The Effectiveness of Several Enclosed Cab Filters and Systems for Reducing Diesel Particulate Matter

James Noll[1], Andrew Cecala[2], John Organiscak[3]

U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Office of Mine Safety and Health Research, 626 Cochrans Mill Road, Pittsburgh, PA 15236

[1]corresponding author: phone: 412-386-6828; fax: 412-386-4917; e-mail: jnoll@cdc.gov

[2] phone: 412-386-6677; fax: 412-386-4917; e-mail: acecala@cdc.gov

[3]phone: 412-386-6675; fax: 412-386-4917; e-mail: jorganiscak@cdc.go

Abstract

Many underground metal/nonmetal mines are using enclosed cabs on mining equipment to reduce the exposure of miners to diesel particulate matter (DPM). However, some enclosed cab systems may not be meeting their expected efficiency in capturing DPM, which could be a result of inappropriate filter use, cab leaks, or insufficient pressurization. NIOSH investigated several types of filters for reducing DPM to determine which type had the best capture efficiency. The laboratory results indicated that a MERV 8 (Minimum Efficiency Reporting Value, as defined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers) filter captured about 50 percent of the DPM, a MERV 16 filter collected 96-98 percent of the DPM, and two HEPA (high efficiency particulate air) grade filters captured over 99 percent of the DPM. NIOSH also performed a field study to measure the efficiency of two cabs at a limestone mine. The cab filtration systems of a loader and haul truck were found to be over 90 percent effective in removing DPM except under certain operating conditions when the efficiency was as low as 41 percent. Evidence seems to suggest that these conditions were when a window was open in the cab.

Introduction

Exposure to elevated diesel exhaust concentrations, which contain diesel particulate matter (DPM), has been linked to negative health effects such as eye and nose irritation, headaches, nausea, and asthma [Kahn et al. 1988, Wade and Newman 1993]. DPM has also been classified as a possible carcinogen by the National Institute for Occupational Safety and Health (NIOSH) and the Environmental Protection Agency (EPA) [NIOSH 1988, EPA 2002]. Underground miners can be exposed to some of the highest levels of DPM in the United States workforce. Therefore, the Mine Safety and Health Administration (MSHA) has promulgated a rule to limit the DPM exposure of metal/nonmetal underground miners to an eight hour time weighted average of 160 $\mu g/m^3$ total carbon [MSHA 2001, 2006]. To comply with this rule, mines are implementing a variety of control technologies such as enclosed or environmental cabs.

Environmentally controlled cabs can provide an environment with lower concentrations of harmful substances such as dust and DPM. In a properly sealed cab, the heating, ventilation, and air conditioning (HVAC) system will create a positive pressure, and the outside air is drawn into the HVAC system after the contaminants are removed via filtration.

Environmentally controlled cabs are a primary engineering control for reducing exposure to airborne dust at surface and underground mines [Organisak and Cecala 2008, Cecala et al. 2005, Organisak and Page 1999, Cecala et al. 2003] and for protecting miners from harmful noise levels [Suter 2002, Efrem et al. 2009]. In several studies, environmentally controlled cab system efficiencies for removing respirable dust ranged from 44 to 99 percent. Variables which affected these efficiencies included the type of filter, cab integrity, pressurization, and the use of a recirculation filter [Organisak and Cecala 2008, Cecala et al. 2005, Organisak and Page 1999, Cecala et al. 2003]. For example, older cabs may be less efficient due to the deterioration of components and the loss of structural integrity. Leaks in the cab as well as an open window or door can also affect the efficiency of its filtration system [Organiscak and Cecala 2008, Cecala et al. 2005]. Dust on the operator's clothing or on the floor of the cab can cause higher exposures because the dust can re-entrain inside the cab atmosphere and be inhaled by the operator. This exposure can be minimized by using a recirculation filter, which causes a multiplicative filtration of the cab interior air [Organiscak and Cecala 2008, Cecala et al. 2005].

DPM has different characteristics than dust which may result in the factors such as type of filter, cab integrity, and leak prevention affecting the protection against DPM differently than the protection against dust. For example, DPM in underground mines has a particle size range around 10-800 nm with an average geometric mass mean diameter (GMD) (the particle diameter in a log normal distribution at which 50 percent (by mass) of the particles are less than that value) close to 100 nm while over 90 percent of coal dust particles are greater than 1000 nm with mass mean diameters (same as GMD except for normal distribution) ranging from 3-30 µm (Bugarski et al. 2006, Noll and Birch 2004). Therefore, a filter that captures submicron particles may not be needed for dust collection but is needed to trap DPM and provide the desired protection. DPM can also cause a higher pressure drop across the filter in enclosed cabs due to its size, density, and chemical composition, increasing the number of filter changes necessary. In this study, NIOSH tested different types of filters to determine their ability to capture DPM.

Besides the efficiency of the filter, other factors mentioned such as cab integrity can also affect the ability of the cab system to protect the operator from DPM. Therefore, NIOSH also performed field testing on cabs to investigate how effective these cab systems as a whole were in capturing DPM under actual mining conditions. The concentrations of DPM inside and outside of two cab systems operating in a limestone mine were measured. Cab systems with different ages were chosen to investigate the effects of deterioration on cab integrity.

Methods

Evaluation of filters for capturing DPM

Filters are systematically tested and given a Minimum Efficiency Reporting Value (MERV) rating based upon their efficiency in removing particulate in different size ranges (see Table 1).

Table 1: Minimum efficiency reporting values (MERV) according to American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)

Group	MERV Rating	Average particle size efficiency (PSE) 0.3-1.0 microns	Average particle size efficiency (PSE) 1.0-3.0 microns	Average particle size efficiency (PSE) 3.0-10.0 microns
1	1			< 20%
	2			< 20%
	3			< 20%
	4			< 20%
2	5			20-34.9%
	6			35-49.9%
	7			50-69.9%
	8			70-84.9%
3	9		< 50%	≥ 85%
	10		50-64.9%	≥ 85%
	11		65-79.9%	≥ 85%
	12		8-89.9%	≥ 90%
4	13	< 75%	≥ 90%	≥ 90%
	14	75-84.9%	≥ 90%	≥ 90%
	15	85-94.9%	≥ 90%	≥ 90%
	16	≥ 95%	≥ 95%	≥ 95%

The higher the MERV rating number, the more efficient the filter is in capturing submicron particles (the size range of DPM).

In this study, four different filters were evaluated in the laboratory: a MERV 8 filter, a MERV 16 filter, and two HEPA (high efficiency particulate air) type filters. These filters use a mechanical mechanism such as synthetic fibers to trap the particulate and were chosen since most enclosed cabs in underground mines use this mechanical type filter. A MERV 8 filter is used in some cab systems for removing dust but not rated to trap submicron particles. A HEPA type filter (rated higher than MERV 16 for capturing submicron particles) is used by mines to capture DPM since it is rated at over 99 percent efficiency in filtering particles as small as 0.3 microns. Though MERV 16 quality filters are not rated as high as HEPA filters, a MERV 16 filter was also tested because they may be over 90 percent efficient for capturing submicron particles and can be significantly less expensive as well as less restrictive to cab airflow. As seen in Table 1, MERV 14 and 15 will also trap submicron particles but at a lower efficiency (usually rated for less than 90 percent) than the HEPA and MERV 16. These filters were not tested in this study but could be topic for future work.

In order to evaluate the efficiency of these different filters at capturing DPM, a commercial filtering system (Sy-Klone® RESPA®), as shown in Figure 1, was set up inside a Marple chamber (an aerosol chamber capable of dispersing particulate, such as DPM, uniformly throughout its mid-sectional volume) [Noll et al. 2005]. The commercial filtering system is designed to filter air before it enters the cab and to pressurize the cab.

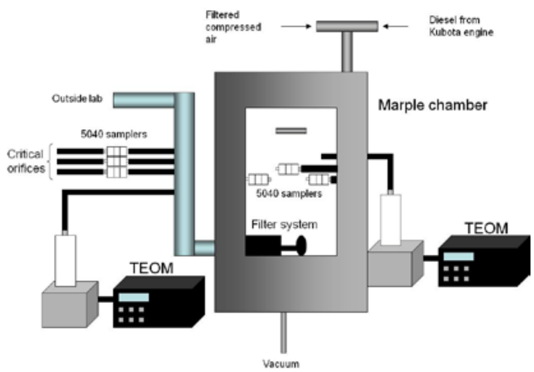


Figure 1: Schematic of laboratory evaluation of enclosed cab filters: Diesel exhaust from a Kubota engine is diluted and uniformly distributed in a Marple chamber to simulate diesel exhaust in mine air. A filter system is used to draw air from the chamber through a filter and then out of the laboratory. Triplicate elemental carbon and total carbon samples (5040 samples) are collected onto filters using critical orifices for flow control. A particulate mass sample, via a Tapered Element Oscillating Microbalance (TEOM), was collected before and after the filters.

In this experimental setup, the commercial filtering system allowed air in the Marple chamber to pass through a filter at 50 cubic feet per minute (cfm) into exhaust tubing and then outside the laboratory. The exhaust from the filter system would represent the air in an enclosed cab, and the air in the chamber would represent air in the mine.

Total DPM concentration, elemental carbon (EC), and total carbon (TC) were measured before and after the filter to determine its efficiency at capturing DPM. EC and TC were measured because they are used to determine compliance for DPM exposures in underground mines [Birch 2004, Noll et al. 2006, MSHA 2006]. TC is used as a surrogate because it represents over 80 percent of DPM; however, TC can be prone to some interferences such as cigarette smoke and oil mist. Therefore, EC is also used to determine DPM exposures because it is selective to DPM and still represents DPM well. More detail on the different surrogates for measuring DPM can be found in Noll et al. (2006).

Three particulate samples were collected onto quartz filters at 1.7 litres per minute (lpm) using critical orifices for flow control both in the chamber and in the exhaust tubing to compare DPM concentrations before and after filtration. Prior to sampling, the quartz filters were heated at 800 ^{o}C for at least a half an hour. Two quartz filters with backing pad were placed into a three-piece SureSeal cassette and pneumatically sealed. The filters were analyzed for EC and TC using NIOSH method 5040 (LOD 0.3 $\mu g/cm^2$) at the NIOSH laboratory in Pittsburgh, Pennsylvania [Birch 2004]. The first filter in the cassette was used to determine DPM concentrations. The second quartz filter in the cassette was used as a dynamic blank to correct for a sampling artifact—adsorption of vapor phase organic carbon—as described by Noll and Birch [2008]. A Thermoscientific Tapered Element Oscillating Microbalance (TEOM) (LOD 1.5 $\mu g/m^3$) was used to measure total particulate mass inside the chamber, and another TEOM was used to measure particulate mass in the exhaust tubing.

For the first test, the commercial filtering system was set up without a filter to evaluate loss of DPM in the experimental setup. The system was sealed, and the filter system and sampling pumps were turned on. A Kubota diesel engine (V1200-B engine, 4 cylinders) was started and run under 80 percent load. After the engine warmed up for at least 10 minutes, the diesel exhaust was introduced into the Marple chamber. The samples were collected until a 99 percent efficiency as shown in the equation below could be detected. The sampling pumps and diesel engine were shut down, and the diesel exhaust was evacuated from the chamber. The quartz filters were sealed and later analyzed for EC and TC. In addition, the TEOM data was downloaded and analyzed.

This same test was repeated using MERV 8, MERV 16, and 2 HEPA's. The MERV 16 filter was repeated for a longer sampling time to investigate if longer sampling times would increase efficiency or analytical accuracy.

The efficiency of the filter for removing DPM was calculated using EC, TC, and mass results with the following equation:

$$\% \text{ efficiency} \equiv \frac{(A_{outside} - A_{inside})}{A_{outside}} x100$$

where $A_{outside}$ = The EC, TC, or mass concentration measured outside of the cab,
and A_{inside} = The EC, TC, or mass concentration measured inside of the cab.

A relative standard deviation (RSD) was determined for the EC and TC measurements by pooling the RSD of each duplicate or triplicate set of each experiment according to *NIOSH Guidelines for Air Sampling and Analytical Method Development and Evaluation* (Kennedy et al. 1995). The precision of the efficiency calculation for EC and TC was determined by propagation of error using the RSD's from the EC and TC measurements as described by Bevington (1969). No experimental RSD could be calculated for the mass measurements because there was only one TEOM instrument for each data point. In order to determine the RSD for the efficiency calculation, the RSD (8 percent) determined when using the TEOM to measure DPM in another study was used (Kelly and Morgan 2002). Again, the propagation of error calculation was performed to determine a relative standard deviation for the efficiency resulting from mass measurements via the procedure described by Bevington (1969).

Field Study

Two environmentally enclosed cabs with factory installed heating, ventilation, air-conditioning (HVAC), and air filtration (using HEPA quality filters) were evaluated in an underground limestone mine for overall performance in protecting miners from DPM exposures under actual mining conditions. The cabs were on a loader (1993 980F Cat Loader) and a haul truck (2007 Catepillar 775). Both older and newer cab systems were chosen, because there can be significant deterioration in the efficiency of cabs as they age if components are not replaced and maintained.

In order to evaluate the efficiency of a cab to reduce DPM, two baskets were prepared, each containing an EC monitor and two or three SKC DPM cassettes. The SKC DPM cassettes collect particulate at a 0.8 μm cut point onto quartz fiber filters to be analyzed for EC and TC using NIOSH method 5040 [Birch 2004]. In previous tests, the SKC DPM cassette has been shown to eliminate 96 percent of the dust and result in no loss of DPM above the experimental error of 12 percent [Noll et al. 2005]. The EC monitor (LOD 3 $\mu g/m^3$ eight hour time weighted average) is a prototype instrument developed by NIOSH to measure near real time submicron EC concentrations [Janisko and Noll 2008, Noll and Janisko 2007].

The flow rates of the pumps and EC monitors were checked and recorded before sampling. One of the sampling baskets was strapped onto a loader outside the cab. Another identical sampling basket was placed inside the cab of the vehicle. The pumps and monitors were turned on and run at 1.7 lpm simultaneously. The loader was used to clean up areas in the mine and was operated during normal production hours for this stone mine. The same procedure was repeated for the haul truck. The haul truck was used to transport rock from the mine face to the crusher. After about six hours of sampling, the pumps and sampling instruments were turned off and removed from the vehicles. The flow rates were rechecked and recorded. This sampling procedure was continued for nine days for the loader and three days for the haul truck.

The quartz filters from the SKC DPM cassettes were analyzed for EC at the NIOSH laboratory in Pittsburgh using NIOSH method 5040. The data from EC monitors were downloaded each day, and the EC concentration was calculated using an established calibration curve.

The reduction efficiency (the effectiveness of the cab system to remove DPM) was calculated using the EC values from the NIOSH 5040 analysis with the following equation:

$$\text{Reduction efficiency} \equiv \frac{(EC_{outside} - EC_{inside})}{EC_{outside}} x100$$

$EC_{outside}$ – The EC concentration measured by NIOSH 5040 outside of the cab.

EC_{inside} – The EC concentration measured by NIOSH 5040 inside of the cab.

In this field part of the study, EC only was used to determine DPM reductions since TC and mass measurements would be unreliable due to interferences from dust, cigarette smoke, and oil mist [Noll et al. 2006].

An RSD for the EC samples taken inside the cab was determined by pooling the RSD's for the duplicate and triplicate EC samples inside the cab as described in the methods section for the laboratory tests. The same calculations were done for the samples measured outside of the cab. A propagation of error calculation was performed from these RSD's to calculate the RSD for the efficiencies as described in the methods section for the laboratory tests.

Results and Discussion

Table 2: Efficiency of cab filters using NIOSH 5040 data

	after filtration		in chamber		EC	TC
Filter type	**EC (μg/m^3)**	**TC (μg/m^3)**	**EC (μg/m^3)**	**TC (μg/m^3)**	**% efficiency**	**% efficiency**
no filter	501	568	513	602	2	5
HEPA	< 3	< 6	625	706	> 99	> 99
Merv 8	310	371	528	604	41	39
Merv 16	19	28	574	668	97	96
Merv 16 long	11	19	690	803	98	98
HEPA 2	< 3	< 6	660	742	> 99	> 99

RSD for EC measurements inside the chamber is 7.6%
RSD for EC measurements in the tubing is 12.7%
RSD for the EC efficiencies is 14.8%
RSD for TC measurements inside the chamber is 6.2%
RSD for TC measurements in the tubing is 12.9%
RSD for the TC efficiencies is 14.3%

Table 3: Cab filter efficiency using TEOM data

	TEOM mass (μg/m^3)		
Filter type	**chamber**	**after filtration**	**% efficiency**
no filter	682	570	16
HEPA	814	< 8	> 99
Merv 8	772	355	54
Merv 16	641	26	96
Merv 16 long	861	7	99
HEPA 2	801	< 8	> 99

RSD for efficiencies is 11.3%

Evaluation of filters for capturing DPM

The Sy-Klone® RESPA® pre-cleaner that removes larger particles (greater than four microns) was part of the commercial filtering system used in this study to evaluate the cab filters. Therefore, the system was first tested without any filter to see if the pre-selector was removing any DPM and to determine if any DPM was being lost through the experimental setup (e.g., by attaching to the walls of the piping). As shown in Tables 2, the loss of EC and TC from the experimental setup was 2-5 percent which is less than the experimental error of the system (6 to 7 percent was determined to be the experimental error in a previous study when measuring EC and TC in the Marple chamber) [Noll et al. 2005, Bugarski et al. 2005, Page et al. 2007]. As seen in Table 3, loss of particulate measured via TEOM due to experimental setup and error was 16 percent.

As shown in Tables 2 and 3, the HEPA filter was over 99 percent efficient in capturing EC, TC, and total particulate from DPM. The

EC, TC, and particulate mass measured were less than the LOD for NIOSH method 5040 and TEOM. If the measurement were at the LOD, the efficiency of the filter would have been 99 percent. Because the results were below the LOD, the efficiency is greater than 99 percent. This efficiency would reduce concentrations above 16 mg/m^3 TC to below the final limit [Noll et al. 2007].

The MERV 8 filter reduced the EC and TC by about 40 percent and total particulate by about 50 percent. This would result in concentrations in a cab above the final limit when the concentration outside the cab was at or above 266 µg/m^3 TC, which can be observed in underground mines [Noll et al. 2007].

The MERV 16 filter was at or above 96 percent efficiency for removing EC, TC, and total particulate. The efficiency observed with the MERV 16 filter would reduce a concentration of 4000 µg/m^3 TC, which DPM concentrations in underground mines are typically below, to at or below the final limit (Noll et al. 2007). The efficiencies reported for the HEPA, MERV 8 and 16 filters only represent filter media efficiency and do not take into account the other parts of the cab system.

Other control technologies such as diesel particulate filters and biodiesel can preferentially reduce EC over other components of DPM [Bugarski et al. 2005]. The MERV 16 and HEPA filters in this experiment reduced all components of DPM (shown by similar percentage reductions of EC, TC, and total particulate), which could be an advantage when using enclosed cabs.

In Tables 2 and 3, there are filters labeled MERV 16 long and MERV 16. The MERV 16 long is the same type of filter as MERV 16 but is sampled for a longer period of time. The MERV 16 long did show a slight increase in efficiency, but the increase was not statistically significant because the difference between the efficiencies of the MERV 16 and MERV 16 long (3 percent) was less than the RSD. An increase in efficiency with loading with mechanical type filters would be expected [Raynor and Chae 2004]. The loading could have been too low to have a significant increase in efficiency with this filter. Other types of filters such as electrostatic which use charge to capture the particles would be expected to decrease in efficiency with loading [Raynor and Chae 2004]. It can also be noted that the two runs with MERV 16 filters (within 3 percent of each other) as well as the two runs with HEPA

Please forward the request for these engine precleaner sizes to John Bernard once you have answered the questions asked in my previous e-mail.

Field Study

As shown in Table 4, the reduction efficiencies of the filter and pressurization system of the cab on the older loader measured using NIOSH method 5040 results were between 41 and 93 percent depending on the day and the operator. One would not expect the DPM reduction efficiency of the filtration and pressurization system of the cab to vary this much from day to day since there were no changes in the cab or vehicle. In addition, the sampling environment did not change drastically, nor was a consistent trend observed in the data (the efficiency of the cab did not decrease or increase over time).

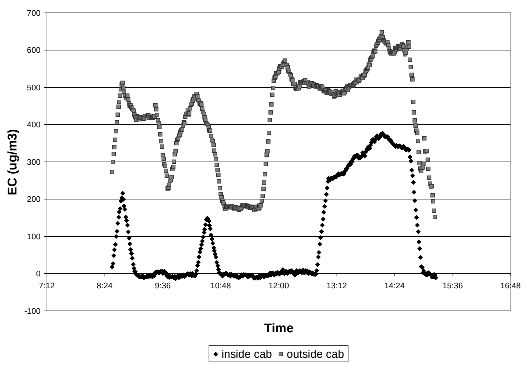
Table 4: Efficiencies of cabs

Operator	Day	outside cab EC (µg/m^3)	inside cab EC (µg/m^3)	% efficiency
operator 1	1	363	74	80
operator 1	2	378	104	73
operator 2	3	645	43	93
operator 3	4	330	194	41
operator 1	5	237	16	93
operator 3	6	121	45	63
operator 4	7	419	55	87
operator 4	8	498	32	94
operator 3	9	271	148	45
operator 5	10	341	15	96
operator 5	11	337	15	96
operator 5	12	516	36	93

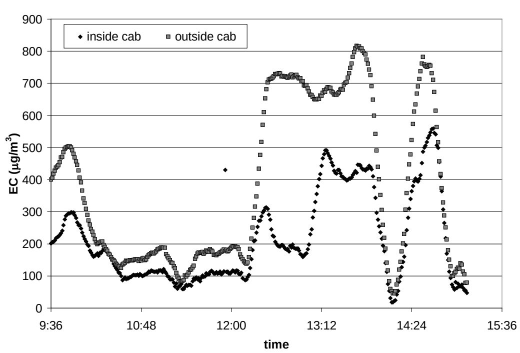
RSD for EC samples outside the cab is 4%
RSD for EC samples inside the cab is 7.6%
RSD for efficiencies is 8.6%

If there were a leak in the system, a leak in the cab filter, or penetration through a sealed cab system, one would expect the real time EC concentration inside the cab to follow the same trend as the concentration of EC outside of the cab. However, this did not always occur. Instead, there is some evidence from the real time data and other observations that some work practices such as opening the window in the cab could have resulted in the lower efficiencies.

If the window were opened periodically throughout the shift, one would expect the concentration of EC inside the cab to increase when the window was open and decrease as the window was closed. This would explain the real time results when 73 percent reduction efficiency was observed (see Figure 3a), because after the operator entered the cab, the EC concentration inside was below the limit of quantification, even though the outside EC fluctuated between 200 and 400 µg/m^3 between about 9:00-10:00 a.m. At around 10:00 a.m, a peak was observed inside the cab, which could indicate a window or door opening and then closing. After about 12:30 p.m, the higher concentration of EC inside the cab, which followed the trend of the EC outside the cab, could have been from a window being slightly open for the remainder of the sampling period.



(a)



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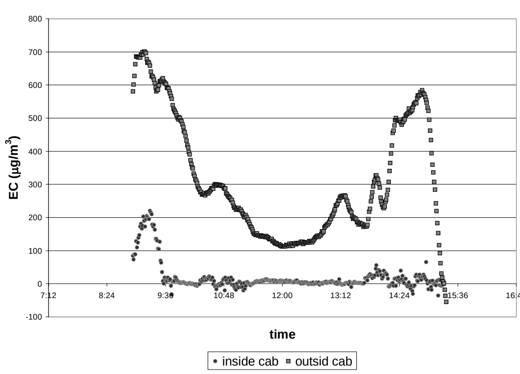

(c)

Figure 3: (a) EC concentration (measured by EC monitor) vs. time of a loader in a limestone mine inside and outside of the cab on the day when about a 73 percent reduction efficiency was observed. An open window or door might have caused an increase in DPM exposures. (b) EC concentration (measured by EC monitor) vs. time of a loader in a limestone mine inside and outside of the cab on the day when about a 41 percent reduction efficiency was observed. A window seemed to be open during most of the shift, causing an increase in DPM exposures. (c) EC concentration (measured by EC monitor) vs. time of a loader in a limestone mine inside and outside of the cab on the day when over a 90 percent reduction efficiency was observed. Windows and doors seemed to be kept sealed.

If the window were kept open for most or all of the shift, the results of the real time EC data inside the cab could follow the trend of the EC concentration outside and behave as a leak in the system. The efficiency of the cab system to reduce DPM would be lower for that day than when the window was closed for part or most of the shift. If the window were not kept open at a constant width, the inside EC concentration could also fluctuate when the window was opened wider. This would explain the results on the days with the lowest reduction efficiencies. Figure 3b shows a real time graph of the concentration of EC inside the cab for a day when the reduction efficiency was at its lowest value (41 percent). There was some EC penetration through most of the shift, which could be a result of the window being open for the majority of the time. The concentration of EC inside the cab occasionally increased when there was no increase in concentration outside the cab, which could indicate the window being opened wider at times throughout the shift.

If the window and door were kept sealed for the entire shift, one would expect the concentration of EC inside the cab, if detectable, to follow the trend of the EC concentration outside. When the reduction efficiencies were above 90 percent (as seen in Figure 3c), the real time results for inside the cab were below 25 µg/m^3 (real time limit of quantification) for most of the shift. The reduction efficiencies from these days are more likely to represent the expected efficiency of the cab system.

The percentage of DPM penetration inside the cab being dependent upon which operator was working also suggests some evidence of an open window causing the variation in reduction efficiencies. As seen in Table 4, the three lowest efficiencies (41, 45, 63) observed for the two weeks occurred when operator 3 was working. When operators 1, 2, and 4 were working, the efficiencies (73, 80, 94, 87, 94, 93) were similar from day to day (a coefficient of variation of only 10 percent). Even in this relatively close subset, the two lowest values both occurred when operator 1 was working. These results suggest that operator 3 and perhaps, at times, operator 1 was using different work practices such as opening windows or doors. Due to the nature of the mining operation and the lack of input from the machine operator we were unable to determine definitively if the window or door was open and if it was open, the actual number and extent of door and window openings during the data collection period. However, if the low efficiencies were due to the opening and closing of windows as suggested by some evidence, work practices and cab maintenance (e.g. properly working air-conditioning) might help minimize the operator's need to open windows and doors.

This cab system should reduce DPM by over 90 percent when it is operating correctly and the cab is kept sealed. In this case, the older loader probably did not have leaks. A 90 percent efficiency would result in the operator being exposed to concentrations below the final limit when the concentration outside the cab was under 1600 µg/m^3 TC, and that was every time in this mine. It is important to note that the concentration inside the cab did not exceed the permissible exposure limit (PEL) in this mine since the PEL at the time that these measurements were taken was 350 µg/m^3 TC.

The reduction efficiency in the haul truck was above 90 percent for all days sampled (see Figure 2). As shown in Figure 4, the real time data showed small peaks for a short period each day, which could have been during a lunch break. This would indicate minimal opening of the window and/or door. The same operator ran the vehicle for all three days.

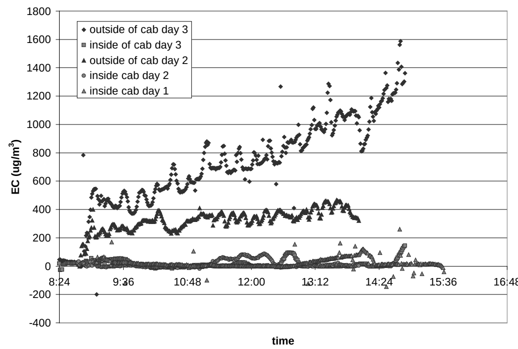

Figure 4: EC concentration vs. time of a haul truck in a limestone mine inside and outside of the enclosed cab for the days sampled. The DPM concentration inside the cab was well below the final limit. The results for outside of the cab for day 1 were lost.

Conclusion

In order to use an enclosed cab for reducing DPM exposures, one should use a filter designed for collecting submicron particles. HEPA filters work well for capturing DPM but may not be necessary. A MERV 16 filter has been shown to reduce DPM by over 95 percent and may be less expensive and restrictive to cab airflow than some HEPA filters. Enclosed cab systems can reduce DPM concentrations by over 90 percent when properly sealed using the correct filter. If a cab system is not performing to expectations, it can be from leakage, using an inappropriate filter, not being properly sealed, or from opening windows and doors.

Disclaimer

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