An Overview of USBM/NIOSH Technology to Reduce Silica Dust in Metal/Nonmetal Mines and Mills

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ABSTRACT: Inhalation of respirable silica dust can lead to silicosis, a disabling and potentially fatal lung disease. For the metal/nonmetal industry, silica exposures occur during the mining and processing of the ore. A focus of the U.S. Bureau of Mines (USBM) and now the National Institute for Occupational Safety and Health (NIOSH) has been to conduct research to lower silica concentrations in metal/nonmetal operations. This report reviews various control techniques that have been developed at the USBM/NIOSH over the past 30 years and have been demonstrated to be successful at lowering respirable silica levels at metal/nonmetal mines and mills.

INTRODUCTION

In 1977, the Mine Safety and Health Administration implemented the Federal Mine Safety & Health Act which states "the first priority and concern of all in the coal or other mining industry must be the health and safety of its most precious resource—the miner" (MSHA 2009a). Obviously, this Act impacted the health and safety research program of the USBM, and subsequently NIOSH. One of these research programs was to lower the respirable dust exposure of mine workers, and as it specifically relates to this paper, silica dust in metal/nonmetal mines and mills.

The U.S. metal/nonmetal mining industry is composed of a wide range of different types of mineral operations and processes. In 2007, there were 12,270 mines (256 underground/12,014 surface) in the metal, nonmetal, stone, and sand and gravel industries, employing 149,180 miners (MSHA 2009b).

Throughout the metal/nonmetal mining cycle, ore is mined underground or in open pits/quarries. The ore is then processed in a mineral processing facility where it goes through a series of crushing, grinding, cleaning, drying, and product sizing sequences as it is processed into a marketable commodity. Because these operations are highly mechanized, they are able to process high tonnages of ore. This in turn generates large quantities of dust, often creating elevated levels of respirable silica dust, which is liberated into the work environment and exposes the miners that work at these operations.

The serious health effects from overexposure to respirable dust from these mining operations has been known for many years. When one considers that the ore being processed within the M/NM mining industry often contains crystalline silica, the health effects to the miners are even greater (NIOSH 2002; Hessel et al. 1988). This is the reason that the Mine Safety and Health Administration (MSHA) mandates a reduced respirable dust standard when silica is present (MSHA CFR 2008).

The purpose of this document is to review control techniques that have been developed over the past 30 years by the USBM and the NIOSH since the implementation of the 1977 Safety and Health Act. Many different engineering control techniques developed in this research program have improved the health of miners by lowering respirable silica dust exposure at U.S. metal/nonmetal mines and mills.

DUAL BAG NOZZLE SYSTEM

The dual bag nozzle system was designed to reduce major dust sources of the bag filling process, and thus, lower the dust exposure of the bag operator. A number of dust sources must be controlled to achieve this goal. The primary dust sources from the fill nozzle and bag valve area are product blowback and product spewing from the fill nozzle area. Product blowback occurs as excess pressure builds inside the bag during bag filling and is then relieved by air and product exiting the bag around the fill nozzle, creating a considerable amount of dust. As the bag is ejected from the filling machine, a "rooster tail" of product is thrown from the bag valve and fill nozzle. The rooster tail occurs because the bag is pressurized as it leaves the machine, releasing dust into the air and contaminating the outside of the bag. These contaminated bags then become a major dust source for the bag stacker and any other individuals handling the bags.

Figure 1 depicts the components of the dual-bag nozzle system. The dual-bag nozzle device uses a two-nozzle arrangement with an improved bag clamp to control the dust sources. The two-nozzle arrangment uses an inner nozzle to fill the bag and an outer nozzle to relieve excess pressure from the bag after it has been filled. Depressurizing of the bag is accomplished once filling is completed with the aid of an eductor, which uses the venturi principle to exhaust excess air from the bag at approximately 50 ft^3/min. A pinch valve is then used to open and close the bag exhaust. The bag is slightly overfilled and held in place until the exhaust system depressurizes the bag. After a few seconds, the bag clamp opens and the bag falls from the fill station. The exhaust system continues to operate as the bag falls away, cleaning the bag valve area. The exhausted material is then recycled back into the system.

The other key component of the system is an improved bag clamp. This bag clamp makes direct contact with approximately 60 percent of the nozzle, thus reducing the amount of product blowback during bag filling. A controlled amount of blowback is necessary so the bag does not rupture, but this occurs at the bottom of the nozzle, minimizing dust contamination to the outside of the bag.

Several field evaluations were performed to determine the effectiveness of the dual-bag nozzle system (Cecala, Volkwein, and Thimons 1984). During one study, there was an 83 percent reduction in the bag operator's dust exposure with the dual-bag

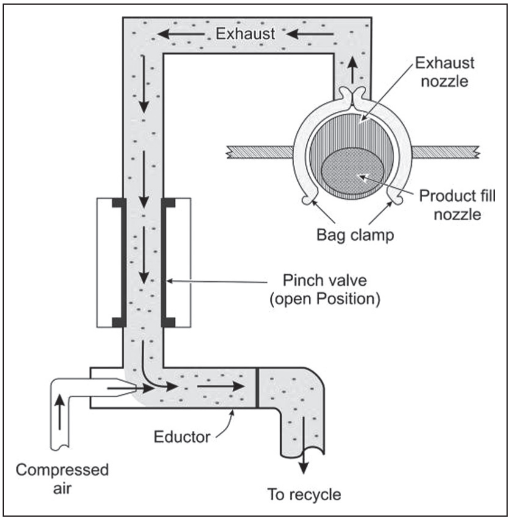

Figure 1. Dual bag nozzle system design

nozzle system. Further, a 90 percent reduction was measured in the hopper below the fill station, indicating a substantial reduction in product blowback during bag filling.

The use of the improved bag clamp allows for a significant decrease in the amount of dust and product on the outside of the bag. This resulted in a 90 percent reduction in the bag stacker's dust exposure while bags were being loaded into an enclosed vehicle during the testing of this system.

The dual-bag nozzle system is mainly recommended for operations with three- and four-fill nozzle bag machines because there is a slight decrease in production due to the time needed to depressurize the bags after filling is completed. The system can be used on a one- or two-nozzle machine, but this decreases the production rate even further because the bag operator must wait on each individual bag instead of a cycle of bags.

OVERHEAD AIR SUPPLY ISLAND SYSTEM

The overhead air supply island system (OASIS) was developed to provide an envelope of clean, filtered air to a worker at a stationary location (Volkwein, Engel, and Raether 1986). One of the main advantages of the OASIS is that it is suspended over a worker and operates independently of any processing equipment, as shown in Figure 2. Mill air is drawn into the unit and passes through a primary HEPA cartridge filter. After the air exits the primary filter, it passes through an optional heating or cooling chamber, which can be incorporated in the unit if temperature control is desired. The air then flows through a distribution manifold, which also serves as a secondary filter, and finally exits the unit. The resulting filtered air flows down over the worker at an average velocity of roughly 375 ft/min, which normally keeps any mill air from entering this clean air core. The system can detect a filter overload based upon an increase in pressure and automatically self-clean the HEPA filter using one of various cleaning techniques.

During an evaluation on the OASIS at two different sites, the operator's respirable dust exposure was reduced by 82 and 98 percent, as compared to when the unit was not being operated. At both of these operations, the dust concentration within the clean filtered air of the OASIS remained under 0.04 mg/m^3.

An additional benefit provided by the OASIS is that the filtering system provides some general cleaning and reduces the overall air quality at the structure. During one of the evaluations, there was a 12 percent reduction in respirable dust levels in the entire mill building where the OASIS was installed. The volume of clean air delivered by the OASIS is variable based upon the size of the unit, but it is normally in the range of 6000 to 10,000 cfm. The OASIS is generic in design and can be fabricated and installed in-house or through any local engineering company that handles ventilation and dust control systems.

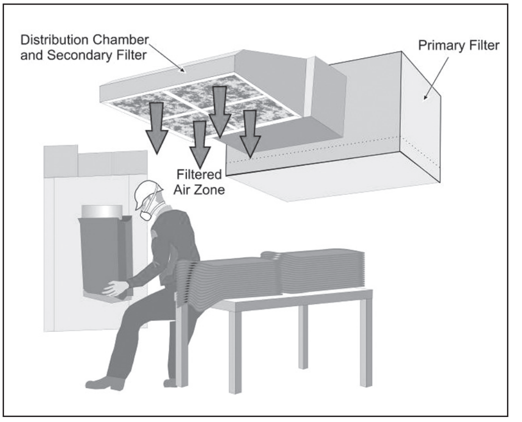

Figure 2. OASIS positioned over bag operator to deliver clean filtered air down over work area

BAG AND BELT CLEANING DEVICE

The bag and belt cleaner device (B&BCD) is designed to reduce the amount of dust escaping from bags as they travel from the bag loading station to the stacking/palletizing process. It is intended to be self-supporting so that it can be incorporated anywhere along the conveyor belt line. This device reduces the dust exposure of all workers in and around the conveying process, as well as, anyone handling the bags once they are filled at the loading station. This system should be applicable to any mineral processing operation that loads product into 50- to 100-lb paper bags.

It is more logical to place the cleaner in close proximity to the loading station to eliminate the dust hazard as quickly as possible. Also, it is important to have the B&BCD unit under sufficient negative pressure to insure that any dust removed from the bags of product or from the conveyor belt, does not leak from the unit.

A prototype B&BCD, which was designed and built by the USBM, was 10 ft long and used a combination of brushes and air jets to clean all sides of the bags, as shown in Figure 3. As the bag travelled through the B&BCD, it entered through a curtain made of clear, heavy-duty flexible plastic stripping and into the device. Inside, a stationary brush on a swing arm started the cleaning process on the front and top of each bag. The bag would go through a second set of plastic stripping and into the main chamber section, where it travelled under a rotating circular brush that further cleaned the top of the bag. The sides were cleaned by a stationary brush located on each side of the bag. An air jet was located at the end of these brushes to provide for additional cleaning. The side with the bag valve used a higher volume (velocity) air jet to provide for the maximum amount of cleaning. After passing through the air jets, the bag travelled over a rotating circular brush located beneath the bag which cleaned the bottom of the bag. The bag exited the device by traveling through another air lock chamber with flexible plastic stripping.

A chain conveyor was used for the entire length of the device in the prototype design to allow product removed from the bags during cleaning to fall into a hopper. Product collected in this hopper was then recycled back into the process. Once exiting the B&BCD, both the bags of product and the conveyor belt should be essentially dust-free.

An evaluation of the B&BCD was conducted at two mineral processing plants. The device showed very favorable results in lowering respirable dust levels. The most relevant reduction data for this testing was the amount of dust removed from the surface of the bags, which ranged from 78 to 90 percent (Cecala, Timko, and Prokop 1995).

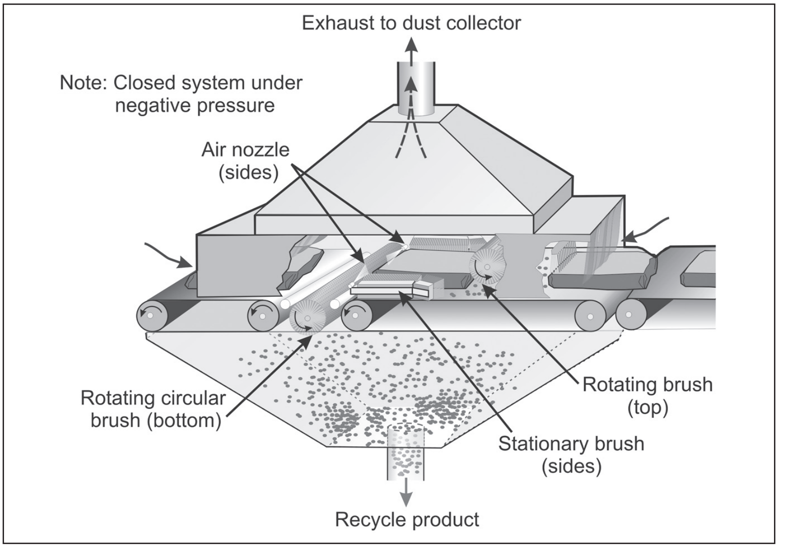

Figure 3. Bag and Belt Cleaner Device

BAG STACKING

There are many different types of semi-automated systems that assist workers by performing some tasks in the bag loading and stacking process. Two of these systems will be discussed in this section. In the first system which was designed by the USBM, a worker performs the bag stacking task manually, but is assisted by using a hydraulic lift table. This lift table allows the height for stacking the bags to remain constant throughout the entire pallet loading cycle. The bag loading height is set to approximately knuckle-high for the worker, which is the most ergonomic loading height, as shown in Figure 4. A push-pull ventilation system is used on either side of this pallet to capture the dust liberated during the bag stacking (palletizing) process (Cecala and Covelli 1991).

In the second system, the worker slides the bag of product on an air table one layer at a time, but the actual stacking of the bags onto the pallet is performed automatically. Since bag injuries are a major lost-time injury for bag stackers, this design significantly reduces the stress by not requiring them to manually lift any bags of product. One problem with an air slide device is that it can cause dust to be blown from the bags of product into the worker's breathing zone. A NIOSH study (Cecala et al. 2000) revealed that the OASIS system worked very effectively along with this air slide device. In addition to the OASIS system, an exhaust hood was used next to the air slide area to capture the dust blown from the bag, as seen in Figure 5. This exhaust system is then tied into the facilities local exhaust ventilation (LEV) system.

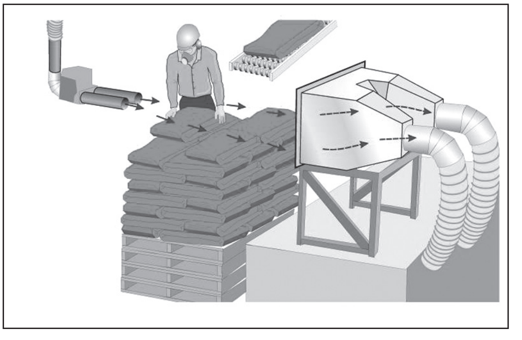

Figure 4. Semi-automated bag palletizing system to ergonomically improve bag stacking process using a push-pull ventilation to capture the dust generated

CLEANING DUST FROM SOILED WORK CLOTHING

A significant source of respirable dust exposure to workers at mineral processing operations can come from contaminated work clothing (NIOSH 2002). It must be noted also that once a worker's clothing becomes contaminated, it is a continual source of dust exposure until the cloths are changed or cleaned.

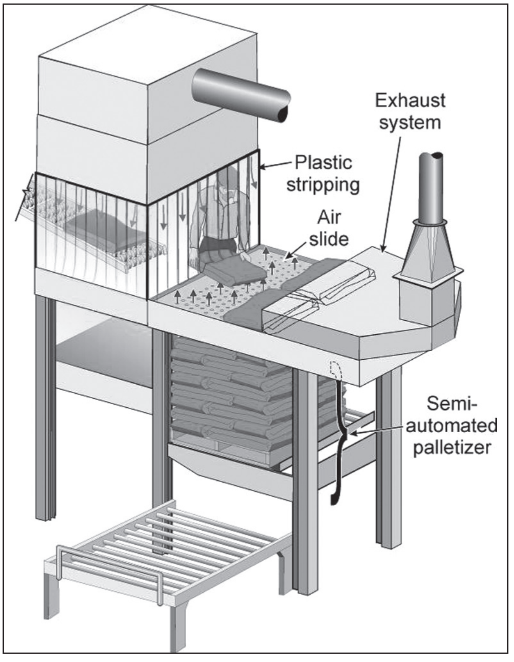

Figure 5. Semi-automated bag palletizing system where a worker transfers the bags onto air slide and then positions each layer of bags on the pallet. Both OASIS and LEV systems are used to lower the worker's dust exposure during this bag palletizing process.

A cooperative research effort between Unimin Corporation and NIOSH led to the development of a clothes cleaning system. This clothes cleaning system consists of four major components: (1) a cleaning booth, (2) an air reservoir, (3) an air spray manifold, and, (4) an exhaust ventilation system. Figure 6 represents the design of the clothes cleaning system.

The clothes cleaning booth is 48 by 42 inches which provides the worker with sufficient space to rotate in front of the air spray manifold to perform the cleaning process. An air reservoir is necessary to supply the required air volume to the air nozzles used in the spray manifold. The size requirement can be either a 120- or 240-gallon for the reservoir, depending on the number of workers needing to clean their clothes in sequence. If multiple individuals will be using the booth one after another, then the 240-gallon reservoir should be used. This reservoir should be pressurized to at least 150 psi and it should be located close to the cleaning booth and be hard-piped to the air spray manifold located in the booth. A pressure regulator must be installed immediately before

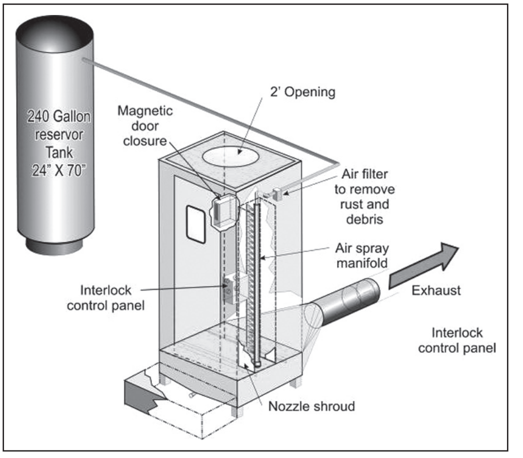

Figure 6. Design of clothes cleaning system

the air spray manifold to regulate the nozzle pressure to a maximum of 30 psi.

Intake air enters the booth through a 2-foot opening in the roof, and then flows down through the enclosure before exiting through an air plenum on the bottom back wall of the booth. As this intake air flows through the booth, it entrains dust removed from the worker's clothing during the cleaning process and forces it down towards the air plenum and away from the worker's breathing zone. The exhausted dust-laden air then travels from this air plenum at the base of the booth to the exhaust ventilation system.

The air spray manifold is composed of 26 spray nozzles spaced 2 inches apart. The bottom nozzle is located 6 inches from the floor and is a circular designed nozzle for cleaning the worker's boots. This nozzle is used in conjunction with an adjustable ball-type fitting so that it can be directed downward. The other 25 air spray nozzles are flat-fan sprays, which lab testing proved to be the most effective for cleaning at close distances. The air spray nozzles deliver slightly less than 500 cfm of air.

In order to perform the clothes cleaning process, a worker dons personal protective equipment, enters the cleaning booth, activates a start button and rotates in front of the air spray manifold while dust is blown from the clothing via forced air. After a short time period (18 seconds), the air spray manifold is electronically de-activated and the worker can exit the booth with significantly cleaner work clothing.

For effective dust removal, it is critical that the cleaning booth be ventilated under negative pressure at all times so as to not allow any dust liberated from the clothing to escape from the booth and into the

Table 1. Amount of dust remaining on coveralls after cleaning and cleaning times for 100% cotton and polyester/cotton blend coveralls

	100% Cotton		Polyester/Cotton Blend	
Cleaning Method	Dust Remaining on Coveralls, grams	Cleaning Time, seconds	Dust Remaining on Coveralls, grams	Cleaning Time, seconds
Vacuuming	63.1	398	45.5	346
Air Hose	68.8	183	48.4	173
Clothes Cleaning Booth	42.3	17	21.9	18

work environment. In the design stage of this technology, testing validated that an exhaust volume of 2,000 cfm was sufficient to maintain a negative pressure throughout the entire clothes cleaning cycle (Cecala et al. 2008).

During development, the new clothes cleaning technology was compared to both the MSHA-approved vacuuming approach and a single handheld compressed air hose. In this testing, several 100% cotton and cotton/polyester blend type coveralls were soiled with limestone dust before the worker entered the clothes cleaning booth. Table 1 shows the cleaning times and effectiveness of the three different techniques. Clearly, the use of the clothes cleaning system was much more effective than the other two approaches, and required only a fraction of the time. Table 1 also shows that the polyester/cotton blend coveralls were cleaned more effectively than the 100% cotton type. Figure 7 depicts a worker before and after entering the clothes cleaning booth.

Figure 7. Test subject wearing polyester/cotton blend coveralls before and after using clothes cleaning booth

TOTAL STRUCTURE VENTILATION DESIGN

The first strategy to lower dust exposures in any structure is to have an effective primary dust control plan that captures major dust sources at their point of origin, before the dust is allowed to liberate out into the plant and contaminate workers. Engineering controls discussed in this manuscript are effective at reducing and capturing the dust generated, but they do not address the continual buildup of dust from background sources, such as:

- Product residue on walls, beams, and other equipment which becomes airborne from plant vibration
- Product that accumulates on walkways, steps, and access areas, and which may be released as workers move through the plant and by plant vibration
- Leakage or falling material from chutes, beltways, and dust collectors
- Lids and covers of screens that are damaged or when they are removed for inspection and cleaning
- Product released because of imperfect housekeeping practices

Since most mineral processing structures can be considered closed systems, the background dust sources can cause dust concentrations to continually increase as the day or shift progresses inside these closed buildings. One method that can be used to control these background dust sources is a total structure ventilation system.

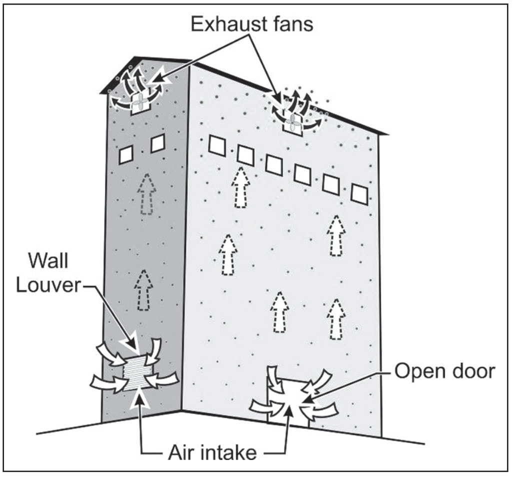

Figure 8. Basic design of total structure ventilation system

The basic principle behind the total structure ventilation design is to use clean outside air to sweep up through a building to clear and remove the dust-laden air. This upward airflow is achieved by placing exhaust fans at or near the top of the structure and away from plant personnel working both inside and outside the structure. The size and number of exhaust fans is determined based upon the initial respirable dust concentration and the total volume of the structure. It must be noted that all the processing equipment within a mill generates heat and this produces a thermodynamic "chimney effect" that works in conjunction with the total structure ventilation design (Cecala and Mucha 1991). Figure 8 shows the concept of the total structure ventilation design. To be effective, the total structure ventilation design must meet three criteria: (1) provide a clean makeup air supply, (2) an effective upward airflow pattern, and (3) a competent shell structure.

Intake air needs to be brought in at the base of the structure by strategically located wall louvers or open plant doors. It is very important that this air be free from outside dust sources such as bulk loading, high traffic areas, etc, which could cause dust-laden air to be drawn into the structure and could increase respirable dust levels. Through the use of wall louvers or closing doors, the intake air locations could be changed based upon the outside dust conditions.

The system should provide an effective upward airflow pattern that ventilates the entire structure by sweeping the major dust sources and work areas. Strategic positioning of both exhaust fans (high in the walls or roof) and makeup air intakes (at the base) create the most effective airflow pattern for purging the entire mill.

A competent outer shell of the structure is necessary because the ventilation system draws the makeup air through the points of least resistance. Therefore, the structure's outer shell must be free of open or broken windows, holes, cracks, and openings, especially in the vicinity of the exhaust fans.

A normal range of airflow for a total structure ventilation design would be in the 10–35 air changes per hour (acph) level. During the development of the total structure ventilation design concept, two different field studies were performed in an effort to document its effectiveness. In the first study, with a 10 acph ventilation system, a 40 percent reduction in respirable dust concentrations was achieved throughout the entire structure. In the second study, the total structure ventilation system was capable of providing both 17 and 34 acph. Average respirable dust reductions throughout the entire structure ranged from 47 to 74 percent for the two exhaust volumes, respectively, (Cecala, Klinowski, and Thimons 1995).

OPERATOR BOOTHS/CONTROL ROOMS/ ENCLOSED CABS

Many times at mineral processing plants, workers will be located in an operator's booth, control room, or enclosed cab to give them a safe work area and to isolate them from dust sources. If these areas are properly designed, they can provide very good air quality to the worker. On the other hand, if these enclosed areas are not properly designed and maintained, the air quality can deteriorate to unacceptable and unsafe levels.

The most effective technique for reducing operators' exposure to airborne dust in booths/control rooms/enclosed cabs at mineral processing operations is with filtration and pressurization systems. The most effective filtration and pressurization systems have the heating and air conditioning (HVAC) components tied in as an integral part of the system.

NIOSH conducted a controlled laboratory study to evaluate the key factors necessary for achieving an effective enclosure filtration and pressurization system (Organiscak and Cecala 2008). In the course of the laboratory study, the significance of the filtration system parameters were evaluated and the following mathematical model was developed:

$$PF = \frac{C_o}{C_i} = \frac{Q_I + Q_R\eta_R}{Q_I(1-\eta_I + l\eta_I) + Q_W}$$

(Note: The above equation is dimensionless, therefore air quantities used must be in equivalent units. Also, filter efficiencies and intake air leakage must be fractional values (not percentage values).

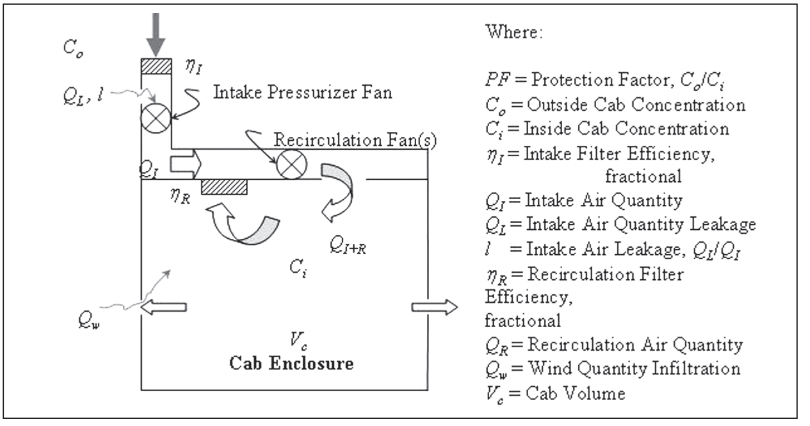

Figure 9. Key factors for effective enclosure filtration and pressurization system

This model (see Figure 9) was formulated from a basic time-dependent mass balance model of airborne substances within a controlled volume with steady state conditions. It determines the protection factor in terms of intake air filter efficiency, intake air quantity, intake air leakage, recirculation filter efficiency, recirculation filter quantity, and outside wind quantity infiltration into the cab. The equation allows for a comparison of how changes in the various parameters and components in the system impact the protection factor. The wind quantity infiltration (Q_W) can be assumed to be zero if the cab pressure exceeds the wind velocity. By using this equation, operations have the ability to determine the desired parameters necessary to systematically achieve a desired protection factor in an operator's booth, control room, or enclosed cab to improve the air quality to safe levels, and to ultimately protect their workers.

The results of this laboratory study indicate that intake filter efficiency and the use of a recirculation filter had the greatest impact on improving the air quality. When considering the use of an intake air filter, the addition of the recirculation component significantly improved the air quality due to the repeated filtration of the cab's interior air. The addition of an intake pressurizer fan to the filtration system increased both intake airflow and cab pressure significantly. The cab air quality was also affected by intake filter loading and air leakage.

Through this laboratory and numerous field studies, the following items were identified as key components to an effective system:

- **Ensure booth/control room/cab integrity.** Effective protection factors were realized in various field studies when pressures between 0.01 and 0.40 inches of water gauge were achieved because of good enclosure integrity. These pressures correspond to wind velocity equivalents of 4.5 and 29 miles per hour, respectively, and prevent wind penetration (Cecala et al. 2009).
- **Use high efficiency filters on intake air.** Only intake filters with an efficiency of 95% or greater were used during field studies. Laboratory experiments showed an order of magnitude increase in protection factors when using a 99% efficient filter versus a 38% efficient filter on respirable sized particles (Organiscak and Cecala, 2009a).
- **Use an efficient recirculation filter.** All the field evaluations used recirculation filters that were 95% or greater on respirable sized dusts. Laboratory experiments showed a 10-fold increase in protection factors when using an 85% to 94.9% efficient filter on respirable sized dusts as compared to using no recirculation filter. Laboratory testing also showed that the time needed for the interior to stabilize after the door was closed was reduced by more than 50% when using the recirculation filter (Organiscak and Cecala, 2009b).
- **Minimize interior dust sources.** Good housekeeping practices are needed to keep enclosure interiors clean and eliminate any dust sources. One field study showed a significant increase in dust levels (0.03 mg/m^3 to 0.26 mg/m^3) when a floor heater was used. The fan from the floor heater stirred up dust lying on the cab floor (Cecala et al. 2005).
- **Keep doors closed.** In a study on an enclosed cab of a surface drill, the operator's dust exposure averaged 0.09 mg/m^3 inside the cab with

> the door closed and 0.81 mg/m^3 when the door was briefly opened to add drill steels. This procedure was performed after drilling stopped and the visible dust dissipated, it nevertheless produced a nine-fold increase in dust concentrations inside the cab each time a drill steel was added (Cecala et al. 2007).

As determined in both laboratory and field studies, there are two critical factors for an effective filtration and pressurization system. First, the filtration system needs to be comprised of an effective outside intake (make-up) air, and a recirculation air component. Second, it is also critical to establish and maintain cab integrity in order to achieve an acceptable level of positive cab pressurization. Without positive pressure in the cab, both the effectiveness of the system and the air quality are greatly compromised.

PRIMARY CRUSHING

The primary dump and crushing operation is a significant dust source at metal/nonmetal operations. As previously mentioned, a very effective method to minimize the crusher operator's respirable dust exposure is to place the operator in a control booth with a filtration and pressurization system. This is not always possible and the dust generated during the dumping and crushing process does expose and contaminate secondary workers in and around this area. A number of techniques have been studied in an attempt to minimize the dust generated and liberated during this mining process in both underground and surface operations.

In a study performed at an underground facility, a comparative evauation was performed to determine if a portable diesel-powered propeller fan could perform more efficiently for dust dilution and transport than an axial fan for localized ventilation. The results of this testing indicated the propeller fan reduced both respirable and silica dust by 20 pct at the dumping/crushing facility as compared to the vane-axial fan (Chekan, Colinet, and Grau 2006).

In another study, water spray suppression systems were evaluated to lower respirable dust generated at the primary dumping location. The general rule of thumb is to add one percent of moisture to the product, which is based on the weight of ore processed compared to the weight of the water added (Quilliam 1974). From this point, the percentage can be adjusted based upon the improvement gained from additional moisture versus any consequences from adding too much water. It must be noted that the amount of moisture that can be added at primary dump locations is normally not as sensitive as in later stages of the mineral processing cycle, and thus, higher rates or percentages can usually be tried. One important feature with a primary dump application is to only activate the water sprays during the actual dump cycle through the use of a photo cell or a mechanical switching device.

Enclosures for primary dump application normally require a custom design and are usually dependant on the type and size of dump vehicles being used. In some cases, walls can be constructed around the primary dump location to form an enclosure. The walls can be either stationary or removable, based on maintenance requirements. In some cases for a removable enclosure, a breathable tarp fabric material, similar to the material used on over-the-road haul trucks, can simply be laid over to seal the top of the enclosure.

Overlapping plastic can also be used to provide for an effective seal over the front of the enclosure, as shown in Figure 10. This plastic stripping is not damaged when contacted by the bucket of the front-end loader or the bed of the haul truck during dumping and remains very durable over time.

When using an enclosure, it is also possible to incorporate a LEV system to filter the dust-laden air from the hopper area. This would be most applicable when the primary dump is at a location where the dust could enter an adjoining structure or impact outside miners. The enclosure helps to contain the dust cloud that billows up from the hopper during the dumping process, but the dust remains airborne unless it is suppressed or removed. An LEV can be an effective technique incorporated to remove and filter this dust if it is properly designed and sized to the hopper.

Another dust source at primary dump operations is the dust that is allowed to liberate or to roll back under the dumping mechanism. A tire stop or jersey barrier should be positioned at the most forward point of dumping for the primary hopper. To the back side of this tire stop, a water spray manifold should be attached to knock down and force the dust that would otherwise roll back under the dumping mechanism to remain in the hopper. Additionally, a shield should be placed over this water spray manifold to protect it from damage from falling ore. Finally, a system should also be incorporated that allows the water sprays to only be activated during the actual dumping process, as previously discussed.

CONCLUSION:

The USBM and NIOSH has and continues to perform research to reduce the dust exposure to miners in the U.S. metal/nonmetal mining industry. This

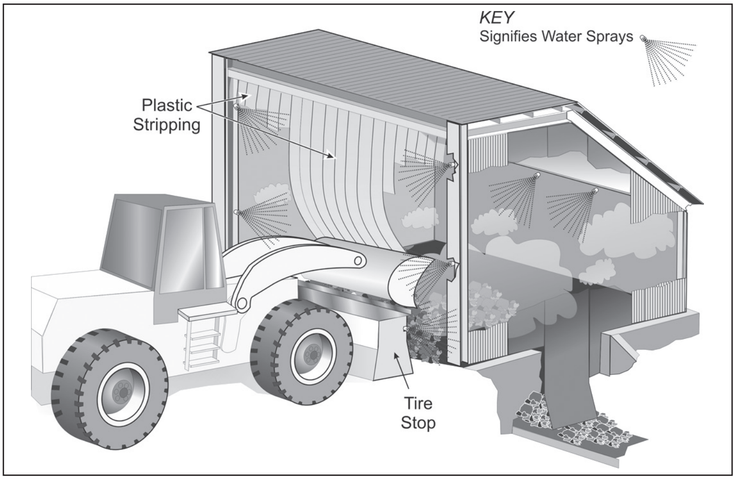

Figure 10. Flexible plastic stripping used to hold dust inside enclosure and water sprays used to knock down airborne dust

manuscript briefly highlighted some of the engineering control technologies that have been developed through this research effort at the Pittsburgh Research Laboratory over the past 30 years. Through the implementation of these control technologies, it is our hope that the likelihood of miners developing silicosis and/or other respiratory diseases in this industry would be eliminated.

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