Lecture 15: Transport and Fate; Contaminants in the Atmosphere II

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Discussion on Pasquill-Gillford Plume Model Continued

- Turbulence that mixes air pollutants comes from interactions with buildings and trees but also the heating of the ground surface from the sun (figure 4-8).
- So σ for y and z are also dependant on prevailing atmospheric conditions especially wind velocity and atmospheric stability.
- A widely used approach to estimate σ for y and z is to use atmospheric stability categories based on wind speed, cloudiness and insolation (solar heat input). See Table 4-6, page 338.

Correlation of σ for y and z with Stability Categories, Figure 4-25, page 340

- Category A-Intense Sunshine, B & C refer to less unstable conditions, D is neutral stability and E & F refer to stable conditions with atmospheric inversions.
- Standard deviation of mass distribution in the y plane and z planes are on figure 4-25 by distance from source.
- Note that the less stable categories have slopes that change more rapidly with distance downwind.

Example 4-8, Page 340

- Smokestack Effective Height, 25m; emits SO_2 at 10kg/hr. What is the contribution of this stack to ground level [SO_2] at a school yard 8km downwind-if wind speed is 4.5 m/sec on a sunny midwinter day? (assume unlimited mixing height)
- Use [4-16] **$C=Q/u\ (g_1\ g_2/2\pi\ \sigma y\ \sigma z)$** From Table 4-6 a wind speed of 4.5 m/sec is a Pasquill stability category C (winter when insolation is low).
- Use Figure 4-25 and σ for y and z are 700m and 400m respectively (remember that y=0 directly downwind and z=0 at ground level). So;
- $Q/u= (10kg/hr)/(4.5\ m/sec*3600\ sec/hr)=6.2*10^{-4}$ kg/m
- Now use [4-17] to estimate the Gaussian Distribution Factors

$g1 = \exp(-0.5*0^2/700m^2)=1$

$g2= \exp(-0.5\ (-25m)^2/\ 400m^2) + \exp(-0.5\ (25)^2/\ 400m^2)=2$

So $C_{school\ yard}= 6.2*10^{-4}$ kg/m* (1) (2)/2π*700m*400m= $7.0*10^{-10}$ kg/m^3

Example 4-8, Page 340- Continued

- Use the formula on page 342, Table 4-7 instead of the graphs to obtain **σy σz** – for open rural country
- **σy = 0.11*8000m/(1+ 0.0001* 8000m)$^{.5}$= 660m**
- **σz =.08 *8000m/(1+0.0002*8000m) $^{.5}$ = 400m**
- **So C becomes** 8.0*10^{-10} kg/m^3 –indeed close to the graph estimation.

Calculating σ for y and z, Empirically and using other Models

- See Table 4-7 on page 342.
- If mixing height L [L] is low and restricts plume ascension-assume the plume is fully mixed below L and spread out only horizontally, here use-

$C=Q/u\ (g_1/2\pi\ \sigma y)*\ 1/L$

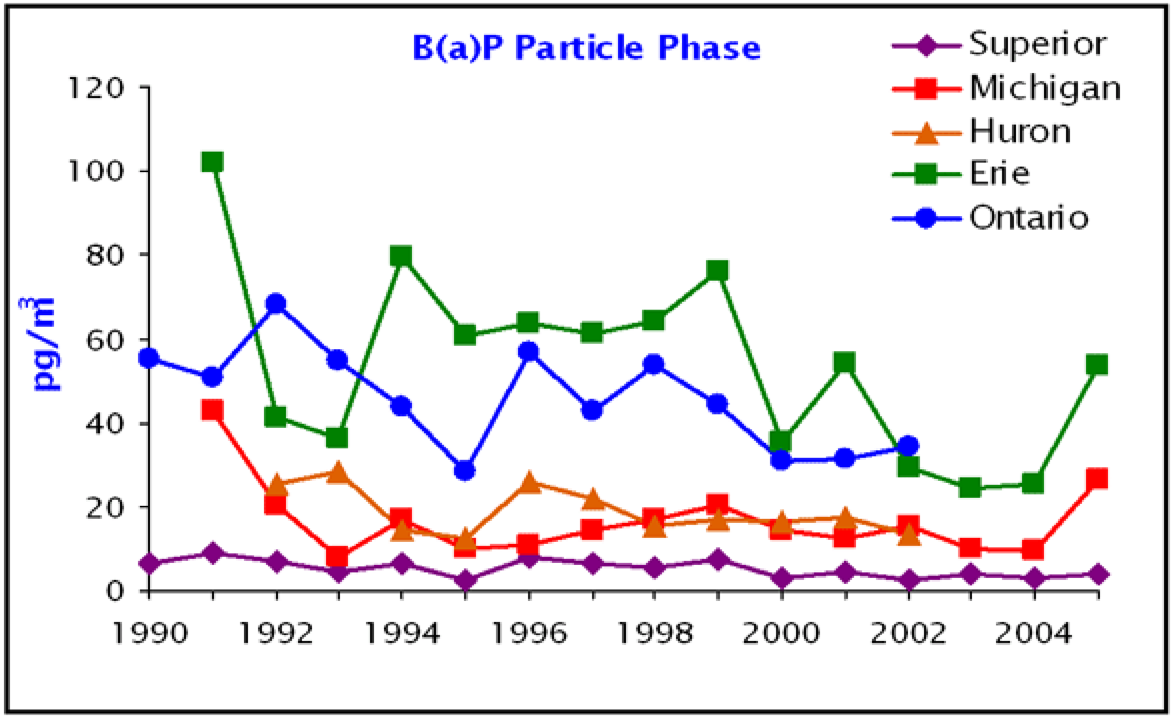
- The best method to estimate σ for y and z is when you take direct measurements of turbulence-which can be estimated from continuous measurements of wind velocity in the x, y and z planes. See figure 4-26, page 343. Knowing this we could use Pasquill measures to obtain estimates of turbulent intensity in the lateral and vertical planes.
- [4-21] So turbulent intensity (unitless) $i_y = \sigma y/u$. The formula is the same in w direction and here the standard deviation is of the wind velocity.
.
- σ for y and z can be obtained by σ = i*f*x where f are semiemperical functions of distance and stability categories in both planes—See Table 4-8, page 344.

Example 4-9, page 345

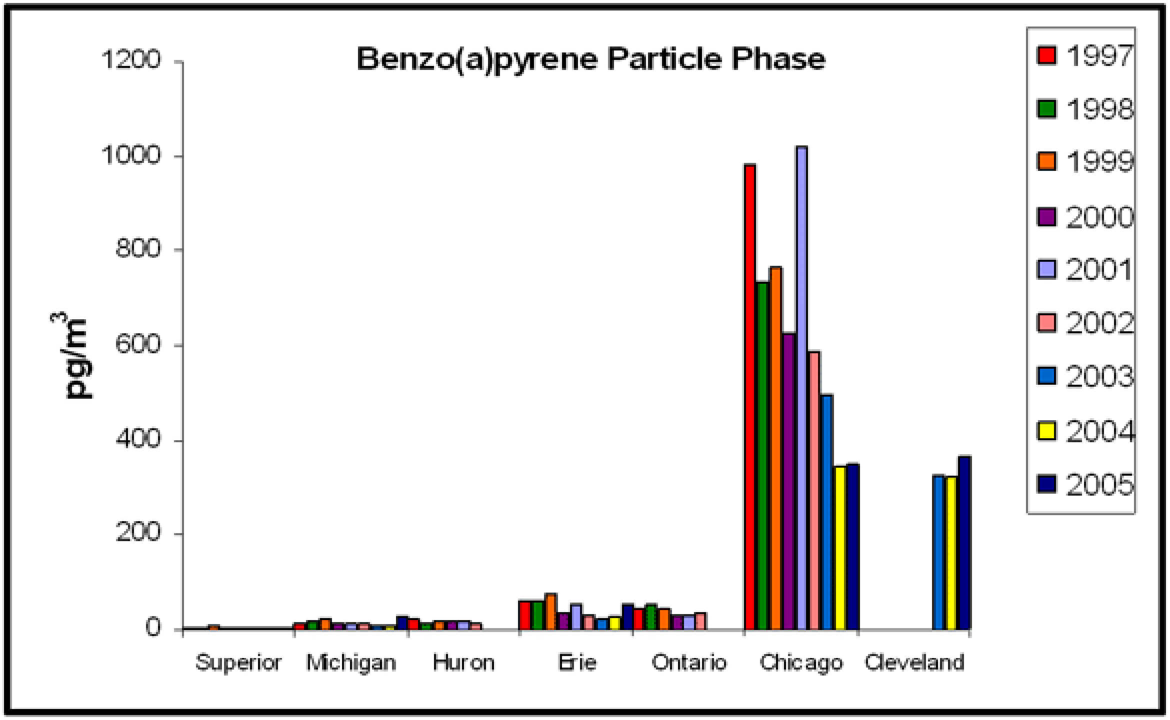
- Smelter stack in rural area emits very fine particulate containing Pb, Cu and Ni. Ni rate is 0.1g/sec at effective stack height of 120m and the wind speed is 5.5m/sec (insolation is slight). Data from a vertical oriented wind velocity instrument, which produces data corresponding to the plot of w' versus time in Fig 4-26 gives the std. dev. of vertical air velocity of 0.15 m/sec. The standard deviation of wind velocity in y plane is 0.25 m/sec. What is the [Ni] at ground level directly downwind at 8km from the stack?
- Using Table 4-6 the Pasquill stability category is D and turbulent intensity in the vertical direction is given by Eq[4-21] i_z= σw/u = 0.15 m/sec/ 5.5 m/sec = 0.027 and the lateral turbulent intensity is i_y= σv/u =0.25 m/sec/5.5 m/sec = 0.045.
- So we must now arrive at σ for y and z by σ = i*f*x but need first the semiemperical functions of distance and stability (table 4-8) therefore
- fz= 1/(1+0.0015*8000m)$^{.5}$= 0.28 so σz = i*f*x =(.027)*(.028)*(8000m)= 61m and
- fy= 1/ /(1+0.0001*8000m)$^{.5}$= 0.75 so σy = i*f*x =(0.045)*(0.75)*(8000m)= 271mm
- So using 4-16 **C=Q/u (g_1 g_2/2π σy σz) the nickel concentration is**
- **C=0.1g/sec/5.5m/sec*** exp(0) * exp (-0.5 (-120$)^2$/ 61m^2) + exp (-0.5 (120$)^2$/ 61m^2) /2π (271m) (61m)= 4.9*10^{-8} g/m^3

Particulate Size and Size Distribution

- Monodisperse or polydisperse-the first term means particles are the same size but the second implies a distribution of sizes.
- All particulate matter in the atmosphere is polydisperse.
- Polydisperse particles usually have a natural or log normal distribution and the cumulative distribution plots of yields a straight line when log of diameter is plotted against cumulative mass, area or number-see Figure 1-1 in Hesketh.
- Note that size distribution by mass-area and number have essentially the same slope so they also have the same geometric standard deviation.
- One way to relate mass mean $đ_m$ and number medians $đ_n$ is by;
- In $đ_m / đ_n = C1 \ln^2 \sigma_g$ and C1-a constant is 2.66. And $\sigma_g = d_{84.13}/đ$ to use the table on 1.1 we must specify if we are referring to mass, area or number.
- In figure 1.1 the mean diameter by number is .98μ and the mass mean diameter MMD is 9.5μ. A formula for the MMD of spherical particles is
- MMD $=(\text{mass mean}/(1/6)\pi\rho)^{1/3}$ where ρ is the density of the particle.-for other than a spherical particle an aerodynamic equivalent diameter can be found.



http://www.epa.gov/glindicators/air/airb.html


Benzo(a)pyrene Particle Phase
pg/m3
1200
1000
800
600
400
200
0
Superior
Michigan
Huron
Erie
Ontario
Chicago
Cleveland
1997
1998
1999
2000
2001
2002
2003
2004
2005

Particle Removal by Dry Deposition

- There are three types-gravitational settling, impaction and absorption
- Gravitational Settling is the most important route of deposition for particles-especially those larger than 1 micron.
- The rate of settling can be estimated by Stokes Law-which expresses settling velocity as a function of size and density of particle and viscosity of the fluid.-**Remember air viscosity is much lower than water so settling velocity is much higher and air density is a negligible fraction of particle density.**
- Stokes law is applicable to spherical particles when no turbulence is created by the particle and when the diameter is less than 100 microns.
- $W_f = (2/9)g*r^2*\Delta\rho/\mu_f$
- Where settling velocity is equal to 2/9 the acceleration due to gravity times the particle radius squared times the difference between the particle and fluid density divided by the dynamic viscosity of the fluid.
- Dynamic viscosity is also the coefficient of viscosity and that the dynamic viscosity divided by density gives kinematic viscosity as in 2-20 on page 95.
- Dynamic viscosity increases with temperature for gases. At 18 degrees C the dynamic viscosity of air is $1.83*10^{-4}$ **poise in g/(cm*sec).**
- **For particles of < 1 micron in radii with a density of 1 g/cc gravitational settling can be neglected-cover again.**
- Although particles may not settle directly they can form larger particles by collision and coagulation. Small particles are often removed from air by forms of precipitation.

Settling Velocity

- $v_s = d^2 g\rho / 18\mu_g$ for .01< Reynolds Number< .1 microns (Continuous Regime)
- Where v_s is settling velocity, d is diameter, g is acceleration due to gravity, ρ is particle density and μ_g is the viscosity of the gas.
- Reynolds number is a useful relationship to fluid flow and his overall system is used to obtain critical velocities where flow changes from laminar to turbulent.
- RN particle = d (v particle-v gas)ρ particle/viscosity of gas
- There are other particle size regimes as shown in figure 1.8 of Hesketh and this even determines the ability to settle– Particles in the Free Molecule Regime—really move mostly by diffusion and settling becomes unimportant in their physics.

Impaction

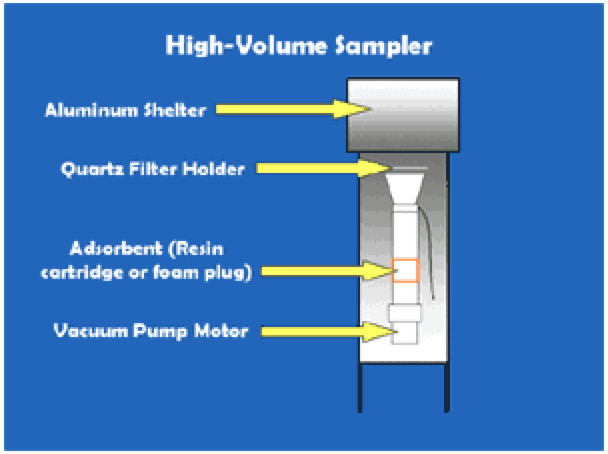
- Impaction occurs when air having particles flows past stationary objects.
- As moving air is deflected by the object some particles are also deflected. But some particles with larger size-mass cannot make the acute turn and contact the object (this is one reason that certain particles are taken out in the nose –throat and bifurcation of the bronchi).
- Contact is most likely for particles that pass through a stagnation point in front of the object at which fluid velocity is 0.
- As we have seen some particles are so small they don’t settle and these free ranging molecular range particles do not impact but only diffuse.
- A flux density of particles can be calculated as a product of a deposition velocity and concentration of particles in air.-So;
- J= V deposition * C particles see 4-25 on page 357
- Go over Example 4-12

Absorption of Gases

- The third mechanism for dry deposition.
- Atmospheric gases are adsorbed on to solid surfaces like soil or vegetation.
- This is done by a thin layer model like that for air-water transfer. See figure 4-31 with an adjacent stagnant boundary layer of air.
- We then assume that any gas that diffuses through the stagnant air layer is adsorbed to the surface-the flux of vapor onto the surface is given by;
- $J = (C \text{ air} - C \text{ at surface}) * D/\sigma$ the flux density of vapor in mass per length squared times time is equal to the vapor concentration in bulk air minus the vapor concentration at the solid surface times the vapors diffusion coefficient in air in length squared per time divided by the thickness of the stagnant air layer.

The high volume sampler collects pollutants in the gas and particle forms. A vacuum pump inside the air sampler pulls air through a filter and then through an adsorbent (resin or a foam plug) over a 24-hour period. Both the adsorbent and filter are sent to a laboratory for analysis after the 24-hour period is over.

Particles are caught on the filter. The adsorbent captures the pollutants in the gas form. At the laboratory, the pollutants on the filter and in the adsorbent are measured. The amount of each pollutant on the filter is used to determine the concentration in the air as particles. The amount in the adsorbent tells us the concentration in the gas form in the air. These two concentrations help determine the amount of pollutants transferred into the Great Lakes by dry deposition (particles) and gas absorption, respectively.



http://www.epa.gov/glindicators/air/airb.html