Emission Factors for Visibility Impairment from Fugitive Dust Emissions

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What are the Important PM Standards?

1. Health-Based ($PM_{2.5}$ and PM_{10} mass density).
2. Visibility (Extinction)

"The 1999 Regional Haze Rule requiring states to reduce light extinction to natural levels in 156 U.S. national parks and wilderness areas by 2065 is possibly the most ambitious, and most stringent, air quality goal ever promulgated."

Reference: Watson, J. G. (2002). "2002 Critical Review -- Visibility: Science and Regulation." *J. Air & Waste Manage. Assoc.* **52**, 626-713.

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Q.: What do PM Emission Factors and Ambient PM Standards have in Common?

A.: They are specified in terms of particle mass.

Q.: Why?

A.: Because we can measure mass.

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Is PM Mass the Right Metric for Health Based Standards?

1. Maybe (for soluble PM).
2. Who knows (for insoluble PM).
3. Continuous measurements of PM mass are difficult to do!

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Health-Based Standards

- The Regulated Parameter is Mass Density (units of g m^{-3})
- Mass Density = Mass per Volume
- Emission Factors and Fluxes are specified in terms of Mass (units of g) per time or activity.

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Visibility Standards

- The Relevant and Regulated Parameter is Extinction (units of m^{-1})
- Extinction = Cross Section per Volume
- Emission Factors and Fluxes <u>should be</u> specified in terms of Cross Section (units of m^2) per time or activity.

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Connection between Extinction Cross-Section and Mass

Ext. Cross-Sect.(m^2) = Ext. Eff.(m^2/g) X Mass(g)

Extinction Efficiency is a function of PM size distribution, refractive index, and morphology!

These parameters are generally not well known!

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Extinction = Scattering +Absorption

All three quantities can be measured in real time with good time resolution:

<u>Extinction:</u> Long path (integrated) or folded path
<u>Scattering:</u> Nephelometer (truncation error)
<u>Absorption:</u> Photoacoustic or Filter-Based

Ambient extinction is normally dominated by scattering

Scattering Cross-Section Emission Factors from Fugitive Dust Emissions

- **Dust Entrainment from Military Vehicles at Fort Bliss, TX**
- **Measurements with Novel Nephelometer**

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Ideal Nephelometer:

- Gives a direct measurement of total scattering of suspended particles, after calibration.
- Independent of aerosol properties such as size, composition and physical composition.

Real Nephelometer => Real Problems:

- Imperfect aerosol sampling => Large particles may not be sampled
- Imperfect wavelength response => Measures only effective scattering
- Truncation errors (light scattered at $<7^0$ and $>170^0$ is not detected) => Does not detect the near-forward scattering from large particle (50%) => 25% cutoff at 2.5 µm.

Reference:

Moosmüller, H. and W. P. Arnott (2003). “Angular Truncation Errors in Integrating Nephelometry.” *Rev. Sci. Instrum.* **74**, 3492-3501.

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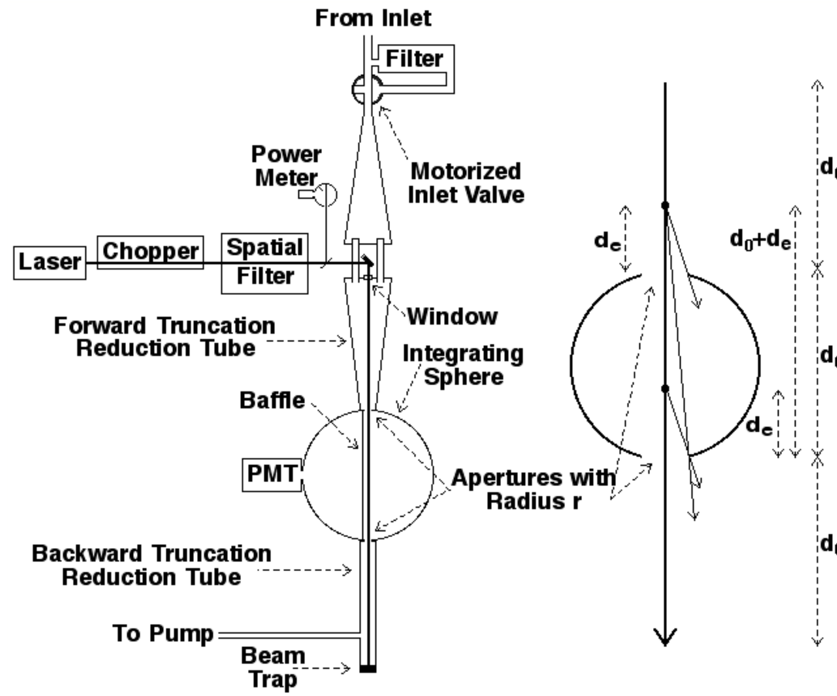
DRI Integrating Sphere Integrating Nephelometer (ISIN)

- Vertical sampling for reduced sampling losses.
- Perfect wavelength response by use of a laser (532 nm).
- Truncation angle reduced to 1^0 and 179^0 through use of truncation reduction tubes => 25% cutoff at 16 µm.



Reference: Varma, R., H. Moosmüller, and W. P. Arnott (2003). "Toward an Ideal Integrating Nephelometer." *Opt. Lett*. **28**, 1007-1009.

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Application of DRI-ISIN at Fort Bliss, TX

- Measurement of visibility impairment from dust entrainment.
- Good agreement of DRI-ISIN with commercial Radiance Research M903 nephelometer for ambient fine particles.
- . DRI ISIN measures up to four times larger scattering than M903 for freshly entrained coarse particle in dust plume.
- This large discrepancy is attributed to the improved angular response, including a reduction of the truncation error by up to a factor of two, and the improved large particle sampling of the DRI-ISIN compared to the M903.

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Emission Factor Methodology

- Absorption = 0 => Extinction = Scattering
- Single vehicles are traveling on unpaved road
- Road is 100 m upwind of measurement tower.
- ISIN scattering measurement at 5.7 m height.
- Wind profile and DustTrak PM profile up to 12.2 m height.

$$EF_{VKT} = \frac{s}{d} = \frac{\int B_{sca}\, dV}{d} = \int B_{sca}\, dA = \int \left(\int v_{\perp}\, B_{sca}\, dt \right) dh$$

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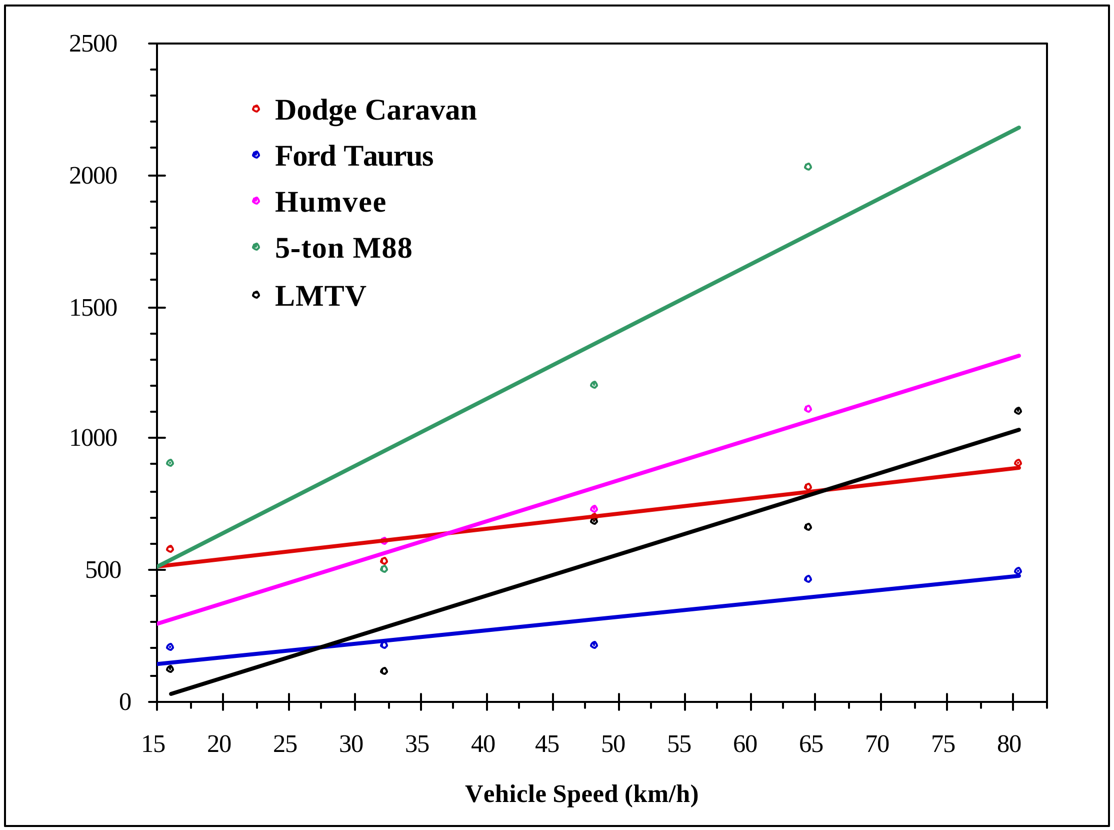
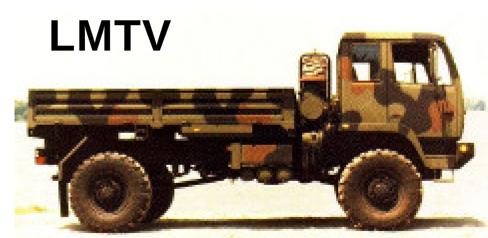
Examples of Emission Factors





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Examples of Emission Factors

- Emission factors are a function of vehicle and speed
- Emission factors are about proportional to speed
- The slope ?(Emission Factor)/?Speed has been calculated

Vehicle	?(Emission Factor)/?Speed
Ford Taurus	5.2 (m^2/VKT)/(km/h)
Dodge Caravan	5.7 (m^2/VKT)/(km/h)
Humvee	12 (m^2/VKT)/(km/h)
LMTV	16 (m^2/VKT)/(km/h)
5-ton M88	25 (m^2/VKT)/(km/h)

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THANK YOU FOR YOUR ATTENTION