# Ventilation strategies to meet future needs of the South African platinum industry

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Transaction Paper

## Synopsis

**This paper provides an overview of possible approaches for structuring the ventilation systems for mines that will become operational within the next decade. Features addressed in the paper include: aspects of airway design and layout in the absence of centralized vertical return shafts, the impact of using diesel-powered trackless equipment in conjunction with conveyor belts in the development and production phases of the project, and the need to balance increasing electrical power costs against the requirement for reduced capital expenditure.**

**The paper provides brief descriptions of the strategies employed in real-life situations and presents an overview of various operational parameters affecting the design of ventilation systems that will be used as 'platforms' for much deeper mines in the future.**

## Introduction

The provision of ventilation systems for modern mines is an integral part of a mine's technical design. The art of mine ventilation consists in finding a balance between what is a safe and healthy environment while providing a cost-efficient infrastructure in terms of both capital and operational expenditure.

The definition of a safe and healthy working environment is derived from baseline risk assessments aimed at identifying the hazards and quantifying the risks relating to the working environment. This process leads to the application of what are termed 'reasonable' protective measures aimed at eliminating or at the least mitigating the detrimental impact of the hazard on workers. The outcome of this process is the ventilation engineered design criteria against which the performance of the system can be measured objectively.

It is against this background that all the various facets of modern ventilation systems are structured. Although ingenuity is a primary requirement of any engineering design process to ensure effectiveness at an acceptable cost, the strategy on which ventilation systems are based must remain focused on the mining and engineering requirements while attaining the design criteria generated in the risk assessment process. Ultimately a functional ventilation system must not become an impediment to mining operations. On the other hand, the adaptation of the system design to meet mining and engineering requirements should not lead to the transgression of boundaries beyond which the resilience of any ventilation system will fail.

It is for these reasons that the challenges presented by modern platinum mining operations to the ventilation engineer have to be addressed in a logically structured and methodical manner. The design process to which a modern ventilation system has to be subjected must interact iteratively within the parameters posed by the mining and engineering requirements of the project so as to provide solutions that reflect the dynamic nature of a mining project and that cater for different system performance requirements at different stages in the life of the project.

## Background

The range of platinum mining operations currently undertaken in Southern Africa varies greatly from new operations where the reef outcrops or is very close to surface to operations currently approaching a third phase in their lifespan at depths approaching and sometimes beyond 2 000 m below surface. The challenges presented by the latter type are obvious in terms of the need for cooling and the provision of more extensive and sophisticated air conditioning systems. In addition, the extent of these operations on strike can be as much as 6 000 m necessitating relatively high electrical power demand to circulate the required air quantities

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Mining methods are also varied and affect the ventilation system requirements significantly. Modern platinum mining operations are characterized by a higher degree of mechanization. Machinery is employed primarily for safety purposes where the worker is removed from the danger zone. In addition, mechanization can accelerate and streamline production and enhance flexibility of mining methods. For example, the introduction of ultra low profile vehicles designed for hard rock mines has been stimulated primarily by the needs of this sector of the mining industry. Even in narrow channel width mining operations, it is not uncommon to encounter conveyor belts in strike gullies that are developed by low profile LHDs. The ore is dumped on a comprehensive conveyor belt network that leads to vertical or inclined shaft systems for hoisting or that is extended all the way to surface surge bins directly. The use of conveyor belts is further justified in terms of the extent of these operations on strike where the advantages of this mode of transport become apparent and also where the life of the project is relatively long.

It is also typical that a trackless equipment fleet should be powered by diesel combustion engines that offer greater flexibility and better all-round performance in terms of production per unit power output. The use of trackless equipment is maximized during the primary development of the orebody's infrastructure in order to reduce production lead times and anticipate creation of revenue.

For the purpose of this paper it might be useful to categorize different mine types into three groupings:

- *Category A* consists of mines that operate from surface down to a depth of 700 m below surface. These operations tend to be relatively new and in many cases represent the first stage of mines that will expand to a greater depth in this century. These operations are characterized by direct access from surface by means of adits and vehicle and conveyor belt declines. Chairlifts may be provided for the transport of workers. Hoisting shafts are not used and will form part of the next phase of the project. Typically the infrastructure is limited—not only due to restrictions imposed by the strategy of a 'pay as you go' strategy—but also due to restrictions posed by limitations in infrastructure availability such as electrical power and process water supply. Being the latest generation mines, occupational environmental impacts are of primary importance. These also affect the location and number of access points into the mine for ventilation purposes.
- *Category B* operations typically extend from about 700 m to a depth of about 1 200 m below surface. These operations are beyond the initial phase and are well into their production target zone. The infrastructure is more developed than that of category A mines and typically inclined or vertical shafts are in use forming platforms for production as well as for the next phase of expansion. The use of air cooling to varying degrees of complexity through the use of mechanical refrigeration is a reality for these operations. Aspects related to the availability of electrical power and water supply are managed, although future expansion will entail super-linear increases in power demand for hoisting, pumping, ventilation and cooling. The surface infrastructure in terms of ventilation shafts is in place and further expansion at depth will maximize the use of the existing and older infrastructure in terms of intake and return airways. For this category air cooling is in the form of primary surface bulk air coolers that process various proportions of the downcast air quantity.
- *Category C* comprises mines that can be termed 'ultra-deep' from a ventilation system design perspective. In some cases these mines operate at depths approaching and in excess of 2 000 m below surface where the rock temperature is in well in excess of 60°C. Mines in this category are in the third stage of development typically employing deep vertical shafts or sub-decline clusters that extend on dip the reach of the current surface vertical shafts. In future, this category of mines will see the sinking of sub-vertical shafts. These systems are an extension of the surface intake shaft infrastructure and play an essential role in conveying fresh air to the workings. At this stage of the development of these mines, primary surface air cooling is supplemented by secondary underground air cooling as well as by in-stope cooling in some instances. In this category of mines underground chilled water reticulation systems are employed and electrical power requirements are affected significantly by higher water pumping and refrigeration capacity.

In all cases return air is conveyed through the reef horizon to main horizontal return airways that are linked to the various upcast shaft systems. The dependence of ventilation systems on the worked-out reef horizon and abandoned levels as return airways present challenges and risks—particularly for deeper mines where the risk of increased airflow resistance and airway failure is heightened by stress-induced deterioration and eventual failure of excavations and by the effects of seismic activity.

## Primary ventilation

Perhaps the most dreaded question asked of a ventilation planner is: 'What size airway (shaft or decline) do you require?' This is not an easy question to answer at the time it is usually asked—usually at the very start of the project. The size of the main intake airways may be determined only once the mine layout (both in terms of production levels and methods), extent of mining operations served by the airway and production scheduling are established with a degree of finality.

The mine layout determines quantitatively the air flow requirements at different stages of the life of the project. This is dictated by the tonnage produced and the methodology adopted (usually degree of mechanization). The size of ventilation systems is also determined by the degree of scatter of mining operations. The creation of a number of stopes in a regular array will require less air per ton than that consisting of clusters scattered both on dip and on strike.

The primary requirement in both a breast stoping or room and pillar arrangement is the provision of adequate air velocities at the face (for breast mining) or in the last through road (room and pillar). Consideration for air leakage completes the air quantity requirements per stope. The air requirements for each stope together with the air requirements for development activities determine the air quantity for each half level. Table I summarizes a set of air velocity criteria in stoping sections.

Similarly, during the development phases of a vertical shaft or a decline cluster, criteria are used to provide the required air quantity. Typically, these are based on providing a minimum flow rate per unit area of the excavation—for example 0.20 $m^3/s/m^2$ for development ends and 0.30 $m^3/s/m^2$ for sinking shafts—that will allow and adequate number of air changes during the re-entry period. Usually, however, the development of a decline cluster may need to handle air volumes well in excess of the values thus obtained and this may affect the dimensions of the decline itself. The additional air flow requirements cater for any development operations that originate from these primary structures.

The use of diesel-powered vehicles in the development of decline cluster on minor gradients is favoured as it provides greater flexibility and has the potential of faster rates of advance. Figure 1 shows schematically a typical twin development arrangement. The dimensions of the ends are 4.0 m wide and 3.5 m high for a total area of 14 $m^2$. A primary flow of 50 $m^3/s$ is induced by fans at the head of the return airway. In accordance with the criterion ventilation rate of 0.2 $m^3/s/m^2$, each end will require a minimum of 4.2 $m^3/s$. However, mining operations require the use of diesel powered LHDs and trucks. The application of an exhaust diesel fume factor of 0.06 $m^3/s/kW$ (as will be discussed later) increases the fresh air flow requirements at the face to 13.0 $m^3/s$, for, say, a total rated power of 210 kW.

Figure 1 (not to scale) also indicates the use of rigid exhaust ducting. These are usually sized to handle the required air quantities and are likely to interfere with loading, transport and construction operations. In vertical shaft systems development operations will be set off once the shaft is completed and a permanent up-cast facility is in place. For decline systems, as considered presently, development of levels may be set off as soon as the level elevation is reached and therefore the system has to handle enough fresh and return air for operations until through-ventilation is established on each level. A cursory analysis of Figure 1 highlights the fact that the number of levels that may operate from such a primary system is limited by the capacity of the primary air mover at the top of the return airway and the number of diesel-powered vehicles operating simultaneously.

In some instances the need to integrate mining and engineering requirements to the maximum create very complex arrangements, as shown schematically in Figure 2. The figure represents a layout that was proposed for an operating platinum mine and although this is not an engineering drawing, the relative proportions of the equipment are consistent with the size of the excavation. The mining team proposed in this case to combine two excavations into a single larger entity. On paper the layout is feasible but in reality it presents a number of issues that are too detailed for the purpose of this discussion. Suffice to say that the capacity of this arrangement to support further development is very limited and that therefore the net advance rates were affected accordingly. It is also to be noted how the relatively small ducts (maximum total capacity of about 40 $m^3/s$ of air for significant distances) limits the size of vehicles that may effectively operate in this decline.

As part of the longer-term use of shafts and decline clusters as airways, the following should be noted:

- Although equipped shafts inherently present a higher frictional resistance to airflow, they are designed for higher air velocities. Air velocities in equipped shafts may be as high as 12 m/s whereas in access declines the velocity is limited to 8 m/s due to worker and vehicular access.

*Table I*

**Stoping air velocity criteria**

| | MInimum face air velocity (m/s) | Notes |
|---|---|---|
| *Breast mining*<br>Depth to 650 m below surface | 0.40 | For VRT < 37.5°C only; else use next value |
| Between 650 m and 1500 m<br>Depth in excess of 1500 m | 0.60<br>1.00 | |
| *Room and pillar*<br>Last through road<br>Adjacent road | <br>1.50<br>1.00 | |

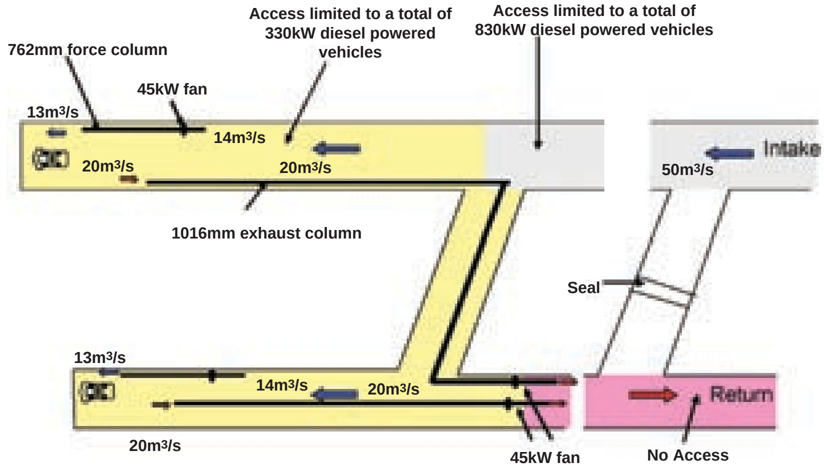


**Figure 1—Schematic twin development end layout**

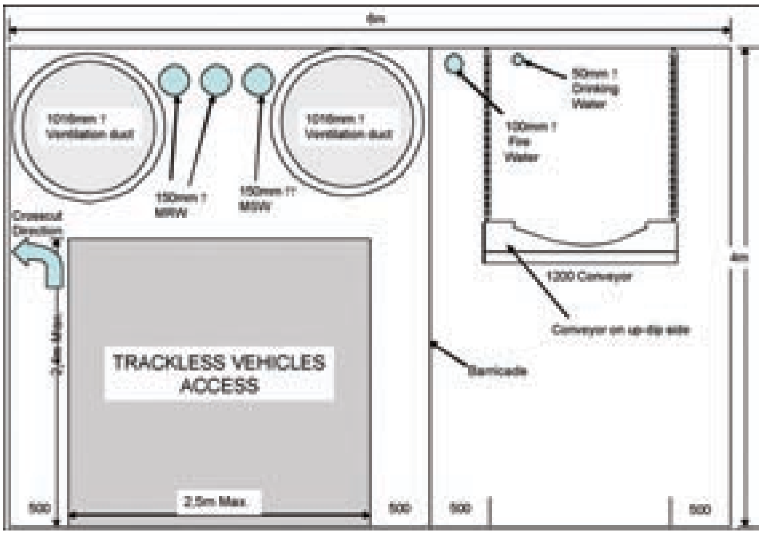


**Figure 2—Schematic layout of decline development**

- ➤ Air velocities of up to 22 m/s may be tolerated in unequipped shafts—particularly in instances where they have been raise-bored.
- ➤ Vertical shafts are shorter than inclined airways and therefore for equivalent frictional losses, they are more aerodynamically efficient.
- ➤ Use of declines for equipment such as conveyor belts and chairlifts limit the capacity of the excavations. For conveyor belts a maximum velocity of between 3.0 m/s and 5.0 m/s is recommended (for an airflow contrary to the conveyor's operational direction) while the air velocity in chairlift excavations is limited to 6.0 m/s. Furthermore, due to the fire risk posed by conveyor belts, there an increasing reluctance to use excavations containing this equipment as a main intake airway.

Therefore, although the concept of surface or sub-surface decline systems may offer a number of opportunities, the potential limitations that these might impose on the ventilation system capacity must be recognized and considered accordingly. At present the capacity of surface decline cluster is increased by positioning vertical raise-bored holes that can 'inject' high velocity fresh air from surface to strategically advantageous positions in the mine's intake airway system.

A last remark in terms of ventilation requirements is needed at this point. Although the criteria and parameters discussed previously give adequate indications of the airflow requirements, the sequential use of air will assist in limiting the airflow. This 'optimization' may be possible particularly in breast stoping environments where there is very limited or no use of diesel-powered vehicles. In well-ventilated room-and-pillar sections where the relative vehicle power to tons to air ratio is low, reuse of air may be possible as long as the air quality entering the last working place in the series is within acceptable standards. Breast stopes may also be ventilated sequentially if these are developed in regular grid pattern.

The ability of ventilating working places sequentially maximizes the utilization of fresh air but has its limitations. In fact the limiting factor in many instances proves to be high wet bulb temperature increase experienced as the air absorbs heat energy in working places further downstream.

## Considerations relating to heat loads

Another question that the ventilation engineer is often asked is, 'When will refrigeration be required?' The answer depends on a number of variables that include the mean rock breaking depth, production rate, strike distance over which operations take place (linked to the ambient rock temperature), the equipment operating in the mine and the criterion used to determine the acceptability of the environment, to name the more significant ones.

Currently the air wet bulb temperature is the thermal property that is used to define the acceptability criterion for ambient conditions in the occupational environment. However, there is a growing support to use the concept of air cooling power as a more adequate indication of the working environment's ability to provide the necessary cooling capacity. Presently there are two shortcomings preventing the wide-scale use of the air cooling power concept as a criterion:

- ➤ air cooling power is not readily measurable at the working place and, more importantly,
- ➤ scientific verification of a data-set that would validate the acceptability of such a criterion has not been performed.

It is for these reasons that a wet bulb temperature varying between 26.5°C and 28.5°C (depending on the operation) and termed 'reject wet-bulb temperature' is used as the design criterion. Figure 3 demonstrates the versatility of the air cooling power concept in defining 'equivalent environments'.

Figure 3 shows that an air stream at a wet bulb temperature of 29.0°C and an air velocity of 1.2 m/s has an air cooling power of 300 W/$m^2$. This is equivalent to another air stream at 27.4°C wet bulb temperature at an air speed of 0.6 m/s. The concept forms the basis of the differentiated face air velocity criteria demonstrated earlier in Table I above and allows greater latitude for the introduction of air cooling —particularly in borderline situations

The geophysical properties of formations constituting the Bushveld Igneous Complex (BIC) are such that the temperature gradient increase with depth is twice as severe as in the West Wits Basin. This is depicted in broad terms by Figure 4. The graph indicates the variation of virgin rock temperature with depth and also shows that 'milestone' rock

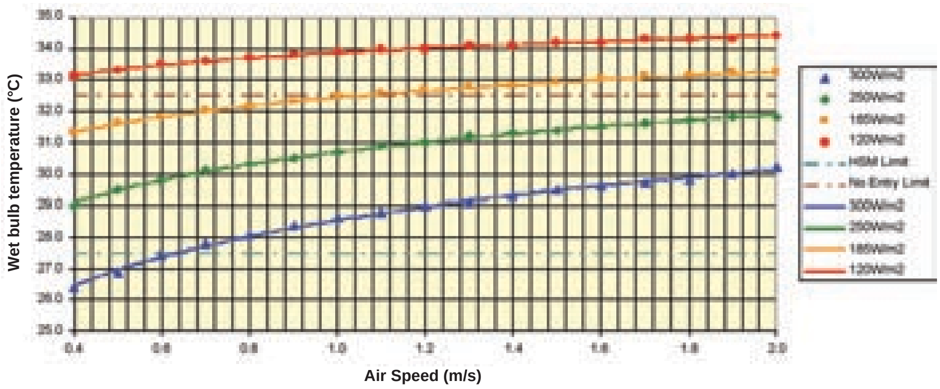


Figure 3—Equivalence of air cooling power

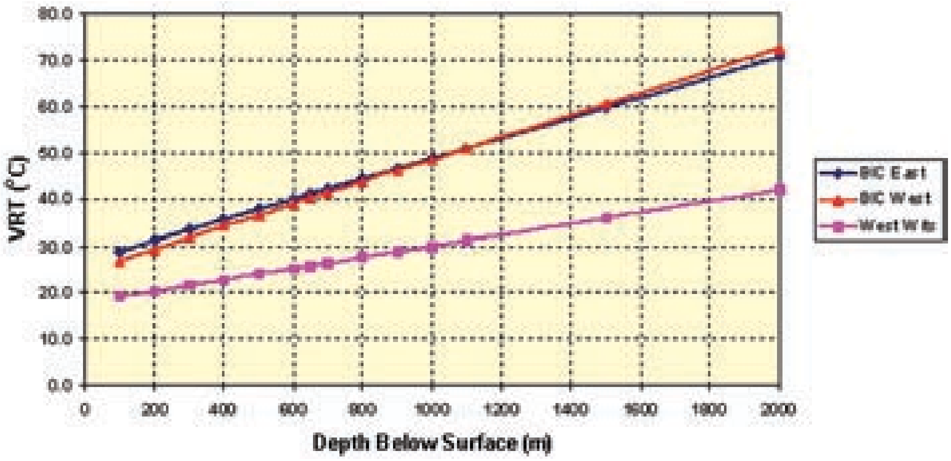


Figure 4—Virgin rock temperature variation

temperatures in the BIC are reached at much shallower depths than in the West Wits Basin. Therefore, in the BIC a virgin rock temperature of 40.0°C will be reached at an approximate depth of 650 m as compared to a depth of about 1 800 m in the West Wits Basin.

Another observation in relation to Figure 4 is that the trends shown are generic and that actual profiles will vary from site to site in relation to geophysical properties of overlying rock structures. In addition, the presence of hills and mountains close to the surface will increase the effective temperature gradient as a function of 'depth below surface' irrespective of wherever surface might be. This effective increase is not directly proportional to the height of the hill or mountain but effectively decreases significantly with the depth below collar at which 'milestone' temperatures are encountered.

The virgin rock temperature and the geophysical properties of the host rock in the design of a ventilation system determines the surface temperature of the rock exposed to the airflow. This in turn establishes the heat energy flux form the rock into the cooler air and results in the increase of the air temperature of the airstream.

Computerized modelling of the mine using software packages such as VUMA and ENVIRON 2.5 assists designers in determining the aerodynamic and the 'thermodynamic' performance of the system.

These tools are used to:

- Generate a balanced airflow model of the mine to ensure that airflow patterns meet the distribution determined by the application of the design criteria
- Determine the fan performance characteristics to verify fan operating points, and the need for main booster fans
- Optimize the location and dimensions of main airways.
- Determine heat load and temperature variations throughout the mine to verify compliance with design criteria (be these in terms of reject wet bulb temperature or air cooling power)
- Determine the capacity and position of primary, secondary and tertiary air coolers
- Provide an indication of the overall cooling system extent, capacity and performance.

All the data gathered from these simulations are collated into a set of performance specifications that are used in the selection of equipment, optimization of the chilled water distribution system and the positioning and selection of the refrigeration plants. Other software packages such as Coolflow may be used in conjunction with these to assist in this process.

All this software simulates steady-state conditions and is deemed to be adequate for the purpose of defining performance parameters. However, in hot environments the effect of transient conditions has to be considered as a function of the geophysical properties of the host rock.

The thermodynamic properties of the BIC rock mass being mined (mostly norite) are such that the rock will cool more rapidly than quartzite (representative of the West Wits Basin) and will find equilibrium at a sensibly lower surface temperature. This will result in a lower energy flux per unit tunnel length for the same virgin rock temperature and the same air temperature, as shown in Figure 5. The figure shows the theoretical heat flux variation over a period of ninety days after exposing a section of the tunnel to an airstream having a constant dry bulb temperature of 30.0°C. It is stressed that the results shown here are approximate and indicative but that they point to the fact that the heat flux in norites is considerably lower. The figure also indicates the limited effect that tunnel insulation (100 mm thick and with a conductivity of 0.1 W/m2/K) would have in reducing the heat flux and that indeed norites are better off than the best insulated tunnel excavated in quartzite.

The following points are noted from the above and Figure 5:

- The heat flux in the first three to four hours after the blast is extremely high, resulting in high temperatures during re-entry and at the beginning of the cleaning shift
- Although in terms of 'average conditions', temperatures may appear to be acceptable, on re-entry and during cleaning operations conditions at the face are likely to exceed acceptability criteria
- The use of diesel-powered vehicles during cleaning operations will aggravate the situation further
- The use of tertiary cooling (at the face) together with extensive use of chilled service water (water jetting) will assist in cooling the excavation, the ambient air and the blasted rock relatively quickly and reduce the heat flux at a rate greater than that induced by the air flow alone
- Design of the cooling system in terms of equipment and capacity must cater for high demand peaks to handle this additional load profile.

The foregoing comments briefly highlight the challenges presented both in terms of design and operational issues that will arise with deeper operations. The findings also point out the usefulness of software currently available in arriving at these conclusions. It is stressed that the results are very site specific and that, as with many other types of modelling, the validity of the results is dependent on the quality of the input data. Also it is noted that the results obtained from a steady-state analysis of the system are suitable for system design purposes but that transient conditions may differ significantly from the average. Designers must be aware of these pitfalls and adapt systems to cater for transient demands.

The usefulness of software simulations is highlighted in terms of the speed with which alternative designs may be evaluated and the data that may be obtained detailed as well as from 'first order' analyses. Figure 6 shows the variation of cooling load as a function of virgin rock temperature (VRT) for a number of reject wet bulb temperatures. This analysis is typically performed at prefeasibility and feasibility level to assess the extent of the cooling requirements. The results shown in Figure 6 are for a deep level platinum project in the BIC. The results are once more very site specific and depend on the production rate, strike extent and mine methods, among the most relevant parameters.

Figure 7 demonstrates further how software simulations may be used in the analysis of different mining methods. The graph shows the variation of heat load as a function of depth below surface for a set of different mining methods. The heat load is 'normalized' by the tonnage produced at different depths—which in this case would represent mean rock breaking depth. The mining methods analysed as part of this work were variations of breast stoping operations with different ore transport and access strategies and different cooling system applications. The noteworthy aspect of this analysis is the comparison of the two 'I series alternatives'. These options are identical except that the 'D' option utilizes diesel powered vehicles while the 'E' option has a corresponding fleet of electrically powered vehicles.

The difference in the heat loads between the two options is appreciable and it is shown in relation to the overall heat load that comprises the effect of the rock mass temperature, depth, extent and auto-compression of the air in circulation. Although the use of electrically powered machinery offers distinct advantages in that it will translate into lower cooling plant costs, these have to be offset against the higher cost of the electrical vehicles, higher infrastructure costs and ease of operation (trailing cables, battery recharging).

This example demonstrates that trade-off studies involving aspects relating to the underground environment may be undertaken with relative ease and will yield results within the required degree of confidence in order to enhance the validity of the comparison.

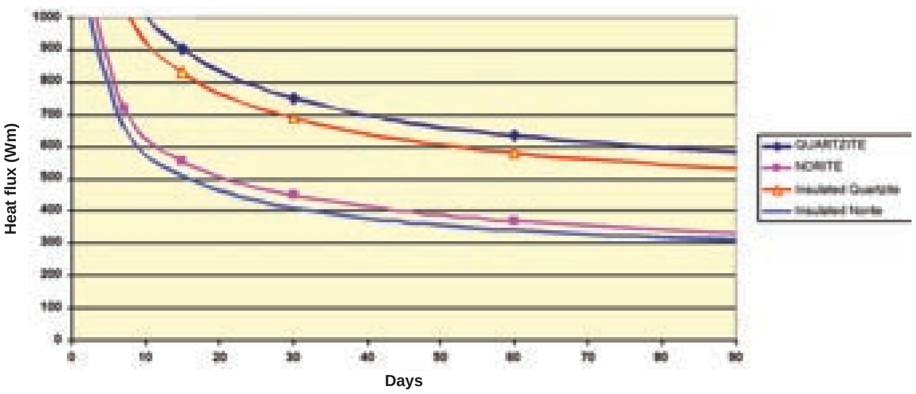


**Figure 5—Comparison of heat flux variation as a function of time**

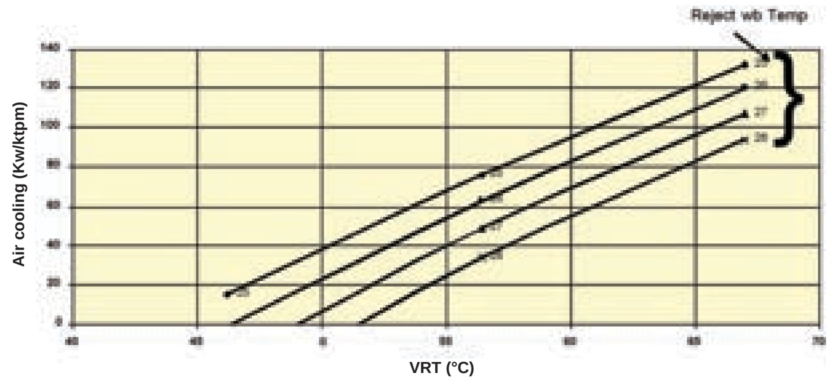


**Figure 6—Air cooling variation as a function of VRT and design reject wet bulb temperature**

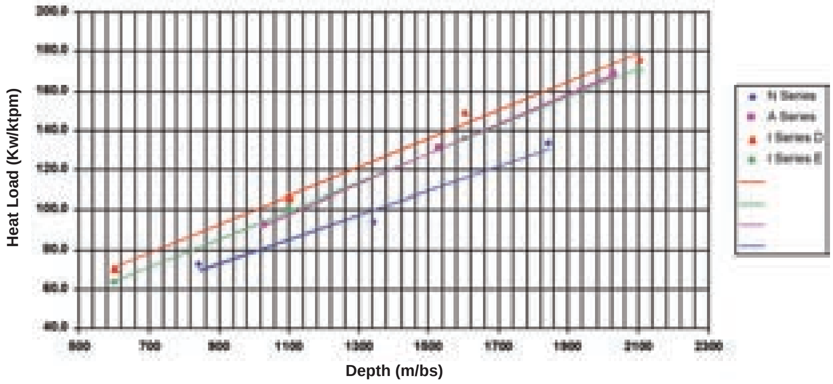


**Figure 7—Heat load variation as a function of VRT for different mining methods**

## Aspects of health and safety

As stated previously, the objective of any ventilation system is the provision of safe and healthy conditions within the working environment. In this section certain aspects environmental health and safety relating to modern platinum mining requirements will be highlighted.

### *Choice of power plant*

The comparison outlined above highlights one aspect of the many dilemmas facing modern mine designers: diesel or electric mining equipment? Part of the answer was given and, in terms of the ‘bigger picture’, the choice of diesel-powered equipment for the options described by Figure 7 may be the correct one.

However, it is a fact that, excluding the case where thermodynamic work is done (as for example where a loaded truck hauls ore up a ramp) diesel-powered vehicles will produce three times more energy as heat energy discharges to the surroundings as is drawn mechanically by the engine. In the case of an electrically powered unit, the heat energy emission is equal to the energy drawn by the motor.

Another aspect that has to be considered is the fresh air dilution that must be provided to minimize the adverse effect of diesel exhaust fumes. The dilution factors will dictate primarily the air quantity required in sections where diesel-powered vehicles are operated—as was mentioned earlier in this paper. In the case of highly mechanized operations, vehicle operation may be seriously hampered by limited fresh air quantity availability. In addition, the nature of operations is such that maximum dilution will be required in ends being mucked where poor ventilation conditions and accumulation of exhaust fumes, particulate and hot air are more likely.

The dilution factors are selected in terms of best practice and are in general not regulated in terms of the Mines Health and Safety Act. The dilution factor mostly applied is 0.06 $m^3/s$ of fresh air arriving at the point of application for every kilowatt of rated diesel power operational in the working place. In general, this represents a minimum applied by the industry and assumes that a number of other protective measures are in place:

- Latest generation (at least Euro IV) engines are in use
- Catalytic converters are installed as part of the vehicles’ exhaust systems
- Particulate filters are used and maintained properly and regularly
- Low emission diesel fuel is used
- All vehicles are maintained regularly by suitably qualified and equipped staff.

Without these ‘additional’ measures, the required dilution factor would increase to 0.08 $m^3/s/kW$ and up to 0.12 $m^3/s/kW$ thus requiring more extensive ventilation systems, which will complicate mining operations as demonstrated previously.

### *Underground fires*

The danger posed by fire is another aspect of large-scale mechanization in mining operations. Fire is a constant hazard wherever large sources of energy are stored and used, as is the case in mining machinery. The outbreak of a sudden, highly intense fire underground has the potential for catastrophic outcomes and must be avoided at all costs.

The combination of combustible materials such as hydraulic oils and rubber tyres in the vicinity of hot surfaces has to be managed continuously and safely wherever vehicles operate. The fire risk posed by diesel-powered machinery is further intensified by the presence of diesel fuel, which may participate in the combustion process and increase the intensity of the heat, smoke and gas emissions in the event of a fire.

A further dimension to the risk in terms of using diesel power underground is found in the large-scale transport and distribution of the fuel as part of routine operations. The storage of fuel underground requires awareness in terms of a thorough risk assessment and the adoption of protective and preventative measures to limit the fire risk.

The large-scale use of conveyor belts also presents a significant risk for the rapid development of underground fires. The flow of fresh air over conveyor belts provides a continuous source of oxygen that may cause the fire to become self-sustaining under certain circumstances. In addition, the location of conveyor belts in intake airways provides the potential for large-scale contamination of the mine's atmosphere.

These hazards are managed effectively by the analysis of various risk scenarios and the implementation of protective and preventative measures devised in accordance with such analyses:

- ➤ Issue-based risk assessments are essential to identify practices and situations that require specific intervention
- ➤ The prevention of fires through the adoption of adequate design, equipment, procedures, maintenance and inspections is an essential aspect of this process.
- ➤ Routing of fresh air away from high risk areas (conveyor belts, underground rubber tyre, fuel and oil storage areas, etc.) will limit air contamination during a fire.
- ➤ The identification of high risk areas by management and workers will highlight the presence of the hazard and provide the necessary awareness
- ➤ The provision of early detection systems, action protocols and firefighting procedures is essential in limiting the spread of a fire. This includes the remote monitoring of the air flowing through high risk areas, the provision of adequate and back-up communication systems and protocols, the provision of effective fire-fighting equipment (e.g. on-board automatic and manual fire suppression systems; fire hoses at strategic position within the high risk areas; automatic sprinkler/water deluge systems; etc.) In addition and more importantly, adequate training of key personnel such as operators, supervisors, etc. in fighting fires safely using the equipment at their disposal is essential in preventing the degeneration of a small fire into a major catastrophe
- ➤ The timely provision of protective measures and the training of workers in the use of protective equipment is the last component of the strategy. Of particular importance are systems designed to provide respirable atmosphere to workers who are affected by the smoke and gases emanating from the fire and who may not be able to reach a point in fresh air. These measures typically include the provision of self-contained self-rescuers and the location of adequately equipped refuge bays at strategic positions that may be reached by workers using self-rescue devices
- ➤ Adequate awareness and training are essential in providing adequate and timely response as soon as the fire is detected.

## Conclusions

This paper has provided a brief overview of the 'ventilation perspective' on future challenges facing the expansion of platinum mining operations. The space and time at one's disposal make it difficult to provide a justly extensive coverage of the many facets of this subject. The authors have provided an insight on the more important aspects.

The most significant aspect is that the solutions to these challenges are well within reach of technologies currently at the disposal of designers. Having said this, the importance of integrating the ventilation system design as a fully fledged component of the overall mine design is emphasized.

Maximizing the use of the infrastructure to convey air to the various working places at different stages of the life of the mine is likely to reduce costs. The integration of ventilation requirements in the planning of primary development and production methods has been highlighted in the paper. Ventilation systems designed as 'afterthoughts' are likely to provide the required outcome but at a considerable additional cost—both measured in terms of time and money. The impact of inefficiencies on operational costs seen against the backdrop of ever increasing power costs is going to hamper future profitability considerably. In shallow operations where the metallurgical process is off the mine site, the cost of electrical power for ventilation systems is likely to rank second only to that of ore transport.

The 'modular' design approach to new operations and to extensions of existing ones provides opportunities to devise a ventilation infrastructure to a large extent also modular in nature. It is important, however, not to lose sight of the 'final' picture so that adequate capacity is incorporated to avoid delays or becoming an excessive burden on the financial viability of the project.

The paper has also shown the value of using computer modelling for the generation of comparative tools that are essential for the preliminary as well as for the detailed phases of the project. The software provides a basis for more sophisticated analysis of costs and facilitates the completion of trade-off studies.

Cooling strategies pioneered in the gold mining sector serve as a useful basis for aspects of future ventilation planning. However, the adaptation and expansion of this knowledge to meet requirements particular to platinum mine operations has already been undertaken by designers and equipment manufacturers alike.

The challenge remains the provision of a healthy and safe working environment that is effective and cost-efficient and that is adequate for all facets of mining operations from the initial establishment to closure of operations.

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