UNDERGROUND ENVIRONMENTAL CHALLENGES IN DEEP PLATINUM MINING AND SOME SUGGESTED SOLUTIONS

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Abstract

Platinum mines in the Bushveld Complex are located in areas with a high geothermal gradient. This means that, compared to, for example, gold mines of the Witwatersrand region, high rock temperatures are encountered at relatively shallower depths. Thus air cooling and refrigeration need to be considered at early stages in mine development. Another factor that influences air cooling and ventilation requirements is the use of trackless diesel equipment for loading and hauling broken rock. At shallower depths it will be more cost-effective to locate the cooling and ventilation equipment on surface, whereas for deeper mines the more cost-effective option is to locate cooling equipment underground. For intermediate depths, trade-off studies need to be undertaken to determine the optimum mix between more cooling and less air or more air and less cooling, as well as the optimum location for this cooling equipment. Factors that are taken into account include power requirements, positional efficiency, and additional infrastructure requirements.

Traditionally the approach has been to ventilate 'all of the mine all of the time'. However, with increasing power costs and growing pressure to ensure sustainability, this strategy must be modified to apply ventilation and cooling on demand. In other words, both cooling and ventilation equipment should be operated only when needed and should be adjusted to the demand at the time. Obviously there will be areas that will need to be ventilated (and cooled) continuously (for example, for dilution of flammable gases), but this can be built in to the overall strategy. In addition, in devising ventilation on demand (VoD) strategies, occupational criteria relating to exposure to gases, noise, and heat need to be taken into account.

This paper discusses options available for implementing energy-efficient ventilation and cooling systems and suggests ways of changing traditional thinking in the overall ventilation and cooling of mines. Efficient ventilation and cooling designs can play a major role in improving sustainability and reducing energy costs and carbon footprint.

Introduction

The main general challenges in all mining relate to:

- Depletion of easy-access reserves, which means mining has to take place further away from the surface infrastructure
- Increased electrical power demands at a time of increasing costs
- Efforts to achieve more efficient ore extraction, which generally means increased use of mechanization.

From the ventilation/environmental engineer's point of view, the above challenges have significant consequences. Deeper mining results in higher heat loads due to geothermal and autocompression effects, which must be combated by delivering more air or by implementing refrigeration. Increased mechanization results in more heat from equipment as well as the need for more air for dilution of pollutants. However, delivering more air and cooling to deeper workings requires more power for fans and for pumping.

Traditionally mines have been ventilated in a brute-force manner, with all of the mine being ventilated all of the time. Thus there were generally no controls except to direct primary flow to overall working areas. In the present economic climate, mine operators need to be more focussed in providing air (and cooling) to areas that need it rather than over-ventilating non-active areas. This approach has been termed ventilation (and cooling) on demand (VoD) and has been implemented in various forms in many mines.

It is possible to implement VoD on existing operations, but the most effective practices should be included in the design/planning stages. Computer planning tools are available for ensuring sufficient air gets to particular areas, as well as for operating cooling systems in energy efficient ways.

Ventilation design parameters

The main design parameters driving ventilation and cooling requirements are:

- Surface design conditions
- Design reject condition
- Dilution of pollutants (heat, dust, diesel fumes)
- Production requirements.

Surface design conditions

Surface design conditions are important for the specification of cooling equipment. For example, if the inlet design specification of a surface refrigeration plant cooling 1000 kg/s of air is 1°C higher than it need be, then this would result in an over-specification of cooling of between 3 to 4 MW, with serious capital implications plus significant operating costs over the life of the plant. Similarly, under-specification of the surface conditions would mean that refrigeration equipment will be under-sized with the result that underground conditions will be too hot. It is important that accurate surface weather data over a long period is analysed to obtain confidence in the selected surface design condition.

Design reject temperature

Numerous studies on productivity and accident frequency have been carried out that show that there is an optimum range for workplace temperatures. Design wet-bulb temperatures between 27.5°C and 29.0°C are specified (Figure 1).

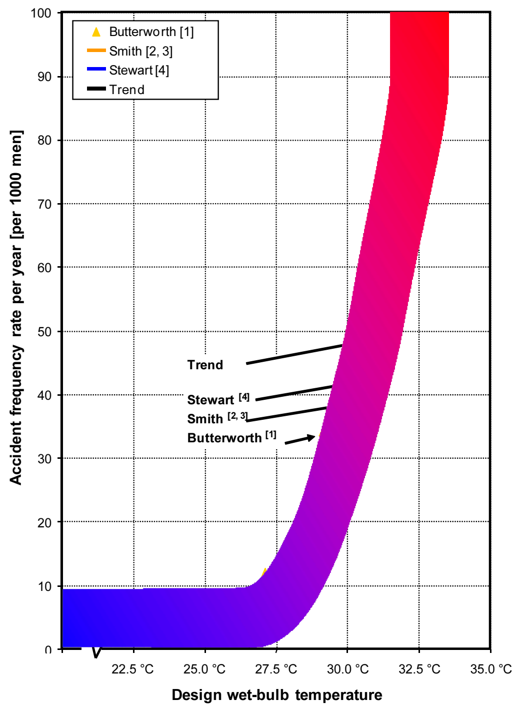

Figure 1-Relationship between accident rate and productivity and wet-bulb temperature

There are also direct relationships between the costs of providing refrigeration and the depth and design reject temperature.

Figure 2 shows the typical relationship between total refrigeration plus human-related costs and wet-bulb temperature. The human-related costs are a cost penalty allocated to increasing number of accidents and decreasing labour productivity as a result of rising temperatures.

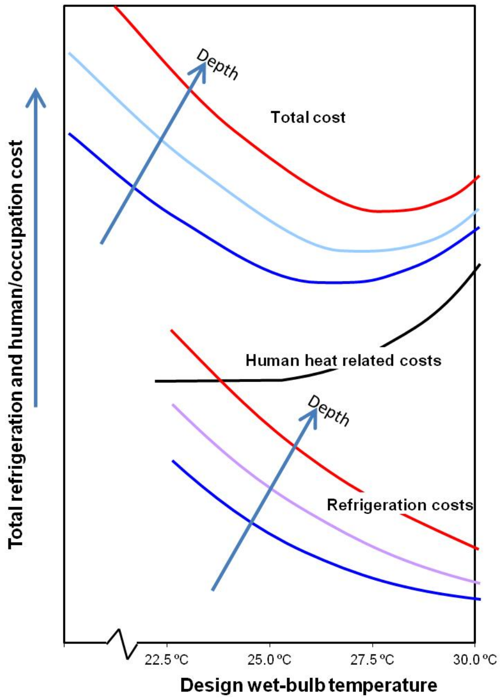

Figure 2-Total cost variation trends related to design wet-bulb temperature

Dilution of pollutants

The main pollutants relevant to this paper are heat and diesel fumes. As mines progress deeper, geothermal heat and autocompression play more significant roles and eventually a point is reached where provision of uncooled air to counteract the heat will no longer be adequate. In South African platinum mines, the introduction of cooling, normally in the form of surface bulk air coolers, must be applied at depths of about 800 m, whereas this depth will be close to 1 400 m in gold mines. The horizon for introducing ice in South African gold mines is about 3 000 m (although this is getting less with higher power costs). Recent studies indicate that the depth for introducing ice in platinum mines is much closer to 2 000 m. Figure 3 shows the best general cooling options with increasing depth.

The selection of the optimum cooling system will depend on a number of site-specific factors, including design reject temperature, ultimate depth of mining, electricity costs, and surface design temperature. The question of sizing underground refrigeration plant will often play a role in strategic planning, and a useful rule of thumb in this regard is that about 100 kg/s of reject ventilation air will allow heat rejection from cooling plant with a capacity of 6 MW.

Figure 3-Generic selection of optimum cooling system as a function of depth

For effective planning it should be noted that, although the ventilation system is the fundamental medium for controlling the environment, there is a complex interaction with the refrigeration and cold water systems. For detailed planning at the correct level of accuracy, there is a need for a balance-sheet, audit-type approach for evaluating different scenarios on a systematic and consistent basis. The thermodynamic and flow calculations must be solved progressively and interactively throughout any particular mine network. Many variables are involved, and the best way to plan this systematically is through the use of specific software tools.

Increased mechanization has implications on heat as well as the quantity of air required for dilution of diesel fumes. Because of practical requirements such as the need for freedom of movement, diesel equipment is preferred over electrical equipment, although electrical equipment produces significantly less heat and no fumes when compared to diesel equipment (at full load, heat production of a diesel engine is about 3 kW of heat per rated kilowatt, whereas heat production of an electric motor is 1 kW of heat per rated kilowatt). Advances are being made to improve the quality of diesel fuel and to make engines more efficient, but these parameters are still significant driving factors in setting the levels of ventilation and cooling in a mine design. In June 2012 the International Agency for Research on Cancer (IARC) classified diesel engine exhaust as carcinogenic to humans (Group 1) based on sufficient evidence that exposure is associated with an increased risk for lung cancer[7].

Following this announcement there will be an increased drive towards better-quality engines and diesel, and a greater emphasis on ensuring that sufficient air is provided to mechanized areas for dilution of diesel fumes.

Production requirements

Mine layout and mining method ultimately dictate the minimum quantity of air required and how this is distributed. In hot mines, the air will be required to deliver cooling to hot zones or where equipment is working. The more scattered a mine layout is the more primary air will be required. Generally, for shallower applications a ventilation factor of approximately 3.5 kg/s of air per kiloton of rock hoisted is used as a rule-of-thumb, while for deeper applications this can increase to 5 kg/s per kiloton. The worst-case scenario for determining a mine's overall air requirements demands that every available production area be ventilated with sufficient air to cope with the peak activities in that zone, plus the usual allowances for leakage etc., irrespective of whether the activities are actually taking place at certain times during the day.

Strategies for energy efficient ventilation and cooling systems

Ventilation on demand

An energy-efficient primary distribution system delivers air to areas that need it - rather than ventilating for the worst case of all of the mine being ventilated all of the time, the minimum quantity of air should be directed to each area depending on the activity. Ensuring that leakages and short circuits are minimized is also important. This will require controls (regulators or fans), but the cost of these would be offset by the energy saved.

As mining moves from one area or level to the next, ventilation resources need to be reallocated and non-working areas sealed off. For example, in a mechanized mine, where equipment moves freely throughout the mine, the air distribution must be modified to ensure that there is always sufficient air to dilute fumes and heat wherever the equipment is working or travelling. This is the principal of ventilation on demand (VoD). Under normal circumstances a loading zone will be provided with the minimum air quantity to dilute the fumes of the LHD and the truck being loaded, but when the full truck leaves, the area could be over-ventilated. The controls would ensure that the air delivered to the loading area is reduced but the air delivered to the truck route is increased. Equipment would be fitted with sensors so that it could automatically switch fans on/off as it moves through areas. An example of an end ventilated by fan fitted with a variable speed drive (VSD) is shown in Figure 4. The minimum flow for gas dilution will be provided when no equipment is present, but when an LHD alone or an LHD and a truck are present then the minimum flow that is provided depends on the rating of the equipment present.

VoD systems can be applied in conventional as well as mechanized mines, with mechanized mines generally requiring more rapid variations in localized flow delivery because of the transitory nature of equipment usage.

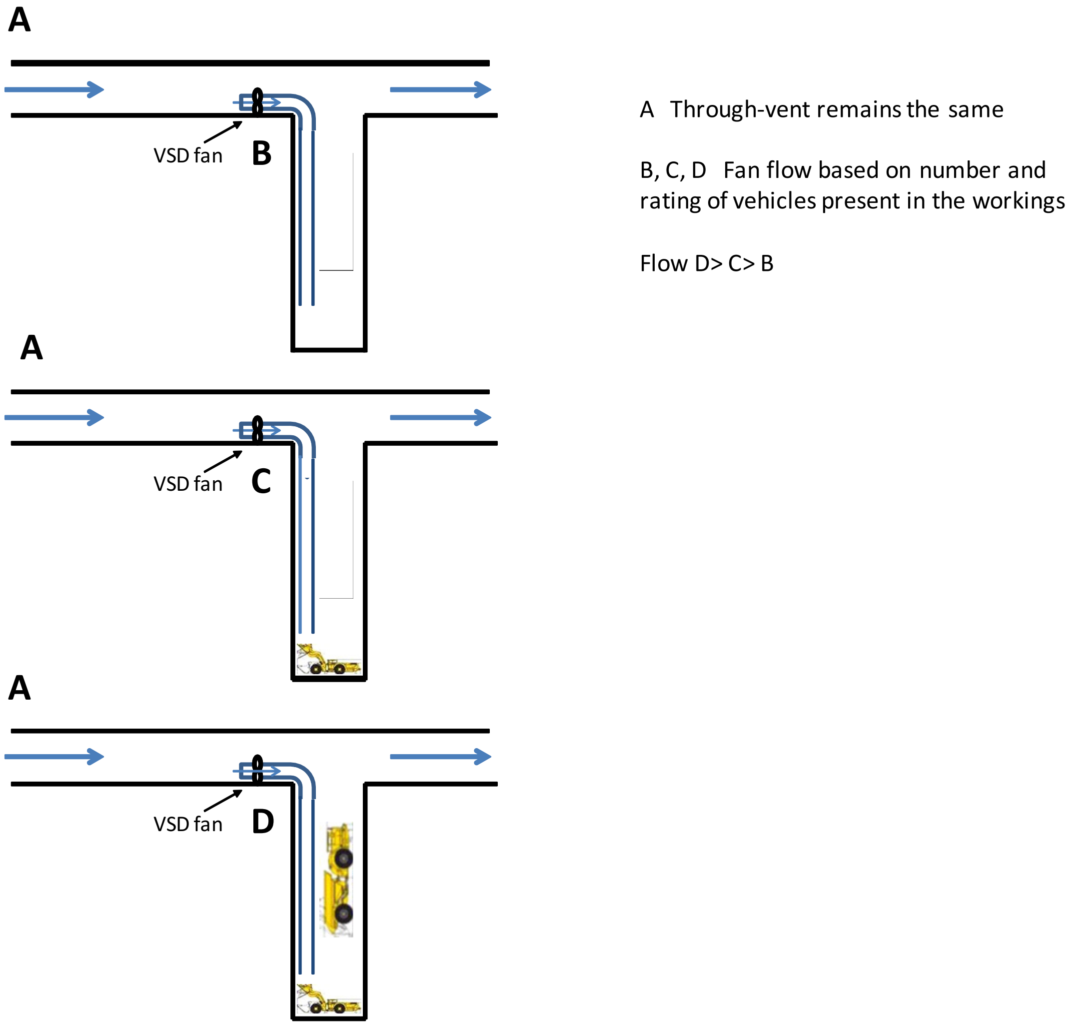

Figure 4-Example of VoD to vary flow in workings based on presence of equipment

Care must be taken when making changes to the ventilation distribution that minimum quantities are still being delivered to areas where equipment is no longer working and that fans and regulators in the circuit are operating within their envelopes. Software such as VUMA-live can be used to predict the effect of alterations to the circuit. In this system a mine ventilation network model is set up and initially calibrated to ensure that predictions and measured values agree.

The ventilation network model is linked with a mine monitoring system and the predicted values are compared with monitored data at a few (maximum 5 or 6) strategic locations. The monitored values are used as reference points in the network and will enable predictions for areas downstream of the monitored locations to be accepted with confidence. During the ongoing monitoring process, differences between predicted and monitored values can be used to identify potential problems in the circuit, for example, excessive change in temperature required will indicate that a cooler is not operating; similarly, excessive changes required in fan pressure or airway resistance indicate that a primary airway could be blocked. The system is used as follows:

- If primary ventilation and cooling is to be reduced during periods of low activity, the prediction can check that minimum quantities are available in all areas for flammable gas dilution (this would set the level to which flow is reduced) and temperatures can be checked prior to arrival of personnel to ensure that acceptable conditions are achieved in all areas (this would set the time when cooling must be re-started and level of initial cooling required)
- If the mine is mechanized, the effect of reallocating air to different locations as the equipment moves around the mine can be simulated and the effect on distribution of primary air to all locations checked
- The system would identify whether sufficient air is being supplied to working places. A central control station could be alerted whenever conditions do not satisfy minimum requirements. If the program is linked to a central vehicle despatch system, it would ensure that sufficient air follows equipment as it moves through the mine. VUMA-live could instruct the SCADA system to manipulate fans/regulators and indicate whether equipment is allowed to move to certain locations.

The system has successfully been implemented in a number of projects on gold mines, with good correlation being obtained between measured and predicted values[8]. Figure 5 shows a screen capture of a mine model with the measurement locations shown.

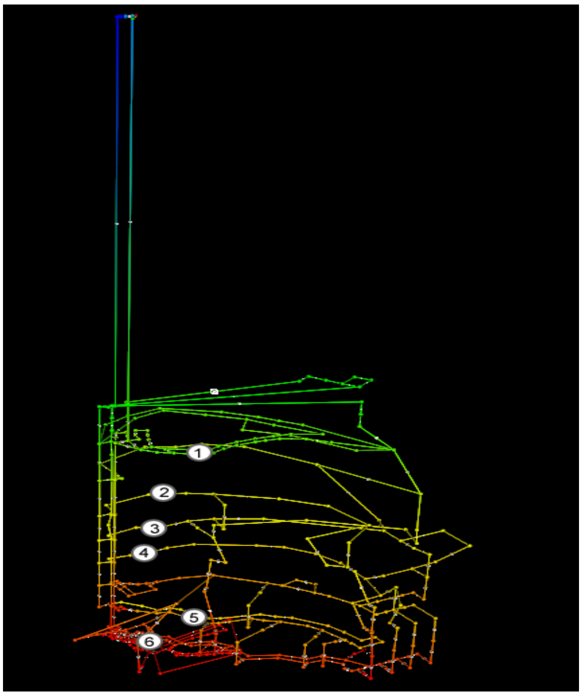

Figure 5-Screen capture of VUMA-live model, showing measuring stations

Control of primary air flow

Mine fans are major energy consumers, with the equipment generally operating 24 hours per day, seven days per week. A number of projects have been undertaken to identify energy-saving opportunities at surface fans. Initially, three different technologies to reduce main fan absorbed power during strategic periods of the day and week were examined, namely, fan outlet dampers, variable-speed drives, and fan pre-rotational inlet guide vanes [IGV]. Pooe *et al.*[9] showed that energy savings of between 27 per cent and 29 per cent were achieved in three projects where main fan flow was reduced by 10 per cent during the peak energy demand period of 18:00 to 20:00 using IGV control (Table I).

Table I-Targeted and achieved power savings[9]

	Target			Achieved		
Mine	Baseline (MW)	Savings (MW)	% of baseline	Baseline (MW)	Savings (MW)	% of baseline
Kloof	22.8	5.6	24.6	20.2	5.4	26.7
Driefontein	30.0	7.5	25.0	19.3	5.3	27.5
Impala	25.5	7.4	29.0	24.5	7.1	29.0

Figure 6 shows the absorbed power savings achieved during a typical measurement period.

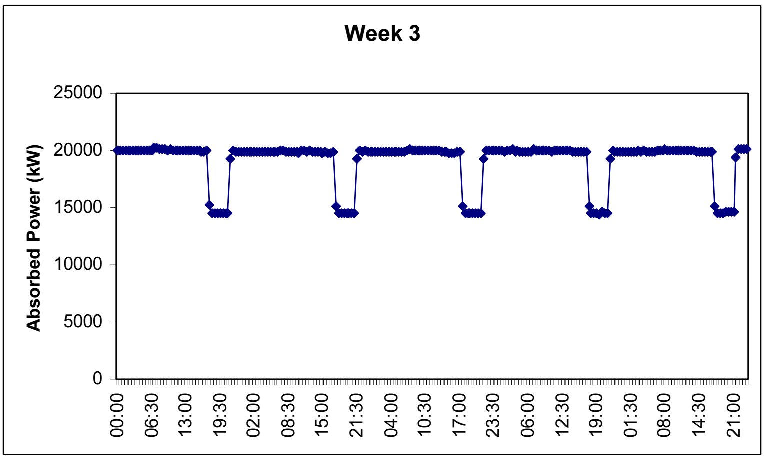

Figure 6-Measurement of absorbed main fan power at Kloof Gold Mine

This technology is now being implemented at other mines, including conventional and mechanized mines in both the platinum and gold sectors.

Refrigeration plant surplus cooling capacity

Swart[10] has shown that, because of Eskom's time-of-use tariff structure, considerable power cost savings can be achieved by utilizing refrigeration plant surplus cooling capacity and chilled water storage capacity to shift load from the higher tariff periods to the lower tariff periods.

Surplus cooling capacity is the difference between the maximum cooling capacity and the normal operational required cooling capacity (operational cooling capacity). The required operational cooling capacity for surface refrigeration plants is highly dependent on the ambient air conditions. Surplus capacity during the winter season (low wet-bulb temperature) can be twice as much as during the summer (high wet-bulb temperature). The underground water demand is fed from the surface chilled water storage dams. The ideal scenario during peak Eskom tariff periods will be to stop all refrigeration equipment and supply the mine with the required water from the chilled dams. The surplus cooling capacity must then be utilized during low tariff periods to prepare dam levels for the next peak tariff period. The calculation of the maximum load shift potential of a refrigeration plant requires complex mathematical modelling and simulation. Each piece of equipment within the mine's water handling and water transfer system needs to be characterized and modelled. All these models are then linked within a larger simulation model to simulate the mine's complete water handling process. The decision engine is then integrated with the simulation model to calculate the optimized running schedule for each piece of equipment in order to minimize power cost while adhering to all mine constraints.

Modification of main fans to improve efficiency

An investigation of the operation of main fan efficiency on gold and platinum mines revealed that a large number of fans operate at aerodynamic efficiencies below 65 per cent (Fourie *et al.*[11]). Typically the fan impellers were designed for higher pressures at the design operating point, but the fans generally operate at lower efficiencies because of changes over many years in the planned mine development.

As a result of the lower operating pressures, significant losses occur due to flow separation as the impeller blades are designed for a larger supply head. Fan shaft power is proportional to fan air power and inversely proportional to the aerodynamic efficiency of the fan impeller. Therefore a considerable energy reduction could be achieved by improving the aerodynamic efficiency of the fan impeller.

On mines where fans do not operate at the design or best efficiency point, drop-in impeller replacements are feasible (Fourie *et al.*[11]).

The purpose of a drop-in impeller is to replace the existing impeller with a new, more efficient impeller. The design uses the actual operating point as the best efficiency point for the new impeller design. An important feature of the drop-in concept is that the changeover requires minimum changes to the existing structural design of the fan. This is done to reduce the costs of implementation and, more importantly, to reduce the effect on production time during the installation of the new drop-in impeller. Typically the hardware replacement of a drop-in impeller design will be the new impeller, a new shrink-wrapped shaft, and minor modifications to the existing casing.

The new impeller design is more aerodynamically efficient and reduces the shaft load on the motor. As a result the electrical load is reduced, therefore reducing the electrical running costs at all times of the day.

Belle[12] carried out a desktop study to examine the benefits of impeller replacement. The study showed that the combined effect of both the electricity savings and carbon credits is significant, even at low expected increases in main fan efficiencies. A 10 per cent increase in fan efficiency with 10 per cent reduction in electricity consumption resulted in an electricity saving of about 11 MW per annum. The present value of this benefit amounted to some US$16 million over 10 years. With the inclusion of carbon credits at US$26 per ton, this benefit rose to US$42 million in total. The study showed that up to 81 000 t of CO_2 equivalent (CO_2e) could be saved.

Energy efficiency at Impala Platinum

As part of a major project at Impala Platinum, a guideline document for designing energy-efficient plants has been drawn-up for application from the earliest stages of project development, including concept phase studies[13].

The primary purpose of the document was to raise awareness of energy efficiency in all engineering disciplines. The objective is that application of the guidelines will result in mine and plant designs with reduced demand on grid electricity, and thus reduced electrical energy operating costs. Specific examples relating to the main ventilation and cooling systems include the following.

Main fan control and energy management

The main fan station drift, bends, and duct split will be designed to minimize aerodynamic losses. The main surface fans will be controlled to unload (load clipping) during Eskom peak tariff periods - this will be achieved through programmed automatic control routines and specially engineered inlet guide vanes.

Secondary auxiliary fans

The secondary auxiliary fans will be selected for optimum aerodynamic efficiency with high-efficiency motors.

Refrigeration system energy management

The refrigeration system will be designed and operated with thermal storage (ice) systems that will be used to dampen load variations between day and night and ensure full utilization of high-efficiency colder night-time operation. In conjunction with the thermal storage, the refrigeration system will be controlled to unload during Eskom peak tariff periods - this will be achieved through specially-programmed automatic control routines and optimization software.

Service water cooling tower

The service water cooling tower systems will be designed to be operated only during the cold daily 12 hour period.

Mine water pumps

The mine water pump system will be designed to be operated only outside Eskom peak tariff periods. The interaction between MPS and IPS pumps and all the dam levels will be optimized to minimize total power tariffs.

Controlled recirculation

In the 1990s there was significant interest in the recirculation of air underground; see, for example, Rose and Bluhm[14]. In a recirculation system, a portion of the return air used to ventilate a mining section is cooled and reintroduced into the area. The main benefits of recirculation are the increased volume circulating through the area and hence the reduction in volume required to be delivered from surface. Because the recirculated air does not travel from surface it does not undergo the effects of autocompression and the associated increase in temperature, and the additional fan pressure to deliver the air from surface and back is not required. One of the concerns relating to recirculation was the potential increase in contaminants, particularly radiation. However, recent work has shown that it is possible to design and build scrubber systems to reduce contaminants to acceptable levels in recirculation systems.

Conclusions

In the future there will be increased pressure for sustainability, with the main focus being on energy and carbon as well as water resource efficiencies. Technologies are available to implement energy-efficient ventilation and cooling systems. Ventilation-on-demand system designs are being addressed in most major mining groups and will become the norm within the next decade. Within the mine ventilation and cooling discipline, there are very significant changes being driven by energy costs and carbon considerations. Projects are being undertaken where significant energy savings are being achieved both in primary ventilation as well as refrigeration systems. The issues raised in this paper will form part of a number of additional initiatives to reduce the footprint and ensure sustainability.

The proposed solutions can be applied in both mechanized and conventional mines. Pre-requisites for successful implementation include:

- Risk assessments
- Management buy-in
- Cooperation of all mining disciplines
- Effective modelling of systems.

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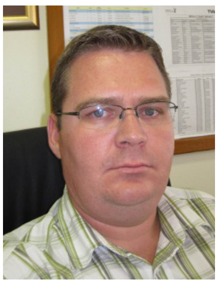
The Author



Lukas Mackay, *Ventilation Manager - Projects*, Impala Platinum

Lukas Mackay started in the Ventilation discipline in January 1994 at Buffelsfontein gold mine where he worked for a year and during which he achieved his Practical as well as Elementary qualification in Ventilation. He also successfully completed the Radiation Protection Officer modules in that year.

In March 1995 Lukas went over to Hartebeestfontein gold mine as a Ventilation officer and worked there for a 5 year period during which he successfully completed his Certificate in Mine Environmental Control in May 1999.

In February 2000 Lukas joined AngloGold Ashanti - Tau Lekoa mine where he worked as Senior Ventilation officer for a two year period.

Lukas was offered a promotion post at Impala Platinum as Chief Ventilation Officer and in February 2002 Lukas joined the Impala team. Lukas has worked on a number of shafts during which he also did relieving work as Ventilation Manager as well as Occupational Hygiene Manager in the group.

Milestones during his time as a Chief Ventilation Officer at 14 shaft were the Optimization project on the 14V main fans to improve performance as well as the trackless optimization project which significantly improved the conditions in the trackless section.

Lukas was transferred to the projects section in January 2009 as Chief Ventilation Officer and was promoted to Ventilation Manager – Projects in February 2010. Lukas is responsible for the existing projects shafts for Impala as well as for the planning of all new projects.

Lukas is married to Erma a dietician of trade and has two daughters Michélle aged 9 and Jana aged 7.

Lukas enjoys fishing, playing squash and cycling and watching rugby.