Investigating the accuracy of the inhalable dust sampling devices

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ABSTRACT

Coal mining still has many challenges in terms of health and safety. There are many types of coalmine hazards, for instance methane explosion and spontaneous combustion, and coal dust-related health problems, such as Coal Workers' Pneumoconiosis (CWP). Coal dust in operating mines is mainly produced by mechanical cutting of the coal in both production and development areas. The exposures to coal dust are monitored in terms of inhalable and respirable fractions in Australia. Inhalable dust refers to the particle that can be breathed into the nose or mouth and respirable dust refers to the dust that can be breathed into the gas exchange regions of respiratory system. Inhalable and respirable standards refer to particles with median diameter of 100 µm and 4 µm, respectively.

As recommended in the AS3640 (Standards Australia, 2009), a sampling system for the inhalable dust is essentially, an inhalable dust sampling device with a filter which the dust sample is collected and a pump for drawing the air through the sampling device. The inhalable dust sampling device is to be placed within the worker's breathing zone. A series of tests were carried out to examine the effects of the dust laden airflow orientation on the efficiency of the Institute of Occupational Medicine (IOM) inhalable dust sampler and other most used samplers in Australian coalmines. The experimental parts of the study were executed at Commonwealth Scientific and Industrial Research Organisation (CSIRO) Mineral Resources Pinjarra Hill site utilising a large dust chamber and at operating coalmine site.

The results of the testing show that the coal dust collection efficiency and accuracy of the inhalable dust samplers are significantly affected by the samplers' inlet orientation to the oncoming airflow direction. Based on the particle size distribution analysis results of laboratory and field sampling, it is concluded that the inlet orientation of the IOM sampler to the oncoming airflow also have a significant effect on the coal dust particle size ranges captured by the sampler. Based on these findings, it is concluded that the science behind the inhalable sampler may not be well comprehended yet and further investigation and design evaluation of current inhalable IOM sampler may be required to warrant consistent approach to inhalable dust sampling.

INTRODUCTION

As per the AS3640 – *'Workplace atmospheres – method for sampling and gravimetric determination of inhalable dust'* (Standards Australia, 2009), the inhalable dust sampling system consist of an inhalable dust sampling head followed by a filter and a pump. The inhalable dust sampling device is to be placed within the worker's breathing zone. The inhalable fraction is collected by using a sampling device should conform with the sampling efficiency curve as specified in the ISO 7708. There are several devices or heads available that generally satisfy the ISO 7708 criteria.

AS3640 provides a few examples of sampling devices available such as modified personal United Kingdom Atomic Energy Authority (UKAEA) sampling head, Institute of Occupational Medicine (IOM) inhalable dusting sampling head and conical inhalable sampling head. It has suggested that UKAEA and IOM sampling heads are more suitable for sampling particles smaller than approximately 30–50 µm equivalent aerodynamic diameter. If a significant proportion of particles are larger than these ranges, IOM sampler should be used in preference to the UKAEA sampling head.

AS3640 also suggests that a sampling bias of less than ± 5 per cent is typical for the IOM inhalable dust sampler, but the conical inhalable and multi-orifice samplers may have larger biases (either positive or negative) under same workplace conditions. Workplaces with high air velocities and large particles are generated by the work process (a common situation in a typical modern Australian longwall production face) often could lead to negative bias. Positive bias usually a resultant from incorrectly handling of the samplers such as the conical and UKAEA after use, as these sampler designs could allow unintended contamination of the filter. This study aimed to identify any potential issues associated with AS3640 and to validate the applicability of the inhalable dust monitoring program currently implemented by Australian coal mining industry.

INHALABLE SAMPLING HEADS

Inhalable sampling heads collect all fractions of particulates (up to 100 µm) which enter the nose and mouth during breathing, ie everything that is available in the air to be inhaled. Table 1 provides a summary of inhalable samplers available currently or in the past. It should be noted that the closed face cassette (CFC) was not designed to be an inhalable sampler but are still used in the US to assess exposures relative to total dust limits.

TABLE 1

Inhalable samplers available.

Sampler	Flow rate (L/min)	Include wall deposits	Region of use	Manufacturer / distributor
Closed face cassette (CFC) - 37 mm	1.0–2.0	No	US (‘total dust standards’)	SKC Inc., SureSeal Cassette etc.
IOM Inhalable	2.0	Yes	Europe, US, Australia	SKC Inc.
Button Inhalable	4.0	No	US	SKC Inc.
Conical inhalable sampler (CIS)	3.5	No	UK HSE, Germany	Casella CEL, UK
Multi-orifice (7-hole)	2.0	No	UK HSE	Casella CEL, UK
GSP (Gesamtstaub-Probenahmesystem)	3.5	No	Germany	GSMGesellschaft für Schadstoffmesstechnik, GmbH; Neuss-Norf, Germany
Personal Air Sampler (PAS-6)	2.0	No	Netherlands	University of Wageningen, Netherlands
CIP10-I	10.0	No; Ver. 2 reduces loss	France (wood dust)	Arelco ARC, France
PERSPEC	2.0	-	Italy	Lavoro e Ambiente No longer commercially available

With the development of the inhalable sampling criteria, researchers began to develop samplers that collect dust at efficiencies matching this criterion so that occupational exposures could better reflect the true dust concentrations inhaled by workers. The most widely used sampler in the United States and Australia is the IOM inhalable dust sampler. It was developed in the mid-1980s.

The basis for development of the IOM sampler was to design a sampler that represents the amount of aerosol of workers breath into their noses and/or mouths. There are two main components to the IOM sampler, the filter cassette and the sampler housing. The sampler housing is made up of two pieces, which screw together to the filter cassette. The interior filter cassette has a 15 mm opening, and at the opposite side has a 25 mm filter held to the cassette with a mesh screen behind.

Kenny *et al* (1997) investigated the sampling efficiency of the IOM sampler comparing to the inhalable criterion over various air velocities, airflow/sampler orientations, and sampling flow rates. When performing at air velocities of 0.5 m/s and 4.0 m/s, the IOM sampler was found to sample adequately compared to the inhalable convention when facing the dust source. The IOM oversampled compared to the inhalable particulate matter curve, but not enough to cause concern at 0.5 m/s. Sampling efficiency at 4.0 m/s was found to decrease as particle size increased until particle size was larger than 80 µm. Efficiencies at these larger particle sizes were found to be above 60 per cent.

Baldwin and Maynard (1997) found that air velocities may be much lower in some workplaces (around 0.2 m/s) than the testing conditions of the inhalable samplers as tested by Kenny *et al* (1999). Therefore, the IOM sampler was tested at these lower air velocities to determine if the sampler still satisfied the inhalable sampling criteria. Sampling efficiency was found to decrease as particle size increases in low wind speed conditions, which is to be expected. In higher air velocity wind tunnel experiments, sampling efficiency slightly increased. IOM sampler was determined acceptable in low air velocities less than 0.2 m/s (Kenny *et al*, 1999).

For an inhalable sampler to match the inhalable sampling curve, the sampler must follow the inhalable fraction when averaged overall orientations relative to the oncoming airflow. The IOM has been tested under multiple orientations in order to determine whether it does in fact keep to the inhalability standard at all orientations. A study undertaken by Li, Lundgren and Rovell-Rixx (2000) found that the IOM sampler oversampled when facing the oncoming airflow, but under sampled when at orientations of 90° and 180°. When facing the wind, efficiency increased above 100 per cent as sizes of particles increased 60 µm. Zhou and Cheng (2009) also investigated the effect of sampling flow rate on the collection efficiency of the IOM sampler using 10.6 L/min along with the standard 2.0 L/min flow rate and air velocities of 0.6 and 2.2 m/s. The performance of the IOM sampler was reported to be similar when sampling at 10.6 L/min, compared to the standard sampling flow rate, though sampling efficiency was approximately 20 per cent less when particle sizes were larger than 80 µm.

Another possible concern is that AS3640 simply recommends that weighing of filters after sampling is to be undertaken at a suitable time (eg overnight) to allow filters to come to equilibrium with the balance room atmosphere. The IOM sampler could have a large weighing imprecision because of the fact that the entire filter cassette, which can be made of plastic or stainless steel, is weighed as a unit along with the filter. Humidity in this case could cause large weighing imprecisions due to moisture absorbing to the much larger and heavy plastic cassette comparing to the filter alone. Keeping the cassettes in humidity controlled weighing room for seven days before and after use is recommended in order to keep weight fluctuation to ± 0.05 mg. However, a study done by Liden and Bergman (2001) shown that to fully equilibrate the cassette to the weighing environment, 15 to 20 days of equilibration may be required. The results of the same study found that the oils on human hands add a statistically significant amount of weight to the filter cassette.

With the emergence of inhalable samplers and exposure limits based on inhalable criterion, inhalable measurements were compared to historical total dust measurements. It has become a common practice that total dust concentrations to higher inhalable concentrations are compared using a value called the performance ratio (inhalable dust/total dust ratio). A commonly used performance ratio of 2.5 is used for various dusts found in the workplace, after results from multiple studies from 1980 to 1996 were compiled by Werner, Spear and Vincent (1996).

The Button inhalable sampler was developed to minimise the effects of wind direction and velocity on sampling efficiency. This inhalable sampler was developed to allow smooth flow over a front, mesh surface in high air velocities. The Button sampler has a porous curved surface with multiple 381 µm diameter openings, with an overall porosity of 21 per cent. Air velocity and orientation were found to have no effect on the sampling efficiency of the Button sampler in a laboratory setting (Aizenberg *et al*, 2000). While Button inhalable sampler has the advantage of sampling efficiency not affected by air velocity and orientation. it is recommended by the manufacturer that the Button Sampler is better used for low level personal or area inhalable sampling (SKC Ltd, Europe, 2023). Currently, no Button inhalable sampler application was found within the Australian coal mining industry. This could be due to its lower sampling efficiencies and more suitable for low level dust laden condition.

LABORATORY TESTING OF THE IOM INHALABLE DUST SAMPLER

A series of tests was carried out on the IOM inhalable dust sampler commonly used in Australian coalmines at CSIRO Mineral Resources Pinjarra Hill site utilising a large dust chamber designed for another Australian Coal Association Research Program (ACARP) funded project. Tests were set to examine the effects of the oncoming dust laden airflow orientation on the performance efficiency of the IOM inhalable dust samplers.

The laboratory testing undertaken involves placing one IOM inhalable dust with its sampling inlet opening pointing toward the dust laden airflow direction (0°) and the other sampler's opening pointing at 90° that is perpendicular to the oncoming airflow direction within the breathing zone of a mannequin. During the tests, the respirable dust concentrations were measured concurrently using PDM3700. Figure 1 shows the test chamber set-up and details of the two IOM samplers placed in two orientations to the oncoming dust laden airflow within the test chamber.

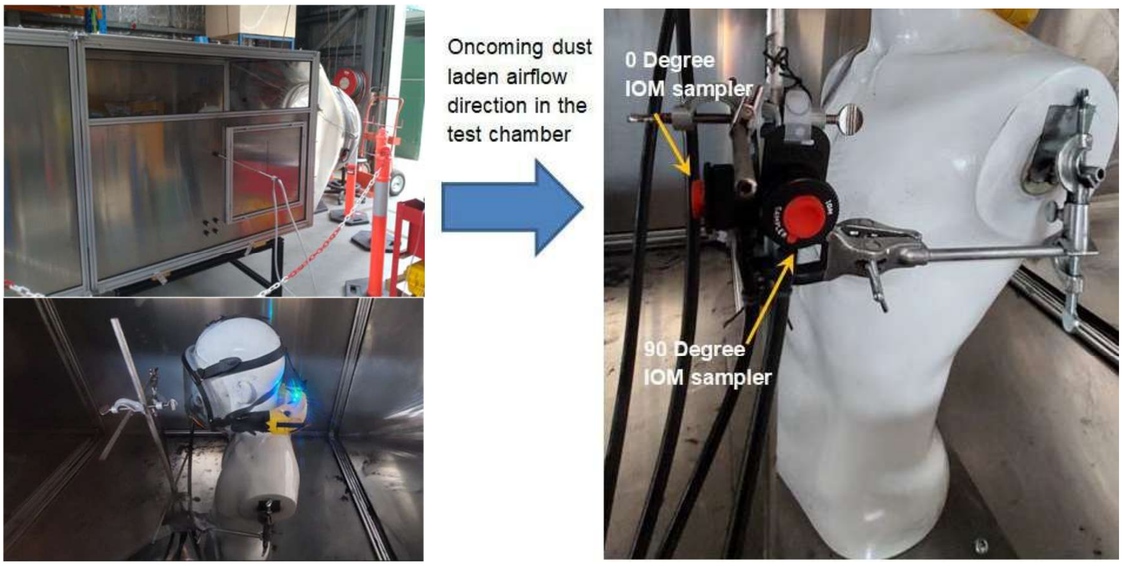


FIG 1 – Set-up of IOM samplers in the test chamber.

Fine coalmine dust sample in the inhalable dust size range for feeding into the test chamber was prepared by the Metallurgical Engineering Laboratory Facilities at The University of Queensland. The coal dust sample sourced from the Coal Handling and Preparation Plant (CHPP) flotation product of a central Queensland coal was screening at 100 per cent passing of 125 μm. This fine coal dust was then fed into the test chamber from the centre top of the chamber about 1.5 m from the mannequin using a precision controlled dust feeder.

Total of eight tests were conducted. Test series were undertaken with sampling period ranging from 3.5 to 5.0 hrs with inhalable dust levels of up to 11.8 mg/m^3 and respirable dust levels of up to 2.7 mg/m^3. Air velocities of oncoming dust laden airstream over the mannequin were ranging from 1.9 to 3.7 m/s which are similar to common air velocity ranges in the face areas of Australian underground coalmine sites. First six test series were done with pairing of two IOM samplers placed in two orientations, 0 and 90° to the oncoming airflow. The last two test series were carried out with pairing of three IOM samples placed in three orientations, 0°, 45° and 90° to the oncoming airflow. However, the sampling pump used for the 90° IOM sampler had failed during the sampling in test series No 7. Table 2 shows summarised results of the test series 1 to 6 with two sampler orientations.

TABLE 2

Summary of test series 1 to 6 results – two orientations.

Test no	Direction to airflow (°)	Flow rate (L/min)	Time (mins)	Dust conc (mg/m^3)	90° to 0° ratio
1	0	2.007	242	10.500	31.4%
	90	2.008	242	3.293	
2	0	2.012	265	11.253	34.9%
	90	2.016	265	3.932	
3	0	2.022	235	11.785	34.2%
	90	2.022	270	4.030	
4	0	2.033	272	9.587	30.3%
	90	2.019	273	2.904	
5	0	2.027	308	11.693	31.1%
	90	2.055	308	3.635	
6	0	2.025	272	11.256	29.4%
	90	2.003	272	3.304	

Based on the test results, it is found that the performances (or sampling efficiencies) of IOM inhalable samplers are greatly affected by the orientation of the sampler's inlet to the oncoming airflow. The performance ratio of inhalable coal dust collected between IOM samplers with 0° and 90° orientations is 3.13 to 1. In other words, an IOM sampler with its sampling inlet positioned perpendicular to the oncoming airflow direction only collecting about 32 per cent of inhalable coal dust when compared with that of the IOM sampler with its inlet facing the oncoming airflow. Test series 7 and 8 were done with three sampler inlet orientations namely, 0°, 45° and 90° to the oncoming airflow. As mentioned before, one of the sampling pumps had failed during the test series 8. Table 3 provides a summary of the results from test series 7 and 8.

TABLE 3

Summary of test series 7 and 8 results – three orientations.

Test no	Direction to airflow (°)	Flow rate (L/min)	Time (mins)	Dust conc (mg/m^3)	90° or 45° to 0° ratio
7	0	2.028	215	5.964	
	90	sampling pump failure			
	45	1.998	215	3.958	66.4%
8	0	1.989	307	6.387	
	90	2.027	307	2.090	32.7%
	45	2.015	307	4.042	63.3%

Results of test series 8 show that the ratio between 0° and 90° orientations agrees with the ratios observed in test series 1 to 6. The average performance ratio between 0° and 90° orientation of these seven test series is around 3.13 to 1. The average performance ratio between 0° and 45° orientations is around 1.54 to 1. Interestingly, this ratio is somehow proportional to the ratio observed between 0° and 90°. The following figure shows the relationship among ratios of 0°, 45° and 90° orientations with a linear regression.

Figure 2 shows clearly that the coal dust collection efficiency of the IOM inhalable dust sampler is significantly affected by the IOM sampler inlet orientation to the oncoming airflow direction.

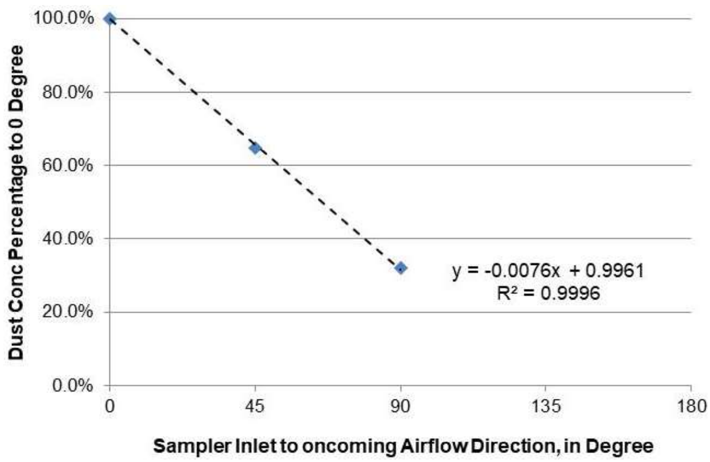


FIG 2 – Inhalable dust collection efficiency and IOM sampler inlet orientation.

Inhalable dust (with orientation variations) and respirable dust concentrations measured in these test series were compared and presented in Table 4. Ratios between inhalable dust (0°), inhalable dust (90°) and respirable dust concentrations are presented in Figure 3. The performance ratio between inhalable dust (0°) and respirable dust concentrations is about 4.3 to 1. A reasonable fit between inhalable dust (0°) and respirable dust concentrations is shown with coefficient of determination, R^2 at an acceptable level of 0.74.

TABLE 4

Comparison of Inhalable and respirable dust concentrations.

Test nso	Respirable dust (PDM3700) (mg/m³)	Inhalable dust (IOM sampler) 0° (mg/m³)	Inhalable dust (IOM sampler) 90° (mg/m³)
1	2.400	10.500	3.293
2	2.730	11.253	3.932
3	2.113	11.785	4.030
4	2.398	9.587	2.904
5	2.601	11.693	3.635
6	2.686	11.256	3.304
7	1.564	5.964	-
8	1.724	6.387	2.090

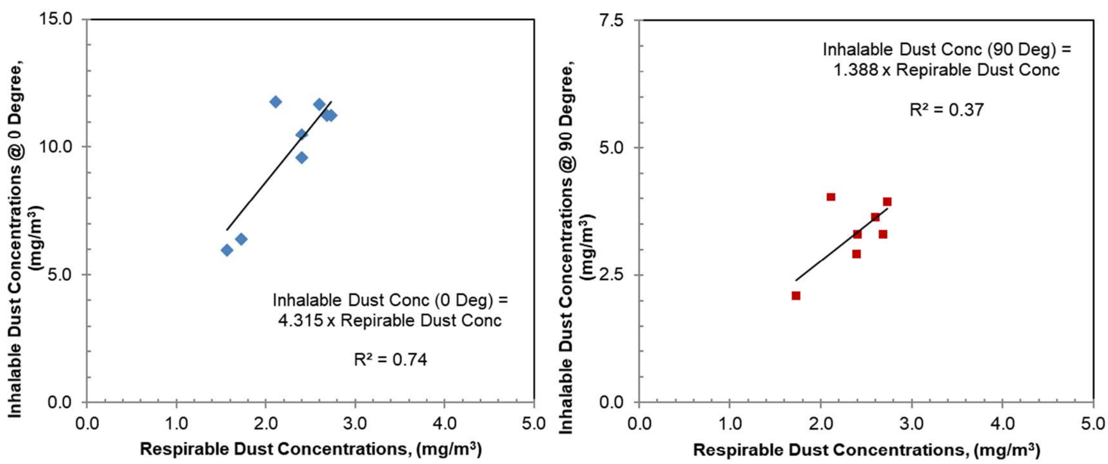


FIG 3 – Ratios of inhalable dust and respirable dust concentrations.

The performance ratio between inhalable dust (90°) and respirable dust concentrations is about 1.4 to 1. However, the goodness-of-fit measure for linear regression (R^2 = 0.37) undertaken shows that it is not as reliable as the one observed for the 0° orientation case. Factors could contribute to this are possibly from turbulent flow around samplers, inconsistence in sampler orientation (angle) setting, gravimetric measurement inaccuracy and so on.

MINE SITE TESTING OF AVAILABLE INHALABLE DUST SAMPLING

A field testing plan at a mine site was proposed as part of the project. The planned site testing involved multiple pairwise sampling of IOM inhalable dust sampler, CFC total dust sampler and respirable dust sampler (Casella Higgins Dewell (HD) cyclone with 2.2 L/min flow rate) at available surface and underground locations of the mine site. The current design of the IOM inhalable dust sampler has a larger open circular inlet (15 mm) with a lip that protrudes 1.5 mm outwards as shown in the following figure. The purpose of the sampler inlet lip is to minimise the potential for particles deposited on the outer surfaces of the inlet to be carried into the sampler. Whereas the CFC sampling head used for total dust collection has an opening inlet size of 4.25 mm as shown in Figure 4.

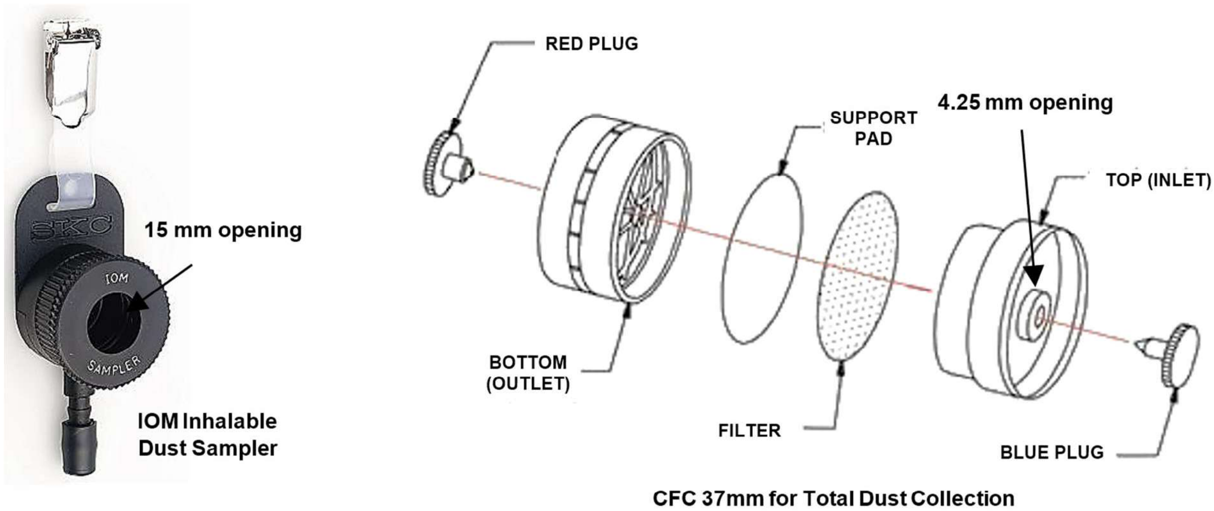
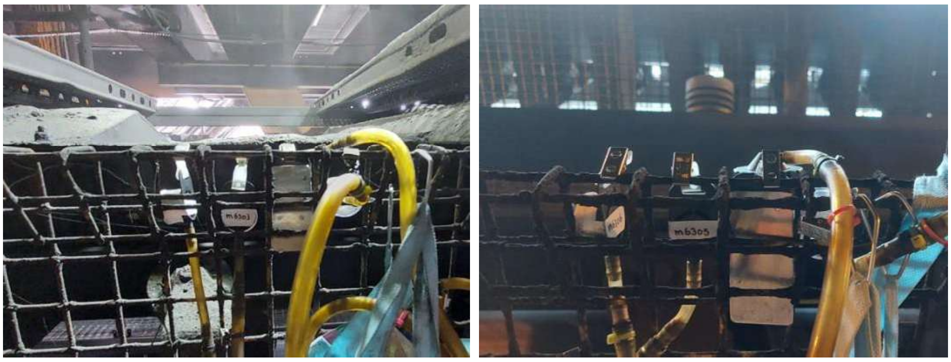


FIG 4 – Sampling inlets of the IOM and CFC samplers.

Thus, there is a high chance of large dust particles ‘falling’ onto the filter of IOM sampler due to its larger opening if the prevalent airflow direction is in line with the inlet of the IOM sampler. On the other hand, it should be noted that CFC total dust sampler would have a higher average sampling velocity of 2.6 m/s (or higher suction force) via a smaller inlet opening with a sampling flow rate of 1.9 L/min when compared with the average inlet sampling velocity (0.19 m/s) of the IOM inhalable dust sampler (sampling at 2.0 L/min). This could mean that dust particle ranges captured by the total dust sampler would be different from the inhalable dust sampler under the same dustiness condition as the aspiration efficiencies, defined as the free stream air velocity over the sampling velocity, of the two samplers are different in an order of magnitude (Kulkarni, Baron and Willeke, 2011).

Dust samples were analysed gravimetrically as well as for their particle size distributions (PSD). Relevant information such as production rate and ventilation condition around the sampling sites was also to be collected. Due to the availability issue of underground locations at the test mine site, mine site sampling was only undertaken at locations near conveyors in the CHPP plant. Figure 5 shows two set-ups of various samplers at sampling stations.

(a)



(b)

FIG 5 – Photographical views of set-ups at sampling locations: (a) Sampling set-up with IOM, CFC and Respirable dust samplers; (b) Sampling set-up with 2 × IOM, CFC and Respirable dust samplers.

A total of 33 sets of pairwise field samples of inhalable (IOM), total (CFC 37 mm) and respirable dust were taken from the mine site. All these samples were pre and post weighed by an independent third party servicer provider. It should be noted that only 26 sets of pairwise samples are valid as seven sets have incomplete pairwise samplings mainly due to unknown failures of sampling pumps. Table 5 shows a summary of these 26 pairwise sampling results.

Based on the field pairwise sampling of the inhalable, total and respirable dust, the following linear relationships between inhalable and total dust, inhalable and respirable dust, and total and respirable dust are observed.

- Inhalable Dust Conc = 1.28 × Total Dust Conc; (R^2 = 0.77).
- Inhalable Dust Conc = 4.60 × Respirable Dust Conc; (R^2 = 0.49).
- Total Dust Conc = 3.49 × Respirable Dust Conc; (R^2 = 0.59).

However, it was found that the relationships between inhalable and total as well as total and respirable pairwise sampling are at acceptable levels with R^2 values at 0.76 and 0.59 respectively. The relationship between inhalable and respirable dust is less reliable and inconclusive with the R^2 value just less than 0.5. It was also found that the performance ratio of 1.28 between inhalable and total dust concentrations is only about half of the performance ratio of 2.5 as compiled and suggested by Werner, Spear and Vincent (1996).

TABLE 5

Summary of pairwise sampling undertaken at an Australian mine site.

Pairwise no	Inhalable dust (mg/m^3)	Total dust (mg/m^3)	Respirable dust (mg/m^3)
1	0.131	0.074	0.037
2	0.202	0.073	0.015
3	0.379	0.573	0.303
4	0.431	0.178	0.118
5	0.733	0.725	0.174
6	0.747	1.207	0.664
7	0.879	1.617	0.377
8	1.060	0.385	0.622
9	1.239	1.880	0.645
10	1.271	1.411	0.713
11	1.503	2.500	0.800
12	1.541	0.708	0.486
13	1.667	2.163	0.473
14	1.780	1.151	0.511
15	1.804	1.748	0.368
16	1.993	1.275	1.062
17	2.384	1.832	0.398
18	2.869	1.659	0.299
19	3.030	3.978	1.185
20	4.058	1.650	0.947
21	4.556	0.889	2.189
22	5.008	5.942	0.717
23	10.081	11.449	2.913
24	12.532	6.141	0.787
25	13.293	5.072	1.200
26	18.536	13.462	2.387
Average	**3.604**	**2.682**	**0.784**

PARTICLE SIZE DISTRIBUTION ANALYSIS

Particle size distribution analyses of selected pairwise dust samples of inhalable and respirable fractions from laboratory testing and field sampling are undertaken. These PSD analyses are done by using a *Mastersizer 3000* (10 nm to 3500 μm, blue light). In each PSD measurement test, the sample was repeatedly measured five times. D_{10} is the diameter of the particles at which 10 per cent of the sample's volume is comprised of particles with a diameter less than this value. D_{50} is the diameter of the particle that 50 per cent of a sample's volume is smaller than this value. D_{90} is the diameter of the particle that 90 per cent of a sample's volume is smaller than this value.

Sample preparation was done with the following procedures:

- the coal dust samples on the filters were dispersed in the distilled water/ethanol by sonication, and/or
- the coal dust samples were dispersed in isopropanol by sonication.

A total of seven coal dust samples from the laboratory testing were selected for the PSD analysis with one sample from the original bulk coal dust sample used for laboratory testing feed and three pairwise sampling sets of inhalable dust at two different sampling inlet orientations, 0° and 90° to the oncoming airflow. It should be noted that the PSD analysis requires a minimum dust particle mass. The respirable portion of coal dust particle collected by respirable dust samplers during the laboratory testing is insufficient. Therefore, they are not analysed for the PSD.

Table 6 shows a summary of the PSD analysis results for these laboratory coal dust samples. It can be seen that inhalable dust sampler with its sampling inlet at 90° to the oncoming dust laden airflow is collecting finer inhalable portion of dust particles when comparing with the sampler's inlet oriented at 0° or directly facing the oncoming airflow. This observation is particularly evident in the larger dust particle fraction (D_{90}) collected by the IOM inhalable dust samplers. The 90° oriented samplers are collected a much smaller particle size in average, 18.8 μm at D_{90} compared with the 0° oriented samplers with the D_{90} particle size at 40.6 μm. However, D_{50} particle sizes (ranging from 3 to 23 μm) of laboratory inhalable coal dust samples captured by the IOM samplers were much lower than the ISO sampling efficiency curve (D_{50} = 100 μm).

TABLE 6

Summary of PSD analysis results for lab inhalable samples.

Sets	No	Orientation (°)	Sample inhalable	Mass on filter (mg)	D_{10} μm	D_{50} μm	D_{90} μm
Bulk coal dust sample feed			-	4.2	23.0	89.5	
A	1	0	A3	6.0	1.6	4.5	30.5
	2	90	A4	2.1	1.3	3.3	10.5
B	3	0	B1	5.6	1.6	4.7	40.8
	4	90	B2	2.2	1.4	3.6	22.7
C	5	0	C1	7.3	1.6	5.2	50.6
	6	90	C2	2.3	1.3	3.8	23.1

As for the dust samples collected in the field sampling program, a total of 12 samples have been selected for the PSD analysis. These samples are from four pairwise sampling sets of inhalable and respirable dust. However, due to much less dust particle mass collected by the respirable dust samplers, PSD analyses of the respirable dust samples are combined into two lots for the PSD analysis. Table 7 shows the PSD analysis results of the field coal dust samples.

TABLE 7

PSD analysis results of the field coal dust samples.

Sets	No	Sample	Filter no	Mass on filter (mg)	D_{10} µm	D_{50} µm	D_{90} µm
A	1	Inhalable 0	6303	14.458	3.8	11.3	30.5
	2	Inhalable 90	6304	14.365	4.1	11.7	32.5
	3	Respirable*	6482	2.756	1.9	5.0	11.4
B	4	Inhalable 0	6309	14.871	3.6	11.9	35.1
	5	Inhalable 90	6310	16.735	3.7	11.7	33.2
	6	Respirable*	6484	4.706	1.9	5.0	11.4
C	7	Inhalable 0	6307	8.689	2.3	6.8	18.5
	8	Inhalable 90	6308	8.834	2.2	6.5	18.2
	9	Respirable*	6483	4.625	1.7	4.4	9.4
D	10	Inhalable 0	6543	6.394	4.8	12.8	36.2
	11	Inhalable 90	6311	6.431	4.0	11.5	30.3
	12	Respirable*	6604	1.088	1.7	4.4	9.4

* Note that respirable dust samples (3 and 6 as a pair and 9 and 12 as another pair) are combined to form enough dust particle mass for the PSD analysis.

Further analysing of the PSD results among inhalable 0°, inhalable 90° and respirable show that in a general trend, the 0° samples have only marginal larger PSD compared with the 90° samples. The effect of sampler's inlet orientation on the PSD is not as obvious in the filed sampling program compared with the laboratory testing. This could be due to the oncoming airflow directions were varying during the field sampling unlike the controlled oncoming airflow setting during the laboratory testing.

Based on the PSD analysis results from laboratory and filed sampling, it is concluded that the inlet orientation of the IOM sampler have a significant effect on the sampling efficiency and resulting variations (D_{50} ranging from 3 to 23 µm) in coal dust particle size captured by the IOM sampler. Even through, this effect observed in the field sampling is not as evident as observed in controlled laboratory testing. The reason for this is probably due to the uncontrolled airflow directions during field setting. However, results from laboratory and filed sampling indicate that coal dust particles captured by the IOM sampler were significantly different from the sampling efficiency curve as specified in the ISO 7708 (D_{50} = 100 µm).

In a typical longwall production face, shearer and chock operators are walking along the longwall face-line between Maingate (MG) and Tailgate (TG) as shearer cutting from MG to TG or TG to MG. The orientation of oncoming airflow to the operator wearing an IOM inhalable dust sampler would vary dramatically. The diagrams in Figure 6 illustrate variations in sampling inlet orientation in common situations in the longwall production face.

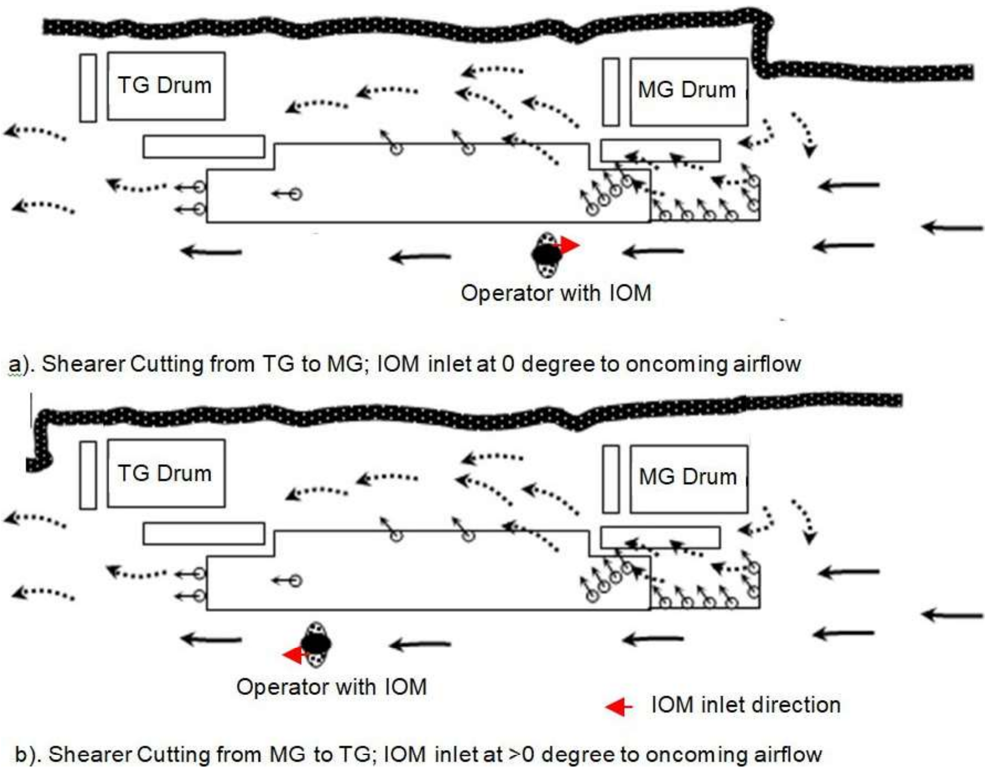


FIG 6 – Examples of operator with IOM samplers at a longwall face.

When shearer is cutting from MG to TG, the operator would have more time with the sampling inlet of the IOM sampler inlet at angles (could be ranging from 15 to 180°) instead of direct facing (at 0°) to the oncoming airflow. When cutting from TG to MG, the operator would face towards MG as the operator walking toward MG direction. In this setting, the sampling inlet of the IOM sampler worn would have more chances facing directly towards oncoming airflow.

In the above situations, the IOM sampler used for sampling inhalable coal dust could either under-sampling or over-sampling the actual inhalable dust level inhaled by the operator. Therefore, it is recommended that a review of the current sampling inlet design the existing IOM inhalable dust sampler should be considered. Button inhalable sampler was developed to reduce the effect of orientation of oncoming airflow to the sampling efficiency of the IOM sampler. However, Button inhalable sampler only has sampling loading limitation issue and only suitable for workplaces with low inhalable dust level applications.

CONCLUSIONS

The laboratory test, delved into a comprehensive exploration of various inhalable dust monitoring devices recommended by AS3640, aiming to provide practical insights into their efficiency and application in Australian coal mining operations. Undertaken at independent testing facilities and coalmine sites, the research extensively evaluates inhalable dust sampling systems, focusing on the AS3640 recommended devices like the modified personal UKAEA sampling head, IOM inhalable dusting sampling head, and conical inhalable sampling head. The lab study examined the performance of sampling systems as per AS3640 criteria. It provided a thorough analysis of inhalable sampling heads, notably the widely used CFC and the IOM sampler. The research highlights the nuances of each sampler, such as the impact of particle size and air velocity on their efficiency. Laboratory tests, conducted at CSIRO Mineral Resources Pinjarra Hill site, scrutinise the effects of airflow orientation on IOM sampler efficiency. The study indicates significant disparities in sampling results based on orientation, emphasising the need for standardised sampling protocols. Field tests, although limited to conveyor areas due to site constraints, provide valuable real-world data on the comparability of inhalable, total, and respirable dust samplers.

In-depth PSD analysis reveals variations in dust particles captured by inhalable samplers oriented differently to airflow and also significantly differences (D_{50} ranging from 3 to 23 µm) to the Inhalable dust size selective curve (D_{50} = 100 µm). The study underscores the importance of orientation in capturing the true inhalable fraction, especially in dynamic workplace conditions like a longwall production face.

The research advocates for a critical review of existing inhalable dust samplers, especially the IOM sampler, concerning airflow orientation. The findings suggest potential under sampling or over sampling scenarios, especially in mobile workspaces. Considering the limitations of existing devices, a re-evaluation of sampler designs is crucial to ensure accurate and representative inhalable dust measurements under various mining scenarios.

This study provided an intricate analysis of inhalable dust sampling devices and highlighted challenges and limitations on their practical applications in coalmines. The results emphasise the need for thoughtful consideration of airflow orientation, urging the industry to re-evaluate current sampling methodologies. As coal mining operations demand precise dust monitoring for worker safety, this research acts as a foundational resource and guiding future advancements in inhalable dust monitoring technologies.

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