Fugitive Emissions from a Dry Coal Fly Ash Storage Pile

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Why Are Fugitive Particulate Emissions Important?

- Upcoming coal ash storage regulation may rely on dry ash handling
- Potential impact to local communities
- EPA proposing to lower annual PM$_{2.5}$ standard to 12 µg m$^{-3}$.
- Detailed prevention of significant deterioration (PSD) analyses are required for a new/modified source when emissions for PM$_{2.5}$ >10 tons per year (tpy), for PM$_{10}$ >15 tpy and for TSP >25 tpy.
Technical Motivation to Re-evaluate Fugitive Emissions

• Inaccurate fugitive emissions can lead to ineffective emissions control

• Fugitive EFs for fly ash highly uncertain
  – Ash handling, wind erosion or pile maintenance, transfer…
  – May not account for most important materials characteristics, site-specific data, or current materials handling practices
Overall Study Plan

- Phase 1: Dry fly ash – TVA Colbert Plant (AL) 1200MW
- Phase 2: Coal dust – TVA Gallatin Plant (TN) 1000MW
- Phase 3: TBD - Limestone/gypsum? Road dust? Fly ash in Western U.S.?
Project Goals

• Quantify fugitive particulate emissions at coal-fired power plants for different handling practices.

• Compare new emission rates with those from EPA AP-42 handbook.

• Utilities use to inform facility permitting.

• May help evaluate emission mitigation strategies.
Origins of AP-42 Fugitive Emission Factors

• Studies in 1970s measured airborne dust near unpaved roads and material handling. Multi-component statistical analyses to develop formulations. Dropping factors -1980s

• Used old measurement technologies.
• Most sources were staged & not done under actual operating conditions.
• Involved limited types of materials & limited range in conditions (vehicle speed, material moisture content, silt content).
Ash handling

- Dumping $\approx 25$ m$^3$ per load
- Leveling to 0.5 m high x 4 m dia.
- Grading time $\approx 8$ min
- Grader speed $\approx 5$ mph
- Loads per hr $\leq 12$
Colbert Field Study Layout

Photos:
(Top) Camera triggered by trucks moving along berm road south of air monitoring sites.
(Bottom) Camera triggered by activity on fly ash dry stack.
## Monitoring Instrumentation

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Measurement/Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meteorological</strong></td>
<td></td>
</tr>
<tr>
<td>R. M. Young 81000RE sonic anemometers (2 &amp; 10 m)</td>
<td>Wind speed, direction, vertical velocity, horizontal &amp; vertical turbulence; vertical gradient of speed, direction &amp; turbulence</td>
</tr>
<tr>
<td>Vaisala HMI41 aspirated temperature &amp; humidity sensors (2 &amp; 10 m)</td>
<td>Air temperature &amp; relative humidity; vertical temperature &amp; moisture gradients</td>
</tr>
<tr>
<td>Campbell Scientific CNR2 net radiometer (~1.8 m)</td>
<td>Radiation flux (shortwave, longwave &amp; net)</td>
</tr>
<tr>
<td>Novalynx Corp. 260-2501-A tipping bucket raingage</td>
<td>Precipitation amount</td>
</tr>
<tr>
<td>Campbell Scientific CS616 water content reflectometer (top 30 cm of soil)</td>
<td>Soil moisture content</td>
</tr>
<tr>
<td><strong>Air Quality</strong></td>
<td></td>
</tr>
<tr>
<td>Met One beta attenuation monitors (BAMs) at downwind &amp; background sites</td>
<td>PM$<em>{2.5}$/PM$</em>{10}$ concentrations (semi-continuous) @ downwind &amp; background sites</td>
</tr>
<tr>
<td>BGI PQ-200 PM$_{10}$ particle filter sampler</td>
<td>Filtered PM$_{10}$ sample, ~12-hr samples (for chemical analysis) @ downwind &amp; background sites</td>
</tr>
<tr>
<td>TSI 3563 3-λ nephelometer</td>
<td>Continuous $\beta_{\text{scat}}$ @ 3 wavelengths @ downwind site</td>
</tr>
<tr>
<td>Optek nephelometer</td>
<td>Semi-continuous single-wavelength $\beta_{\text{scat}}$ @ downwind site</td>
</tr>
<tr>
<td>Campbell Scientific video camera</td>
<td>Semi-continuous images of fly ash disposal site</td>
</tr>
</tbody>
</table>
Dry Fly Ash Handling at Colbert

- Fly ash is pneumatically conveyed to hoppers where it is conditioned with 15% moisture before transference to haul trucks.
- Each truck moves 25-28 m³ of ash per load.
- Ash is dropped at disposal area and leveled to a depth of about half a meter (18-24 in).
- Ash grading takes about 8 min with grader moving at 2.2 m s⁻¹ (5 mph).
- Fugitive emissions are primarily due to dropping and grading operations (haul trucks moving over bottom ash road produces very little fugitive dust).
Average Particulate Concentrations by Direction
May-August 2011

Nearest Downwind Site (2)

Farthest Downwind Site (3)

Background

One-hr average concentrations were measured by FRM BAMs and reported here in µg m⁻³. Wind direction was measured at a height of 10 m.

Data recovery >99%

Data recovery 81%
Hourly Concentrations at each Site: May-September 2011
Clean Period (No Emissions)
28 June, 1300-1400 LST
No-Vehicle Period (Fly Ash Activity only)
8 July, 1000-1200 LST
3-Vehicle Event
22 July, 0700-0800 LST

All three dust spikes were caused by dump trucks on the berm road.
Particle Concentrations (SSE-SSW)

PM$_{2.5}$ Concentration vs. $b_{scat}$

- Linear equation: $y = 0.225x + 1.854$
- Coefficient of determination: $R^2 = 0.770$

PM$_c$ Conc. vs. $\sigma_{bscat}$

- Quadratic equation: $y = -0.014x^2 + 6.432x - 2.745$
- Coefficient of determination: $R^2 = 0.725$
Models of Hourly PM_c & PM_{2.5}

Multivariate linear regression yields

\[
C_{\text{fine}} = f_{b_{\text{scat}}} b_{\text{scat}} + f_{U_2} U_2 + C_{\text{int}} \quad r^2=0.89
\]
\[
C_{\text{coarse}} = f_{\sigma_{b_{\text{scat}}}} + f_{U_2} U_2 + f_{\text{fine}} C_{\text{fine}} + C_{\text{int}} \quad r^2=0.77
\]

\(f\): regression slope constants
\(b_{\text{scat}}\): light scattering coefficient (Mm\(^{-1}\))
\(\sigma_{b_{\text{scat}}}\): standard deviation of \(b_{\text{scat}}\) (Mm\(^{-1}\))
\(U_2\): wind speed at level 2 (m s\(^{-1}\) @10 m)
\(C_{\text{int}}\): intercept constants (µg m\(^{-3}\))
\(C_{\text{fine}}\): concentration of PM\(_{2.5}\) mass (µg m\(^{-3}\))
\(C_{\text{coarse}}\): concentration of PM\(_c\) mass (µg m\(^{-3}\))
Steps in Estimating Fly Ash Emission Rates

For each particle size:

1. Select hours meeting minimum data requirements
2. Calculate "adjusted" concentrations at sites 2 & 3 to remove effects of nearby emissions
3. Calculate "excess" concentrations (i.e., values above background), $C_{xs}$
4. Compute normalized concentrations ($C/Q$)
5. Compute $Q_i = C_{xs}/(C/Q)$
Fly Ash Emission Equations

Based on AP-42:

\[ E_{\text{ash}} = N_{\text{loads}} \left( E_{\text{drop}} + D E_{\text{grad}} / m \right) \]

- \( N_{\text{loads}} \) = ash loads per unit time
- \( D \) = grader distance traveled per load processed
- \( m \) = ash mass per load

\[ E_{\text{drop}} = C_{\text{drop}} \left( \frac{U}{2.2} \right)^{1.3} \left( \frac{M}{2} \right)^{1.4} \]

\[ E_{\text{ir}} = C_{\text{ir}} \left( \frac{S}{12} \right)^{0.45} \left( \frac{W}{3} \right)^{0.45} \]

Based on field data & modeling:

\[ C_{\text{xso}} = C_{\text{obs}} - C_{\text{local}} - C_{\text{bck}} \]

\[ Q_{\text{ash}} = C_{\text{xso}} / (C/Q)_{\text{model}} \]

\[ E_{\text{ash}} = Q_{\text{ash}} / M_{\text{ash}} \]

- \( M_{\text{ash}} \) = ash mass deposited per area per time
Overall Emission Factors

Study mean: 53
Coarse Mass (PM$_{10-2.5}$)

AP-42 mean: 260

Study mean: 19
Fine Mass (PM$_{2.5}$)

AP-42 mean: 29

g particles/ metric ton of processed ash
Assuming an infinite line source and a Gaussian plume mass profile, calculate an emission rate of mass per unit length of road per unit time as (following Hanna et al., 1982)

\[ Q_i = 2.46 C_i (Ku x)^{1/2} \exp \left[ \frac{uz^2}{4Kz} \right] \]

where \( C_i \) is observed concentration of mass component \( i \), \( u \) is wind speed, \( x \) is downwind distance, \( K \) is eddy diffusivity, and \( z \) is the vertical height displacement from the plume centerline (\( z=0 \) for a ground level source). Near the ground under steady-state conditions, \( K \) can be determined using the relation

\[ u_*^2 = K(du/dz) \]

with both \( u_* \) and \( du/dz \) known from measurements at the nearby meteorological tower.
## Emission Factor Summaries

<table>
<thead>
<tr>
<th>Emission Factor</th>
<th>Coarse Mass, PM$_c$</th>
<th>Fine Mass, PM$_{2.5}$</th>
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</thead>
<tbody>
<tr>
<td>Fly Ash, AP-42 (g PM per Mg ash)</td>
<td>250</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>232</td>
<td>41</td>
</tr>
<tr>
<td>Fly Ash, this study (g PM per Mg ash)</td>
<td>63</td>
<td>14-18</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>5-7</td>
</tr>
<tr>
<td>Road dust, AP-42 - industrial sfc.</td>
<td>193</td>
<td>34</td>
</tr>
<tr>
<td>(g PM per km traveled)</td>
<td>200</td>
<td>36</td>
</tr>
<tr>
<td>Road dust, AP-42 - public roads</td>
<td>32</td>
<td>5.7</td>
</tr>
<tr>
<td>(g PM per km traveled)</td>
<td>26</td>
<td>4.6</td>
</tr>
<tr>
<td>Road dust, this study (g PM per km</td>
<td>68$^e$</td>
<td>3.3</td>
</tr>
<tr>
<td>traveled)</td>
<td>38$^e$</td>
<td>1.4</td>
</tr>
</tbody>
</table>
What controls total ash disposal EFs?

- Grading activity accounts for >95 percent of total computed fugitive fly ash emissions.
- AP-42 grading EF formulation is for vehicles on *industrial roads* but was developed from surfaces relatively low (<25%) in silt content, no moisture, higher speeds.
- Tested both AP-42 unpaved road dust formulations at Colbert on 2 roads/42 events.
- Results*:  
  
  | Road Type          | AP-42 EF | Observed for PM<sub>c</sub> | Observed for PM<sub>2.5</sub>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>10x</td>
<td>23x</td>
<td>2x</td>
</tr>
<tr>
<td>Public road</td>
<td>2x</td>
<td>4x</td>
<td></td>
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</table>

* Differences between AP-42 and field results are even larger when vehicle wake effects are considered.
Conclusions

• Despite conservative assumptions, AP-42 derived fly ash handling EFs are higher than EFs derived by field measurements for both PM$_c$ and PM$_{2.5}$.

• Disparity is likely due to high bias in industrial unpaved road dust formulation (grading).

• EFs from field measurements have higher tail than AP-42 EFs. May be due to higher variability in atmospheric or ash handling conditions in real operations.

• Use of more realistic EFs can lower fugitive dust emission estimates for fly ash handling by 33% (PM$_{2.5}$) to 80% (PM$_{10}$). *Can benefits be expanded to TSP?*

• Observed EFs for vehicles on unpaved roads also differ from AP-42 EFs.
Together…Shaping the Future of Electricity