Diesel Power Vehicles, Pollution, and the Economic Balance Thereof

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ABSTRACT

Our underground environment is valuable to us. With technology improvements and constant advancements made in underground mining methods and systems, pressure is exerted on ventilation and occupational engineering services to maintain and improve the ambient air at the highest standard required for operations thereby improving their productivity and demand for the product.

This paper focuses on the increased use of trackless equipment in South African mines, their benefits, fuel type and usage, and the economic implications of incurred in such operations. A notional mine is used to demonstrate the use of low sulphur fuel, high sulphur fuel, and increased or reduced amounts of air needed to counter the airborne pollutants within the overall system of dilution employed.

1. INTRODUCTION

Mines in South Africa are generally of the conventional type, i.e. drilling blasting, scraping the ore into rock passes, and removal of the broken rock (ore or waste) from the production areas to central shaft ore passes by means of locomotive transport (diesel or electrical).

To give an idea of rock transport, the following systems are described briefly.

(a) Gold Mines:

There are three rock removal systems given, i.e. (a) Conventional narrow reef (80 cm width) orebody where ore is loaded at boxhole positions into locomotive “train type” skips and transported to the central station positions and tipped onto the rock pass leading to the shaft storage bins, (b) Conventional narrow reef orebody where scraper pull the broken rock into dip gullies where an LHD diesel vehicle transports the rock to a central rock pass system or to a conveyor belt leading to the central shaft storage system (hybrid type mining system), and (c) a massive mining operation using a rock caving mining operation where diesel vehicles (combination of LHDs and trucking) are used to transport the broken rock to central crushing or storage systems or onto conveyor belt type systems.

(b) Platinum Mines:

There are basically only two primary rock removal systems given, i.e. (a) Hybrid mining system (updip/downdip mining) where the rock is blasted, scraped into dip gullies, scraped further into a rock pass leading to the haulage, loaded via diesel LHD's from the ground and transported to conveyor belt systems which further transports the rock to the central station positions, tipped onto the rock pass leading to the shaft storage bins, and (b) Fully trackless mining (Board & pillar type mining) where the broken rock is loaded directly via LHDs and transported to a strike conveyor belt. The strike conveyor belt leads to a central conveyor belt system transporting the ore either directly to surface or to a vertical shaft handling facility.

(c) Diamond Mines (underground operation):

There are basically only one primary rock removal systems used, i.e. (a) a fully trackless mining (massive mining – Block cave type) where the broken rock is loaded directly via LHDs in the drift and transported to a waiting truck which transports the rock to the central crusher, generally located close to the vertical rock handling shaft. Other mining methods for underground diamond mines are currently under review, i.e. sub-level caving, incline caving, etc., and the outcome not decided on to date. The LHDs and trucking operations are in some instances fully remote controlled by either the driver standing close to the vehicle or from a central surface control room.

To demonstrate the use of diesel vehicles in our underground diamond mines, a notional mine was used where actual ventilation design principles were used in the determination of vehicles, amounts thereof, diesel fuel, etc., and further described in this paper.

2. MINE DESCRIPTION

In order to facilitate the description of this notional mine, a drawing is given to show the mine plan with levels and infrastructure.

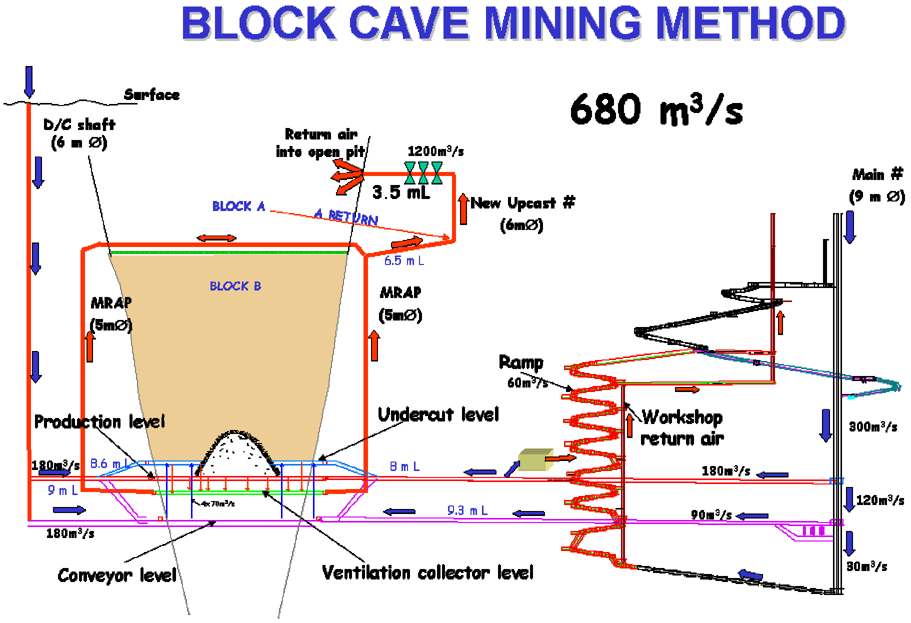

Figure1: Block Cave Mining method showing air directions and infrastructure.

In about 95% of the LHDs and trucks are used on the production level or otherwise known as the extraction level, in this case 88 level. There are four primary levels for this Block Cave mining method, i.e. at the top is the undercut level (LHDs also used here during development and to load swell later in the production cycle), below this is the production level, below this is the ventilation level, and below this is the conveyor level. In some cases can the ventilation level and the conveyor level be on the same elevation as was the case with the block mined above this new block. It all depends on the structure and size of the footprint.

We will focus on the production level as this is where the majority of the trackless equipment operate.

3. TRACKLESS EQUIPMENT AND VENTILATION REQUIREMENTS

The amount of LHDs to be used in the build-up phase (Torro 006) and ultimately in the full production (Torro 007) operation are thirteen (13). The following Table 1 gives some detail of the LHD equipment.

The diesel LHD equipment to be used in this scenario would be:

Engin type: Detroit Diesel; DDEC 6043-GK32, 8.5l Series 50

From an air supply perspective, the diesel dilution factor of 0.06 $m^3/s/kW$ is only valid if the engines use low emission diesel, catalytic purifiers and outlet pipe Diesel Particulate Matter (DPM) filters (where very old equipment is used)

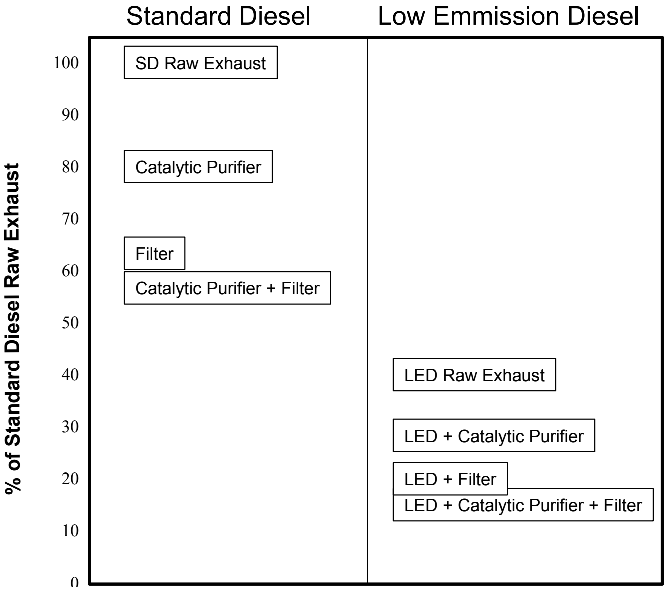

Figure 2: Diesel Particulate Matter dilution requirements

The anticipated legal Occupational Exposure Limit (OEL) requirement for DPM is 1.0 mg/m^3 with the international OEL now set at 0.2 mg/m^3. The economics of using higher "at point of operation" dilution factors to satisfy anything lower than 2.0 mg/m^3 is debatable.

Figure 3: DPM change vs air supply change to diesel vehicles used.

Figure 3 shows the change in dilution air required as the Diesel Particulate Matter (DPM) OEL becomes more stringent. The curve follows an exponential trend and the question should be asked, "Can the industry practically sustain such anticipated change?" Table 1 gives a sample of the data used to construct Figure 3.

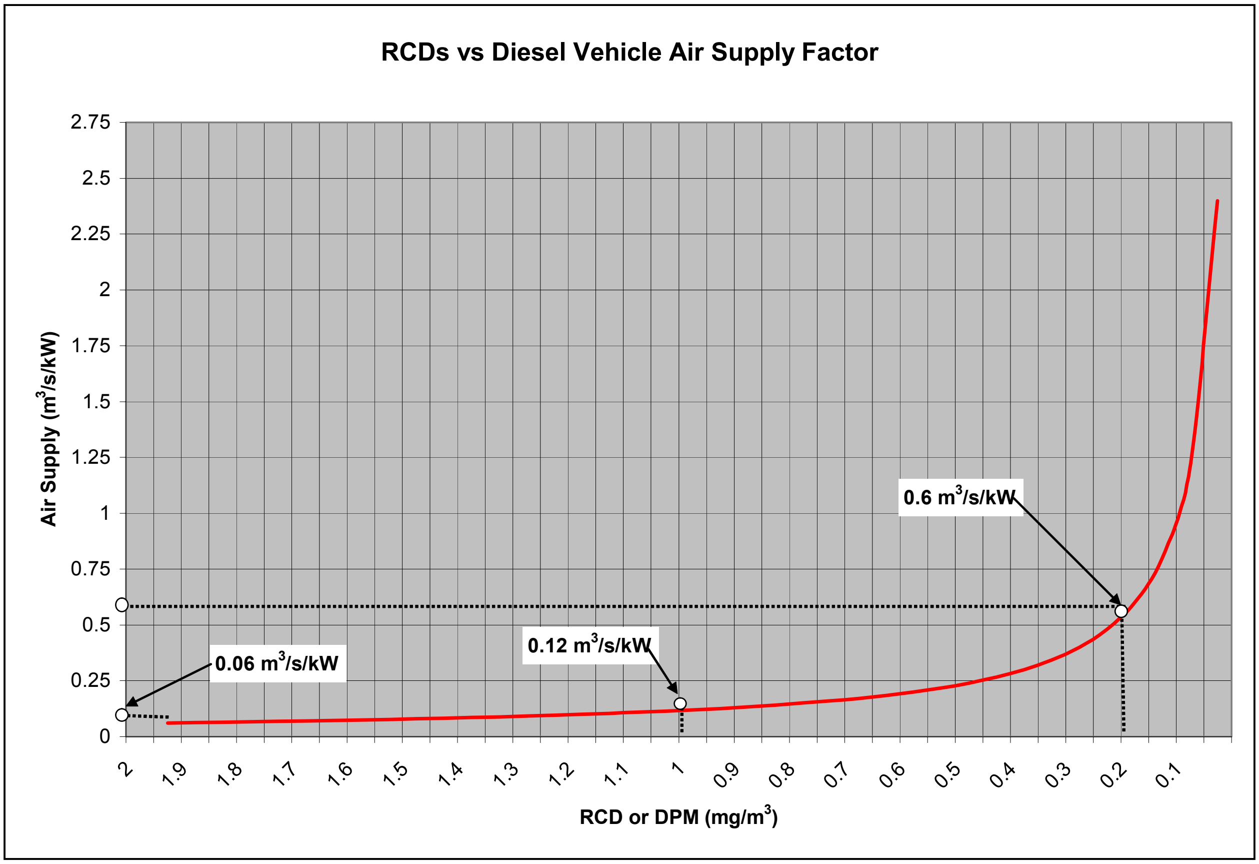

Table 1: Changes in DPM vs an equal change in air supply.

DPM (mg/m^3)	Change in DPM (Factor)	Air Supply (m^3/s/kW)
2.0	0.0	0.06
1.5	1.3	0.08
1.0	2.0	0.12
0.5	4.0	0.24
0.2	10.0	0.60

To satisfy 0.2 mg/m^3 (DPM) the fresh air quantity supply would be very high (0,6 m^3/s/kW) giving 112.2 m^3/s for a 187 kW TORO 007 LHD. To satisfy 1.0 mg/m^3 (RCD) would require 22.4 m^3/s for a 187 kW diesel unit. The 112.2 m^3/s is technically unobtainable in a drift where the dimensions are 4 x 4 m and people are working (7 m/s – out of the design range for velocity where people travel), and the second quantity (22.4 m^3/s) is still very high and would require very large infrastructure to cope.

For the South African industry it is suggested that the solution lies in the operation of low emission diesel machines and the use of modern clean engine technology. These systems are being used in Canada and the USA. The use of alternate power sources for the LHDs such as electricity is another avenue worth consideration.

Table 2: CANMET data sheet for the Detroit S50 LHD type used in the Block Cave mining system.

Engine Rating and Maximum Fuel Rate at Sea Level	**Sulphur in Fuel.**	**CSA Ventilation Prescription**		
	%wt	**CFM**	**m^3/s**	**m^3/s/kW**
(187 kW) 250 HP @ 2100 RPM 91.0 lb/hr	0.05	17 600	8.3	0.0444
	0.25	23 600	11.1	0.0594
	0.50	31 200	14.7	0.0786

The air requirement shown above was taken from CANMET tests conducted on this type of vehicle (Table 2). For the 0.05% sulphur content in the diesel fuel the quantity required is 8.3 m^3/s (0.0444 m^3/s/kW) and the 0.5% sulphur fuel content relates to 14.7 m^3/s quantity supply (0.0786 m^3/s/kW).

The detailed calculation of the air requirements for diesels was demonstrated in the reference paper (Rawlins, 2004, MDEC). The following is an example of the calculation method used:

Fresh Air Quantity (Q) = 187 kW x 0.06 m^3/s/kW
= **11.22 m^3/s/LHD**

This quantity calculated corresponds with the CANMET quantity recommended for the sulphur in fuel percentage of 0.25%. It was given that "Medium" Emission Diesel (MED) fuel with sulphur content of at least ≤ 0.25% will be used in the underground diesel fleet.

Therefore about 11.2 m^3/s air required per diesel machine. There is a difference of 6.4 m^3/s between the LED and the HED.

This difference in air supply per unit combined with fuel price differences is now described to illustrate the economic basis for decisions on diesel fuel to be used.

4. ECONOMIC BASIS AND ANALYSIS OF FUEL TYPES

To demonstrate the economic basis of an analysis on diesel fuel to be used the following parameters are given.

- Operation life: 10 years
- Interest rate: 10%
- Electrical power cost: CAD $ 300 per kW per annum
- LED cost: CAD $ 1.21 per litre
- MED cost: CAD $ 1.16 per litre
- HED cost: CAD $ 1.10 per litre
  (5% cost difference between different fuel types).
- Fuel consumption: 0.17 l/hr/kW (i.e. 31.8 L/hr - mean value taken)
- Operational time: 24 days per month
- LHD utilisation: 70%

Exchange rate: CAD $ 1.00 = R 5.00 (South African)

A detailed capital cost of equipment, i.e. main fans, pressurisation fans, auxiliary fans, and ducting requirements were done. During the design to determine the total air quantity needed, other aspects such as minimum air velocity in drifts, heat load, etc, were taken into account and ultimately amounted to 680 m^3/s for the overall mine. To narrow down the requirement for diesel vehicles and specifically for the LHDs used, the quantity of air allocated was determined as follows:

PRODUCTION LEVEL

9 LHD x 11.2 m^3/s = 100.8 m^3/s
5 other drifts x 11.2 m^3/s = 56 m^3/s
Total production quantity = 156.8 m^3/s, say 157 m^3/s

UNDERCUT LEVEL

4 LHD x 11.2 m^3/s = 44.8 m^3/s
9 other drifts x 11.2 m^3/s = 100.8 m^3/s
Total undercut quantity = 145.6 m^3/s, say 146 m^3/s

Total undercut & production sections = 303 m^3/s

WORKSHOPS, DIESEL BAYS & CRUSHERS

Workshops = 40 m^3/s
Diesel bays = 20 m^3/s
Crusher blasting = 20 m^3/s
TOTAL = 80 m^3/s

TOTAL QUANTITY REQUIRED = 383 m^3/s

By adding the workshop and diesel fuel bay quantities as well as some air for when crusher rock blasting takes place to the overall fresh air quantity required results in a total fresh air supply requirement of 383 m^3/s (303 m^3/s + 80 m^3/s).

By only allowing air for the 13 LHDs that would be used throughout the mine the quantity allocation would be (100.8 + 44.8) 145.6 m^3/s, say 146 m^3/s.

Table 4 shows the results of the comparison analysis done. The value for "mean electrical power to quantity ratio" was determined from the overall power required to facilitate the whole mine supply quantity and factored to include for the LHDs only. The electrical power was calculated directly from the equipment selected for the mine.

Table 4: Summary of comparison analysis.

Description	HED	MED	LED	Units
Mean electrical power to quantity ratio	11.7	11.7	11.7	kW/m^3/s
Electrical power required	2242	1711	1267	kW
Capital cost	963			CAD $/kW
Total capital cost	2,2	1,6	1,2	CAD (million)
PV of power cost over period	4,1	3,2	2,3	CAD (million)
Total cost	6,3	4,8	3,6	CAD (million)
Total cost including diesel fuel	**10,1**	**8,8**	**7,7**	**CAD (million)**

The change in the total cost value indicated above relates to the fact that although the diesel fuel price increases as the sulphur content reduces (left to right in the table), so does the air requirement reduce from 191 m^3/s to 146 m^3/s to ultimately 108 m^3/s. Thus the fuel price is not as sensitive as a change in the air quantity supply and associated equipment to ensure the air is provided where needed.

The cost difference over the 10 year period taken would mean a difference of about CAD $ 1,3 million and CAD $ 2,3 million from using HED to LED fuel. This is a substantial amount and cannot be ignored lightly.

Furthermore, this relates to about CAD $ 52,831 per m^3/s over the ten year project life. In this perspective, air is an expensive commodity and should be applied with great care.

5. CONCLUSIONS AND FINDINGS

In this study an actual mine design was used to demonstrate the use of trackless equipment and air supply associated with their application. The focus of this paper was to demonstrate the use of different fuel types and their related air quantity requirements and this related to an economic evaluation to determine any financial contributions and sensitivity analysis.

The following is summarised:

- Fuel price is important but relative insensitive in relation to air quantity.
- Air quantity is more important when design studies are done especially when fuel type is considered and influences trackless engine types offered.
- The financial benefits can be important (millions of dollars) when making a decision on fuel type and engine make chosen.
- For this notional mine the cost was determined to be CAD $ 52,831 per m^3/s of air circulated through the mine for diesel equipment use.

This paper focused on air supply with direct relation to the type of trackless equipment used, its application (utilisation), and the specific mining operation. This is one specific area concentrated on and there are other areas that also need attention when an overall design is considered such as heat from the underground operation (VRT), minimum air velocity to dilute airborne dust, heat from machinery, i.e. one, two, and three vehicles traveling in series behind each other, etc. An important factor always to be considered is the safety and health of the workforce. Diesel fuel with low sulphur content is more environmentally friendly, the workers health protected, and should therefore get first priority besides its secondary economic benefits attainable.

In the diamond massive mining method ventilation system design the overall air requirement was determined to be 680 m^3/s and therefore more than indicated for the LHDs alone (146 m^3/s) and therefore related to the global mine design philosophy adopted.

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