MAXIMIZING AIR QUALITY INSIDE ENCLOSED CABS WITH UNI-DIRECTIONAL FILTRATION AND PRESSURIZATION SYSTEM

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Abstract

Enclosed cabs have been used on surface mining equipment for many years to protect equipment operators from health and safety hazards. The surface mining and quarrying process is a highly mechanized process that generates large quantities of respirable dust. Due to economic factors, more older mining equipment is being used today than in years past. With this older equipment, it is common to observe deterioration of many components on the enclosed cabs which greatly reduce their protection effectiveness. NIOSH has performed a number of different field studies, as well as a comprehensive laboratory study evaluating various factors and parameters regarding enclosed cabs. NIOSH has recently completed a cooperative research effort with Sy-Klone International and Vulcan Materials Company to evaluate the effectiveness of a newly designed uni-directional filtration and pressurization system that brings all the clean filtered air in at the roof of the cab and extracts all recirculated air near the floor. This design provides the highest air quality to the equipment operator. Testing on this new system showed an almost 10-fold reduction in respirable dust inside the enclosed cab. The uni-directional design is easy to incorporate and should be considered for all new and retrofit systems in surface mining equipment.

Introduction

Enclosed cabs have been used for many years in the mining industry to isolate workers from dust sources. Workers in enclosed cabs at these operations are surrounded by dynamic working conditions and highly variable dust sources. The enclosed cabs create a microenvironment where they can be either better protected or more vulnerable to respirable dust. This issue came to light from a study performed in 1996 and 1997 which showed an alarming prevalence of silicosis in the surface coal mining industry. This study was undertaken at eight different surface coal mining operations in central Pennsylvania and was performed by the Mine Safety and Health Administration, the Pennsylvania Department of Health, the Department of Health Evaluation Sciences of the Pennsylvania State University College of Medicine, and the CDC's National Institute for Occupational Safety and Health (NIOSH). This was a voluntary program that screened 1,236 miners for lung diseases and determined that 6.7 percent of these workers were classified with at least category 1/0 silicosis. In an anomaly that was noted in one particular county (Clearfield), 16 percent of the 213 participants were classified with silicosis [1]. This investigation noted that a number of young miners with relatively few years of mining experience were developing silicosis from using surface drills with enclosed cabs that were not providing an acceptable level of protection. Further, although surface drills provided the highest risk of overexposure, operators of other types of mechanized equipment such as bulldozers, loaders, and haul trucks were also being overexposed to crystalline silica and respirable dust.

To address these issues, a substantial amount of research was initiated by a number of organizations to analyze the problem and investigate methods and solutions to improve the air quality in enclosed cabs. The National Institute for Occupational Safety and Health entered into a number of cooperative research efforts with mining companies, heating and air-conditioning companies, and cab-filtration manufacturers to improve the air quality in enclosed cabs in the surface mining industry. The work in this report discusses one such study on a uni-directional filtration and pressurization system, which is thought to be the optimal design for the airflow pattern inside the enclosed cab.

The uni-directional design is one that uses a top-down clean-air flow pattern in the enclosed cab. In most recirculation systems, the intake and discharge air vents are located at the roof of the cab. This design has two shortcomings. First, some of the clean air discharged is immediately short circuited right back into the recirculation vent (intake) without ever flowing through the enclosed cab. Second, dust-laden air from the operator's clothing, on the inside walls of the cab, and the floor, is drawn up over the operator's breathing zone as it travels into the recirculation duct at the roof of the cab. A better design is to have all the clean filtered air brought in at the roof of the cab and all the recirculated air withdrawn near the floor of the cab, in a one-directional or uni-directional design.

This uni-directional filtration and pressurization study was a cooperative research effort involving NIOSH, Sy-Klone International, and Vulcan Materials Company, to determine the impact of retrofitting an older piece of mining equipment with a uni-directional pressurization and filtration system. One objective was to perform a worst-case scenario to determine the degree of improvement when retrofitting a poor-quality cab with a new pressurization and filtration system. Vulcan reviewed its internal dust sampling records and chose its worst cab and filtering system at one of its limestone operations near Birmingham, Alabama, where a pneumatic rotary drill was being used. The first aspect of this research study was to take baseline dust measurements on the drill before any changes or modifications were made to the unit. This drill had the heater/air conditioner unit that was provided by the original equipment manufacturer when the drill was purchased. Over time, this HVAC unit, as well as the cab's gaskets and seals deteriorated to a point where they needed to be replaced and/or refurbished, although dust and noise levels were still within the acceptable standard. When completed, both Sy-Klone and Vulcan removed the old HVAC and filtering system and installed a new Red Dot 9777 HVAC unit and a Sy-Klone uni-directional filtration and pressurization system. Once it was determined the system was working properly, the post-evaluation was performed using the identical dust analysis performed during baseline testing.

Background

Before reviewing the details of this retrofit uni-directional cooperative study, a brief overview of the common terminology used in evaluating the effectiveness of enclosed cabs, as well as a brief summary of some previous field studies and a recently performed laboratory study, will be presented.

Effectiveness Terminology

When evaluating the effectiveness of filtration and pressurization systems to provide clean air to enclosed cabs, a few different factors can be used. These factors are all interrelated and compare outside with inside respirable dust concentrations. These factors are:

$$\textit{Protection factor} \quad (PF) = \frac{C_O}{C_i} \; (\textit{ratio})$$

$$\textit{Efficiency} \quad (\eta) = C_O - \frac{C_i}{C_O}$$ (fraction, or multiplied by 100 for percent value)

$$\textit{Penetration} \;\; (Pen) = 1 - \eta \;\; \text{(fraction)}$$

Where:
C_o = outside respirable dust concentration
C_i = inside respirable dust concentration.

A comparison of these descriptors can be provided by the following:

$$PF = \frac{C_o}{C_i} = \frac{1}{1-\eta} = \frac{1}{Pen}$$

Obviously, the higher the value for both *protection factor* and *efficiency,* and the lower the value for *penetration* that can be achieved the better the air quality inside the enclosed cab. For convenience, the term *protection factor (PF)* will be used in this report to evaluate the effectiveness of the uni-directional system.

Field Studies

Based on the outcome of the previously mentioned health study, which showed a high prevalence of silicosis among study participants, a number of organizations began investigating enclosed cabs to better understand the problem and to determine methods and solutions to improve the air quality and protect workers. This led to a number of studies in which new filtration and pressurizations systems were installed on older pieces of mining equipment in an attempt to improve the air quality inside these enclosed cabs. A few of these studies can be seen in Table 1, listed in ascending order of performance [2-5].

These studies highlighted some very important factors relevant to improving the air quality in enclosed cabs and ultimately protecting the workers. Cab integrity, and the related ability to achieve positive pressurization, was found to be a critical component. As seen in the first two studies listed in Table 1, when there was very little to no cab pressure detected, this resulted in minimal improvement in the cab's air quality. In fact, similar filtration and pressurization systems were installed on a rotary drill and front-end loader, listed as items 1 and 3 in Table 1, with the protection factor ranging from 2.8 to 10. One notable difference between these two systems was that a small amount of pressurization was achieved in the front-end loader, whereas it was not possible to achieve any pressurization in the rotary drill.

Table 1. Summary of field studies evaluating upgraded cabs.

Cab Eval. [Ref]	Cab Press. inches w.g.	Avg. Inside Cab Dust Level, mg/m^3	Avg. Outside Cab Dust Level, mg/m^3	Protection Factor Out/In
Rotary Drill [2]	None Detected	0.08	0.22	2.8
Haul Truck [3]	0.01	0.32	1.01	3.2
Front-end Loader [2]	0.015	0.03	0.30	10.0
Rotary Drill [5]	0.20 to 0.40	0.05	2.80	56.0
Rotary Drill [2, 4]	0.07 to 0.12	0.07	6.25	89.3

Another critical factor determined was the quality and effectiveness of the filtration system. The various studies presented in Table 1 indicated substantial improvement in the interior air quality from effectively removing the dust particles from the outside air and delivering this clean filtered air into the enclosed cab. Very good air quality (and protection factor) was obtained in these cabs when sufficient pressurization was achieved, along with an effective filtration system.

Laboratory Study

From these various field studies, a number of different factors emerged that were relevant to the effectiveness of filtration and pressurization systems. In an effort to evaluate this area, a controlled laboratory experiment was performed to systematically examine multiple cab designs. Figure 1 shows the cab filtration system setup used for this controlled laboratory study and the various parameters that were evaluated [6, 7].

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.

Throughout the course of the laboratory study, the significance of various filtration system factors was evaluated and the following mathematical model was developed [7]. It was formulated from a basic time-dependent mass balance model of airborne substances within a control 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.

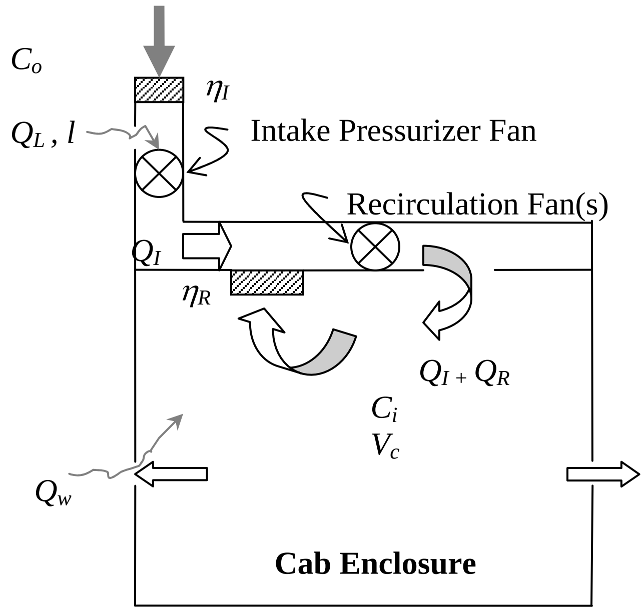
$$PF = \frac{C_o}{C_i} = \frac{Q_I + Q_R \eta_R}{Q_I (1 - \eta_I + l \eta_I) + Q_W}$$

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).

This equation allows for a comparison of how changes in the various parameters and components in the system impact the protection factor. By using this equation, operations have the ability to systematically achieve a desired protection factor in an enclosed cab to improve the air quality to safe levels and ultimately to protect their workers.

Testing

The objective of this research was to determine the improvement in the air quality inside an enclosed cab of a surface drill with a uni-directional cab filtration and pressurization system. The sampling strategy was designed to provide a quantitative analysis of the change in the respirable dust concentration inside the cab relative to outside before (baseline) and after (post-testing) the new system was installed. The pre-testing analysis (baseline) was performed on the drill as originally found and operated without any changes. This drill was then retrofitted with a uni-directional flow filtration and pressurization system and three different series of identical post-testing analyses were performed.



Where:

PF = Protection Factor, C_o/C_i
C_o = Outside Cab Concentration
C_i = Inside Cab Concentration
η_I = Intake Filter Efficiency, fractional
Q_I = Intake Air Quantity
Q_L = Intake Air Quantity Leakage
l = Intake Air Leakage, Q_L/Q_I
η_R = Recirculation Filter Efficiency, fractional
Q_R = Recirculation Air Quantity
Q_w = Wind Quantity Infiltration
V_c = Cab Volume

Figure 1. Laboratory test setup to evaluate various operational parameters on filtration and pressurization system for an enclosed cab.

Four main sampling locations were used for this study: (1) inside the enclosed cab (top), (2) inside the enclosed cab (floor), (3) outside the enclosed cab, and (4) outside the enclosed cab on the far side pneumatic leveling cylinder. Obviously, the two inside sample locations were used to provide the respirable dust exposure levels that the drill operator would be exposed to while performing his drilling functions. The inside floor location was only used during post-testing with the new system. All dust sampling instruments were placed on sampling racks at each of the four sample locations. For the two inside locations, these sampling racks were positioned directly behind the drill operator. The top location was behind the operator's head and the floor location was immediately above the recirculation pick-up point. Both sampling racks were composed of two gravimetric samplers and a pDR instantaneous respirable dust monitor.

For the two outside sampling locations, the first location was attached to the drill cab directly under the rear window. The second outside location was located on the far side pneumatic leveling cylinder, which also had two gravimetric samplers and a pDR instantaneous dust monitor. The reason for two outside sample locations was to determine the respirable dust generated during drilling no matter which direction the wind was blowing.

Two gravimetric samplers were located side by side on each of the sampling racks to provide respirable dust concentrations at each sample location. MSA Escort Elf (MSA, Pittsburgh, PA) sampling pumps were used and calibrated to a flow rate of 1.7 L/min before each field survey, which is the required flow rate as established by the American Conference of Governmental Industrial Hygienists (ACGIH) for the metal/nonmetal industry [8].[1] Dust samples were collected with a 10-mm Dorr-Oliver cyclone, which classifies the respirable portion of dust, then deposited on a 37-mm MSA filter. Filters were pre- and post-weighed to the nearest 0.001 mg on a microbalance in a temperature/humidity controlled weighing room. All sampling pumps were also post-calibrated to ensure that an acceptable flow rate of 1.7 L/min (±0.015L/min) was maintained throughout testing. For every 10 gravimetric filters used in the field, a blank cassette was used to determine a correction factor for the filter weighing process that was then applied to all the field gravimetric measurements.

All instantaneous respirable dust measurements were taken with personal Data RAM (pDR) instruments (model 1200, Thermo Fisher Scientific Corp., Waltham, MA). This is a real-time aerosol monitor that measures the respirable dust concentration based upon the light scatter of particles in an internal sensing chamber. The respirable dust levels were recorded on an internal data logger every 10 seconds and were downloaded to a laptop computer at the end of each day of testing. All pDR units were operated in the passive mode in which dust particles

[1] Mention of any company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

flow through the sampling chamber without mechanical assistance.

The average gravimetric respirable dust value at each sample location was used to determine a correction factor for the pDR instantaneous dust monitor at that same location. The average respirable dust concentration measured by the two gravimetric samplers was compared to the instantaneous respirable dust concentration as measured by the pDR monitor for the exact sampling time period. A correction factor was then calculated by dividing the pDR average concentration value into the gravimetric value. This calculated correction factor was then multiplied by all the individual dust measurements taken with the pDR device in an Excel spreadsheet. Using both types of respirable dust monitoring equipment provided a good profile of the dust concentrations throughout testing, as well as variations and changes in respirable dust concentrations throughout each day.

All cab pressure measurements were taken with a TSI model 8705 DP-CALC Micromanometer (TSI Inc., St. Paul, MN). These pressure measurements were taken every 30 seconds and recorded on the unit's internal datalogger.

Baseline testing was performed on this drill for three days, September 26-28, 2006. Upon the completion of this testing, the old air filtration system was removed and the new uni-directional filtration and pressurization unit was installed. Sy-Klone partnered with Red Dot Corporation in a design that incorporated the filtration and pressurization unit into a heating and air conditioning system. Figure 2 shows a design drawing of this uni-directional filtration and pressurization system.

The new system is composed of a make-up and a recirculation air component. The make-up air unit takes outside air and draws it through two parallel Sy-Klone Gideon technology powered air pre-cleaners. Each Gideon pre-cleaner unit delivered approximately 40 cfm of air, making the potential make-up air quantity total roughly 80 cfm. These pre-cleaners use a centrifugal design to spin off larger dust particles (larger respirable range and above (> 5.0 micron)). After the Gideon pre-cleaners, the air passed through a canister filtering cartridge. Once passing through this filter, the clean air then entered a plenum where it was mixed with the recirculation air. At this point, the combined air then travels through the HVAC unit where it is conditioned for temperature control before being blown through air vents into the enclosed cab.

The recirculation component was designed to incorporate a return air duct, which captured the recirculation air near the floor of the cab, isolating it from the cab, and then transporting it to the filtering unit at the roof. This recirculated air then passed through a similar canister filtering arrangement as with the make-up air. This recirculated air then entered the same plenum with the make-up air, passed again into the HVAC unit, and then back into the cab. The approximate quantity of air recirculated was 300 cfm.

For the HVAC system, the fan always operated when the drill was running. The drill operator manually adjusted a solid-state control with three fan speeds. The fan speed mainly affected operator comfort and had a very minor effect on cab pressurization. The unit also had a second control that was used to adjust the air temperature inside the cab to the operator's comfort. The volume of this enclosed cab on this drill was measured to be slightly over 50 ft^3.

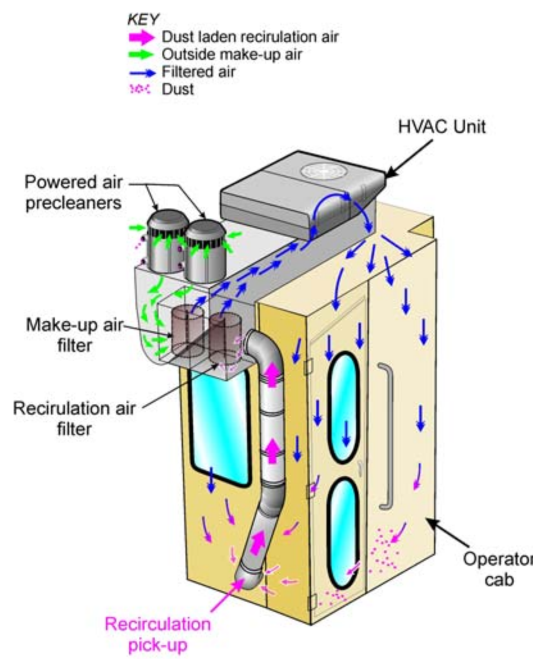


Figure 2. Design of uni-directional cab filtration and pressurization system as installed on enclosed cab of pneumatic drill.

The filter canisters used in this study had efficiency ratings of greater than 99 percent, (0.3 micron particles). Although intake and recirculation filters are normally at different efficiencies, (recirculation filters normally have lower efficiencies), Sy-Klone decided to use the same efficiency filters for both the intake and recirculation components in this study since it eliminates confusion when the filters need to be changed. Although these filters were rated at greater than 99 percent, there appeared to be a filter seating issue which caused dust to leak through the filter gasket material in some cases. This caused the filter to operate at a lower efficiency level.

Before each post-testing analysis, an evaluation was performed in the shop area to ensure that the uni-directional pressurization and filtration system was working properly. Part of this analysis was to use ARTI HHPC-6 particle counting instruments (Hach Ultra Analytics, Grants Pass, OR) to determine dust particle counts inside and outside the enclosed cab. These particle count values were used to calculate the actual filter efficiency based upon this leakage component, which was determined to be 97 percent (0.3 micron particles).

After the uni-directional filtration and pressurization system was installed and determined to be working properly, the post-evaluation was performed. Originally, two different post-evaluations with identical testing procedures as during baseline testing were scheduled to be performed. During the first post-evaluation performed in December 2006, there was very limited drilling because of a lack of production needs. In addition, for the second day of testing on December 14, the drilling area was extremely wet, which minimized respirable dust concentrations. Because of this, it was decided to perform two additional post-testing surveys, which took place in March and August of 2007.

Results

The main objective of this research was to determine the impact on the operator's respirable dust exposure inside the drill cab by the implementation of a uni-directional pressurization and filtration system. Table 2 shows the average respirable dust concentrations obtained by averaging the two gravimetric dust units at each sampling location. The values in this table include the entire day of testing from the time of drilling the first hole to the completion of the last hole at the end of the shift. It must be noted, though, that this time frame included periods of downtime and breaks, which lowers the overall dust levels.

The most important trend in this table is revealed by comparing the dust levels inside the enclosed cab between baseline and post-testing. During baseline testing, the average respirable dust concentration ranged from 0.43 to 0.95 mg/m^3 inside the cab for the three days of testing. This compares to the range of 0.06 to 0.23 mg/m^3 for the seven days of post-testing, using the identical sampling procedure (other than the second sample location being added near the floor). This definitely indicates the improvement to the air quality with the new filtration and pressurization unit.

Figure 3 shows the calculated protection factor for each day of testing for both the baseline and post-evaluations. For the baseline testing, the protection factor averaged 1.8 for the three days of testing. This compares to an average PF of 17.7, 12.3, and 27.8, for the post-testing 1, 2, and 3, respectively, with an average of 18.3 for all the days of post-testing combined.

Table 2. Respirable dust concentrations measured at inside and outside enclosed cab sample locations during evaluation.

	Outside Cab, mg/m^3		Inside Cab, mg/m^3	
	rear	left	top	floor
Baseline				
9/26/2006	0.84	1.06	0.43	n/a
9/27/2006	1.62	2.73	0.95	n/a
9/28/2006	1.68	0.33	0.54	n/a
Post-Test 1				
12/12/2006	3.64	4.76	0.22	0.19
12/14/2006	0.54	1.23	0.06	0.06
Post-Test 2				
3/13/2007	1.52	5.48	0.23	0.19
3/14/2007	0.70	6.12	0.23	0.18
3/15/2007	0.44	0.93	0.21	0.16
Post-Test 3				
8/21/2007	1.01	2.27	0.09	0.14
8/22/2007	2.52	8.71	0.14	0.13

The most revealing trend in the PF results is the respirable dust levels inside the enclosed cab. The other component that determines the PF value is the outside dust concentration. Since the outside dust concentration can vary greatly, this can significantly impact the PF. This is probably most evident when comparing the values from the post-test 2 in March. The individual values for PF were 16.6, 16.7, and 3.7, for March 13, 14, and 15, respectively. When considering the inside respirable dust concentrations (Table 2), the values were all very similar

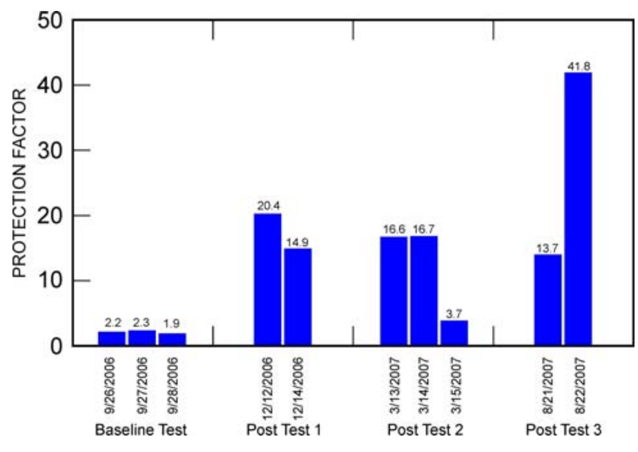


Figure 3. Protection factors for the drill cab during baseline and post-testing analysis

for all three days of testing. But when one considers the outside respirable dust levels, the values on March 15 were substantially lower than for the other two previous days of testing, which greatly affected the lowering of the PF value. Although it was the exact same system being used for all three days of testing, since the outside respirable dust concentration was so low on March 15, it could appear as though the system was not working as well, which was not the case. The purpose of this comparison is to indicate that the PF values can sometimes be misleading based on how substantial the differences are in outside dust concentrations. Obviously, higher outside dust concentrations provide higher PF levels. Conversely, it is impossible to achieve high PF values with very low outside concentrations.

One critical area that has been determined both from the previous field studies and the laboratory study is the ability to seal the enclosed cab and achieve positive pressurization. This issue was closely monitored during all phases of this cooperative research effort. During baseline testing, the cab pressure was minimal. After the installation of the new uni-directional cab filtration and pressurization system and before any modifications were made to improve the integrity of the enclosed cab, the pressure was measured to be 0.045 inches w.g. After this measurement, a significant amount of time and effort was put into sealing around the door with new gasket foam, sealing around drill levers with a flexible foam material, and sealing all large cracks and holes using silicon caulking. After this was completed, the cab pressure increased to approximately 0.3 inches w.g. As more time and effort was taken to seal all minor cracks and around gauges in the control panel, the cab pressure was increased even further to approximately 0.45 inches w.g. This indicates the impact that can be achieved in relation to protection when the time and effort is spent to thoroughly seal a cab.

During post-tests 1 and 2, cab pressures remained at levels near 0.4 inch w.g., similar to levels achieved after the improvements were incorporated. During the five months from post-test 2 to post-test 3, the integrity of the cab started to deteriorate. For the two days of post-test 3, the cab pressure ranged from 0.1 to 0.15 inch w.g. Although this is still an acceptable cab pressure, this was a significant drop and indicates that time and effort should once again be dedicated to improving the cab integrity by replacing gaskets and sealing all holes and cracks.

Discussion

When considering the results of this evaluation to reduce respirable dust concentrations inside the enclosed cab of the pneumatic drill with the use of a uni-directional cab filtration and pressurization system, it was decided to compare the actual values achieved during the post-testing to those derived from the mathematical equation formulated from the laboratory study. Once again, the equation derived during laboratory testing for the Protection Factor is:

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

The following are the actual operating parameters of the new system: Intake Air Quantity, (Q_I) = 80 cfm; Recirculation Air Quantity, (Q_R) = 300 cfm; Intake Filter Efficiency, (η_I) = 0.97 (97 percent efficiency); Recirculation Filter Efficiency, (η_R) = 0.97 (97 percent efficiency).

To determine the Wind Quantity Infiltration, the follow equation is used:

Wind Velocity Equivalent =
(4000 $\sqrt{\Delta p_{cab}}$) fpm × 0.011364 mph/fpm
@ Standard Air Temp and Pressure

Using a positive pressure of 0.4 inch w.g., which was typical cab pressure during the testing for the Δp_{cab}, the calculated wind velocity equivalent would be 28.7 mph. This means that a wind velocity of greater than this value would be necessary to blow dust-laden air from outside into the enclosed cab. Since the wind velocity remained below this value, we can assume that Q_W = 0. Based upon these values, the model provides a PF of 155.

When this calculated value of 155 is compared to the actual measured average value of 18.3 for all of post-testing, it initially appears that the laboratory derived value does not closely approximate the actual value measured during field testing. But when considering the actual test conditions, there was a significant factor observed during testing that allowed dust-laden air to enter the drill cab. During post-test 2 in March 2007, 110-ft boreholes were being drilled. Since the drill steels are 25 ft long, five steels are required to drill a hole to this depth. Each time the drill operator would add an additional drill steel, he would open the cab door, lean out, and with his left arm manually guided the drill steel into the previous steel. The total time to add a new drill steel was approximately 3 minutes. Approximately 2 minutes into the process, the drill operator opened the cab door to guide the next drill steel into place. The cab door was normally open somewhere between 30 and 45 seconds before being closed again. Since no drilling was occurring and no dust cloud was visible as the operator opened the cab door, the impact in respirable dust concentrations in the cab was thought to be very minor. However, when this issue was investigated by analyzing the pDR monitor results inside the enclosed cab, a substantial increase in respirable dust concentrations was noted during the periods when the door was open [9, 10].

The impact of this increase in respirable dust concentrations can be seen in Figure 4. The graph shows the average respirable dust concentrations inside the enclosed cab of the drill for all three days of testing for time periods when the cab door was closed versus open. The average concentration for all three days of testing was 0.09 mg/m^3 with the cab door closed and 0.81 mg/m^3 with the cab door open. Despite there being no visible dust cloud during these time periods when the cab door was open, the respirable dust concentrations were 9 times higher than when the door was closed. Further adding to the problem, once dust enters the enclosed cab and coats the inside surfaces, it also becomes a dust source to the drill operator at later times as it is disturbed and then becomes airborne.

Although the problem of the cab door being open was not noticed until the second field evaluation because of the greater drill depth and constant changing of the drill steels, it was decided to analyze the potential impacts of this problem for all post-evaluations. Table 3 presents the average respirable dust concentrations at both inside cab sample locations during periods when the cab door was closed and open. The information was determined from the instantaneous respirable dust concentrations from the pDR dust monitors.

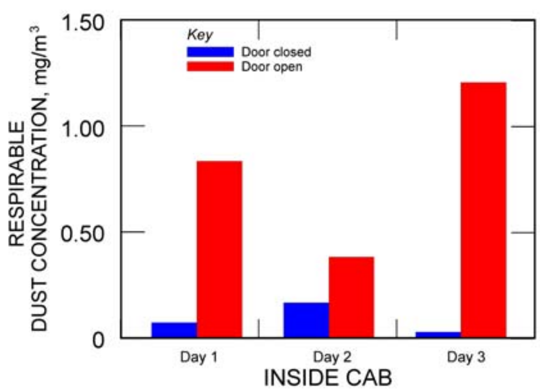


Figure 4. Average respirable dust concentration inside drill cab during periods with cab door closed and open for three days of testing.

Averaging all the values for post-testing with the cab door open and closed, the average respirable dust concentration was 0.11mg/m^3 and 0.52 mg/m^3, respectively. This represents an increase 4.7 times higher when the cab door was open during non-drilling activities, such as changing drill steels or to measure the depth of a borehole, than when compared to the actual time of drilling, when the cab door was closed. It also needs to be noted that the cab door was closed for a much greater percentage of the time as compared to when it was open.

Table 3. Respirable dust concentrations at top and floor sample locations for 3 post-test evaluations for time periods when the cab door was closed and open.

	Inside Cab, mg/m^3			
	Cab Door Closed		Cab Door Open	
	top	floor	top	floor
Post-Test 1				
12/12/2006	0.3	0.2	0.2	0.2
12/14/2006	0.0	0.0	0.1	0.0
Post-Test 2				
3/13/2007	0.1	0.1	0.8	0.6
3/14/2007	0.2	0.2	0.4	0.2
3/15/2007	0.0	0.1	1.2	0.6
Post-Test 3				
8/21/2007	0.0	0.1	0.9	0.9
8/22/2007	0.1	0.1	0.6	0.5

In order to achieve a protection factor of 18.3 for the actual test conditions, an intake air leakage l of 0.23 would need to exist. Based on the degree of dust leakage into the cab during the times that the door was open, an equivalent air leakage of 23 percent seems like a realistic value. Comparing the laboratory calculated value of 155 to the actual measured value of 18.3 stresses the importance of having a sealed cab with positive pressure, and also the importance of keeping the door and windows closed at all times other than when entering or exiting the cab.

The purpose of this cooperative effort was to retrofit the enclosed cab of a pneumatic drill at a crushed limestone operation with a new uni-directional filtration and pressurization system and to quantify the reduction in respirable dust to the drill operator in the enclosed cab with this new system. Although NIOSH has been involved in a number of similar cooperative effort studies, this was the first formal field evaluation of a uni-directional design. Figure 5 shows the uni-directional design as compared to one with both intake and return in the roof of the cab. Since the clean air introduced into the enclosed cab could not short-circuit and was forced to travel down near the floor area, and because dust generated or leaked into the cab would not be drawn up over the operator's breathing zone, it was believed that the uni-directional design was the optimum design in relation to the most effective in-cab airflow pattern. Although it is still believed to be the optimal design, this was not supported from actual field testing data described in this case study. The two sampling locations inside the enclosed cab did not show any significant difference between the top and near floor sample locations. In addition, in some limited and un-documented laboratory testing, it appears that the air discharged from the clean air vents at the roof of many systems may exit with enough air velocity to provide a complete mixing of the cab air and thus somewhat inhibit a uni-directional flow pattern. Although it is still believed that the uni-directional (roof to floor) flow pattern is the optimal design, study results suggest that the difference between the two different flow patterns may not be as significant as originally believed.

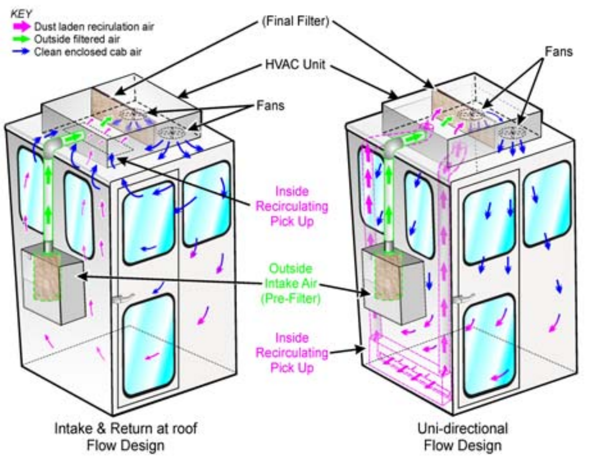


Figure 5. Airflow pattern for typical design with intake and return at roof of cab and with uni-directional airflow design.

Conclusion

This field study on a uni-directional cab filtration and pressurization system showed the system to be very effective at reducing respirable dust levels inside the enclosed cab of a pneumatic drill, thus providing the drill operator a more comfortable and safer work environment. During baseline testing, respirable dust concentrations inside the enclosed cab ranged from an average of 0.43 to 0.95 mg/m^3 for the three days of testing. There were three post-test evaluations and small modifications and improvements were continually made during these evaluations to optimize the filtration effectiveness and provide the cleanest air quality to the drill operator inside the enclosed cab. In the third and final post-evaluation, the average respirable dust concentration ranged from 0.09 to 0.14 mg/m^3 for the two days of testing. This comparison indicates the improved air quality inside the enclosed cab with the filtration system and ultimately, the improved protection to the drill operator. As seen in previous field studies as well as the laboratory study, there are a number of critical components for an effective filtration and pressurization system, also verified in this study. First, an effective filtration system needs to be composed of both an outside (make-up) air and a recirculation air component. 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. The uni-directional flow pattern should also help to maximize system performance, although the result from this field analysis did not show a significant difference in this application.

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