Role of environmental enclosures in reducing exposure of underground miners to diesel aerosols

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Exposures of underground miners to diesel aerosols and gases can be effectively reduced using combination of several strategies.

- **Controlling pollutants after they become airborne by:**
  - diluting by ventilation;
  - enclosing operators in environmental cabins;
  - using personal protective equipment.
- **Controlling diesel emissions at their source:**
  - reducing engine-out emissions;
  - implementing exhaust aftertreatment technologies;
  - alternative fuels;
  - advanced maintenance practices;
  - treating crankcase emissions.
- **Implementing administrative controls such as:**
  - substitution;
  - better utilization and management of available resources;
    - "no idling" policy…

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Environmental enclosures are traditionally used to provide a safe environment and reduce exposure of underground miners to elements, noise, and dust.

- Under certain conditions and right circumstances enclosing operators in the environmental cabins with pressurization and filtration systems should also help underground mining industry to reduce exposure of workers to diesel particulate matter (DPM).

- Environmental cabs might be viable DPM control strategy in cases where the majority of the duties can be executed by workers that do not have to leave environmental cabs on frequent basis.

- Environmental enclosures can be used on:
  - mobile equipment;
  - stationary equipment (control rooms and booths).

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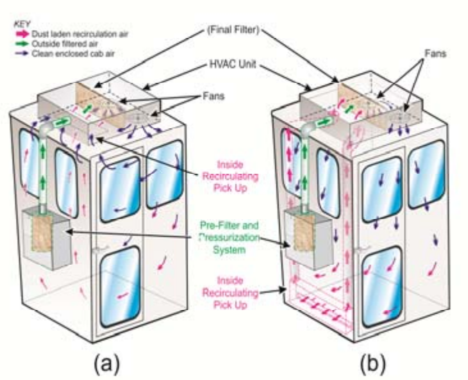
Design of Environmental Enclosures for Mobile Equipment

- Two typical designs of pressurization, filtration, and air-conditioning systems on the environmental cab used to protect miners from dust and diesel aerosols are:
  - intake and return at the roof flow design, and
  - unidirectional flow design.



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Design of Environmental Cabs: Air Flow

- The heating, ventilation, and air-conditioning (HVAC) system on environmental cab has to provide sufficient airflow to keep concentrations of gases and heat at acceptable levels.
- Occupant(s) of environmental cabs are the source of CO_2.
- Depending on level of physical activity, humans exhale between 220 and 1650 ml/min of air with CO_2 concentrations between 38,000 to 56,000 ppm.
- CO_2 levels in passenger car cabin with 3 passengers and air-recirculation on rise to 4,500 ppm in 10 minutes (Zhu et al. 2007).

Reference:

- Zhu YF, Eiguren-Fernandez A et al. (2007). In-cabin commuter exposure to ultrafine particulates on Los Angeles freeways. Env Sci Technol 41 (7) 2138-2145.

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Design of Filtration Systems: Air Flow

- The change of concentration of the CO_2 in the cab (C_C, $\frac{mg}{m^3}$) without ventilation and leaks can be estimated using following equation (Jung 2013):

$$C_C(t) = \frac{n * C_{ex} * Q_{ex}}{V_C} * t + C_{C_0}$$

  where n is number of occupants, C_{ex} is concentration of CO_2 in exhaled air [$\frac{mg}{m^3}$], Q_{ex} is flow rate of exhaled air [$\frac{m^3}{s}$], V_C is volume of cabin [m^3], and C_{C_0} is in-cabin CO_2 concentration at t=0 [$\frac{mg}{m^3}$].

- In the case of leak or/and existence of ventilation (Q_l, $\frac{m^3}{s}$) the C_C can be estimated using following equation (Jung 2013):

$$C_C(t) = \left(C_{C_0} - \left(C_0 + nC_{ex}\frac{Q_{ex}}{Q_l}\right)\right) * \exp\left(-\frac{Q_l}{V_c}t\right) + \left(C_0 + nC_{ex} * \frac{Q_{ex}}{Q_l}\right)$$

  where C_0 is concentration of CO_2 in ambient air [$\frac{mg}{m^3}$].

Reference:

- Jung H (2013). Modeling CO_2 concentrations in vehicle cabin. SAE Technical Paper 2013-0101497.

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Design of Filtration Systems: Air Flow

- It is generally accepted that in order to keep concentrations of CO_2 and other pollutants in the enclosure on the reasonable levels, the intake air flow in the system on mobile equipment environmental cabs should be maintained at least at 0.42 m^3/min (15 ft^3/min) per enclosed person.
  - The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard 62 limits CO_2 concentrations in the ventilated area to 700 ppm over ambient concentrations.

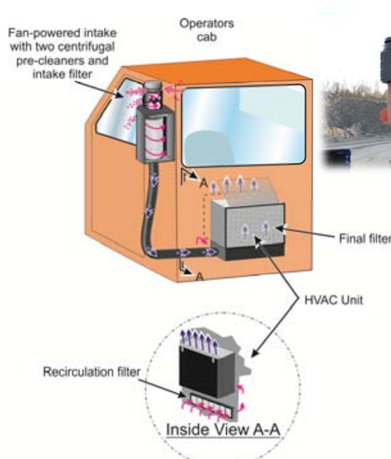
- Total cab air flow for mining enclosures should be between 1.13 and 3.96 m^3/min (40 and 140 ft^3/min) to assure minimal cab pressurization and air exchange (Cecala et al. 2014).

Reference:

- Cecala AB, Organiscak JA, Noll, JD, Rider JP [2014]. Key components for an effective filtration and pressurization system for mobile mining equipment. Mining Engineering, 66(1), 44-50.

Design of Environmental Enclosures: Filtration Systems

- The contemporary HVAC systems on environmental enclosures use three types of filter systems (Cecala et al 2014, Organiscak et al. 2013):
  - pre-filtration system,
  - main or final filtration system, and
  - recirculation filtration system.

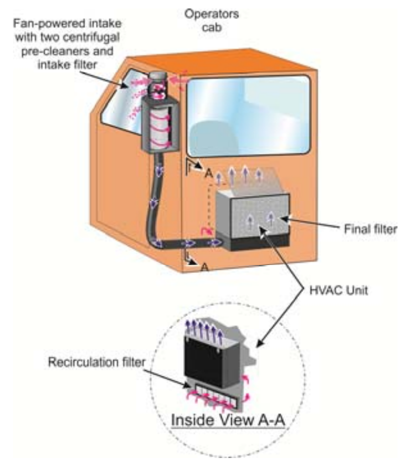


Reference:

- Cecala AB, Organiscak JA, Noll, JD, Rider JP [2014]. Key components for an effective filtration and pressurization system for mobile mining equipment. Mining Engineering, 66(1), 44-50.
- Organiscak JA, Cecela AB, Noll JD (2013). Field assessment of enclosed cab filtration system performance using particle counting measurements. J Occ. Environ. Hyg 10 (9) 468-477.

Design of Filtration Systems: Filtration Systems

- In general, the flow is typically provided by main fan located on the suction side of main filter.
- The additional fan can be used to pressurize the intake side of the system:
  - Operator should not have the ability to turn off the filtration/pressurization system.
  - Operator should only be able to control fan speed and temperature.
- The majority of the flow through main filter and HVAC system is made of recirculation filtration system flow.
  - The amount of recirculation is limited by CO_2 buildup (Jung 2013, Zhu et al. 2007).



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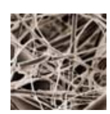
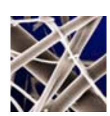
Efficiency of Filtration Elements used in the Environmental Enclosure Systems

- Single-use, disposable resin-bonded glass or plastic fiber filters are most widely used in the intake and main filtration systems in the cabs and other heating, ventilating, and air-conditioning (HVAC) systems.
- Mechanical filters:
  - fine fiber media;
  - particles removed mechanically;
  - the efficiency and restriction increase with buildup of the cake.



- Electrostatic filters:
  - coarse/electret fibers, relatively large in size;
  - easier and less expensive to produce;
  - fibers are charged during the manufacturing process;
  - combustion particles or oil mist, may neutralize charges and filter performance might suffer over time.



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The ASHRAE (Standard 52.2) requires reporting effectiveness of the filters in removing dust (0.3 – 10.0 µm) in terms of Minimum Efficiency Reporting Values (MERVs).

Group	MERV Rating	Average particle-size efficiency (PSE) 0.3–1.0 µm	Average particle-size efficiency (PSE) 1.0–3.0 µm	Average particle-size efficiency (PSE) 3.0–10.0 µm
1	1	N/A	N/A	< 20%
	2	N/A	N/A	< 20%
	3	N/A	N/A	< 20%
	4	N/A	N/A	< 20%
2	5	N/A	N/A	20%–34.9%
	6	N/A	N/A	35%–49.9%
	7	N/A	N/A	50%–69.9%
	8	N/A	N/A	70%–84.9%
3	9	N/A	< 50 %	≥ 85%
	10	N/A	50%–64.9%	≥ 85%
	11	N/A	65%–79.9%	≥ 85%
	12	N/A	80%–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 MERV efficiencies are established by particle counting.
- In general, filters with higher MERV ratings are more efficient in capturing particles.
- The filters with MERV ratings of 12 and above are suitable for filtering respirable dust.
- Filters with MERV ratings of 14 and above filter more than 75% of aerosols with average diameter between 0.3 and 1.0 µm.

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What would the efficiency be of the filters in removing diesel aerosols?

- The MERVs for sub-0.3 µm aerosols are not listed in ASHRAE reports.
- The literature reports that efficiency of MERV 16 filters in removal of sub-0.03 µm, sub-0.10 µm, and sub-0.30 µm to be 96, 95, and 99 %.
- The filters with better- than-MERV 16 rating are high-efficiency particulate air (HEPA) filters.
- Those remove at least 99% of airborne particulates of all sizes.
- The most penetrating particle sizes (MPPSs) of electret and fiberglass filter media were found to be between 50 and 160 nm (Li et al. 2012).

Reference:

- Li L, Zuo Z, Japuntich DA, Pui DY (2012). Evaluation of filter media for particle number, surface area and mass penetrations. The Annals Occup Hygiene, 56(5), 581-94

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The effectiveness of several types of filtration systems used in underground mining applications to remove diesel aerosols (EC and TC mass) was evaluated at the NIOSH OMSHR laboratory and field.

- Two types of MERV 16 and two types of HEPA filters demonstrated relatively high efficiencies in removing diesel aerosols.
- MERV16 filters might be viable alternative to the substantially more expensive and flow restrictive HEPA filters (Noll et al. 2014).

Filter	Concentrations before filters		Concentrations after filters		Efficiency in removal of EC	Efficiency in removal of TC
	EC	TC	EC	TC		
	μg/m³	μg/m³	μg/m³	μg/m³	%	%
No filter	513	602	501	568	2	5
MERV 8	528	604	310	371	41	39
MERV 16	574	668	20	42	96	94
MERV 16 long	690	803	11	19	98	98
HEPA	625	706	< 3	< 6	> 99	> 99
HEPA – low resistance	660	742	< 3	< 6	> 99	> 99

Reference:

- Noll, J.D.; Cecala, A.B.; Organiscak, J.A.; Rider, J.P. [2014]. Effects of MERV 16 filters and routine work practices on enclosed cabs for reducing respirable dust and DPM exposures in an underground limestone mine. Mining Eng 66(2), pp. 45-52.

Life Expectancy of the Filter Elements

- In general, the life expectancy of the filter depends on the size of the element, concentration and type of the filtered particulates.
  - Organiscak et al. (2013) reported that MERV 16 final filters used on the face drill cab lasted over 1000 hours.
  - Recirculation filters are typically much smaller and last much shorter.
- When to change filter? Filter elements can be changed in:
  - predetermined time intervals;
  - based on measurements of filter loading:
    - cab pressure monitoring gives indirect measure of filter loading
- Due to concerns over integrity, the filter elements should be changed in any case after 1000 hours in use and/or at least once a year (Cecala et al. 2014).

Reference:

- Cecala AB, Organiscak JA, Noll, JD, Rider JP [2014]. Key components for an effective filtration and pressurization system for mobile mining equipment. Mining Engineering, 66(1), 44-50.
- Organiscak JA, Cecela AB, Noll JD (2013). Field assessment of enclosed cab filtration system performance using particle counting measurements. J Occ. Environ. Hyg 10 (9) 468-477.

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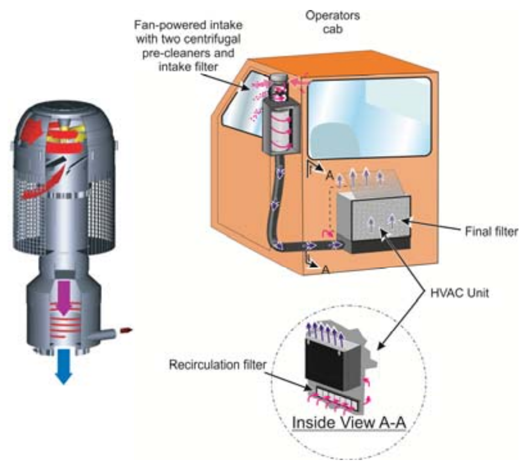
Life Expectancy of the Filter Elements

- Life expectancy of the filters can be extended using (Cecala et al. 2014):
  - Self cleaning
    - Back flushing
    - Reverse pulse
  - Centrifugal pre-separator



Reference:

- Cecala AB, Organiscak JA, Noll, JD, Rider JP [2014]. Key components for an effective filtration and pressurization system for mobile mining equipment. Mining Engineering, 66(1), 44-50.

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High levels of protection can only be achieved with tightly sealed pressurized environmental cabs and HVAC system.

- The integrity of the walls and the seals on the doors, windows, HVAC system and various other openings are critical to maintaining the air tightness of environmental cabs.
- The positive pressure in the cabs is maintained by pressurization, which is extremely important because the penetration of pollutants into the cab is primarily prevented by maintaining positive pressure inside of the cab.
- Positive pressure should be maintained inside of environmental cabs to assure the adequate protection of workers inside the cab.
- Higher inside pressure forces any potential leakage to occur from inside of the cab to outside.
- For the smaller enclosures, the positive pressure should be in the range between 24.9 and 50 Pa (0.1 – 0.2 in H_2O).

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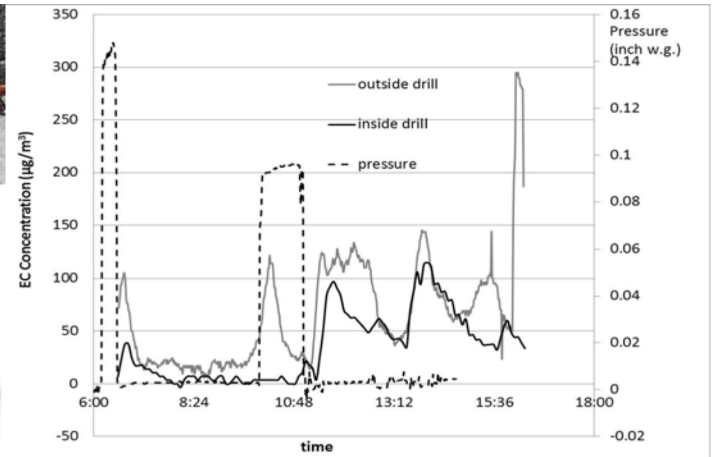
The field evaluations at an underground stone mine showed importance of maintaining the air tightness of environmental cabs.

- The EC concentrations were measured continuously outside and inside the enclosure on the drill using FLIR Airtech DPM/EC monitor.



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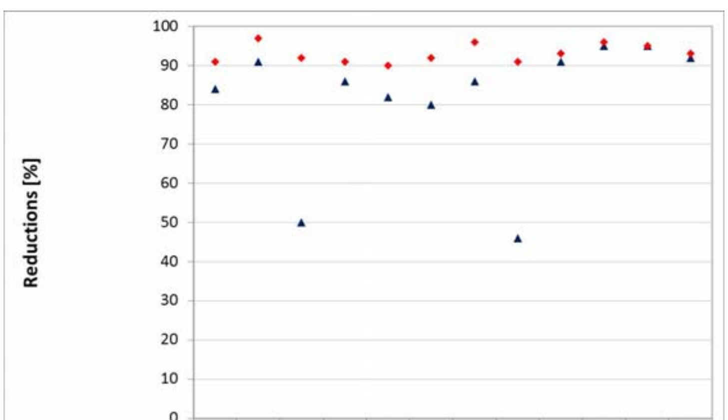
The long term measurements showed that the efficiency in reducing exposures of the miners to EC was substantially higher during the periods when doors and windows were completely closed.



Cases	1	2	3	4	5	6	7	8	9	10	11	12
▲ Average	84	91	50	86	82	80	86	46	91	95	95	92
◆ Average (door closed)	91	97	92	91	90	92	96	91	93	96	95	93

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Integrity of Environmental Enclosures

- The integrity of the cab and filtration system is typically verified by pressurizing the cab and measuring pressure losses due to leaks.
- The alternative method for assessing the integrity of the filtration and air-conditioning systems in cabs is based on measurements of the penetration of selected gases from the environment in those systems.
- Method based on CO_2 measurements (Organiscak and Schmitz 2012) require filter which scrubs CO_2 from intake air.

Reference:

- Organiscak JA, Schmitz M (2012). A new leak test method for enclosed cab filtration systems. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2012-145, RI 9690, May; :1-41

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Environmental Enclosure Maintenance

- Cleanliness of the cab contribute to the quality of the cab air and extend life of recirculation filter or/and main filter.
- Visual pressure indicator should be used to inform the equipment operator of the enclosure pressure and when a filter is damaged or clogged.
  - Decrease in cabin pressure indicates:
    - increase in filter loading,
    - development of leak
  - Increase in cabin pressure indicates:
    - compromised integrity of the element.

Strategy of reducing exposure of underground miners to DPM using environmental cabs has certain limitations.

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- Cabs provide protection only to workers who are spending the majority of their work time enclosed in the cabs.
- Frequent opening of the doors and/or windows, or leaving the cab reduces the effectiveness of this strategy.
- Smoking in the cabs can result in elevated concentrations of ultrafine aerosols and CO.

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Typical filtration, heating, and air-conditioning units are not designed to reduce concentrations of other diesel pollutants such as CO, CO_2, NO, NO_2, and hydrocarbons.

- Therefore, environmental cabs can provide adequate protection to operators only if areas are ventilated with adequate quantities of fresh air to dilute concentrations of criteria gases at or below corresponding standards.
- Constant demand for power to systems on environmental enclosures might conflict with desire to minimize engine operation time (e.g. idle time).

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The Issues Affecting Wide Implementation of Environmental Cabs in Underground Mining

- Capital cost of acquiring cab;
- Operational costs;
- Safety issues, primarily reduced visibility;
- Space requirements for retrofit applications;
- Operational issues;
- Human factors.

Conversion →

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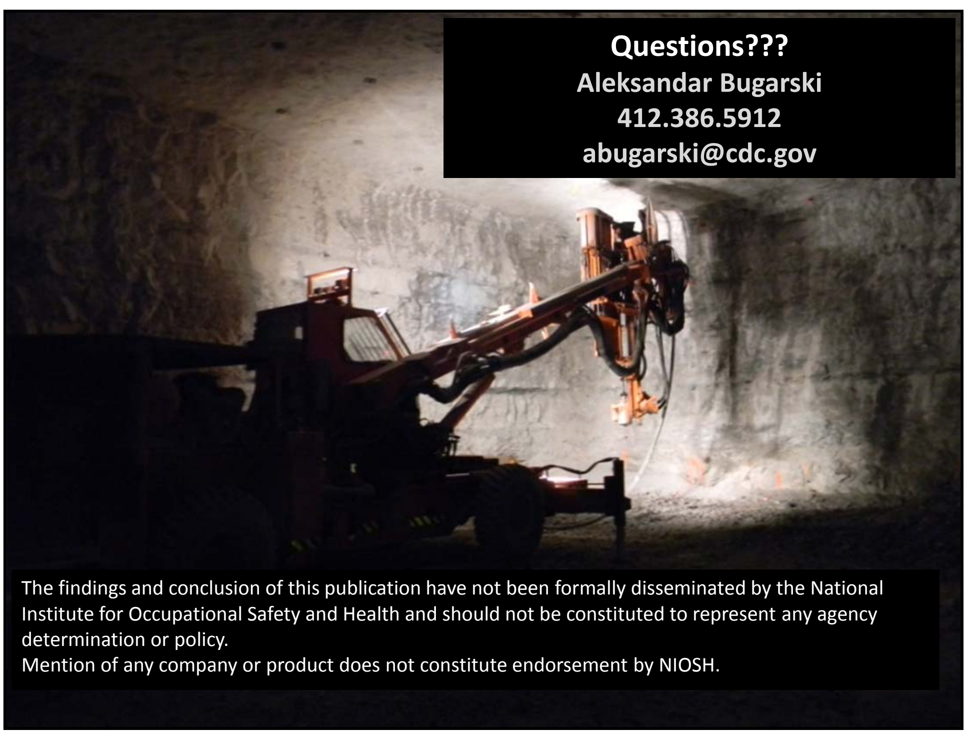

Questions???

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