Disposable filter elements used in underground mining applications

Presented by
Aleksandar Bugarski, Ph.D.
National Institute for Occupational Safety and Health (NIOSH)
Pittsburgh Mining Research Division (PMRD)

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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:
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).

\[ T_{ex} < 185 \, ^\circ C \]  

**Dry Scrubber**

\[ T_{ex} < 302 \, ^\circ C \]  

**Wet Scrubber**

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.
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:

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:
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:
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).

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

<table>
<thead>
<tr>
<th>Mode</th>
<th>Exhaust Temperature at Inlet to DFEs °C</th>
<th>Temperature at Outlet from DFEs °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>R50</td>
<td>203</td>
<td>154</td>
</tr>
<tr>
<td>R100</td>
<td>328</td>
<td>238</td>
</tr>
<tr>
<td>I50</td>
<td>157</td>
<td>120</td>
</tr>
<tr>
<td>I100</td>
<td>313</td>
<td>230</td>
</tr>
</tbody>
</table>
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).
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.
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.
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.

<table>
<thead>
<tr>
<th>MSHA Approval Number</th>
<th>Make and Model, kW (hp) @ rpm</th>
<th>Max. Engine Backpressure [in H₂O/mbar]</th>
</tr>
</thead>
<tbody>
<tr>
<td>07-EPA040001</td>
<td>Cummins C8.3, 138 (185) @ 2200</td>
<td>41/102</td>
</tr>
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<td>07-EPA060001</td>
<td>Caterpillar 3126B HEUI, 168 (225) @ 2500</td>
<td>80/199</td>
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<td>27/67</td>
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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.
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