Department of Civil Engineering-I.I.T. Delhi
CEL 212: Environmental Engineering
Second Semester 2011-2012
Home Work 12 Air Pollution Solution

Correction:
For determining velocity at height Z:

$$[v/v_0]=[z^k]/z_0 \qquad \text{where } k=1/7$$

Problems

Q1. Define following terms and show figure if necessary:

- **(i)** **Neutral plume**
- **(ii)** **Looping plume**
- **(iii)** **Ambient lapse rate**
- **(iv)** **Adiabatic lapse rate**
- **(v)** **Maximum pollutant concentration at ground and at source height**
- **(vi)** **Inversion (when surface temperature is cooler than temp. at some height)**
- **(vii)** **Need for calculating additional height using the Holland's formula (i.e., plume rise)**
- **(viii)** **importance of wind speed and direction in determining ground level pollutant concentrations**
- **(ix)** **Pasquill stability classes**
- **(x)** **Dispersion constants**

Q2. Given that dry adiabatic lapse rate (Γ) = (-) 1°C/100m (in this question, this is for information and no question is being asked here)

lapse rate (°C/m)	**atmospheric conditions (stable/unstable/neutral)**	**plume type**
-0.0209	unstable	looping
-0.0125	unstable	looping
-0.01	neutral	coning (i.e., cone like shape about the plume line)
lapse rate is negative (i.e., temp. increases with height)	extremely stable air (inversion case)	fanning (here plume spread horizontally with minimal vertical mixing

Q3. Comment on plume types observed during early morning and late evening in summer and winter seasons.

Solution:

time of day	**season**	**plume type**
early morning	summer	End of surface inversion (i.e., fanning) as surface temp. is becoming warmer due to Sun and thus start of unstable condition (fumigation situation as surface temp. is becoming warmer but air above is still cooler)
	winter	End of surface inversion (i.e., fanning) as surface temp. is becoming warmer due to Sun and thus start of unstable condition (fumigation situation as surface temp. is becoming warmer but air above is still cooler) (this could delay depending on temp. during winter season)
late evening	summer	Start of surface inversion (i.e., fanning) as surface temp. is becoming warmer and thus start of unstable condition
	winter	Start of surface inversion (i.e., fanning) as surface temp. is becoming warmer and thus start of unstable condition

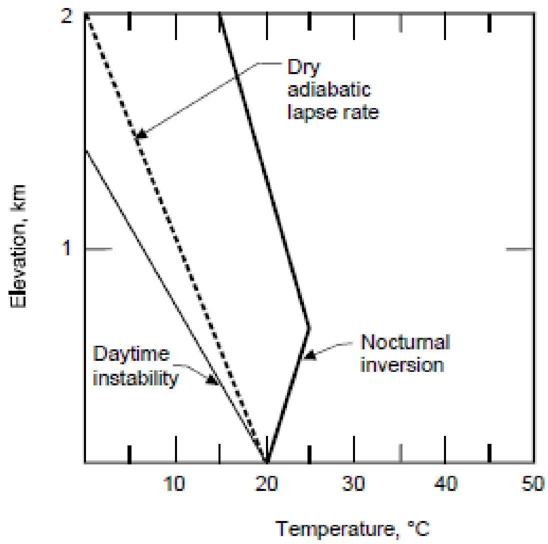

Figure 4-14. Diurnal cycle

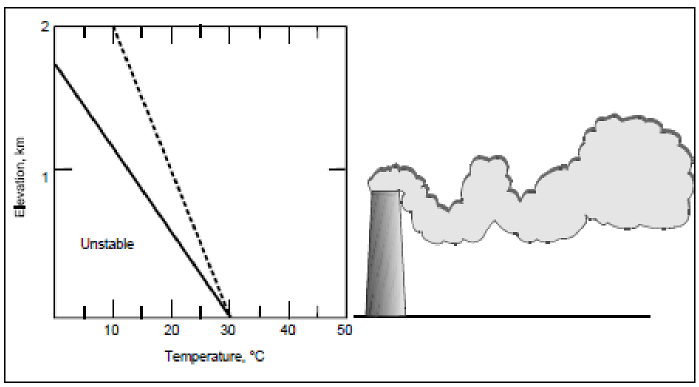

Figure 4-19. Looping plume

The **fanning plume** (Figure 4-20) occurs in stable conditions. The inversion lapse rate discourages vertical motion without prohibiting horizontal motion, and the plume may extend downwind from the source for a long distance. Fanning plumes often occur in the early morning during a radiation inversion.

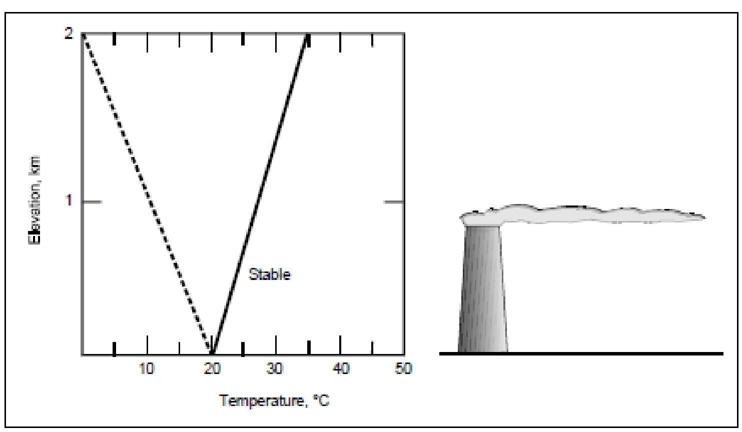

Figure 4-20. Fanning plume

The **coning plume** (Figure 4-21) is characteristic of neutral conditions or slightly stable conditions. It is likely to occur on cloudy days or on sunny days between the breakup of a radiation inversion and the development of unstable daytime conditions.

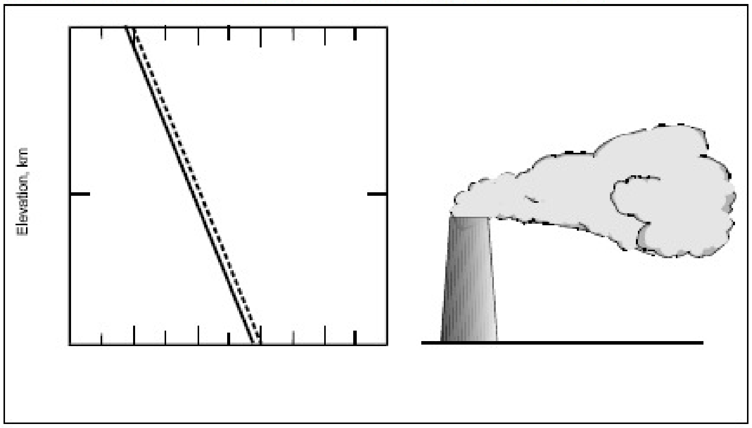

Figure 4-21. Coning plume

Obviously a major problem for pollutant dispersion is an inversion layer, which acts as a barrier to vertical mixing. The height of a stack in relation to the height of the inversion layer may often influence ground-level pollutant concentrations during an inversion.

When conditions are unstable above an inversion (Figure 4-22), the release of a plume above the inversion results in effective dispersion without noticeable effects on ground-level concentrations around the source. This condition is known as **lofting**.

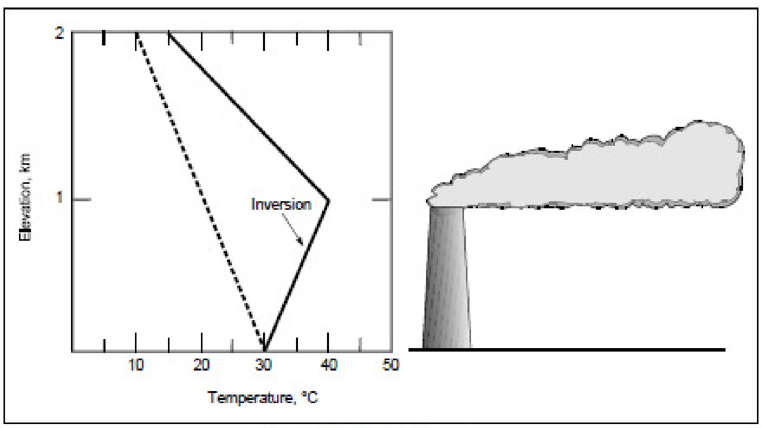

Figure 4-22. Lofting plume

If the plume is released just under an inversion layer, a serious air pollution situation could develop. As the ground warms in the morning, air below an inversion layer becomes unstable. When the instability reaches the level of the plume that is still trapped below the inversion layer, the pollutants can be rapidly transported down toward the ground (Figure 4-23). This is known as **fumigation**. Ground-level pollutant concentrations can be very high when fumigation occurs. Sufficiently tall stacks can prevent fumigation in most cases.

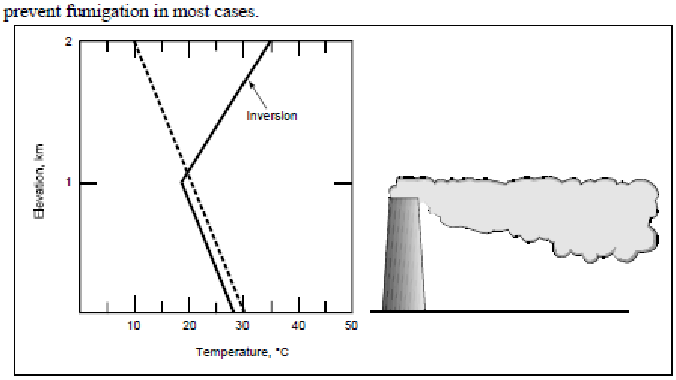

Figure 4-23. Fumigation

Q4. Calculate effective stack height.

physical stack height	**203 m (H_0)**
inside diameter (D_{stack})	**1.07m**
wind velocity (u_{wind})	**3.56 m/sec**
air temperature (°C)	**13**
barometric pressure (p)	**1000 millibars**
stack gas velocity (u_{stack})	**9.14m/sec**
stack gas temperature (°C)	**149**

Hint:

- Convert temp to ^{0}K.
- Use pressure in millibars.
- Use Holland's formula for calculating plume rise (Δh).
- then calculate effective height $=H_{eff}=H_0+(\Delta h)$

See class notes.

Q5. Plot values of Z-direction dispersion constant with stack height (Heff)=60 m, 80 m, and 120 m. Also comment on variation of σ_z with effective stack height.

Solution:

this relationship can only be obtained at ground level when y=0.

As we know σ_z and σ_y depend on X(i.e., distance from source), X need to be given for solving this question. More in next assignment.

Q6. A rising plume of stack gas has a temperature of 1000°C at 200m. Assuming a dry adiabatic lapse rate, determine the temperature at 1000m?

Solution:

Dry adiabatic lapse rate (Γ) = (-)1°C/100m (standard value for dry adiabatic lapse rate)

Z0=200m and T0= 1000°C

Z1=1000m and T1=?

ambient lapse rate = [T1-T0]/[Z1-Z0] = Dry adiabatic lapse rate (Γ) = (-)1°C/100m (given)

So

[T1-1000]/[1000-200] = (-)1°C/100m

T1= [-1/100*(800)]+1000

T1=1000-8=**992°C (answer)**

Case 2: What would be the temperature at 1000m if we assume wet adiabatic lapse rate (i.e., -6.8°C/Km)?

Q7. A power plant burns 7.3 tonnes (i.e., 7.3*1000 =7300 Kg) coal per hour and discharges the combustion products through a stack of effective stack height of 75m. The coal has a sulfur content of 4.2% and the wind velocity at the top of the stack is 6 m/sec. The atmospheric conditions are moderately stable. Answer following:

- **(i)** **Determine SO_2 concentrations for following locations: (0,0,0); (850m, 0,0); (850m, 0,75m); (850m, 0,-75m); (-850m, 0,75m); (0, 0,75m); (850m, σ_y, σ_z).**
- **(ii)** **Determine distance from stack at which the maximum occurs.**

Hint:

emission rate for sulfur per hour = 7300 Kg coal/h * (purity=4.2%)=306.6 Kg Sulfur/h

$S+O_2 \leftrightarrow SO_2$

As 32 g sulfur gives (32+2*16=64 g/mole) sulfur dioxide.

So 306.6 Kg sulfur/h would emit =594 Kg SO_2/h (this is Q_{SO2} which is used in Gaussian formula).