Disposable filter elements used in underground mining applications

Presented by
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• 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).
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).
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, 150, 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.
• Due to effects of exhaust temperatures on formation and transformation of aerosols, the efficiencies in removal of aerosols were substantially different between test modes.

![Graph showing total concentration reduction for different engine operating modes.](image)

<table>
<thead>
<tr>
<th>Engine Operating Mode</th>
<th>R50 DFE #1</th>
<th>R50 DFE #2</th>
<th>R100 DFE #1</th>
<th>R100 DFE #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>S/N (number)</td>
<td>96.6</td>
<td>86.3</td>
<td>75.3</td>
<td>68.6</td>
</tr>
<tr>
<td>D/E/L (number)</td>
<td>66.0</td>
<td>61.7</td>
<td>69.8</td>
<td>61.9</td>
</tr>
</tbody>
</table>

**Observation 7: Efficiency of DFEs depended on engine operating conditions.**
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>
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<tr>
<td>07-EPA040001</td>
<td>Cummins C8.3, 138 (185) @ 2200</td>
<td>41/102</td>
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<td>80/199</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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