Aerosol Concentrations and Atmospheric Residence Times

Aerosol concentrations are reported as a number density (# particles/m^3) or a mass density (μg/m^3).

Typical values range from 10 – 500 μg/m^3, ranging from rural temperate climates to coastal areas or arid interior climates.

Urban areas → 200 μg/m^3

Rural forested areas → 10- 50 μg/m^3

Open ocean → 10- 150 μg/m^3

Settling velocity (due to gravity) is governed by;

$$v_t = \frac{(\rho_P - \rho_{air}) C\, g\, d_P^{\,2}}{18\,\eta}$$

where;

- ρ_P is density of the aerosol particle (in g/m^3)
- ρ_{air} is density of the surrounding air (1.2×10^3 g/m^3; at P=1.0 atm & T = 298K)
- C is a correction term which depends on the particle diameter (from Table 6.4)
- g is 9.81 m/s^2
- d_P is the particle diameter (in m)
- η is the viscosity of surrounding air (1.9×10^{-2} g/m s; at P=1.0 atm & T = 298K)

Co-agulation rate is governed by;

$$\text{rate of change in the number of aerosol particles(N)} = \frac{-\,dN}{dt} = 4\,\pi\, D\, C\, d_P\, N^2$$

where;

- N is number density of the aerosol particles (in particles/m^3)
- D is the diffusion co-efficent of the aerosol particle
- C is a correction term which depends on the particle diameter (from Table 6.4)
- d_P is the particle diameter (in m)

Since D, C and d_P are constants, this can be re-written as $\frac{-\,dN}{dt} = k_2\, N^2$ where;

k_2 is analogous to a second order rate constant given by $k_2 = 4\pi\, D\, C\, d_P$

Table 6.4 Aerosol transport properties assuming spherical particles, density 2.0 g cm^{-3}, in air at P^o and 25 °C

d_p/μm	C	v_t/cm s^{-1}	D/m^2 s^{-1}	$t_{1/2}$
0.001	216		5.14×10^{-6}	1 min
0.005	43.6		2.07×10^{-7}	0.5 h
0.01	22.2		5.24×10^{-8}	2 h
0.05	4.95		2.35×10^{-9}	38 h
0.1	2.85	1.7×10^{-4}	6.75×10^{-10}	110 h
0.5	1.326	2.0×10^{-3}	6.32×10^{-11}	520 h
1.0	1.164	6.8×10^{-3}	2.77×10^{-11}	690 h
5.0	1.032	1.5×10^{-1}		
10.0	1.016	6.0×10^{-1}		
50.0	1.003	15		
100.0	1.0016	58		

For half-life calculations, particle number density in the atmosphere is taken as 10^9 m^{-3}.

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Solved problems for Atmospheric Aerosols

Q1. Compare the settling velocity of 10 µm diameter water droplets to that of carbon soot particles (density = 2.5 x 10^3 kg/m^3). The correction term for a droplet of 10 µm diameter is 1.016, the viscosity of surrounding air is 1.9 x 10^{-5} kg/m s, the acceleration due to gravity is 9.8 m/s^2, and air density is 1.2 kg/m^3.

Solution

$$v_t = \frac{(\rho_d - \rho_{air})Cgd_d^2}{2\eta}$$

$\rho_{air} = 1.2 \text{ kg/m}^3$, $C = 1.016$, $g = 9.8 \text{ m/s}^2$, $\eta = 1.9\times10^{-5}$ kg/m

$\rho_d = 2.5\times10^3$ for soot, and $\rho_d = 1000 \text{ kg/m}^3$ for water

$d_P = 10 \text{ µm} = 10\times10^{-6}$ m

For soot

$$v_t = \frac{(2.5\times10^3 - 1.2)\times1.06\times9.8\times(10\times10^{-6})^2}{18\times1.9\times10^{-5}}$$

$$v_t = \frac{2.60\times10^{-6}}{3.42\times10^{-4}} = 0.760\times10^{-2} \text{ m/s}$$

For water

$$v_t = \frac{(1000 - 1.2)\times1.06\times9.8\times(10\times10^{-6})^2}{18\times1.9\times10^{-5}}$$

$$v_t = \frac{1.04\times10^{-6}}{3.42\times10^{-4}} = 0.304\times10^{-2} \text{ m/s}$$

$$\frac{v_t(\text{soot})}{v_t(\text{water})} = \frac{0.760\times10^{-2}}{0.304\times10^{-2}} = 2.5$$

the soot particles will settle 2.5 times faster than water droplets of equal size

Q2, How long will it take for a collection of fine aerosol particles ($N = 10^9$ m^{-3}; d_P = 0.01µm) to drop to 5 x 10^8 m^{-3} through co-agulation processes.

$$-\frac{dN}{dt} = k_2 N^2$$

$$k_2 = 4\pi D C d_P$$

$$\int_{N_o}^{N_f} \frac{dN}{N^2} = k_2 \int_0^t dt$$

$$\left(-N^{-1} \Big|_{N_o}^{N^f} \right) = k_2 t$$

$$-\frac{1}{N^f - N_o} = k_2 t$$

$$t = -\frac{1}{k_2 (N^f - N_o)} = -\frac{1}{4\pi D C d_P \times (N^f - N_o)}$$

$$t = -\frac{1}{(4\pi \times 5.24 \times 10^{-8} \times 22.2 \times 0.01 \times 10^{-6})(5 \times 10^8 - 10^9)}$$

$$t = -\frac{1}{14.61 \times 10^{-14} \times (-5 \times 10^8)} = \frac{1}{7.3 \times 10^{-5}} = 13698 \text{ s}$$

$$t_{1/2} = \frac{13698}{2} = 6849 \text{ s} = 6849 \text{ s} \times \frac{1 \text{ hr}}{3600 \text{ s}} \approx 2 \text{ hr}$$