An Evaluation of Cab Filtration and Pressurization Systems: Two Case Studies

Gregory J. Chekan, Andrew B. Cecala, and Jay F. Colinet
Mining Engineer, Mining Engineer, and Section Chief, respectively
National Institute for Occupational Safety and Health
Pittsburgh Research Laboratory, Pittsburgh, Pennsylvania

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ABSTRACT

Many equipment operators at stone, sand, and gravel operations are exposed to respirable silica dust and other harmful particulate. To protect workers from this health hazard, operators typically purchase equipment with enclosed cabs. As equipment ages, many of the original components on the cab enclosure deteriorate through normal operation in the harsh mine environment, reducing the integrity of the cab and its effectiveness for protecting the operator. In an effort to improve the protection provided by enclosed cabs, The National Institute for Occupational Safety and Health (NIOSH) entered into two cooperative research efforts with companies that manufacture and install cab filtration and pressurization systems. The systems are affordable, can be adapted to most cabs, are installed on-site in several days, and are a practical solution for older cabs where excessive dust levels may be an issue. For these two studies, new systems were retrofitted onto a haul truck at an underground stone mine and a surface drill at a sand operation. These systems have three primary features. First, the outside air is cleaned with high-efficiency filters before it enters the cab. Second, for efficiency and operator comfort, the systems have heating and air conditioning features where a majority of the air inside the cab is recirculated , filtered, and combined with a smaller portion of outside makeup air. Third, the cab seals are upgraded to reduce air leakage and aid in achieving positive pressure within the cab to prevent dust penetration. In both case studies, a significant improvement in lowering respirable dust levels in the cab was achieved with the new systems. Comparing outside to inside cab respirable dust levels after the new units were installed, a 76% cab efficiency was achieved for the haul truck and 93% for the surface drill. This paper describes the specifications, installation, and the results from the dust sampling conducted before and after the systems were installed.

INTRODUCTION

Inhalation of excessive levels of respirable silica dust can lead to the development of silicosis, an irreversible and progressive lung disease that can cause disability and death. Workers who develop silicosis have an increased incidence of lung cancer and pulmonary disorders. In June 1997, based on studies of human subjects, the International Agency for Research on Cancer (IARC) ruled that there is sufficient evidence that inhaled crystalline silica in the form of quartz and cristobalite from occupational sources is carcinogenic (**1**). The metal/nonmetal industry employs about 180,000 workers in underground, surface, and milling operations. Surveillance dust data of Mine Safety and Health Administration (MSHA) inspectors sampling during the 5-year period from 1997 to 2001 indicate that more than 65,000 personal respirable dust samples were taken from underground mines, surface mines, and mills. This dust data indicates that in the four segments of metal/nonmetal operations (metallic minerals, nonmetallic minerals, stone, sand and gravel) an average of 14% of the samples exceeded the permissible exposure limit (PEL) for crystalline silica (**2**).

One of the primary programs at NIOSH's Pittsburgh Research Laboratory is the development and evaluation of dust control methods and techniques in both the coal and metal/nonmetal mining industries. One of these control technologies is the development of filtration and pressurization systems for enclosed cabs. Normally when equipment is new, the cabs are fairly airtight. These tightly sealed cabs, combined with good filtration systems, generally provide the operator with good dust protection. However, at many mining operations, this equipment is older, which means many components of the enclosure have deteriorated, the structural integrity of the cab diminishes, and the effectiveness of the air filtration system degrades.

NIOSH has been working with a number of manufacturers to develop cost-effective methods to improve both filtration effectiveness and cab integrity on these older cabs with the goal of providing a healthier work environment for mining equipment operators. Several studies evaluating the installation of retrofit systems on a front-end loader and overburden drills have been published for surface coal operations (**3, 4**). The systems have air-conditioning, heating, filtration, and pressurization features, which recirculate and filter a majority of the inside cab air combined with a smaller portion of outside makeup air. Outside air is cleaned with high-efficiency filters before it enters the cab, and the cab enclosure is maintained under a positive pressure.

In the two case studies discussed in this paper, NIOSH worked with several companies to evaluate the impact of retrofitting older cabs with a new filtration/pressurization system to reduce the operator's exposure to silica dust. In the first case study, NIOSH and Sigma Air Conditioning Inc (**5**) entered into a cooperative cost-sharing agreement to install a new system on a haul truck at an underground limestone mine. In the second case study, NIOSH worked with Clean Air Filter Company and Red Dot Corporation to upgrade a surface drill at a silica sand operation with a new system. Details on the performance of the new systems and results of the dust sampling surveys before and after the units were installed will be provided. Although these case studies were conducted at mining sites, the results also apply to other industries where enclosed cabs are being utilized (e.g., construction and agriculture).

SAMPLING STRATEGY

The sampling strategies for both studies were similar and were designed to provide a quantitative analysis of dust levels outside and inside the cab before and after the new systems were installed. Two types of dust sampling instruments were used in these studies. The primary dust-measuring instrument was the gravimetric sampler operated at 1.7 liters/minute to follow MSHA requirements for sampling in metal/nonmetal mines. The respirable fraction of the airborne dust (<10 microns) was obtained using a 10-mm Dorr-Oliver cyclone and was deposited onto a 37-mm polyvinyl chloride (PVC) filter. The filters were weighed before and after sampling to calculate overall respirable dust concentrations based on the sampling rate and time. The second sampling instrument used was the ThermoMIE personal DataRAM (pDR). The pDR is a real-time aerosol monitor that measures and records the concentration of respirable airborne dust using a light-scattering technique. Light-scattering instruments offer only a relative measure of concentrations, but provide a continuous record of dust levels so that concentrations can be evaluated over any time interval during the sampling period.

CASE STUDY 1: HAUL TRUCK - UNDERGROUND LIMESTONE MINE

Background

At this mine, a Euclid Model R-50, manufactured in 1975, was selected for evaluation. This haul truck was used to load fines from the processing plant, transport these fines to different locations, dump the fines, and then return to the plant for the next load. The operator dumped the fines at outside locations on the property, or hauled the fines into the mine and dumped them for backfill. This truck was originally fitted with a heating and air-conditioning unit that had minimal dust filtering capabilities for intake air and was not equipped with a pressurizer to positively ventilate the cab. The unit was functional but outdated, and in need of replacement.

Pre-installation Sampling Results

As described earlier, both gravimetric and pDR samplers were used to measure dust concentrations outside and inside the truck cab. Two gravimetric samplers and a pDR were positioned outside of the cab below the front window as shown in figure 1. Two gravimetric

Figure 1 - Location of samplers on the front of truck.

samplers and one pDR were also hung inside the cab to the right of the operator, at the same height as his breathing zone. Outside dust levels were compared to dust levels in the cab to calculate the "cab efficiency" or percent reduction in dust afforded by the enclosed cab. The gravimetric filters were also analyzed for silica content with X-Ray Diffraction (XRD) using the NIOSH 7500 Method (**6**). Pre-installation sampling was conducted for three days for approximately 6 hours per shift. During sampling, a time study was conducted on truck activity and general dust conditions were noted for each day.

Table 1 shows the results of sampling from the gravimetric samplers for the haul truck. The concentration values for each day are the average of the two gravimetric samplers for that day of sampling. The "average" row contains the survey average. Days 1 and 2 of the survey were dryer, windier days producing more dust at the plant and on the haul roads, compared to day 3, which was wetter and less windy. These conditions are reflected in the concentration values. As shown in the table, the 3-day survey average resulted in respirable dust and respirable silica dust reductions of 34% when comparing outside to inside dust levels.

Table 1. Summary of Gravimetric Dust Concentrations for Haul Truck.

	Respirable Dust Concentrations			Respirable Silica Concentrations		
Euclid R-50 Pre-Installation	Outside Cab mg/m^3	Inside Cab mg/m^3	Reduction, %	Outside Cab mg/m^3	Inside Cab mg/m^3	Reduction, %
Day 1	0.401	0.271	32	0.033	0.020	39
Day 2	0.662	0.369	40	0.056	0.042	25
Day 3	0.213	0.197	8	0.015	0.008	47
Average	***0.425***	***0.279***	***34***	***0.035***	***0.023***	***34***
Euclid R-50 Post-Installation	Outside Cab mg/m^3	Inside Cab mg/m^3	Reduction, %	Outside Cab mg/m^3	Inside Cab mg/m^3	Reduction, %
Day 1	1.037	0.430	59	0.083	0.026	69
Day 2	1.069	0.288	73	0.068	0.016	76
Day 3	0.924	0.234	75	0.061	0.010	84
Average	***1.010***	***0.317***	***69***	***0.071***	***0.017***	***76***
Komatsu Truck	0.707	0.215	70	0.036	0.009	75

To further quantify the respirable dust and evaluate dust reduction in the truck cabs, the pDRs were used to monitor the dust levels for the trucks during the haulage cycle. The pDRs were set to log dust concentrations at 10-second intervals, providing approximately 2,200 data points for 6 hrs of sampling. From the time studies conducted on the trucks, the dust concentrations during each operation were determined by correlating loading, tramming, and dump times with those times and concentrations recorded on the pDRs.

Figure 2 graphs the inside and outside dust concentration data from the pDRs for the different operations of the haulage cycle. As shown in figure 2, the shift cycles were separated into four operations. The graph shows that the highest concentration occurs when dumping in the mine, followed by loading at the plant. Tramming full/dumping outside and tramming empty are the lowest. Also note that during the tramming operations the inside dust concentrations are higher than the outside. This can be expected due to the location of the outside sampler at the

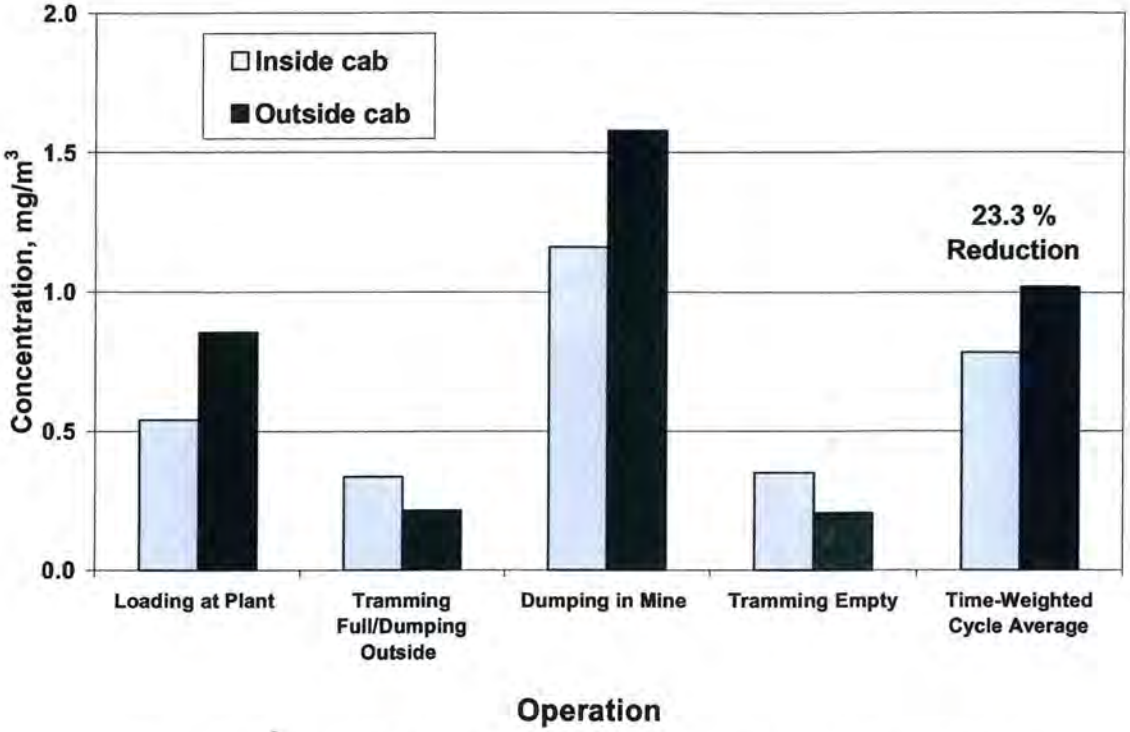

Figure 2 - Pre-installation dust levels during haulage cycle from pDRs.

front of the truck in that, very little dust enters the cyclone sampler as truck speed increases. The last bar graphs in the figures show the percent reduction of respirable dust in the cab based on the time-weighted cycle average. The results show that the reduction in respirable dust for outside versus inside the cab are 23.3% and is comparable to the reductions obtained from the gravimetric samplers.

Unit Specifications and Installation

For this study, the original air-conditioning system on the Euclid R-50 was replaced with a Sigma Model EC5BX3C rooftop-mounted unit. The cost of the unit was approximately $6,000 plus the cost of installation. The new system included heating, cooling, and pressurization, with high-efficiency filter media for both the pressurizer filter and the return air filters. The pressurizer filter is a pleated cartridge-style filter using a spun polyester washable media rated at 99% efficiency for particles greater than 0.5 microns. The pressurizer has a separate blower, which introduces outside fresh air to positively pressurize the cab. The return air has a 2-stage filter design. The first stage uses a Farr 30/30 filter, which is designed to remove the larger particles and reduce loading of the second and final stage filter. The final stage filter, which also has a 99% efficiency rating, again uses the pleated spun polyester washable media in a 2-in. flat panel design.

Mounting rooftop systems on haul trucks may require special installation because there may not be sufficient space for the unit to fit between the top of the cab and cab protector on the truck bed, as can be seen in figure 1. In these situations, the cab protector must be modified and a raised steel box welded into place for clearance. However, NIOSH would recommend that mine operators adopting this technology contact the original equipment manufacturer and MSHA prior to making equipment modifications.

Installation of the unit and modification of the cab protector required two workers approximately two 8-hour shifts to complete. Another shift was utilized for resealing the cab with foam weather stripping around the doors and service panels and caulking to seal smaller cracks. A positive static pressure of 0.01 inches of water gauge was achieved after resealing. Figure 3 shows the unit installed on top of the truck cab and the steel box (constructed from 0.5-in steel plate) welded to the top of the cab protector on the truck bed for clearance.

Figure 3 - Sigma unit (left) and steel box (right) installed on haul truck.

Post-Installation Sampling and Results

Table 1 shows the concentrations values from the gravimetric samplers for the three days of sampling for post-installation of the system. The number of gravimetric samplers and their location was the same as in the pre-installation sampling. The concentration values for each day are the average of the two gravimetric samplers for that day of sampling. The "average" row contains the survey average. The reduction of respirable dust and respirable quartz dust was 34% before the new system was installed. After installation of the new system, the reduction improved to 69% and 75%, respectively.

Figure 4 graphs the inside and outside dust concentration data from the pDRs for the different operations of the haulage cycle. The pattern is similar to the pre-installation pDR concentrations in figure 2, but the reductions in dust concentration are greater for "loading at plant" and "dumping in mine." The reduction in respirable dust from outside to inside the cab based on the time-weighted cycle average is 61% as compared to 23% (see figure 2) before installation. Figure 4 illustrates that the new unit afforded a greater protection to the operator from outside dust levels.

Table 1 represents the comparison of outside to inside levels of dust for the pre- and post-

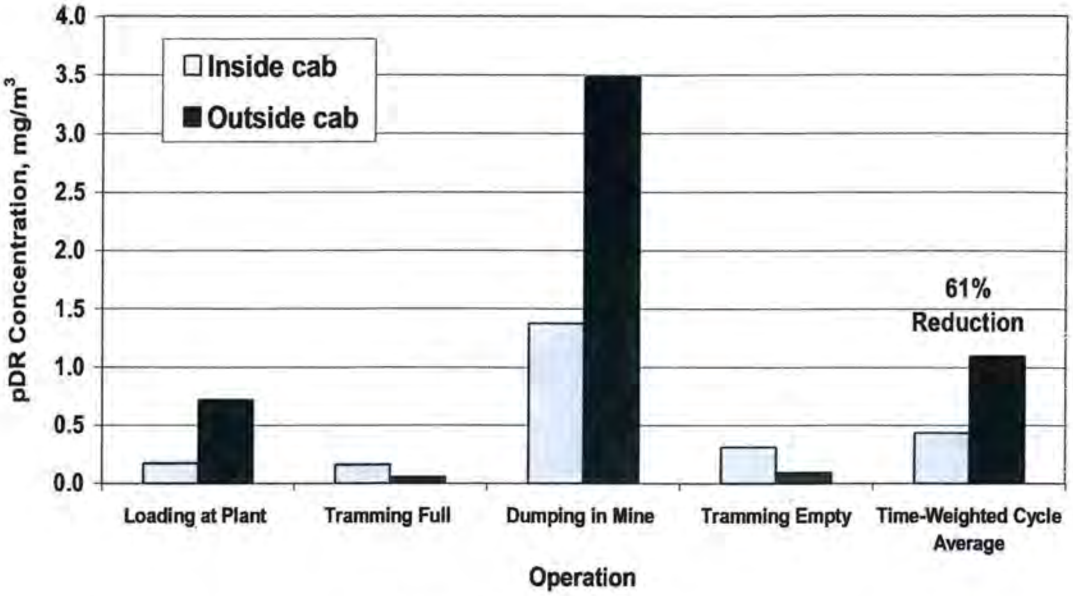

Figure 4 - Post-installation dust levels during haulage cycled from pDRs.

installation of the unit. However, to obtain an actual reduction in dust inside the cab, measured dust levels taken within the cab must be compared. It should be noted that the conditions for all three days, during post-installation sampling, were much dustier than during pre-installation. This was visually noted during sampling and supported by the measured dust concentration in table 1. Thus, the respirable dust and the quartz dust concentrations outside the cab during post-installation sampling are double the values during pre-installation. These higher concentrations influence the amount of dust actually penetrating the cab. This needs to be taken into account to determine the actual reduction in cab dust before and after installation of the unit. Figure 5 takes these higher outside concentrations into account by normalizing the average concentration values during post-installation to the baseline values during pre-installation inside the cab. Using this analysis, a 52% reduction in respirable dust and a 63% reduction in respirable quartz dust are achieved in the post-installation of the new system. This is a measure of the actual improvement in the cab working environment that could have been expected if outside dust levels had been equal.

As a final measure to evaluate the new system installed on the haul truck, dust sampling was conducted on a 5-year-old 100-ton Komatsu truck, used to haul stone from the mine. This truck was sampled for one day to determine and compare the effectiveness of the factory-installed pressurization and filtration system supplied on this newer truck. The number of samplers (gravimetric and pDRs) and their positioning on the outside and inside of the cabs was kept consistent with the previous sampling. Table 1 shows the one-day gravimetric sampling results for the Komatsu. The Komatsu truck reductions are very similar to the Euclid R-50 after retrofit with the new system, indicating that the Sigma system successfully upgraded the cab protection to that of the newer truck.

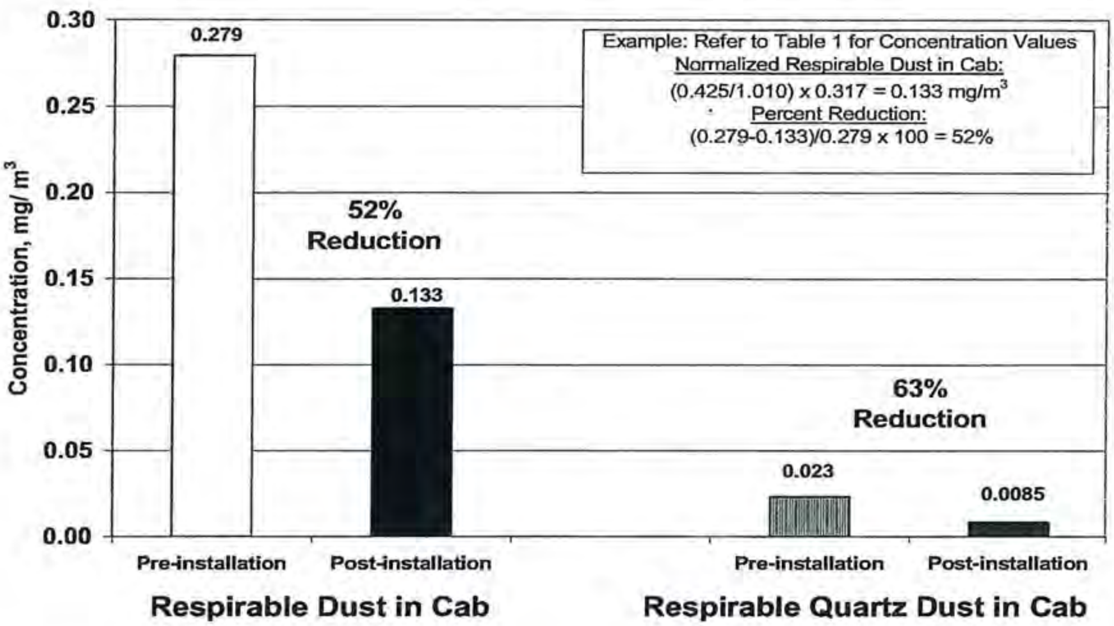

Figure 5 - Reduction in dust concentrations in cab when normalizing values to baseline.

Haul Truck Conclusions

This field study on a haul truck at a limestone mine retrofitted with a new filtration and pressurization unit demonstrates that older model trucks can be successfully upgraded to protect the operator from silica dust. In this study, gravimetric samplers and real-time aerosol monitors were used to collect respirable dust concentrations to evaluate the performance of the Sigma system. In all cases, the data analysis showed that the unit reduced respirable dust when comparing inside versus outside dust levels as well as levels within the cab before and after the unit was installed. The gravimetric sampling data, when normalized to baseline levels, showed that a 52% reduction in respirable dust and a 63% reduction in respirable quartz dust were achieved in the cab after the Sigma system was installed. The pDR data were used to evaluate the dust levels present during the haulage cycle, and the analysis regarding the reduction of respirable dust was in agreement with the gravimetric samplers. Finally, the new filtration and pressurization system compared favorably to a newer Komatsu truck, with factory-installed pressurization and filtration system, as the reductions in respirable dust were very similar.

CASE STUDY 2: SURFACE DRILL - SILICA SAND OPERATION

Background

The main objective of this research effort was to determine the impact of various modifications designed to improve the air quality to the operator working in the enclosed cab of a surface drill at a silica sand operation. Initially the goal was to determine baseline respirable dust levels both inside and outside the enclosed cab, as well as some other additional parameters, before any modifications were made. The drill being evaluated was a Drill Tech D40KII rotary percussion drill which was approximately 20 years old. It was a rubber-tire vehicle and was operated by a drill operator and drill helper at this site. The drill was driven into place by the drill helper from a driver's compartment located in the front of the drill rig. Drilling was performed by the drill operator located in the drill cab at the back of the drill rig. When the drill was moved at this operation, the drill operator exited the drill cab and stood outside on the driver's side of the drill rig to provide hand motions to aid the drill helper in positioning the drill in place for the next hole. This drill cab had a Red Dot R-9727 12-volt air-conditioning unit located on the roof of the cab. This unit had two internal fans that moved approximately 320 cfm (22,000 Btu/hr) of air to the enclosed cab, but there was no filtering of this air. The only dust filtering for this system was from an external filter housing that brought outside air into the system. At the time of testing, the filter housing on the Red Dot unit was substantially dented and the general condition of the unit was poor.

Preliminary Sampling Results

In this study, gravimetric samplers were positioned both inside and outside the enclosed cab. Inside the cab, a rack of three gravimetric samplers was positioned behind the operator's chair. Outside the cab, a similar package was placed directly under the window where the operator views the drilling process. Preliminary sampling to assess the dust levels in the cab was conducted over a 4-day period. During this sampling, outside dust levels were typically under 2.5 mg/m^3, and dust levels were less than 0.08 mg/m^3 inside the cab. Pressure measurements were taken inside the cab with a magnahelic gauge and a Solomat pressure instrument indicating that there was very minimal cab pressurization (approx. 0.005" w.g.). Based upon the visual conditions of the filtration system and the structural integrity of the cab, respirable dust levels measured inside the cab during this initial testing were much lower than expected. It was hypothesized that the major factor contributing to this was the air-conditioning unit being operated for a significant portion of each day of testing. As the cab air traveled through the condenser unit on the air conditioner, dust was being removed from the air which increased the filtering efficiency of the system.

After this preliminary testing was completed, modifications were made to upgrade the pressurization and filtration system on the cab. Since the R-9727 roof mounted unit appeared to be in poor working order, a good maintenance overhaul and cleaning was performed on the unit. During this process, it was noted that the system could be improved by the addition of an external makeup air and pressurization system. With the current design, the roof-mounted unit was under negative pressure. Therefore, any leaks in this unit would allow dust-laden air from the outside to be drawn into the unit and be blown directly into the enclosed cab. Because of this, a Clean Air Filter Company "cab filtration and pressurization system" was added to the existing system, providing approximately 70 cfm of makeup air to the system. The volume of the enclosed cab was approximately 45 ft^3, which represents approximately 1½ changes of filtered air every minute. The Clean Air system was composed of a pre-filter, a blower, and a respirator-medium secondary filter as shown in figure 6. The pre-filter was a two-stage media type filter located in a steel housing. Obviously, this filter was on the negative side of the fan and was used to remove the larger particles (greater than 20 microns) and extend the life of the final filter. A three-inch cylindrical chamber housed the final-stage filter and connected the fan to the Red Dot unit. This filter was a near-respiratory quality electrostatic media (97 pct of 0.3 micron particles). After the filtering system was installed, the cab was pressurized to a static

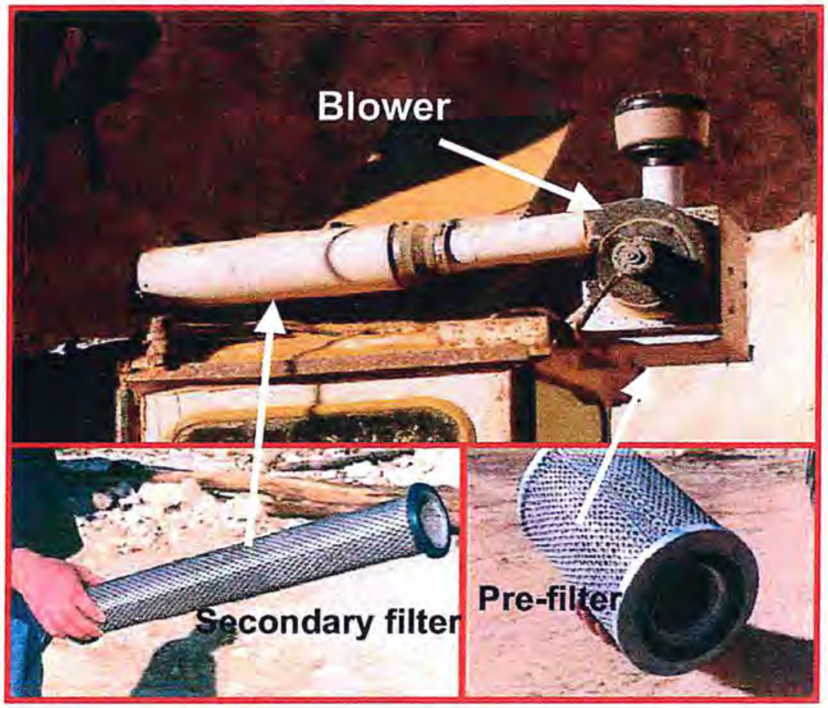

Figure 6 - Cab filtration and pressurization system blower and filters.

pressure of 0.01" (w.g.). Key to the design effectiveness was the location of the final filter which was on the positive side of the fan so that all air delivered into the enclosed cab had to pass through this secondary filter. Leaks in the system would discharge filtered air into the environment as opposed to dust-laden air into the system, as was the case with the previous design.

Another significant modification was to improve the sealing effectiveness of the enclosed cab. New door gaskets were installed and all small cracks and holes in the shell of the cab were plugged with silicon caulking. Closed cell foam material was used to better seal around some control linkages that extended outside of the cab. All control levers had rubber boots placed around them to provide the highest quality of seal possible. A 10-fold increase in the cab pressurization was achieved through these numerous efforts and resulted in a cab pressure of approximately 0.1" w.g. Achieving this level of pressurization is important because this prevents moderate wind velocities from forcing dust-laden air into the cab. It was determined from a previous study that in order to prevent wind from forcing contaminated air into the cab, the cab's static pressure must be greater than the wind's velocity pressure (7).

<u>Initial Modification Sampling Results - "Study A"</u>

After making these upgrades, a study was conducted to evaluate these modifications. Racks consisting of 3 gravimetric samplers were positioned both inside and outside the cab in the same locations as described earlier. Sampling was conducted for approximately 8 hrs per shift. Table 2 shows the results of the sampling survey, called "Study A," which was conducted over a 5-day period during the winter months. The concentration values for each day are the average of the three gravimetric samplers for that day of sampling. The "average" row contains

Table 2. Summary of Gravimetric Dust Concentrations for Surface Drills.

Study A	Outside Cab Respirable Dust Conc, mg/m^3	Inside Cab Respirable Dust Conc, mg/m^3	Reduction, %
Day 1	2.74	0.38	86
Day 2	2.47	0.58	76
Day 3	11.07	1.16	89
Day 4	14.09	0.72	94
Day 5	73.33	0.54	99
Average	***20.74***	***0.68***	***96***
Study B	Outside Cab Respirable Dust Conc, mg/m^3	Inside Cab Respirable Dust Conc, mg/m^3	Reduction, %
Day 1	3.01	0.07	98
Day 2	0.28	0.11	61
Day 3	0.31	0.02	94
Day 4	6.06	0.10	98
Day 5	29.91	0.13	99
Day 6	1.95	0.04	98
Day 7	3.83	0.04	99
Average	***6.48***	***0.07***	***99***

the survey average. As shown in the table, the outside dust concentrations varied considerably, averaging 20.74 mg/m^3. In comparison, the inside concentrations were more stable, averaging 0.68 mg/m^3. This gave an average reduction in dust concentration (from outside to inside) of 96%. Generally, this is an acceptable reduction, but the average inside dust concentration is of primary concern.

During the preliminary sampling, inside levels were generally under 0.08 mg/m^3 Originally, it was anticipated that dust levels would decrease from preliminary sampling levels because of the modifications and improvements made to the filtration and pressurization system on the enclosed cab. Instead, respirable dust levels inside the enclosed cab increased considerably from concentrations under 0.08 mg/m^3 to 0.68 mg/m^3. After considering all the factors in this analysis, it was hypothesized that the floor heater in the cab was the primary cause of the increased dust concentrations. Preliminary sampling was conducted during the humid summer months, while Study A measurements took place in winter conditions with low outside air temperatures and with the radiator-type floor heater in constant use in the cab. This type of heater, shown in figure 7, is commonly used in heavy equipment during the winter months and is preferred by equipment operators since it keeps their feet warm. It was believed that dust was generated from the drill operator grinding his boots and stirring up material on the floor and from dust being blown off of the operator's clothing.

Figure 7 – Floor heater location inside enclosed cab.

To determine if the floor heater was indeed responsible for the higher dust concentrations in the cab, the drill was taken into the maintenance shop and tested using two Grimm particle counting instruments. The Grimm instruments were used to monitor dust particles inside and outside of the enclosed cab under three different operating conditions. The first test condition had the filtration and pressurization system operating along with the re-circulation system. For the second test condition, only the re-circulation system was operating. The final test condition was similar to the first but with the floor heater also operating. Once this test series was completed, the Grimm instruments were switched to minimize any effects of instrument bias and the test series was repeated.

Figure 8 shows the results from this testing. The first test condition recorded the lowest average respirable dust concentration at 0.01 mg/m^3, while the second test condition averaged 0.03 mg/m^3. However, the final test condition, with the floor heater operating, recorded the highest average dust concentration at 0.26 mg/m^3. Significantly, Grimm measurements outside of the cab indicated that the outside dust levels remained relatively constant throughout this testing. One other point to note is that respirable dust levels inside the enclosed cab with the floor heater operating were higher than outside cab levels. These tests indicated that floor heaters can create high dust levels in the cab and their relocation is recommended (8).

After this testing, it was determined to make additional changes on the Dril Tec drill to further improve the air quality in the enclosed cab. It was decided to replace the Red Dot-9727 AC unit with a newly designed low-profile plastic body R-9777 unit, which provides both heating and

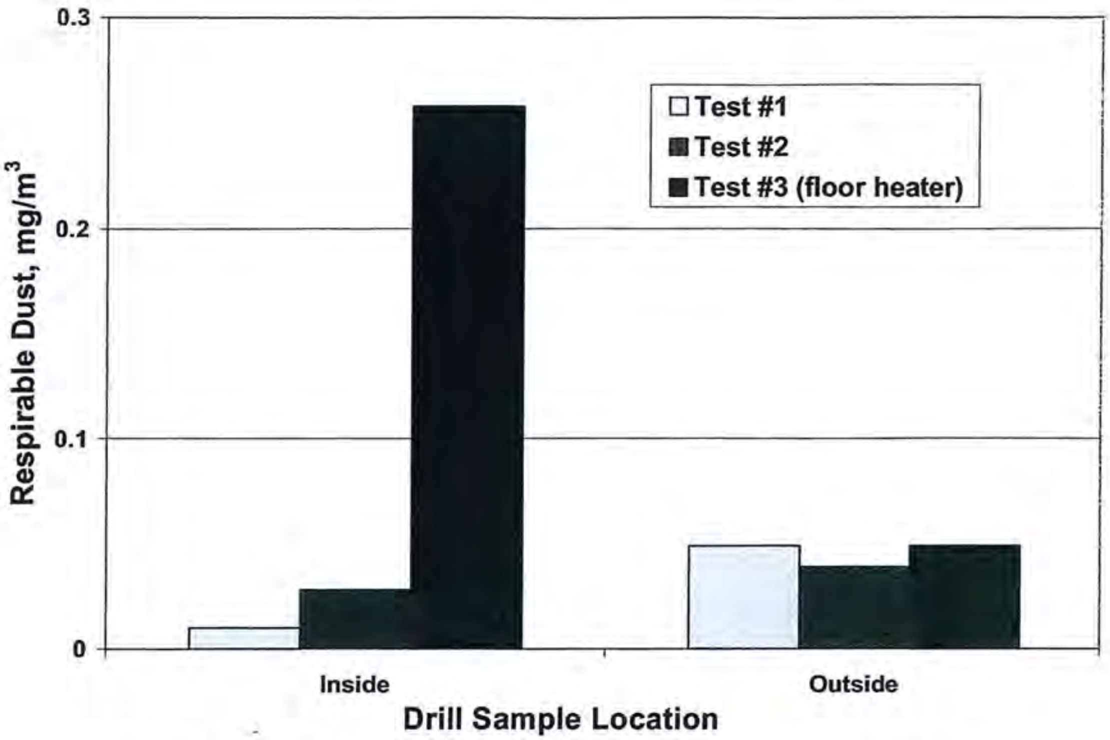

Figure 8 - Results of testing to examine increase in respirable dust levels inside cab with floor heater.

air-conditioning capabilities. This unit was donated by Red Dot for this research study and allowed the floor heater to be removed. Clean Air Filter Company also developed a high-efficiency pleated electrostatic re-circulation filter, which was placed inside this unit. This re-circulation filter was located immediately before the heating and air-conditioner core. An electrostatic filter media was chosen because it provided less restriction per unit area of filtering when compared to a standard mechanical type filter. One goal was to maximize filtered re-circulation to prevent air-conditioning freeze-ups. After inspecting and repairing all holes and possible leak areas into the cab again, between a 0.07 and 0.12" w.g. positive pressure was achieved.

The following is a breakdown of the different equipment used and the installation times necessary for this equipment: 1) Red Dot Corporation R-9777 heater and air-conditioner system (approximate cost: $2,200 donated by Red Dot Corporation); 2) Clean Air Filter Company - external air filtration and pressurization system (approximate cost: $1,000 - donated by Clean Air Filter Company); 3) installation of components 1 and 2, removal of floor heater, and sealing and inspection of cab - approximately 40 man-hours.

Final Modification Sampling Results - "Study B"

After completing these additional modifications, testing was performed to evaluate the new filtration and pressurization system's ability to improve dust levels in the cab. The number of gravimetric samplers and their locations were the same as in the pre-installation sampling.

Sampling involved seven different days over a 12-month period to evaluate the effectiveness of the system over a range of weather conditions, involving periods when either heating or air conditioning is in use. Table 2 shows the sampling results from this survey, called "Study B." As in "Study A," the outside dust levels varied, but the dust levels inside the cab remained stable. When examining table 2 (both Study A and B), there appears to be very little correlation between the outside and inside levels because the percent reductions are consistently high (>90%) on most sampling days. The average reduction (outside versus inside concentrations) was 96% for "Study A" and 99% for "Study B."

The most notable results in table 2 demonstrate that dust levels inside the cab were improved by modifications to the pressurization and filtration system and relocation of the heater. The dust concentrations averaged 0.68 mg/m^3 for pre-installation and 0.07 mg/m^3 for post-installation. This is a reduction of 90% in dust levels in the cab after the system was modified, and shows that the floor heater was a primary factor causing the higher levels.

Surface Drill Conclusions

An evaluation of the enclosed cab on a surface drill at a silica sand operation was conducted in an effort to improve protection provided by an older filtration system on the cab. Baseline sampling resulted in unexpectedly low dust levels inside the cab, with an average of less than 0.08 mg/m^3. It was thought that operation of the cab air-conditioner unit was contributing to the low dust levels by removing dust as the cab air traveled through the condenser unit of the air conditioner.

Maintenance was performed on the existing Red Dot filtration system and a Clean Air Filter Company "cab filtration and pressurization system" was also installed. In addition, gaskets and seals on the cab were replaced and cracks and holes were filled with silicon caulking to improve pressurization. After the completion of these modifications, five days of testing were performed and dust levels in the cab were much higher than expected, averaging 0.68 mg/m^3. This testing was conducted during the cold winter months and it was hypothesized that a floor heater might be the primary factor causing the higher levels. The drill was then taken into the maintenance shop and testing verified that the floor heater significantly increased respirable dust levels inside the enclosed cab. This was caused by dust and dirt on the floor and the operator's boots/clothing being stirred up by the floor heater fan.

The original filtering system was replaced with a heating/air-conditioning/filtration unit, a high-efficiency re-circulation filter was installed, and the floor heater was removed. After these final modifications, seven days of sampling were conducted over a 12-month period to include a wide range of temperature conditions, including days when the cab heater or the air conditioner was in use. This sampling showed a significant improvement in the quality of air within the cab. The average dust concentrations during this sampling were 0.07 mg/m^3, which is a reduction of 90% when compared to dust levels with the floor heater operating in the cab.

DISCUSSION

The knowledge gained from this research effort, as well as from other studies, can be applied to all types of equipment using enclosed cabs. This research has shown that there are two key components necessary for an enclosed cab to be effective from a dust control standpoint: 1) effective filtration, and 2) cab integrity. Both of these components are important and must be properly addressed for a system to be effective. The filtration system should consist of both re-circulation and outside (makeup) air units, with separate fans and filters. The majority of air inside an enclosed cab should be re-circulated through a high-quality filter medium. This allows air to be conditioned to the cab operator's comfort (heating and air conditioning) without unnecessarily increasing the size of the air -conditioner or heater units. It is also highly recommended that the makeup air be positively pressurized after being filtered to eliminate any possibility of dust-laden air being drawn into the system. Additionally, the makeup air inlet should optimally be located on the cab away from the primary dust sources (9). This reduces the amount of loading on the filters and increases the time between cleaning or replacement.

The second factor for dust control effectiveness is cab integrity, which is necessary to achieve some level of positive pressurization. Positive air pressure within the cab prevents outside dust-laden air from leaking into the cab. Field testing has shown that installing new door gaskets and sealing cracks and holes in the shell of the cab have a major impact on increasing cab pressurization. To prevent dust-laden air from infiltrating into the cab, the cab's static pressure must be higher than the wind's velocity pressure. However, higher static pressure requirements can necessitate more air being delivered by the outside air unit, potentially increasing dust loading on the filters and/or increasing the size and cost for this equipment.

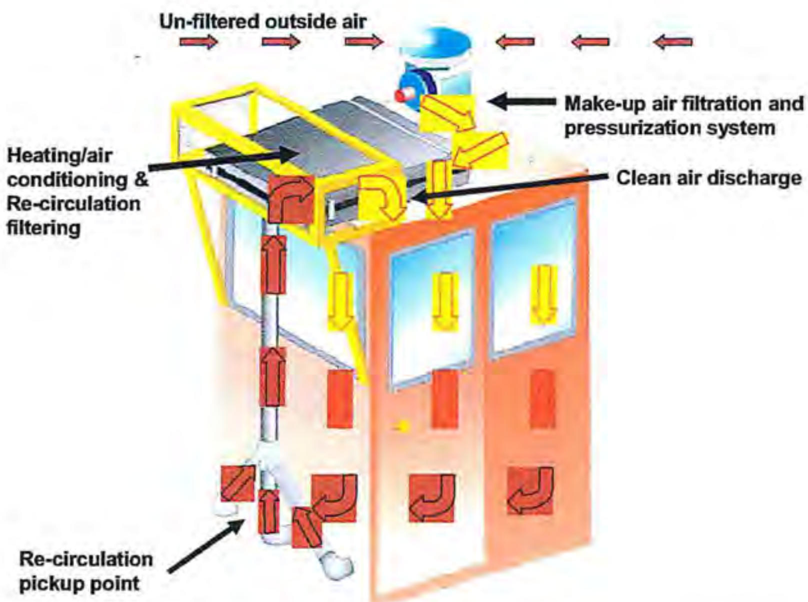

Figure 9 – Ideal schematic for effective filtration and pressurization system.

Another design criterion that should be considered is for the filtration system to use a top-down approach to the clean air flow pattern as shown in figure 9. In these case studies, as well as in most systems currently in use, the intake and discharge for the re-circulation air is located in the roof of the cab. Although this is acceptable, we believe the most beneficial design would be to draw the re-circulated air from the bottom of the cab. This allows the dust-laden air to be drawn out of the cab near the worker's feet and away from the breathing zone, while clean air is blown down over the operator. The discharge of clean air should never be low in the cab because, as was observed, this can entrain a significant amount of dust from soiled work clothes, boots, and a dirty floor. Finally, because of the significant increase in dust levels observed with the use of the floor heater, it is recommended that they not be used in their present form. If needed, they should be repositioned to a higher area in the cab where they are less prone to pick up dust from the floor and the operator's clothes. Probably the best solution would be to implement a heating and air-conditioning unit into the clean air and pressurization system.

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