Disposable filter elements used in underground mining applications

Presented by
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Occupational exposure to traditional diesel exhaust is linked to acute and chronic health problems.

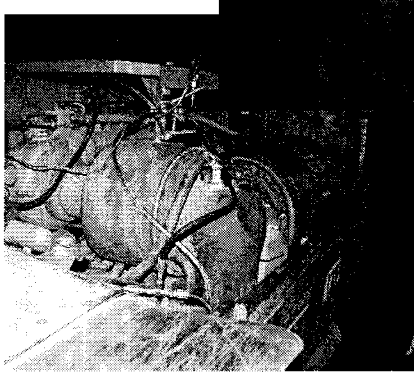
- In the States, exposure of underground miners to diesel particulate matter is limited by two rules promulgated in 2001:
  - 30 CFR Part 72 - Diesel Particulate Matter Exposure of Underground Coal Miners
  - 30 CFR Part 57 - Diesel Particulate Matter Exposure of Underground Metal and Nonmetal Miners
- In 2012, the IARC (2012) declared diesel engine exhaust as a carcinogen to humans (Group 1).
  - Lung cancer (sufficient evidence);
  - Bladder cancer (limited evidence).
- The IARC decision was partially based on the findings of NCI/NIOSH "The Diesel Exhaust in Miners Study" (Attfield et al. 2012, Silverman et al. 2012).

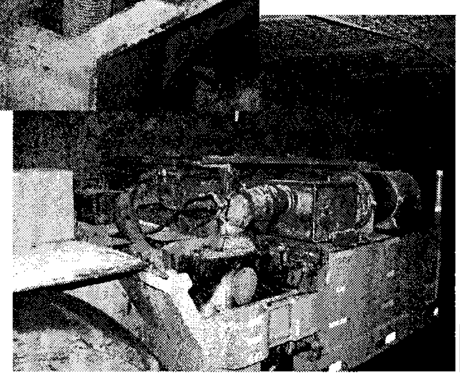
Reference:

- IARC (2012). IARC: Diesel engine exhaust carcinogenic. Press Release N° 213 . International Agency for Research on Cancer. World Health Organization.
- Attfield M, Schleiff P, Stewart P, et al. (2012). The Diesel Exhaust in Miners Study: A cohort mortality study with emphasis on lung cancer. J Natl Cancer Inst 104:869–883.
- Silverman DT, Samanic C, Lubin JH, et al. (2012). The Diesel Exhaust in Miners Study: A nested case-control study of lung cancer and diesel exhaust. J Natl Cancer Inst 104:855–868.

Filtration systems with disposable filter elements (DFEs) are primarily designed to control DPM emissions from heavy-duty diesel power packages intended for use in areas of underground coal and some gassy non-metal mines where permissible equipment is required.

- In the States, the U.S. Mine Safety and Health Administration (MSHA) approves permissible engines and packages:
  - Existing engines (30 CFR Part 7 Subpart F) e.g. 7E-A00*
  - Newly introduced (30 CFR Part 72.500) e.g. 07-EPA0*000*

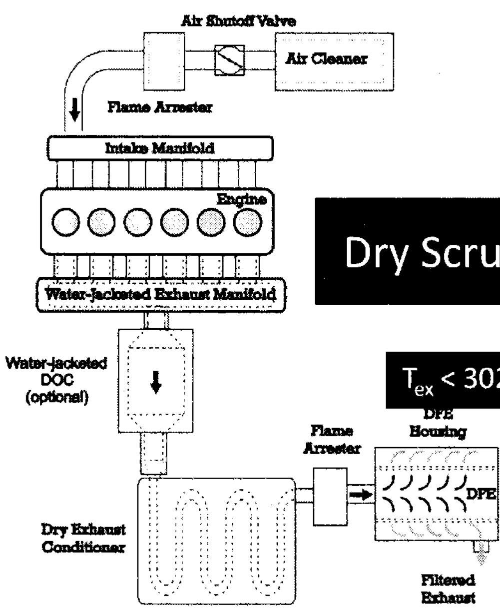




In the States, two types of those systems are currently used in over 300 underground coal mining permissible applications (MSHA 2016).

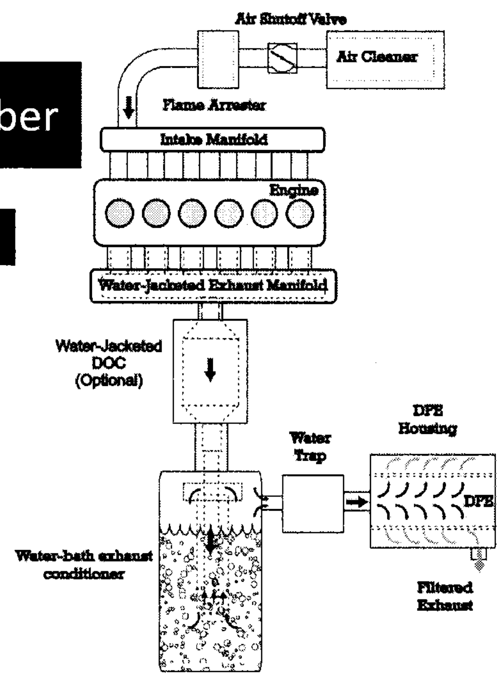
Dry Scrubber

$T_{ex} < 302$ °C



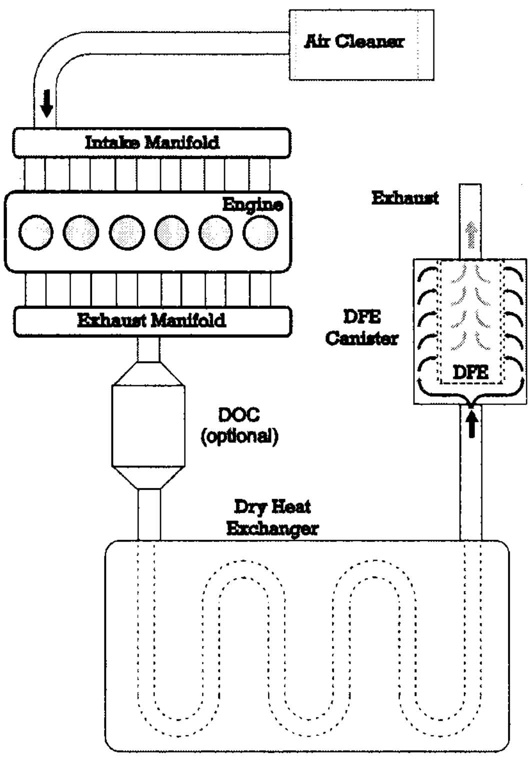
Wet Scrubber

$T_{ex} < 185$ °C



MSHA (2016). MSHA National Inventory. https://lakegovprod3.msha.gov/DieselInventory/ViewDieselInventoryExternal.aspx

Filtration systems with DFEs are also used in over 900 non-permissible coal mining applications (MSHA 2016).



- Simplified version of permissible systems.
- No surface and exhaust temperature requirements.
- However, dry heat exchangers are used to keep exhaust temperatures below 343 °C (650 °F).
- DFEs are used to control DPM emissions below the 2.5 g/hour- (heavy-duty non-permissible) and 5.0 g/hour- (light-duty non-permissible) standards.

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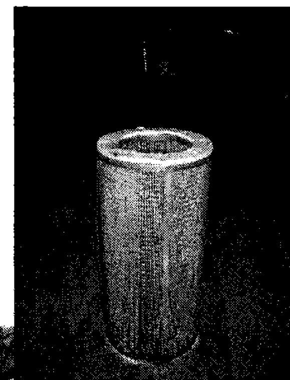
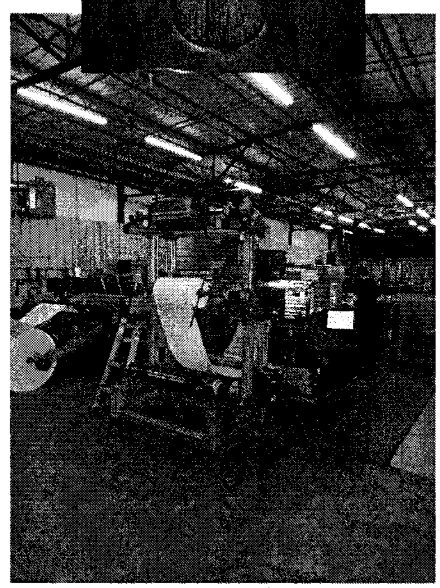
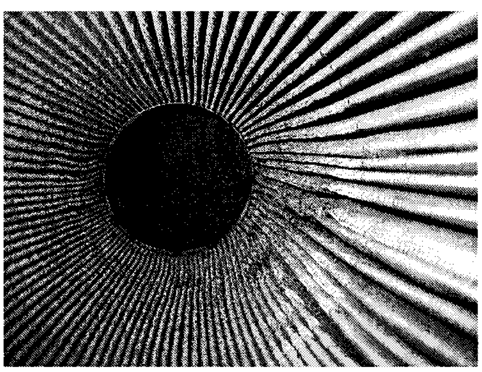
Disposable filter elements (DFEs) are used in those filtration systems to remove particulates from cooled exhaust.

- The elements are made of paper and synthetic materials (polyesters, polypropylene, fiberglass...).
- The pleated DFE cartridges consist of a thin felt or woven mat of fibers supported by mesh.
- Because the fiber media collects soot throughout their depth, the DFEs are classified as deep-bed filters.







MSHA approves DFEs for use in underground mining applications.

- DFEs for low temperature (185 or 302 °F) and high temperature (650 °F) are approved by MSHA following Part 7 testing procedures [MSHA 61 Fed. Reg. 55411 (1996)].

- The actual filtration efficiencies of those low temperature DFEs are not reported, but expressed in terms of the equivalency to the "gold" standard paper DFE [MSHA 2015].

- The efficiencies of two verified high temperature DFE are listed as 83 and 80 % (at 650 °F).

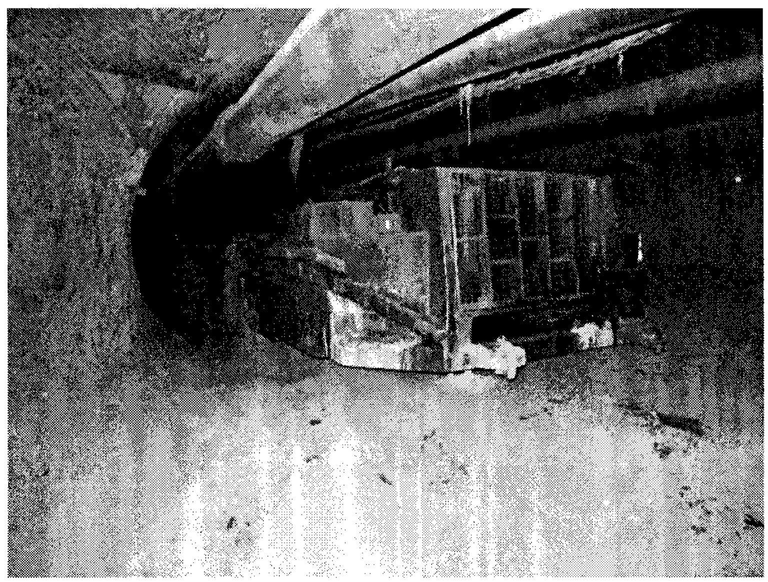
Reference:

- 61 Fed. Reg. 55525 (1996). Mine Safety and Health Administration: 30 CFR Part 36. Approval requirements for permissible mobile diesel-powered transportation equipment. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

- MSHA (2015). Diesel particulate matter (DPM) control technologies. U.S. Department of Labor, Mine Safety and Health Administration. [http://arlweb.msha.gov/01-995/Coal/DPM-FilterEfflist.pdf].

Filtration systems with DFEs are the only technology available to reduce DPM emissions from high emitting antiquated engines used in permissible applications (MSHA National Diesel Inventory).

- Relatively large fleet powered by older technology engines.
- Permissibility requirements contribute to complexity:
  - surface temperatures;
  - exhaust temperatures.
- Relatively small market for permissible engines.
- Current decline in coal production in the States and worldwide reduced further demand for those engines.

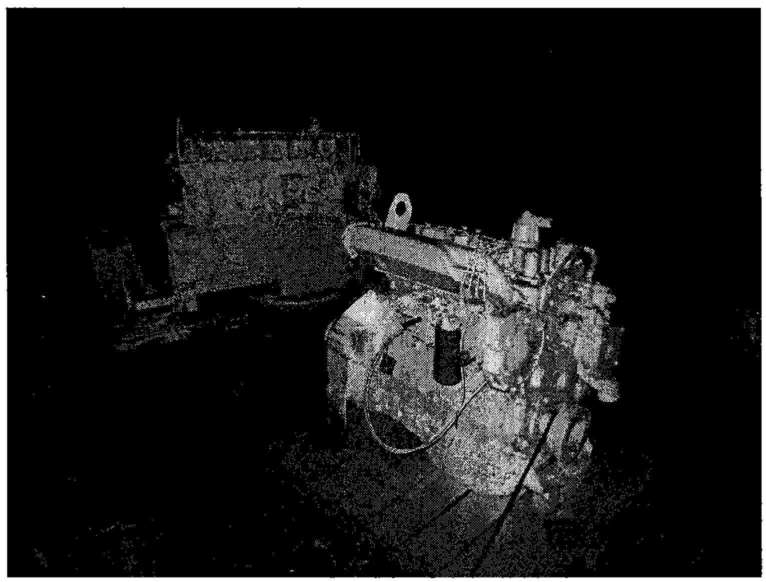


Reference:

- MSHA National Diesel Inventory: https://lakegovprod3.msha.gov/ReportView.aspx?ReportCategory=AllMineInventory

Technological advancements in engine and exhaust aftertreatment technologies, driven by technology forcing regulation, resulted in dramatic reductions in PM emissions from non-road engines.

- E.g. U.S. EPA standards [66 Fed Reg. 5001 (2001)] for class of engines with output between 130 and 560 kW (175 and 750 hp):
  - 1996 (Tier 1): PM = 0.54 g/kW-hr (0.40 g/hp-hr);
  - 2003 (Tier 2): PM = 0.20 g/kW-hr (0.15 g/hp-hr);
  - 2006 (Tier 3, never adopted): PM = 0.20 g/kW-hr (0.15 g/hp-hr);
  - 2011-2014 (Tier 4i and Tier 4f): = 0.02 g/kW-hr (0.01 g/hp-hr).



Reference:

- 66 Fed. Reg. 5001 [2001] Environmental Protection Agency: 40 CFR Parts 69, 80, and 86. Clean diesel trucks, buses, and fuel: heavy-duty engine and vehicle standards and highway diesel fuel sulfur control requirements; final rule. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

However, the majority of the engines in MSHA approved permissible diesel-powered packages do not even meet EPA Tier 2 PM standard (PM = 0.20 g/kW-hr / 0.15 g/hp-hr).

MSHA Approval Number	Make and Model, kW (hp) @ rpm	DPM [g/kW-hr / g/hp-hr]	DPM [g/hr]
07-EPA040001	Cummins C8.3, 138 (185) @ 2200	0.24 / 0.18	23.08
07-EPA060001	Caterpillar 3126B HEUI, 168 (225) @ 2500	0.26 / 0.19	34.10
07-EPA080001	Deutz BF4M1013FC, 112 (150) @ 2200	0.10 / 0.07	7.58
07-EPA110001	Cummins 6CTAA 8.3, 172 (230) @ 2200	0.18 / 0.13	15.26
07-EPA120001	Cummins 6CTAA 8.3, 138 (185) @ 2200	0.20 / 0.15	12.35
07-EPA140001	Cummins 6CTAA 8.3, 123 (165) @ 2200	0.34 / 0.25	21.72
7E-A001	Deutz MWM 916, 70 (94) @ 2300	0.68 / 0.50	25.49
7E-A002	Caterpillar 3306 PCNA, 112 (150) @ 2200	0.72 / 0.53	45.88
7E-A003	Caterpillar 3304 PCNA, 75 (100) @ 2200	0.69 / 0.51	29.74
7E-A005	Caterpillar 3306 PCTA, 142 (190) @ 2200	0.58 / 0.43	52.68

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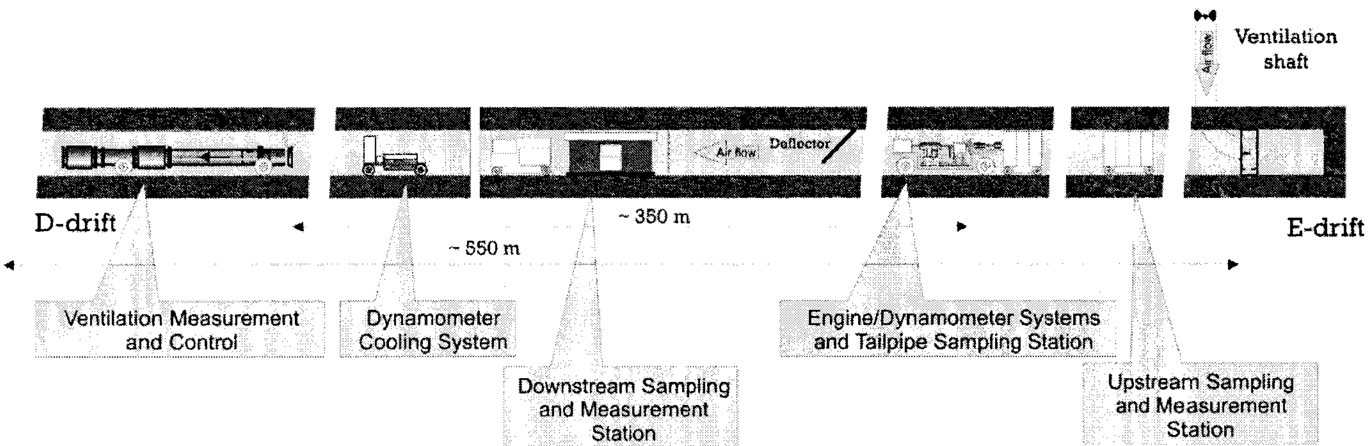
DFE technology currently used in underground mines had space for improvement.

- Results of the experimental mine evaluation of two popular types of high-temperature DFEs were used to demonstrate some of those issues.

- The experimental work was done in the D-drift of the NIOSH Lake Lynn Experimental Mine.



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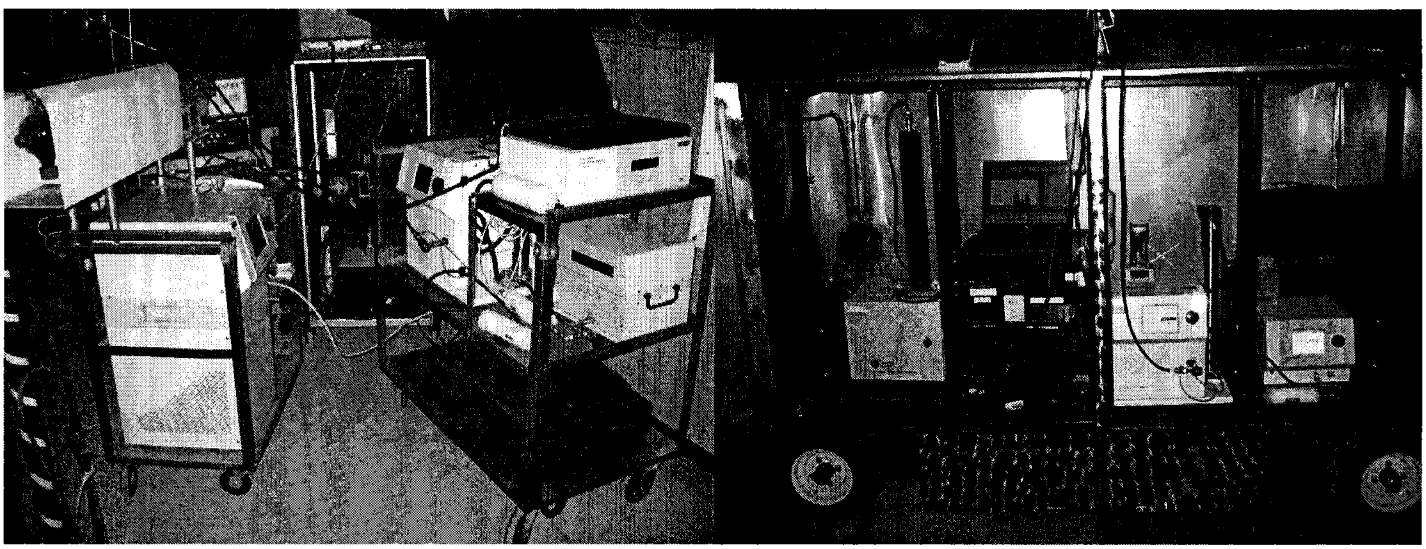
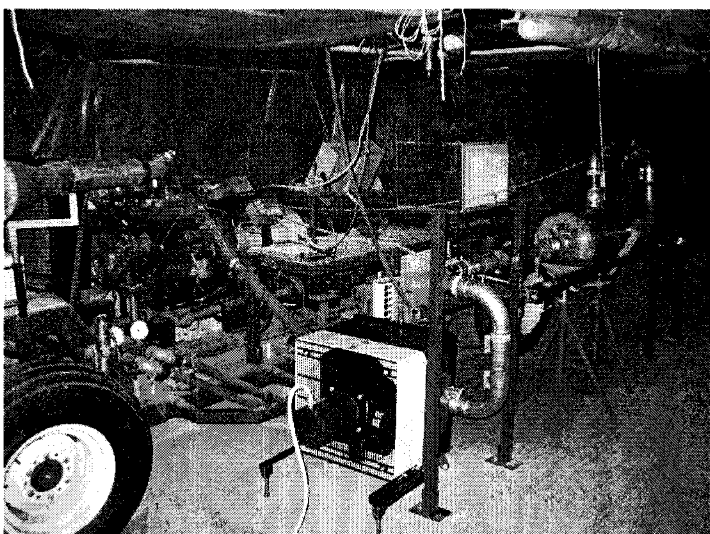
The effects of DFE on size distributions and concentrations were discussed using results of measurements performed at upstream and downstream stations

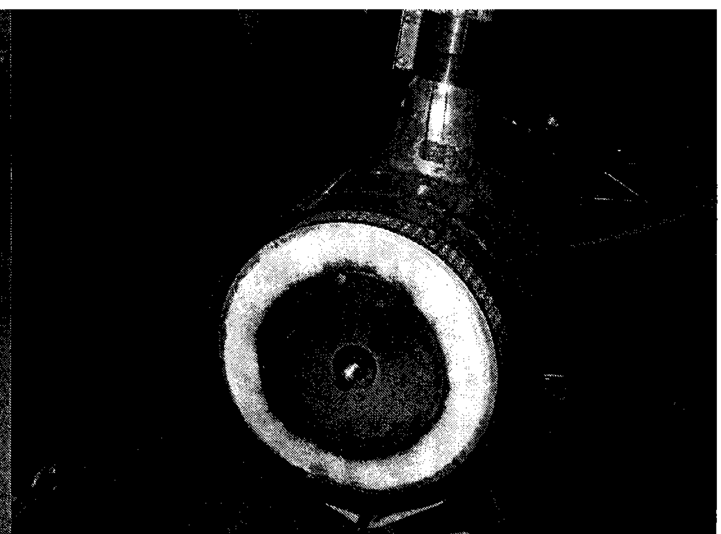
- TSI Scanning Mobility Particle Sizes (Model 3936),
- Dekati Electrical Low Pressure Impactor (ELPI DAS 3100), and
- Thermo Tapered Element Oscillating Microbalance (TEOM 1400a).



Experimental Setup

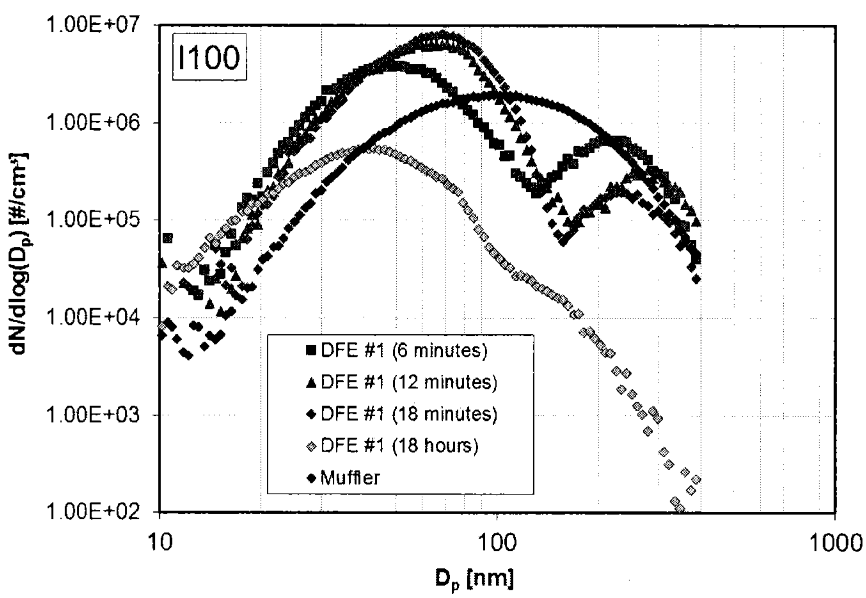
- The DFEs were tested using Isuzu C240 engine (rated at 41.8 kW/56.0 hp) @ 3000 rpm) coupled to 150 kW eddy current dynamometer.
- Engine was operated over four steady stare operating conditions: R50, R100, I50, and I100.





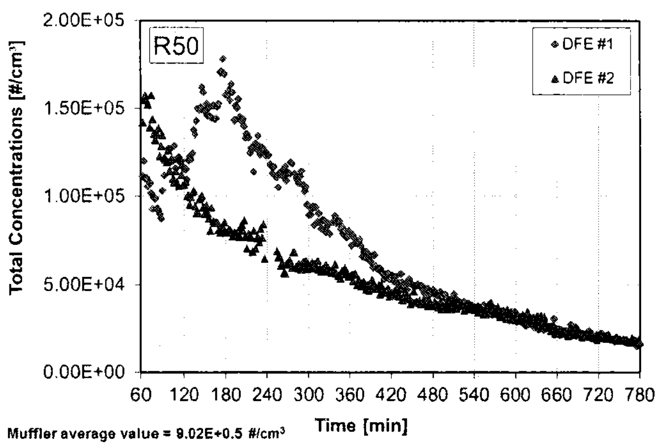
Observation 1: During an off-gassing process, the filter media used in DFEs give off aerosols.

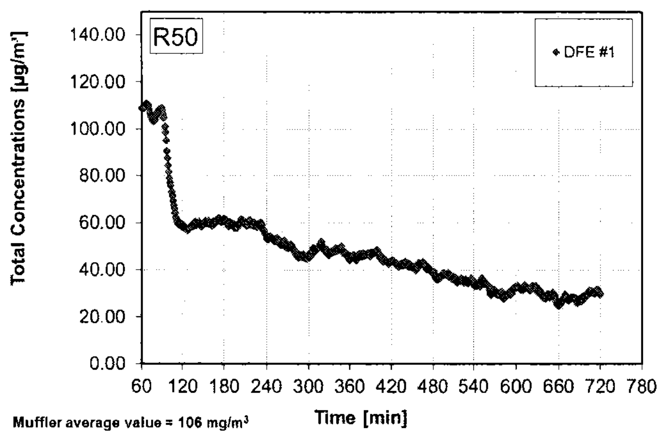
- Breakdown of the paper and synthetic filter material cause the production of secondary emissions of various compounds and aerosols.



Observation 2: It might take couple hours before some of currently used DFEs reach their terminal efficiency.

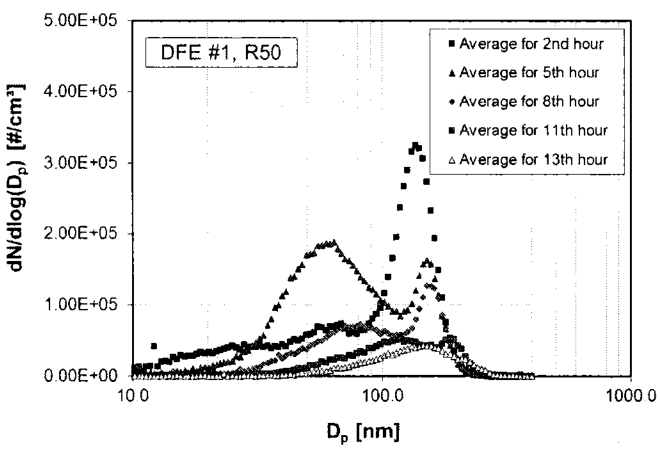
- The number (SMPS) and mass (TEOM) concentrations of aerosols in mine air decreased with test time and accumulation of DPM in the media.

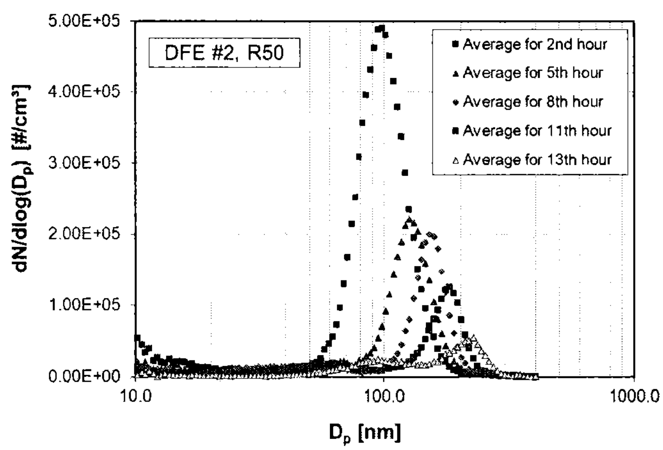




Observation 3: Size distributions and number concentrations of aerosols emitted out of DFEs gradually changed during life of filter.

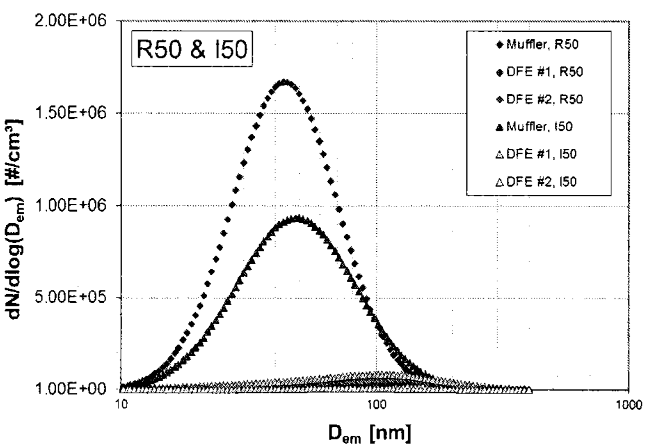
- With accumulation of DPM in the filters, the concentrations of aerosols in mine air decreased and geometric mean of aerosols increased.

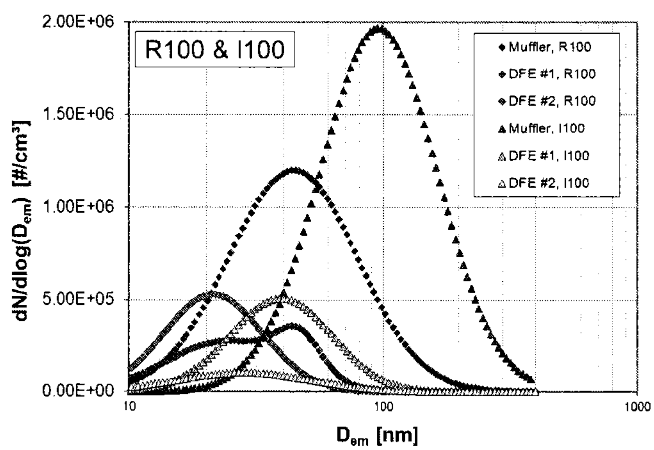




Observation 4: Size distributions and number concentrations of aerosols emitted out of DFEs depend on engine operating conditions /exhaust temperature

- For R50 and I50, aerosols emitted by DFEs were distributed exclusively in accumulation mode.
- For R100 and I100, relatively large concentrations of aerosols were found in nucleation mode.

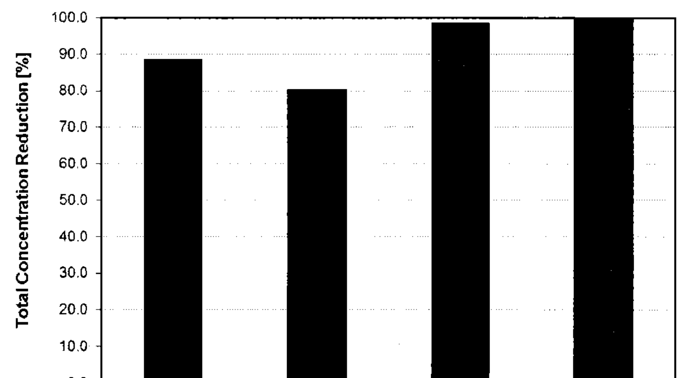




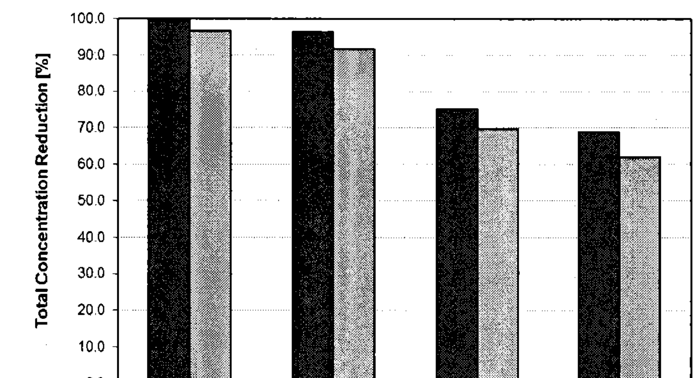
Mode	Exhaust Temperature at Inlet to DFEs °C	Temperature at Outlet from DFEs °C
R50	203	154
R100	328	238
I50	157	120
I100	313	230

Observation 5: After 12 hours in operations, tested filters were found to be relatively effective in reducing particulate mass and number.

- For R100, I50, and I100, tested DFEs reduced aerosol mass concentrations modes by more than 95% (TEOM).
- For R50, the reductions in aerosol mass concentrations were above 80% (TEOM).
- For R50 and I50, tested DFEs reduced aerosol number concentrations modes by more than 93% (SMPS) and 84% (ELPI).
- For R100, the reductions in aerosol number concentrations were 69% (SMPS) and 62% (ELPI).



	R50 DFE #1	R50 DFE #2	R100 DFE #1	R100 DFE #2
■ TEOM (mass)	88.4	80.4	98.4	100.0



	R50 DFE #1	R50 DFE #2	R100 DFE #1	R100 DFE #2
■ SMPS (number)	99.6	96.3	75.0	68.8
□ ELPI (number)	96.6	91.7	69.8	61.9

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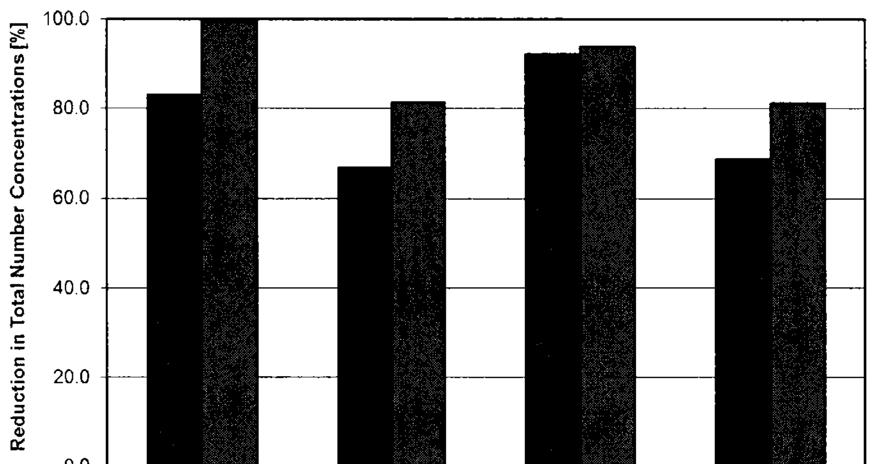
Observation 6: The calculated efficiencies differ substantially as a function of use of different subsets of data collected during the same test.

- Data collected during 2-hour test were divided in 20-minute subsets and averages were compared.
- The data demonstrate importance of establishing test and data processing protocols.

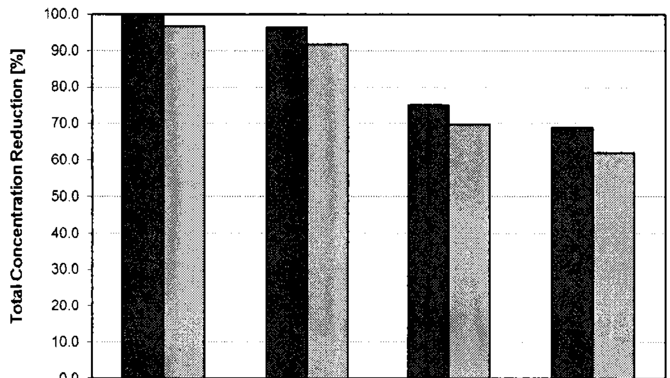


	R50	R100	I50	I100
■ Low	83.0	66.8	92.1	68.7
■ High	99.6	81.4	93.8	81.2

Engine Operating Mode

Observation 7: Efficiency of DFEs depended on engine operating conditions.

- Due to effects of exhaust temperatures on formation and transformation of aerosols, the efficiencies in removal of aerosols were substantially different between test modes.



	R50 DFE #1	R50 DFE #2	R100 DFE #1	R100 DFE #2
SMPS (number)	99.6	96.3	75.0	68.8
ELPI (number)	96.6	91.7	69.8	61.9

Engine Operating Mode

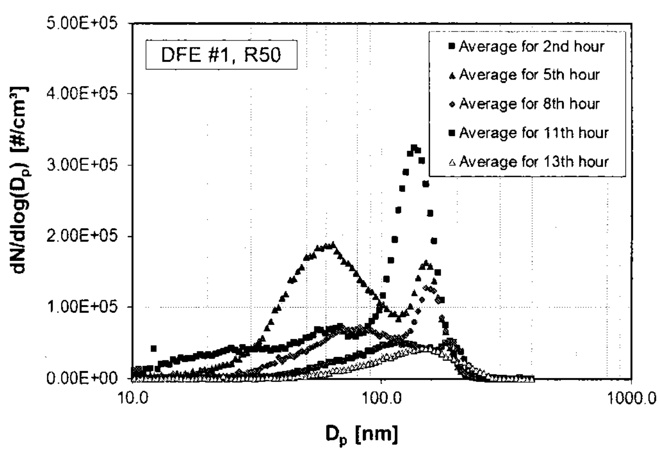
Observation 8: Some of DFEs are replaced at their prime.

- The life of DFE depends primarily on exhaust flow rate and emissions.
- DFEs are replaced:
  - at the point when engine backpressure exceeds engine manufacturer recommended maximum engine backpressure;
  - every shift.

MSHA Approval Number	Make and Model, kW (hp) @ rpm	Max. Engine Backpressure [in H_2O/mbar]
07-EPA040001	Cummins C8.3, 138 (185) @ 2200	41/102
07-EPA060001	Caterpillar 3126B HEUI, 168 (225) @ 2500	80/199
07-EPA080001	Deutz BF4M1013FC, 112 (150) @ 2200	60/149
07-EPA110001	Cummins 6CTAA 8.3, 172 (230) @ 2200	60/149
07-EPA120001	Cummins 6CTAA 8.3, 138 (185) @ 2200	60/149
07-EPA140001	Cummins 6CTAA 8.3, 123 (165) @ 2200	60/149
7E-A001	Deutz MWM 916, 70 (94) @ 2300	40/100
7E-A002	Caterpillar 3306 PCNA, 112 (150) @ 2200	34/85
7E-A003	Caterpillar 3304 PCNA, 75 (100) @ 2200	34/85
7E-A005	Caterpillar 3306 PCTA, 142 (190) @ 2200	27/67

Observation 9: Alternative/additional metric might be needed to adequately assess the efficiency of DFE elements.

- Method currently used for assessing DFEs is solely based on particulate mass measurements.
- The data indicate that alternative/additional metric, most probably number of particles, would greatly improve quality of the evaluation process.

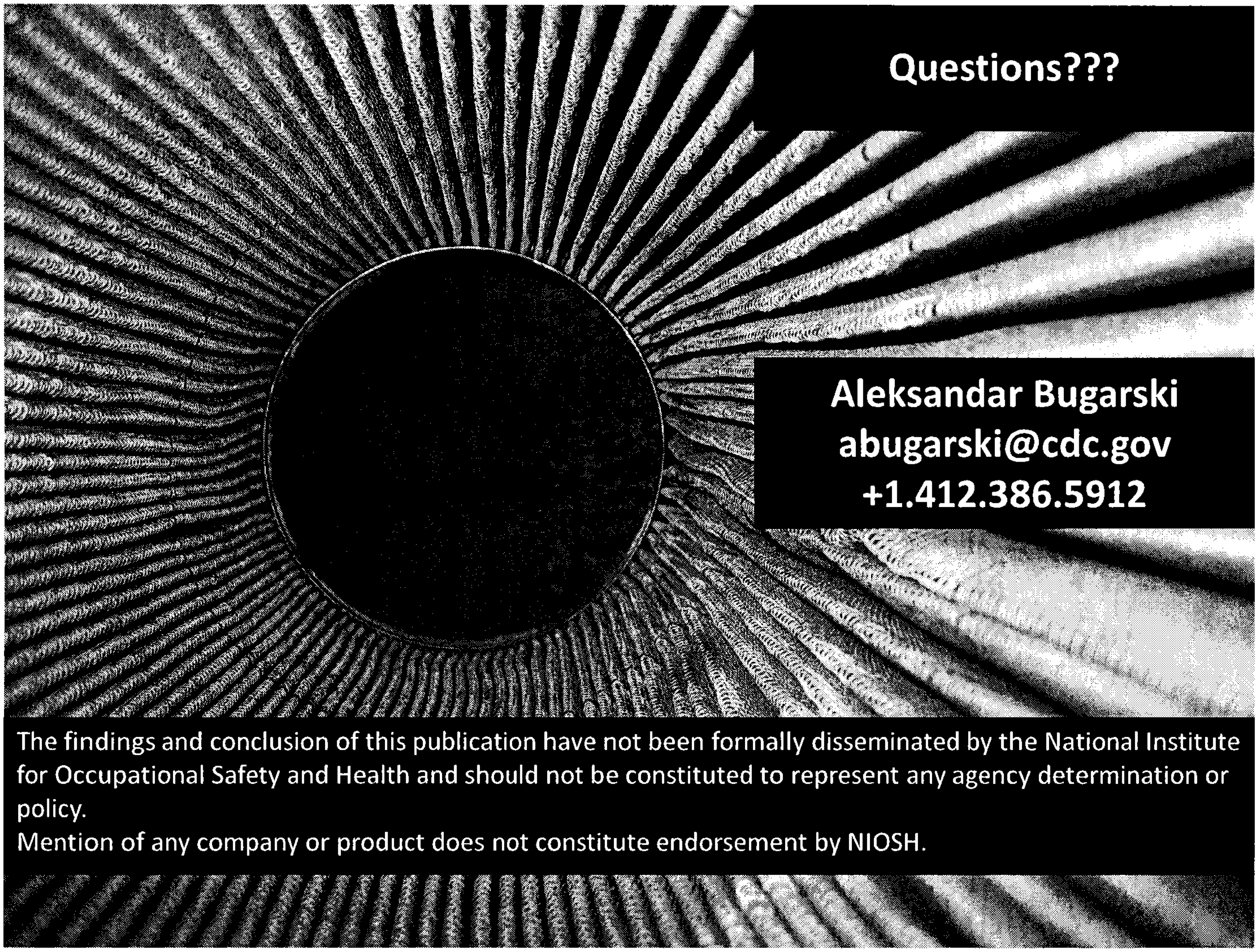


In Summary

- Engines in heavy-duty permissible and non-permissible underground mining power packages are identified as a potentially major contributors to exposure of underground miners to diesel aerosols.

- Filtration systems with disposable filter elements have a proven record as a primary mean of controlling particulate emissions from permissible and non-permissible engines.

- However, improvements in engines, DFE technology, and testing protocols are needed to further reduce health impact associated with operation of diesel engines in underground mines.



Questions???

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