The Development of a Dustless Dry Gunite Pump System in Underground Coal Mining – A Case Study

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ABSTRACT

Gunite was invented in 1907 by Carl Akeley to repair a crumbling facade of the Field Columbian Museum in Chicago. The method used was to blow dry material out of a hose with compressed air and inject water at the nozzle as it was released. In 1911, he was granted a patent for his invention, the 'cement gun'; the equipment used; and 'gunite', the material that was produced.

The advantages of using the dry mix process is that the water content can be adjusted instantaneously, allowing more effective placement in overhead and vertical applications without using accelerators. The dry mix process is useful in repair applications when it is necessary to stop frequently as the dry material is easily discharged from the hose.

This paper describes the applications and principles of the gunite pump system in underground coal mining and discusses why it is the preferred spraying system for both cement and plaster products.

It also addresses improving productivity and examines dust, respirable crystalline silica (RCS) and health issues around gunite pump systems. The solutions include development of the latest componentry for current gunite pumps to improve their efficiency and allow their operation to be dustless.

In particular, this paper addresses:

- why and where RCS is a problem in underground coal mining
- how RCS hazards and its propagation can be managed
- how the gunite pump system has become dustless
- how the gunite system has become more productive
- gunite occupational health and safety issues and how they have been solved
- a case study of gunite dry spraying.

INTRODUCTION

Almost all gunite pumps are of a very robust design that began life in the civil industry in 1919, where dust and occupational health and safety (OHS) were not an issue. While gunite pumps have not changed since then, we still use them in a stringent OHS, confined-space environment. The other of the two most popular pumps is much younger, having been developed in 1956 and unchanged since then. The underground coal industry has not asked for these original designs to be changed or upgraded.

What is respirable crystalline silica (RCS)? Silica is silicon dioxide, a naturally occurring, widely abundant mineral that forms the major component of most rocks and soils. There are non-crystalline and crystalline forms of silicon dioxide, with crystalline silica also known as free silica. Crystalline silica dust particles tat are small enough to penetrate deep into the lung are termed 'respirable'. Crystalline silica can be harmful when inhaled as a dust in the respirable range (<5 µm particles) (Parks, Conrad and Cooper, 1999) and may cause lung damage. The non-crystalline form of silica does not cause this kind of lung damage.

There have been extensive epidemiological and toxicological studies about whether RCS dust is a risk factor for lung cancer mortality among exposed workers. In 1997, the International Agency for Research on Cancer (IARC) concluded that 'crystalline silica inhaled in the form of quartz or cristobalite from occupational sources is carcinogenic to humans (Group I)' (IARC, 1997). The working group noted that there was 'sufficient evidence' in both the epidemiologic studies and animal data to support these conclusions (IARC, 1997, p 210). In its review, the IARC considered more than 40 lung cancer studies (both cohort and case-control) among silica-exposed workers and workers diagnosed with silicosis (silicotics). The IARC based its overall finding on studies of nine occupational cohorts that it considered to be the least influenced by confounding factors as well as selected studies of registered silicotics with lung cancer. Most of these studies

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reported found an excess lung cancer risk in occupationally exposed populations.

While acknowledging some inconsistency in the studies, the IARC stated that:

> *… in view of the relatively large number of epidemiological studies that have been undertaken and, given the wide range of populations and exposure circumstances studied, some non-uniformity of results would be expected* (IARC, 1997, p 208).

The IARC also noted that some studies demonstrated increasing risk gradients (positive exposure-response trends) in relation to cumulative silica exposure, duration of exposure and/or radiographic-diagnosed silicosis, and that '… these observed associations could not be explained by confounding or other biases' (IARC, 1997, p 208).

Unlike a work-related injury where the effects are seen immediately, silicosis and other silica-related illnesses may not show up for many years after exposure. The most common early symptoms are a chronic dry cough and shortness of breath with physical activity. There are three types of silicosis:

1. chronic silicosis, which occurs after ten or more years of exposure to low concentrations of RCS
2. accelerated silicosis, which occurs five to ten years after exposure to high concentrations of RCS
3. acute silicosis, which occurs a few weeks to five years after exposure to very high concentrations of RCS.

Other minerals found in blended dry construction materials can have as serious and fatal health outcomes for personnel exposed to the respirable dust as RCS.

DOES BLENDED GROUT CONTAIN RESPIRABLE CRYSTALLINE SILICA?

A blended grout, which is composed of cement, sand and supplementary cementing materials such as fly ash, definitely contains crystalline silica because of the presence of aggregate – sand. Sand contains 96–100 per cent quartz, which results in a source of RCS. However, if the sand is a ground product, particle sizes are strictly controlled to be larger than 10 µm, which means that the sand will not contain RCS at all (Zhang, 2015).

The binder ingredient cement usually does not contain RCS because a quality-ensured cement only consists of clinker and gypsum ($Ca_2SO_4 \cdot nH_2O$). The clinker is made by heating a mixture of limestone and clay, or other materials of similar bulk composition and sufficient reactivity, to a temperature of about 1450°C. If the limestone and clay are of high quality, the clinker will not contain RCS. However, it may contain RCS if the raw materials contain certain fractions of quartz.

Fly ash is a solid waste by-product that is disposed of from coal-fired power stations. It has become a commercial product that is mainly used by the cement and concrete industries. The main components of fly ash include SiO_2, Al_2O_3, Fe_2O_3 and CaO (see Table 1). The SiO_2 presents in a predominantly amorphous state rather than in a crystalline state. This is because the high-temperature formation process (up to 1700°C) melts the clay (such as kaolin and feldspar) and quartz particles in the coal particles while it burns. However, when fly ash is formed at relatively low temperatures (<1700°C), some of the quartz may remain in a crystalline state. As fly ash particles are usually very fine (from <1 to 150 µm), some of the quartz may be smaller than 10 µm, which makes them a source of RCS.

Most Australian fly ashes contain RCS. As shown in Table 1, this can be calculated by weight per cent as 1.34 per cent of a typical blended composition.

This low RCS content means that the health issues from the other minerals contained in the component parts of the typical blend composition are greater. Tables 1 and 2 show the mineral content in the components of a typical blend, with several of these minerals being hazardous to human health.

UNDERSTANDING DUST

While dust is a problem in many workplaces, RCS is seen as a significant issue. Smaller dust particles (less than 10 µm) are the most concerning as a health issue. Airborne dust particles larger than 10 µm can be expelled by the human body, whereas particles smaller than 10 µm lodge in the airways or lungs and remain as irritants, triggering the propensity for these diseases. Silica is a component in this respirable dust and is one of the more harmful. However, other minerals contained in dust can also cause lung disease, including tin, beryllium, talc, kaolin, mica, lead, aluminium, fluorspar and chromium. Most of these minerals can be found in dry construction materials, as shown in Table 1. Dust particles can also reduce visibility and cause equipment damage and personnel discomfort.

The best dust solutions are not to produce dust in the first place nor to allow dust to reach breathable air. If dust particles are distributed as a result of swirling up of dust deposits or improper storage or transport, it is already too late.

By monitoring and understanding dust and RCS behaviour, workplaces can develop effective management plans, procedures and controls through risk assessments to help personnel manage and control these dust hazards to prevent issues (such as those shown in Figure 1).

DUST CONTROL AND RISK MANAGEMENT

This paper deals with respirable dust (less than 10 µm in size) in the underground mining environment, examining where it comes from and how to manage the associated safety and health hazards. RCS fits in the size category shown in Figure 2.

Mine safety legislation in Australia includes statements that cover supervision, allocation of tasks and safety considerations, responsibility and accountability. Among these statements is the requirement that management and supervisors must consider dust control, amongst other considerations, when allocating tasks in a mine for safe execution.

As shown in Table 3, the size of a particle will influence the health outcomes and how the particle can best be managed to prevent exposure by personnel. The author hopes that this dust

TABLE 1

Compositions of cement, fly ash and sand determined by X-ray fluorescence, wt per cent (Zhang, 2015).

	CaO	MgO	Fe_2O_3	Al_2O_3	SiO_2	K_2O	Na_2O	SO_3	P_2O_5	MnO	TiO_2	Loss on ignition
Cement	62.52	2.84	3.33	4.66	20.42	0.54	0.05	2.85	0.07	0.03	0.24	1.85
Fly ash	0.43	0.46	2.79	14.13	79.78	1.02	0.10	0.29	0.07	0.045	0.55	0.49
Sand	0.07	0.06	0.02	0.11	98.74	0.02	0.00	0.19	0.01	0.00	0.04	0.14

TABLE 2

Chemical compositions of ten fly ashes generated in Australian power stations, wt per cent (Heidrich, 2003).

Fly ash	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	Loss on ignition
A	58.0	26.5	3.2	1.6	0.9	0.4	0.4	0.1	3.0
B	56.7	26.7	5.0	1.1	0.9	0.4	1.3	0.1	3.5
C	63.2	27.4	1.0	0.2	0.2	0.6	2.2	0.2	10.0
D	69.2	21.8	3.5	1.2	0.7	0.5	1.4	0.1	1.3
E	58.6	28.5	6.3	1.6	1.0	0.3	1.2	0.7	1.3
F	65.0	23.0	5.0	0.2	0.3	0.4	1.8	0.2	1.3
G	59.0	26.4	3.3	5.9	1.8	3.7	0.7	0.1	0.2
H	48.1	30.3	12.2	3.2	1.5	0.4	0.5	0.2	2.0
I	62.4	26.8	1.9	1.6	1.1	1.0	0.7	0.3	2.1
J	71.0	24.9	0.7	0.1	0.2	0.1	0.4	0.0	1.1
Mean	61.1	26.2	4.2	1.7	0.9	0.8	1.1	0.2	2.6
Standard deviation	6.62	2.48	3.31	1.74	0.54	1.05	0.62	0.19	2.78

FIG 1 – Dust example in an underground mine (NEPSI, n/d).

TABLE 3

Dust particle size and suspension in air relationships (NEPSI, n/d).

Fall velocity (cm/s)	Duration of fall from a height of 1 m	Particle size (µm)
0.00006	500 h	0.1
0.006	5 h	1
0.6	3 min	10
15	6 s	50

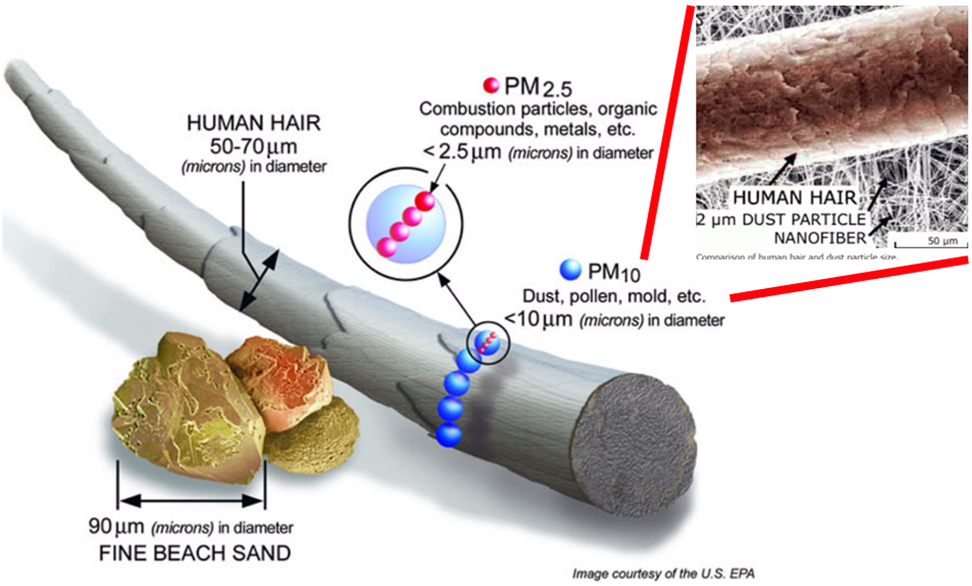

FIG 2 – Comparison of human hair to particle size (Golsby after Newmont Mining, 2010; Dirr, 2013).

exposure and management hazard matrix will drive legislation towards not only total particle weight, but also particle size, distribution, morphology (shape and sharpness), the relationship to disease and suspension and dust management considerations (Figure 3).

Where the risks cannot be eliminated, effective controls need to be developed and used. Management and supervisors should apply a hierarchy of hazard control and strive to adopt higher-order control measures rather than relying on administrative controls such as rules and procedures.

For controls to be effective, the potential for human error also has to addressed and managed. Involving those undertaking the task in the risk assessment process will help the mine site ensure that hazards are recognised and understood and that mitigating controls are implemented.

A mine's health and safety management system must also provide ways of ensuring that each worker's exposure to respirable dust at the mine is kept to an acceptable level, and that dust levels are calculated to Australian Standard AS 2985 (Coal Services Pty Ltd, 2008; New South Wales Department of Industry, Resources and Energy, 2007).

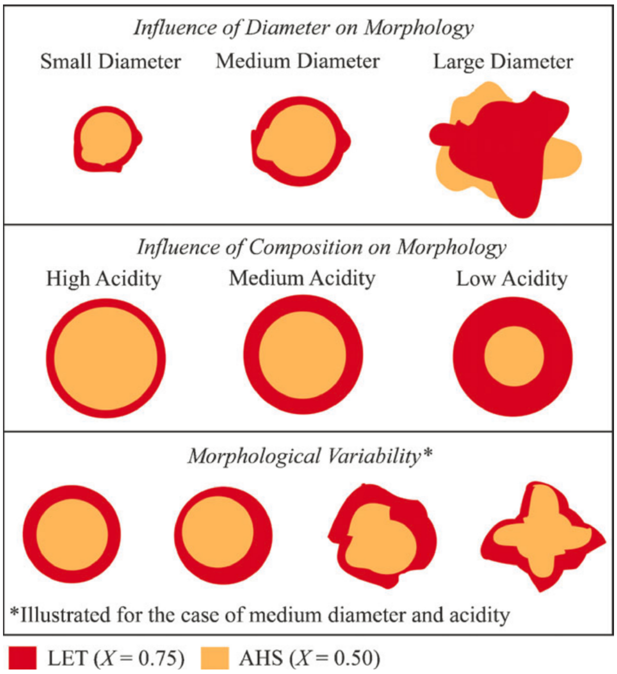

FIG 3 – Morphology hypothesised to influence aerosol particle deliquescence (Mifflin, Smith and Martin, 2009).

GUNITE DRY SPRAYING – TIME FOR A REVIEW

The gunite application case study included in this paper discusses some of the issues and solutions in the management of RCS in the mining environment.

When surveyed for this paper, the majority of mine workers answered that they were not aware that they were working with products containing RCS. At the time of questioning, the workers were installing a product that contained RCS. Often, the procedures for the use and installation of products containing RCS are labour-intensive and include manual handling of the product. Most workers working with products containing RCS are usually in close proximity to the product and the RCS dust raised when the product is agitated for application or installation. Many of the mine workers, supervisors and management were unable to comprehensively list products containing RCS on the mine site, meaning that they were unaware of the products that need dust control management practices during use. An increased awareness of these products and their related safety hazards will reduce these issues at mine sites.

A typical Piccola gunite pump used for dry gunite spraying in an underground mine is shown in Figure 4. These types of pumps are designed to be fine-tuned to reduce the dust emitted from the pump. However, they require constant resetting as the rubber adjustment plate wears, allowing dust to escape from around the base of the hopper during operation. Dust can also escape from around the top of the hopper as it is loaded or mixed and during the nozzle application process.

While many of the modifications discussed in the case study reduce the dust raised through dry guniting, they also improve the consistency of the application, safety of the personnel operating the equipment and the ergonomics during the dry guniting process, and reduce the maintenance required. Many of these functions create less downtime as there are less blocked hoses, better pump throughput, better bonding to the substrate being sprayed, mitigation of dust from the dry guniting process affecting operations and more consistent delivery to the guniting pump. These benefits have been seen to speed up the whole dry guniting process and thus allow other tasks to continue in close proximity, reducing the time that it takes to install critical infrastructure such as ventilation seals, over cast construction or rib support. This means less downtime and more production time underground.

The dustless gunite pump is modified to include a pump rev meter and air pressure gauges so that the nozzle operator can refine their technique. They can use the nozzle to keep a constant ideal pressure to reduce dust and product wastage and optimise application (as shown in Figure 5). The two gauges can be preset using a recommendation data sheet in the training manual. The various gunite mix requirements can be documented and kept at the machine, meaning that all the operators have to do is ensure that the recommended revs and pressure are set so the system is near optimum performance and then fine-tune as necessary.

Modifications to the gunite pump were driven by necessity. Some of the gunite pump changes were for dust mitigation while others were to remove operational issues. Another problem we had to deal with during this case study was that the left water trap base could not be removed due to the yellow tap forward of the drain tap on the right. The oiler could not be adjusted as it was hard against the bracket, resulting in the oil running dry and blowing the motor.

These issues were present in the off-the-shelf gunite pump used in this case study as the operational engineering design

FIG 4 – A typical Piccola gunite pump (M Moore, October 2014, personal communication).

FIG 5 – Pump rev meter gauge for nozzle management (M Moore, October 2014, personal communication).

of the machine by the assemblers had not been optimised. The gunite pump used in the case study had been designed over 100 years ago, with little design modification from the original concept.

CASE STUDY

The recognition of RCS is usually based on two methods. The first is 'visual observations', where 'if there is dust then there is usually RCS'. This is despite the fact that RCS has a size of 10 µm or below, which makes it invisible to the human eye. The other method is much more scientific, whereby dust pumps are established at the point of the dust generation and inbye from there. The only problem with this system is that it relies on analysis that can take considerable time and will likely delay a scheduled spray application program.

Figure 6 shows the dust collector and bag breaker provided for a Lova pump. The Antec dust hood has an open grate that allows any back pressure to simply puff vertically up. The collection rim can be seen as the angled flanges at the bottom of the hood, and the bag breaker is an OHS fall problem. The personnel loading the pump with product often toss the bags onto the wide rim from a couple of metres away, causing clouds of dust. This practice would create dust no matter how effective the bag breaker design manages and controls dust.

Figure 7 is a breakdown of the high-pressure water gunite nozzle that has been developed for dry spraying, with a unique pattern of holes in the steel sleeve in the middle. The nozzle operates at around 1300–1400 psi, fully atomising the water but at the same time providing the required volume of product and reducing the dust usually produced by a dry

FIG 6 – Antec dust hood and bag breaker (M Moore, October 2014, personal communication).

FIG 7 – Modified gunite nozzle for reduced dust (M Moore, October 2014, personal communication).

gunite nozzle to almost zero. The modified nozzle was used on an off-the-shelf but modified dustless gunite pump.

The new modified dust hood reduces the dust raised from tipping the bags of gunite mixture into the hopper of the gunite pump. This allows for much longer gunite spray delivery hoses to be used as the 'puff back' through the pump from hose back pressure is now captured. This reduces the number of pump moves and set-ups, speeding up the pumping process.

In almost all mines, the dry gunite system is used to build anything that requires a high to medium volume of product to be sprayed (eg stoppings).

Recently, only one original equipment manufacturer manufactured a dust collector, and less than half a dozen are currently used in the entire industry. The collector is the only one available, and its efficiency in recovering all the dust generated at the pump hopper is very limited. By overfilling the hopper, an operator could easily transfer a fair proportion to the dust collector and clog it. In addition, the filter unit was not equipped for self-purging, meaning that the filter could not be cleaned underground.

A large proportion of fines is blown dry from the nozzle and also generates dust. This is due to the fact that the old style of water ring generated low-pressure water at a large particle size. This has been overcome by introducing high-pressure (up to 1500 psi) water through a super-fine holed nozzle assembly that atomises the water but maintains a sufficient volume to 'wet' the product efficiently.

In addition, a new polymer has been added to most dry mix products that changes the polarity of the fine particles, making them agglomerate into much larger particles and drop out more quickly due to gravity. As a result, any agglomerated airborne product (containing RCS) that escapes from the new gunite system drops quickly to the ground.

A typical example of a simple change in operational practice that can impact everyone is maintaining an exclusion zone within an airway at a calculated distance and ensuring that doors are not opened during spraying. To manage the logistics, the spraying would need to flow from inbye to outbye so that the delivery of product to new set-up points by a loader would always be outbye of the spray crew, thus maintaining the exclusion zone.

Figure 8 shows a typical dust collector filter after a shift. Modified deflection baffle plates and a manual purge bar have been added so that it now comes out almost clean, with the fines left in the bottom of the drum. This makes the pump and collector dustless.

The Antec dust hood pick-up was too low to the hopper rim and collected solids if the hopper was missed when being filled, picking up the airborne dust from the hopper. The new hat solves both problems and is shown in use in Figure 9.

The effectiveness of the dust collector can be seen by the amount of dust collected in one shift underground (as shown in Figure 10). While not all of the dust is RCS, it is collected and removed from the air at the same time as the visible dust.

FIG 8 – Modified dust collector (M Moore, October 2014, personal communication).

FIG 9 – Operator dumping bag into gunite feeder unit with new dust collector hood installed (M Moore, October 2014, personal communication).

FIG 10 – Dust collector filter after one shift (M Moore, October 2014, personal communication).

There is a need for a staged filtration system including a high-efficiency particulate arrestance filter. When the dust is removed, it improves visibility and reduces safety and health hazards on the worksite. There is a need to measure the dust improvement measures, which is the next step in the case study development process.

CONCLUSIONS

While many of the modifications discussed in the case study reduce the dust raised through dry guniting, they also improve the consistency of the application, safety of the personnel operating the equipment and the ergonomics during the dry guniting process, and reduce the maintenance required. Many of these functions lead to less downtime in the dry guniting process as there are less blocked hoses, higher-volume and more consistent pump throughput, better bonding to the substrate being sprayed and a reduction in dust from the dry guniting process affecting operations. These benefits have been seen to speed up the whole dry guniting task and thus allow other tasks to continue in close proximity, reducing the time that it takes to install critical infrastructure such as ventilation seals, over cast construction or rib support. This means less downtime and more production time underground.

Recommended RCS control measures include:

- display recommended silica content on the outside of product packaging with a standardised regime of RCS levels (possibly micrograms per kilogram and high, medium and low concentrations)
- develop a regime for concentrations of RCS levels in each product
- include RCS and other products containing dust components in material safety data sheets
- state how much is free silica and the particle size
- implement the gunite pump modifications outlined in this paper to reduce dust generated while spraying
- develop safe and efficient procedures based on safety and health test data
- make pump modifications
- optimise the operation of gunite processes by using gauges and pump monitoring.

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