In-Stope Dust Control at Beatrix Gold Mine

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ABSTRACT: The risk of silicosis in mining has been well documented and various means of dust controls implemented. The basis of many of these controls remains the use of water to either suppress airborne dust or prevent dust from becoming airborne. One of the more difficult areas to contain dust is within the stope area. Most mines recommend watering down at the start of and during the shift. In this study use of a stope atomiser spray on worker exposure levels was investigated. The average reduction in the TWA quartz concentration across all occupations was calculated to be 79.2%.

Introduction

The risk of silicosis associated with South African gold mining industry is well documented and many studies have highlighted the continued presence of silicosis, as well as additional associated health risk factors that are unique to the South African gold mining sector. Silicosis is an incurable disease with a number of recognised complications such as tuberculosis (TB), loss of lung function, severe lung fibrosis and lung cancer. Exposure to silica dust alone is a risk factor for TB and the presence of human immunodeficiency virus (HIV) and silicosis has been shown to increase the risk of TB 15-fold. This is a serious health concern given the prevalence of HIV in South Africa [1].

As part of the tripartite initiatives, the mining industry agreed to a new set of industry milestones in 2014 to be achieved by 2024 [2]. The milestones applicable to the hard rock gold mines are stated below:

- By December 2024, 95% of all exposure measurement results will be below the milestone level for respirable crystalline silica of 0.05 mg/m^3 (these results are individual readings and not average results).
- Using present diagnostic techniques, no new cases of silicosis, pneumoconiosis or coal worker's pneumoconiosis will occur among previously unexposed individuals.

Where "previously unexposed individuals" are those unexposed to mining dust prior to December 2008, i.e. equivalent to a new person who entered the industry in 2009.

In the SIMHEALTH 606 study conducted during 2000 and 2001 the exposure of workers was investigated. It was concluded from this study that the following occupations, in descending order of risk, were most at risk [3]:

- Mining crews in stopes
- Team leaders
- Drill operators
- Scraper winch operators
- Loco drivers and crews

In this study [3] it was stated that their research supported the conclusions of [4] that a reduction of the quartz OEL from 0.1 mg/m^3 is required to reduce substantially the risk of silicosis. The researchers in this case study concluded that the earlier (1993) South African studies and their findings both suggest that a reduction of the OEL for exposure to quartz dust to at least 0.05 mg/m^3 would be necessary to achieve such protection. A summary of the shift exposures for different occupations from this study is shown in Figure 1.

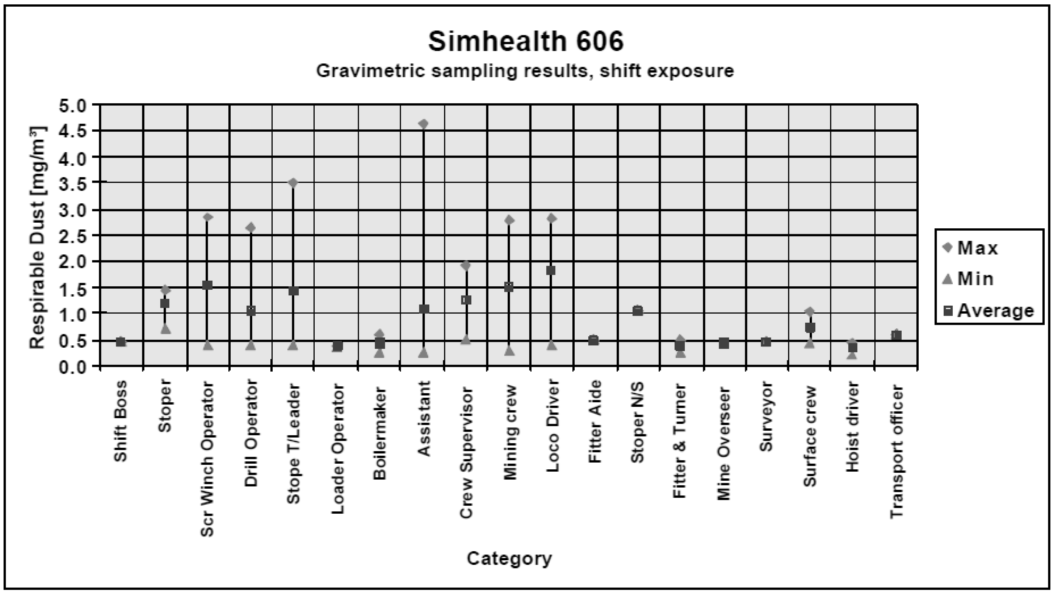

Figure 1: Findings from SIMHEALTH 606 – Shift exposures [3]

From Figure 1 the range of exposures (minimum to maximum exposures) reported for some of the occupations are shown. From this data set it can be concluded that employees associated with these occupations can be deemed to be at risk. Alternatively, the reported concentrations indicate that during different activities within an occupation there is a potential risk of overexposure. These findings also indicate that the controls implemented at the time did not reduce exposures effectively throughout a full mining cycle.

In a follow-up study the quantification of dust sources in underground mines was attempted [5]. Table 1 summarises their findings in the gold industry.

Stope face	**Min concentration (mg/m^3)**	**Max concentration (mg/m^3)**	**Ave concentration (mg/m^3)**	**Quartz concentration (%)**
West Wits	0.57	1.40	0.9	9.92
Vaal	0.41	4.22	1.69	39.05

Table 1: Dust concentrations in stope faces [5]

From the table it is clear that the concentrations measured during the study covered a wide spectrum, with the minimum and maximum concentrations differing considerably. The quartz concentrations reported in this study were also significantly different for the different regions. Unfortunately, no measurements were done during this study in the Free State gold fields, which are the focus of the present study. In this study they also attempted to quantify the dust concentration associated with scraping (dust source) activity. These were unfortunately only done for the two platinum operations included in the study. The results are shown in Table 2.

Stope face	**Min concentration (mg/m^3)**	**Max concentration (mg/m^3)**	**Ave concentration (mg/m^3)**
Platinum 1	0.71	1.51	1.19
Platinum 2	0.25	0.92	0.54

Table 2 Dust concentrations from scraping [5]

Although this study was not conducted in a gold mine it is included to demonstrate the potential additional dust levels associated with scraping.

A master's study was conducted on two Free State gold mines focusing on the exposure of rock drill operators [6]. Results indicated that rock drill operators using pneumatic percussion rock drills are exposed where rock is pulverised and dust liberated, even when wet drilling is practised. In this study it is reported that the TWA dust concentration values found were between 0.69 and 0.22 mg/m^3 for mines 1 and 2 respectively, with an average of 0.46 mg/m^3 for both. The average sample quartz percentage was determined to be 25.45% for mine 1 and 38.49% for mine 2, resulting in an average of 30.67% for both mines. When comparing the individual samples against the OEL of 0.1 mg/m^3 it was found that 32% of all rock drill operators sampled were potentially overexposed. When using the proposed OEL level of 0.05 mg/m^3, potentially 72% of the rock drill operators sampled were overexposed. Based on these results, the study concludes that rock drill operators working without appropriate respiratory equipment will be overexposed and therefore potentially suffer ill health as a result in the long term.

Through the years a variety of dust control methods have been identified and implemented to suit South African gold mines [7]. In this study, a brief overview of the major dust sources is given and appropriate dust control measures and practices are described. The basis of many of these controls remains within the context of using of water to either suppress airborne dust or prevent dust from becoming airborne.

The results from these studies support the view that stope areas of gold mines pose a high risk of exposure to airborne silica dust. In most of the studies presented so far, this risk was identified despite the fact that most of the mines still required watering down at the beginning of and during a shift as the main control. At the Beatrix operations these practices also remain in place. From previous studies at Beatrix operations it is clear that watering down of the stope and development areas, especially during re-entry examination and face scraping operations in stopes, remains ineffective. In a presentation of the results from one such study [8] the top 20 most-exposed occupations at the Beatrix operations is shown in Figure 2. This shows, in descending order from left, highest number of personal exposure samples greater than the 0.05 mg/m^3 to the right of the graph with lowest number of samples greater than the 0.05 mg/m^3.

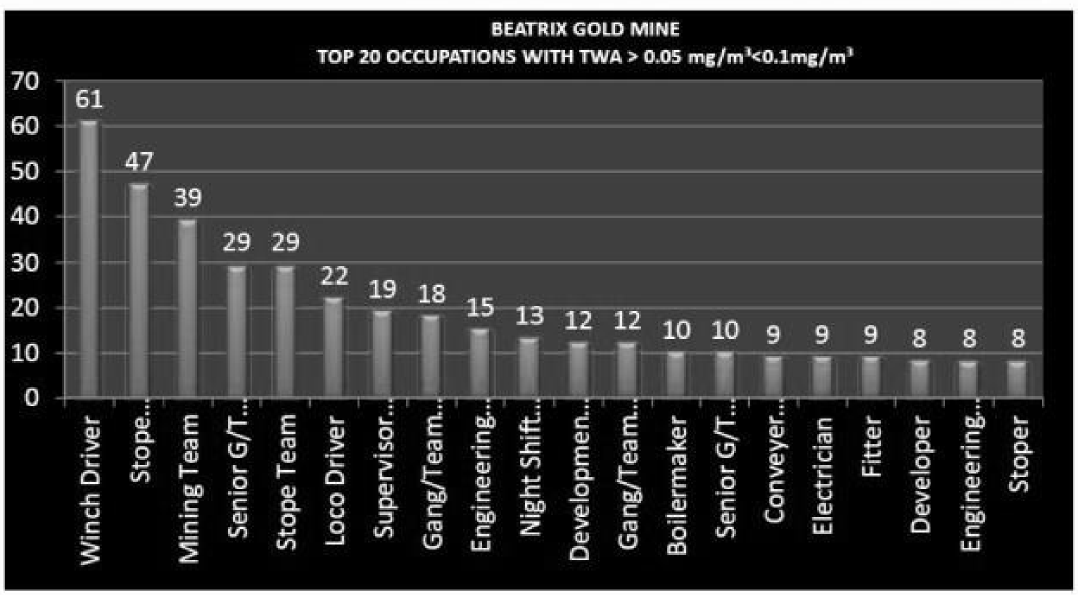

Figure 2: Number of samples per the top 20 exposed occupations [8]

From Figure 2 the top five occupations listed as potentially being exposed to silica dust are within the stope area, indicating that further and additional controls within this area need to be investigated, trialled and implemented. There is also still a very good correlation between these findings and those reported in the SIMHEALTH 606 [3] study, as shown in Figure 1. Thus although the level of exposure may have reduced over time, the at-risk occupations have remained the same for more than a decade.

Mines have implemented a number of initiatives over the years in an attempt to improve the effectiveness of dust controls and thus reduce the potential of worker exposure. Some of these initiatives implemented at the Beatrix Mine are listed below [8]:

- Establishment of the Project 4 M which was an attempt at the holistic management of identified occupational hygiene risks as described by the Mine Health and Safety Council Industry Milestones of 2003 [9],[10].
- An improved gravimetric dust sampling strategy, including increased and improved silica content measurements
- Increased silicosis awareness
- Improved dust control measures including tip filtration, footwall treatment, winch covers, use of tip covers, boxing" of transfer chutes, use of additional water prays in shafts and haulages , improved watering-down regime during the shift, development and implementation of water-blasts and the use of stope atomiser sprays

In an attempt to alleviate the identified dust problem within the stope area, it was decided to conduct a study to identify the more effective practices, as well as to identify additional controls that could be used within the stope area. During the second part of the study, the value of implementing an in-stope water-blast was investigated. The study included a field trial to determine the effectiveness of in-stope water-blasts in reducing worker's exposure to silica dust in the stope face environment.

Underground study

As part of this study underground in-stope visits were undertaken and observations were recorded listing the methods and practices currently employed during first-entry examinations and during the shift, especially with respect to watering down.

From the historical and current exposure measurement data the constant overexposures of winch drivers were identified. These overexposures were noted mostly during the night shift. A summary of the observations made during the underground site investigations is given below:

- In most cases watering down is done with an open-ended hose, which can result in dust being liberated into the atmosphere during the watering-down activity.
- The "watering-down tool" (to replace the use of open-ended hoses) currently in use, is effective when used correctly, but is very time-consuming, and for this reason, watering down is not always done effectively.
- The night-shift crew normally consists of only two or three winch drivers and a team leader. Their normal modus operandi is to first get their rigging installed and in a number of instances started work without watering down. When questioned they claimed that to water down effectively is too time consuming.
- The perception of the crew members is that as they are positioned on the intake-air side of the panel being cleaned, they are not exposed. They do not consider that the liberated dust could contaminate downstream working panels (working in the stope return air) as stopes are often ventilated in series.
- When watering down is done before scraping is started, there is limited benefit, and after scraping has been done for a few minutes there is very little evidence of any benefit or for that matter of any watering down having been done at all.
- Watering down during scraping and loading operations is very seldom practised underground.

With this in mind it was decided to use the water-atomising device, similar to a development water-blast, as a means of watering down before and during dust-creating and liberating activities underground. This will also remove the additional human/equipment interface requirement for effectiveness of dust control.

Description of the stope atomiser spray

The device chosen for use in the trial study as a water-blast was a Terrablast™ unit. For its operation the unit uses both water and compressed air to atomise the water droplets. One of the identified advantages of the device is that it uses an 8 mm nozzle, therefore not requiring additional fine water filters. The manufacturer claimed that none of the operational units at other operations was blocking and that the large aperture of the actual nozzle being used did not require additional filtration.

Water atomisers used in mines require good quality water, high water pressures and filters to prevent blockage. The deployed unit requires a water flow rate of 0.75 ℓ/s and normal mine water pressure (4 to 6 bar). It is connected to the water supply using a standard 25 mm PVC hose connection. This provides sufficient flow and pressure for effective operation.

The photos in Figure 3 show the venturi water-blast (single-nozzle unit) with the individual water and air inlets, each with its own valve.

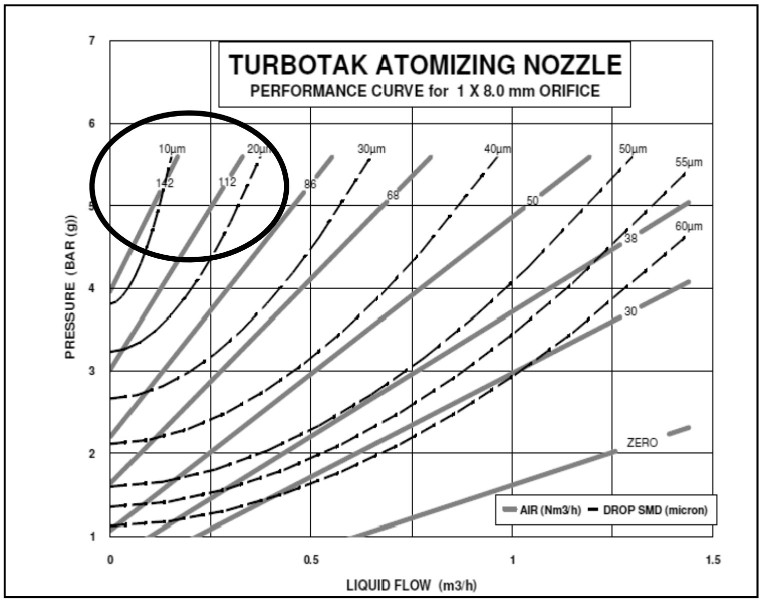

Figure 3: Performance curve for the single-nozzle stope atomiser spray [11]

Figure 3 shows the optimal operating point. This is when the compressed air supply is between 4 and 6 kPa, with water consumption of between 0.25 m^3/h and 0.5 m^3/h liquid flow rate as illustrated in the graph in Figure 3. If this liquid flow rate is used it can be calculated that the associated water flow rate will be between 0.069 and 0.139 ℓ/s when a single-nozzle water-blast is used.

Underground site

During the experimental design it was decided to identify a workplace that could be considered as the potential worst-case scenario to trial the unit's effectiveness. The positions of the individual venturi water-blasts were chosen to ensure proper watering down of all areas in the stope without wasting any resources through overdesign. The main objective was to demonstrate that one could achieve the desired dust concentration results within the whole of the stope area.

The identified workplace consisted of a stope area with two mining panels, using six winches to clean the two stope face areas. The plan view of the trial site with the position of the installed winches is shown in Figure 4.

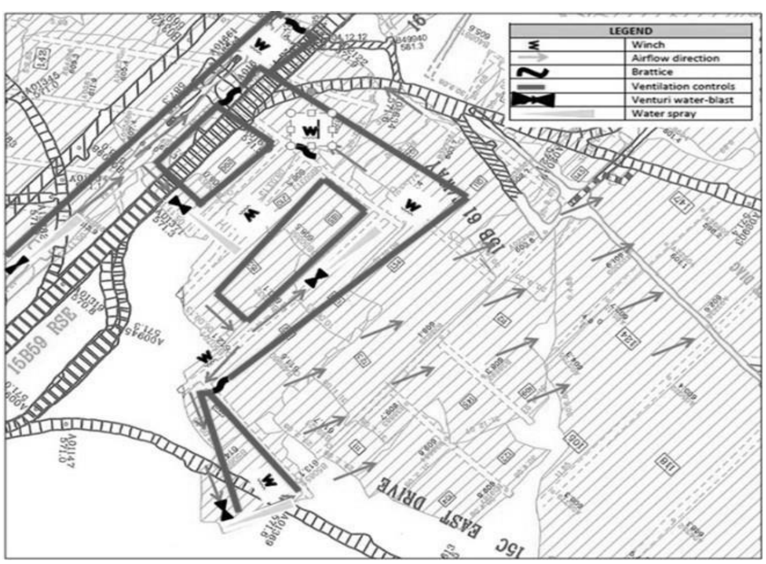

Figure 4: Plan view of the underground trial site

In the plan view the positions of the stope atomiser sprays, ventilation controls and winch positions are shown. The airflow direction is shown by the arrows. The specific layout chosen is typical of an old mine where numerous old remnants are being mined and is definitely not an ideal site when ease of operation and potential product success are considered. In total, four stope atomiser sprays were installed, assisting airflow as well as providing effective area coverage. Figure 5 shows a photo of a typical installation of an atomiser spray in a stope at the underground trial site. The ease of installation, as well as both the water and compressed air pipes is shown. The atomised water mist leaving the water-blast is clearly seen. This type of water-blast has the additional benefit of inducing airflow by means of the venturi design, utilizing the compressed air and water pressure effectively to create atomised water mist.

Figure 5: One of the underground installations at the trial site at Beatrix Gold Mine

Methodology

The methodology used to evaluate the effectiveness of the implementation of the stope atomiser spray was to do a comparative study of the personal respirable dust exposure levels of the different occupations of in-stope workers before and after the installation of the in-stope water-blasts. The personal exposure measurements of several occupations [12] were taken using standard on-mine sampling and analytical techniques for a trial period of eight weeks. The definition of personal sampling is that the dust sample collected needs to be in the breathing zone of a worker performing his or her occupational duties during a work shift. The worker wears the sampling train (cyclone, gravimetric sampling pump, tube and sample filter) for the entire shift (bank to bank). The airborne dust concentration is expressed as mass per cubic metre (mg/m^3) of air and referred to as sample dust concentration in the air. Using the sampling period, flow rate and mass of sample collected on the filters, the sample concentration is obtained as follows [13]:

$$\text{Sample concentration}(c) = \frac{(m_f - m_i)}{V \times t} \ldots\ldots\ldots\ eq\ 1$$

where

c is the dust concentration measured in mg/m^3
m_i is the corrected initial filter mass in mg
m_f is the corrected final filter mass containing dust in mg
V is the sample flow rate in m^3/minute
T is the sampling time in minutes

If the sampling period is not an 8-hour period, a calculated 8-hour time-weighted average dust concentration (TWA–8 h) is obtained as follows:

$$\text{TWA} - 8\ \text{h}_{conc} = \frac{(\text{c} \times \text{t})}{480} \ldots\ldots\ldots.\ eq\ 2$$

where

c is the dust concentration measured in mg/m^3
t is the sampling time in minutes

When silica dust concentration is calculated, an adjustment is made by determining the actual quartz content (% quartz) on the filter by doing, for example, X-ray diffraction analysis. The correction made is as follows:

$$\text{TWA} - 8\text{ h}_{quartz} \quad = \text{TWA} - 8\text{ h } \times \%\text{ quartz}\ldots\ldots\ldots eq\ 3$$

The concentration is in mg/m^3, with the South African Occupational Exposure Limit (OEL) being 0.1 mg/m^3 [14]. Personal exposure monitoring was conducted on both the day shift and night shift using gravimetric sampling pumps. A total of 20 personal exposure samples were collected over the 8-week period. Samples were collected from team leaders, winch drivers, stope teams and rock drill operators. There daily activities were also observed during the study period. The areas monitored during the project focused on the listed occupations. These occupations work activities happens in the stoping faces, strike gullies, centre gullies and back area sweepings.

Field trial results

The personal exposure dust concentrations for the rock drill stope operator (RDO), winch operators and the in-stope crew are shown in Table 3 [15]. The mass concentrations were calculated using equations 1 and 2 and averaged for the number of measurements.

Occupation	Before concentration (mg/m^3)	After concentration (mg/m^3)	Exposure reduction (%)
RDO	1.163	0.231	80.1
Winch operator	1.358	0.200	85.3
Stope team	1.450	0.317	78.1

Table 3: Average measured dust concentrations

From Table 3 it is clear that the average respirable dust concentration as determined from personal exposure monitoring results decreased significantly, with the lowest reduction being measured for the stope team workers at 78.1% and the highest reduction of 85.3% being measured at the winch operator.

In previous studies (See Figure 2) the winch operators were found to be the most exposed in-stope workers but the before dust concentrations showed that the general stope workers was more exposed than the winch operators in this study and for the post dust concentration results the winch operator had the lowest average exposure.

The time-weighted average (TWA) quartz corrected exposure measurements for the RDOs, winch operators and in-stope crew are shown in Table 4. The TWA concentrations were calculated using equation 3 and averaged for the number of measurements.

Occupation	Before concentration (mg/m^3)	After concentration (mg/m^3)	Exposure reduction (%)
RDO	0.129	0.02	79.8
Winch operator	0.249	0.0366	85.3
Stope team	0.168	0.046	72.6

Table 4 Average measured TWA quartz dust concentration

From Table 4 it can be seen that an average reduction of between 72.6 and 85.3% in the TWA quartz concentration was achieved during the trial, with the highest reduction being achieved for winch operators. The combined average reduction in the TWA quartz concentration across all occupations was calculated to be 79.2%. When comparing the different occupations, the in-stope team members are now the occupation with the highest average exposure. Although this is still well within the current OEL, it is close to the new proposed OEL of 0.05 mg/m^3.

A summary of additional field observations made during the study within the study area is as follows:

- Water covers the total face area from a fixed point.
- There is no need to enter into any unsafe area to water down.
- The water spray washes the blasted face, assisting in exposing misfires.
- Induces airflow with a measured air quantity of up to 2.5m^3/s.
- There is an increased face velocity measured 15 m from the water-blast of 3.3 m/s.
- There is an increased face velocity measured 30 m from the water-blast of 1.6 m/s.

- The measured water flow rate was 0.75 ℓ/s or 45 ℓ/min.
- No additional watering down was done during the trials.

Conclusion

The Mine Health and Safety Council Milestones includes the requirement that 95% of all individual exposure measurement results be below the milestone level for respirable crystalline silica of 0.05 mg/m^3. For the industry to meet this exposure level, significant and focused efforts will be required and alternative dust control methods will have to be developed and implemented.

In this paper the use of an in-stope water-blast was investigated and the impact on worker exposure was quantified. From the worker dust exposure concentrations obtained during the control study it is clear that a significant reduction in worker exposure is possible when effective in-stope dust control is implemented.

An average reduction of between 72.6 and 85.3% in the TWA quartz concentration was recorded during the trial. The combined average reduction in the TWA quartz concentration across all occupations was calculated to be 79.2%. When comparing the different occupations, the in-stope team members are now the occupation with the highest average exposure, but this is still well within the current OEL. The reported worker exposures were achieved during an 8-week trial period.

It is also postulated that the application of this technology will not only reduce worker exposure for operational stopes, but also that of vamping crews working in old stopes.

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