Reducing enclosed cab drill operator's respirable dust exposure at a surface coal operation using a retrofitted filtration and pressurization system

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Abstract

The mobile equipment used in surface coal mining often have enclosed cabs to protect equipment operators. The overburden-removal process is extremely dusty and can cause excessive exposure to respirable dust, especially crystalline silica. After the equipment has been used for years, many components of the enclosure deteriorate, and their effectiveness is greatly reduced. This report discusses a cooperative research study performed on an Ingersoll Rand DM45E surface drill, retrofitted with a new Sigma pressurization and filtration system. Respirable dust concentrations in the drill cab were substantially reduced from 0.64 mg/m³ during pre-testing to 0.05 mg/m³ during post-testing with the new system, a 92% reduction. This new system appears to be a very well built and sturdy device that is well suited for the mining industry.

Introduction

Surface coal miners are often exposed to high levels of respirable dust. Because much of the overburden at these operations contains silica-bearing strata, the health effects of this dust are even more hazardous (Silicosis and Silicate Committee, 1988; Nnizdo and Sluis-Cremer, 1991; Ng and Chan, 1994). In an effort to lower the respirable dust exposure of surface miners, the National Institute for Occupational Safety and Health (NIOSH) has been conducting research in a number of areas. Recently, one of the major thrusts has been to improve the protection to workers operating surface-mining equipment inside enclosed cabs. Normally, when this equipment is new, the cabs are fairly airtight, and the filtration systems are in good working order. However, most mining equipment is older, and as aging occurs, many components of the enclosure deteriorate. This causes the structural integrity of the cab to diminish and the effectiveness of the air filtration system is considerably lessened. When this occurs, the cab does not adequately protect the equipment operator from harmful contaminants, including respirable dust. Compounding the problem, dust-sampling records indicate that drill operators and drill helpers have some of the highest dust exposures of all workers at surface-mining operations (Tomb et al., 1995).

In an effort to improve the protection to workers exposed in older mining equipment, NIOSH entered into a number of cooperative research efforts with mining companies, heating and air-conditioning companies and cab-filtration manufacturers (Heitbrink et al., 2000; Organiscak et al., 2000). The research discussed in this report is one such study. This work was a cooperative research effort involving NIOSH, Air International Transit/Sigma Air Conditioning Inc., Lodestar

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Figure 1 — Interior cab sampling on Ingersoll Rand drill.

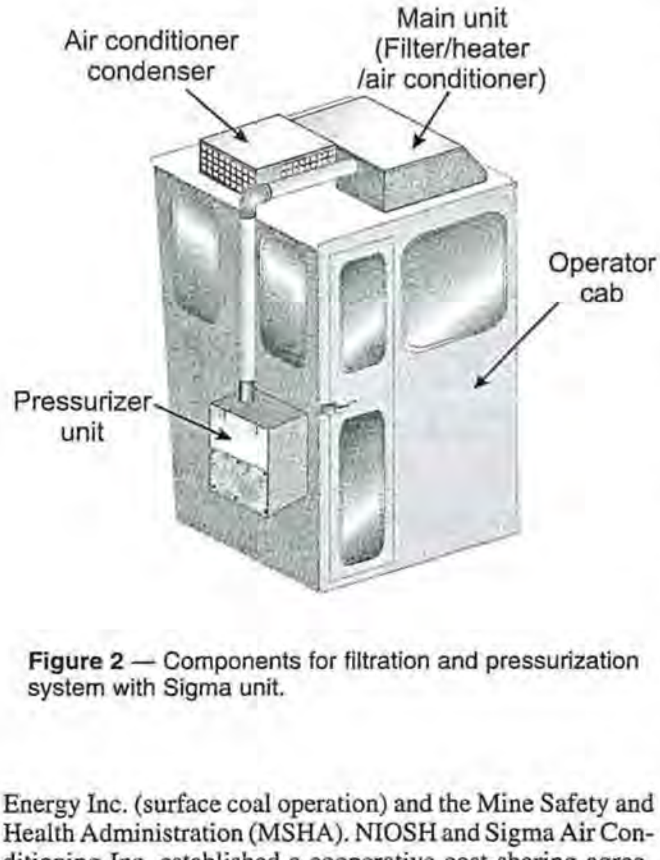

Figure 2 — Components for filtration and pressurization system with Sigma unit.

Energy Inc. (surface coal operation) and the Mine Safety and Health Administration (MSHA). NIOSH and Sigma Air Conditioning Inc. established a cooperative cost-sharing agreement to determine the impact of retrofitting an older piece of mining equipment with a new pressurization and filtration system. In the spring of 2000, NIOSH and MSHA visited Lodestar Energy's Gooseneck Operation in eastern Kentucky to pursue the possibility of performing this evaluation at its surface coal operation. One objective of this study was to perform a worst-case scenario to determine the degree of improvement when retrofitting the poorest-quality enclosed cab with a new pressurization and filtration system. Lodestar Energy Inc. agreed to participate in this study, and after many different pieces of mining equipment were considered, it was decided to perform the study on an Ingersoll Rand DM45E surface drill. Initially, baseline dust measurements were taken on the drill before any changes or modifications were made to it. After this was completed, a new filtration and pressurization system was installed, followed by an identical dust analysis to determine the changes in the drill operator's respirable dust exposure with the new system in operation.

Testing

Because the ultimate objective of this research was to determine the reduction in the drill-operator's dust exposure with the Sigma pressurization and air-filtration system, the sampling strategy was designed to provide a quantitative analysis of the change in the operator's respirable dust exposure. Data collected included gravimetric respirable dust sampling, impactor dust size distribution, instantaneous respirable dust monitoring through Mini-RAM and Data-RAM measurements, instantaneous GRIMM particle counter size distributions, weather conditions (wind speed, direction, temperature and humidity) and documentation of equipment operation. This study was composed of pre-testing and post-testing field analyses. The pre-testing analysis (baseline) was performed on the drill as originally found and operated. The drill was then retrofitted with an improved filtration and pressurization system and an identical post-testing analysis was again performed. During post-testing, temperature-recording devices were also located inside and outside the enclosed cab to compare temperature levels.

The following three main sampling areas were chosen for this evaluation: inside the operator's cab, outside on the drill cab and outside on the sampling tripod. The first sample unit inside the operator's cab monitored conditions that the drill operator would be exposed to during time spent in the cab over the workday. All in-cab sampling instrumentation was placed on a sampling rack located directly behind the drill operator's chair (Fig. 1). This sample unit was composed of three gravimetric samplers, a cascade personal impactor and an instantaneous respirable dust monitor. During pre-testing, a Mini-RAM unit connected to a solid-state data-logger device was used to record instantaneous respirable dust concentrations. At the end of each day of testing, the data-loggers were dumped to a personal computer for permanent data storage and data analysis.

All instrumentation on the outside cab-sampling unit was located on a sampling rack attached to the back of the drill. This sampling unit was composed of three gravimetric samplers, one personal cascade impactor and a temperature-recording device for post-testing. The cascade impactor device was only operated for a short period of time (usually 60 to 90 minutes) because of the high dust concentrations recorded at this outside location. Finally, the tripod sampling location was composed of three gravimetric samplers and was manually moved during testing by NIOSH personnel to be positioned at the windward side of the drill unit in the dust cloud.

Baseline dust measurements were performed on this drill in May of 2000 for three consecutive 10-hour daylight shifts. After the completion of this baseline testing, a Sigma Air Conditioning Inc. representative traveled to the operation to obtain all the necessary design specifications. The new pressurization and filtration unit was then fabricated and installed in September 2000. This Sigma system was made up of the following components: an FFR6 filter/heater/air-conditioning main unit, a TFC6 condenser for the air-conditioning unit and an FVW100 pressurizer unit (Fig. 2).

The FFR6 filter/heater/air-conditioning main unit is designed for rooftop mounting on the cabs of heavy-duty off-highway machinery. The system has high heating and cooling capacities to suit large equipment such as drills, shovels, lozers and trucks. Sigma also uses a modular approach for the pressurization and filtration systems, which provides flexibility to the end user to customize a system to fit user needs and cost. A system can be designed to accept either a standard pressurizer or a self-cleaning pressurizer; the self-cleaning type was used in this study. The FFR6 filter/heater/air-conditioning unit is equipped with a two-stage filter design. The first stage is a Farr 33/30 filter, which has a 95% efficiency rating for particles ≥ 5 µm. This filter is designed to remove the larger particles and reduce the loading of the second and final-stage filter, a pleated spun polyester washable medium, which is 99% efficient on particles ≥ 0.5 µm.

This system uses 134a environmentally friendly refrigerant for air conditioning. The maximum airflow capacity delivered to the enclosed cab with this system is 0.21 m^3/s (450 cfm). The self-cleaner filter medium on the FVW 100 pressurizer unit also uses the final-stage filter medium. Outside air is drawn through the filter before entering the pressurizer system. It is then mixed with the enclosed cab return air in the main unit (FFR6). This mixed air then flows through the evaporator section of the A/C system, where either heating or cooling is applied. The cab operator manually adjusts a solid-state control that sets the fan speed. The fan speed mainly deals with operator comfort and has a minor effect on cab pressurization. The pressurizer system operates for a set time period and then automatically provides a back-flushing cycle to clean the filter using the reverse pulse technique.

After the Sigma system was installed and working properly, the post-dust evaluation was performed in September 2000 for three consecutive days. All monitoring equipment and procedures were identical to pre-testing, with two minor exceptions. Additional temperature-recording devices were used to monitor the air temperature inside and outside the enclosed cab to account for the operator's ability to self-control temperature inside the enclosed cab. The second variation was a change in the instantaneous dust monitor. A Data-RAM unit was used, which has a built-in datalogger unit. Because both instruments were built by the same company, all aspects, excluding the data storage capability on the Data-RAM, were either identical or very similar.

One final analysis was performed during the beginning of November for one day using GRIMM particle counting instruments. This was used to measure the number of dust particles in various size spectrums both inside and outside the enclosed cab. This information was used to compare and confirm the results of other dust-sampling instrumentation and provided a database of other similar analysis performed at other operations.

Results

The main objective of this research effort was to determine the impact on the drill operator's dust exposure by the implementation of the new Sigma pressurization and filtration system. Table 1 shows the average respirable dust concentration as measured by gravimetric sampling for the three sample locations for both pre- and post-installation testing of the Sigma unit. The most important detail to note from this table is the extremely low respirable dust concentrations measured inside the cab during post-testing. The average concentration for the entire three days of post-testing was 0.05 mg/m^3.

Figure 3 shows the calculated protection factors for pre- and post-testing of the enclosed operator cab on this Ingersoll Rand drill. The protection factor values shown in this graph are calculated from average gravimetric dust data. The cab-protection factor is the average outside respirable dust concentration (average outside cab and tripod) divided by the inside cab dust concentration. As shown in the graph, the average pre- and post-protection factors are values of 12 and 52, respectively. One interesting point was the change in outside respirable dust concentrations between pre- and post-testing. For pre-testing, respirable dust levels were in the 7 mg/m^3 range, whereas for post-testing, these values were in the 2 mg/m^3 range. The authors believe the main reason for this change can be associated with the depth of drilling. During pre-testing, the Ingersoll Rand drill was drilling two drill steels, which was approximately 12-m (40-ft) holes. During post-testing, the drill was only drilling roughly 4.5-m (15-ft) holes, thus generating less dust.

Table 1 — Average respirable dust concentration measured by gravimetric samplers.

Location	Pretest, mg/m^3	Post-test, mg/m^3
Average tripod	7.69	2.69
Average outside	7.30	2.82
Average inside	0.64	0.05

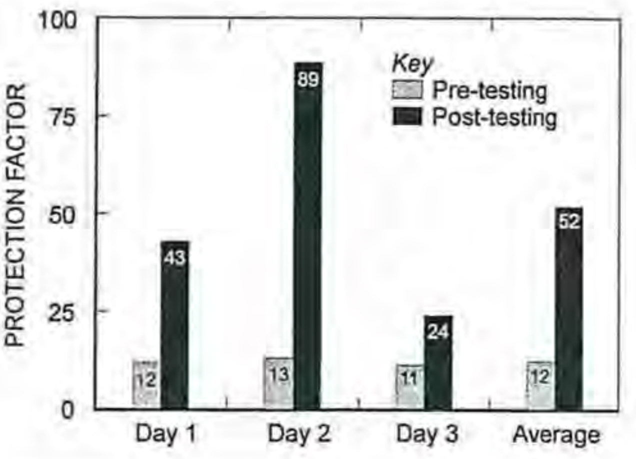

Figure 3 — Protection factors during testing of Sigma unit on Ingersoll Rand DM 45E drill.

Considering the information presented in Table 1, it must be noted that inside the enclosed cab, respirable dust concentrations obtained for pre-testing analysis provided reasonable protection to the drill operator with the original Ingersoll Rand dust-control system. The average inside respirable dust concentration was 0.64 mg/m^3 with a protection factor of 12. This is a respectable value when one considers the age of the drill and that the filter unit had not been actively maintained over the life of the drill.

Table 2 presents the silica analysis of the gravimetric samples analyzed at the analytical lab at the Pittsburgh Research Laboratory. The first part of this table lists the silica content of the respirable dust collected on the sampling filters. The silica content ranged from 3.7% to 18% for all samples, with a mean and a standard deviation of 12.5% and 3.0%, respectively. The first part of the table indicates the consistency in the silica content for both pre- and post-testing. It is important from a comparability standpoint that these values remain very similar. For pre-testing, the silica content mean

Table 2 — Silica content and weight for analysis of sample gravimetric filters.

Location	Day #1 pre-test	Day #1 post-test	Day #2 pre-test	Day #2 post-test	Day #3 pre-test	Day #3 post-test
Silica analysis — Content, %						
Tripod	13.7	13.8	12.5	9.3	12.2	8.9
Outside	12.7	15.3	12.2	14.5	12.4	18.0
Inside	15.4	13.7	12.3	11.9	11.8	3.7
Silica analysis — Weight, µg						
Tripod	823.8	75.3	280.2	672.8	627.9	252.0
Outside	825.4	139.7	330.4	763.6	673.0	137.4
Inside	86.3	1.8	24.6	6.1	60.9	2.5

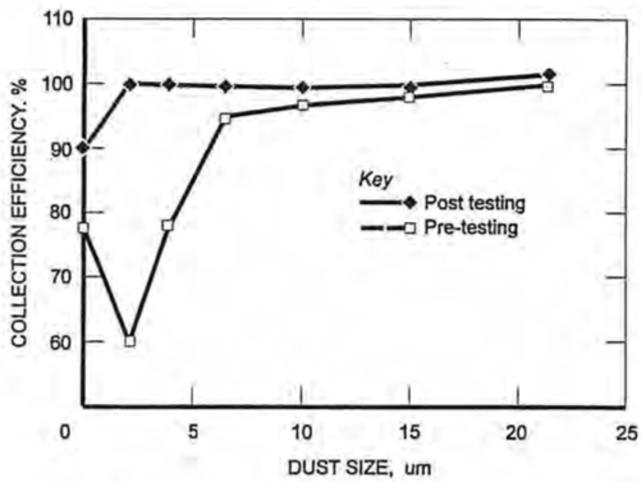

Figure 4 — Improvement in cab collection efficiency with new Sigma system in operation.

and standard deviation were 12.8 and 1.1, respectively. For post-testing, the silica content mean and standard deviation were 12.1 and 4.2, respectively. Hence, the silica content of the overburden being drilled between the two weeks of testing was very similar. The second part of the table lists the micrograms of crystalline silica on the gravimetric filters. An area of prime interest is the silica level inside the operator cab, to which the drill operator is exposed. MSHA's standard for silica, referred to as the Permissible Exposure Limit (PEL), is based on a 100-µg standard. NIOSH's Recommended Exposure Limit (REL) is 50-µg. For pre-testing, the average silica weight was 57 µg; this compares to an average of 3.5 µg for post-testing, which is a 94% reduction.

Another result that underscores the efficiency of the Sigma filtration and pressurization system is the data obtained from the impactor size-distribution measurements. Figure 4 identifies the highlights of the measurements from inside the operator cab for both pre- and post-testing. This graph shows the improvement with the new system. Percentage of efficiency represents a collection efficiency of 100% (points at the top of the graph). As shown, the collection efficiency is almost at the 100% level for the various size ranges of particles collected with the impactor devices.

From information obtained using the instantaneous respirable dust monitor inside the cab and testing performed with the GRIMM particle-counting instrumentation, a significant portion of the dust measured inside the cab resulted from periods when the door was opened on the drill, so that the drill operator or test personnel could enter or exit the enclosed cab. The Data-RAM data showed very low respirable dust levels except for periods when spikes were recorded. The authors believe these periods represent times when the door on the enclosed cab was opened. For approximately a one-hour period during the afternoon of September 26, the drill operator was actually operating the drill with the drill-stem side door open, allowing for better visibility of the necessary drill depth.

The GRIMM particle counting instrument testing on Nov. 8 also indicated significantly higher levels inside the enclosed cab immediately after the door had been opened. Particle size data of the GRIMM instruments indicate that it took approximately 7 minutes for dust levels to stabilize inside the enclosed cab after the door was opened. Once the system operated for this time period, dust levels remained at very low levels. The GRIMM instruments also provide a protection factor calculation for the various size range distributions of dusts as measured by the instrument. The protection factor ranges from a low of around 40 to a high in the low 70s (Fig. 5). The average from all particle size ranges is a protection factor in the low 50s range. These protection factors correlate closely with the average protection factor of 52, which was obtained with the gravimetric samplers.

The cost for this Sigma unit was approximately $10,000 plus installation. The components used for this research study provided a high air-filtering capacity to maximize the protection to the enclosed cab operator. Choosing a smaller capacity unit would have lowered the cost, and most likely the efficiency of the system.

One last area that was monitored and has an impact on reduced respirable dust levels inside the operator cab is the amount of pressurization, or static pressure, from the dust-filtering and pressurization system. During pre-testing, air pressure inside the cab relative to outside was measured using a magnehelic pressure gauge and a Solomat PDM205 pressure meter. When just the pressurizer unit was operated, there was no pressurization detected with either device. When the air conditioner was turned on, a reading of 7.5 Pa (0.03 in. water gauge) was detected. This was checked periodically during the three days of testing with the same values being recorded. During post-testing with the new Sigma filtration and pressurization system, good pressurization was achieved for all three days of testing. The pressurization ranged from approximately 50 Pa (0.20 in. water gauge) to approximately 100 Pa (0.40 in. water gauge). There are three fan speed settings: low, medium and high. A few hundredths, i.e., 5 to 10 Pa (0.02 to 0.04 in. water gauge) difference was evident between the low and high setting.

Cab pressurization is a very important factor affecting protection inside the operator cab under all weather conditions. For pre-test conditions, high wind speeds or currents would have been able to blow dust from the outside into the operator's cab. With the new system installed, the pressurization was great enough that it would eliminate any wind-infiltrating dust into the cab under any reasonable weather conditions.

Discussion

From this study, as well as from other studies on filtration and pressurization systems, the authors believe that there are two key components necessary for an enclosed cab to be effective from a dust control standpoint: effective filtration and cab integrity. Both of these components are important and must be properly addressed for the system to be effective. An effective filtration system should be composed of both a recirculation and outside (makeup) air system. The majority of air inside an enclosed cab should be recirculated through a high-quality filter medium. This allows air to be conditioned to the cab operator's comfort (heating or air conditioning) without major air changes that would significantly affect the size and capability requirements, and ultimately the cost for conditioning the cab air. Another consideration is to have separate fans for makeup and recirculating air.

A major component in an effective system is to have the makeup air positively pressurize the enclosed cab. This results in any system leakage to travel from the inside of the cab to outside, preventing dusty air from entering the cab. 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 should optimally be located on the cab the furthest practical distance from the dust sources (Technology News 485, 2001). This reduces the amount of loading on the filters and increases the time between cleaning or replacement. Finally, the discharge for makeup air into an enclosed cab should be located high in the enclosure, preferably at the roof. This allows the clean air to be blown down over the equipment operator's breathing zone without becoming contaminated by any in-cab dust sources. The Sigma filtration and pressurization system met each of these design criteria as listed.

One last design criteria that the authors recommend for the filtration component of an effective design is to use a top-down approach to the clean-air flow pattern. In the Sigma design tested for this study, as well as in most other systems, the intake and discharge for the recirculation air is located in the roof unit. Although this is acceptable, the authors believe the most beneficial design would be to draw the recirculated air from the bottom of the cab instead of at the roof of the enclosure. This allows the dust-laden air to be drawn out the cab near the worker's feet and away from the breathing zone. Again, the clean air would be blown in at the roof of the enclosure and the dust-laden recirculated air would be withdrawn from the floor of the cab. The authors would never recommend the discharge of clean air low in the cab because, as the authors observed, this can entrain a significant amount of dust from soiled work clothes, boots and a dirty floor (Cecala et al., 2001). Figure 6 represents our ideal schematic for an effective filtration and pressurization system on an enclosure drill cab. Once again, the authors are unaware of any manufacturer who is now pulling the recirculated air low within the cab.

The second factor for dust-control effectiveness is cab integrity. Cab integrity is necessary to achieve some level of pressurization. Field testing has shown that installing new door gaskets and plugging 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 the cab, the cab's static pressure must be higher than the wind's velocity pressure. Although higher static pressure requirements help overcome outside wind speeds, a major drawback is that this necessitates more air being delivered by the outside air unit, causing more loading on the filters. Higher airflow through a filter can also decrease the filter's efficiency by allowing more contaminants to flow through the filter media. Another drawback to higher airflow is that they create more air conditioning (heating and cooling) requirements for operator comfort, which increases the size and cost for this component.

The Ingersoll Rand drill tested in this study was still competent and did not require new door gaskets or repairs to achieve positive pressurization. Although sealing the cab was not necessary during the time of installation in this particular case, the authors do recommend the use of some type of

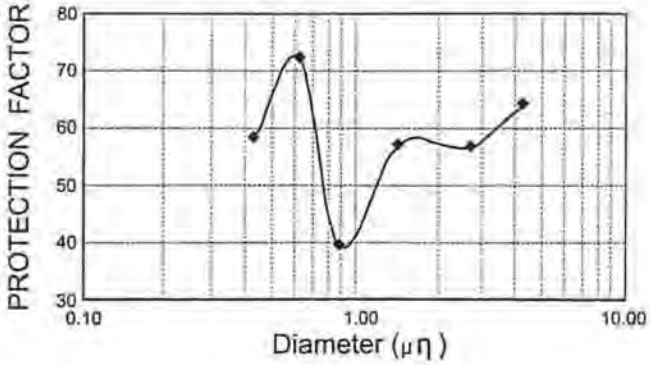

Figure 5 — Protection factors as measured by GRIMM particle monitors

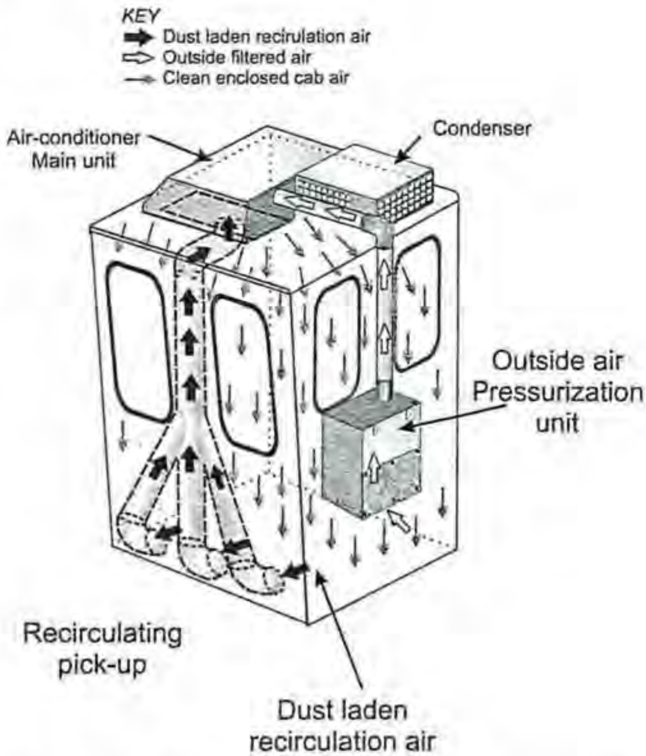

Figure 6 — Ideal schematic for an effective filtration and pressurization system on an enclosed cab.

pressure gauge inside the enclosed cab. This indicates when cab integrity is marginal and maintenance needs to be performed. Loss of pressure indicates either a filter loading problem or a cab integrity failure. Filter maintenance should be performed periodically and every time a predetermined pressure loss occurs over time. A sudden increase in pressure normally indicates a major failure in one of the filters and this problem should be corrected immediately.

Conclusion

The field study on the Sigma air filtration and pressurization system showed this system to be very effective at reducing the drill-operator's dust exposure, as well as providing a working environment that is more controllable and comfortable to the drill operator. A number of different sampling strategies and equipment were used in this evaluation; in all cases, they showed the Sigma air filtration and pressurization unit to be a very effective system.

When considering the gravimetric dust results, the unit reduced the drill operator's respirable dust exposure from a pre-test concentration of 0.64 mg/m^3 to a post-test concentration of 0.05 mg/m^3. This represents a 79% reduction in respirable dust concentrations when outside dust measurements are normalized because pre-testing levels were significantly higher than post-testing. The protection factor provided by the system averaged a value of 52 for the entire evaluation period. When considering the reduction in silica exposure, the drill operator had an average silica exposure of 57 µg/day for pre-testing, as compared to an average silica exposure of 3.5 µg/day for post-testing. When considering the data from the GRIMM particle counting instruments and the cascade impactor devices, the information also supports the effectiveness of the Sigma filtration and pressurization system at the various particle size ranges evaluated. This system was very effective in removing the respirable size range of dust particles (less than 10 µm), which are harmful to a worker's lungs. The Sigma system also provided very good pressurization to the enclosed cab without requiring any changes to the enclosure by the sealing of cracks or leakage points. The pressurization of 50 to 100 Pa (0.2 to 0.40 in. water gauge) also ensured that the wind would not be blowing dust from outside into the cab. Allowing the drill operator to have the flexibility of controlling the temperature level inside the cab and the fan speed keeps the operator involved in the system. Both drill operators stated that they like the system very much.

One last area that the authors were very impressed with is the ruggedness and mine-worthiness of the unit. The unit appears very suitable for a mine environment and should prove to be durable.

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