ChEn 374
Fluid Mechanics

Environmental Considerations

Spiritual Thought

"Now, in conclusion: the earth and all life thereon are much more than items to be consumed and/or conserved; some parts and portions thereof are also to be preserved! As we nurture and appreciate nature, we will become better acquainted with our God, for unspoiled nature is designed to inspire and uplift humankind. Nature in its pristine state brings us closer to God, clears the mind and heart of the noise and distractions of materialism, lifts us to a higher, more exalted sphere, and helps us to better know our God.

…Our test on this earth is whether we will choose wisely and follow God, treat His creations with respect, and use them to bless our fellow man and woman. The better we care for this world and all in it, the better it will sustain, inspire, strengthen, enliven, and gladden our hearts and spirits—and prepare us to dwell with our Heavenly Father with our families in a Celestial sphere, which members of the LDS Church believe will be the very earth upon which we stand today, but in a glorified state."

Elder Marcus B. Nash

OEP # 7 Clip

OEP #7

Open Ended Problem #7
The REAL castaway
GROUP WORK OKAY, Due 11/4/15 at beginning of class

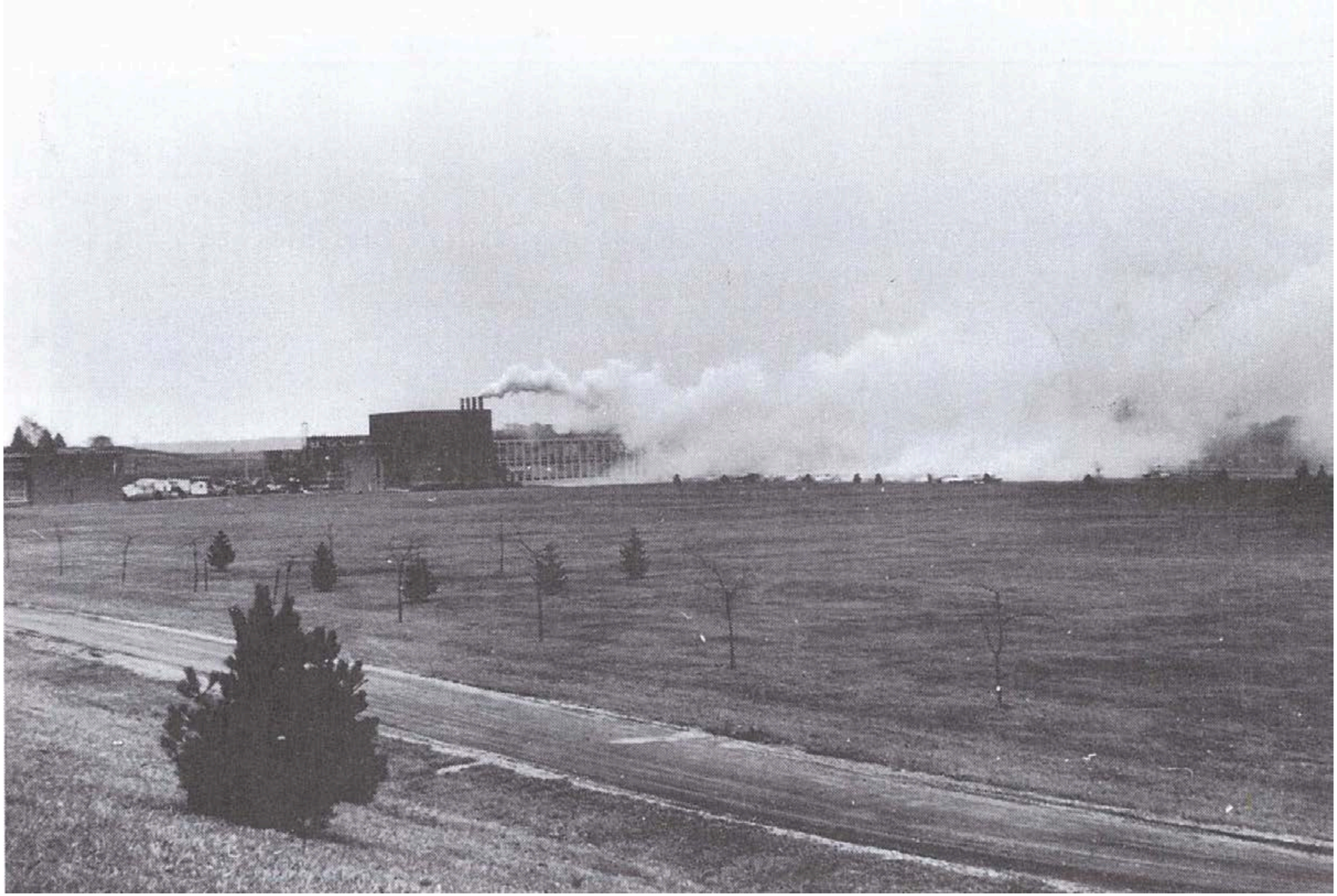
After 18 days on Mars (well, actually 18 sol, but it's close enough), a massive storm forces the abortion of the first manned mission to mars. Astronaut Mark Watney is unfortunately standing in the wrong place at the wrong time, and he is smashed out of sight by a communications array that was knocked off its structure by the wind. Apparently the storm wind force of 8600 N was enough to knock this array loose. What is the wind speed required (on the Martian planet) in order to create 8.6 kN of force on the communications array dish? (hint – we're talking about a force caused by fluids here…)

Environmental Aspects of Fluid Mechanics

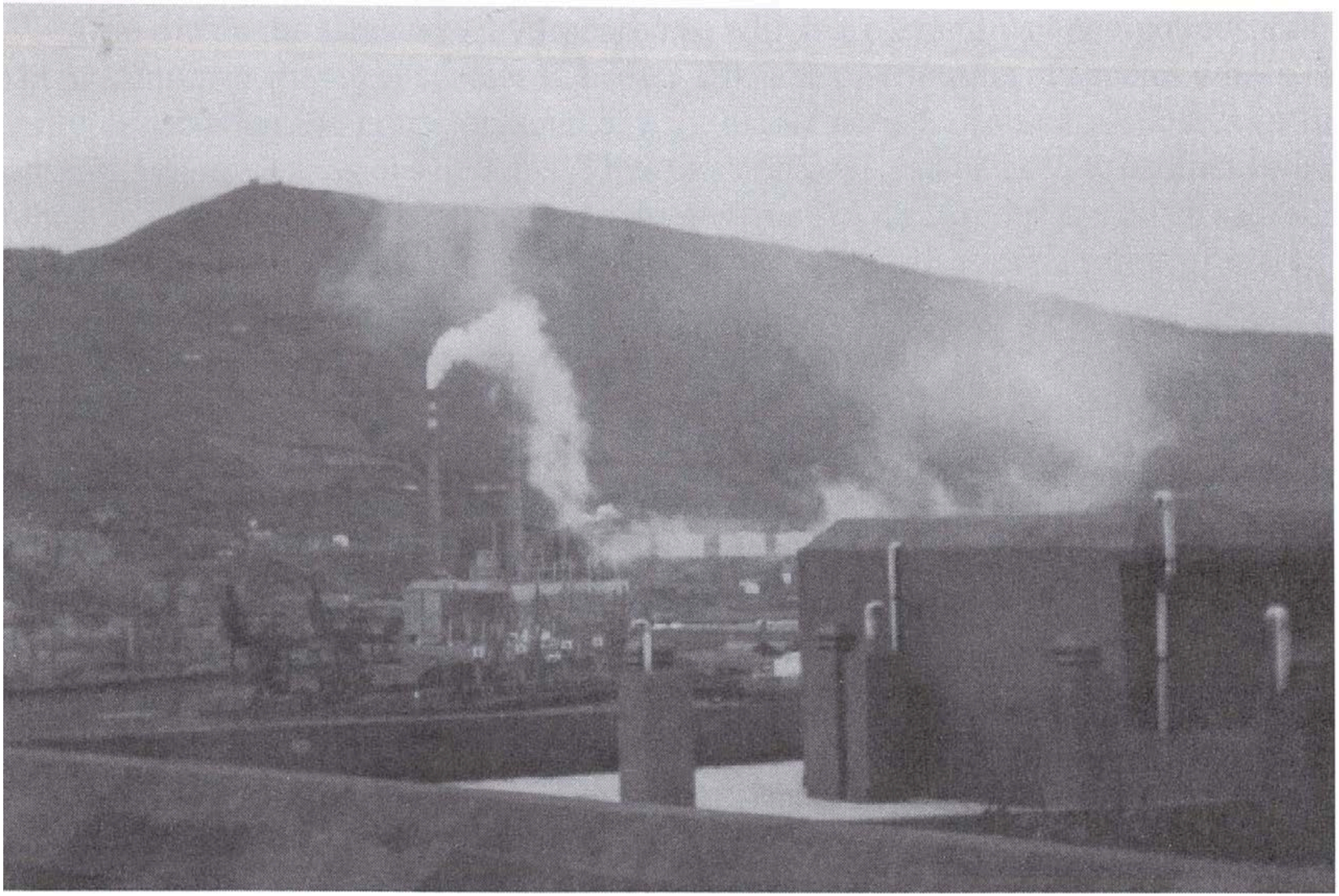
- We are stewards of the Earth and should take care of it.
- Several fluid mechanics related issues
  - Pollution
    - Liquid spills
    - Effluents
    - Leaching
    - Air pollution from emitted substances
  - Environment
    - Meteorology
    - Wind for energy
    - Ocean currents

Smokestacks

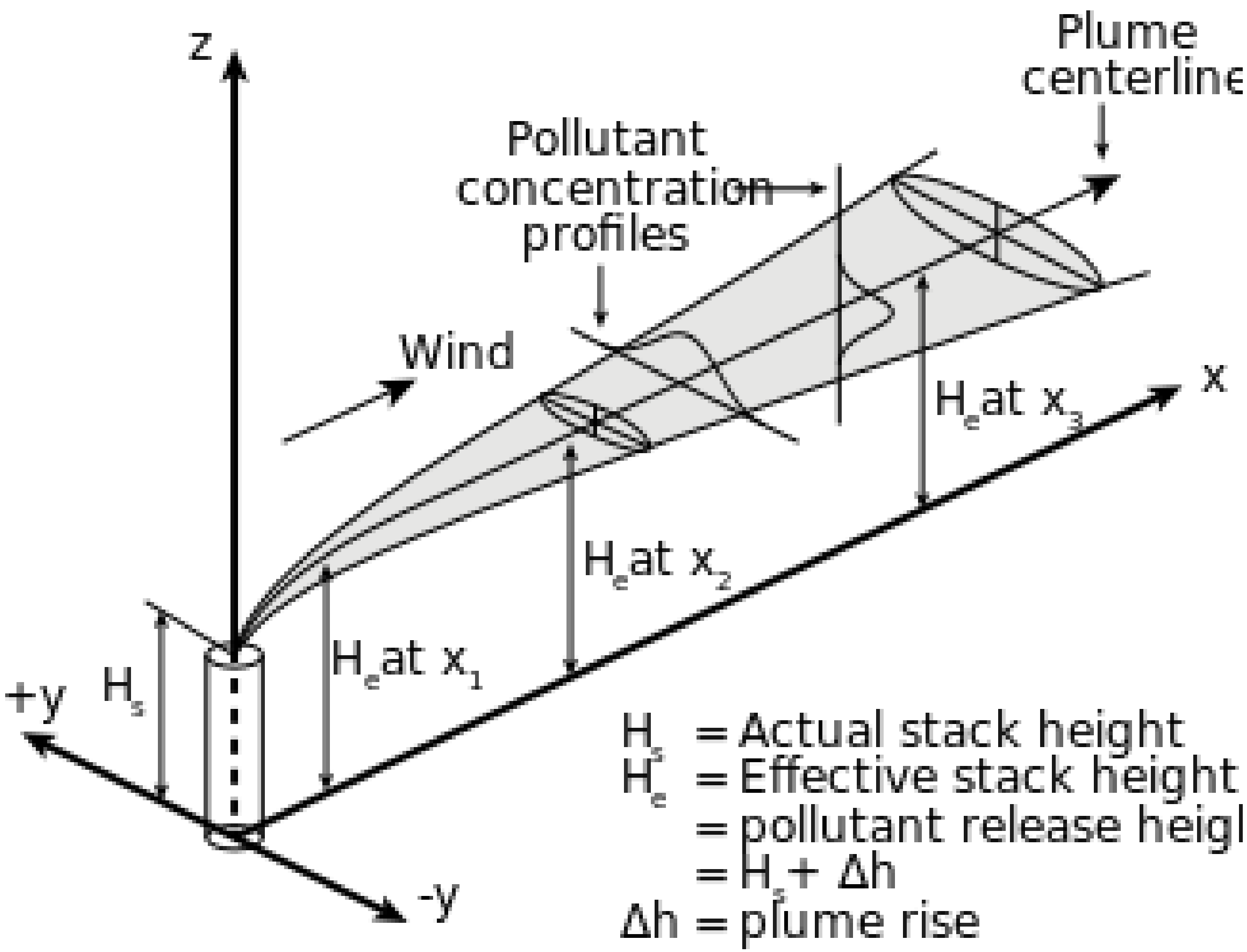
Air pollutant dispersion



Fumigation



Plume Dispersion



Plume dispersion

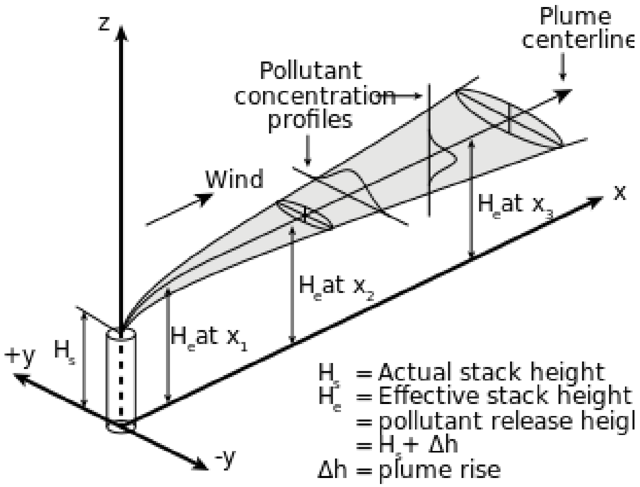
- Model as a Gaussian plume
- Pollutants emitted are convected downstream and spread by turbulent eddies
- Diffusion equation

$$\frac{\partial c}{\partial t} = \mathcal{D}_x \frac{\partial^2 c}{\partial x^2} + \mathcal{D}_y \frac{\partial^2 c}{\partial y^2} + \mathcal{D}_z \frac{\partial^2 c}{\partial z^2}$$

  – Use turbulent diffusion coefficients

- Solution: ignoring streamwise dispersion:

$$c = \frac{Q}{2\pi u \sigma_y \sigma_z} e^{-\left(\frac{y^2}{2\sigma_y^2} + \frac{(z-H)^2}{2\sigma_z^2}\right)}$$

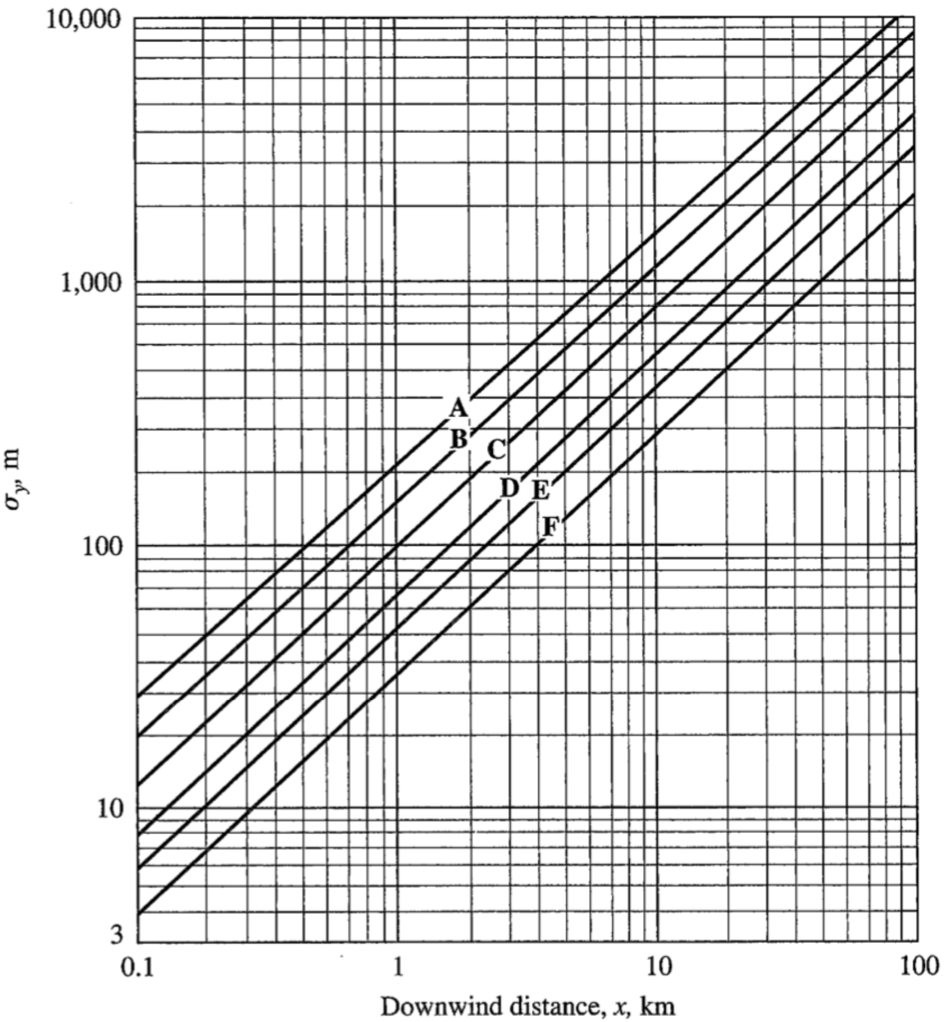


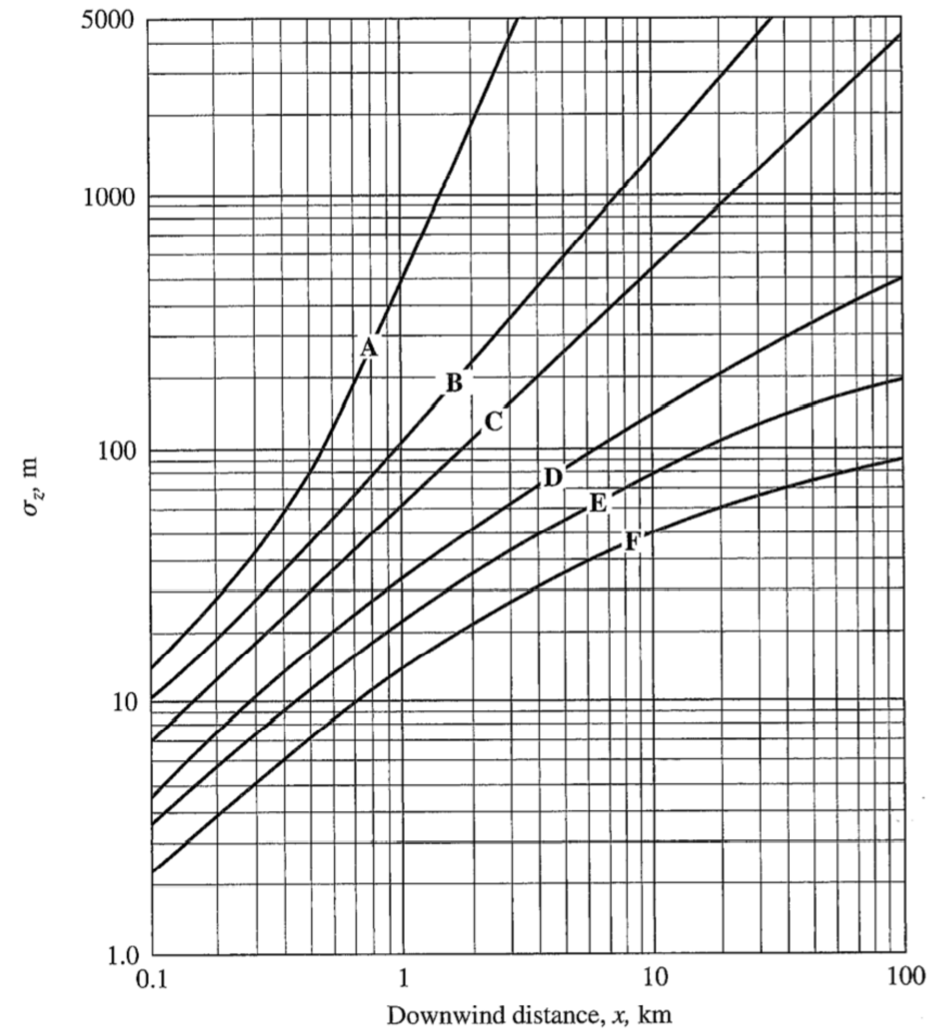
- H is stack height
- Q is emission rate (kg/s)
- u is wind speed
- c is concentration (kg/m^3)
- σ are dispersion factors

Plume dispersion

$$c = \frac{Q}{2\pi u \sigma_y \sigma_x} \exp - \left(\frac{y^2}{2\sigma_y^2} + \frac{(z-H)^2}{2\sigma_z^2} \right)$$

From de Nevers Fluid Mechanics for Chemical Engineers, 3[rd] ed.





Plume Dispersion

Stability category		$x \le 1$ km			$x \ge 1$ km		
	a	c	d	f	c	d	f
A	213	440.8	1.941	9.27	459.7	2.094	−9.6
B	156	106.6	1.149	3.3	108.2	1.098	2.0
C	104	61	0.911	0	61	0.911	0
D	68	33.2	0.725	−1.7	44.5	0.516	−13.0
E	50.5	22.8	0.678	−1.3	55.4	0.305	−34.0
F	34	14.35	0.740	−0.35	62.6	0.180	−48.6

$$\sigma_y = ax^{0.894}$$

$$\sigma_z = cx^d + f,$$

Key to stability categories

Surface wind speed (at 10 m), m / s	Day* Incoming solar radiation: Strong	Moderate	Slight	Night* Thinly overcast or ≥4 / 8 low cloud	≤3 / 8 Cloud
0–2	A	A–B	B	—	—
2–3	A–B	B	C	E	F
3–5	B	B–C	C	D	E
5–6	C	C–D	D	D	D
≥6	C	D	D	D	D

*The neutral class, D, should be assumed for overcast conditions, day or night.

From de Nevers Fluid Mechanics for Chemical Engineers, 3rd ed.

Homework

Equation 19.22 is our best current prediction method for the concentration in steady-state plumes far above the ground. However, we are generally most interested in concentrations at ground level because people and property are exposed at ground level.

From de Nevers Fluid Mechanics for Chemical Engineers, 3rd ed.

The blind application of Eq. 19.22 at or near ground level gives misleadingly low results. The reason is that it indicates that the pollutants continue to disperse at any value of z, even at z less than zero. (Using it alone, we could continue Example 19.9 and compute the concentration underground; the result would bear no relation to what we would observe in nature.) For this reason, it is necessary to account for the effect of the ground.

The ground damps out vertical dispersion. The upward and downward turbulent eddies that spread the plume in the vertical direction cannot penetrate the ground. Thus, the vertical spreading terminates at ground level. The method commonly used to account for this in calculations is to assume that the pollutants that would have carried below $z = 0$ if the ground were not there are "reflected" upward as if the ground were a mirror. Thus, the concentration at any point is that due to the plume itself, plus that reflected upward from the ground. This is equivalent to assuming that there is a mirror-image plume below the ground that transmits as much up through the ground surface as the above-ground plume would transmit down through the ground surface if the ground were not there.

(this is Eq. 19.22)

$$c = \frac{Q}{2\pi u \sigma_y \sigma_z} e^{-\left(\frac{y^2}{2\sigma_y^2} + \frac{(z-H)^2}{2\sigma_z^2}\right)}$$

The concentrations due to the "mirror-image" plume are exactly the same as those shown by Eq. 19.22, except that the $(z - H)^2$ term is replaced by $(z + H)^2$. At the ground, $z = 0$, both the main plume and the mirror-image plume have identical values. High in the air, for example, at $z = H$, the main plume has a high concentration $[\exp - (0) = 1]$ while that for the mirror-image plume $[\exp - (2H)^2 \text{ etc.}]$ is a small number. The combined contribution of both plumes is obtained by writing Eq. 19.22 and the analogous equation for the mirror-image plume, adding the values for the two plumes and factoring out the common terms to find

$$c = \frac{Q}{2\pi u \sigma_y \sigma_z} e^{\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right]} \cdot \left[e^{-0.5\left(\frac{z-H}{\sigma_z}\right)^2} + e^{-0.5\left(\frac{z+H}{\sigma_z}\right)^2}\right]$$

(*a*) Show the form that this equation takes for a point directly downwind of the source ($y = 0$) and at ground level ($z = 0$). This form is the most widely used simple point-source air-pollution modeling equation.

(*b*) Using that equation, estimate the concentration at ground level, directly under the plume centerline, at $x = 1$ km, for $H = 100$ m, $Q = 10$ g / s, $u = 3$ m / s, and C stability.