UNIVERSITY OF WOLLONGONG AUSTRALIA

Coal Services

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Evaluation of the Performance of Water Spraying Dust Suppression Technology within the Coal Mining Industry

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Coal Services

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EXECUTIVE SUMMARY

This project was prompted by the observation from UOW researchers (among many others) that the performance of spray type dust control systems in Australian coal mines is varied and often sub-optimal. To contribute to rectifying this is issue, the project aimed to identify what factors may have been contributing to the different performance between seemingly similar control strategies implemented in coal mines across NSW. This was achieved via a review of existing knowledge, on site investigations, coal sample testing, and spray nozzle testing. With the data collected from these investigations and testing it was aimed to provide industry some insight into how dust suppressions system can be better designed in the future.

The first phase of the project aimed to investigate the current conditions and where possible dust suppressions systems currently operating in Australia. Four different broad areas where dust emissions are commonly an issue in coal mines were considered and investigated, this included dust emissions from the longwall, roadway development, bin loading, and conveyor transfers. Dust monitoring was undertaken at various sites to gain an understanding of typical concentrations that workers or the broader environment may be exposed to. Monitoring of respirable dust concentrations found that, at the sites tested, dust concentrations were typically less than 5mg/m^3. While monitoring of total suspend particles resulted in measurements in excess of 60mg/m^3, and estimates were made based on qualitative data that the concentrations in some scenarios could exceed 100g/m^3 (viz. ROM bin loading). Air velocities in the region of dust emissions were also considered, where it was found that velocities are typically in the range of 2-10m/s. The data from this phase of the project served as a reference for laboratory testing work and also allowed for the collection of the various samples tested.

A total of 10 different coal samples were collected for testing, including nine from Australian sites and one from overseas for comparison. The material testing found significant difference between each of the samples tested where the dustiness of the coals varied from 4.6% to a maximum of 27.5%. This highlighted the need for a fit-for-purpose approach to dust suppression system design rather than a one size fits all approach. From the range of particle and bulk tests performed across the range of coal samples tested, it was found that only one produced a trend which could be used as a predictor for the dustiness of a coal sample. In relative terms, the lower the saturation moisture content of a coal sample, the lower the dust extinction moisture will be. This may be a useful result for industry in that it gives an indicative method for estimating dust extinction moisture content through a relatively quick and easy experiment. It is recommended that more research be conducted on this to understand why this relationship occurs and if there is any further significance.

As well as testing different coal samples, the project also investigated the different types of nozzles used for dust suppression. The data collected included pressure vs. flow curves, droplet sizing, and dust capture performance. In the first instance, the data collected will serve as a useful reference source for engineers working to select nozzles for the design of dust suppression systems. Having this reference source of data that is often not available from suppliers will allow engineers to select nozzles with the correct spray characteristics to match the specific conditions of any individual application being considered.

The analysis conducted on spray characteristics also led to the development of a spray efficiency parameter to improve the ability for engineers to judge the suitability of a nozzle for airborne dust suppression through a simple calculation. Although further research should be conducted, the results to date provide a strong argument for the use of a spray efficiency parameter for nozzle selection and a recommendation of how it should be applied has been given. This method can be used in addition to the previous work conducted by UOW to predict the penetration of a spray under different wind conditions. Together, the spray efficiency parameter and spray penetration data provide a framework that engineers can use in the design of airborne dust suppression systems.

Overall, the project has generated some useful data sets that can be used by the industry as a reference for the different characteristics of coal samples, and the characteristics of the sprays produced by some commonly used nozzles. Furthermore, some new recommendations on how engineers can more easily select nozzles for dust suppression systems has been given which should enable them to improve existing systems or design more effective systems in the future.

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1 INTRODUCTION

1.1 Project Background and Objectives

Research by UOW (and others) has found that there is significant variation in the performance of spray type systems used for dust control. Typically, this is a result of the incorrect application of nozzle technology based on the conditions present. Some examples would be, coarse-droplet sprays utilised for airborne dust control, air-atomisers used in high crosswind conditions, or high energy sprays used unnecessarily in confined spaces. New technology, particularly high-energy micro-mist systems have shown significant potential for highly effective airborne dust control, however, quantification of the factors contributing to this remains limited. Furthermore, the suppliers and manufacturers of such systems do not have the capabilities or resources to address all the issues associated with the design of these systems.

To overcome such issues, this research aims to progress two important questions regarding the performance and implementation of dust suppression technology in coal mines:

1. What are the factors contributing to the effectiveness or efficiency of water spraying dust suppression systems?
2. Can the material and/or application conditions be related to a set of performance characteristics that would be used to maximise airborne dust suppression efficiency?

By answering these questions, it will be possible to quantify and evaluate the performance of existing systems and identify areas of improvement (e.g., maximising mist curtain and hence, dust control efficiency). It will also be possible to apply a scientific/engineering approach to optimise the design and implementation of new dust suppression systems for a given set of conditions (addressing all relevant properties and external/application factors).

1.2 Scope of Work

The research is broken up into two primary stages:

1. Review of current practices using water sprays for airborne dust suppression, including a review of systems installed in various NSW mines.

2. Laboratory analysis and modelling of coal and spray properties, as well as relevant application conditions.

The first stage relies on multiple data sources, including previously collected data, available literature, and new data collected during the project. The aim is to provide the background on what current practices are being implemented and/or recommended and where possible understand what the effectiveness of these practices are.

The second stage consists of laboratory work to characterise and model the properties of the materials and sites/systems being studies. This includes collecting nozzles from mines or the suppliers to mines and OEMs for study.

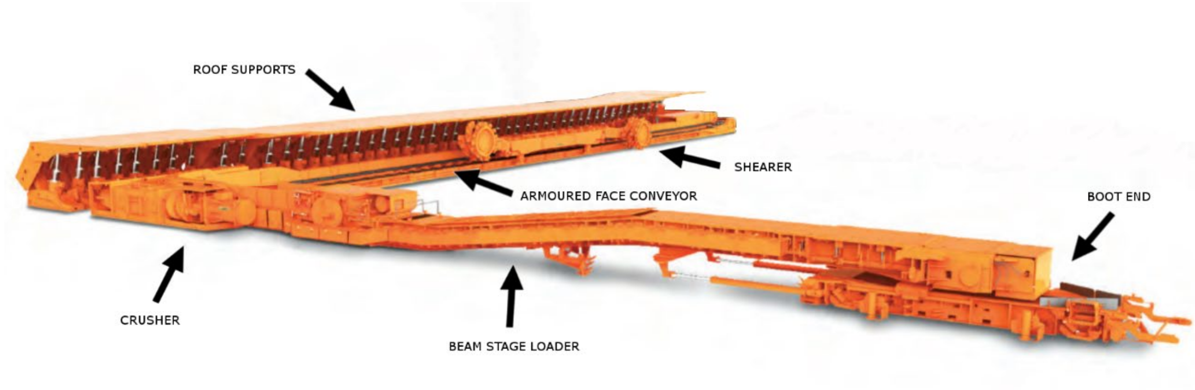
All the data collected is de-identified where possible to ensure sensitive information from site is not distributed in the public domain.

2 REVIEW OF DUST SOURCES AND CURRENT CONTROL PRACTICIES

To provide context to the experimental work being undertaken for this project, it is important that the typical dust sources and control practices are well understood. Hence, the first stage of the project consisted of a review of existing literature on the subject and visits to various sites to collect firsthand data.

2.1 Longwall Dust

Previous research [1] has indicated at least six individual sources of dust on the longwall face of a coal mine. The longwall shearer is the primary dust generator with dust first being generated by the leading drum as it cuts and then again by the trailing drum, but to a lesser extent. The next source is in the motion of the chocks as they are lowered, advanced and set; large amounts of coal are crushed and disturbed during these operations allowing material and dust to fall into the ventilation airflow and spread along the face. Dust can also be generated by spalling of the face ahead of the shearer that can also be picked up by the ventilation and be carried along the face. Similarly, dust can be picked up from the AFC (armoured face conveyor) by the ventilation as the direction of travel for the AFC/material is typically against the flow of ventilation air. This is also the case for any dust that is generated at transfer points or any other material disturbing operations along the intake airways; a commonly reported dust event is at the start-up of a conveyor where settled dust is jolted into the air and subsequently lifted off by the ventilation airflow. Once the material reaches the Beam Stage Loader (BSL) via the AFC the material is crushed, generating large amounts of dust that needs to be controlled in some way (to avoid being picked up by the ventilation airflow). The last typical generation area is from roof and goaf falls, which cause significant plumes of dust to be suddenly generated and once again be spread across the face by the ventilation air. Figure 2-1 shows a typical longwall layout with each of the areas described above labelled.



The major sources of dust in a longwall mine may generate varying quantities of dust and as such their contribution to the concentrations experienced by mine workers varies; this has been quantified in past research particularly for shearer operators as shown in Table 2-1 [2]. This research identified that the majority of dust that shearer operators are exposed to comes from the cutting process itself, with a significant portion also originating at the stage loader.

Table 2-1: Contribution of dust sources to shearer operator exposure [2]

		Mine A	Mine B	Mine C	Mine D	Mine E	Mine F
s.n.	Source	%	%	%	%	%	%
1	Intake	1	5	5	5	9	8
2	stage loader	25	57	19	20.5	64	13
3	supports	10	31	1	1	0	29
4	shearer - cutting	60	10	28	53	15	50
5	shearer - cleaning	4	7	47	20.5	12	0

Figure

2-2 shows outbye dust levels, the dust concentration averaged approximately 0.21 mg/m^3 during steady state conditions with the belt running. The concentration peaked at 0.43 mg/m^3, this occurred when the belt was started after a period of not running. It is assumed that this occurs due to the drying out of fine material on the belt while it is stopped, the belt is then started causing an acceleration to increase lift-off of dust and thus resulting in the increased dust levels experienced downstream. During the testing there were no dust suppression measures in place by the mine directly aimed at capturing the dust coming from outbye on the belt road. However, moisture addition from spray systems on the longwall, crusher, and BSL may have been contributing to reduced dust emissions.

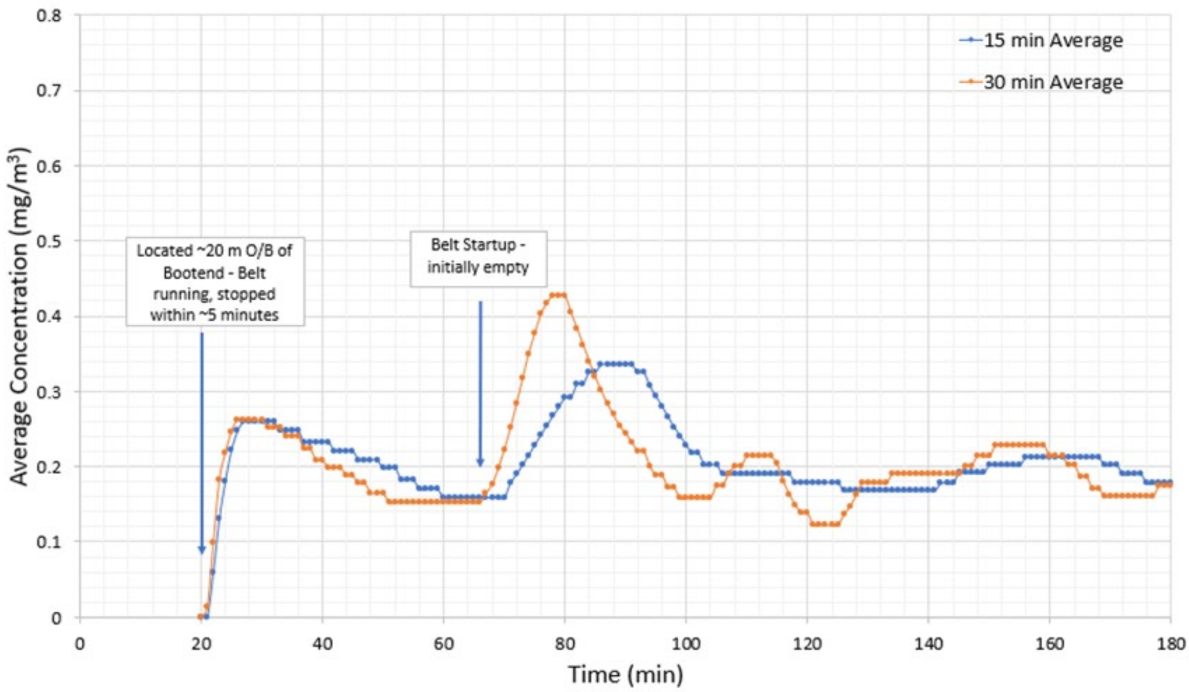


Figure 2-2: Dust levels 20 m outbye of the longwall demonstrating increased dust emissions occurring as a result of belt start-up

The next location looked at was the beam stage loader. Dust on the stage loader platform was evaluated at the mine over two shifts, a day shift (D/S) and an afternoon shift (A/S) to gain an understanding of how concentrations of dust varied from shift to shift. The data collected from the two shifts are overlayed on each other in Figure 2-3; there is considerable variation in concentrations between the two shifts. This highlights that there can be considerable variation in dust make depending on instantaneous conditions or the practices of individual operators.

On average, the data collected during afternoon shift was 40% higher than what was recorded during the day shift. Over both shifts, the average concentration recorded at the stage loader was 0.36 mg/m^3. During monitoring, a high-pressure dust suppression system was in operation. Given that the dust concentration from the intake air was already averaging approximately 0.21 mg/m^3 the contribution of dust coming from the boot end of the stage loader was about 0.15 mg/m^3. The results also showed distinct peaks for dust concentration during certain mining activities, suggesting these activities may require extra dust control measures. The high-pressure dust suppression system operating during the monitoring utilised a series of EnviroMist nozzles located at the entry to the crusher, inside the crusher, and at the boot end discharge. These nozzles will be tested later in this project to assess their efficacy under laboratory conditions.

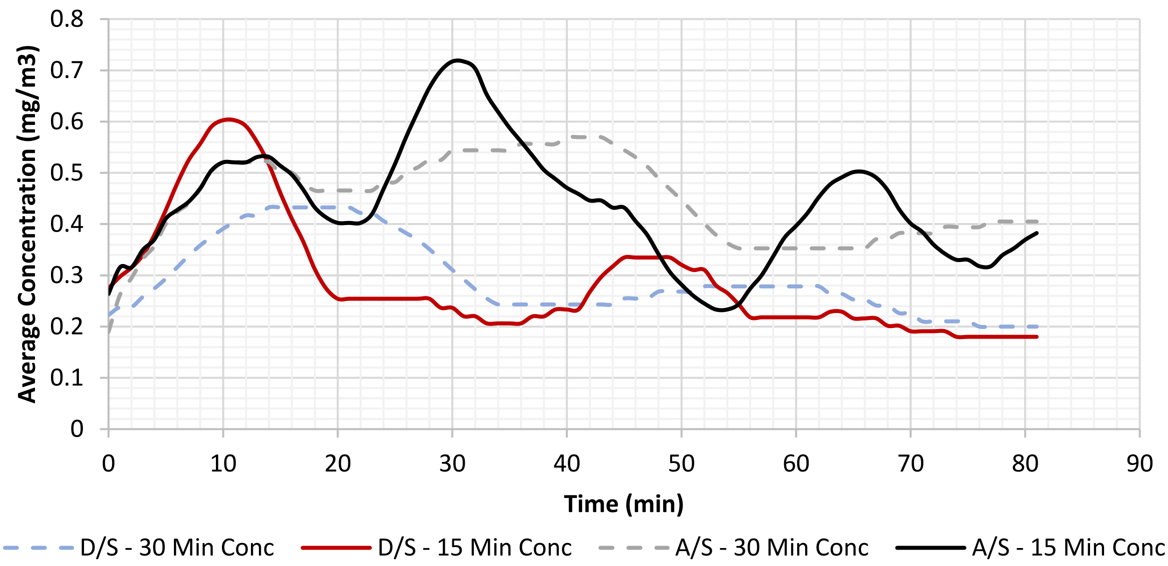


Figure 2-3: Stage loader average dust concentration

As roof supports are lowered, advanced and set the crushed and loose coal falls from between the shields and into the airstream ventilating the face. This material gets picked up by the airflow and dust can be dispersed along the face and thus be a source of exposure for the operators. Some of the control methods used to varying effect, based on anecdotal evidence, include increasing airflow, sprays mounted on the top side of the roof supports and sprays mounted on the underside of the roof supports. Increasing airflow is seen as a way of diluting the dust in the air, however, with increased airflow the levels of dust lift-off also increases which can negate the benefits of dilution. Water sprays spraying onto the top of the roof have also been used as a way of wetting the material to try and reduce the liberation of dust. This can be effective, however, spraying onto the top side of the supports is difficult to achieve and limiting damage to the sprays is extremely difficult. Sprays mounted below the roof facing towards the face are another method, these sprays can pick up dust as it falls and if well designed can aid in directing air flow where desired.

To quantify dust from roof supports, dust monitoring again took place at the same NSW mine. The dust monitor was first placed on the 2nd roof support on the longwall, this location was chosen as it is reasonably protected from shearer dust and thus allows some quantification of the dust being generated due to the movement of the support independent of dust from the shearer. The results of this monitoring are shown in Figure 2-4. The peaks in concentration are well defined and coincide with the movement of the supports, there is a reasonable amount of variability in the results between different support movements and the shifts. Assuming that the level of dust detected at the stage loader is carried through to the roof supports, which is supported by the concentration at the troughs of the graph, then the dust contribution from the longwall due to the movement of the roof supports could be as much as 0.8 mg/m^3 for each movement. Note that the shearer was not cutting during the period circled in red (approximately 20 minutes).

Moving further away from the main gate, the dust concentration was also monitored at the 16th roof support. The 16th roof support allowed the dust generated due to a series of roof support movement sequences to be analysed. Again, well defined peaks are present (Figure 2-5) correlating with the movement of the supports, in this case the peak concentrations are a result of multiple roof support movements in sequence. The contribution of dust from the roof support movements sequentially up to the position of the dust monitor (at support 16) resulted in peak 15-minute average dust concentrations between 1.5 and 2 mg/m^3, up from a concentration of 0.6 mg/m^3 in the troughs when the supports were not moving.

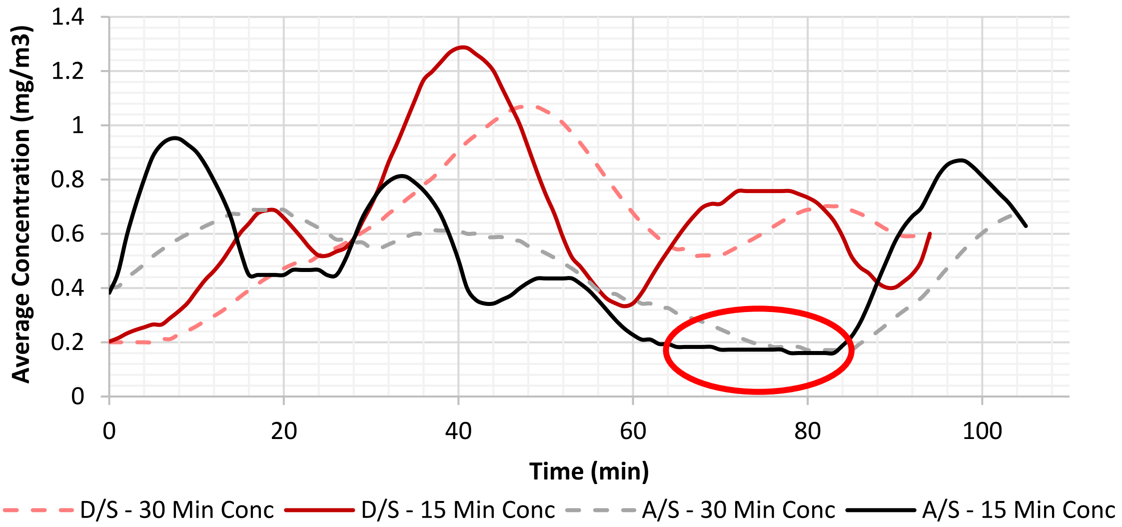


Figure 2-4: Dust concentration at the #2 roof support on the longwall

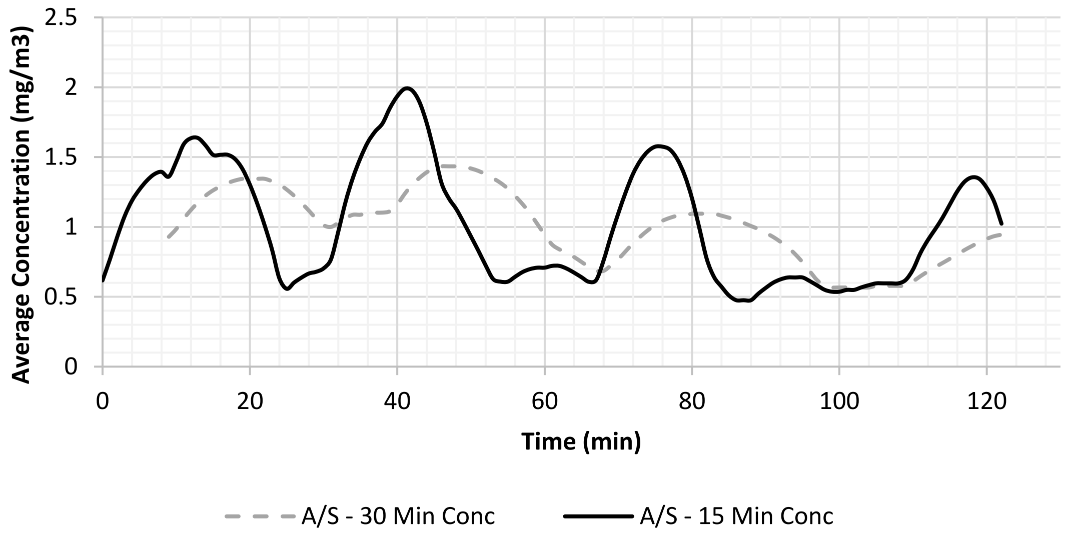


Figure 2-5: Dust concentration at #16 roof support on the longwall

Later monitoring following the installation of a dust suppression system to tackle dust from roof support movement was also conducted, with the results shown in Figure 2-6. During this testing it was possible to vary the water pressure supplied to the dust suppression system to investigate this affect. The system was operated at 16, 60, and 100bar with the corresponding percentage reduction of dust concentration compared with the system off being 27%, 49%, and 83%, respectively. This is an important data set showing the effect of pressure on the performance of a system which is further studied under laboratory conditions in Section 5 of the report.

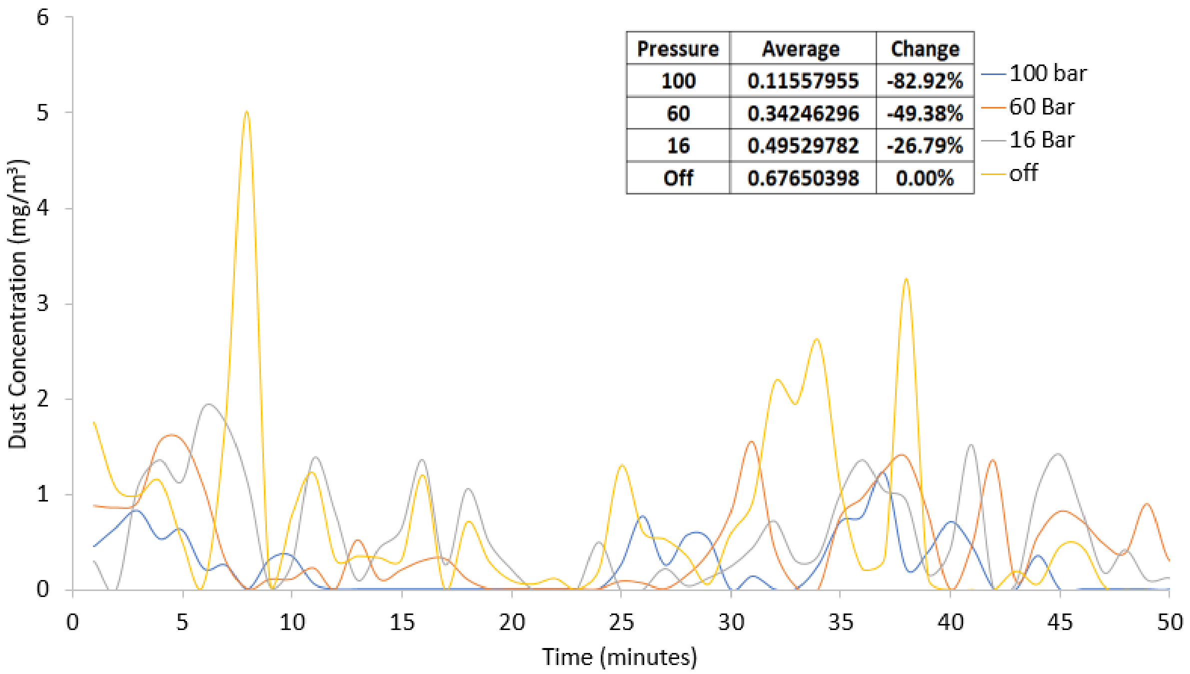


Figure 2-6: Dust concentrations measured with a dust suppression system operating on a series of roof supports at various water pressures

On most longwall faces it is the cutting of the face by the shearer that produces the majority of dust [3]. The primary method of dust control here is through ventilation, which has the effect of both moving dust from the source as well as diluting dust levels in the air. Ventilation air velocity is generally in the range of 2-10 m/s; this is an important metric to consider in the design of a spraying system and will be considered in later laboratory testing. Typically, ventilation is determined based on the need to remove noxious gasses produced by the coal seam and as such the air velocity will be determined by the quantity of air required and the cross-sectional area of the longwall; higher velocities are sometimes used in an attempt to minimise the amount of dust reaching the walkway/working areas. This has been found to be effective in some circumstances especially with the use of directional water sprays [4]. An increased air velocity does, however, create the potential issue of increasing dust lift off and potentially exacerbating the issue. This effect can be reduced by increasing the moisture content of the material closer to its dust extinction moisture [5] using wetting sprays. Wetting sprays can be applied at the shearer drum to increase moisture at the source, it is important at this point, however, that the correct spray type and operating pressure is chosen; if coarse droplet wetting sprays are used at higher pressures it has been reported to increase dust levels by forcing dust away from the cutting drum [1]. Directional water sprays are used as a means of not only dust suppression but also as a way of directing airflow and therefore dust in a desirable direction. Ren *et al.* [3] showed reductions of up to 32% through the use of a venturi-based directional spray system with the redirection of air being the major contributing factor. The shearer-clearer system [6] developed in the 1980's is another example of a directional spray system; these sprays are directed downwind towards the face so that contaminated air is contained along the face rather than being able to escape into the walkway.

The main outcomes from looking at data and previous work related to longwall dust are: ventilation rates are typically in the range of 2-10m/s, which should be factored into the laboratory tests; monitoring of respirable dust found maximum concentrations of approximately 5mg/m^3, though the concentration of total suspended particles (TSP) will be much greater than this; and the spray strategies used are varied and as such any outcomes from the laboratory testing should account for this.

2.2 Roadway Development Dust

As with the longwall, the primary means of dust control during roadway development using continuous miners is ventilation air in combination with water to assist in the control of dust by wetting to reduce dust release or through airborne capture using mist or fogging nozzles. An auxiliary fan is typically used to extract air from the face using a vent duct, this allows for dirty air to be removed from the face and replaced with clean air; if the ventilation system is properly designed, the clean air will flow around the workers on the continuous miner and as such limit their dust exposure. The ventilation flow is typically in the order of 5-15m^3/s, which for standard roadways will typically result in maximum velocities of 1.5m/s. The vent duct can be mounted either on board or externally to the continuous miner; mounting the vent duct on board is advantageous as it allows air to be exhausted at a constant distance from the face. While mounting the duct externally usually requires it to be mounted to one side with the workers needing to continuously adjust its position relative to the face as the miner proceeds forward.

Relatively comprehensive reviews of the use of water spray systems for controlling dust generated by continuous miners have been conducted by Kissel [7] and Colinet *et al.* [1]. However, in both cases much of the research referenced is from the 1980s and 1990s and as such, significant changes in processes and technologies have occurred. Regardless, it is useful to review some of the recommendations made, especially in reference to using water sprays for airborne dust capture as is being pursued in this project.

Kissel [7] and Colinet *et al.* [1] recommended the use of the low pressure (<7 bar) hollow-cone nozzles for airborne dust capture with particular emphasis made on not using high-pressure nozzles. The use of air atomising nozzles was also discouraged due to their complexity and associated maintenance issues. The primary reason provided to discourage the use of high-pressure sprays was due to roll-back effects where it had been found that high-pressure sprays that had been used previously resulted in increased dust levels as a result of air movement generated by the sprays causing dust to overwhelm the ventilation airflow and rollback over the miner. It is interesting that the use of high-pressure sprays in these studies resulted in a rollback of dust; this suggests that the sprays used in the studies may not have had the correct properties for airborne dust capture. It is also possible that during the tests conducted, the low-pressure sprays helped to aid ventilation enough to hold dust generated against the face but not so much that they increased the air velocity resulting in flow rolling back over the miner.

Site visits were also conducted to aid in understanding the dust generation from continuous miners, in this case the mine visited utilised a JOY 12CM30. As expected, the primary source of dust is during cutting with a progressive increase in dust being released as the drum cuts from the roof to the floor where qualitatively the maximum amount of dust appears to occur at approximately the mid-point of cutting. Once the cutting drum gets closer to the floor the drop height for material becomes less and the general dispersion of dust reduces, although it is likely that dust is still being released in large quantities, but it is better contained. The main exposure zones observed for the workers was due to: dust rolling back over the miner, dust travelling up the conveyor and escaping out the sides, and dust released during loading onto the shuttle car. Based on this, an effective dust suppression system should aim to capture the initial dust released during cutting using an effective fine mist spray which should eliminate the majority of dust including that travelling up the conveyor. However, additional sprays could be used on the conveyor to help capture any dust that may be remaining in this zone and also to aid in wetting the material to reduce dust released during loading onto the shuttle car.

Dust monitoring on the continuous miner (JOY 12CM30) was conducted in an attempt to quantify circumstances. In the case of the mine monitored, the ventilation rate was approximately $9m^3/s$ and the roadway cross-section was 3.2m by 5.2m giving an average air velocity of approximately 0.6m/s. The miner had an EnviroMist dust suppression system installed, utilising EM.GIZ.06 nozzles operating at 100bar. Unfortunately conducting the dust monitoring on the continuous miner proved quite difficult with the mine not cutting during the first visit and only conducting four cuts on the second visit. Regardless, real time monitoring from a PDM3700 allowed a small sample of data to be collected, as shown in Figure 2-7. The mine was utilising an external duct arrangement and the monitor was placed on both sides of the machine close to the standing position of the mine workers. The data shows that the concentrations are relatively acceptable being below the recommended limit for respirable dust concentration ($1.5mg/m^3$). This suggests that the system installed was working as intended. It is, however, interesting that the dust concentration was higher on the duct side, which suggests some level of dust roll back may be occurring.

The primary consideration coming from a review of dust around the continuous miner is the risk that has been previously reported and also noted during site visits of dust roll back. This requires designers to be able to more tightly optimise the pressure of a system to ensure there is not too much energy in the spray. Outside of dust roll back, air velocities are very low and will have limited influence on the spray, while dust concentrations are similar to that experienced on the longwall.

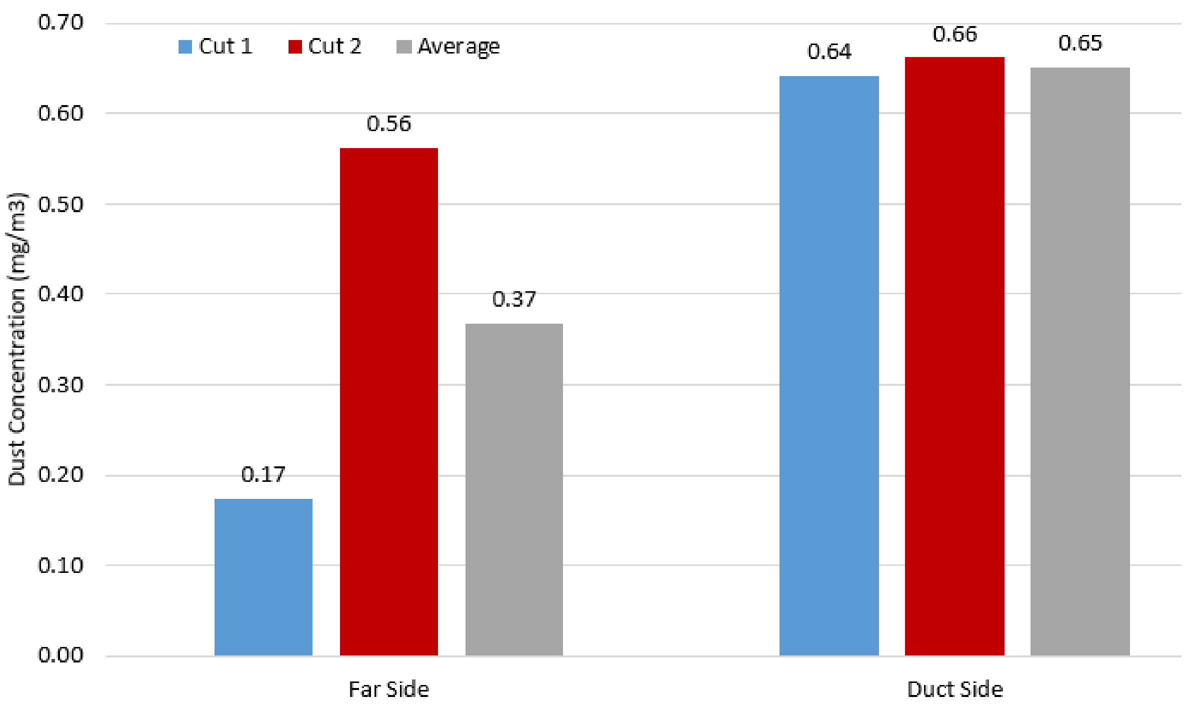


Figure 2-7: Dust concentrations measured on a JOY 12CM30 when cutting in an NSW coal mine

2.3 Dust during Bin Loading

Dust emissions most commonly occur where a bulk material (e.g., coal) is disturbed, where the more rapid the disturbance and larger the quantity of bulk materials the greater the dust emissions are likely to be. As such, loading coal into bins or hoppers is one of the most common areas where significant dust emissions are reported. Two mine sites in NSW were visited to investigate the emissions from this process.

The first site visit was conducted to review the dust emissions occurring at two ROM bins which will be noted ROM bin A1 and ROM bin A2. An elevation view of ROM bin A1 can be seen in Figure 2-8. The ROM bins are similar in design where bin A1 has a hopper opening of 8690mm x 8690mm and bin A2 has an opening of 9600mm x 8690mm. Bin A1 has winged upper walls, as shown in Figure 2-8, where bin A2 has vertical walls. Limited drawings were available for bin A2, however, a photo is provided in Figure 2-9.

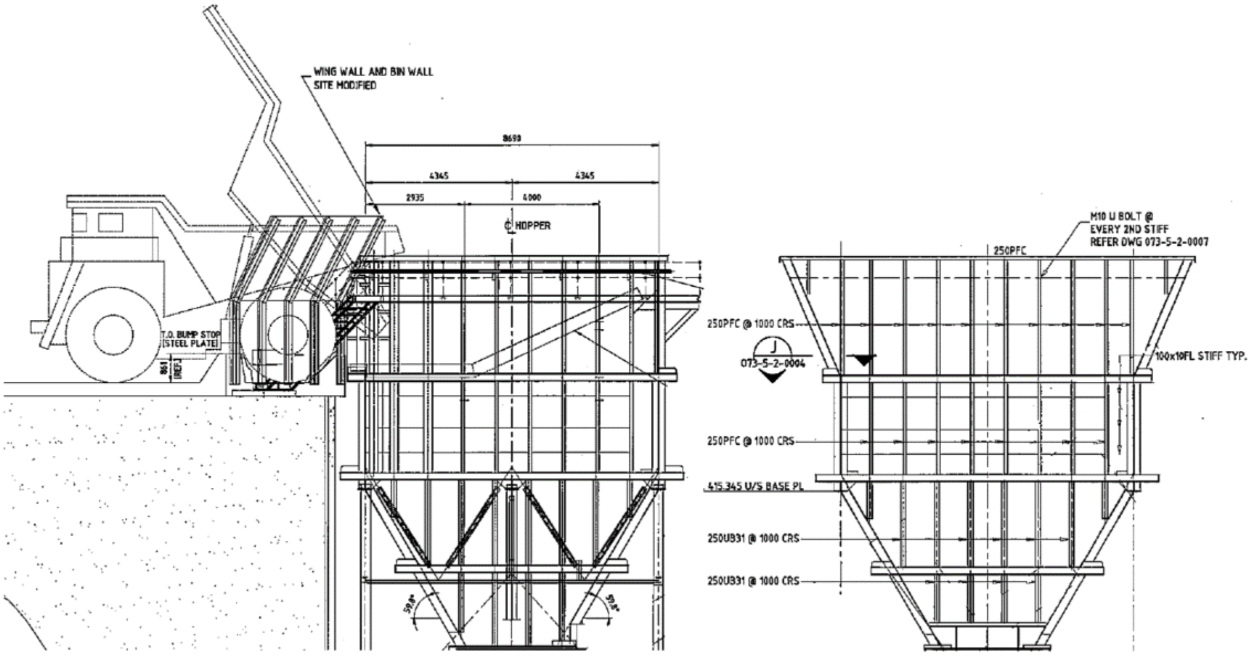


Figure 2-8: Elevation view of the ROM bin A1

Figure 2-9: Photo of ROM bin A2

The bins are loaded by 200 tonne dump trucks where each bin has dust suppression sprays installed for capture of dust generated by the unloading process. The dust suppression systems utilised 1" FF nozzles from Spraying Systems Co.® (see Figure 2-10) operated at 2-5 bar. Each bin had six (6) nozzles installed on each wall (3 off) for a total of eighteen (18) nozzles. The capacity size of the nozzles is not known; however, it can be estimated that the systems are currently using 1440-3100 L/min when all nozzles are operating; most likely it is at the lower end of this range or even lower as it was observed during the site visit that many of the nozzles were not operating due to blockages or other issues.

FF
3/4" to 1-1/4" female conn.
One-piece

N PERFORMANCE DATA:
NARROW ANGLE SPRAY

Inlet Conn. (in.)	Nozzle Type FF	Capacity Size	Flow Rate Capacity (liters per minute) 1.5 bar	3 bar	4 bar	6 bar	7 bar	10 bar
3/4	•	4.8	13.4	19.0	22	27	29	35
	•	9	25	36	41	50	54	65
	•	12	34	47	55	67	72	86
	•	18	50	71	82	101	109	130
1	•	25	70	99	114	140	151	180
	•	35	98	138	160	195	211	252
1-1/4	•	50	140	197	228	279	302	360
	•	70	195	276	319	391	422	505

Highlighted column shows the rated pressure.

Figure 2-10: Nozzle type currently installed in the ROM bins, supplied by Spraying Systems Co. ®

Figure 2 11 shows the dust emissions generated when loading into the bins. The severity of the dust emissions is highly dependent on the origin of the coal being loaded into the bin. It is evident in the photo that the emissions from bin A2 are significantly worse than those from bin A1 which given the similar bin design is most like due to different the coals being fed into the bins. During the site visit, bin A1 was being loaded with Coal E while bin A2 was being loaded with Coal F. It was originally thought that this would be due to differing properties between Coal E and Coal F, however the results in Section 3 of the report show that the two coals are very similar. It is therefore most likely that Coal F had a lower moisture content than that of Coal E which resulted in far greater dust emissions. This highlights the effect that moisture content has on the ability for dust particles to be liberated from bulk solids such as coal.

Figure 2-11: Photo captured of dust emissions released during dumping process

A dust monitor was placed on the walkway of ROM bin A2 during the site visit to provide an indication of the concentration of dust being released per dump. Unfortunately, due to the high wind during the site visit, the sampler had difficulty collecting the dust before it was swept away by the wind. During the site visit dust would be generated, released into the air and swept away from the bin by the wind within approximately 20s.

A sample of the data is provided in Figure 2-12; the monitor (PDM3700) detected an average concentration of 1.2 mg/m^3 and a maximum of 5.5 mg/m^3 over the sampling period. As such, the data collected should be considered as an average per minute keeping in mind that the dust cloud is generated and swept away by the wind in under 20s. Based on this and experience in monitoring dust at other sites it is safe to assume that the actual dust concentration released from the bin is much higher than the figures detected. It is estimated that the actual concentration of suspended particles would be in excess of 100g/m^3 based on the images and videos captured of the dust clouds.

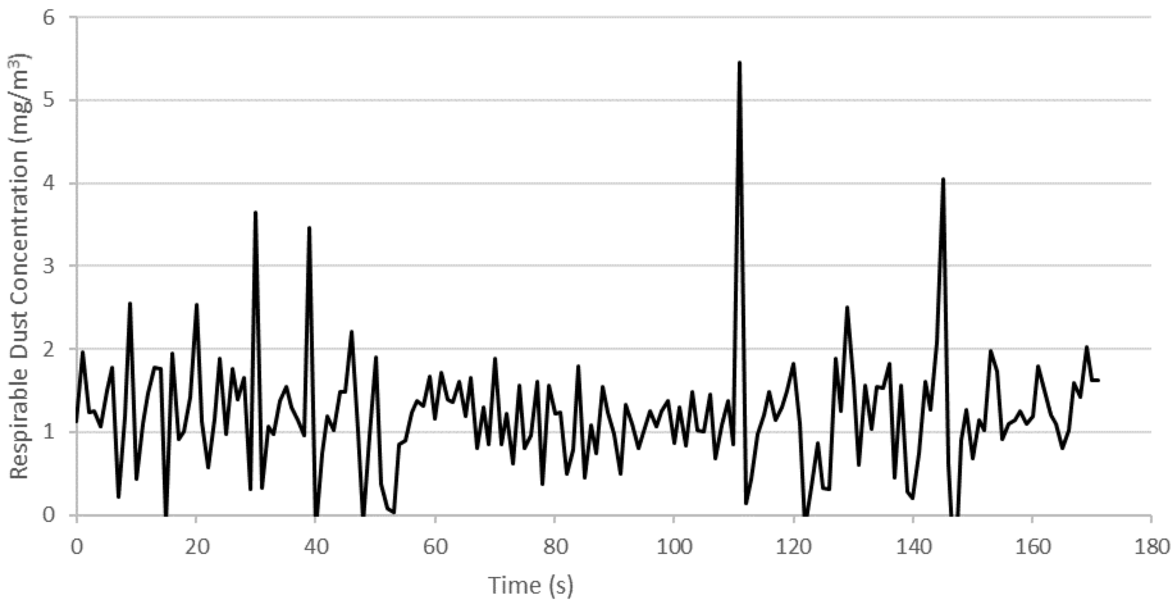


Figure 2-12: Respirable dust concentration measured at ROM bin A2

The site visit allowed for videos to be captured of the dumping process. The sequence of dust generation can be seen in Figure 2-13. The trucks are given a green light signal to allow them to initiate the dumping process (tray circled in yellow). It takes approximately 10-15s for initial dust to be released and flow into the air above the bin walls and another 10-15s for dust to become fully dispersed by the wind, depending on conditions. The primary dust flow zone is up the back wall of the bin which can be seen by the dense cloud in image 3, which is typical of a ROM bin of this type. Another source of dust seen during the visit was from the tray of the truck during initial unloading, where dust was being released from the flow stream due to the high winds present on the day.

Figure 2-13: Sequence of material unloading and dust generation recorded during site visit

The release of dust can be categorised into three primary mechanisms that occur during the dumping process:

1. from material being unloaded from the tray where the fines are dispersed into the air, typically at this stage most of the fines continue to flow with the ore stream, though significant release can occur due to high winds as seen during the site visit;
2. as material flows into the bin, the air within the bin is displaced, which drives the dispersed fines upwards into the air; and
3. a quantity of air is entrained by the accelerating bulk material stream and this air is suddenly pushed out with dust from the impact zone.

Looking at the videos captured during the site visit, the dust cloud velocity can be estimated by measuring the time taken for the dust cloud to travel a known distance. In this case, the platform around the bin has been used as the reference dimension of approximately 1m, allowing for the distance the cloud travelled over 30 frames (video captured at 30 frames per second) to be estimated as 3m. Therefore, it can be estimated that the dust cloud travels at a velocity in the order of 3 m/s or slightly higher. Figure 2-14 provides an example of how the analysis is performed, however, the actual analysis was performed using CAD and Figure 2-14 has been provided as a demonstration only.

Figure 2-14: Estimation of dust cloud velocity using frame by frame analysis of videos captured during site visit

Previous research [8] conducted at UOW investigating air and dust cloud velocity within ROM bins very similar to those at the site visited can also be used to assist with understanding the flow dynamics. Figure 2-15 provides contours of velocity across a slightly larger bin (11m x 12m) being loaded with 250 tonnes of material, whereas the bins at this site were approximately 9m x 9m being loaded with 200 tonnes of material. Due to this bin being larger in size, the velocities developed in the bin are slightly lower than what has been estimated here, though still quite similar. A cross-section of velocity is shown at a position slightly below the top of the bin walls to indicate the potential velocity that the sprays will be exposed to mounted on top of the bin wall. It is evident that the peak flow velocity occurs along the back wall of the bin and in particular in the corners.

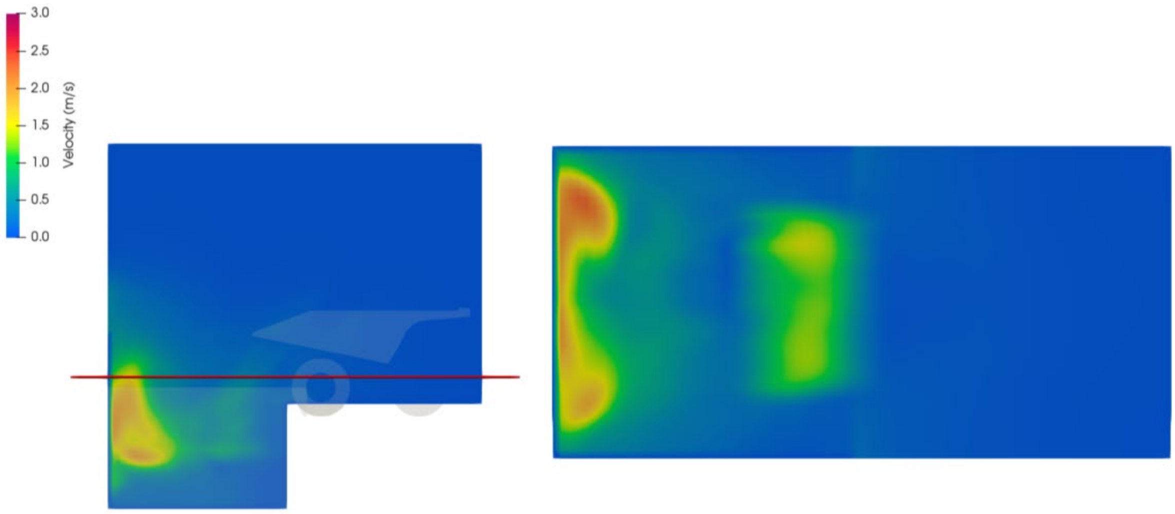


Figure 2-15: Contours of velocity from CFD-DEM simulation. Truck has been shown for reference only.

A second site was also visited to look at the dust emissions from a series of bins being loaded in this case via belt conveyor. An elevation view of the bins can be seen in Figure 2-16. The bins are of 10m diameter, where the coarse coal bins (focus of the investigation) specifically are fed by a tripper conveyor, as shown in Figure 2-17.

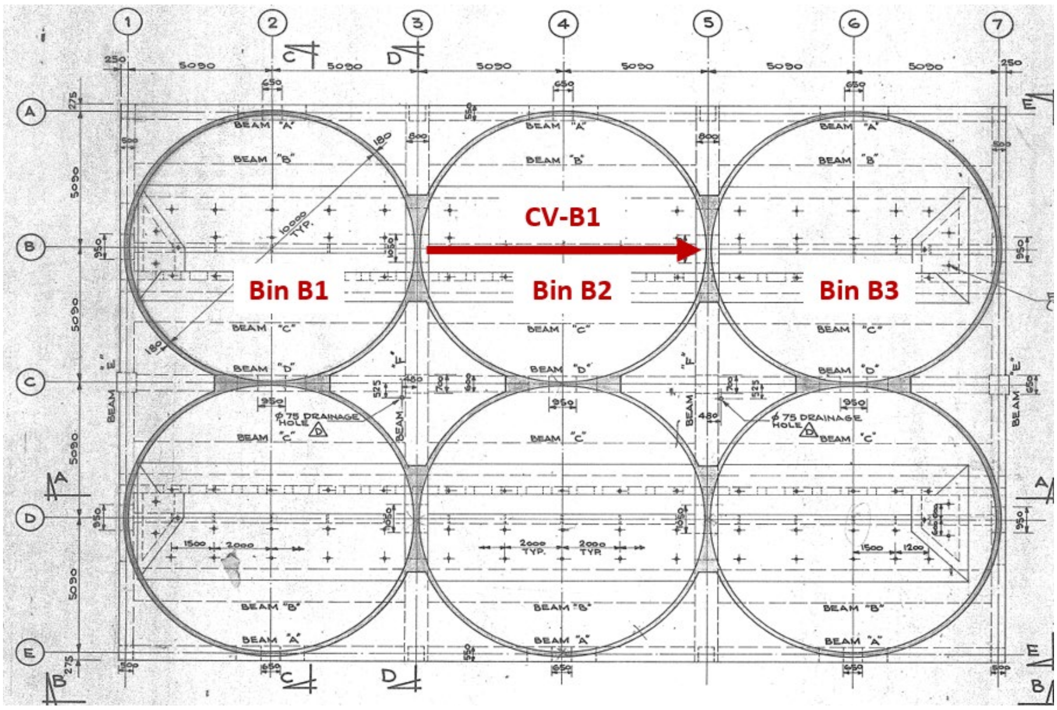


Figure 2-16: Elevation view of the coarse (Top) and fine (Bottom) coal bins

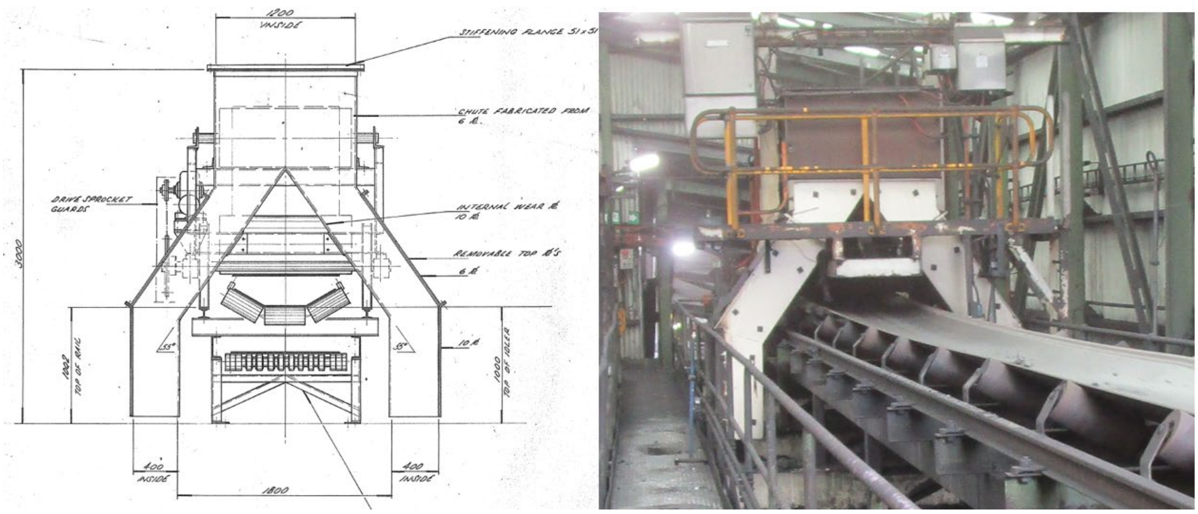


Figure 2-17: CV-B1 Tripper

The bins are loaded continuously at rates of up to 600tph, where each bin is currently fitted with low pressure dust suppression systems which are actuated according to the bin being loaded. Each bin appeared to have approximately twelve (12) nozzles (six located on each side of the conveyor), though during the visit the sprays were only seen operating in bin B2 with at least one of the spray nozzles blocked at the time. The nozzles currently installed are shown in Figure 2-18 alongside the operating pressure seen on the day of 400kPa (4 bar). The current nozzles are supplied by Spraying Systems Co.® and are of type LN. Based on the Spraying Systems catalogue it is estimated that the nozzles will have a nominal flow rate of 1-2 L/min, resulting in a total flow rate of 12-24 L/min for each bin. Test results for this nozzle type are provided in Section 5 of the report.

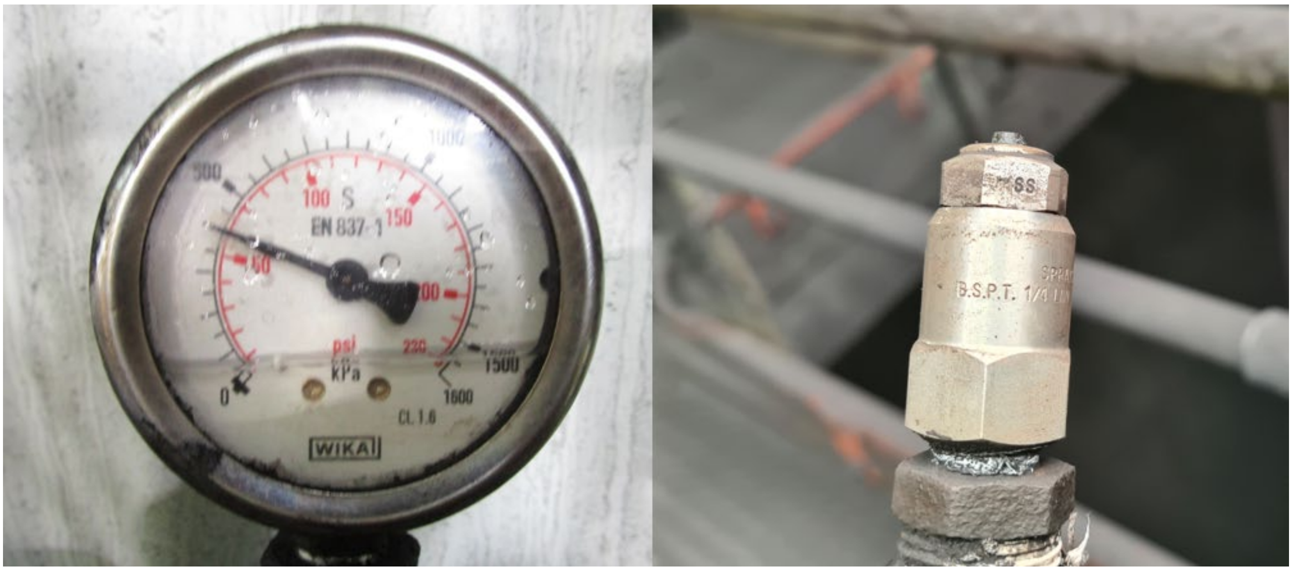


Figure 2-18: Left: System operating pressure, Right: Nozzle type currently installed in the bins, supplied by Spraying Systems Co. ®

The sprays currently installed can be seen in Figure 2-19. As can been seen from the image, the nozzles generate a spray with a high initial cone angle but are low energy, resulting in limited coverage over the bin. This results in a system that is largely passive, relying on a slow dispersion of mist over time to provide enough coverage over the bin for dust capture to occur. It is evident from the image that this is not occurring resulting in large gaps between mist clouds for dust to escape out of the bin through.

Figure 2-19: Sprays currently installed in coarse coal bin B2

Figure 2-20 shows the dust issues qualitatively based on the general haze in the air surrounding the tripper and the dust that settled on the dust monitor over the monitoring period; note that the haze shown in the image is likely to be a combination of dust and mist produced by the sprays. The dust monitor was located on the walkway adjacent to the coarse coal bins for approximately 5 hours to monitor concentrations of respirable dust over that period. The data collected is provided in Figure 2-21; the monitor collected an average of 1.26 mg/m^3 and a maximum of 4.84 mg/m^3 over the sampling period.

Figure 2-20: Left: Photo of dust monitor before and after monitoring, Right: Photo of dust haze surrounding tripper

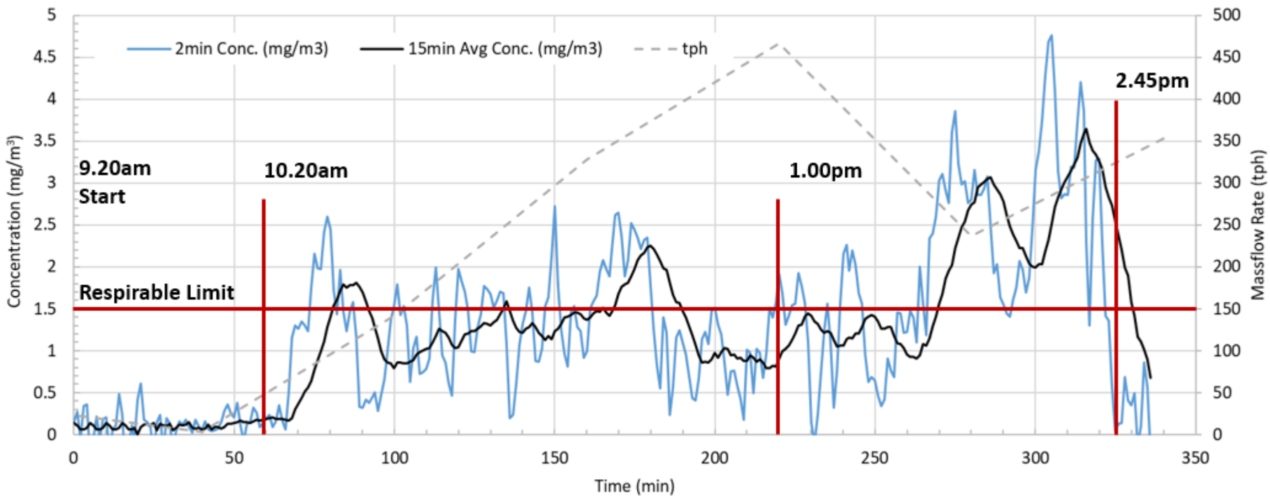


Figure 2-21: Respirable dust concentration measured at coal bins

Looking at Figure 2-21 in more detail there are three periods marked. The first period until 10.20am represents background dust levels when material is not being loaded into the bins, but the conveyors were running. Over this period the average respirable dust concentration was 0.12 mg/m^3. The second period marked (approx. 10.30am – 1.00pm) was noted by site personnel as being lower than typical dust concentrations (qualitatively), the measured average over this period was 1.26 mg/m^3. The third period showed a significant increase in dust concentration which was visible to the eye and was noted by site personnel as representing moderate conditions, the measured average over this period was 2.04 mg/m^3; the monitor was removed from the dust source at 2.45pm.

A CEL-712 Microdust Pro was also used for measuring total suspended particles (TSP) in the air, this device is a passive device which measures all particles passing through a measurement area (e.g., there is no pump or other mechanism forcing dust through the measurement zone). This device allows quick assessment of dust emissions based on a 2 second recording interval. Figure 2-22 shows dust concentration measured on the walkway adjacent to the tripper while loading into the coal bins and directly above the impact plate on the tripper, the average concentrations were 6.14 mg/m^3 and 2.75 mg/m^3, respectively. This data suggests that the majority of the dust is being generated on impact into the bins rather than within the transfer chute itself. It also shows that the TSP concentration is significantly higher than the respirable dust concentrations measured using the PDM3700.

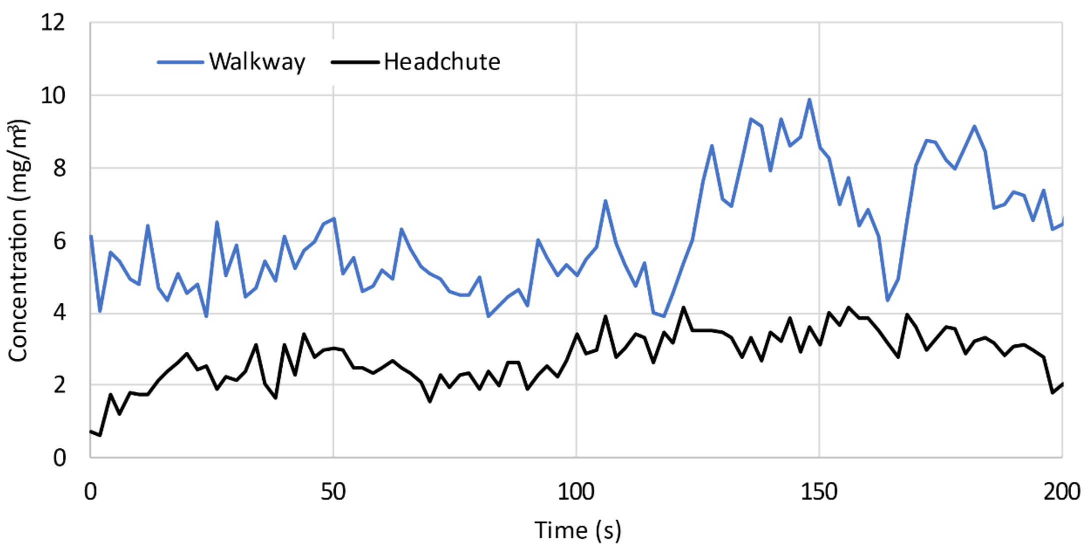


Figure 2-22: Dust concentrations measured over ~3 minutes at coarse coal bin

The main conclusions considering dust from bin loading are dust cloud velocities are in the order of 5m/s and that dust concentrations are very high but difficult to measure due to the short duration. It is estimated that TSP concentrations of greater than 100g/m^3 could be occurring which is likely the highest point source concentration that occurs on a site.

2.4 Dust at Conveyor Chutes

Conveyor transfer chutes are another area where dust emissions are likely to occur. A CEL-712 Microdust Pro was also used for measuring the total dust in the air at the exit of the stilling chambers for a number of chutes. This included the exit of the stilling chamber from a conveyor which loaded the bins described in the previous section. The dust concentration measured over approximately 5 minutes is provided in Figure 2-23, where the average concentration was 5.4 mg/m^3 and the maximum concentration was 13.3 mg/m^3.

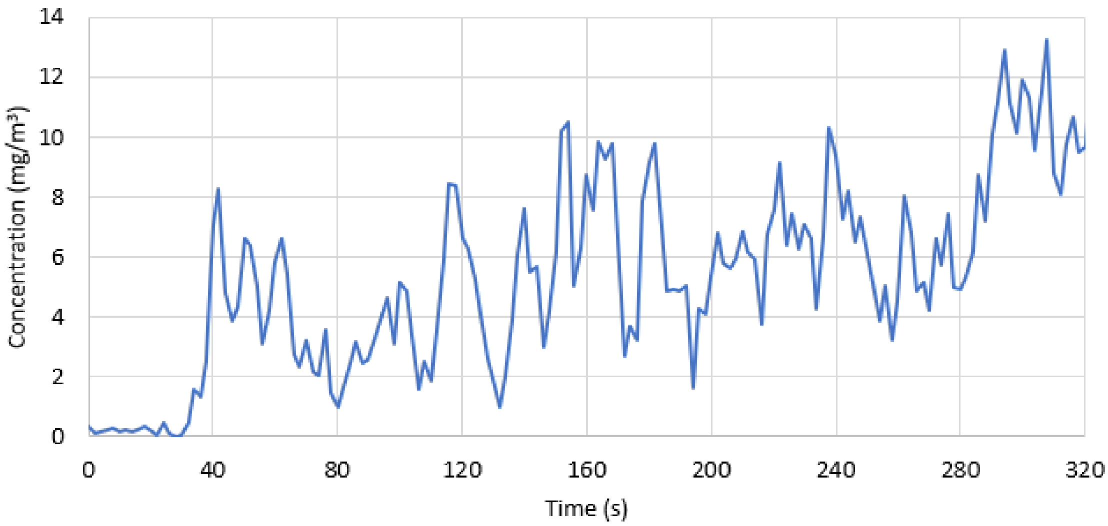


Figure 2-23: Dust concentrations measured over ~5 minutes at exit of a conveyor stilling chamber

The loading points for a series of centrifuges discharging to a conveyor were also measured during a site visit to understand the dust emissions occurring. On the day of testing four centrifuges were operating and an average of 700 tph was being conveyed on the conveyor. Figure 2-24 shows the points of interest that were monitored and Table 2-2 shows the velocity and dust concentration measured at each point. The data in Table 2-2 indicates a clear correlation between the air velocity out of the stilling chamber at each location and the dust concentration measured at that location. The highest average dust concentration of 44 mg/m^3 was measured at location F, corresponding to the exit of the stilling chamber from a series of 5 centrifuges in a row and had an air velocity of approximately 2 m/s out of the stilling chamber.

The lowest average dust concentration of 0.12 mg/m^3 was measured at point E which had an air velocity of approximately 0.5 m/s into the stilling chamber.

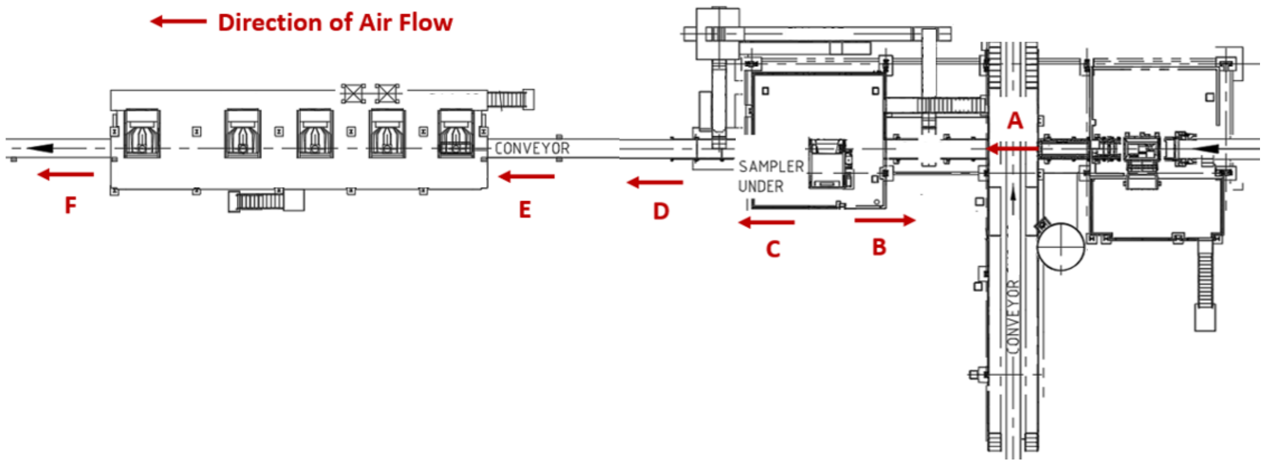


Figure 2-24: Locations of dust monitoring and air velocity sampling points

Table 2-2: Air velocity and dust concentrations measured along conveyor

Location	Air Velocity (m/s)	Average Dust Concentration (mg/m^3)	Max Dust Concentration (mg/m^3)
A	0.4	0.22	1.46
B	1.2	20.55	66.62
C	0.75	16.21	23.39
D	0.3	0.61	1.51
E	0.5	0.12	0.28
F	2.0	43.78	59.74

Location A corresponds to the outlet immediately following a dust collector (viz. Figure 2-26) which showed relatively low dust concentrations on average but did show short increases corresponding to dust release from a dust collector during the cleaning cycle, as shown in Figure 2-25. This highlights the importance of any intermittent operations that may cause short term dust emissions.

Locations B and C, either side of one of the centrifuges, provides a good example of the impact the conveyor stilling chamber is having on dust release. While operating it is clear that the centrifuge is increasing the volume of air within the stilling chamber, resulting in the high velocity seen at the inlet of the chamber (Point B) against the direction of flow, however the airflow is less at the outlet (Point C) which is likely due to the greater stilling chamber length at the outlet which helps reduce the velocity and consequently the concentration of dust.

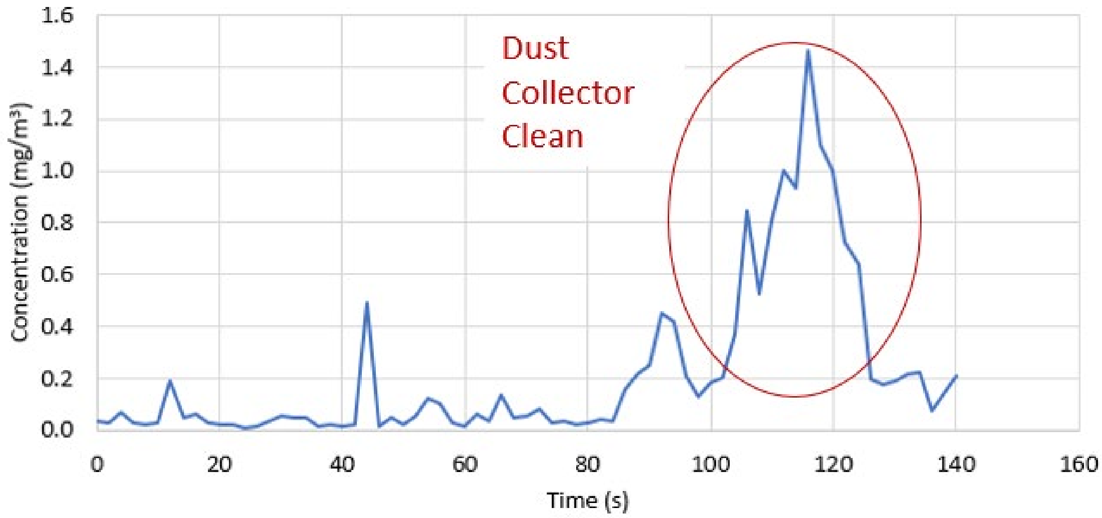


Figure 2-25: Dust concentration measured at conveyor stilling chamber outlet following a dust collector

Figure 2-26: Dust monitoring at conveyor stilling chamber outlet connected to a dust collector

The conclusions that can be made regarding dust around conveyor transfers is that the velocities occurring are relatively low (~2m/s) but due to the concentrated nature of a stilling chamber the dust concentrations can be quite high with a maximum concentration of 67mg/m^3 measured on site. The concentrated nature of the dust emissions does, however, make dust suppression system design easier due to the clearly defined area for sprays to provide coverage over.

2.5 Summary

This phase of the project aimed to investigate the current conditions and where possible dust suppressions systems currently operating in Australia. Four different broad areas where dust emissions are commonly an issue in coal mines has been considered and investigated, this included dust emissions from, the longwall, roadway development, bin loading, and conveyor transfers. Dust monitoring was undertaken at various sites to gain an understanding of typical concentrations that workers or the broader environment may be exposed to. Monitoring of respirable dust concentrations found that, at the sites tested, dust concentrations were typically less than 5mg/m^3. While monitoring of total suspend particles resulted in measurements in excess of 60mg/m^3, and estimates were made based on qualitative data that the concentrations in some scenarios could exceed 100g/m^3 (viz. ROM bin loading). Air velocity in the region of dust emissions were also considered across all areas considered where it was found that velocities are typically in the range of 2-10m/s. This data serves as a reference for the experimental testing in the second phase of the project.

3 LABORATORY TESTING RESULTS – COAL PROPERTIES

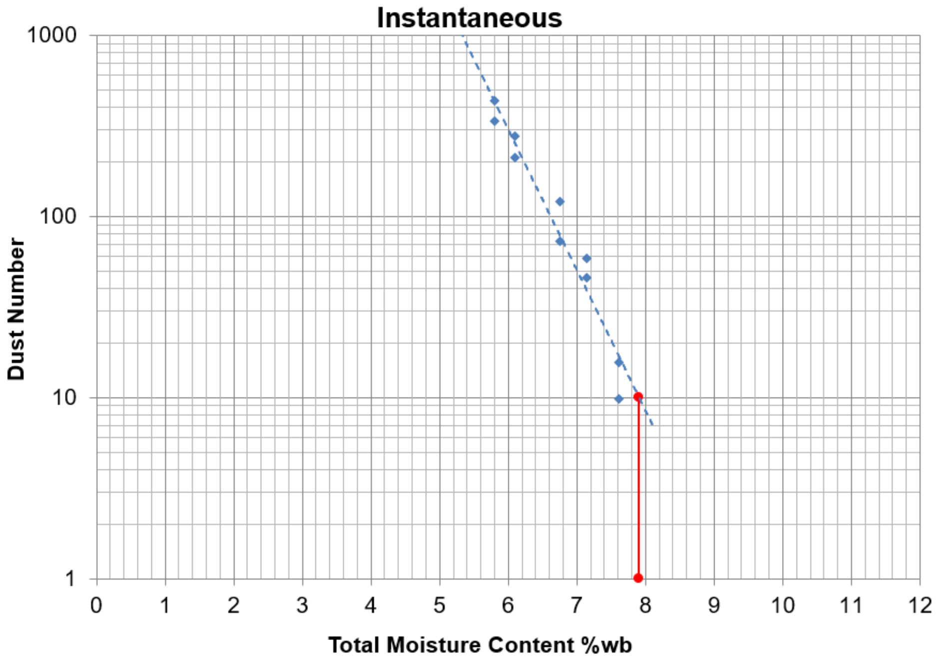
The purpose of this chapter is to present and analyse data from various coals to quantitatively measure and determine the differences in how each coal behaves in different circumstances. Coal A to Coal G are coals sourced from numerous New South Wales coal mines. Coal H is an coal sourced from overseas, included in the data to show the vastly different results which can exist in coal samples.

3.1 Dustiness

This section will follow the specifications set by AS 4156.6-2000 to produce a dust/moisture curve of various coals and determine the dust extinction moisture (DEM) content for the tested materials. The dust/moisture curves and DEM will be presented for both the instantaneous dust levels i.e. measured immediately after testing, and using the standard presentation of the 24hr settled measurement. The moisture levels for all samples were calculated using a standard moisture test. A summary of all dust extinction moistures can be found in Table 3-1.

3.1.1 Coal A

(a)



(b)

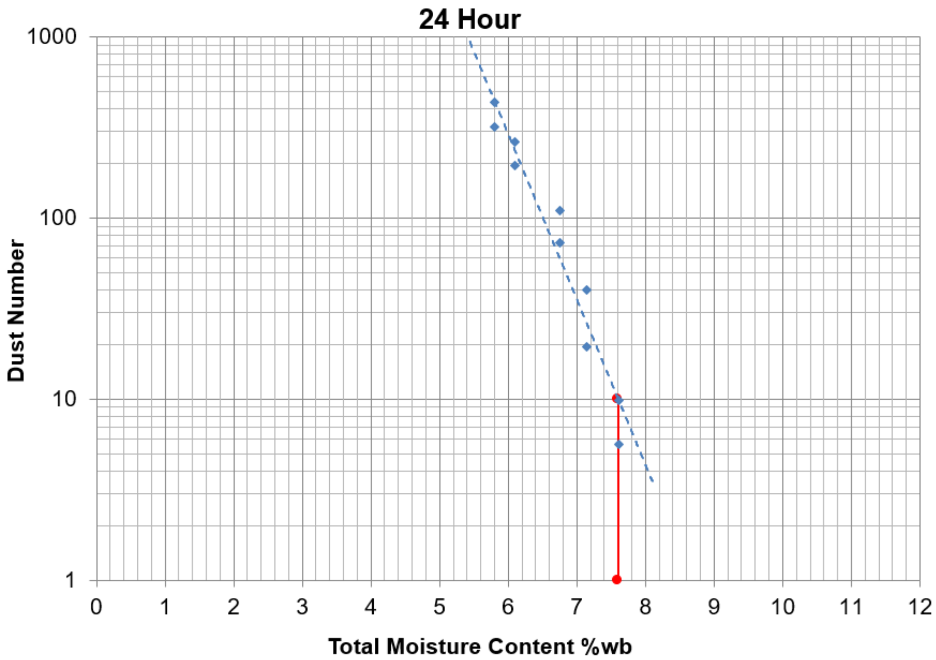
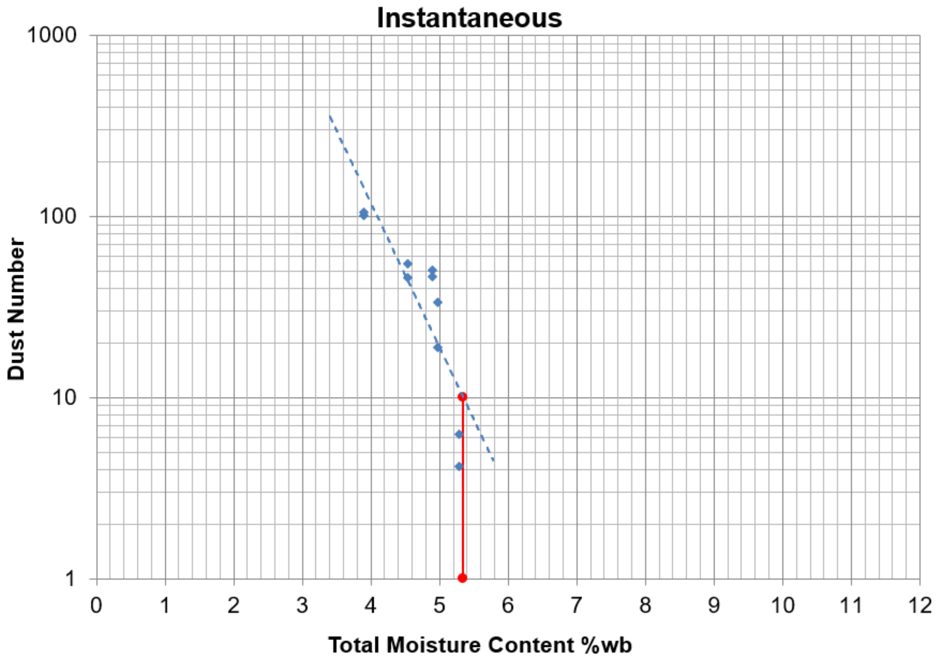


Figure 3-1 Australian Standard Dust/Moisture Curve (Coal A) for (a) Instantaneous Dust Number (b) 24-hour Dust Number

3.1.2 Coal B

(a)



(b)

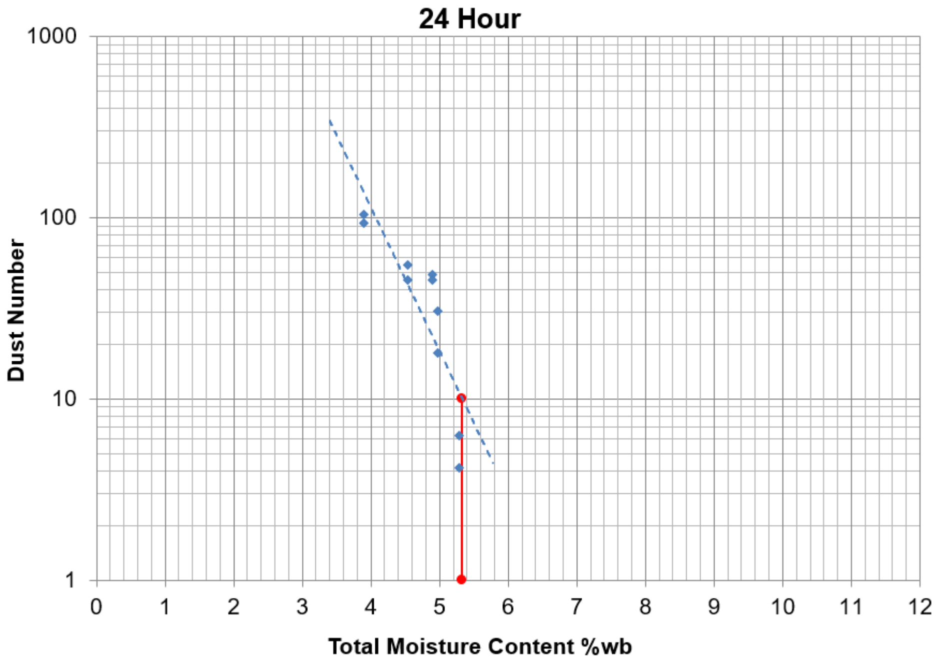
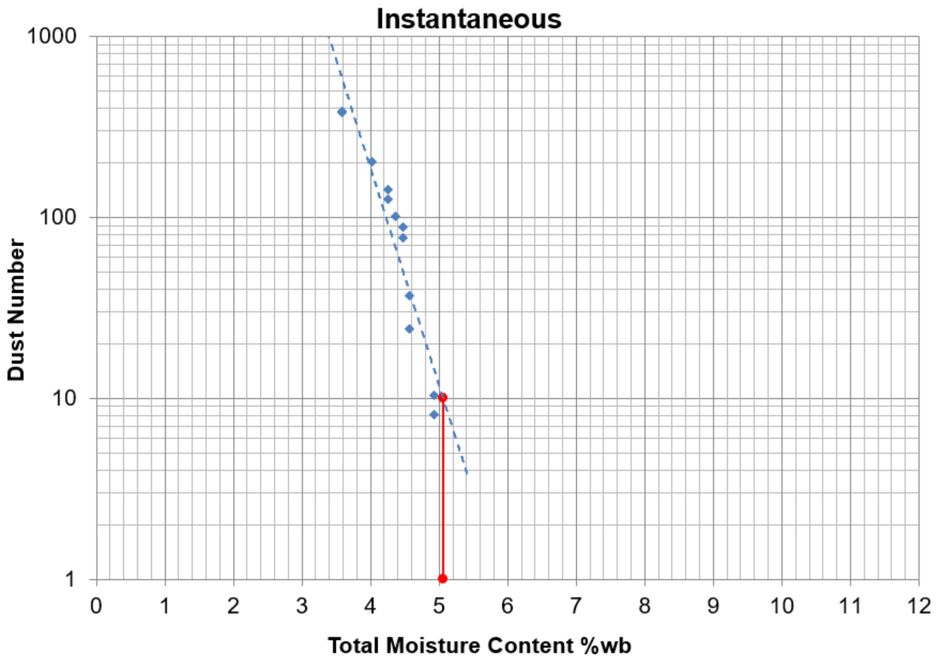


Figure 3-2 Australian Standard Dust/Moisture Curve (Coal B) for (a) Instantaneous Dust Number (b) 24-hour Dust Number

3.1.3 Coal C

(a)



(b)

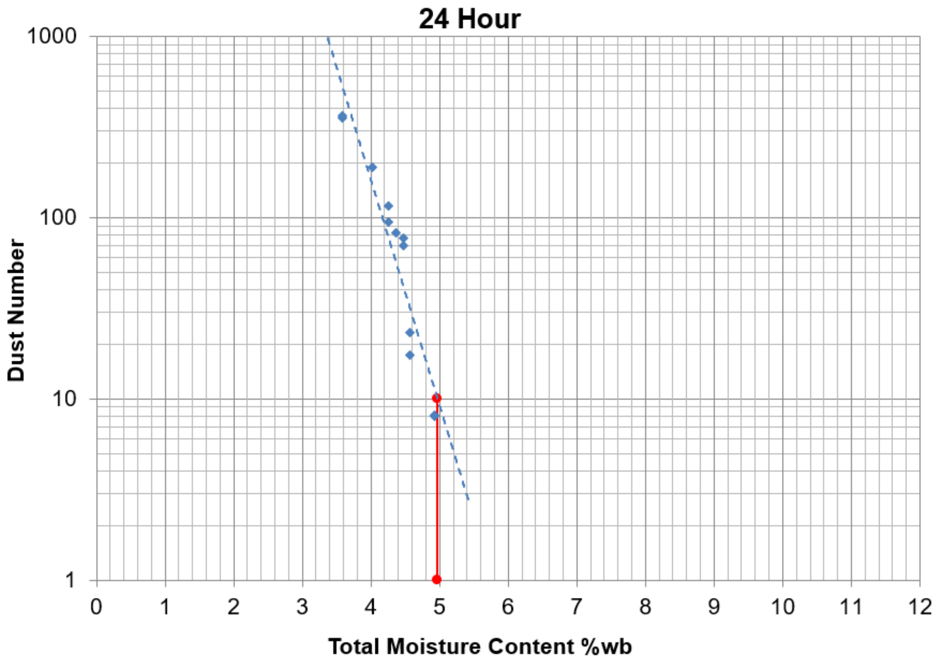
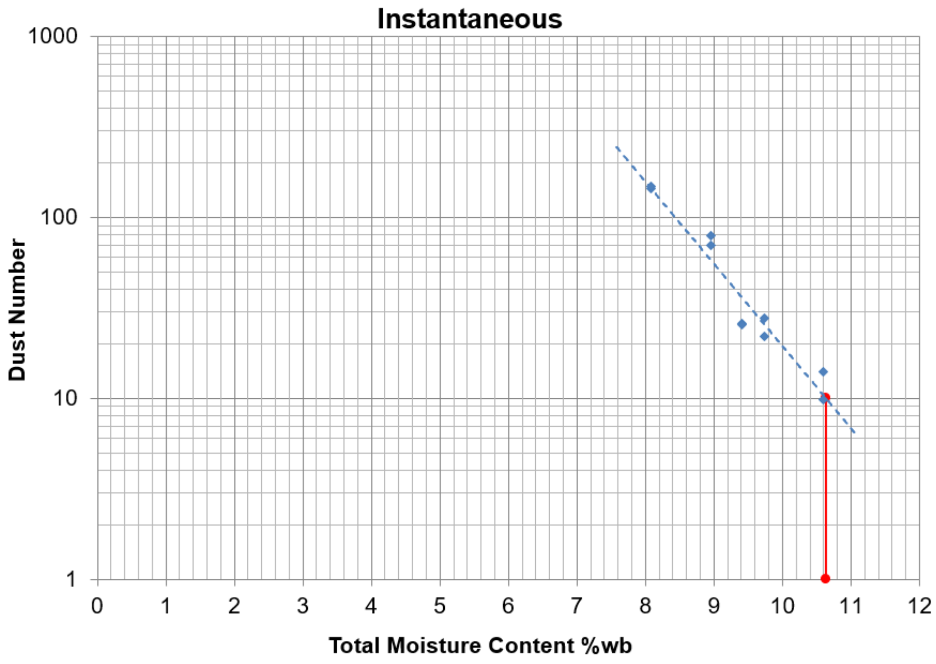


Figure 3-3 Australian Standard Dust/Moisture Curve (Coal C) for (a) Instantaneous Dust Number (b) 24-hour Dust Number

3.1.4 Coal D

(a)



(b)

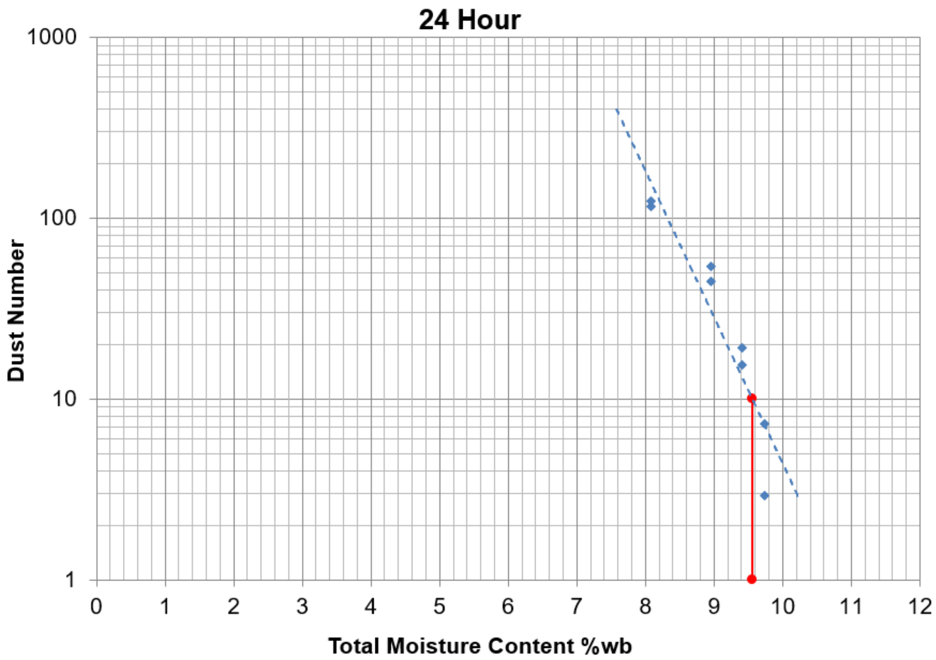
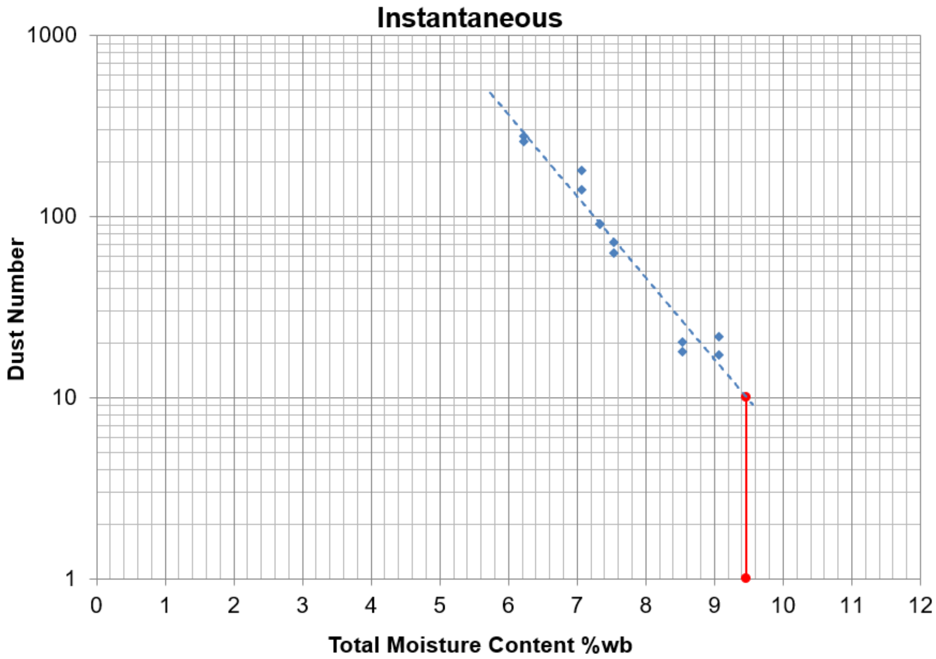


Figure 3-4 Australian Standard Dust/Moisture Curve (Coal D) for (a) Instantaneous Dust Number (b) 24-hour Dust Number

3.1.5 Coal E

(a)



(b)

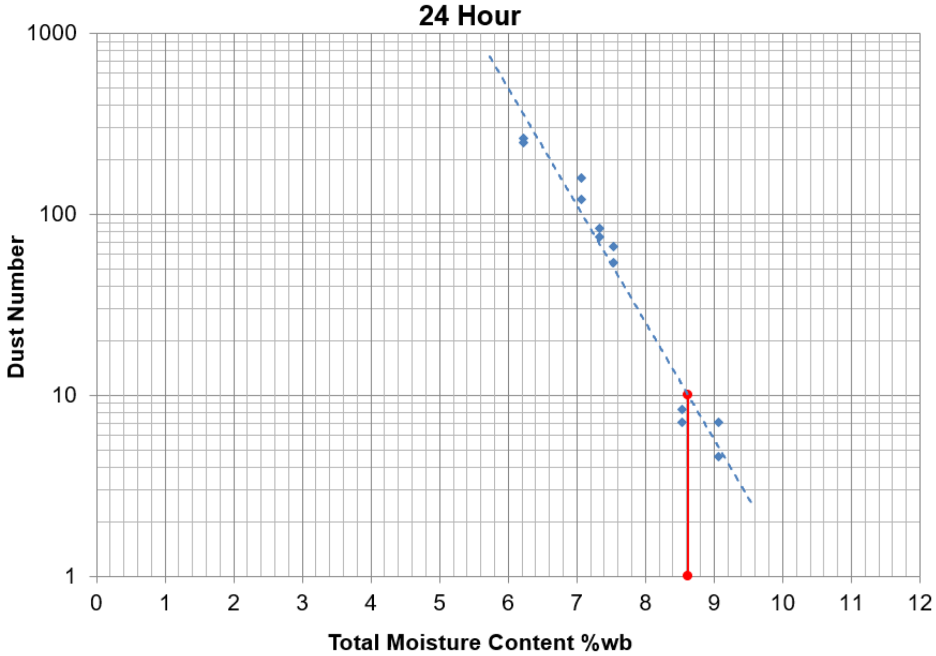
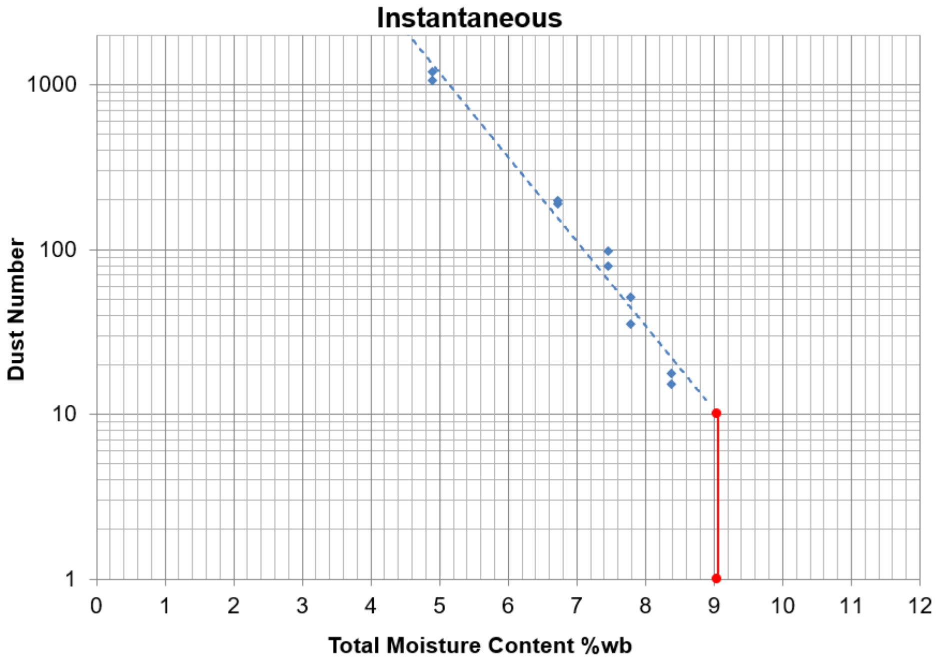


Figure 3-5 Australian Standard Dust/Moisture Curve (Coal E) for (a) Instantaneous Dust Number (b) 24-hour Dust Number

3.1.6 Coal F

(a)



(b)

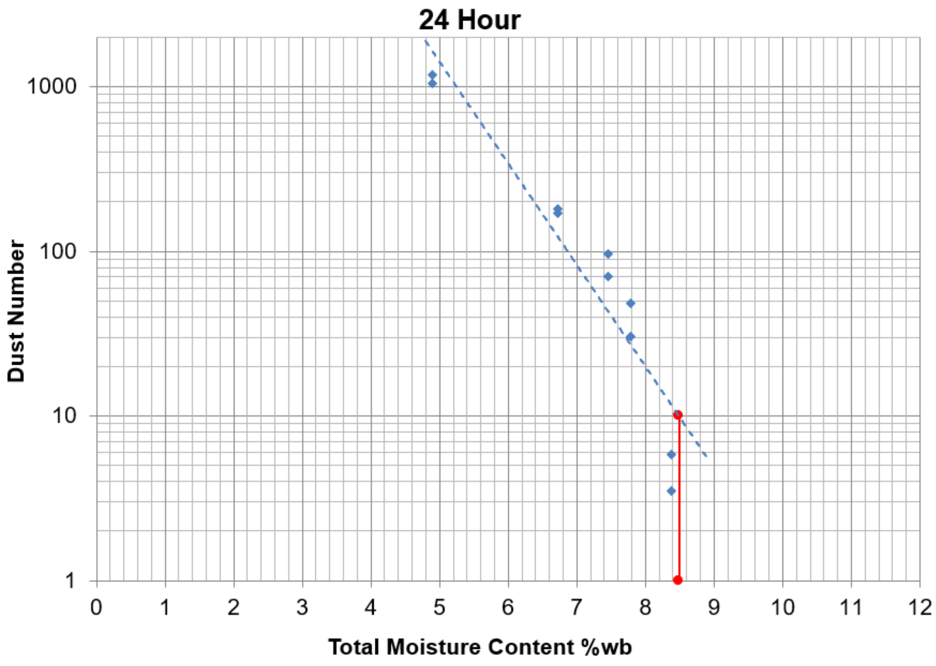
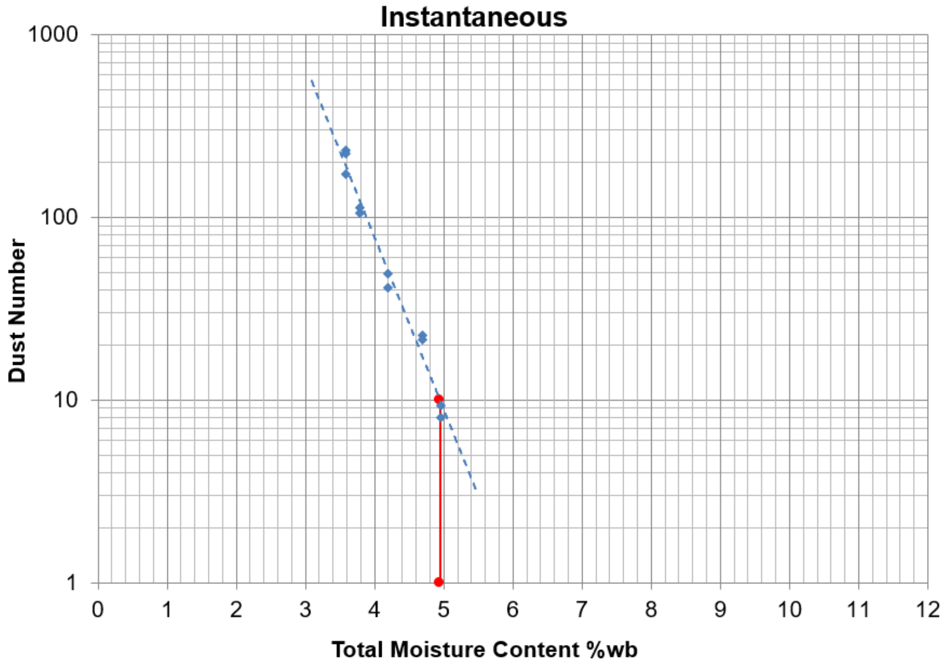


Figure 3-6 Australian Standard Dust/Moisture Curve (Coal F) for (a) Instantaneous Dust Number (b) 24-hour Dust Number

3.1.7 Coal G

(a)



(b)

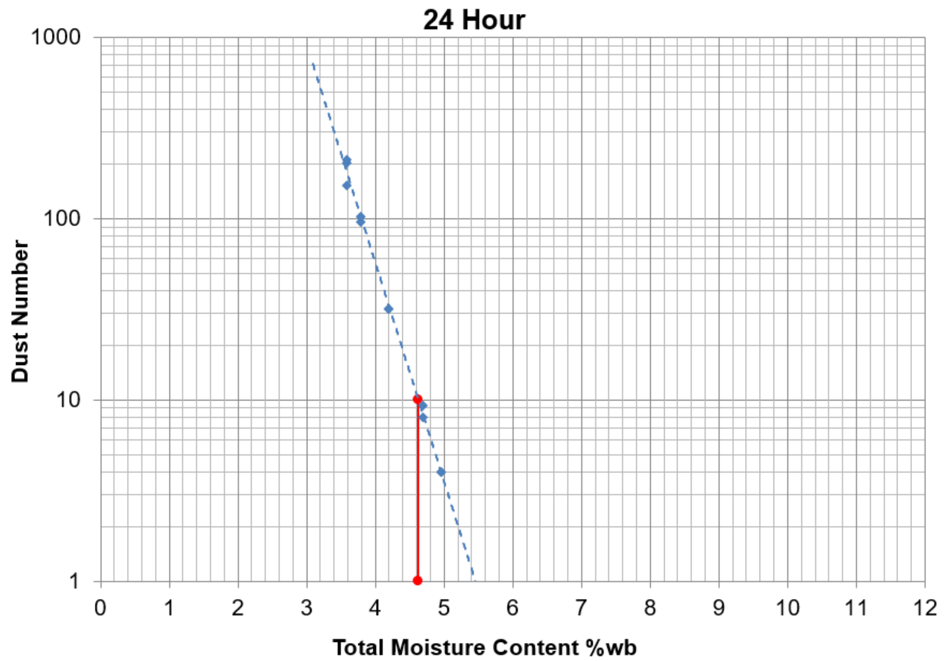
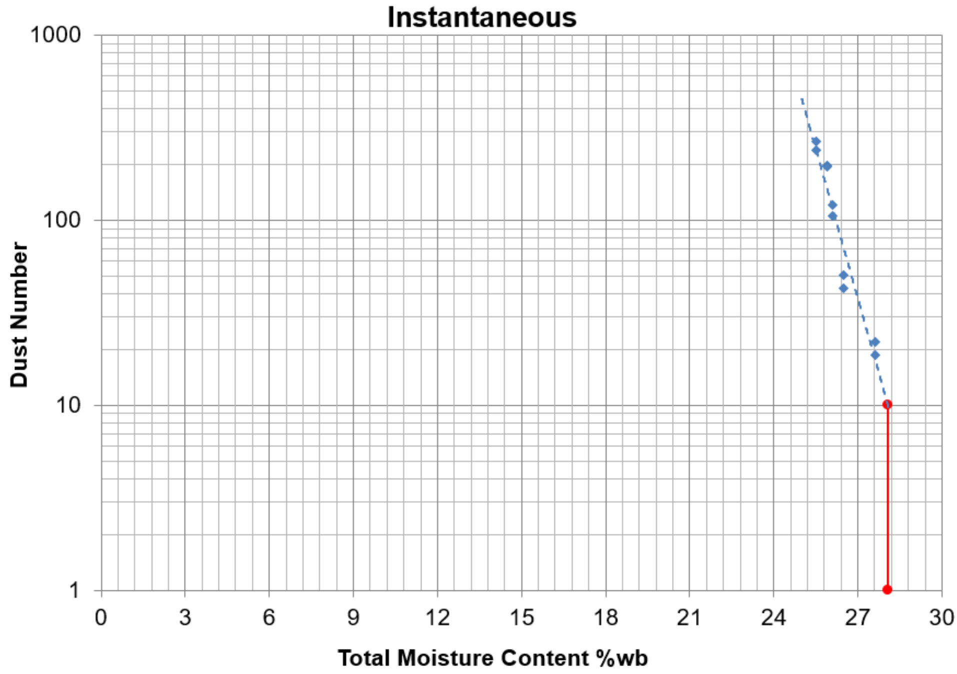


Figure 3-7 Australian Standard Dust/Moisture Curve (Coal G) for (a) Instantaneous Dust Number (b) 24-hour Dust Number

3.1.8 Coal H

(a)



(b)

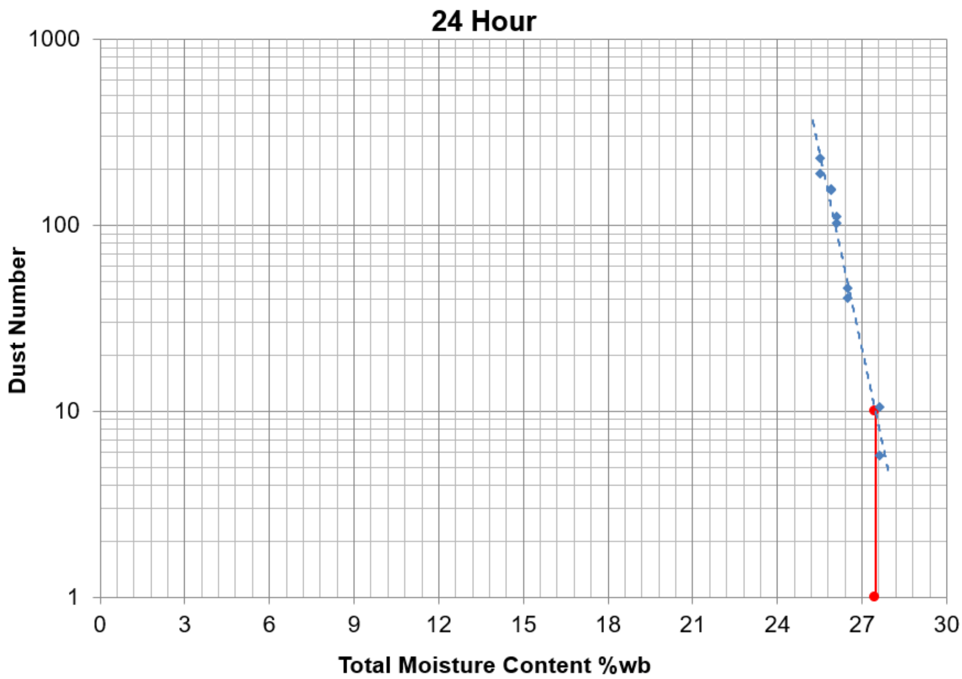


Figure 3-8 Australian Standard Dust/Moisture Curve (Coal H) for (a) Instantaneous Dust Number (b) 24-hour Dust Number

Table 3-1 Dust Extinction Moisture Summary of Coals for the Instantaneous and 24 Hour Measurements

	Dust Extinction Moisture	
ID	**Instantaneous**	**24 Hour**
Coal A	7.9	7.6
Coal B	5.4	5.3
Coal C	5.1	5.0
Coal D	10.6	9.6
Coal E	9.5	8.6
Coal F	9.1	8.5
Coal G	4.9	4.6
Coal H	28.1	27.5

3.2 Particle Size Distribution

This section presents the particle size distribution results for various coals using mechanical sieving and laser diffraction analysis.

The mechanical sieving provides the size distribution of the complete sub 6.3mm material samples used for the DEM testing. The incremental sieve sizes are relatively coarse. Mechanical sieving was conducted three times for each coal sample and an average mass fraction was taken to determine the overall PSD, which was then plotted to show the average PSD for percent mass undersize.

The Malvern laser diffraction analysis has been performed on the sub 1mm size fraction as this method of size analysis is best suited for fine particles. This analysis provides finer levels of detail for the particle range which is expected to generate the dust.

3.2.1 Coal A

Table 3-2 Averaged Sieve Test PSD Results (Coal A)

Average		
Sieve (mm)	**Avg. Σ Mass (%)**	**Σ Mass (%) Undersize**
6.300	0.00	100.00
4.000	23.13	76.87
2.000	49.95	50.05
1.000	68.99	31.01
0.500	79.79	20.21
0.250	87.88	12.12
0.125	93.19	6.81
0.001	100.00	0.00
d_{10}	0.20	mm
d_{50}	2.00	mm
d_{90}	5.22	mm

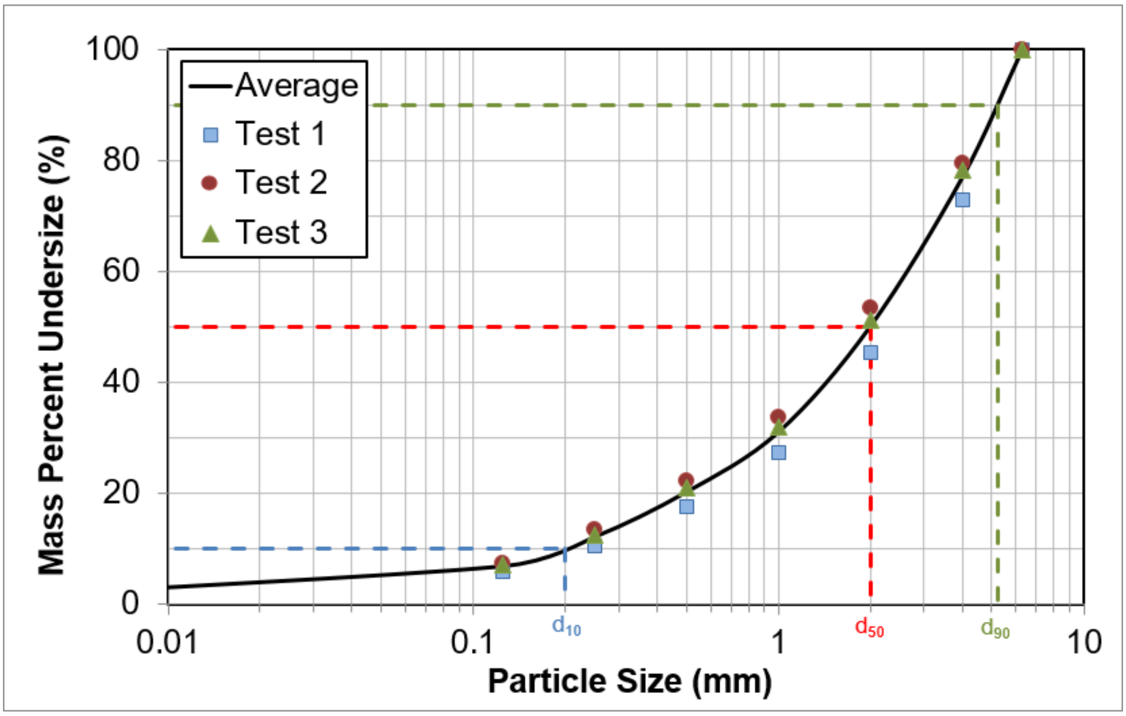


Figure 3-9 Individual and Averaged Sieve PSD Mass Undersize (%) Test Results (Coal A)

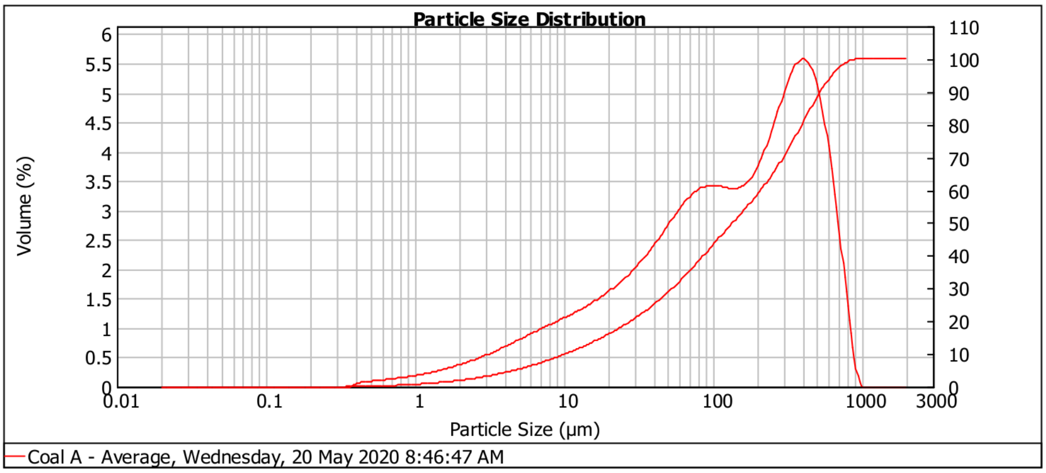
Result Analysis Report

Sample Name:	Sample Source & type:	Measured:
Coal A - Average	Research	Wednesday, 20 May 2020 8:46:47 AM
		Measured by: johnwebb

Particle Name:	Accessory Name:	Size range:	Dispersant Name:	Dispersant RI:
Carbon	Hydro 2000G (A)	0.020 to 2000.000 um	Water	1.330
Particle RI:	**Absorption:**		**Obscuration:**	**Weighted Residual:**
2.420	1		9.26 %	0.715 %

Specific Surface Area:	Surface Weighted Mean D[3,2]:	Vol. Weighted Mean D[4,3]:	Result units:
0.299 m²/g	20.055 um	210.905 um	Volume

d(0.1): **10.139** um **d(0.5):** **135.206** um **d(0.9):** **524.359** um



Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %
0.010	0.00	0.105	0.00	1.096	0.20	11.482	1.16	120.226	3.05	1258.925	0.00
0.011	0.00	0.120	0.00	1.259	0.23	13.183	1.24	138.038	3.06	1445.440	0.00
0.013	0.00	0.138	0.00	1.445	0.27	15.136	1.32	158.489	3.14	1659.587	0.00
0.015	0.00	0.158	0.00	1.660	0.30	17.378	1.41	181.970	3.33	1905.461	0.00
0.017	0.00	0.182	0.00	1.905	0.35	19.953	1.52	208.930	3.64	2187.762	0.00
0.020	0.00	0.209	0.00	2.188	0.39	22.909	1.63	239.883	4.04	2511.886	0.00
0.023	0.00	0.240	0.00	2.512	0.44	26.303	1.76	275.423	4.47	2884.032	0.00
0.026	0.00	0.275	0.00	2.884	0.50	30.200	1.91	316.228	4.83	3311.311	0.00
0.030	0.00	0.316	0.00	3.311	0.56	34.674	2.07	363.078	5.03	3801.894	0.00
0.035	0.00	0.363	0.03	3.802	0.62	39.811	2.26	416.869	4.95	4365.158	0.00
0.040	0.00	0.417	0.07	4.365	0.69	45.709	2.46	478.630	4.53	5011.872	0.00
0.046	0.00	0.479	0.09	5.012	0.76	52.481	2.65	549.541	3.78	5754.399	0.00
0.052	0.00	0.550	0.10	5.754	0.83	60.256	2.83	630.957	2.75	6606.934	0.00
0.060	0.00	0.631	0.12	6.607	0.89	69.183	2.98	724.436	1.57	7585.776	0.00
0.069	0.00	0.724	0.13	7.586	0.96	79.433	3.06	831.764	0.42	8709.636	0.00
0.079	0.00	0.832	0.15	8.710	1.02	91.201	3.09	954.993	0.00	10000.000	
0.091	0.00	0.955	0.18	10.000	1.09	104.713	3.08	1096.478	0.00		
0.105		1.096		11.482		120.226		1258.925			

Figure 3-10 Malvern PSD Mass Undersize (%) Test Results for Sub 1mm (Coal A)

3.2.2 Coal B

Table 3-3 Averaged Sieve Test PSD Results (Coal B)

Average		
Sieve (mm)	**Avg. Σ Mass (%)**	**Σ Mass (%) Undersize**
6.300	0.00	100.00
4.000	2.99	97.01
2.000	31.07	68.93
1.000	58.94	41.06
0.500	79.73	20.27
0.250	93.60	6.40
0.125	97.16	2.84
0.001	100.00	0.00
d_{10}	0.31	mm
d_{50}	1.26	mm
d_{90}	3.24	mm

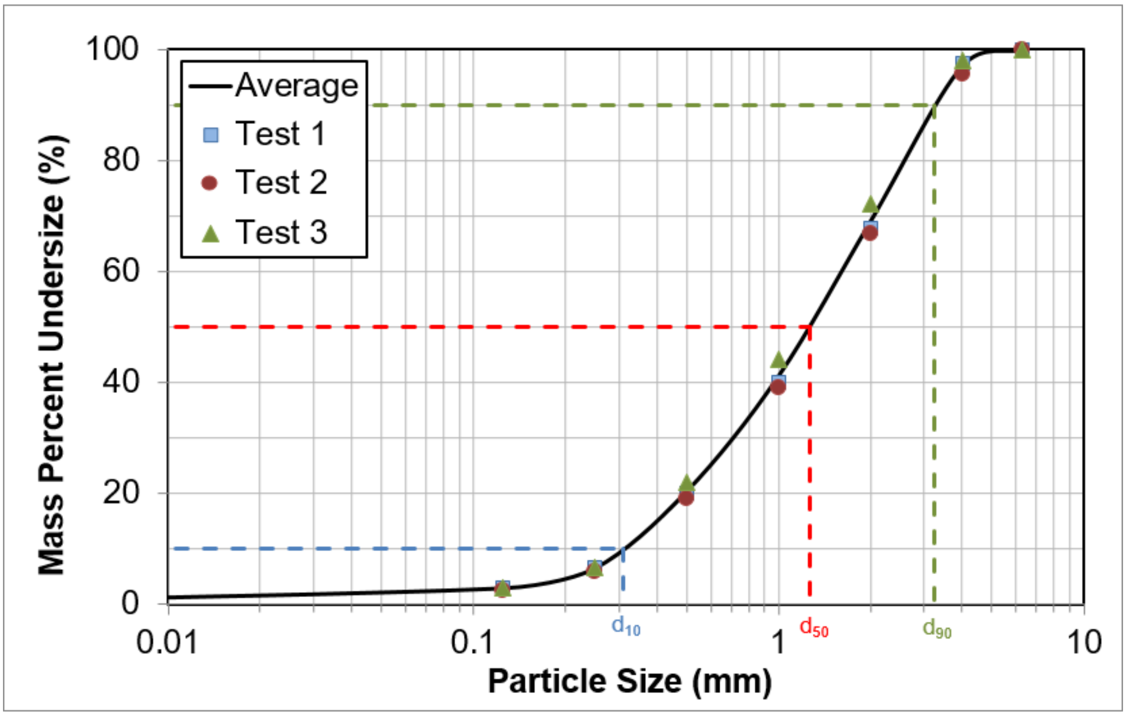


Figure 3-11 Individual and Averaged Sieve PSD Mass Undersize (%) Test Results (Coal B)

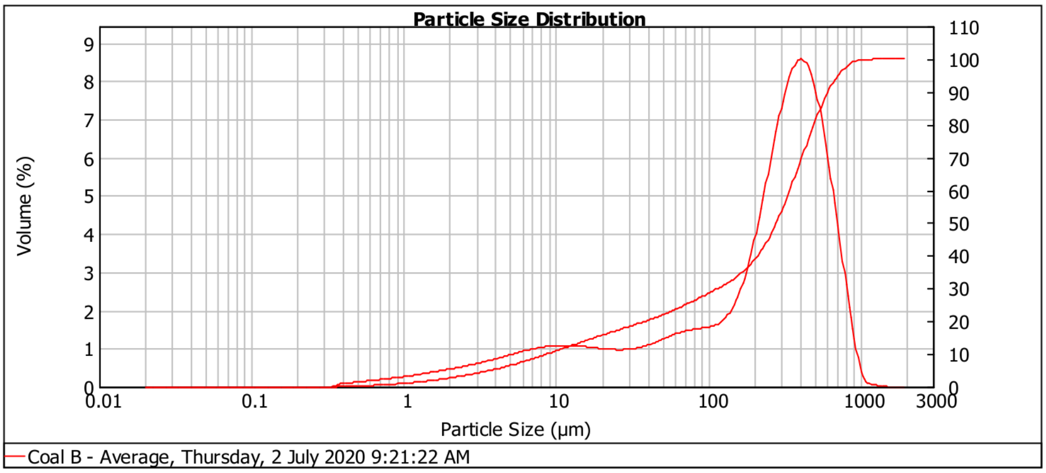
Result Analysis Report

Sample Name:	Sample Source & type:	Measured:
Coal B - Average	Research	Thursday, 2 July 2020 9:21:22 AM
		Measured by: johnwebb

Particle Name:	Accessory Name:	Size range:	Dispersant Name:	Dispersant RI:
Carbon	Hydro 2000G (A)	0.020 to 2000.000 um	Water	1.330
Particle RI:	**Absorption:**		**Obscuration:**	**Weighted Residual:**
2.420	1		8.75 %	0.498 %

Specific Surface Area:	Surface Weighted Mean D[3,2]:	Vol. Weighted Mean D[4,3]:	Result units:
0.33 m²/g	18.191 um	294.193 um	Volume

d(0.1): 8.744 um **d(0.5): 280.173 um** **d(0.9): 613.616 um**



Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %
0.010	0.00	0.105	0.00	1.096	0.28	11.482	0.98	120.226	1.61	1258.925	0.02
0.011	0.00	0.120	0.00	1.259	0.31	13.183	0.96	138.038	1.93	1445.440	0.00
0.013	0.00	0.138	0.00	1.445	0.35	15.136	0.94	158.489	2.47	1659.587	0.00
0.015	0.00	0.158	0.00	1.660	0.38	17.378	0.92	181.970	3.26	1905.461	0.00
0.017	0.00	0.182	0.00	1.905	0.42	19.953	0.89	208.930	4.24	2187.762	0.00
0.020	0.00	0.209	0.00	2.188	0.47	22.909	0.88	239.883	5.36	2511.886	0.00
0.023	0.00	0.240	0.00	2.512	0.51	26.303	0.88	275.423	6.43	2884.032	0.00
0.026	0.00	0.275	0.00	2.884	0.56	30.200	0.90	316.228	7.28	3311.311	0.00
0.030	0.00	0.316	0.00	3.311	0.61	34.674	0.95	363.078	7.71	3801.894	0.00
0.035	0.00	0.363	0.08	3.802	0.67	39.811	1.02	416.869	7.61	4365.158	0.00
0.040	0.00	0.417	0.09	4.365	0.73	45.709	1.11	478.630	6.95	5011.872	0.00
0.046	0.00	0.479	0.12	5.012	0.79	52.481	1.20	549.541	5.81	5754.399	0.00
0.052	0.00	0.550	0.14	5.754	0.85	60.256	1.28	630.957	4.35	6606.934	0.00
0.060	0.00	0.631	0.16	6.607	0.90	69.183	1.34	724.436	2.81	7585.776	0.00
0.069	0.00	0.724	0.19	7.586	0.94	79.433	1.37	831.764	1.38	8709.636	0.00
0.079	0.00	0.832	0.21	8.710	0.96	91.201	1.40	954.993	0.31	10000.000	
0.091	0.00	0.955	0.24	10.000	0.98	104.713	1.46	1096.478	0.06		
0.105		1.096		11.482		120.226		1258.925			

Figure 3-12 Malvern PSD Mass Undersize (%) Test Results for Sub 1mm (Coal B)

3.2.3 Coal C

Table 3-4 Averaged Sieve Test PSD Results (Coal C)

Average		
Sieve (mm)	**Avg. Σ Mass (%)**	**Σ Mass (%) Undersize**
6.300	0.00	100.00
4.000	25.31	74.69
2.000	64.73	35.27
1.000	84.61	15.39
0.500	92.25	7.75
0.250	95.22	4.78
0.125	96.91	3.09
0.001	100.00	0.00
d_{10}	0.66	mm
d_{50}	2.63	mm
d_{90}	5.22	mm

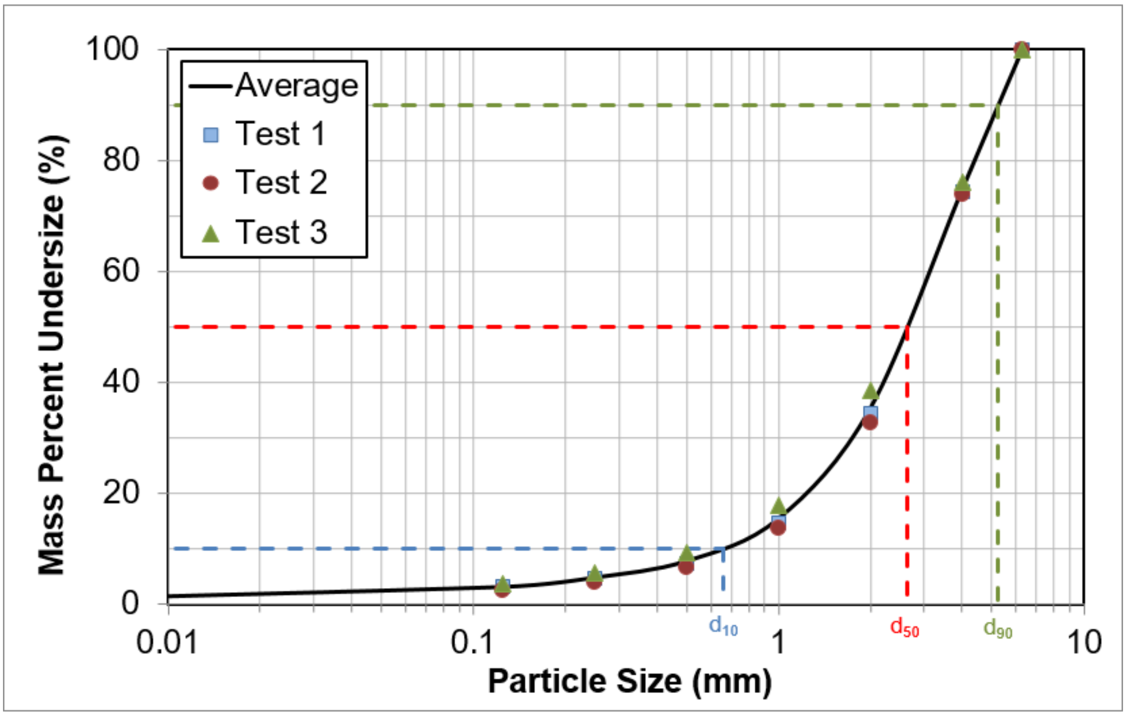


Figure 3-13 Individual and Averaged Sieve PSD Mass Undersize (%) Test Results (Coal C)

BME AUSTRALIA MALVERN INSTRUMENTS MASTERSIZER 2000

Result Analysis Report

Sample Name:
Coal C - Average

Sample Source & type:
Research

Measured:
Thursday, 2 July 2020 10:42:25 AM

Measured by: johnwebb

Particle Name:
Carbon

Accessory Name:
Hydro 2000G (A)

Size range:
0.020 to 2000.000 um

Dispersant Name:
Water

Dispersant RI:
1.330

Particle RI:
2.420

Absorption:
1

Obscuration:
11.14 %

Weighted Residual:
0.455 %

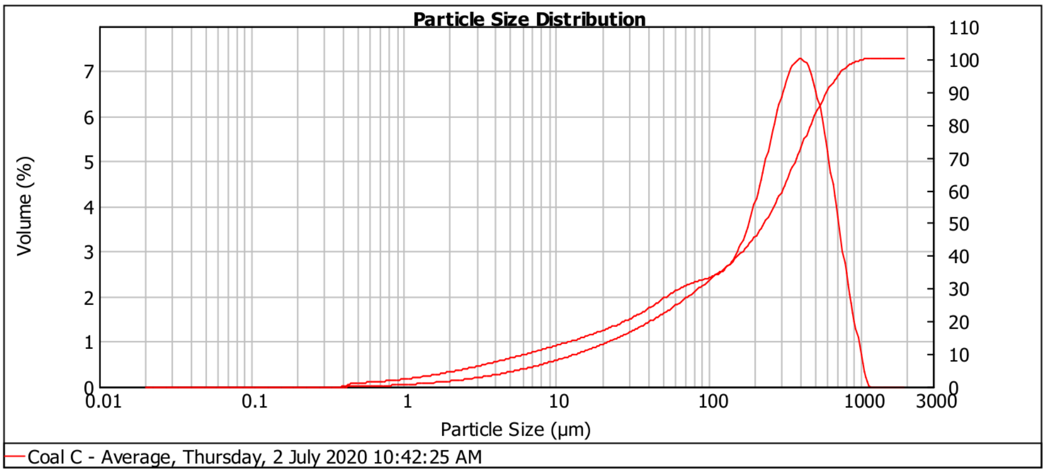
Specific Surface Area:
0.245 m²/g

Surface Weighted Mean D[3,2]:
24.459 um

Vol. Weighted Mean D[4,3]:
272.641 um

Result units:
Volume

d(0.1): 13.593 um **d(0.5):** 234.567 um **d(0.9):** 603.033 um



Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %
0.010	0.00	0.105	0.00	1.096	0.18	11.482	0.90	120.226	2.35	1258.925	0.00
0.011	0.00	0.120	0.00	1.259	0.21	13.183	0.96	138.038	2.58	1445.440	0.00
0.013	0.00	0.138	0.00	1.445	0.23	15.136	1.02	158.489	2.95	1659.587	0.00
0.015	0.00	0.158	0.00	1.660	0.27	17.378	1.09	181.970	3.50	1905.461	0.00
0.017	0.00	0.182	0.00	1.905	0.30	19.953	1.15	208.930	4.17	2187.762	0.00
0.020	0.00	0.209	0.00	2.188	0.34	22.909	1.23	239.883	4.94	2511.886	0.00
0.023	0.00	0.240	0.00	2.512	0.38	26.303	1.31	275.423	5.68	2884.032	0.00
0.026	0.00	0.275	0.00	2.884	0.42	30.200	1.40	316.228	6.27	3311.311	0.00
0.030	0.00	0.316	0.00	3.311	0.46	34.674	1.50	363.078	6.55	3801.894	0.00
0.035	0.00	0.363	0.00	3.802	0.50	39.811	1.61	416.869	6.44	4365.158	0.00
0.040	0.00	0.417	0.06	4.365	0.55	45.709	1.73	478.630	5.91	5011.872	0.00
0.046	0.00	0.479	0.07	5.012	0.60	52.481	1.85	549.541	4.99	5754.399	0.00
0.052	0.00	0.550	0.09	5.754	0.65	60.256	1.96	630.957	3.83	6606.934	0.00
0.060	0.00	0.631	0.10	6.607	0.70	69.183	2.05	724.436	2.60	7585.776	0.00
0.069	0.00	0.724	0.12	7.586	0.75	79.433	2.12	831.764	1.49	8709.636	0.00
0.079	0.00	0.832	0.13	8.710	0.80	91.201	2.17	954.993	0.56	10000.000	
0.091	0.00	0.955	0.16	10.000	0.85	104.713	2.23	1096.478	0.00		
0.105		1.096		11.482		120.226		1258.925			

Figure 3-14 Malvern PSD Mass Undersize (%) Test Results for Sub 1mm (Coal C)

3.2.4 Coal D

Table 3-5 Averaged Sieve Test PSD Results (Coal D)

Average		
Sieve (mm)	**Avg. Σ Mass (%)**	**Σ Mass (%) Undersize**
6.300	0.00	100.00
4.000	9.32	90.68
2.000	40.11	59.89
1.000	63.22	36.78
0.500	77.95	22.05
0.250	91.52	8.48
0.125	98.25	1.75
0.001	100.00	0.00
d_{10}	0.27	mm
d_{50}	1.53	mm
d_{90}	3.90	mm

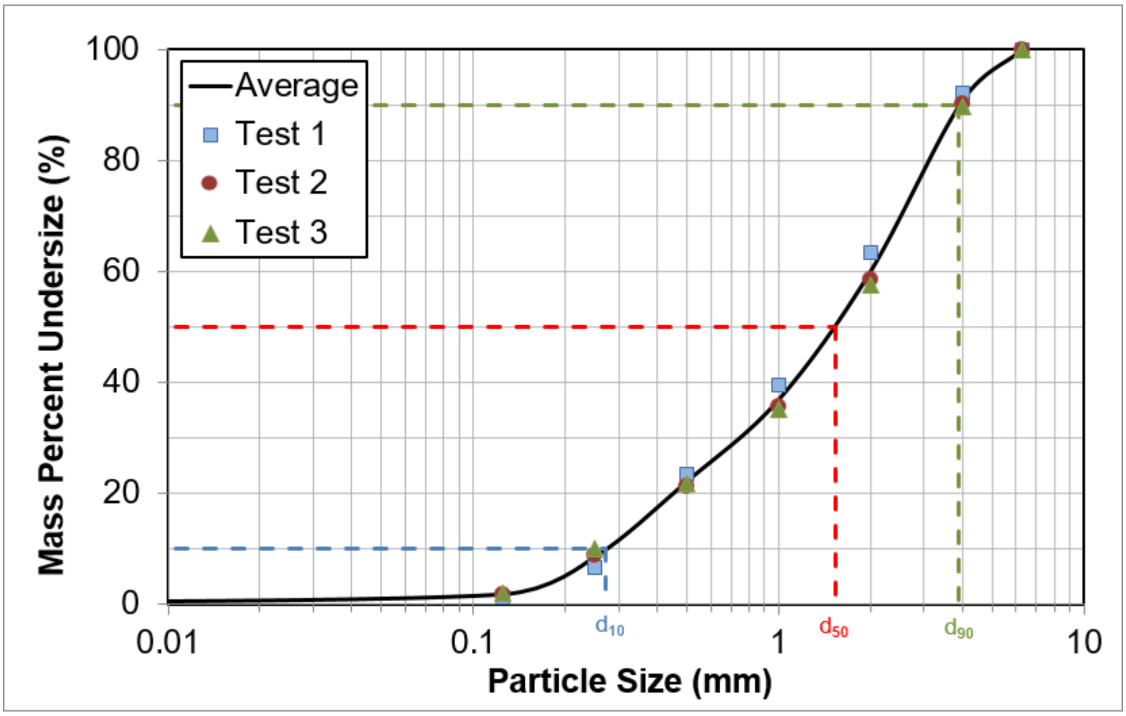


Figure 3-15 Individual and Averaged Sieve PSD Mass Undersize (%) Test Results (Coal D)

Result Analysis Report

Sample Name:
Coal D - Average

Sample Source & type:
Research

Measured:
Friday, 13 November 2020 8:28:19 AM

Measured by: johnwebb

Particle Name:
Carbon

Accessory Name:
Hydro 2000G (A)

Size range:
0.020 to 2000.000 um

Dispersant Name:
Water

Dispersant RI:
1.330

Particle RI:
2.420

Absorption:
1

Obscuration:
5.00 %

Weighted Residual:
0.536 %

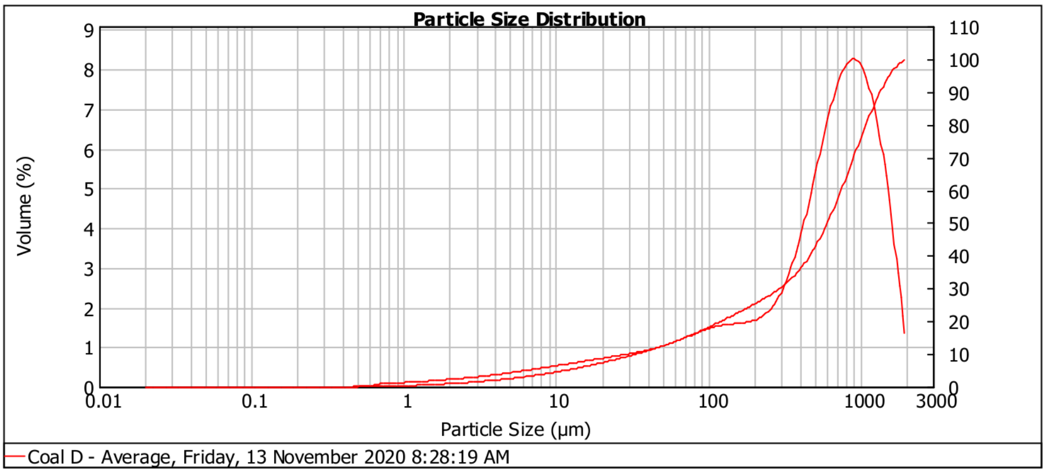
Specific Surface Area:
0.133 m²/g

Surface Weighted Mean D[3,2]:
45.129 um

Vol. Weighted Mean D[4,3]:
649.422 um

Result units:
Volume

d(0.1): **33.666** um **d(0.5):** **607.160** um **d(0.9):** **1349.434** um



Size (μm)	Volume In %
0.010	0.00
0.011	0.00
0.013	0.00
0.015	0.00
0.017	0.00
0.020	0.00
0.023	0.00
0.026	0.00
0.030	0.00
0.035	0.00
0.040	0.00
0.046	0.00
0.052	0.00
0.060	0.00
0.069	0.00
0.079	0.00
0.091	0.00
0.105	

Size (μm)	Volume In %
0.105	0.00
0.120	0.00
0.138	0.00
0.158	0.00
0.182	0.00
0.209	0.00
0.240	0.00
0.275	0.00
0.316	0.00
0.363	0.00
0.417	0.00
0.479	0.02
0.550	0.02
0.631	0.06
0.724	0.08
0.832	0.09
0.955	0.10
1.096	

Size (μm)	Volume In %
1.096	0.11
1.259	0.12
1.445	0.14
1.660	0.15
1.905	0.17
2.188	0.19
2.512	0.21
2.884	0.23
3.311	0.25
3.802	0.28
4.365	0.31
5.012	0.34
5.754	0.37
6.607	0.40
7.586	0.43
8.710	0.46
10.000	0.49
11.482	

Size (μm)	Volume In %
11.482	0.53
13.183	0.56
15.136	0.59
17.378	0.63
19.953	0.66
22.909	0.70
26.303	0.73
30.200	0.77
34.674	0.81
39.811	0.86
45.709	0.92
52.481	0.99
60.256	1.07
69.183	1.15
79.433	1.24
91.201	1.31
104.713	1.37
120.226	

Size (μm)	Volume In %
120.226	1.41
138.038	1.43
158.489	1.46
181.970	1.50
208.930	1.59
239.883	1.77
275.423	2.08
316.228	2.56
363.078	3.21
416.869	4.03
478.630	4.94
549.541	5.86
630.957	6.67
724.436	7.23
831.764	7.46
954.993	7.28
1096.478	6.67
1258.925	

Size (μm)	Volume In %
1258.925	5.64
1445.440	4.28
1659.587	2.47
1905.461	0.59
2187.762	0.00
2511.886	0.00
2884.032	0.00
3311.311	0.00
3801.894	0.00
4365.158	0.00
5011.872	0.00
5754.399	0.00
6606.934	0.00
7585.776	0.00
8709.636	0.00
10000.000	

Figure 3-16 Malvern PSD Mass Undersize (%) Test Results for Sub 1mm (Coal D)

3.2.5 Coal E

Table 3-6 Averaged Sieve Test PSD Results (Coal E)

Average		
Sieve (mm)	**Avg. Σ Mass (%)**	**Σ Mass (%) Undersize**
6.300	0.00	100.00
4.000	7.76	92.24
2.000	34.09	65.91
1.000	58.49	41.51
0.500	73.95	26.05
0.250	87.92	12.08
0.125	95.80	4.20
0.001	100.00	0.00
d_{10}	0.22	mm
d_{50}	1.30	mm
d_{90}	3.75	mm

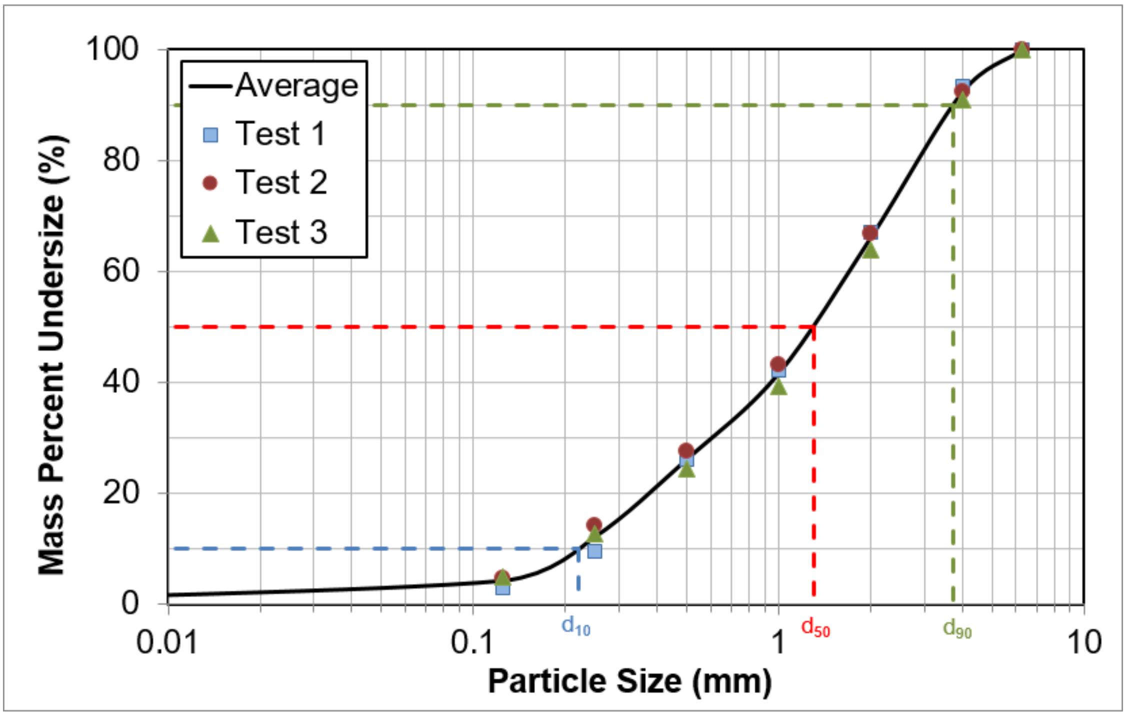


Figure 3-17 Individual and Averaged Sieve PSD Mass Undersize (%) Test Results (Coal E)

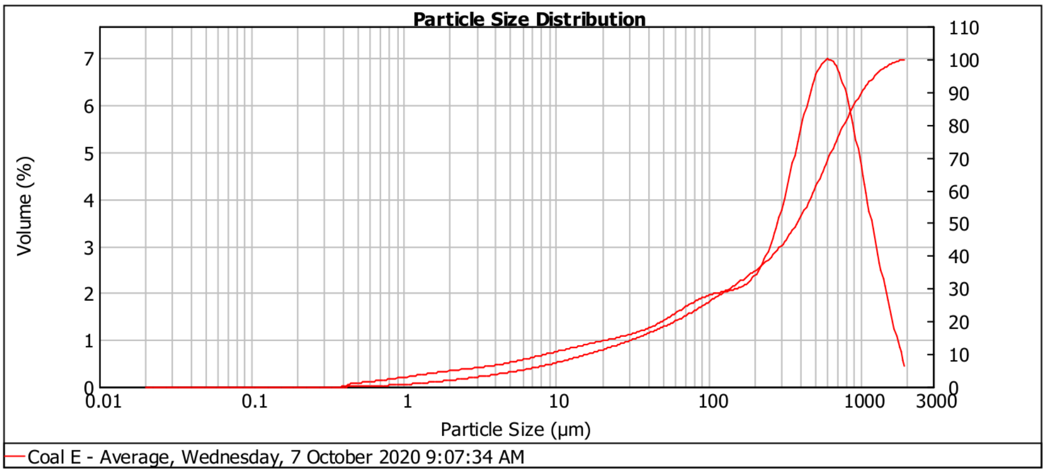
Result Analysis Report

Sample Name:	Sample Source & type:	Measured:
Coal E - Average	Research	Wednesday, 7 October 2020 9:07:34 AM
		Measured by: johnwebb

Particle Name:	Accessory Name:	Size range:	Dispersant Name:	Dispersant RI:
Carbon	Hydro 2000G (A)	0.020 to 2000.000 um	Water	1.330
Particle RI:	**Absorption:**		**Obscuration:**	**Weighted Residual:**
2.420	1		7.82 %	0.520 %

Specific Surface Area:	Surface Weighted Mean D[3,2]:	Vol. Weighted Mean D[4,3]:	Result units:
0.235 m²/g	25.498 um	455.933 um	Volume

d(0.1): 16.421 um **d(0.5): 383.774 um** **d(0.9): 1024.919 um**



Size (μm)	Volume In %
0.010	0.00
0.011	0.00
0.013	0.00
0.015	0.00
0.017	0.00
0.020	0.00
0.023	0.00
0.026	0.00
0.030	0.00
0.035	0.00
0.040	0.00
0.046	0.00
0.052	0.00
0.060	0.00
0.069	0.00
0.079	0.00
0.091	0.00
0.105	

Size (μm)	Volume In %
0.105	0.00
0.120	0.00
0.138	0.00
0.158	0.00
0.182	0.00
0.209	0.00
0.240	0.00
0.275	0.00
0.316	0.00
0.363	0.00
0.417	0.06
0.479	0.08
0.550	0.10
0.631	0.12
0.724	0.14
0.832	0.16
0.955	0.19
1.096	

Size (μm)	Volume In %
1.096	0.21
1.259	0.24
1.445	0.26
1.660	0.29
1.905	0.31
2.188	0.33
2.512	0.35
2.884	0.37
3.311	0.39
3.802	0.42
4.365	0.45
5.012	0.48
5.754	0.52
6.607	0.57
7.586	0.61
8.710	0.65
10.000	0.70
11.482	

Size (μm)	Volume In %
11.482	0.74
13.183	0.78
15.136	0.82
17.378	0.86
19.953	0.90
22.909	0.94
26.303	0.98
30.200	1.03
34.674	1.09
39.811	1.16
45.709	1.25
52.481	1.35
60.256	1.46
69.183	1.57
79.433	1.67
91.201	1.75
104.713	1.80
120.226	

Size (μm)	Volume In %
120.226	1.83
138.038	1.87
158.489	1.94
181.970	2.08
208.930	2.33
239.883	2.73
275.423	3.29
316.228	3.98
363.078	4.73
416.869	5.45
478.630	6.01
549.541	6.29
630.957	6.22
724.436	5.79
831.764	5.07
954.993	4.17
1096.478	3.22
1258.925	

Size (μm)	Volume In %
1258.925	2.32
1445.440	1.54
1659.587	0.81
1905.461	0.19
2187.762	0.00
2511.886	0.00
2884.032	0.00
3311.311	0.00
3801.894	0.00
4365.158	0.00
5011.872	0.00
5754.399	0.00
6606.934	0.00
7585.776	0.00
8709.636	0.00
10000.000	

Figure 3-18 Malvern PSD Mass Undersize (%) Test Results for Sub 1mm (Coal E)

3.2.6 Coal F

Table 3-7 Averaged Sieve Test PSD Results (Coal F)

Average		
Sieve (mm)	**Avg. Σ Mass (%)**	**Σ Mass (%) Undersize**
6.300	0.00	100.00
4.000	10.28	89.72
2.000	43.28	56.72
1.000	65.59	34.41
0.500	77.85	22.15
0.250	87.24	12.76
0.125	94.81	5.19
0.001	100.00	0.00
d_{10}	0.21	mm
d_{50}	1.66	mm
d_{90}	3.92	mm

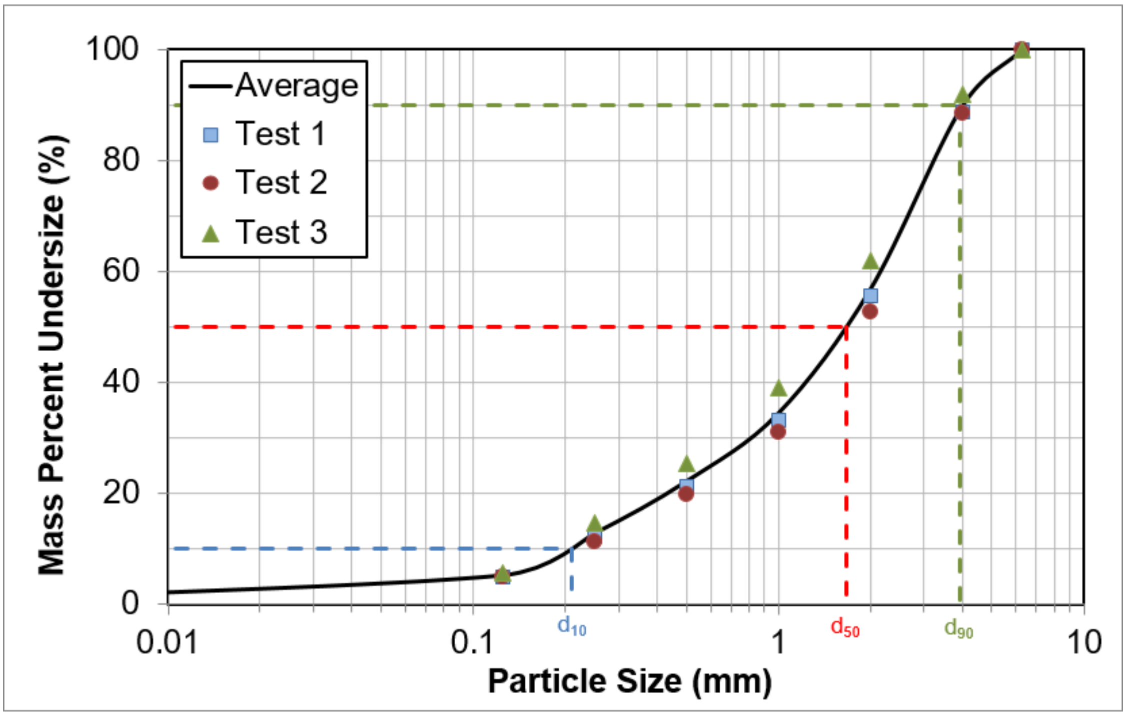


Figure 3-19 Individual and Averaged Sieve PSD Mass Undersize (%) Test Results (Coal F)

MASTERSIZER 2000

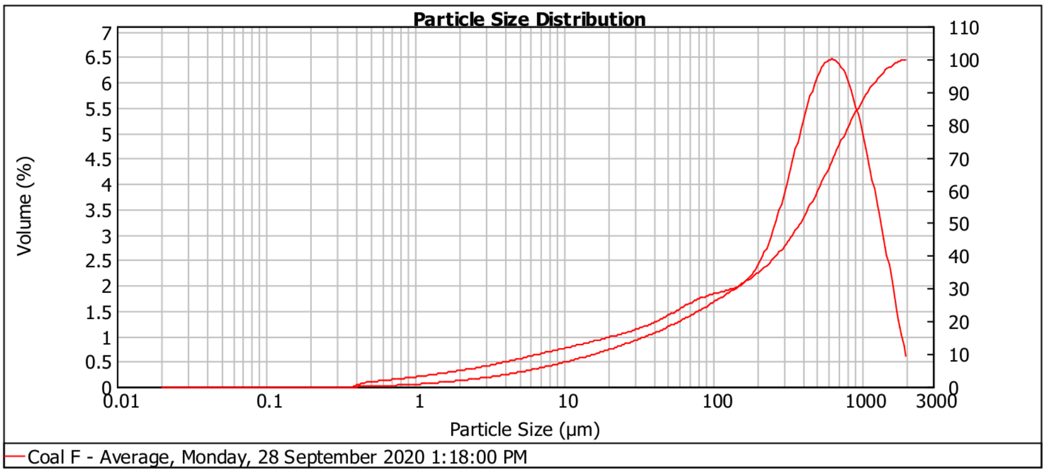
Result Analysis Report

Sample Name:	Sample Source & type:	Measured:
Coal F - Average	Research	Monday, 28 September 2020 1:18:00 PM
		Measured by: johnwebb

Particle Name:	Accessory Name:	Size range:	Dispersant Name:	Dispersant RI:
Carbon	Hydro 2000G (A)	0.020 to 2000.000 um	Water	1.330
Particle RI:	**Absorption:**		**Obscuration:**	**Weighted Residual:**
2.420	1		12.26 %	0.300 %

Specific Surface Area:	Surface Weighted Mean D[3,2]:	Vol. Weighted Mean D[4,3]:	Result units:
0.237 m²/g	25.369 um	474.992 um	Volume

d(0.1): 16.085 um **d(0.5):** 386.034 um **d(0.9):** 1096.995 um



Size (μm)	Volume In %
0.010	0.00
0.011	0.00
0.013	0.00
0.015	0.00
0.017	0.00
0.020	0.00
0.023	0.00
0.026	0.00
0.030	0.00
0.035	0.00
0.040	0.00
0.046	0.00
0.052	0.00
0.060	0.00
0.069	0.00
0.079	0.00
0.091	0.00
0.105	

Size (μm)	Volume In %
0.105	0.00
0.120	0.00
0.138	0.00
0.158	0.00
0.182	0.00
0.209	0.00
0.240	0.00
0.275	0.00
0.316	0.00
0.363	0.01
0.417	0.07
0.479	0.09
0.550	0.10
0.631	0.12
0.724	0.14
0.832	0.16
0.955	0.18
1.096	

Size (μm)	Volume In %
1.096	0.20
1.259	0.22
1.445	0.24
1.660	0.27
1.905	0.29
2.188	0.32
2.512	0.35
2.884	0.38
3.311	0.41
3.802	0.44
4.365	0.48
5.012	0.52
5.754	0.56
6.607	0.59
7.586	0.63
8.710	0.67
10.000	0.70
11.482	

Size (μm)	Volume In %
11.482	0.74
13.183	0.78
15.136	0.82
17.378	0.86
19.953	0.90
22.909	0.94
26.303	0.99
30.200	1.04
34.674	1.10
39.811	1.17
45.709	1.26
52.481	1.34
60.256	1.44
69.183	1.52
79.433	1.59
91.201	1.64
104.713	1.68
120.226	

Size (μm)	Volume In %
120.226	1.73
138.038	1.79
158.489	1.91
181.970	2.11
208.930	2.41
239.883	2.83
275.423	3.35
316.228	3.96
363.078	4.57
416.869	5.14
478.630	5.57
549.541	5.80
630.957	5.80
724.436	5.55
831.764	5.08
954.993	4.44
1096.478	3.69
1258.925	

Size (μm)	Volume In %
1258.925	2.87
1445.440	2.05
1659.587	1.14
1905.461	0.27
2187.762	0.00
2511.886	0.00
2884.032	0.00
3311.311	0.00
3801.894	0.00
4365.158	0.00
5011.872	0.00
5754.399	0.00
6606.934	0.00
7585.776	0.00
8709.636	0.00
10000.000	

Figure 3-20 Malvern PSD Mass Undersize (%) Test Results for Sub 1mm (Coal F)

3.2.7 Coal G

Table 3-8 Averaged Sieve Test PSD Results (Coal G)

Average		
Sieve (mm)	**Avg. Σ Mass (%)**	**Σ Mass (%) Undersize**
6.300	0.00	100.00
4.000	13.94	86.06
2.000	38.37	61.63
1.000	61.66	38.34
0.500	76.33	23.67
0.250	86.41	13.59
0.125	92.82	7.18
0.001	100.00	0.00
d_{10}	0.18	mm
d_{50}	1.43	mm
d_{90}	4.65	mm

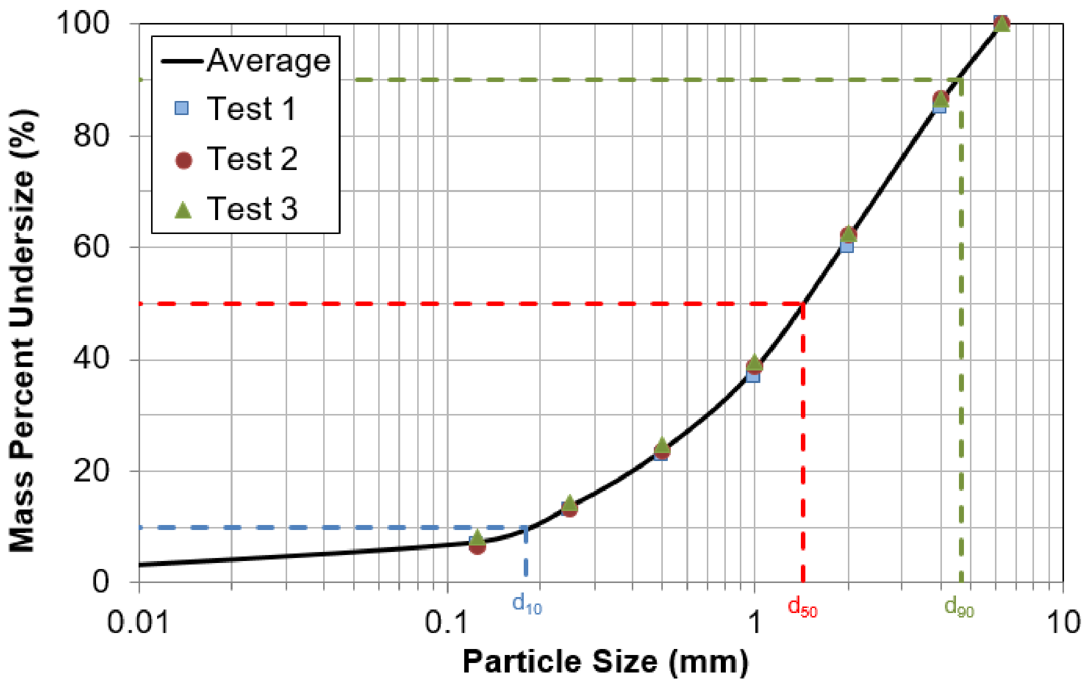


Figure 3-21 Individual and Averaged Sieve PSD Mass Undersize (%) Test Results (Coal G)

Result Analysis Report

Sample Name: Coal G - Average

Sample Source & type: Research

Measured: Tuesday, 28 September 2021 2:16:22 PM

Measured by: johnwebb

Particle Name: Carbon

Accessory Name: Hydro 2000G (A)

Size range: 0.020 to 2000.000 um

Dispersant Name: Water

Dispersant RI: 1.330

Particle RI: 2.420

Absorption: 1

Obscuration: 14.49 %

Weighted Residual: 0.289 %

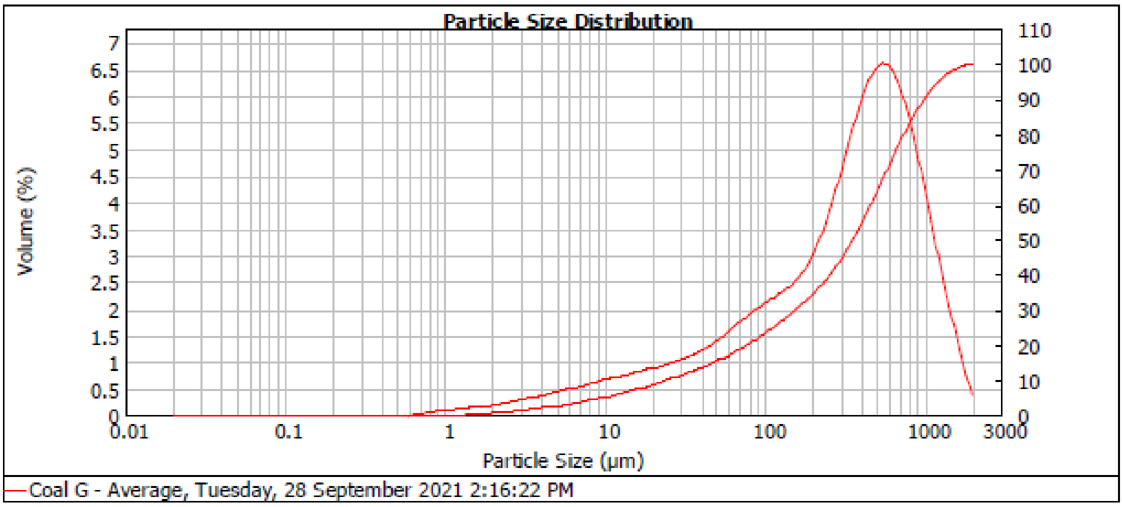
Specific Surface Area: 0.148 m²/g

Surface Weighted Mean D[3,2]: 40.522 um

Vol. Weighted Mean D[4,3]: 438.391 um

Result units: Volume

d(0.1): 24.027 um **d(0.5):** 353.530 um **d(0.9):** 987.708 um



Size (μm)	Volume In %
0.010	0.00
0.011	0.00
0.013	0.00
0.014	0.00
0.016	0.00
0.018	0.00
0.020	0.00
0.022	0.00
0.025	0.00
0.028	0.00
0.032	0.00
0.035	0.00
0.040	0.00
0.045	0.00
0.050	0.00
0.056	0.00
0.063	0.00
0.071	

Size (μm)	Volume In %
0.071	0.00
0.079	0.00
0.089	0.00
0.100	0.00
0.112	0.00
0.126	0.00
0.141	0.00
0.158	0.00
0.178	0.00
0.200	0.00
0.224	0.00
0.251	0.00
0.282	0.00
0.316	0.00
0.355	0.00
0.398	0.00
0.447	0.00
0.501	

Size (μm)	Volume In %
0.501	0.00
0.562	0.01
0.631	0.03
0.708	0.04
0.794	0.06
0.891	0.07
1.000	0.08
1.122	0.09
1.259	0.10
1.413	0.12
1.585	0.13
1.778	0.15
1.995	0.16
2.239	0.18
2.512	0.20
2.818	0.23
3.162	0.25
3.548	

Size (μm)	Volume In %
3.548	0.27
3.981	0.30
4.467	0.33
5.012	0.35
5.623	0.38
6.310	0.41
7.079	0.44
7.943	0.46
8.913	0.49
10.000	0.52
11.220	0.55
12.589	0.57
14.125	0.60
15.849	0.63
17.783	0.66
19.953	0.69
22.387	0.72
25.119	

Size (μm)	Volume In %
25.119	0.75
28.184	0.79
31.623	0.83
35.481	0.89
39.811	0.95
44.668	1.02
50.119	1.10
56.234	1.19
63.096	1.29
70.795	1.38
79.433	1.47
89.125	1.56
100.000	1.63
112.202	1.70
125.893	1.77
141.254	1.87
158.489	1.99
177.828	

Size (μm)	Volume In %
177.828	2.17
199.526	2.40
223.872	2.70
251.189	3.05
281.838	3.45
316.228	3.87
354.813	4.27
398.107	4.61
446.684	4.85
501.187	4.97
562.341	4.93
630.957	4.74
707.946	4.41
794.328	3.97
891.251	3.45
1000.000	

Figure 3-22 Malvern PSD Mass Undersize (%) Test Results for Sub 1mm (Coal G)

3.2.8 Coal H

Table 3-9 Averaged Sieve Test PSD Results (Coal H)

Average		
Sieve (mm)	**Avg. Σ Mass (%)**	**Σ Mass (%) Undersize**
6.300	0.00	100.00
4.000	17.34	82.66
2.000	42.36	57.64
1.000	64.53	35.47
0.500	80.07	19.93
0.250	90.56	9.44
0.125	95.92	4.08
0.001	100.00	0.00
d_{10}	0.25	mm
d_{50}	1.58	mm
d_{90}	4.80	mm

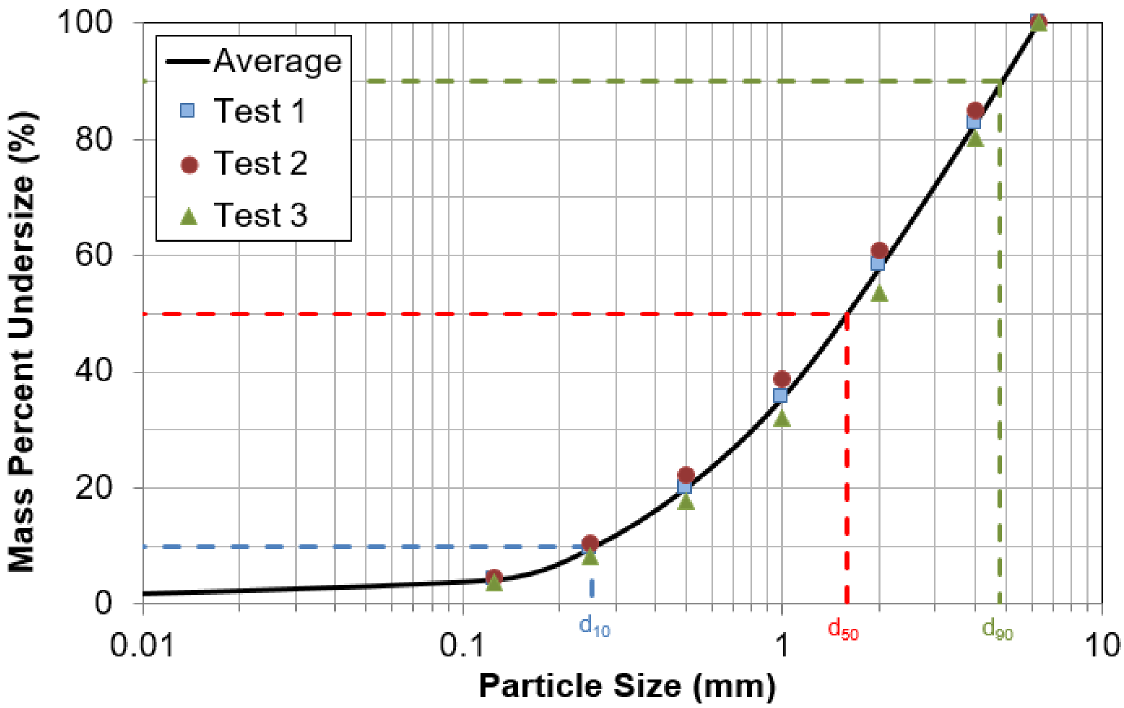


Figure 3-23 Individual and Averaged Sieve PSD Mass Undersize (%) Test Results (Coal H)

Result Analysis Report

Sample Name: Coal H - Average

Sample Source & type: Research

Measured: Tuesday, 24 November 2020 11:37:05 AM

Measured by: johnwebb

Particle Name: Carbon

Accessory Name: Hydro 2000G (A)

Size range: 0.020 to 2000.000 um

Dispersant Name: Water

Dispersant RI: 1.330

Particle RI: 2.420

Absorption: 1

Obscuration: 8.39 %

Weighted Residual: 0.633 %

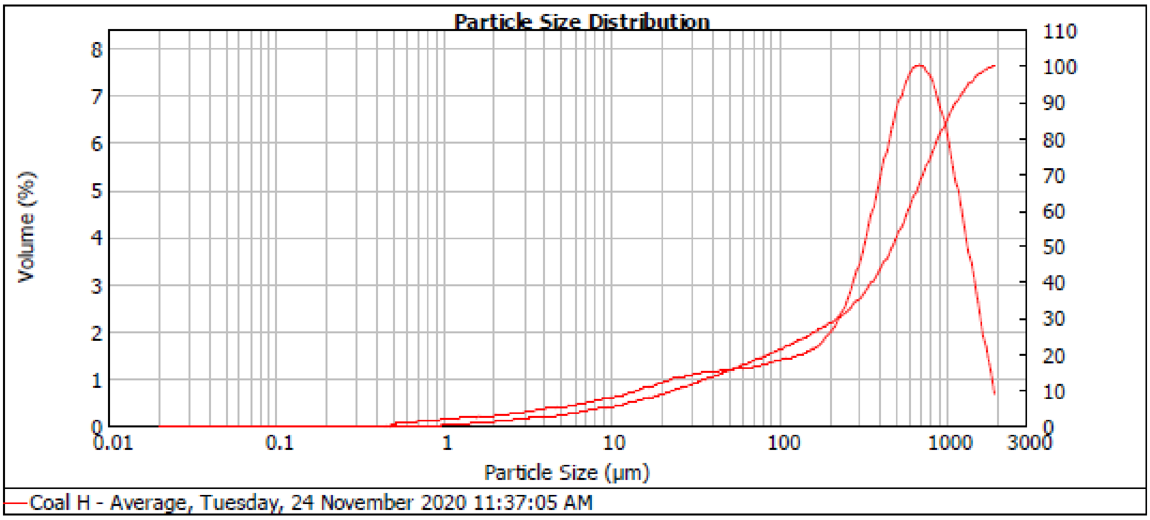
Specific Surface Area: 0.172 m²/g

Surface Weighted Mean D[3,2]: 34.806 um

Vol. Weighted Mean D[4,3]: 539.138 um

Result units: Volume

d(0.1): 23.848 um **d(0.5):** 479.966 um **d(0.9):** 1157.883 um



Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %
0.010	0.00	0.071	0.00	0.501	0.06	3.548	0.26	25.119	0.79	177.828	1.38
0.011	0.00	0.079	0.00	0.562	0.06	3.981	0.28	28.184	0.82	199.526	1.55
0.013	0.00	0.089	0.00	0.631	0.07	4.467	0.30	31.623	0.84	223.872	1.79
0.014	0.00	0.100	0.00	0.708	0.08	5.012	0.32	35.481	0.86	251.189	2.12
0.016	0.00	0.112	0.00	0.794	0.09	5.623	0.34	39.811	0.88	281.838	2.53
0.018	0.00	0.126	0.00	0.891	0.10	6.310	0.37	44.668	0.89	316.228	3.03
0.020	0.00	0.141	0.00	1.000	0.11	7.079	0.39	50.119	0.90	354.813	3.58
0.022	0.00	0.158	0.00	1.122	0.12	7.943	0.41	56.234	0.92	398.107	4.17
0.025	0.00	0.178	0.00	1.259	0.13	8.913	0.44	63.096	0.94	446.684	4.73
0.028	0.00	0.200	0.00	1.413	0.14	10.000	0.47	70.795	0.97	501.187	5.22
0.032	0.00	0.224	0.00	1.585	0.16	11.220	0.51	79.433	1.00	562.341	5.57
0.035	0.00	0.251	0.00	1.778	0.17	12.589	0.54	89.125	1.03	630.957	5.74
0.040	0.00	0.282	0.00	1.995	0.18	14.125	0.58	100.000	1.06	707.946	5.70
0.045	0.00	0.316	0.00	2.239	0.20	15.849	0.63	112.202	1.10	794.328	5.45
0.050	0.00	0.355	0.00	2.512	0.21	17.783	0.67	125.893	1.14	891.251	5.00
0.056	0.00	0.398	0.00	2.818	0.23	19.953	0.72	141.254	1.19	1000.000	
0.063	0.00	0.447	0.01	3.162	0.24	22.387	0.76	158.489	1.27		
0.071		0.501		3.548		25.119		177.828			

Figure 3-24 Malvern PSD Mass Undersize (%) Test Results for Sub 1mm (Coal H)

3.3 Solids Density

The solids density for each coal sample has been tested with the Stereopycnometer and the averaged results are presented in Table 5-10.

3.4 Saturation Moisture

The saturated moisture content for each coal sample has been tested and the averaged results are presented in Table 3-10.

Table 3-10 Solids Density and Saturation Moisture of Coal Samples

ID	Solids Density (kg/m^3)	Saturation Moisture Content (%)
Coal A	1908	23.2
Coal B	2799	19.3
Coal C	2751	16.2
Coal D	1632	25.2
Coal E	1866	23.6
Coal F	2568	24.3
Coal G	1923	20.9
Coal H	1699	43.0

3.5 Summary

This chapter has presented the experimental findings from completing the following test work on all eight coal samples:

- Dustiness testing
- Dust extinction moisture content
- Particle size distribution
- Solids density
- Saturation moisture

Table 3-1 to Table 3-10 clearly show that there is a noticeable difference in the properties of each coal sample, which has the potential to complicate the determination of the most effective dust suppression system to be used and reinforces the need for a fit-for-purpose approach rather than a one size fits all approach.

4 COMPARISON OF COAL PROPERTIES MEASURED

4.1 Comparisons to Dust Extinction Moisture

In this chapter, the properties determined in Chapter 3 will be compared in an attempt to identify trends which may aid in the selection of the most appropriate dust suppression method to minimise the effects of dust on site.

Using the data provided in Table 3-1 to Table 3-10, the relationships shown below have been derived to determine if any clear trends can be used in identifying the propensity for a particular to result in high dust emissions or any important considerations for the design of dust control systems

Figure 4-1 to Figure 4-3 compare the average d_{10}, d_{50} and d_{90} particle sizes for each coal sample to the dust extinction moisture and it can be seen that no clear trend is present.

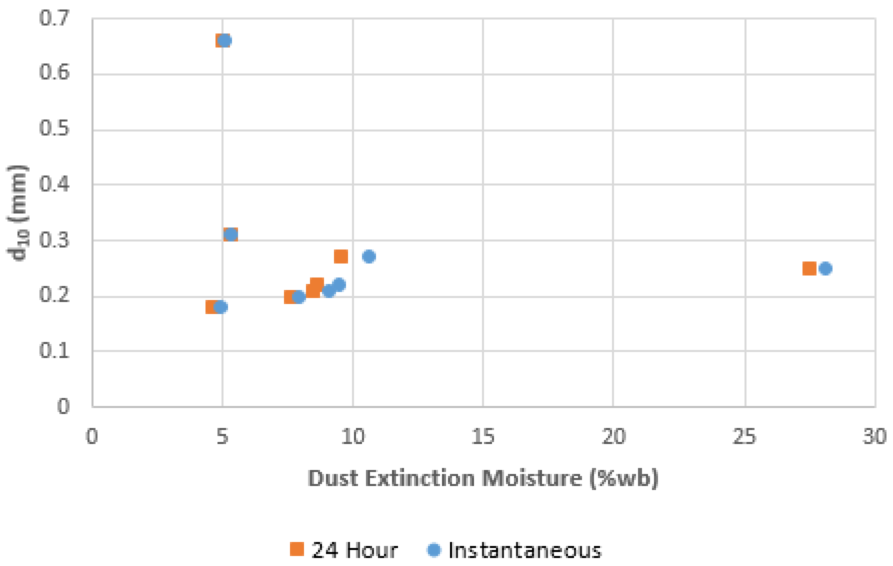


Figure 4-1: Dust Extinction Moisture (%wb) versus d_{10} (mm) particle size for all coal samples

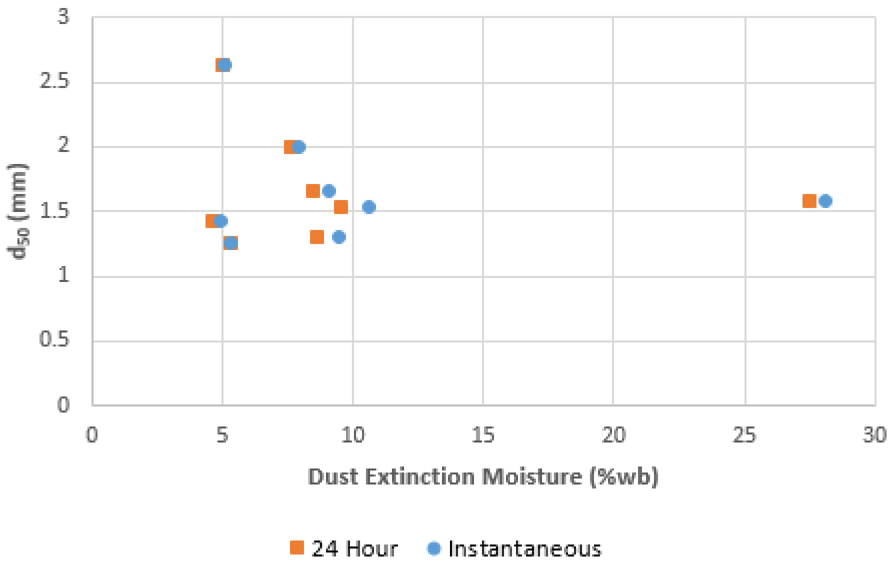


Figure 4-2: Dust Extinction Moisture (%wb) versus d_{50} (mm) particle size for all coal samples

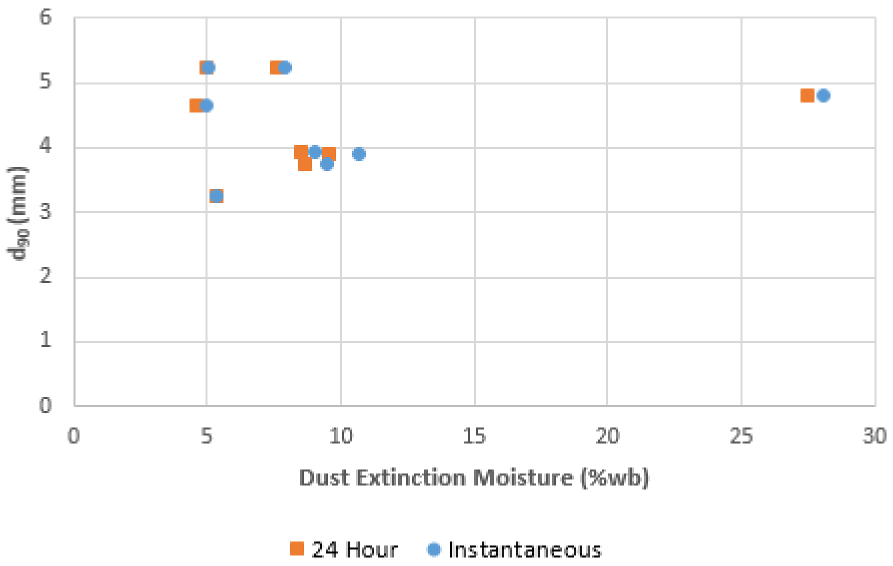


Figure 4-3: Dust Extinction Moisture (%wb) versus d_{90} (mm) particle size for all coal samples

Figure 4-4 and Figure 4-5 compare the solids density and loose poured bulk density to the dust extinction moisture and again it can be seen that there is no clear trend present.

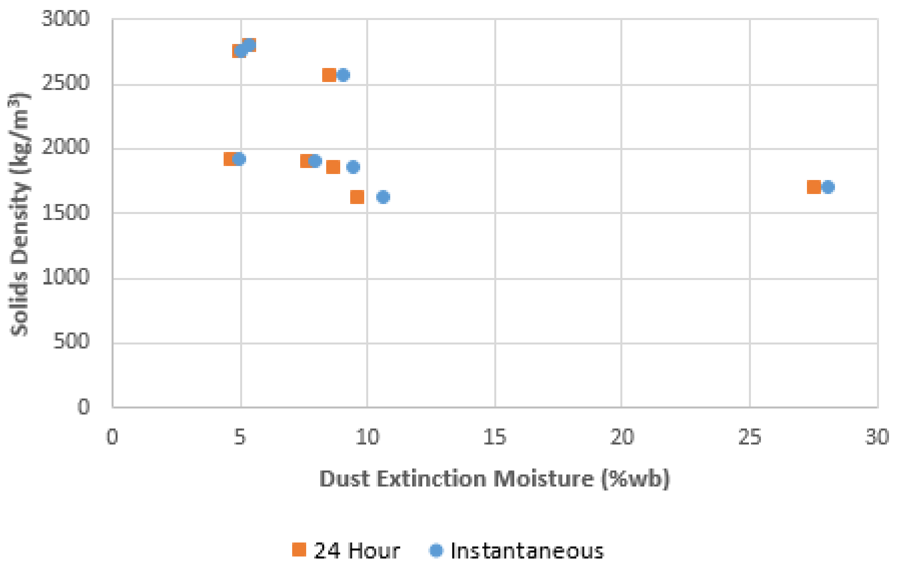


Figure 4-4 Dust Extinction Moisture (%wb) versus Solids Density (kg/m^3) for all coal samples

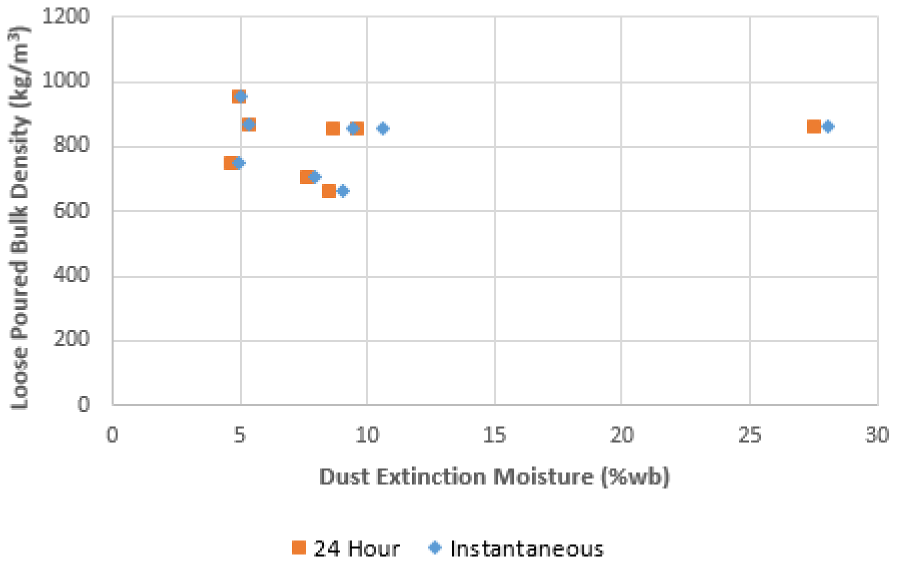


Figure 4-5 Dust Extinction Moisture (%wb) versus Loose Poured Bulk Density (kg/m^3) for all coal samples

Figure 4-6 compares the saturation moisture content to the dust extinction moisture and in this case it can be seen that there is a clear trend present, indicating that as the saturation moisture content increases, so too does the dust extinction moisture of the coal samples.

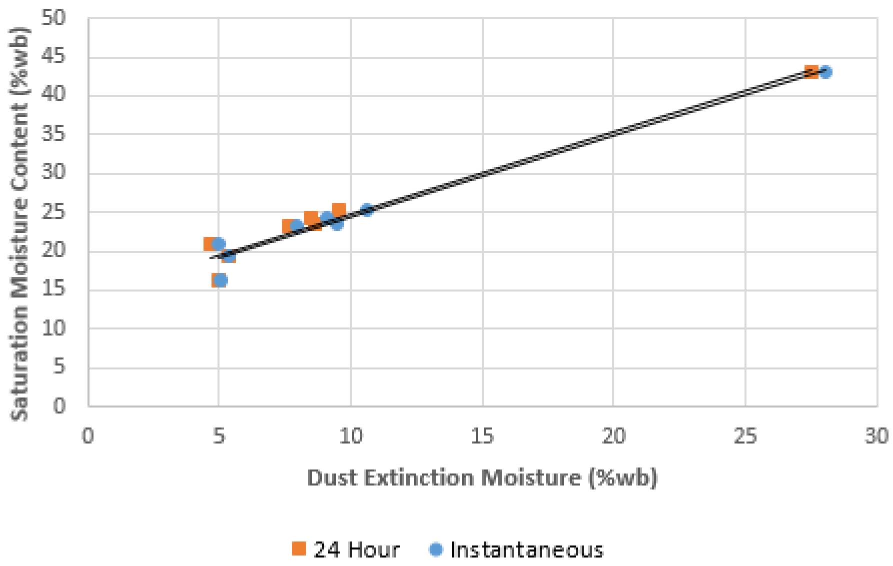


Figure 4-6 Dust Extinction Moisture (%wb) versus Saturation Moisture Content (%wb) for all coal samples

4.2 Discussion

From the range of particle and bulk tests performed across the range of coal samples tested, it was found that only one produced a trend which could be used as a predictor for the dustiness of a coal sample. In relative terms, the lower the saturation moisture content of a coal sample, the lower the dust extinction moisture will be. This may be a useful result for industry in that it gives an indicative method for estimating dust extinction moisture content through a relatively quick and easy experiment. It is recommended that more research be conducted on this to understand why this relationship occurs and if there is any further significance.

In regard to dust control system design there has unfortunately not been any significant findings to aid in the design of airborne dust suppression systems. However, the results do demonstrate part of the reason for the inconsistent performance of dust control systems in industry; the variation in dust extinction moisture content from 4.6-27.5% demonstrates that all coals will exhibit different dustiness characteristics which highlights the fact that dust suppression systems need to be designed based on the specific requirements of each individual site, coal, or application.

5 LABORATORY TESTING RESULTS – NOZZLE TESTING

The purpose of this chapter is to present and analyse the characteristics of various nozzles that are commonly used by the Australian coal industry for airborne dust suppression. This section aims to provide a quantitatively measure of the characteristics of common nozzles being used to determine their differences and how that impacts the ultimate performance of nozzles being used in industry. In this study, the following characteristics are measured:

1. Nozzle characteristic curve (flow rate vs. pressure)
2. Droplet Size Distribution
3. Dust Capture Effectiveness

This data will serve as a useful resource for engineers designing dust suppression systems for the industry where the favourable characteristics of a nozzle are dependent on the application. A total of 12 nozzles were tested for the study representing a broad range of spray types used in industry. The nozzles tested are provided in Table 5-1.

Table 5-1: General details of spray nozzles included in the study

Supplier	Nozzle ID	Spray Type	Orifice Size (mm)	Cone Angle (°)
EnviroMist	EM.GIZ.06	Full Cone	0.6	20
	EM.GIZ.08	Full Cone	0.8	20
	EM.GIZ.10	Full Cone	1	20
	EM.GIZ.15	Full Cone	1.5	20
	EM.GIZ.20	Full Cone	2	20
Spraying Sytems	GG 3	Full Cone	1.6	60
	LN 2	Hollow Cone	0.7	70
SprayTech*	ST33	Full Cone	-	30
Joy/Komatsu	FF1	Flat Fan	2	60
Tecpro/PNR	DCM1370	Full Cone	2	45
	RXT1230	Hollow Cone	2.2	80
	RBQ1230	Hollow Cone	2.4	60

*Ultrasonic air atomising nozzle

5.1 Nozzle Characteristic Curve

5.1.1 EnviroMist

Figure 5-1 provides the flow rate curves for the range of EnviroMist nozzles tested for this project. The GIZ06-GIZ15 nozzles are commonly used EnviroMist nozzles in NSW coal mines. It is evident that, excluding the GIZ20, they have low to moderate water consumption all the way up to high water pressures of 150bar. The consumption of the GIZ20 nozzle is moderate to high across the range of pressures tested.

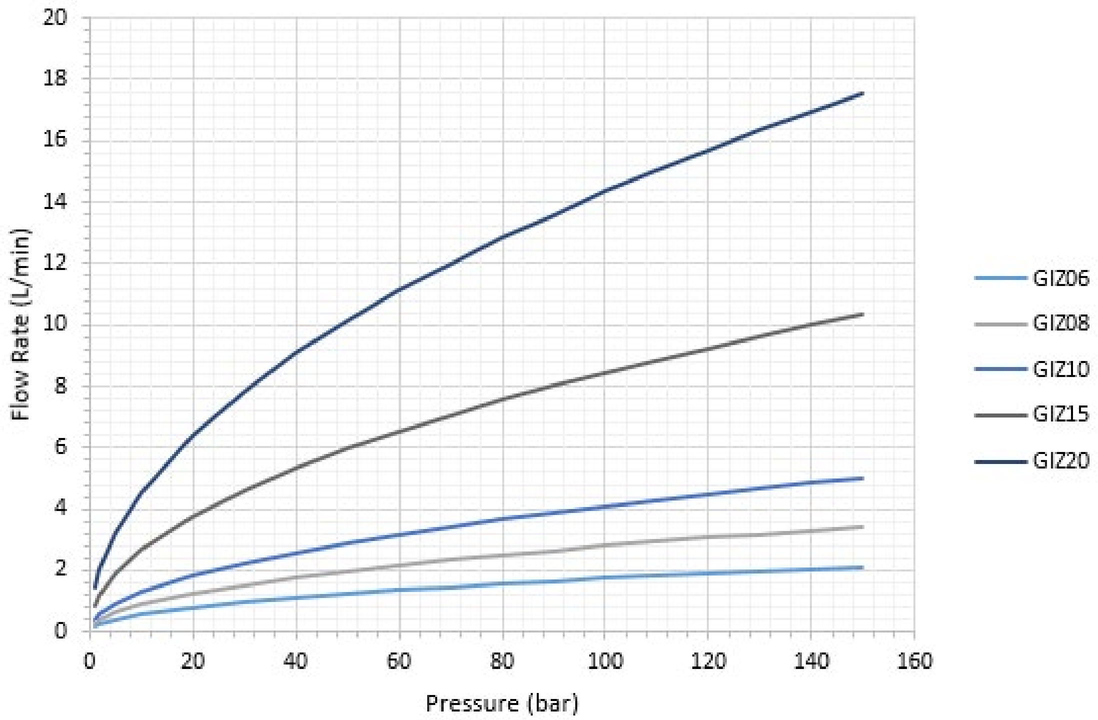


Figure 5-1: Characteristic curves for the range of EnviroMist nozzles tested

5.1.2 Spraying Systems

Figure 5-2 provides the flow rate curves for the two Spraying Systems Co. nozzles tested for the project. The two nozzles have drastically different characteristics, where the GG3 nozzle moderate water consumption up to its maximum pressure of 20bar, while the LN2 nozzle has extremely low consumption with a flow rate of approximately 0.65L/min at the maximum operating pressure of 70bar.

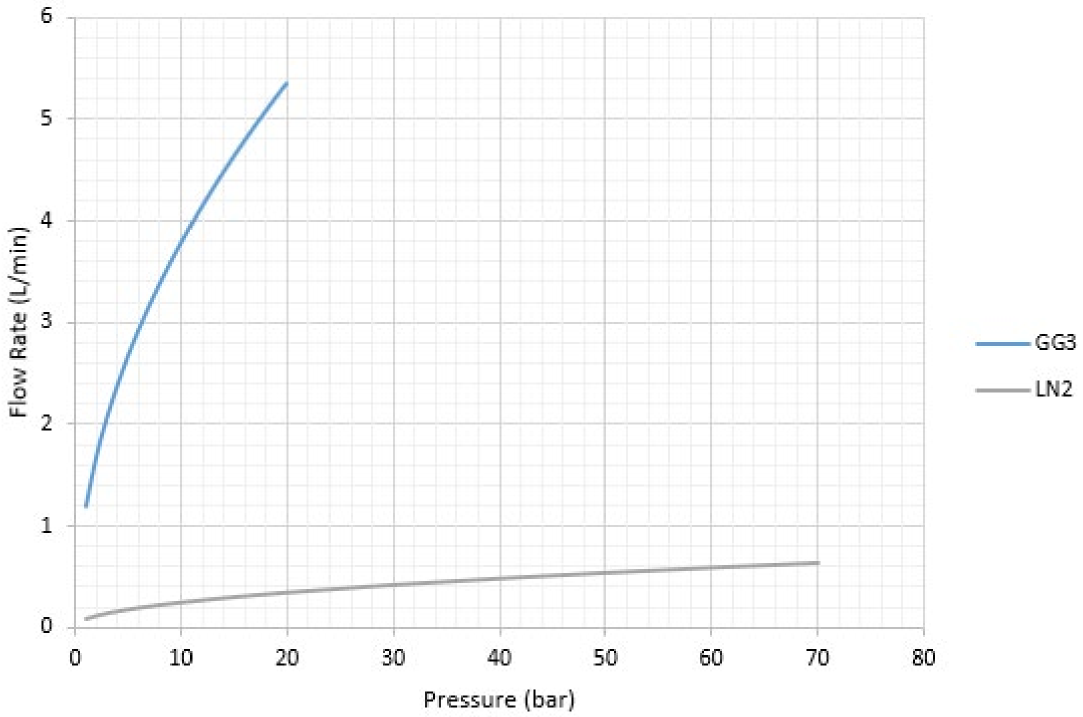


Figure 5-2: Characteristic curves for the Spraying Systems Co. nozzles tested

5.1.3 Tecpro/PNR

Figure 5-3 provides the flow rate curves for the three PNR nozzles supplied by Techpro for the project. The hollow cone RXT and RBQ nozzles have relatively moderate flow rates, while the water consumption of the full cone DCM becomes quite high when operated at higher pressures.

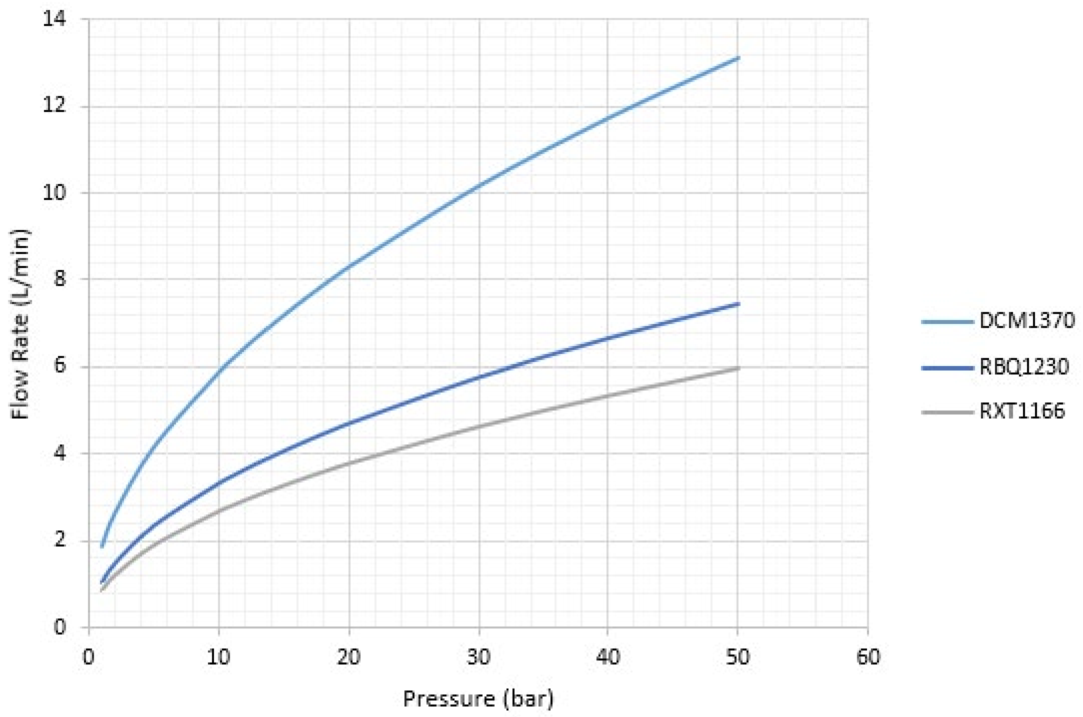


Figure 5-3: Characteristic curves for the Techpro/PNR nozzles tested

5.1.4 Others

A generic ultrasonic air atomising nozzle (ST33) supplied by Spraytech was also tested and reflects a common type of air atomiser used in industry. Table 5-2 provides the pressure and flow specifications for the ST33 air atomiser tested, the water consumption is relatively low, however, the air consumption is quite high and as such is an important consideration. Figure 5-3 provides the flow rate curve for generic flat fan nozzle that was pulled from a Joy/Komatsu mining machine and can be considered typical of many flat fan nozzles found in Australian coal mines.

Table 5-2: Spraytech ST33 air atomising nozzle pressure and flow specifications

	Pressure (bar)	Flow rate (L/min)
Air	4	263
Water	3	1.5

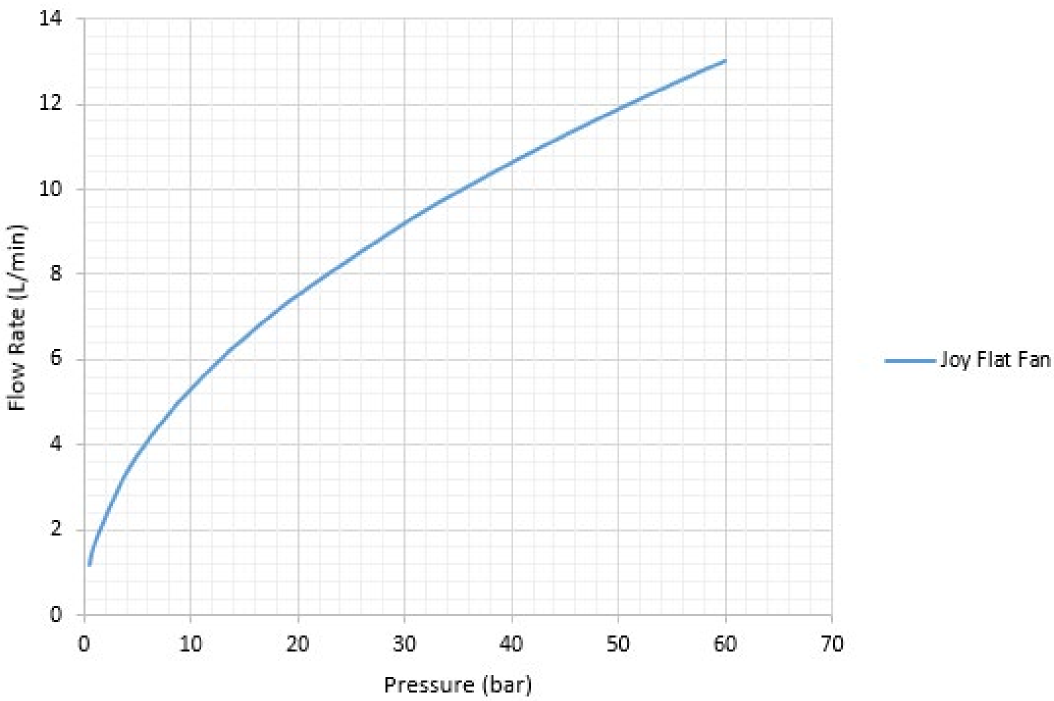


Figure 5-4: Characteristic curves for the flat fan nozzle tested

5.2 Droplet Size Distribution

The droplet size distribution generated by the nozzles tested was found using a JNWinner 319A laser diffraction droplet size analyser. The maximum droplet size that can be measured by this machine is 500µm and therefore limited data could be collected for any nozzles producing droplets greater than this size. The data provided for nozzles producing droplets greater than 500µm is based on the droplets measured up to 500µm and as such they indicative only.

Table 5-3 provides a range of values to characterise the droplet size distribution for each of the nozzle and pressure combinations tested for the project. The characteristics used to describe the droplet size distributions are as follows:

- DV_{10}: A value where 10% of the total volume of liquid sprayed is made up of drops with diameters smaller or equal to this value.
- DV_{50}: Volume Median Diameter (VMD) is the value where 50% of the total volume of liquid sprayed is made up of drops with diameters larger than the median value and 50% smaller than the median value.
- DV_{90}: A value where 90% of the total volume of liquid sprayed is made up of drops with diameters smaller or equal to this value.
- $D_{3,2}$: Surface area moment mean or Sauter Mean Diameter (SMD) is a means of expressing the fineness of a spray in terms of the surface area produced by the spray. SMD is the diameter of a drop having the same volume to surface area ratio as the total volume of all the drops to the total surface area of all the drops.
- $D_{4,3}$: De Brouckere Mean Diameter is the volume weighted mean diameter of the droplet size distribution. The De Brouckere mean is more sensitive to larger droplets which take up the largest volume of the sample.

Each of these characteristic diameters are useful for understanding the overall characteristics for the spray or specific aspects of the spray such as its propensity for airborne dust capture. Regarding dust capture DV_{50} provides a reasonable way to compare the median droplet size of different sprays but does not provide any information on the overall distribution. $D_{3,2}$ and $D_{4,3}$ provide better overall comparison of a droplet size distribution where D3,2 is more biased to smaller droplets and $D_{4,3}$ to larger droplets.

Table 5-3: Summary of droplet size measurements of each nozzle tested

Supplier	Nozzle	Pressure (bar)	Droplet Size (µm) DV$_{10}$	DV$_{50}$	DV$_{90}$	D$_{3,2}$	D$_{4,3}$	Distance (mm)	
Techpro/PNR	DCM1370	1	355	426	485	435	441	500	*
		3	59	152	323	117	179	500	*
		10	33	100	240	74	126	750	
		30	21	62	159	46	82	750	
		50	20	47	113	37	60	750	
	RBQ1230	10	25	75	180	59	96	500	
		30	21	53	126	41	67	500	
		50	19	45	105	34	57	500	
	RXT1166	3	42	107	227	81	128	500	
		10	24	75	180	58	96	500	
		30	20	54	129	40	68	500	
		50	13	41	104	29	54	500	
EnviroMist	EMGIZ06	3	43	110	280	85	143	500	*
		50	32	71	131	53	86	500	
		100	16	46	87	37	54	500	
	EMGIZ08	50	32	70	139	55	89	500	
		100	14	44	76	35	49	500	
	EMGIZ10	10	44	111	224	84	131	500	*
		50	31	71	125	51	79	500	
		100	14	43	80	34	50	500	
	EMGIZ15	3	44	107	257	83	136	500	*
		50	29	66	123	48	77	500	
		100	14	41	76	29	44	500	
	EMGIZ20	3	47	119	314	92	156	500	*
		20	32	86	228	70	115	500	
Spraying Systems	GG3	3	49	124	269	93	148	500	
		6	40	94	191	75	111	500	
		10	23	68	147	53	82	500	
	LN2	3	25	63	132	53	77	500	
		30	18	32	73	28	41	500	
Spraytech	ST33	W1 A4	18	22	28	23	23	500	
		W3 A4	20	43	97	38	53	500	
Komatsu	FF	3	47	129	270	92	148	500	*
		6	31	90	275	82	129	500	
		10	26	75	222	71	107	500	

*Produced droplets greater than 500µm, values given are based on droplets in 1-500µm range

5.3 Spray Dust Capture Performance

All of the nozzles noted in Table 5-1 have been tested using UOW's custom dust capture efficiency test rig that was setup as a part of this project. A diagram of the dust capture efficiency test rig is given in Figure 5-5. The test rig consists of a push-pull fan system where dust is injected at one end and passed through a duct where the concentration is measured prior to the spray zone, an open section allows a spray to be operated for dust capture to occur and on the other side a receiving duct draws any remaining dust in and allows the concentration to again be measured. The difference between the two dust concentration measurements represents the dust captured by the spray and allows for the dust capture performance of the spray to be determined. Dust is fed into the system via a vibratory feeder connected to venturi air pump, this allows the dust concentration to be varied based on the speed of the feeder. The velocity of the dust is controlled using variable speed controllers connected to each fan.

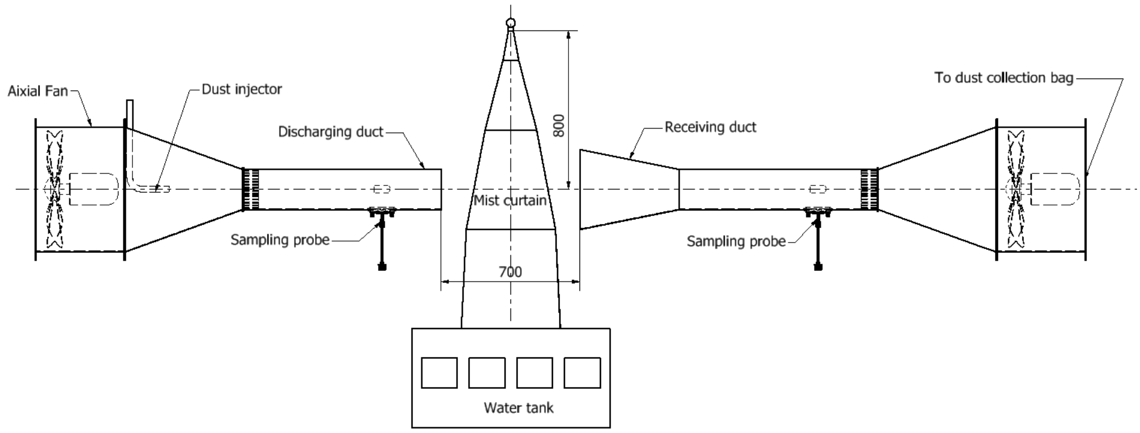


Figure 5-5: UOW dust capture efficiency test rig

The results of the testing completed is given in Table 5-4. The influence of the following parameters were investigated for the project:

1. Spray flow rate
2. Nozzle operating pressure
3. Dust concentration
4. Dust velocity

Table 5-4: Dust capture efficiency test results

Nozzle ID	Pressure (bar)	Concentration (mg/m^3)	Dust Velocity (m/s)	Efficiency (%)
EM.GIZ.06	4	1000	4	49.2
EM.GIZ.06	60	1000	4	94.3
EM.GIZ.06	4	500	4	52.9
EM.GIZ.06	20	500	4	91.3
EM.GIZ.06	60	500	4	95.6
EM.GIZ.06	100	500	4	96.9
EM.GIZ.06	20	500	8	85.2
EM.GIZ.06	60	500	8	93.4
EM.GIZ.06	100	500	8	96.9
EM.GIZ.08	20	500	4	93.4
EM.GIZ.08	60	500	4	96.7
EM.GIZ.08	100	500	4	97.8
EM.GIZ.08	60	1000	4	95.4
EM.GIZ.10	4	1000	4	74.8
EM.GIZ.10	4	500	4	77.8
EM.GIZ.10	60	500	4	93.7
EM.GIZ.15	4	1000	4	88.7
EM.GIZ.15	4	500	8	81.3
EM.GIZ.20	4	1000	4	93.1
EM.GIZ.20	4	500	8	86.2
GG 3	4	500	4	91.2
GG 3	6	500	4	93.3
GG 3	10	500	4	94.1
GG 3	4	500	8	87.0
GG 3	6	500	8	91.8
GG 3	10	500	8	92.9
DCM1370	2	1000	4	17.8
DCM1370	2	500	4	11.2
DCM1370	4	1000	4	84.6
RXT1166	4	1000	4	67.5
RXT1166	15	1000	4	93.4
ST33	W3 A4	500	4	96.8
ST33	W3 A4	500	8	91.3
FF	4	500	4	85.5
FF	4	500	8	74.8
FF	6	500	8	83.4
FF	10	500	8	86.2

5.3.1 Influence of spray flow rate

The availability of the EnviroMist nozzles of identical design but with four different orifice sizes allowed for the influence of water flow rate to be investigated independently of operating pressure. Figure 5-6 shows the change in dust capture performance for the EnviroMist nozzles as the orifice size increased from 0.6mm up to 2.0mm; there is a clear increase in dust capture with the increasing flow rate as a result of the larger orifice size. Given that all the nozzles were operated at the same pressure (~4-5 bar) and that droplet size is a function of pressure (viz. droplet size should be similar for all) then this result implies that the dust capture efficiency is strongly influenced by the number of droplets. This conclusion makes logical sense but quantifying the result also allows for further investigation of these factors to be undertaken, which is conducted in Section 5.4.

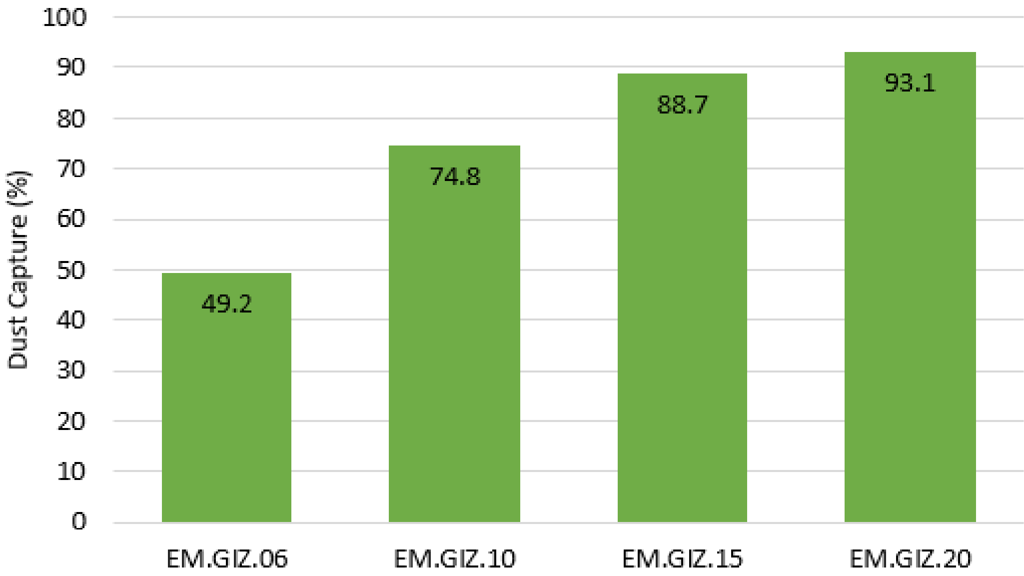


Figure 5-6: Dust capture performance of various size EnviroMist nozzles operated at mains water pressure (~4-5 bar)

A similar test was conducted with the nozzles operated at higher pressure (60bar), however, this resulted in high dust capture efficiency (>90%) for all the nozzles tested and as such the result is less conclusive. The result of this is shown in Figure 5-7, where the differences are within the margin of error for the overall test method.

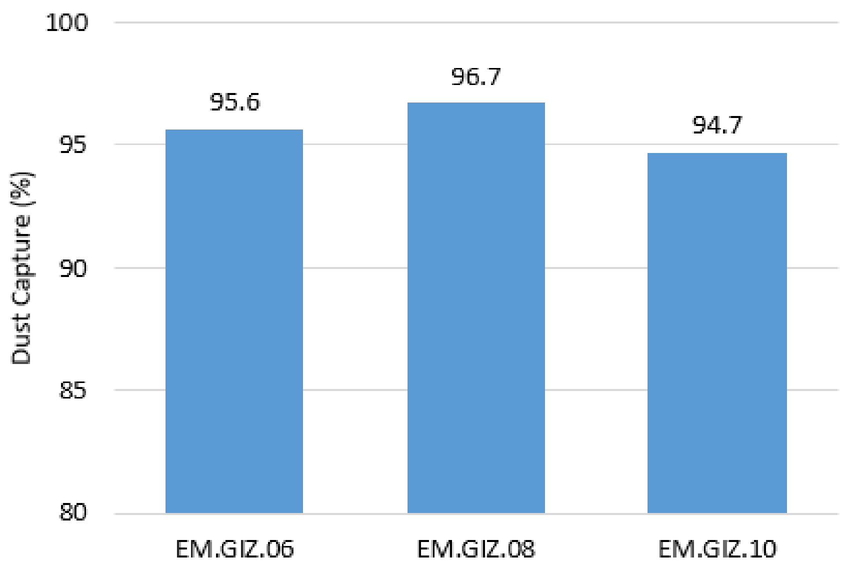


Figure 5-7: Dust capture performance of various size EnviroMist nozzles operated at 60bar water pressure

5.3.2 Influence of nozzle operating pressure

The effect of adjusting the pressure has been investigated for most of the nozzles tested. Figure 5-8 shows the effect across four different nozzles studied in the project, in all cases the dust capture performance increases with pressure. This shows that the performance of a dust suppression system can generally be improved by operating at a higher pressure, however given the performance of each nozzle is different at each pressure, it is not possible to determine the optimum pressure for a system without already having the data. The reason for the improved dust capture performance with increasing pressure cannot be determined as yet. From the previous section it is clear that an increased flow rate will improve dust capture, which will account for at least some of the improved performance occurring when pressure is increased. However, droplet size is also a function of pressure which means not only is the flow rate increasing but the droplet size is also getting smaller, leading to greater number of droplets in the spray as a result of both aspects. It is quite likely that the dust capture performance is not a function of just droplet size or flow rate but the combination of the two producing the greatest droplet concentration. This will be investigated in later sections.

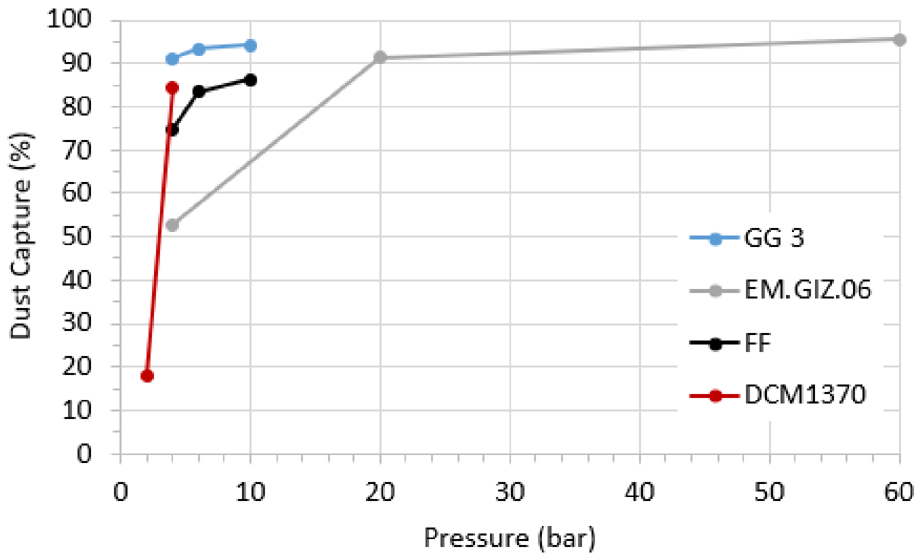


Figure 5-8: Dust capture performance of various nozzles at multiple pressures

5.3.3 Influence of dust concentration on capture performance

The influence of dust concentration on the dust capture performance of a spray is another important factor to understand. The test rig developed for the study allowed for dust concentration up to approximately 1000mg/m^3, where the maximum concentration was a limitation of the feeder and filtration system used though it was excepted the range chosen would be acceptable based on the data collected in Section 2. To understand the influence of dust concentration, tests were conducted with concentrations of approximately 500mg/m^3 and 1000mg/m^3. The result generated from these tests were unfortunately inconclusive, five nozzles/pressure combinations were tested at the two concentrations with four of the configurations resulting in lower performance at higher dust concentration, but one did not. The average reduction in performance of the four nozzles with lower performance was 2.32% which is not significant and lies within the margin of error for the experiment. The configuration that did not produce a lower performance with higher concentration had a dust capture of 11.2% at 500mg/m^3 and 17.2% at 1000mg/m^3, it is likely that the variation is due to the overall very low performance of the spray in this configuration which creates a higher margin for error. Comparing the concentrations in the test compared to the extremes of what is found in industry is likely the main reason for not finding a significant difference; Although all of the measurements directly made as a part of this project were within the capability of the test rig, it is still common to find dust concentrations more than 100 times greater than what is possible using the test rig. For example, dumping coal into a ROM bin as shown in section 2.3 where the dust cloud is clearly visible and opaque is likely to have concentrations >100g/m^3 TSP. Based on this, UOW intends to continue this aspect of the research through further development of the current test rig to allow testing of concentrations of at least 100g/m^3.

5.3.4 Influence of dust cloud velocity on dust capture performance

The influence of dust cloud velocity on dust capture performance is another important aspect given that every application will have different dust and wind velocities that need to be accounted for. To investigate this, ten nozzle/pressure combinations were tested at 4m/s and 8m/s with the results given in Table 5-5. The velocities were chosen to be representative of the findings from industry detailed in Section 2. Across the twenty configurations tested, the average dust capture performance was 4.6% lower when the dust cloud velocity was 8m/s compared to 4m/s with the maximum difference being 10.7%. The results show that for the nozzles tested there is a clear reduction in performance with higher dust cloud velocity. The reason for the change is dust capture with the increasing dust cloud velocity is most likely a function of the spray velocity, where it is easier for a hole to be blown through a low velocity spray compared to a high velocity spray. This is an important finding that can be included in the analysis conducted in the next section.

Table 5-5: Influence of dust cloud velocity on dust capture performance

	4m/s	8m/s	Diff.
Dust Capture Performance (%)	91.3	85.2	6.1
	95.6	93.4	2.2
	96.9	96.9	0.0
	88.7	81.3	7.4
	93.1	86.2	6.9
	91.2	87.0	4.2
	93.3	91.8	1.5
	94.1	92.9	1.2
	96.8	91.3	5.5
	85.5	74.8	10.7
Average	92.7	88.1	4.6

5.4 Quantifying the performance of a spray for dust capture

From the data collected and outlined so far it is clear that there are a lot of factors affecting the performance of a water spraying dust suppression system and this has been one of the long running difficulties with the design of these systems. To reduces the difficulty of designing these systems it is proposed that a means of quantifying a nozzle for dust capture performance should be developed. Based on the data outline in Section 5.3 it is clear that water consumption, droplet size and spray velocity all play a role in the effectiveness of a spray. Therefore, it is proposed to define a spray efficiency parameter that can be used for the evaluation of the potential performance of a spray for dust capture, this is given in Equation 4-1.

$$S_\eta = \frac{kQv}{D_{3,2}} \qquad \text{Equation 4-1}$$

Where, k is a constant to convert S_η to a dimensionless parameter dependent on the units used, Q is the volumetric flow rate through the nozzle, V is the theoretical exit velocity of spray out of the nozzle, and $D_{3,2}$ is the Sauter mean diameter. Table 5-6 provides the spray parameter calculated for each of the nozzle and pressure combinations tested, where k is equal to $16.67 s^2/m^3$ corresponding to the units given in the table. This provides a single parameter that can be used to directly compare each of the tests conducted such that a better understanding of the results can be developed.

Table 5-6: Calculated spray parameter for each nozzle/pressure combination tested

Nozzle ID	Orifice Size (mm)	Pressure (bar)	Flow Rate (L/min)	$D_{3,2}$ (μm)	Exit Velocity (m/s)	Spray Parameter
EM.GIZ.06	0.6	4	0.3	85	17.7	1.0
EM.GIZ.06	0.6	20	0.82	60	48.3	11.0
EM.GIZ.06	0.6	60	1.43	53	84.3	37.9
EM.GIZ.06	0.6	100	1.84	37	108.5	89.9
EM.GIZ.08	0.8	20	1.4	60	46.4	18.1
EM.GIZ.08	0.8	60	2.43	53	80.6	61.6
EM.GIZ.08	0.8	100	3.14	34	104.1	160.3
EM.GIZ.10	1	4	0.68	84	14.4	1.9
EM.GIZ.10	1	60	3.04	51	64.5	64.1
EM.GIZ.15	1.5	4	1.48	83	14.0	4.1
EM.GIZ.20	2	4	2.39	92	12.7	5.5
GG 3	1.6	4	2.07	93	17.2	6.4
GG 3	1.6	6	2.93	75	24.3	15.8
GG 3	1.6	10	3.78	53	31.3	37.2
DCM1370	2	2	1.3	435	6.9	0.3
DCM1370	2	4	3.1	117	16.4	7.3
RXT1166	2.2	4	1.3	81	5.7	1.5
RXT1166	2.2	15	2.67	58	11.7	9.0
ST33	0.5	W3 A4*	1.5	38	127.3	83.8
FF	1.5	4	2	125	18.9	5.0
FF	1.5	6	3.9	71	36.8	33.7
FF	1.5	10	5.1	61	48.1	67.0

*Water = 3bar, Air = 4bar

Figure 5-9 shows the spray parameter plotted against dust capture performance for all the tests conducted. Considering Figure 5-9, there are two clear zones present (indicated by the dotted red line) in the relationship between capture performance and the spray parameter. The first section of the plot shows a steep improvement in dust capture as the spray parameter increases from 0 up to a spray parameter of approximately 3 where the efficiency climbs above 80%. The second section shows a levelling out of the curve where the spray parameter needs to increase significantly for there to be an increase in capture performance. This is likely to be a valuable insight for designers of dust suppression systems as it can be used to improve the efficiency of a system being designed. For example, a system designed to give a spray parameter of 100 is unlikely to perform significantly better than one with a spray parameter of 10, however it may have much higher water and/or energy consumption. Another example where this data may be useful is in the selection of spray for a continuous miner where the risk of dust and spray roll back can be an issue. In this scenario it is important to select a spray with good dust capture characteristics, but it cannot have excessive energy (high pressure) otherwise there is a risk of rollback. The spray parameter can be used to aid in optimised selection of a nozzles operating condition.

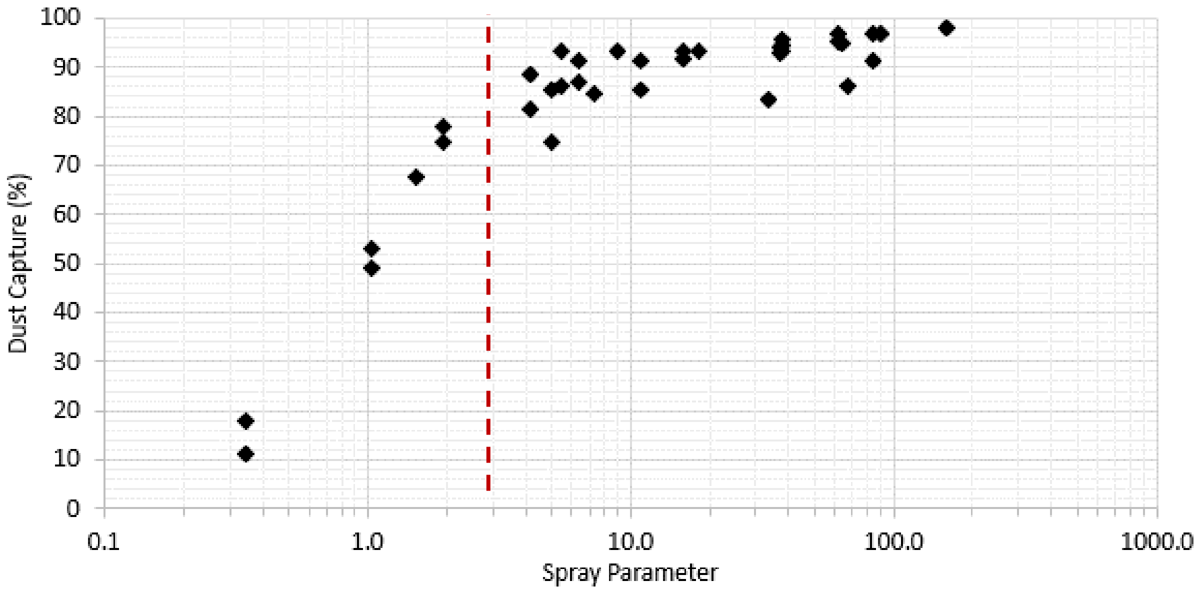


Figure 5-9: Dust capture performance vs. spray parameter for all tests conducted

Figure 5-10 and Figure 5-11 shows the differences with varying concentration and dust velocity, respectively, to aid in understanding the effect of these. Again, there is not a significant difference appearing between the two concentrations tested which will remain an important caveat to the result of this project that needs to be further research with higher concentrations. Considering Figure 5-11 the difference between the different dust cloud velocity is relatively clear with majority of the 8m/s velocity points clearly below those tested at 4m/s. The significance of this is that the value for the spray parameter needs to be higher in order to achieve a required dust capture efficiency. In this case it is not until a value of 10 that all spray configurations give a dust capture of greater than 80% and based on the data collected it may require a spray number of more than 80 to reliably achieve greater than 90% dust capture. Further data should be collected to provide a more detailed evaluation of the effect of dust cloud velocity, however, given that most industry applications will result in dust cloud velocities in the range of 2-10m/s the following recommendations can be made:

- A spray parameter of greater than 10 should be used for dust clouds up to 5m/s.
- A spray parameter greater than 50 should be used for dust clouds of 5-10m/s.

Based on the data collected, these recommendations should result in greater that 85% dust capture under the stated conditions and assuming the dust concentration is significantly greater than that tested.

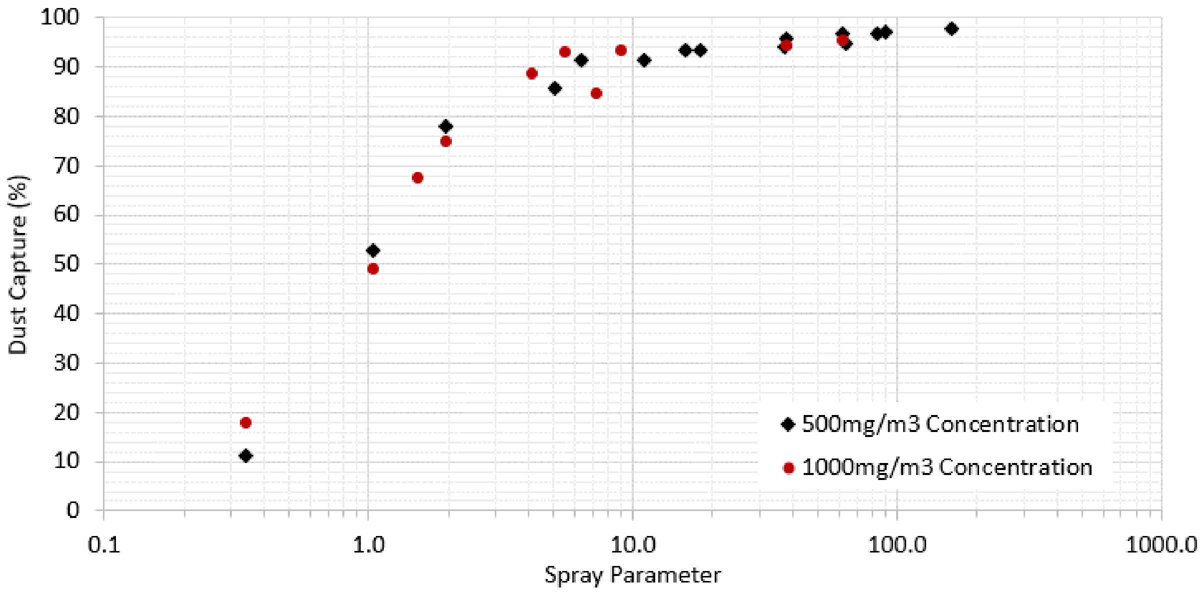


Figure 5-10: Dust capture performance vs. spray parameter for 500mg/m^3 and 1000 mg/m^3 concentrations

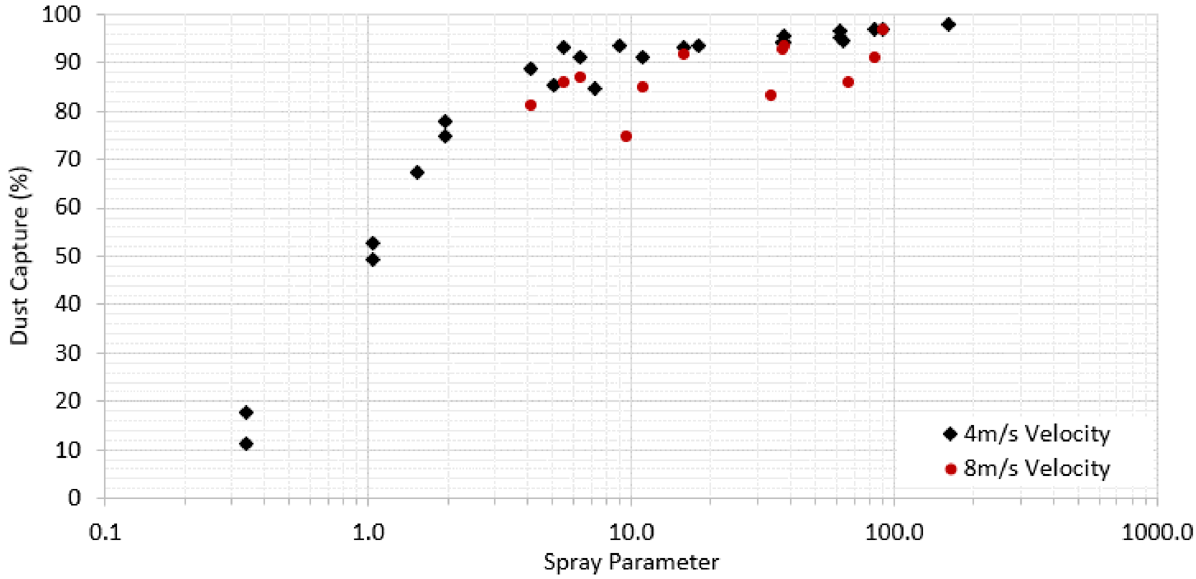


Figure 5-11: Dust capture performance vs. spray parameter for 4m/s and 8m/s dust cloud velocities

5.5 Other Considerations – Spray Deflection

Previous work conducted at UOW [9] has looked at the influence of different air velocities (viz. wind or ventilation flow) on sprays operated perpendicular to the flow. A similar approach was taken in that work to provide a reference source for engineers to be able to select nozzles based on application conditions. This resulted in the data set shown in Figure 5-12 which provides a reference chart for selecting a nozzle to achieve a certain penetration based on the theoretical input power to the nozzle and the velocity of an airflow operating perpendicular to the nozzle. The theoretical input power of the nozzle is defined as the product of pressure and volumetric flow rate. This data can be used in combination with the recommendations made in Section 5.4 such that the suitability for a nozzle for dust capture can be determined based on the spray efficiency parameter and the coverage of the spray produced can be predicted via the data in Figure 5-12. The data in Figure 5-12 is relevant for nozzles producing a spray cone angle up to 30°, with work on going to collect the required data for nozzles with wider cone angles and different spray patterns.

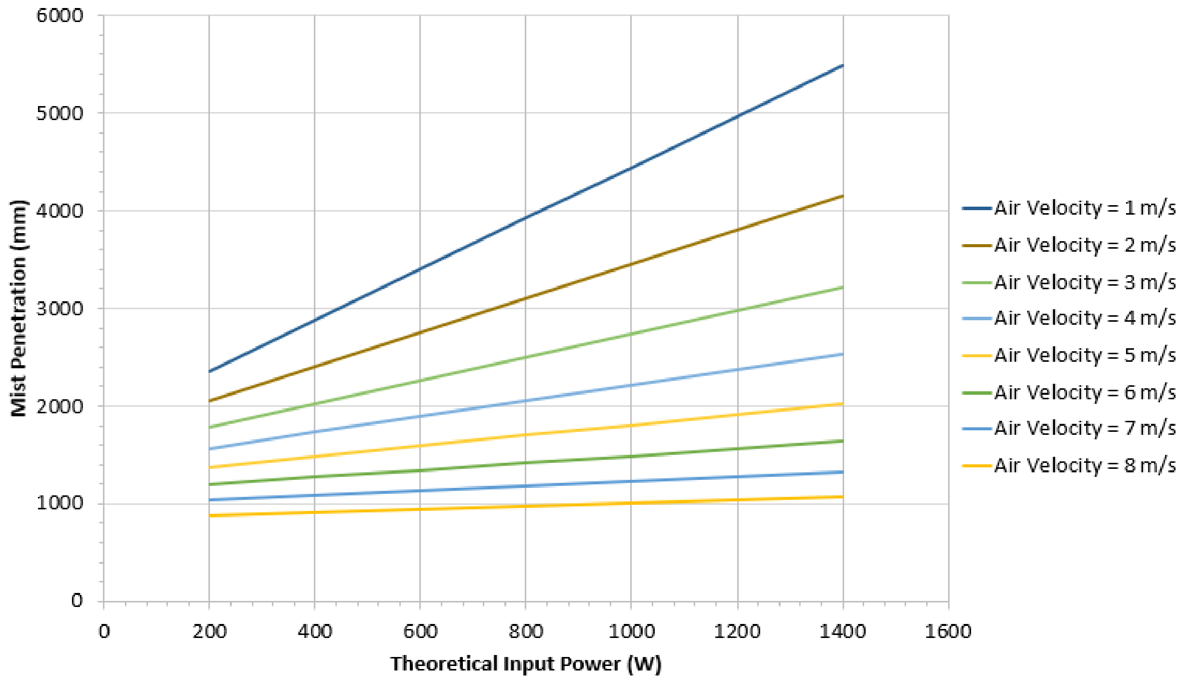


Figure 5-12: Spray deflection as a function of perpendicular air velocity [9]

5.6 Summary

This chapter has outlined the data collected on various spray nozzles that are commonly used in the Australian coal industry. In the first instance, the data collected will serve as a useful reference source for engineers working to select nozzles for the design of dust suppression systems. Having this reference source of data that is often not available from suppliers will allow engineers to select nozzles with the correct spray characteristics to match the specific conditions of any individual application being considered.

Furthermore, the analysis conducted has also led to the development of a spray efficiency parameter to further improve the ability for engineers to judge the suitability of a nozzle for airborne dust suppression. Although further research should be conducted, the results to date provide a strong argument for the use of a spray efficiency parameter for nozzle selection and a recommendation of how it should be applied has been given. This method can be used in addition to the previous work conducted by UOW to predict the penetration of a spray under different wind conditions. Together this work provides a framework that engineers can use in the design of airborne dust suppression systems. UOW will continue to collect additional data to further extended the applicability of the work to a broader spectrum of nozzle characteristics.

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