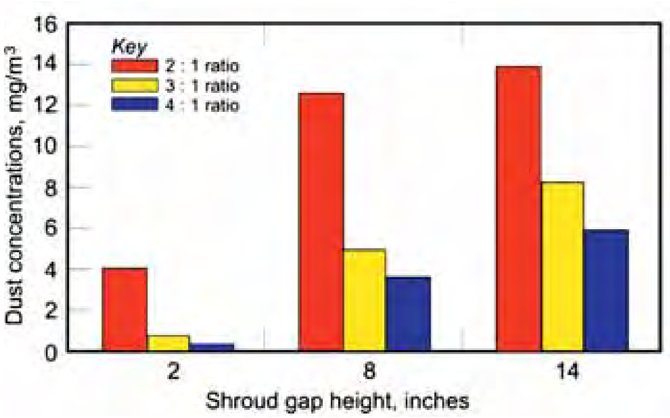

Figure 4. Effect of different shroud gap heights at various dust collectors to bailing air ratios (Cecala et al., 2012)

According to Maksimovic and Page (1985) (in Cecala et al., 2012), the dust that drops from the collector dump cyclone / filter may account for up to 40% of the respirable dust emissions of a drill rig. The bottom of the dust collector dump point (cyclone / filter underflow) is on average between 60 and 90 cm from the ground. At that height the respirable dust escapes into the atmosphere when it falls through the air and when it hits the ground. It is therefore, necessary to install a brattice cloth on the underflow of the cyclone / filter with the aid of large hose clamp. This allows most of the dust particles to settle onto the dump pile. According to Reed et al., (2004) (in Cecala et al., 2012), the installation of this brattice can reduce the respirable dust level into between 63 and 88%. The efficiency is, however, dependent on wind speed and direction. The advantage of this brattice is that it is inexpensive and quick to install.

DRILLING RESULTS AND DISCUSSIONS

Dust pumps with pre-weighed filters (NIOSH sampling method 0500) (Clere and Hearl, 1994) were used to test dust concentrations in various stationary working areas (environmental samples) and on various personnel while working. It can be seen from Table 1 that two of the spotters and samplers around the drill rigs were exposed to dust concentrations above the OEL (10 mg/m^3) (Government Gazette of the Republic of Namibia (Act 6 of 1992)). This is a major concern as these employees may contract respiratory diseases.

Table 1. Dust sampling results

Location/ Activity	Type of test	Results (mg/m^3)
Spotters & samplers	Personnel	14.1
Spotters & samplers	Personnel	5.66
DR 04 drilling	Environmental	8.32
Roc-L8	Environmental	3.04
Roc-L8	Personnel	0.21
Geology pit area	Environmental	0.39
Drill rig training	Personnel	1.62
Spotters & samplers	Personnel	4.31
Spotting at DR-02	Personnel	14.2
DR-02	Environmental	2.52

DM45 DRILL RIG

It was observed that large amounts of dust escaped from the bush that acts as a sealing ring where the drill stem enters the drill deck (see Figure 5). After investigation it was revealed that the escaping dust was a result of poor maintenance. It must be emphasised that it is necessary to replace the sealing ring more regularly by following the correct installation procedures.

It can be seen from Figure 6 that there are separate rubber belts hanging from the drill deck with open slits between them. Holes and cuts were also present in these hanging rubber belts.

Figure 5. Dust escaping the sealing ring where the drill stem enters the drill deck

Additional open slits were also present at the corners of the shroud. All these slits, voids and holes cause the vacuum pressure to drop within the shroud, causing the dust to escape through these openings and into the atmosphere. It is therefore recommended that new rubber belts that overlap each other be installed, as well as angled rubber belts at the corners of the shroud. This will seal the shroud and ensure a higher negative pressure inside the shroud, thereby reducing the amount of dust escaping from the shroud. It is also recommended that regular maintenance be done on the shroud to ensure that there are no holes, cuts or open voids in the rubber belts.

Figure 6. *Open slits between rubber belts of the shroud*

It was realised that there was no air-blocking shelf on the inside of the shroud. It is therefore recommended that a 150 mm wide rubber belt be installed along the inside perimeter of the shroud that will act as an air-blocking shelf. The shelf should be installed half-way up the shroud and can be fastened to the sides of the shroud with angle iron, nuts, bolts and washers. This will allow most of the dust to circulate in the upper section of the shroud, to be extracted through the dust collector system.

It was unfortunately not possible to measure the volume flow rate of the dust collector extractor fan due to the mine not owning the equipment required to measure the airflow rate.

It is therefore, recommended that a vane anemometer, wire anemometer or pitot tube be acquired in order to make regular collector flow rate readings at the drill rigs. This will enable the mine to know when to do maintenance on the dust collector system or when to change air flow settings if the QC:QB ratio drops below 3:1.

ROC-L8 DRILL RIGS

It was noted that drill operators only use water during drilling when the holes are collapsing to stabilise the sidewalls. Drilling while introducing water into the bailing air is one of the most effective ways to reduce dust levels. It is therefore, recommended that drilling operators should always drill with water, even if the sidewalls are stable by nature.

Similar to the DM45 drill rig, large amounts of dust passed through the sealing ring where the drill stem enters the shroud. It is therefore recommended that the sealing ring be replaced more often following the correct standard maintenance procedures.

Figure 7. *Blocked dust collector pipe between shroud and cyclone*

The drill operators often do not flush the dust collector system while drilling. This blocks the suction pipe between the shroud and the cyclone (see Figure 7). Blockages in the suction pipe prevent the dust collector system from drawing the dust out of the shroud, causing the dust to escape into the atmosphere. It is therefore recommended that the drill operators flush the dust collector system more regularly by relieving the pull-down pressure and increasing the flow of the bailing air. In addition, the drill operators, assistants, spotters or grade controllers often remove the suction pipe from the shroud to prevent blockages from occurring in order to reduce downtime and to increase production. This creates excessive amounts of dust and it is therefore recommended that stricter supervision be exercised. The supervisor should ensure that the drill operators flush the dust collector system more regularly and that the suction pipe is always connected to the shroud.

It was also realised that the dust collector pipes are susceptible to bending, which will causes a higher airflow resistance in the suction pipes. If the flow rate is reduced, the dust collector system will be less effective and more dust will escape into the atmosphere at the shroud. It is therefore recommended that regular maintenance be done on the suction pipes to ensure that they are whole, have no bends, and are tightly fastened to the remaining components (shroud, cyclone and filters). Large amounts of dust were also coupled with bad drilling practices. More dust was liberated when the drill chippings were very fine and less dust was observed when the drill chippings were larger in size. Inexperienced drill operators use excessive amounts of rotational pressure compared with the pulldown pressure on the drill bit. This prevents the tungsten carbide teeth from indenting into the rock, and causes the drill bit to grind the host rock. The grinding action at the drill bit creates excessive amounts of fine drill chippings which become airborne much more easily when they are bailed out of the drill collar. It is therefore recommended that drill operators be trained to drill correctly and more efficiently. This will not only reduce dust levels, but also increase the drill bit life.

CONCLUSIONS

The dust concentrations reported from the sampling measurements on the mine indicated that spotters and samplers around the drill rigs are exposed to dust levels above the standard set for occupational exposure limit (OEL).

From the field investigation it was found that maintenance on the dust collector systems of the drill rigs was not being done to acceptable standards. More regular maintenance is required on the shroud, suction pipes, filters, and especially the sealing ring (where the drill stem enters the shroud) of the drill rigs. It was also recommended that new overlapping rubber belts be installed on the shroud of the DM45, as well as an air-blocking shelf on the inside perimeter of the shroud.

The mine needs to purchase and install an airflow meter to ensure that the QC:QB ratio never drops below 3:1.

The drill operators should be required always to drill with water and to the flush the dust collector system more frequently to prevent any blockages in the suction pipes. Improved and advanced training for the drill operators is required. This will improve drilling practices, which will lead to reduced dust levels and increased drill bit life.

The implementation of the recommended improvements in engineering controls, better maintenance practices and better operating practices will assist in preventing any potential respiratory diseases and the degradation of the surrounding environment.

REFERENCES

Cecala, A.B., O'Brien, A.D., Colinet, J.F., Fox, W.R., Franta, R.J., Randolph J.J, Reed, W.R., Reeser, P.W., Rounds, J.R. and Schultz, M.J., 2012. *Dust control handbook for industrial minerals mining and processing*. Department of Health and Human Services. Centers for Disease Control and Prevention. National Institute for Occupational Safety and Health. Office of Mine Safety and Health Research. Pittsburgh, PA, Spokane, WA.

Clere, J. and Hearl, F., 1994. NIOSH/DRDS. *NIOSH Manual of Analytical Methods* (NMAM), 4th ed.

Government Gazette of the Republic of Namibia. Labour Act, 1992. *Regulations Relating to the Health and Safety of Employees at Work. Schedule 1(2), Occupational Exposure Limits for Airborne Hazardous Substances Made under the Labour Act* 1992 (Act 6 of 1992), (section 101, regulation 185 (1)).

Kahramana, S., Bilginb, N., and Feridunoglub, C., 2003. *Dominant rock properties affecting the penetration rate of percussive drills*. International Journal of Rock Mechanics & Mining Sciences 40: 711–723.

Maksimovic, S.D. and Page, S.J., 1985. *Quartz dust sources during overburden drilling at surface coal mines*. U.S. Department of the Interior, Bureau of Mines Informational Circular 9056.

Page, S.J., 1987. *Optimizing dust control on surface coal mine drills*. U.S. Department of the Interior, Bureau of Mines Technology News 286.

Page, S.J., 1991. *Respirable dust control on overburden drills at surface mines. Coal mining technology, economics, and policy.* Session papers from the American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, 2–5 June, pp. 523–539.

Potts, J.D. and Reed, W.R., 2008. *Horizontal air blocking shelf reduces dust leakage from surface drill shroud*. Transactions of the Society of Mining, Metallurgy, and Exploration, 324:55–60.

Potts, J.D. and Reed, W.R., 2010. *Field evaluation of air-blocking shelf for dust control on blasthole drills*. Submitted to Mining Engineering.

Reed, W.R. and Potts, J.D., 2009. *Improved drill shroud capture of respirable dust utilizing air nozzles underneath the drill deck*. Transactions of the Society of Mining, Metallurgy, and Exploration, 326:1–9.

Reed, W.R. Organiscak, J.A. and Page, S.J., 2004. *New approach controls dust at the collector dump point*. Coal Age, June: 20-22.

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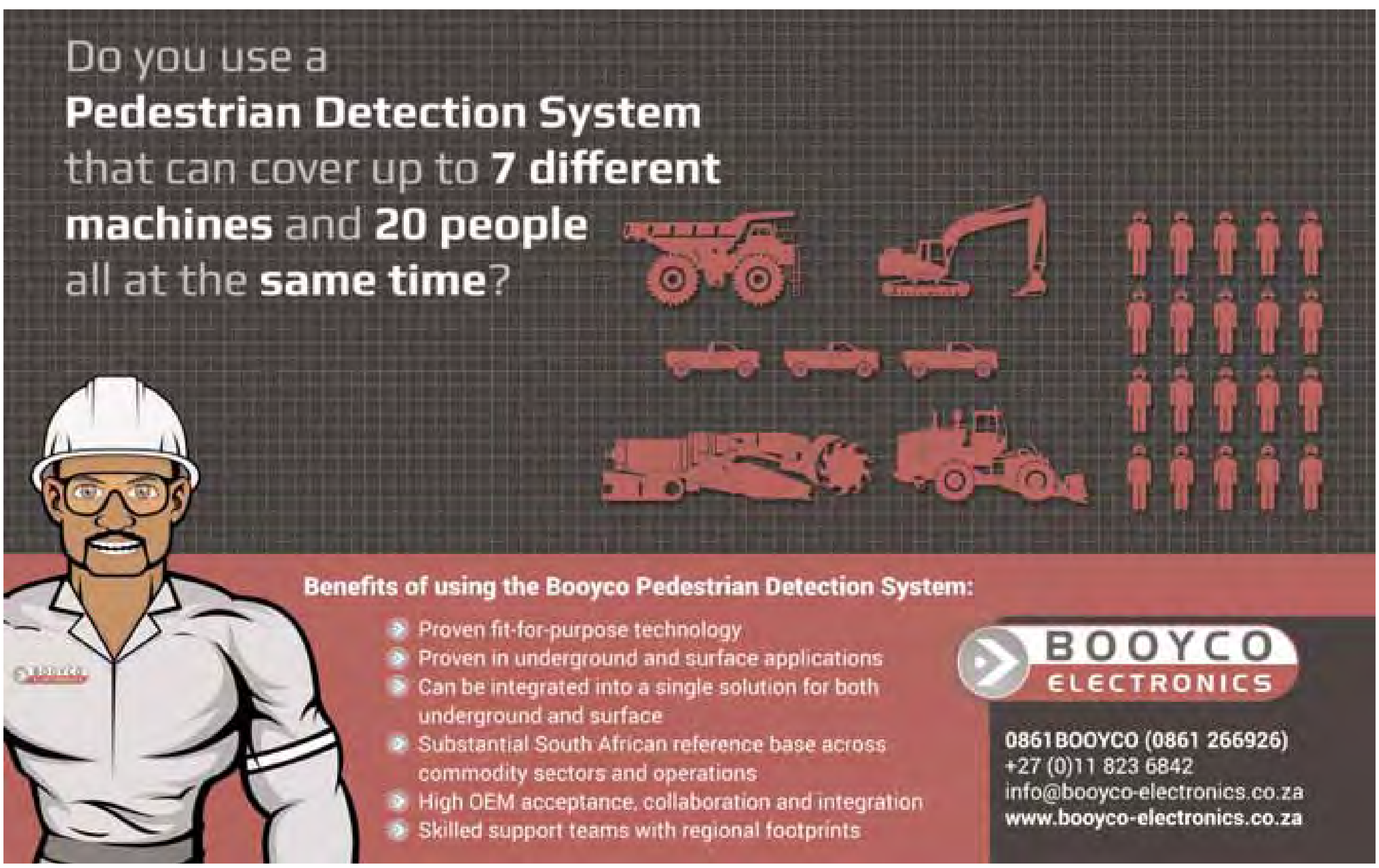

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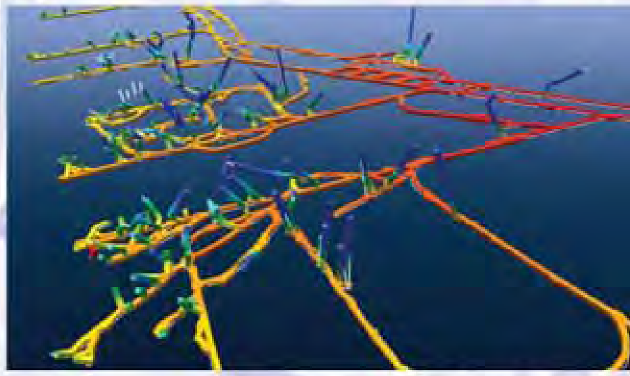

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