Particle-capturing performance of South African non-corrosive samplers

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ABSTRACT: In view of the international drive to eliminate silicosis, it is critical that reliable and consistent results are obtained from respirable dust sampling and analysis so that effective control measures can be implemented on mines. Two locally manufactured samplers were evaluated to determine how they perform in terms of the sampling of respirable dust. Various laboratory controlled tests were conducted to determine the physical and aerodynamic properties of the samplers and the particle size distribution of each filter sampled with one of the samplers. Results showed that there was relatively good consistency among the samplers from the same supplier. However, the two groups of samplers produced different results from one another. It is recommended that respirable dust samplers be subjected to more tests after manufacturing to ensure good quality control. Measuring one or two properties alone is insufficient to deem a sampler suitable for use within the general mining industry.

1 INTRODUCTION

The eradication of silicosis and the lowering of the dust exposure of mine workers still remain two of the biggest challenges faced by the South African mining industry. It is imperative that reliable and consistent results are obtained from respirable dust sampling and analysis so that effective control measures can be implemented on the mines.

Samplers are used by mine occupational hygienists to assess exposure of personnel to respirable dust. Size selective samplers are used to remove the respirable fraction of airborne dust (smaller than ten microns (µm)) from the breathing zone of a worker and deposit this dust onto a filter. The sample taken should be representative of the dust exposure of the mine worker during his work shift.

Different samplers are used world-wide and even in South Africa there is not a national standard sampler for respirable dust. It becomes a great concern when poor sampler performance results in unreliable and inconsistent silica concentration measurements.

A pilot study was conducted in South Africa during 2007/2008, in which the particle size distribution (expressed as D50) for samples taken in a platinum mine was evaluated (Pretorius 2008). The D50 values of the dust collected on the filters were scattered between 2 and 42 µm, when the expected cut-point for these respirable samplers should be at approximately 4 µm.

For this reason a controlled laboratory project was proposed to assess the particle-capturing performance of respirable dust samplers (generally referred to as "cyclones") that are manufactured and used in the South African mining industry. Two locally manufactured samplers were evaluated to determine how they perform in terms of the sampling of respirable dust.

Several studies have been conducted and reports published on the performance testing of samplers (Belle et al. 1999, Kenny et al. 2000, Witshger et al. 1997, Aizenberg et al. 2001, Maynard et al. 1995, Maynard 1996, Gimburn et al. 2005), each with its own testing methodology and focusing on different instruments and in different locations; some tests were conducted underground in mines and others in purposely designed test rigs. In all the studies sampler performance was evaluated on the basis of the internationally accepted ISO/CEN/ACGIH (European Standardization Committee (CEN) 1993, International Organization for Standardization (ISO) 1995) curve. In this way the performance of different samplers could be compared for this study.

The National Institute for Occupational Safety and Health (NIOSH) and the American Conference of Governmental Industrial Hygienists (ACGIH) have defined respirable dust as particles with an Aerodynamic Equivalent Diameter (AED) ≤ 10 µm. The AED is the diameter of a spherical particle of density equal to one that has a settling speed equal to the particle in question.

The European Standard EN 481:1993 (CEN 1993) and ISO 7708 (ISO 1995) define the respirable fraction as follows:

"…the percentage E_R of the inhalable fraction convention which is to be collected at an aerodynamic diameter *D* in micrometres shall be given by a cumulative log-normal distribution with a median diameter (D50) of 4,25 µm and a geometric standard deviation (GSD) of 1,5."(CEN 1993)

The Mine Health and Safety Act stipulates the following (Mine Health and Safety ACT 1996):

"Respirable dust is defined as particulate passing through a cyclone with an efficiency that will allow:

- 100% of 0 µm AED;
- 50% of 4 µm AED;
- 30% of 5 µm AED; and
- 1% of 10 µm AED."

The suppliers of respirable samplers specify a specific flow rate so that the cut-point (or D50) for the sampler is ± 4 µm. The convention is to report the particle size distribution (PSD) of dust as the D50 in µm where 50% of the particles have a particle size below this value. In some instances the D10 (10%) or D90 (90%) is also used.

When a respirable dust sampler is used, the user expects to sample only particles from the respirable fraction – particles smaller than 10 µm. As soon as particles larger than 10 µm are deposited onto the respirable dust filter, the X-ray Diffraction (XRD) response is increased during silica analysis. This increased response gives rise to a higher measured silica concentration.

Work by the Health and Safety Laboratory on different samplers used in industry in the United Kingdom (UK) (CSIR 2009) showed that how the samplers deposit dust onto a filter affects the XRD response when silica analysis is carried out. This work was revealed to an ISO working group on the analysis of respirable silica (to which the CSIR belongs) at its 2009 meeting. In response, the working group decided to conduct a similar study among the international bodies of the group. The outcome of this work will form an integral part of the development of a new ISO method for the analysis of silica using XRD.

It is important that all the samplers used in the South African mining industry perform in the same way so that consistent silica results can be determined.

2 OBJECTIVE

The objective of this study was to determine the particle-capturing performance of the non-corrosive samplers used mostly in South Africa. The objective was mainly to compare the performance of two locally manufactured samplers with each another.

The intended outcome was to show how the samplers perform under laboratory conditions with standard test dusts and under real conditions in a mine. The results were expected to determine the confidence levels for respirable dust samples.

The objective of this study was not to discredit the manufacturers or the samplers they produce but rather to illustrate the need for the standardisation of samplers within the South African mining industry.

3 METHODOLOGY

The samplers that were tested were Higgins-Dewell type, non-corrosive samplers from two local manufacturers (Supplier X and Supplier Y). These samplers are commonly used in the South African mining industry because of their durability and cost effectiveness. Twenty-five new samplers with a 25 mm diameter were acquired "off the shelf" from each supplier and no special care was taken in their production. According to the suppliers, these samplers were made from materials that render them non-static.

The samplers from Supplier X are from here on referred to as "X-Samplers" and those from Supplier Y as "Y-Samplers".

Three aluminium samplers were used as control samplers and were tested in exactly the same way as the others. The assumption was made that these samplers are subjected to stricter quality control after manufacturing for export purposes. The aluminium samplers are not classical standard Higgins-Dewell samplers but are manufactured to have the same D50 as the classical standard Higgins-Dewell sampler.

Tests were also conducted on a batch of old and used samplers which varied in age and represented samplers used on the mines on a daily basis.

Initially laboratory controlled tests were carried out on the samplers. The aim was to keep as many variables as possible the same. The samplers were then subjected to normal personal sampling in three platinum mines to compare the performance of the samplers with the laboratory tests.

The laboratory tests conducted on the samplers were used to determine:

1. The physical properties and dimensions of the samplers;
2. The aerodynamic properties of the samplers; and
3. The particle size distribution of each filter sampled with one of the samplers, using different types of test dust:
    - Polydisperse particle standard (PPS) 1-10 µm;
    - ISO 12103-1 A4 coarse test dust 3 – 30 µm (Arizona test dust); and
    - Platinum mine ore from the Rustenburg area that was pulverised for the purpose of the project.

Respirable dust samples were taken, using 25 mm Mixed Cellulose Ester (MCE) filters with a pore size of 0.8 micron (µm). For every respirable sample taken with a sampler, a total dust sample was taken simultaneously in the sampling vessel. The aim was to get enough dust on the filter so that particle size analysis (PSA) could be carried out. The duration of the sampling was established at ± 30 seconds, so the mass of dust collected per sample ranged from 1 to 2 mg.

The flow rates for each sampler were specified by the suppliers. For the X-Samplers and Y-Samplers a sampling flow rate of 2.2 litres (L)/min was used and for the aluminium samplers a flow rate of 2.5 L/min was used. The Gillian sampling pumps were calibrated with a digital flow rate meter.

The test equipment used to sample the standard dusts was adopted from the international method MDHS 101 for determining silica using XRD and Fourier-Transform Infrared (FTIR). The preparation of calibration standards for this method makes use of a dust-generating chamber in which pre-prepared cassettes, filters and samplers are placed. A small amount of standard reference material (SRM) is made airborne so that the airborne dust can be sampled onto a filter with a sampler.

The pulsation of the air flow provided by the standard gravimetric sampling pumps needed to be controlled so that it did not affect sampler performance. For this reason the pulsation was eliminated for the purpose of the tests. The gravimetric sampling pump was connected to a 25 L glass vessel in the sampling chain to eliminate pulsation in the air flow.

The pressure loss due to air flow resistance was measured with a digital micro manometer for each sampler with 2.2 L/min passing through the sampler (2.5 L/min for the aluminium samplers).

PSA was carried out using a fraction cell and with the Horiba LA-950 laser light scattering particle size analyser. This instrument can detect particle sizes of between one nanometre (nm) and three millimetres (mm). This technique uses the refractive index of a material dust to compute the PSD.

After the laboratory and fieldwork sampling was completed, only the X- and Y-Samplers were cut open so that the samplers could be investigated on the inside.

4 RESULTS AND DISCUSSION

4.1 *Results of physical property tests*

4.1.1 *Physical measurements*

The physical properties for each sampler were measured and the tests revealed visible differences between the two locally manufactured samplers, referred to as “X-Samplers” and “Y-Samplers”. There were differences in the barrel length and shape of the top of the samplers. The tops of the X-Samplers were cone shaped and tops of the Y-Samplers were flat. The different top shapes could result in different dust distributions on the filter but this was not determined during this study. The areas of the inlet apertures also differed across the two samplers, which could give rise to different air velocities through the aperture. Despite the differences between the two groups, there was good consistency within each group from the same supplier.

4.1.2 *Aperture appearances*

On some of the X-Samplers, burrs were clearly visible in the inlet and outlet apertures of the sampler.

Figure 1 shows these burrs seen on an X-Sampler, which are caused by poor finishing during the manufacturing of the sampler. The inlets on the Y-Samplers were clean-cut without any burrs.

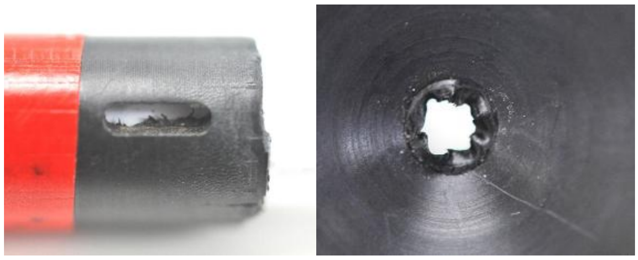


Figure 1. Burrs in the inlet aperture (left) and in the outlet aperture (right) of an X-Sampler

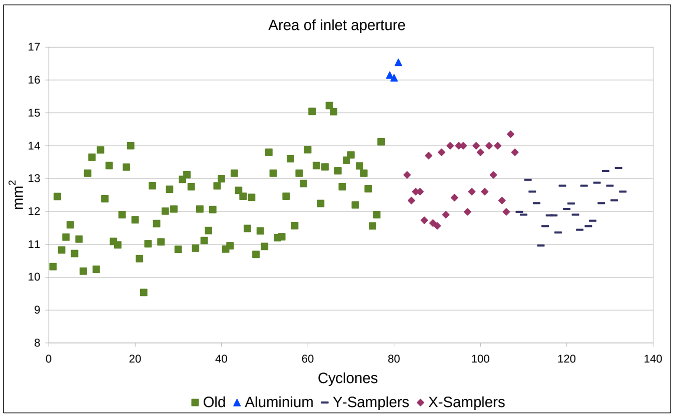
This is disconcerting as burrs in the inlet aperture could affect the air velocity entering the sampler and consequently affect the D50 of the sampler. The burrs in the outlet opening can be expected to disrupt the flow pattern of the air leaving the sampler, and consequently the deposition of the dust on the filters might vary.

The non-uniform distribution of dust will directly affect the analysis of the dust samples by techniques such as XRD and FTIR. These techniques are designed to analyse the concentration of silica in the middle of the filter and if the concentration of dust is non-uniformly distributed inaccurate silica results are determined. Figure 2 shows three different distributions of dust on filters, which will greatly affect the outcome of the analysis results.

Figure 2. Different dust distributions on filters

4.1.3 *Inlet aperture size*

The inlet aperture size, which is critical for the air velocity in the sampler, is graphically shown in Figure 3 for each individual sampler. As expected, the old and used samplers show varying apertures probably due to wear and tear from usage. The standard deviations on the area of the inlet aperture for each sampler group were also determined.



Area of inlet aperture	Old	Aluminium	X-Samplers	Y-Samplers
Average	12.27	16.25	13.00	12.21
Standard Deviations	1.24	0.25	0.91	0.61

Figure 3. Area inlet aperture

The standard deviations of the aperture areas show that the aperture areas of Y-Samplers seem to be more consistent than the X-Samplers. As expected, the standard deviations of the inlet areas of the old samplers showed how worn the samplers can become after years of use. The standard deviations of the aluminium samplers are very low, which is expected from stricter quality control after manufacturing.

4.1.4 *Internal inspection of the samplers*

The X- and Y-Samplers were cut open over the length of the sampler and inspected. Figures 4 and 5 show what the samplers look like on the inside.

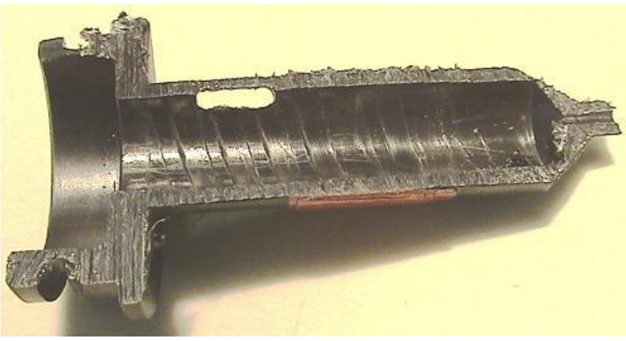


Figure 4. Rough inside surface of an X-Sampler

A finding of concern was that the majority of the X-Samplers have machining marks contra-rotational to the air flow. During the circulating process in the sampler, larger dust particles that would have been sampled out could consequently bounce on the uneven surface and might be re-introduced into the airstream. This could result in particles larger than the respirable fraction being deposited onto the filter.

Figure 5 shows the inside of a Y-Sampler, which seems much smoother than the X-Sampler.

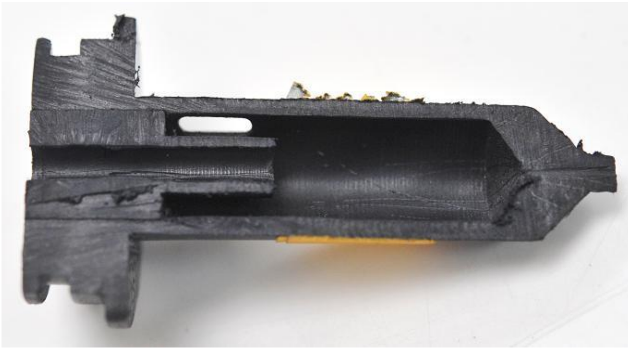


Figure 5. Inside view of a Y-Sampler

The manufacturing quality control of the aluminium samplers on the outside appeared to be of good standard. There were no obvious flaws visible in any one of the three samplers.

4.2 *Results of the aerodynamic property tests*

The aerodynamic properties of the new samplers were evaluated and the results were compared to the old and used samplers. The Kv coefficient value (according to standard NF E 29312), the measure of the flow rate through a device at a specific pressure drop across the device, was used to compare the different samplers on equal criteria. The average air velocity values of the X-Samplers and Y-Samplers were also measured as was the pressure loss of the samplers.

The aerodynamic properties tested showed good consistency among the Y-Samplers. However, the consistency among the X-Samplers was poor compared to the Y-Samplers. There was a good comparison between the X- and Y-Samplers when the air velocities through the apertures were measured.

The aluminium samplers were used as controls and, as expected, the standard deviations on the aerodynamic properties were by far the lowest. In general the standard deviations on the aerodynamic properties of the Y-Samplers were lower than for the X-Samplers, which show that the individual test results were much more consistent within the group.

4.3 *Particle size distribution of sampled filters*

Figure 6 shows the PSD from filters sampled using the polydisperse particle standard (PPS), which is made from spherical glass beads with a particle size of between 1 and 10 µm.

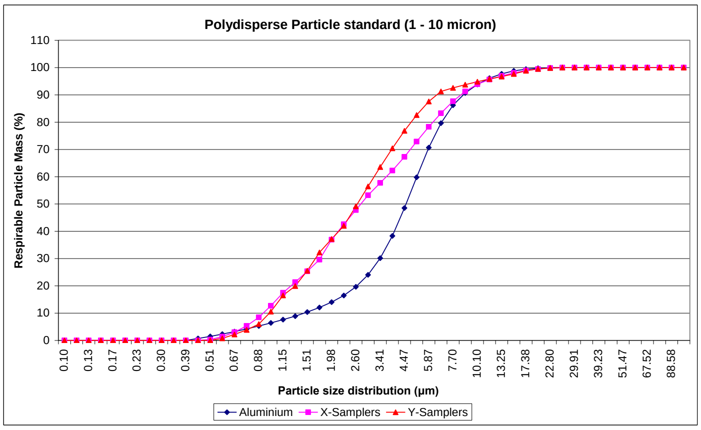


Figure 6. PSD of filters where PPS test dust was sampled

The aluminium samplers showed a D50 of ± 5 µm, whereas the X- and Y-Samplers showed D50s of ± 2.6 µm. The D90 for all the samplers was below 10 µm.

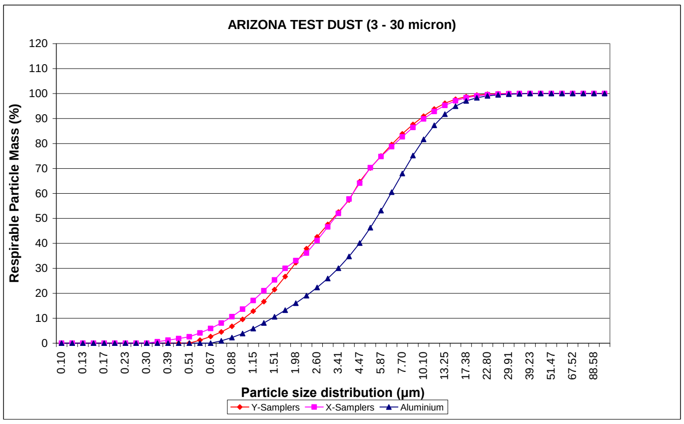


Figure 7. PSD of filters where Arizona test (3 – 30 µm) dust was sampled

The X- and Y-Samplers showed a D50 of ± 3 µm and a D90 of ± 10.10 µm with the Arizona test dust. The aluminum samplers showed a D50 of ± 5.5 µm and a D90 of ± 13 µm. According to the stipulations of the Mine Health and Safety Act (Republic of South Africa 1996), only 1% of particles of 10 µm may be allowed to pass through the respirable sampler. From the PSD, it is clear that more than 1% of particles larger than 10 µm were deposited on the filter (D95 ± 13.25 µm). Both X- and Y-Samplers had very similar PSDs and the slope of the curve corresponded well.

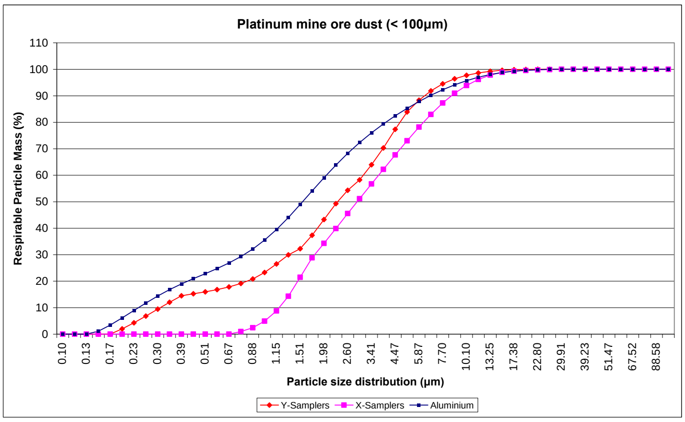


Figure 8. PSD of filters where platinum mine ore dust was sampled

When platinum mine ore dust was sampled under laboratory conditions, the D50s were similar to that of the Arizona test dust. The D90s were lower, which would lead one to assume that particles collected on the filter were within the respirable fraction.

However, the percentage of platinum mine ore dust particles larger than 10 µm deposited on the filter ranged between 3% and 7% for the different samplers (X-Samplers > aluminium > Y-Samplers). The curvature of these PSDs is also visibly poorer than for the Arizona test dust. The conclusion drawn from this result is that the mineral dust type and composition can affect how the sampler performs.

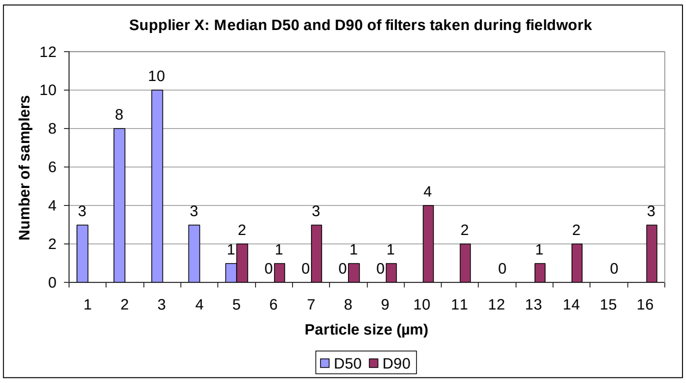


Figure 9. Median D50 and D90 values obtained from the X-Samplers after real sampling at three platinum mines

The median D50 values of ten of the 25 X-Samplers (40%) were ± 3 µm, which is lower than the supplier-specified cut-point of ± 4 µm. Three samplers showed a D50 of ± 4 µm and one sampler had a result of ± 5 µm, which is still acceptable. However, the D90 values of eight samplers (32%) were above ± 10 µm, which is outside the particle range of the respirable fraction.

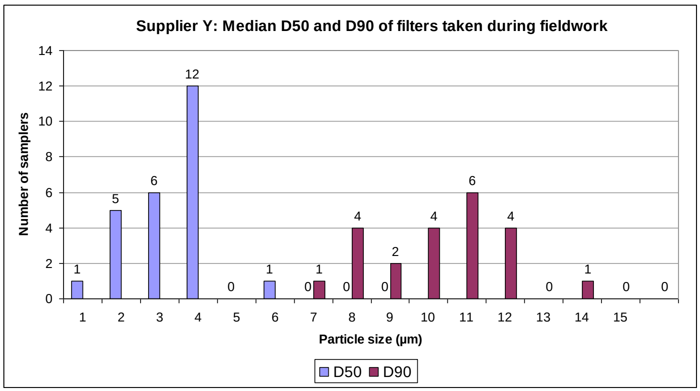
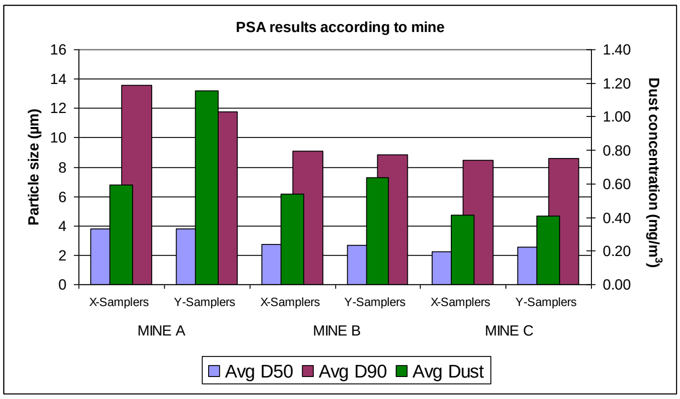


Figure 10. Median D50 and D90 values obtained from the Y-Samplers after real sampling at three platinum mines

The median D50 values of 12 of the Y-Samplers (48%) were ± 4 µm as per the supplier specification and the D50 of one sampler was ± 6 µm. However, the D90 values of 11 samplers (44%) were above ± 10 µm, which is outside the particle range of the respirable fraction.

From the above results, it is clear that more Y-Samplers have D50 values which correspond to the supplier specifications than X-Samplers. However, both groups had individual samplers with D90 values of larger than ± 10 µm or the respirable fraction of dust (Y-Samplers more than X-Samplers). Larger particles deposited on the filters tend to give a greater XRD response, which yields a greater silica concentration for the individual filter.

The average (avg) D50 and D90 values were arranged as shown in Figure 11 according to the mine from which they were sampled and according to the different samplers used at each mine. The average dust concentrations obtained are also displayed with the PSA results.



PSA results according to mine	Mine A		Mine B		Mine C	
	X-Samplers	Y-Samplers	X-Samplers	Y-Samplers	X-Samplers	Y-Samplers
Avg D50 (µm)	3.82	3.82	2.71	2.69	2.27	2.58
Avg D90 (µm)	13.59	11.75	9.12	8.84	8.48	8.58
Avg Dust (mg/m^3)	0.596	1.153	0.538	0.638	0.415	0.409

Figure 11. Average PSA and dust concentrations arranged according to mine

From Figure 11, it can be seen that in general the D50, D90 and dust results for Mine A are slightly higher than for Mine B and C for samplers from both suppliers. The average D50 for samplers from both X-Samplers and Y are 3 – 4 µm. The D90 values for Mine A are outside of the respirable fraction of ± 10 µm, whereas the D90 values for Mines B and C are within range.

The dust concentrations on all the filters are very similar, apart from those taken with Y-Samplers at Mine A. It is not clear why the results in this instance would be so different. It could be that the sampler performs differently with the type and composition of ore dust from Mine A.

Table 1. Standard deviations of the PSA and dust concentration results

Standard Deviations	All mines	Excluding Mine A
Avg D50 (µm)	0.67	0.20
Avg D90 (µm)	2.11	0.29
Avg Dust (mg/m^3)	0.28	0.11

Table 1 shows the standard deviations between the D50, D90 and dust concentration results. As soon as the results from Mine A are excluded, the standard deviations are very low and compare well between the D50 and D90 results. The deviations between the dust concentrations are also very low.

This leads one to conclude that the type of ore dust does influence the performance of the sampler. All three mines produce the same commodity, and the same types of reef were mined at the time of sampling. Differences in composition and overall particle size distribution do seem to produce different PSDs and dust concentrations.

5 CONCLUSION AND RECOMMENDATIONS

The overall conclusion was that there was relatively good consistency among the samplers from the same supplier. However, the X- and Y-Samplers produced different results from one another.

Respirable dust samplers should be subjected to more tests after manufacturing to ensure good quality control. Measuring one or two properties alone is not sufficient to deem a sampler suitable for use within the general mining industry.

The recommendations from this project are that:

- A quality assurance test protocol be developed by an independent party other than the manufacturers, and that the samplers are tested and approved prior to being made commercially available to the South African mining industry; and

- The samplers used in South Africa are standardised so that all mines sample with the same respirable dust sampler and all laboratories analysing for silica use the same sampler to calibrate their methods. This will go a long way towards improving efforts to ensure consistent and reliable dust and silica results produced by the South African mining industry.

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