Effects of Exhaust After-Treatment and Fleet Modernization on Port of Oakland Drayage Truck Emissions

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Acknowledgments

- Bay Area Air Quality Management District
- California Air Resources Board
- Port of Oakland
- National Science Foundation
Diesel Particle Filters (DPFs)
- Installed on 2007+ engines; older engines can be retrofitted with DPF
- Intended to reduce PM, but potential for increased NO$_2$ emissions

Selective Catalytic Reduction (SCR)
- Installed on 2010+ engines
- Intended to reduce NO$_x$, but can lead to formation of N$_2$O

Drayage Truck Rule implemented between Jan 2010 and Dec 2013
- Initially required replacement of oldest engines and retrofit with DPF, and finally required replacement all pre-2007 model year engines
Direct measurement of HDDT emissions

- Research grade analyzers inside van sampled the exhaust plumes of individual trucks via flexible aluminum duct
- Sample line aligned with vertical exhaust of passing trucks for “plume capture method”
Roadside camera captured timing & plates
Based on license plate information, sampled trucks can be characterized as:

<table>
<thead>
<tr>
<th>Technology Category</th>
<th>Engine Model Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>No DPF</td>
<td>(pre-2007 MY engines)</td>
</tr>
<tr>
<td>Retrofit DPF</td>
<td>(1994–2006 MY engines)</td>
</tr>
<tr>
<td>DPF</td>
<td>(2007–2009 MY engines)</td>
</tr>
<tr>
<td>DPF + SCR</td>
<td>(2010+ MY engines)</td>
</tr>
</tbody>
</table>
Port fleet quickly evolved

Median MY = 1997
Median MY = 2008
$\text{NO}_x$ reduced as fleet modernized

Port fleet’s NO$_x$ emissions reduced by $70 \pm 9\%$ between 2009 and 2015

- Median MY = 1997
- Median MY = 2004
- Median MY = 2007
- Median MY = 2008

<table>
<thead>
<tr>
<th>Year</th>
<th>Median MY</th>
<th>2009 Fleet</th>
<th>2011 Fleet</th>
<th>2013 Fleet</th>
<th>2015 Fleet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994 - 2011</td>
<td>2004</td>
<td>17</td>
<td>15</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>1994 - 2013</td>
<td>2007</td>
<td>12</td>
<td>9</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>1996 - 2016</td>
<td>2008</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

(172, 378, 1005, 1218 vessels)
DPFs increase NO$_2$, SCR partly mitigates

Port fleet's NO$_2$ emissions doubled between 2009 and 2015

Median MY = 1997
Median MY = 2004
Median MY = 2007
Median MY = 2008
Median MY = 1999
Median MY = 2008
Median MY = 2005
Median MY = 2012

2009 Fleet
1970 - 2009
(n = 172)

2011 Fleet
1994 - 2011
(n = 378)

2013 Fleet
1994 - 2013
(n = 1005)

2015 Fleet
1996 - 2016
(n = 1218)

No DPF
1996 - 2006
(n = 199)

Retrofit DPF
1994 - 2006
(n = 399)

DPF
2007 - 2009
(n = 1598)

DPF + SCR
2010 - 2016
(n = 403)
SCR systems emit significant amounts of $\text{N}_2\text{O}$.
DPFs reduced Port fleet’s BC emissions

Port fleet’s BC emissions decreased 76 \pm 23\% due to near-universal adoption of DPFs between 2009 and 2013.
DPFs reduced Port fleet’s BC emissions

Port fleet’s BC emissions decreased $76 \pm 23\%$ due to near-universal adoption of DPFs between 2009 and 2013.

But…Port fleet’s BC emissions increased slightly between 2013 and 2015.
Average BC emission rate by 2007–2009 MY engines with DPFs increased by 50% between 2013 and 2015

The increase in BC for the 2007-2009 engine category (red bars) may be due to deterioration of DPFs, which cause some DPF-equipped trucks to become “high-emitters”
High emitters dominate fleet’s BC emissions

Port of Oakland

2015 Fleet:
- 74% DPF (2007–2009 MY)
- 25% DPF + SCR (2010+ MY)

6% high emitters = 65% emitted BC

High emitters dominated by 2007–2009 MY engines (93%)

Average BC emission rate by all high emitters = 3.4 g kg\(^{-1}\)

Fleet average w/ high emitters = 0.31 g kg\(^{-1}\) versus w/ out high emitters = 0.11 g kg\(^{-1}\)

High Emitter = BC emission factor > 1.1 g kg\(^{-1}\) (average for trucks without DPFs)
Conclusions

- DPF and SCR systems significantly reduced BC and NO\textsubscript{x} emissions from Port of Oakland Drayage trucks
  - Concurrent increases in NO\textsubscript{2} and N\textsubscript{2}O emissions

- Recent Port of Oakland emissions inventory reports an 82% reduction in diesel PM between 2012 and 2015
  - Our study observed a 54 ± 27% decline in BC emission rate over similar period between 2011 and 2015

- High emitting trucks are important; may be due to DPF degradation
  - Reduction in BC emissions was 73% between 2009 and 2015 but would be 91% if the high emitting trucks were repaired

- UCB is proposing to work with BAAQMD and ARB to develop an automated platform to identify high emitters
  - Could be used to better understand cause of high emitters
  - Incentivize DPF repair or replacement to ensure long-term benefit to Drayage Truck Regulation investments