Evaluating the Occupational Environment – Particle Behavior

EOH 466B

Spring 2008

Particle Behavior

- Excellent reference: Aerosol Technology. Properties, behavior and measurement of airborne particles, Second Edition by William C. Hinds, Wiley-Interscience, 1999

Particle Behavior

- The physical diameter and density of a particle are important factors affecting behavior of an aerosol. It is convenient to consider particles as spherical.

Particle Behavior

- Stokes diameter is the diameter of a sphere that has the same density and settling velocity as the particle.

Particle Behavior

- Aerodynamic diameter is the diameter of the unit density sphere that has the same settling velocity as the particle.

Particle Behavior

- Terminal settling velocity: can be determined if the size and density of a particle is known. Stokes' law allows an estimation of V_{ts}, for particles between 1 and 100 μ

$$V_{ts} = \frac{gd^2(\rho - \rho_a)}{18\eta}$$

  - g = gravitational acceleration, 9.8 x 10^2 cm / sec
  - d = diameter of particle in cm
  - ρ = density (air = 1.17 x 10^{-3} g/cm^3)
  - η = coefficient of viscosity of air 1.828 10^{-3} g / cm-sec

Particle Behavior

- This can be simplified to
  - $V_{ts} = 0.003 \times SG \times d^2$ at NTP.
  - This equation gives V_{ts} in cm/sec using d in microns.

Compare Physical Diameter and Aerodynamic Diameter

Table 2. Aerodynamic Diameters of Particles with Different Densities

	Low-density particle	ρ_p = 1 gm/cm^3 d_{ps} = 2 µm	d_{pa} = 2.0 µm
	Medium-density particle	ρ_p = 2 gm/cm^3 d_{ps} = 2 µm	d_{pa} = 2.8 µm
	High-density particle	ρ_p = 3 gm/cm^3 d_{ps} = 2 µm	d_{pa} = 3.5 µm

Note: ρ_p = Particle density
d_{ps} = Stokes particle diameter
d_{pa} = Aerodynamic diameter

Particle Behavior

- The equation should be adjusted by the Cunningham slip correction factor, C_C to provide accurate prediction of V_{ts} for particles smaller than 1 micron.

$$V_{ts} = \frac{gd^2(\rho - \rho_a)C_c}{18\eta}$$

Table 1. Cunningham Slip Correction Factors for Air (298° K, 1.0 atm)

d_{pa}(µm)	C_c	d_{pa}(µm)	C_c
0.001	221.6	0.1	2.911
0.002	111.1	0.2	1.890
0.003	74.25	0.3	1.574
0.004	55.83	0.4	1.424
0.005	44.78	0.5	1.337
0.006	37.41	0.6	1.280
0.007	32.15	0.7	1.240
0.008	28.20	0.8	1.210
0.009	25.14	0.9	1.186
0.01	22.68	1.0	1.168
0.02	11.65	2.0	1.084
0.03	7.978	3.0	1.056
0.04	6.151	4.0	1.042
0.05	5.060	5.0	1.034
0.06	4.337	6.0	1.028
0.07	3.823	7.0	1.024
0.08	3.441	8.0	1.021
0.09	3.145	9.0	1.019
		10.0	1.017

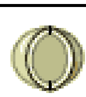
Particle Behavior

- For non spherical particles, V_{ts} must be calculated using a dynamic shape factor, chi, for particle sizes described by the equivalent volume diameter, d_e

$$V_{ts} = \frac{gd^2(\rho - \rho_a)C_c}{18\eta\chi}$$

Compare Different Shape and Aerodynamic Diameter

Table 1. Aerodynamic Diameters of Differently Shaped Particles

	Solid sphere	ρ_p = 2.0 gm/cm³ d_{ps} = 1.4 µm	d_{pa} = 2 µm
	Hollow sphere	ρ_p = 0.5 gm/cm³ d_{ps} = 2.8 µm	
	Irregular shape	ρ_p = 2.4 gm/cm³ d_{ps} = 1.3 µm	

Note: ρ_p = Particle density
d_{ps} = Stokes particle dameter
d_{pa} = Aerodynamic diameter

Particle Behavior

- Stopping distance: when a particle is released at high speed, how far will it travel?
  - This can be calculated, and is related to resistance to travel experienced by the particle. For small particles, generally this is less than 1 cm. Can be significant for denser and larger particles.

Particle Behavior

- Particle size selective samplers apply the principles in V_{ts} to remove particles from an air stream.
  - Cyclones (centrifugal force)
  - Vertical Elutriators (settling velocity)
  - Cascade Impactor (stopping distance)
  - Horizontal Elutriators (settling velocity)

Particle Behavior

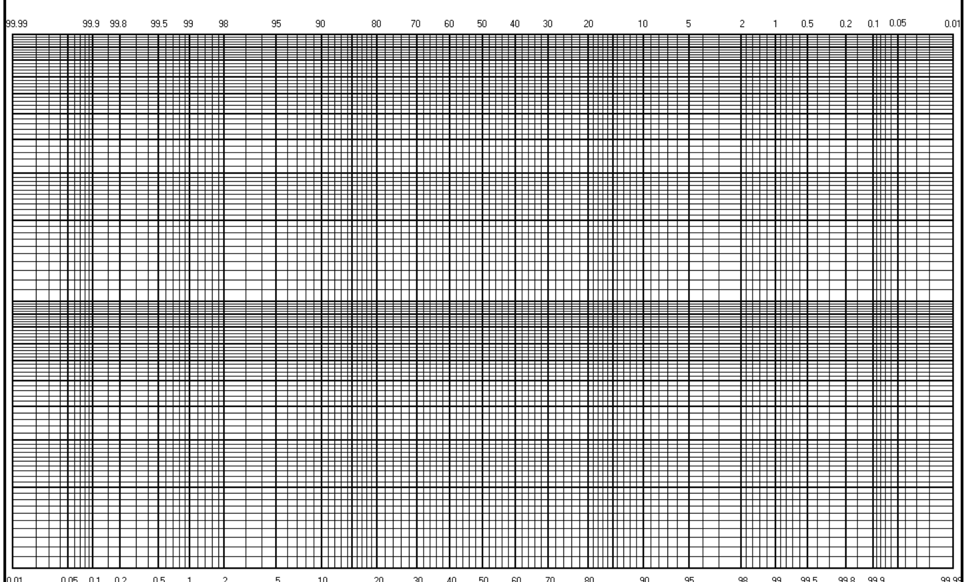
- Particle amount: how much material is present: most often mass, but can be number of particles, radioactivity, surface area, volume or chemical content. Choice of unit depends on application.

Presentation of Particle Size Information

- Cumulative probability plots.
  - Calculate the fraction of total amount in each size class, and sum this fraction from the small to large size classes.
    - Graph this on 'log-probability' paper: a straight line will indicate a lognormal distribution.

Analysis of Particle Count Data

Lower Interval (μm)	**Upper Interval (μm)**	**Midpoint Interval d_i (μm)**	**Number in Interval n_i**	**Fraction Interval (%)**	**Cumulative Fraction less Than d_i (%)**
0.46	0.54	0.50	3770	0.74	0.74
0.54	0.63	0.585	13,000	2.56	3.30
0.66	0.74	0.685	55,100	10.84	14.14
0.74	0.86	0.80	62,900	12.38	26.52
0.86	1.0	0.93	98,800	19.44	45.96
1.0	1.2	1.1	109,000	21.45	67.41
1.2	1.4	1.3	98,800	19.44	86.85
1.4	1.6	1.5	37,200	7.32	94.17
1.6	1.8	1.7	17,000	3.35	97.52
1.8	2.2	2.0	9710	1.91	99.43
2.2	2.5	2.35	2850	0.56	99.99
2.5	2.9	2.7	52	0.01	100
			508,182		



Sample method development

- NIOSH Applet is important to review.
- Concepts:
  - Precision, bias, accuracy
  - Detection limit
  - 95 % accuracy
  - Sample stability
  - Walk through the applet