Adding value to underground mine ventilation designs by using cost-based models

B.K. Belle, AA plc

Abstract

The beginning of 21st century has heralded the global strategic importance of energy among the nations and business enterprises, as evidenced by increase in energy prices and energy generation-emission-utilisation dilemmas. The generation of energy results in by-products called "green house gases" (GHGs) causing global warming. Good business practice and legislation, such as the Kyoto Protocol (1997) and the South African National Energy Efficiency Accord (2005), have put the onus on future-minded companies to make a positive response to climate change and their effect on the environment.

Traditional energy-intensive underground mine ventilation designs are being challenged by ever more stringent health, safety, energy and economic issues. Over the years, 'air factors' have been used to estimate air requirements for a new mine. These have been based on heat loads, gas and dust levels, diesel emissions, mining method, and production rates. Deep level mining, increasing power costs and pressure from shareholders to obtain high rates of returns require effective, and economic use of air through more innovative practices in mine ventilation design.

For example, control of dust from mining operations can require between 5% and 30% of the total mine air quantity. The paper demonstrates 'value addition' through an approach to underground mine ventilation design using spreadsheet-based models. A sample exercise for a diamond mine is demonstrated that could result in combined cost savings of over $17 million over the life of mine by choosing appropriate control techniques and the secondary benefits of energy reduction and carbon credits. It is foreseen that the developed cost models and the philosophies can be applied to the ventilation planning of other underground mines (example, gold, coal, platinum) for cost estimation as well as improved utilisation of air. The model can accommodate additional variables such as depth, fan pressure, fan efficiency, life of mine, ambient gaseous pollutants etc., and can be used as an effective tool in estimating the cost of environment control for an individual mine.

1. Introduction

The beginning of 21st century has heralded the global strategic importance of energy among the nations and business enterprises, as evidenced by increase in energy prices and energy generation-emission-utilisation dilemmas. The generation of energy results in by-products called "green house gases" (GHGs) causing global warming. Good business practice and legislation, such as the Kyoto Protocol (1997) and the South African National Energy Efficiency Accord (2005), have put the onus on future- minded companies to make a positive response to climate change and their effect on the environment.

Traditional energy-intensive underground mine ventilation designs are being increasingly challenged by ever more stringent health and safety issues, energy and economics of mine exploitation. This has necessitated the need for new philosophies in mine ventilation design. Over the years, 'air factors' have been used in estimating the fresh air quantity requirement for a new mine. These have been based on heat loads, gas and dust levels, diesel particulate matter (DPM), mining method, and production rates. Deep level mining, increasing power costs/energy efficiency and pressure from shareholders to obtain high rates of returns require effective, efficient and economic use of mine air through more innovative practices in mine ventilation design.

Developments in technology and new thinking have forced the mine ventilation fraternity to review the existing practices to establish the ventilation requirements for a new mine. Dust is one of the health hazards resulting from processes such as blasting, drilling, cutting, crushing, tipping, and hauling which require a significant portion (from 5% to 30%) of the overall mine ventilation quantity. The cost of providing ventilation air to a mine increases as the cube of the air quantity (power cost μ quantity^3). In certain mining conditions, the generation of dust is an order of magnitude higher than others, for example, diamond mining. This paper describes the use of a spreadsheet-based model that can be used to financially evaluate different control philosophies. A case study of diamond mine ventilation design with specific reference to a dust control philosophy in the light of carbon credits is presented. Cost models of this philosophy in units of Rand/m^3/s of ventilating air have been developed and can be adapted to all mining types viz., coal, gold, base, diamond and platinum. Application of this philosophy in new mine ventilation designs (e.g., gold, platinum, base, and coal mines) is also discussed in the paper.

2. Philosophies in mine ventilation planning

Dust is one of the parameters used in the overall ventilation planning of a new mine amongst others. The method of dust control impacts on the overall ventilation planning of a mine and the methods of dust control must be clearly defined and understood in the early stages of mine ventilation design. The dust control options considered could greatly influence the health and safety of the workforce, the general mining environment and the overall cost of the project. There are two distinct technical options available and practiced in the industry:

- Extract the generated dust from the given operation and discharge the dust laden air into the mine return airways (RAW), therefore requiring more air to be brought into and extracted out of the mine or
- Extract the dust from the given operation and filter or clean the dust-laden air via a suitable mechanism and then re-use the clean filtered air.

There are limited case-specific studies to validate the total cost of discarding air versus the cost of dust filtering and re-use. In order to make a qualitative decision on the choice of the above philosophies in underground mine ventilation designs, cost models have been developed and their application for a diamond mine has been discussed below.

3. Environmental control philosophy in diamond mines

Kimberlite dust is the by-product of comminution processes involved in diamond mining operations. Due to the physical nature of the Kimberlite ore (hygroscopic nature) coupled with the very high run-of-mine (ROM) production rates (from 5 to 8 million tons per annum), the amount of dust generated at the various mining operations is extremely high. Typical high-level dust generating sources in a diamond mine are draw points, loading haulage, tipping area, crushing area, and blasting sites. Respirable and total dust measurements in the diamond mines have indicated that the dust levels are an order of magnitude higher than other mining types such as gold, platinum and coal. For example it was reported that at Wesselton mine up to 100 tons of dust per shift was extracted (Dochat, 1989). Tipping and crushing systems can produce dust loads ranging from 10 to 50 g/m^3 of total dust in the air (Guthrie, 2003). Failure to extract this dust from the dust-generating source would be of safety and health risk. Not only would the visibility be greatly hindered, but also large amount of nuisance and respirable dust would cover everything in a short period and require cleanup operations. This ongoing cleanup could be dangerous to worker health as well.

In many of the existing diamond mine operations, the ventilation designs recommended the extraction of the dust-laden air at various dust generating sources and the transferring of the dusty air into the mine RAWs. This approach to dust control in diamond mines has been practiced by mines, due to a lack of quantification of ventilation costs of rejecting the air and the perceived high maintenance requirements of dust filtration systems.

3.1 Discarding the dusty air

The current practice of discarding the dusty air involves extracting the dust from the specific dust generating operations by means of a fan and suitably designed duct extraction system and rejection of this dust-laden air into the mine RAWs. This system requires the regular and systematic cleaning of the RAWs. This is a difficult, dirty and costly job that can cause major dust problems downstream of the dust disposal operations. The most significant impact of this dust control philosophy is the loss of ventilating air to the mine system that could otherwise be used for the ventilation of mining operations and mine development systems.

In a large diamond mine operation, the amount of air used for dust control at various sources can amount to ±300 m^3/s. The cost of this air can be significant when considering the main fan power input, the shaft size, and the potential for mine airways to be larger than normal to accommodate the required airflow.

3.2 Filtering and re-use of air

In the filtration dust control model, dust laden air is extracted from the specific dust generating operations by means of a suitably designed hood and duct system and then filtered or scrubbed, and re-introduced into the mine ventilation system for re-use. There are various types of dust control systems that exist for use underground, viz., dust suppression and dust extraction. Dust suppression is through the use of single-phase sprays (water alone), two-phase sprays (water and compressed air), or spray systems incorporating surfactants or additives. Kimberlite dust has an affinity for water unlike other dust types (example, coal dust) and therefore, the benefit of adding surfactants to water sprays for suppressing Kimberlite dust is minimal. An effective dust suppression system requires constant water pressure, enclosure of the dust source, continuous monitoring of nozzles and their configuration to prevent blockage and damage. Dust extraction and filtration systems use the principle of enclosing the dust-generating source (negative pressure) and extracting the dirty air using a fan and passing it through a filtration system (dry or wet) resulting in the dirty air being cleaned.

In Kimberlite mining operations, some of the dust suppression techniques include water sprays in development drilling and water sprays in long-hole-fan drilling. Currently, in order to alleviate the problems associated with the use of water in drilling operations, dry drilling extraction systems are common. In this technique, dust generated during the drilling process is captured (extracted) at the collar of the drill hole, and is passed to a filtering and disposal system.

Dust extraction (filtration) systems require fan power to launder the dusty air and excavations to position the dust plants (filtration or scrubbing units). The operating costs of these filtration systems are dependent on the pressure drop (normally ± 1.5 kPa) across the unit. The pressure drop for wet scrubbing is usually higher than for dry types of filtration systems. Each wet scrubbing unit requires clean service water to wash and scrub the dust-laden air. The capture of the dust produces slurry that must be pumped back to the pump stations for final discharge into the settlers and eventual pumping to surface in a mud form. The water removed from the slurry during clarification in the settlers is returned to the service water system for re-use.

In the case of dry filtration (bag or cartridge) systems, filters are used to capture the dust-laden air. In order to keep the filters from clogging up, reverse pulse cleaning of these filters is used (manual cleaning is also an option) and requires compressed air that is moisture free and at a suitably high pressure. The dry captured dust can be carried pneumatically or in a pellet form into the mine ground handling system or can be converted to a slurry form by using water and pumped back to the settlers as in the case of wet scrubbing situations.

4. Cost estimation models for dust control and dust disposal

In order to quantify the benefits of discarding air versus filtration and re-use of air, a cost estimating model has been developed. The unique feature of the model is that every cost component of the dust control philosophy is expressed in terms of Rand per m^3/s of fresh air. The cost model includes adequate maintenance factors for each system. For each system evaluated, the capital cost includes the electrical instrumentation (10%), installation (15%) and transport (10%). The model can accommodate user defined percentage costs for the above parameters.

4.1 Cost of discarding the air

The cost element of discarding the air has three major components, viz., discard of dust-laden air to RAWs; dust extraction system and dust cleanout in the RAWs. Each individual element is discussed briefly below.

4.1.1 Cost of additional supply and rejection of dust-laden air to return

The cost of discarding the air has following components:

- Incremental mining cost of the shafts to handle the additional intake and the discarded air
- Internal intake airway cost for additional air
- Internal return airway cost for discarded air
- Cost of transferring the additional fresh air through the downcast shaft
- Cost of handling the additional return air via the up cast shaft
- Cost of main fan input power to move the additional air through the mine
- Incremental capital cost of the larger main fan required to move the additional air.

4.1.2 Cost of dust extraction

The cost of the dust extraction systems at the dust generating sources (tip and or crusher) has the following components:

- Cost of the auxiliary fan power to extract the air from the dust source to the RAW
- Cost of building walls in the RAW
- Dust extraction ducting cost
- Auxiliary fan and subsequent replacement costs.

4.1.3 Cost of dust cleanup costs in the RAW

The cost of cleaning the dust settled in the RAW has following components:

- Capital excavation cost of dropout zone (excavation in the RAW to handle the deposited dust)
- LHD as equivalent cost (including operator) per annum for cleaning the dropout zone.

4.2 Cost of air filtration and re-use

There are various methods to filter Kimberlite dust underground. Some of them have been tried in the past and found to require dedicated maintenance. However, there is little documented proof of the dust control systems and their failure, as these systems are found to be working efficiently in various other mines such as coal, gold, and platinum. A probable reason for this could be attributed to inadequate provision in terms of labour and maintenance. Based on past experiences of the various available dust filtering units, the following systems are considered for the cost model. In principle the following major type of dust filtering systems are available: dry dust plants (bag or cartridge), and wet scrubbing systems.

Cost components of the dust extraction (dry or wet, bag or cartridge) systems included in the model are, excavation cost (R/m^3), cost of extraction systems, cost of extraction ducting, filter element replacement cost, dust plant fan power cost, compressed air supply cost, compressed air and water reticulation pipe cost, fan power cost, station pump costs, station slurry disposal costs, station slurry pipe costs, sludge tank and mixer costs, maintenance labour cost, screw conveyor costs, rotary valve costs, and the cost of water.

5. Cost model results for hypothetical diamond mine ventilation/dust control design

The application of the philosophy and the cost model is demonstrated in a sample diamond mine and the parameters considered in the ventilation design are summarised in Table 1. All the calculations are based on the present values (real terms).

Table 1: Summary of ventilation design parameters of a sample diamond mine

Number of tipping units (undercut, extraction, conveyor levels)	#	24
Average air quantity at a tip	m³/sec	5
Number of crusher units (minimum 4 and maximum 6)	#	6
Average air quantity at a crusher	m³/sec	30
Total filtration air quantity at the operations	m³/sec	300
Dust load at typical operations (tip, crusher etc.,)	g/m³	40
Main fan pressure	kPa	4.50
Main fan efficiency	%	75
Auxiliary fan pressure	kPa	1.50
Auxiliary fan efficiency	%	65
Downcast shaft air velocity	m/s	10
Upcast shaft air velocity	m/s	20
Depth (length) of the shaft	m	1064
Height x Width x Length of clean-out zone	m x m x m	4.5 x 4.5 x 20
Process operating time-Tipping	hrs/day	2
Process operating time-Crushing	hrs/day	19
Process operation days per month	days/month	29
Life of Mine (LOM) in years	#	18
Interest rate	%	13

(1 Dollar = 6.80 Rands)

The operating cost, capital cost and total owning cost of discarding air and various dust filtration systems for a cubic meter of air (Rand/m³/s) is determined using the cost model.

5.1. Discarding the air versus re-use of cleaned air

Figure 1 shows the plot of cost comparisons (life-of-mine) of discarding the air versus re-use of cleaned air (approximately 260 m³/s) in a sample diamond mine. This includes dust control systems at crusher level, tips at the undercut and extraction level, belt transfer points at the conveyor level. The cost comparisons of the systems in the plot for a dust extraction quantity of 260 m³/s are discarding the air and filtration of air viz., dry cartridge filtration system, dynamic wet scrubbing system (Type A) and venturi type wet scrubbing system (Type B).

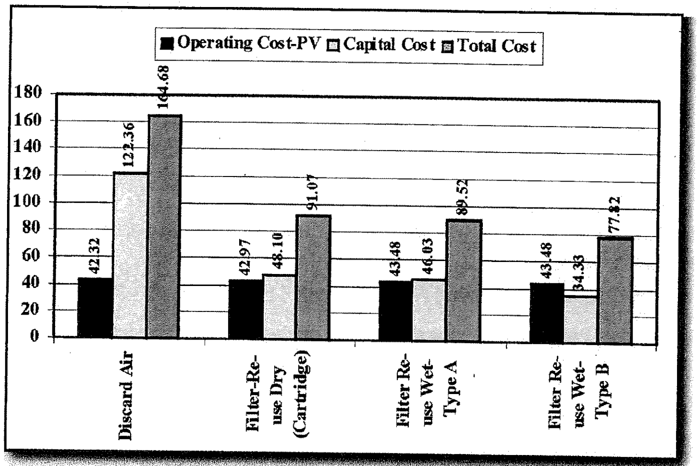

Figure 1: Summary of various costs for the identified dust control options

From the above figure, it is noted that there is a significant cost difference between discarding the air and the re-use of cleaned air by dust extraction systems. Figure 2 shows the relationship between capital costs and air quantities for various options. This difference becomes more pronounced for air quantities greater than 50 m³/s. An increase in ratio for capital costs between discarding the air and filtered air for air quantities greater than 50 m³/s can be attributed to the cost of shafts and airways infrastructure. Similarly, there is a slight cost difference between the dry and wet dust extraction systems due to the size and increased pressure drop between the extraction systems.

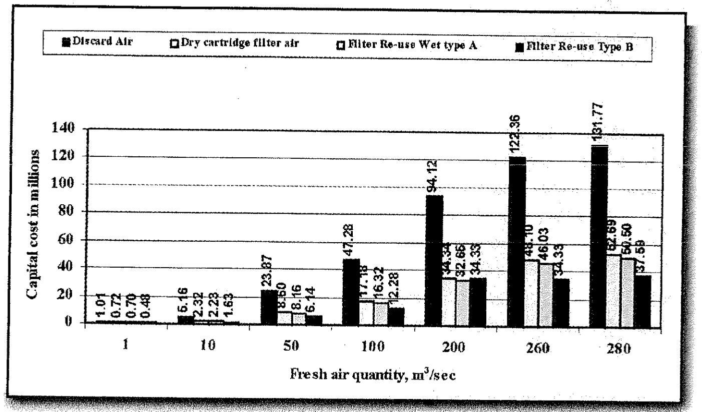

Figure 2: Relationship between capital costs and air quantities

5.2 Estimated carbon savings

The generation of energy results in by-products called "green house gases" (GHGs) causing global warming. Therefore, every user must ensure efficient and effective energy use through technical and administrative means referred to generally as energy savings. This has resulted in a twofold strategic benefit for increasing the efficiency with which energy is used, viz., by lowering the amount and, therefore, costs associated with the use of energy and, reducing the emissions resultant from electricity generation and the then creation of carbon credits via the Clean Development Mechanism (CDM). The secondary financial benefit envisaged from this example (Figure 3) is the expected generation of carbon credits with a monetary value. The carbon revenue is calculated using the following formula:

Carbon revenue ($/yr) = carbon credits (tonnes/yr) × carbon price ($/tonne)

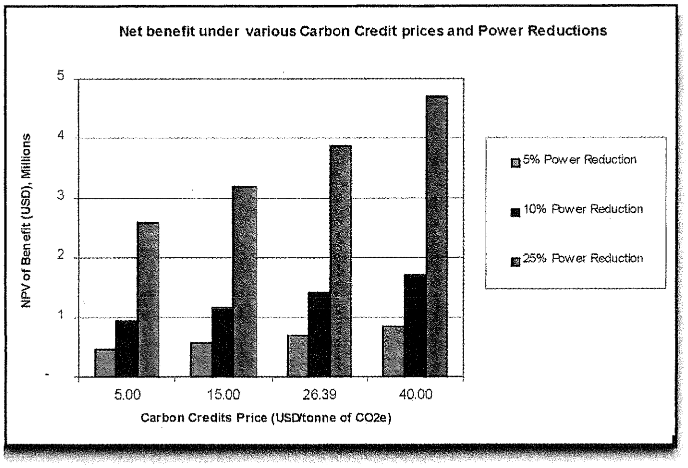

Figure 3: Summary of energy saving benefits through carbon credits

Annual carbon credits are calculated by deducting actual emissions from baseline emissions. The estimation of carbon-dioxide equivalent was obtained from available ESKPM sources (namely average emissions: 0.85 kg CO2/kWh, maximum emissions: 1.08 kg CO2/kWh and minimum emissions: 0.84 kg CO2/kWh). International debates such as the Kyoto protocol have had a large impact on the carbon credits price. Figure 3 shows the estimated carbon savings by the re-use of air philosophy for an air quantity of 260 m^3/s at 4.0 kPa amounting to 28% improvements in energy savings. This philosophy would save an estimated 1.04 MW per year of electricity for the project and between 9'679 tonnes of CO2 equivalent each year. Should electricity prices evolve as forecast currently and using an average emission intensity rate of 0.85 kg CO2/kWh, a desired a power reduction of 28% for the mine would cost only the extraction system costs but, over 10 years, would result in a NPV benefit of USD 4.7m (Figure 3) when carbon credits cost around USD 40/tCO2.

Benefits associated with these type of cost models is that with the appropriate identification of technology include a reduction in electricity costs in main fan operation and, following CDM guidelines, the creation of carbon credits due to the decrease in electricity consumption. The combined impact of both the electricity savings and carbon credits generated is significant. The graph below shows the net benefits of the implementation of the re-use of air technology under the various scenarios outlined above and includes the cost savings on decreased electricity usage as well as the benefit of the carbon credits generated.

7. Conclusions

The paper has demonstrated 'value addition' through an approach to underground mine ventilation optimisation using newly developed cost model. The application of the cost models to the ventilation planning of a sample diamond mine indicates a significant combined cost saving (over $17 million) can be realised over the life of the mine by the re-use of the cleaned air produced by a correctly specified dust control system. In summary, the major benefits derived from the underground mine ventilation control optimisation using newly developed cost models are summarised below:

- The model has demonstrated that there are significant advantages in the "re-use" of air by filtering/cleaning the air and disposing the collected dust, compared to discarding the air, thereby having to cater for larger ventilation infrastructure and operating costs of an underground mine through reduced energy consumption and gains in carbon credits.
- It is envisaged that the developed cost model and the assumptions can be applied to the ventilation planning of other underground mines (example, gold, coal, platinum) to improve air utilisation and reduce costs.
- The model can accommodate additional variables such as depth, fan pressure, fan efficiency, life of mine, etc., and can be used as an effective tool in estimating the cost of dust control systems for an individual mine.

It is important to note that the "re-use of air" philosophy in ventilation planning, where noxious and explosive gases are present, must be adequately addressed using appropriate risk assessment. Where such contaminants exist in significant concentrations, re-use of the air should be approached with caution. It is important that the quality of the filtration system selected is of the appropriate standard, to ensure that the re-used air is clean and the maintenance of the systems is minimised.

Acknowledgements

Author is indebted to the management of Anglo Technical Division (ATD), Anglo American Plc., for their support in preparing this paper.

References

Dochat, H., 1989, Finsch Mine, De Beers Consolidated Mines Limited, Unpub. internal Report, SA.

Guthrie, J., 2003, Personal Communication