Controlling Exposure of Underground Coal Miners to Diesel Aerosols

by
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Introduction

- Diesel engines in permissible heavy-duty (HD) , non-permissible HD, and/or non-permissible light-duty (LD), underground mining equipment are the major contributors to ambient concentrations of criteria gases and submicron aerosols in the U.S. underground coal mines.

- Current MSHA regulations indirectly limit personal exposures of underground coal miners in the U.S. to DPM by limiting particulate matter emissions:
  - **Permissible diesel-powered equipment must emit no more than 2.5 grams per hour of DPM [30 CFR 72.500];**
  - **Non-permissible diesel-powered HD equipment must emit no more than 2.5 grams per hour of DPM [30 CFR 72.501];**
  - **Non-permissible diesel-powered LD equipment must emit no more than 5.0 grams per hour of DPM [30 CFR 72.502].**

References:
- 30 CFR 72.500. Emission Limits For Permissible Diesel-Powered Equipment. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- 30 CFR 72.501. Emission limits for nonpermissible heavy-duty diesel-powered equipment, generators and compressors. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- 30 CFR 72.502. Requirements for nonpermissible light-duty diesel-powered equipment other than generators and compressors. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

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Introduction

- Certain equipment is exempt from aforementioned emission standards:
  - Generators and compressors that discharges its exhaust directly into intake air that is coursed directly to a return air course, or discharges its exhaust directly into a return air course [30 CFR 72.501];
  - Ambulances and fire fighting vehicles [30 CFR 72.502].
- The regulations are prescriptive and rely on:
  - Supplying at least minimum required quantities of ventilation air [30 CFR 75.325];
  - Controlling DPM emissions at their source:
    - use of certified engines;
    - clean fuels;
    - use of exhaust aftertreatment systems;
    - maintaining in-use emissions at certification levels.
- The regulations do not require direct measurements of personal exposure of coal miners to DPM.
- The exposure data is not available to verify the impact of prescribed control strategies.

References:
- 30 CFR 72.501. Emission limits for nonpermissible heavy-duty diesel-powered equipment, generators and compressors. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- 30 CFR 72.502. Requirements for nonpermissible light-duty diesel-powered equipment other than generators and compressors. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- 30 CFR 75.325 - Air quantity. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

The current regulations require from underground operators to report an inventory of diesel equipment used in their mines [30 CFR 72.520]

- The data is self-reported by mines and compiled by MSHA in the national coal inventory [MSHA 2016].
- Although potentially slightly imperfect and not completely up-to-date, the inventory offers good insight in the use of diesel powered vehicles in the U.S. underground coal mines.
- This data base was used as one of the major sources of information for the presented analysis.

References:
- 30 CFR 72.520. Diesel equipment inventory. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- MSHA [2016]. National coal diesel inventory. Mine Safety and Health Administration. [https://lakegovprod3.msha.gov/DieselInventory/ViewDieselInventoryExternal.aspx].

Diesel-Powered Equipment in Underground Coal Mines in the U.S.

- Total of 5113 diesel-powered vehicles are recorded by 185 mines:
  - Permissible HD: 380 (**7.4%**)
  - Non-permissible HD: 1253 (**25.5%**)
  - Non-permissible LD: 3411 (**66.7%**)
  - Fire fighting and ambulance equipment [75.1908]: 16 (0.3%)
  - Unknown: 53 (1.0 %)
- Individual mines reported between 1 and 163 diesel-powered pieces of equipment on their inventory, with around 730 pieces of the equipment shared between nearby mines owned by the same operator.
- Only 93 out of 185 mines have more than 9 diesel-powered vehicles in their inventory.

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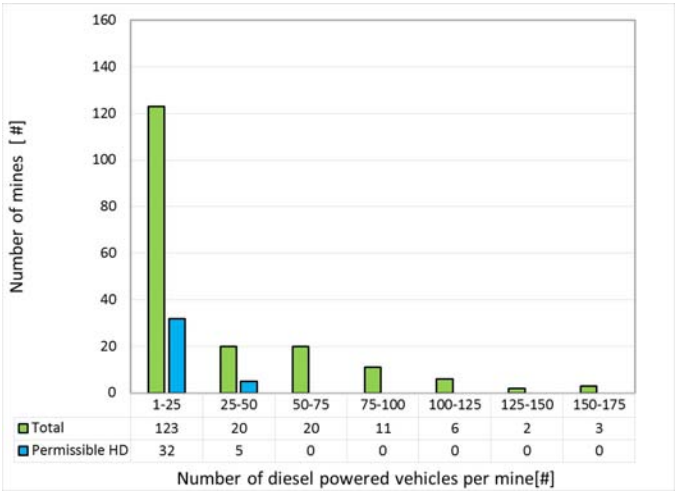
Diesel-powered equipment is not used in equal manner across the U.S. underground coal mining industry.



- Diesel-powered permissible equipment is used only in 37 out of 185 mines. Only 18 of those mines have 5 or more permissible pieces.

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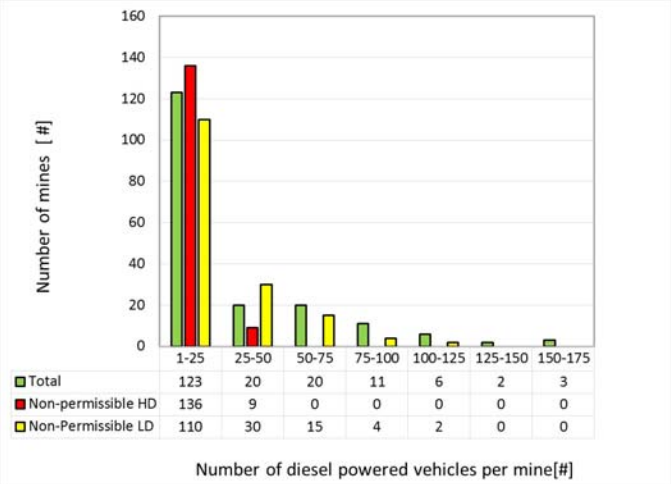
Diesel-powered equipment is not used in equal manner across the U.S. underground coal mining industry.



	1-25	25-50	50-75	75-100	100-125	125-150	150-175
Total	123	20	20	11	6	2	3
Non-permissible HD	136	9	0	0	0	0	0
Non-Permissible LD	110	30	15	4	2	0	0

- Non-permissible HD and LD vehicles are present almost in all mines with more than 9 diesel-powered vehicles.

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Permissible power packages provide power to heavy-duty vehicles that are used in areas of underground coal and some other gassy non-metal mines where additional safety features are required.

- In the United States, the Mine Safety and Health Administration (MSHA) approves diesel engines (and power packages) following procedures described in 30 CFR Part 7 Subpart E for use in:
  - permissible applications [30 CFR 75.1907]:
    - 7E-AXXX
    - 07-EPAXXXXXX
  - non-permissible applications [30 CFR 75.1908]:
    - 7E-BXXX
    - 07-ENAXXXXXX

References:

- 30 CFR 75.1907. Diesel-powered equipment intended for use in underground coal mines. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- 30 CFR 75.1908. Nonpermissible diesel-powered equipment; categories. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

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Permissible HD Equipment in Underground Coal Mines in the U.S.

- MSHA approved permissible power packages under Part 36 (prior 1999) and Part 7.
- Twenty-two of currently used packages have been powered by three high-emitting diesel engines certified by MSHA in late 1990's (not in production any more), and six remaining packages are powered by 07-EPAXXXXXX engines approved between 2004 and 2014.
- Total of 270 permissible HD vehicles in 37 underground coal mines in the U.S. are powered by 15 models of MSHA permissible diesel engines (07-EPAXXXXXX and 7E-AXXX).
- The majority of those, approximately 59%, are still powered by older (7E-AXXX) engines.

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Only a few of the "EPA" and "A" engines found in the MSHA inventory, labeled permissible or non-permissible HD, meet EPA Tier 2/Tier 3 PM standard.

MSHA Approval Number	Make and Model, kW (hp) @ rpm	Approval Year	Engine-Out DPM* [g/kW-hr / g/hp-hr]	EPA Tier 2 / Tier 3 [g/kW-hr / g/hp-hr]	DPM [g/hr]	Number Permissible [#]	Number Non-Permissible [#]
07-EPA040001	Cummins C8.3, 138 (185) @ 2200	2004	0.24 / 0.18	0.20 / 0.15	23.08	71	7
07-EPA060001	Caterpillar 3126B HEUI, 168 (225) @ 2500	2006	0.26 / 0.19	0.20 / 0.15	22.31	2	5
07-EPA060001-1	Caterpillar 3126B HEUI, 168 (225) @ 2500	2006	0.39 / 0.29	0.20 / 0.15	34.10	9	11
07-EPA080001	Deutz BF4M1013FC, 112 (150) @ 2200	2008	0.10 / 0.07	0.30 / 0.22	5.63	1	3
07-EPA080001-1	Deutz BF4M1013FC, 112 (150) @ 2200	2008	0.12 / 0.09	0.30 / 0.22	7.58	4	6
07-EPA110001	Cummins 6CTAA 8.3, 172 (230) @ 2200	2012	0.18 / 0.13	0.20 / 0.15	15.26	7	5
07-EPA120001	Cummins 6CTAA 8.3, 138 (185) @ 2200	2012	0.20 / 0.15	0.20 / 0.15	12.35	8	3
07-EPA140001	Cummins 6CTAA 8.3, 138 (185) @ 2200	2014	0.34 / 0.25	0.20 / 0.15	21.59	4	0
07-EPA140002	Cummins 6CTAA 8.3, 123 (165) @ 2200	2014	0.40 / 0.30	0.30 / 0.22	21.72	4	2
07-EPA140003	FPT N45MSTX20.50, 92 (124) @ 2200	2014	0.30 / 0.22	0.30 / 0.22	14.86	0	1
7E-A001	Deutz MWM 916, 70 (94) @ 2300	1997	0.68 / 0.50	0.40 / 0.30	25.49	42	12
7E-A002	Caterpillar 3306 PCNA, 112 (150) @ 2200	1997	0.72 / 0.53	0.30 / 0.22	45.88	70	9
7E-A003	Caterpillar 3304 PCNA, 75 (100) @ 2200	1997	0.69 / 0.51	0.40 / 0.30	29.74	28	1
7E-A005	Caterpillar 3306 PCTA, 142 (190) @ 2200	1999	0.58 / 0.43	0.20 / 0.15	52.68	13	1
7E-A006	Isuzu 6BG1-MAP, 87 (116) @ 2500	2001	0.66 / 0.48	0.30 / 0.22	30.58	7	2

* Engines tested with 1% CH_4

EPA Tier 2/Tier 3

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Permissible HD Equipment in Underground Coal Mines in the U.S.

- The other 110 vehicles labeled in the inventory as "permissible" are powered by 15 models of MSHA approved non-permissible diesel engines (7E-BXXX and 07-ENAXXXXXX).
- Some of those are out-of- production engines that were converted to 7E-AXXX and 07-EPAXXXXXX engines, but remained erroneously labeled.
- Approximately 69% of engines in this group are 7E-BXXX engines.
- Ninety seven percent of permissible HD vehicles are equipped with a DFE that theoretically allows those to meet the 2.5 g/hr PM standard.

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Relatively large fraction of the "ENA" and "B" engines found on the MSHA inventory labeled as permissible meet EPA Tier 2/Tier 3 DPM standard.

MSHA Approval Number	Make and Model,	Approval Year	Engine-Out DPM [g/kW-hr / g/hp-hr]	EPA Tier 2 / Tier 3 [g/kW-hr / g/hp-hr]	DPM [g/h]	Number [#]
07-ENA040006	Cummins C8.3, 138 (185) @ 2200	2004	0.30 / 0.22	0.20 / 0.15	24.45	9
07-ENA040007	Deutz BF4M1013FC, 129 (173) @ 2300	2004	0.09 / 0.07	0.30 / 0.22	6.2	6
07-ENA040007-1	Deutz BF4M1013FC, 129 (173) @ 2300	2004	0.09 / 0.07	0.30 / 0.22	6.2	7
07-ENA040013	Mitsubishi S4Q2-Y265DP, 36 (48) @ 2500	2004	0.36 / 0.27	0.60 / 0.45	6.93	2
07-ENA050001	Mitsubishi S4S-DT, 57 (77) @ 2500	2005	0.24 / 0.18	0.40 / 0.30	6.91	1
07-ENA060005	Caterpillar 3126B HEUI,168 (225) @ 2500	2006	0.13 / 0.10	0.20 / 0.15	15.26	5
07-ENA070001	Daimler Chrysler 9043MU32, 129 (173) @ 2200	2007	0.11 / 0.08	0.30 / 0.22	7.36	2
07-ENA110009	Cummins 6CTAA 8.3, 213 (285) @ 2200	2011	0.20 / 0.15	0.20 / 0.15	23.89	1
07-ENA130007	Cummins ISB6.7, 164 (220) @ 2900	2013	0.13 / 0.10	0.20 / 0.15	10.7	1
7E-B003	Caterpillar 3306 PCNA, 112 (150) @ 2200	1997	0.66 / 0.49	0.30 / 0.22	39.08	70
7E-B004	Caterpillar 3304 PCNA, 75 (100) @ 2200	1997	0.64 / 0.48	0.40 / 0.30	25.49	5
7E-B086	Isuzu C240, 39 (52) @ 3000	2001	0.21 / 0.16	0.40 / 0.30	4.25	1

EPA Tier 2/Tier 3

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Non-Permissible HD Equipment in Underground Coal Mines in the U.S.

- Over 1250 non-permissible HD vehicles are powered by more than 100 different models of engines.
- Around 1190 of those are powered by 07-ENAXXXXXX and 7E-BXXX MSHA approved engines.
- Around 65 non-permissible HD vehicles are powered by 14 different models of 07-EPAXXXXXX and 7E-AXXX MSHA approved permissible diesel engines.
- Approximately 38%, of those are 7E-AXXX engines.
- However, over 91% of non-permissible HD vehicles are equipped with DPFs and DFEs that allow those to meet the 2.5 g/hr PM standard.

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The majority of engines found in the most prevalent non-permissible HD vehicles meet EPA Tier 2/Tier 3 DPM standard.

MSHA Approval Number	Make and Model, kW (hp) @ rpm	DPM [g/kW-hr / g/hp-hr]	EPA Tier 2 / Tier 3 [g/kW-hr / g/hp-hr]	DPM [g/h]	Number [#]
07-ENA040002	Deutz BF4M2012, 75 (100) @ 2500	0.11 / 0.08	0.40 / 0.30	4.51	28
07-ENA040004	Deutz BF4L2011, 58 (78) @ 2800	0.11 / 0.08	0.40 / 0.30	3.70	58
07-ENA040007-1	Deutz BF4M1013FC, 118 (158) @ 2300	0.09 / 0.07	0.30 / 0.22	6.20	152
07-ENA040011	Deutz F3L2011 (D 2011L03i), 36 (48) @ 2800	0.27 / 0.20	0.60 / 0.45	4.89	21
07-ENA040012	Deutz F4L2011, 48 (64) @ 2800	0.27 / 0.20	0.40 / 0.30	6.52	49
07-ENA040017	Cummins 4B3.3T, 63 (85) @ 2600	0.47 / 0.35	0.40 / 0.30	16.14	31
07-ENA050001	Mitsubishi S4S-DT, 57 (77) @ 2500	0.24 / 0.18	0.40 / 0.30	6.91	28
07-ENA060010	Cummiins QSB6.7, 186 (250) @ 2500	0.17 / 0.13	0.20 / 0.15	17.35	58
07-ENA070001	Daimler Chrysler 9043MU32, 129 (173) @ 2200	0.11 / 0.08	0.30 / 0.22	7.36	68
07-ENA070002	Daimler Chrysler 9063MU32, 150 (201) @ 2200	0.20 / 0.15	0.20 / 0.15	15.67	56
07-ENA070006	Cummins QSB4.5, 82 (110) @ 2500	0.24 / 0.18	0.30 / 0.22	11.10	39
7E-B008	Deutz BF4M 1013C, 115 (154) @ 2300	0.20 / 0.15	0.30 / 0.22	12.74	23
7E-B083	Daimler Chrysler OM906LA, 150 (201) @ 2200	0.09 / 0.07	0.20 / 0.15	7.25	55
7E-B098	Daimler Chrysler OM904LA, 90 (121) @ 2200	0.09 / 0.07	0.30 / 0.22	4.39	68
7E-B099	Cummins QSB-C240, 179 (240) @ 2500	0.09 / 0.07	0.20 / 0.15	9.35	22

EPA Tier 2/Tier 3

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Non-permissible LD Equipment in Underground Coal Mines in the U.S.

- Over 3400 non-permissible LD vehicles are powered by more than 110 different models of engines.
- All but one of those vehicles are powered by 07-ENAXXXXXX and 7E-BXXX MSHA approved engines.
- The LD engines fall into the following categories:
  - 11-25 hp (3.2%),
  - 25-50 hp (12.3%),
  - 50-75 hp (21.8%),
  - 75-175 hp (44.1%), and
  - 175-750 hp (18.6%).
- 673 out of 3,411 LD vehicles, approximately 20% of non-permissible LD fleet, are equipped engines that are retrofitted with DPFs that allows those to meet the 5.0 g/hr PM standard.

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The majority of engines found in the most prevalent **non-permissible LD** vehicles meet EPA Tier 2/Tier 3 DPM standard and few even meet EPA Tier 4 final standard.

MSHA Approval Number	Make and Model, kW (hp) @ rpm	DPM [g/kW-hr / g/hp-hr]	EPA Tier 2 / Tier 3 or Tier 4 [g/kW-hr / g/hp-hr]	DPM [g/h]	Number [#]
07-ENA 030001	Mitsubishi s4s, 47 (63) @ 2500	0.35 / 0.26	0.40 / 0.30	7.65	198
07-ENA040002	Deutz BF4M2012, 75 (100) @ 2500	0.11 / 0.08	0.40 / 0.30	4.51	317
07-ENA040004	Deutz BF4L2011, 58 (78) @ 2800	0.11 / 0.08	0.40 / 0.30	3.70	355
07-ENA040011	Deutz F3L 2011 (D 2011L03i), 36 (48) @ 2800	0.27 / 0.20	0.60 / 0.45	4.89	143
07-ENA040012	Deutz F4L2011, 48 (64) @ 2800	0.27 / 0.20	0.40 / 0.30	6.52	196
07-ENA040015-1	Cummins ISB-325, 160 (215) @ 2900	0.20 / 0.15	0.20 / 0.15	15.56	301
07-ENA050001	Mitsubishi S4S-DT, 57 (77) @ 2500	0.24 / 0.18	0.40 / 0.30	6.91	237
07-ENA070006	Cummins QSB4.5, 82 (110) @ 2500	0.24 / 0.18	0.30 / 0.22	11.10	116
07-ENA100009	Cummins ISB 6.7, 164 (220) @ 2800	0.12 / 0.09	0.20 / 0.15	9.22	119
7E-B086	Isuzu C240 *RETIRED*, 39 (52) @ 3000	0.21 / 0.16	0.40 / 0.30	4.25	123
07-ENA140005	Kubota D902-E4, 16 (22) @ 3200	0.54 / 0.40	0.40 / 0.30	4.25	11
07-ENA140006	Kubota D1105-E4, 19 (25) @ 3000	0.15 / 0.11	0.40 / 0.30	1.42	6

EPA Tier 2/Tier 3

EPA Tier 4 final

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Non-permissible LD Equipment in Underground Coal Mines in the U.S.

- Approximately 48% (1684 out of 3,411) pieces of non-permissible LD diesel-powered equipment emit less than 5.0 g/hr of DPM.
- Approximately 23% (788 out of 3,411) pieces of non-permissible LD diesel-powered equipment emit less than 2.5 g/hr of DPM.
- 116 of those, primarily with outputs between 11 and 25 hp, meet the 2.5 g/hr criteria as supplied by original equipment manufacturers (OEMs).
- The engines of the other 672 LD equipment were retrofitted by a third party supplier with diesel particulate filters (DPFs) or filtration systems with disposable filter elements (DFEs) to meet the 2.5 g/hr DPM criteria.

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Technological advancements in engine and exhaust aftertreatment technologies are driven by technology forcing regulations promulgated around the world.

- Significant developments in emissions reduction technologies in response to regulations by the U.S., Europe, and California is reviewed relatively recently [Johnson, 2013]
- For example, U.S. EPA standards [66 Fed Reg. 5001 (2001)] for class of engines with output between 75 and 130 kW (100 and 175 hp):
  - 1997 (Tier 1): no standard
  - 2003 (Tier 2): PM = 0.30 g/kW-hr (0.22 g/hp-hr);
  - 2007 (Tier 3, never adopted): PM = 0.30 g/kW-hr (0.22 g/hp-hr);
  - 2011-2014 (Tier 4i and Tier 4f): PM = 0.02 g/kW-hr (0.01 g/hp-hr).

Reference:

- Johnson, T. [2013]. Vehicular Emissions in Review. SAE Int. J. Engines 6, 699-715.
- 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.

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Advanced engine technologies did not penetrate underground mining market yet.

- Currently, the majority of the permissible diesel-powered vehicles are powered by engines that do not meet EPA Tier 2/Tier 3 PM standard.
- The fleet of non-permissible HD vehicles is powered predominantly by EPA Tier 2 engines from mid-2000s. Only 54 of 1253 non-permissible HD vehicles are powered by engines approved after 2010.
- Advanced engines are making slow ingress into the market: Approximately 0.5% of non-permissible LD vehicles are currently powered by engines that meet EPA Tier 4 standards.

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In-Use vs. Certification Emissions

- Due to the absence of direct measurements of personal exposure of coal miners to DPM, the success of the applied strategy strongly depends on:
  - Maintaining in-use emissions at certification level;
  - Maintaining the effectiveness of exhaust aftertreatment systems at approval levels.
- Maintaining in-use emissions at certification levels currently depends on limited information obtained via mandated weekly CO-based emissions tests [30 CFR 75.1914].
- Due to limited scope, that testing provides very limited information on the actual levels of emissions and does not allow for direct comparison with certification data.
- Since the underground mining industry is extensively using rebuilt engines , the emissions of those engines should be closely scrutinized.

References:
- 30 CFR 75.1914 - Maintenance of diesel-powered equipment. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

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Use of DFEs and DPFs

- Promulgation of DPM regulations resulted in widespread implementation of exhaust aftertreatment systems, particularly filtration systems with disposable filter elements (DFEs) and diesel particulate filter (DPF) systems.
- According to the inventory:
  - Over 97% of permissible HD vehicles are equipped with DFEs;
  - Over 90% of non-permissible HD vehicles are equipped with DPFs and DFEs;
  - Around 20% of non-permissible LD vehicles are equipped with DPFs and DFEs.
- Apparently, the filtration systems have very pivotal role in removing DPM from diesel fleets, particularly those with large number of antiquated engines.
- In the case of some high-emitting engines, lowering copious levels of DPM emissions to 2.5 g/h levels requires 95% efficient DFEs or DPFs.

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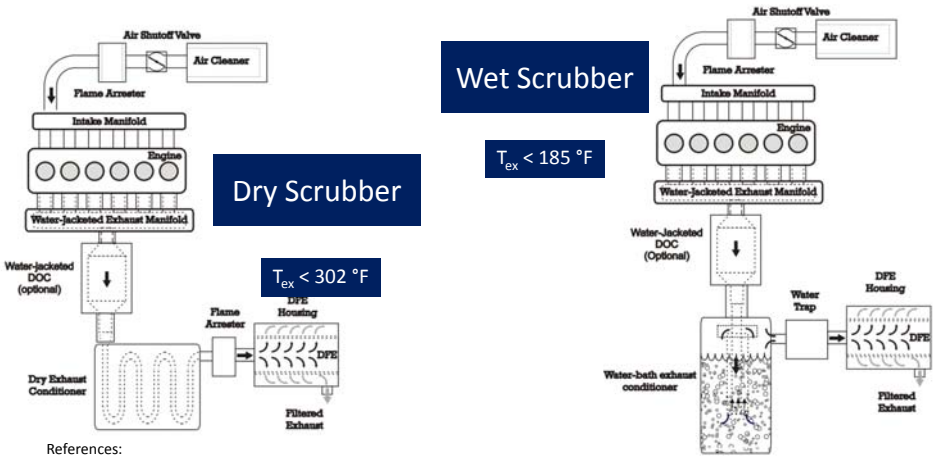
Two general types of filtration systems with DFEs are currently used in permissible and some non-permissible HD applications [MSHA 2016].



References:

- MSHA [2016]. National coal diesel inventory. Mine Safety and Health Administration. [https://lakegovprod3.msha.gov/DieselInventory/ViewDieselInventoryExternal.aspx].

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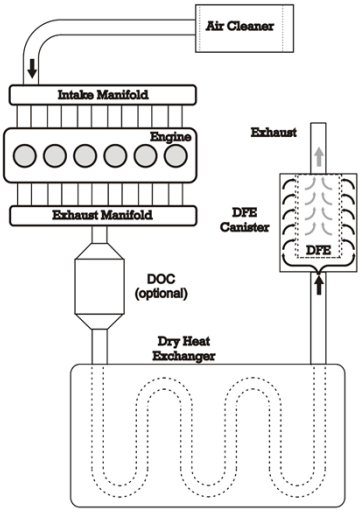
Filtration systems with DFEs are also used in over 900 non-permissible HD and LD coal mining applications (MSHA 2016).



- Some of those systems are identical to those used in permissible equipment.
- The others are systems specifically designed for non-permissible applications.
- With exception of those used in PA, WV and OH, non-permissible power packages do no have additional surface and exhaust temperature safety requirements.
- In non-permissible systems, dry heat exchangers are used to keep exhaust temperatures below 343 °C (650 °F) and therefore prevent damages on DFEs.
- 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 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.

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MSHA tests DFEs for use in underground mining applications.

- DFEs for low temperature (up to 185 or 302 °F) and high temperature (up to 650 °F) applications are assessed by MSHA following Part 7 testing procedures [61 Fed. Reg. 55411 (1996)].
- Several products from 14 manufacturers are currently listed [MSHA 2016].
- The actual filtration efficiencies of low temperature DFEs are not reported, but expressed in terms of the equivalency to the 95% efficient "gold" standard paper DFE.
- The efficiencies of two verified high temperature DFEs 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 [2016]. 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].

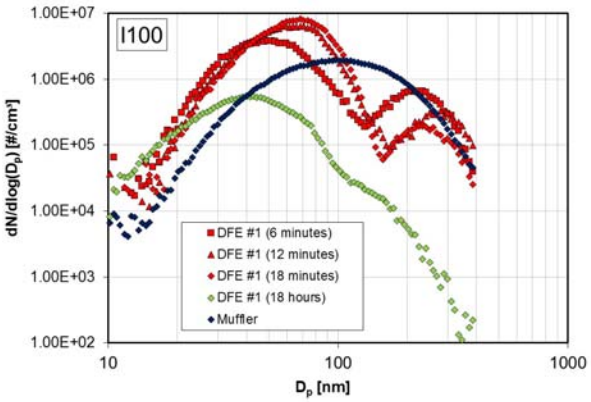
DFE technology currently used in underground mines has space for improvement.

- Results of the evaluation of two popular types of high-temperature DFEs performed at the NIOSH Lake Lynn Experimental Mine were used to demonstrate some of those issues.
- The effects of the DFE on the size distributions and concentration of diesel aerosols were discussed based on the results of measurements performed at upstream and downstream stations with:
  - TSI Scanning Mobility Particle Sizes (Model 3936);
  - Dekati Electrical Low Pressure Impactor (ELPI DAS 3100), and
  - Thermo Tapered Element Oscillating Microbalance (TEOM 1400a).

Reference:
- Bugarski, A.D., Schnakenberg, G.H., Jr., Hummer, J.A., Cauda E., Janisko, S.J., and Patts, L.D. [2009]. Effects of Diesel Exhaust Aftertreatment Devices on Concentrations and Size Distribution of Aerosols in Underground Mine Air. Environmental Science and Technology 43, 6737-6743.

During the off-gassing process, the filter media used in DFEs gives off aerosols.

- The breakdown of the paper and synthetic filter material causes the production of secondary emissions of various compounds and aerosols.



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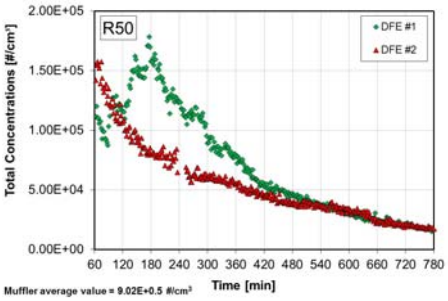
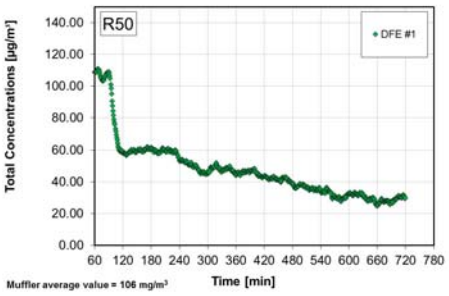
It might take a couple hours before some of currently used DFEs reach their terminal efficiency.

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





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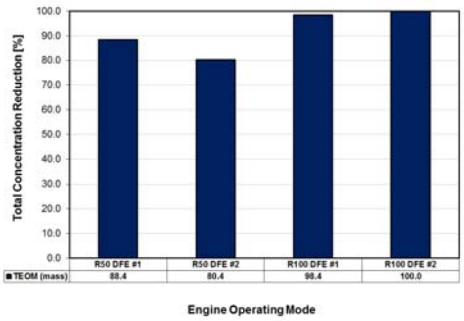
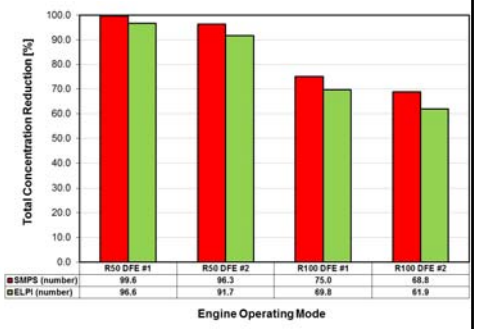
After 12 hours of operations, tested filters were found to be relatively effective in reducing particulate mass and number.

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





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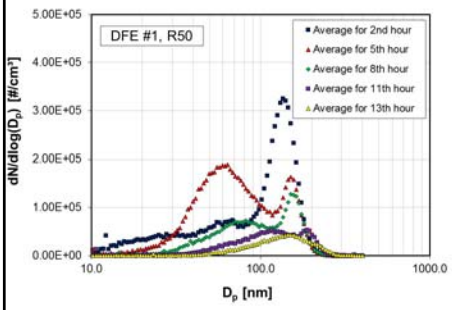
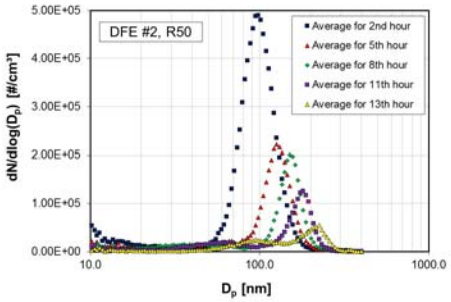
Size distributions and number concentrations of aerosols emitted out of DFEs gradually changed during life of filter.

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





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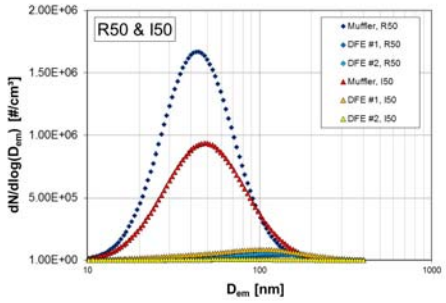
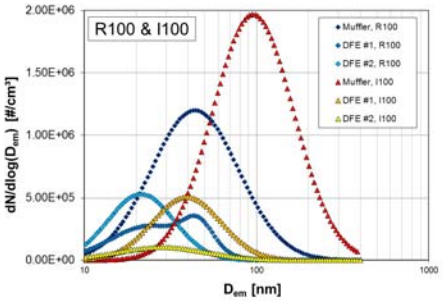
Size distributions and number concentrations of aerosols emitted post DFEs depend on engine operating conditions /exhaust temperature.

- 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 the nucleation mode.

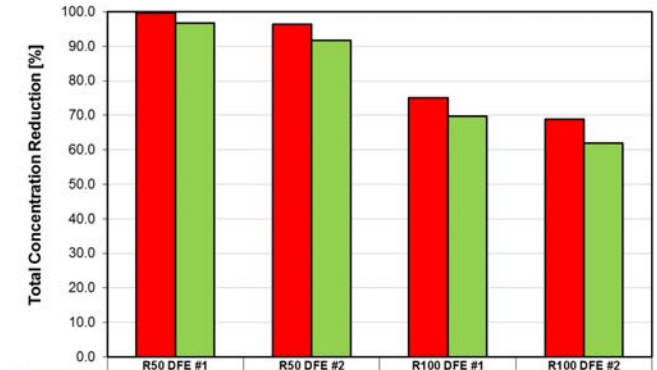




Mode	Exhaust Temperature at Inlet to DFEs	Temperature at Outlet from DFEs
	°C	°C
R50	203	154
R100	328	238
I50	157	120
I100	313	230

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.



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

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Efforts to Reduce Exposure of Underground Coal Miners in the U.S. in Retrospective

- DPM regulations were promulgated in 2001 and requirements for permissible and non-permissible HD equipment were gradually phased in and those took final shape in 2002 and 2005, respectively.
- An emphasis was given to implementation of risk control strategies known at the time of promulgation.
- The regulations undeniably resulted in great improvements in quality of air in underground mines, however due to the absence of direct monitoring, it is impossible to quantify actual impacts.

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Some of the following factors are identified that especially hinder efforts to reduce the exposure of underground coal miners.

- Limited availability of low-emitting diesel-power packages for permissible HD applications;
- Slower-than-anticipated replacement of high-emitting diesel engines in permissible and non-permissible HD applications;
- Extensive use of high-emitting diesel engines in LD applications;
- Extensive dependence on use of disposable filter elements that in some cases might not provide advertised protection;
- Currently applied in-use emissions monitoring strategy might not be adequate to support the idea of maintaining emissions at certification levels;
- Absence of information on the levels of personal exposure of underground coal miners to DPM impedes evaluation of efficacy of prescribed control strategies.

- Addressing some or all of these issues would greatly facilitate efforts to reduce the exposure of underground coal miners.

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Questions???

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