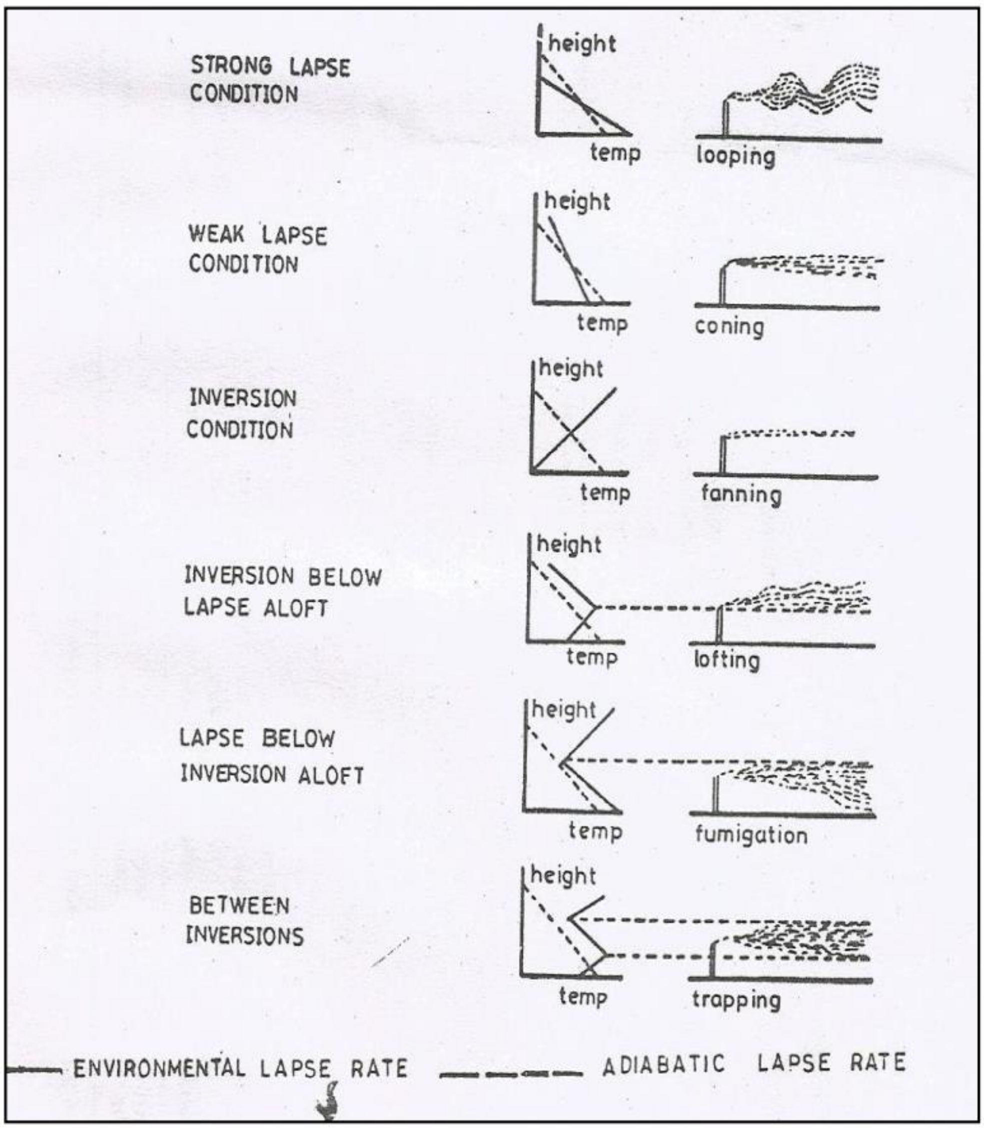
Plume behaviour

- Plume refers to the path and extent in the atmosphere of the gaseous effluents released from a source, usually a stack.
- The behavior of a plume emitted from any stack depends on localized air stability.
- Typical situations as shown in the Fig E, are generally encountered in the lower atmosphere (less than 300m above ground level)

- Six types of plume behavior are shown below . The spread of the plume is directly related to the vertical temperature gradient as shown on the left hand side of the figure.



Types of Plume Behaviour

Types of Plume Behaviour

- Looping
- Coning
- Fanning
- Lofting
- Fumigation
- Trapping

Various types of the plumes and their characteristics, occurrence and related weather conditions, etc., are shown in following Table

Various types of plumes and their characteristics

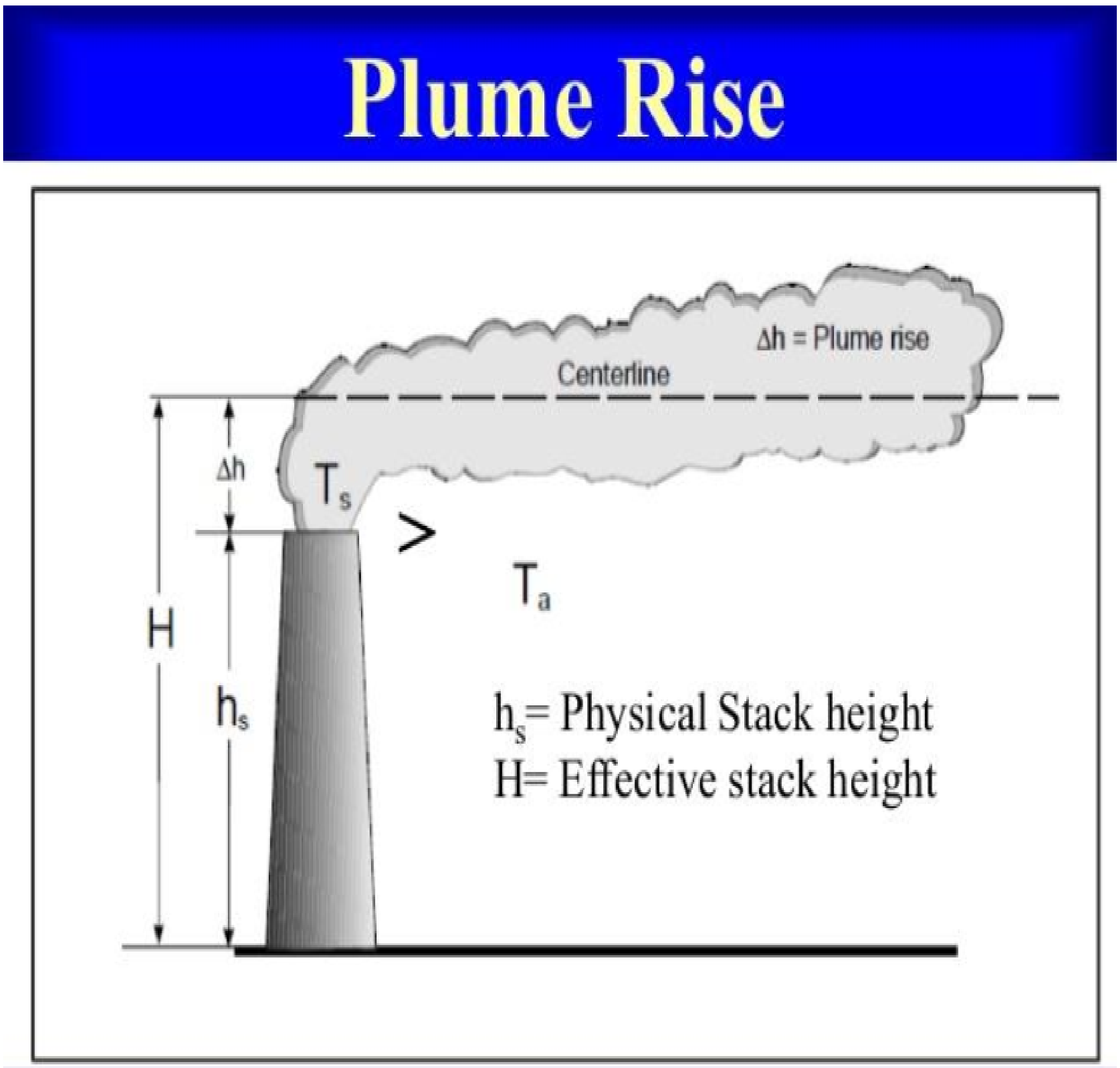
Type of plume	Description of visible plume	Typical occurrence	Temperature profile and stability	Associated wind and turbulence	Dispersion and ground contact.
Looping	Irregular loops dissipates in patches and relatively rapidly with distance	During day time with clear or partly cloudy skies and intense solar heating.	Adiabatic or super adiabatic lapse rate. Unstable.	Light wind with intense thermal turbulence	Disperses rapidly with distance, large probability of high concentrations sporadically at ground relatively close to the stack.
Coning	Cone shaped with horizontal axis, dissipates further downwind than looping plume.	During windy conditions, day or night. Layer type cloudiness favoured in day	Lapse rate between dry adiabatic and isothermal/ Neutral or stable.	Moderate to strong winds. Turbulence largely mechanical rather than thermal.	Disperses less rapidly with distance than looping plume, large probability of ground contact some distance downwind. Concentration less but persists longer than looping plumes
Fanning	Narrow horizontal fan. No vertical spreading for Kms downwind. If effluent is warm, plume rises slowly, then drifts horizontally	At right and in early morning, any season, usually favoured by light winds.	Inverted and isothermal lapse rate. Very stable	Light winds, very little turbulence	Disperses slowly, concentration aloft high at relatively great distance downwind, small probability of ground contact, though increase in turbulence can result in ground contact

Lofting	Loops or cone with well defined bottom. Diffuses to top	During change from lapse to inversion condition, usually near sunset on fair days.	Adiabatic lapse rate at stack top and above. Inverted below stack. Lower layer stable, upper layer neutral or unstable	Moderate winds and considerable turbulence aloft, very light winds and little turbulence in layer below.	Probability of ground contact is small unless inversion layer is shallow, considered to be the best condition for dispersion size pollutants are dispersed in upper air with small probability of ground contact.
Fumigation	Fan or cone with well defined cone and dragged or diffused bottom	During change from inversion to lapse condition, may occur with sea breeze in late morning or afternoon.	Adiabatic or super adiabatic lapse rate at stack top and below. Isothermal or inverted lapse rate above. Lower layer unstable or neutral upper layer stable.	Winds light to moderate aloft and light below. Thermal turbulence in lower layer, little turbulence in upper layer.	Large probability of ground contact in relatively high concentration especially after plume has stagnated aloft.

Plume rise

- Figure shows the plume rising a distance Δh, called the plume rise, above the top of the stack before leveling out.
- Most of us have observed that the visible plumes from power plants, factories, and smokestacks tend to rise and then become horizontal as sketched in figure
- Plumes rise buoyantly because they are hotter than the surrounding air and also because they exit the stack with a vertical velocity that carries them upward.

- They stop rising because, as they mix with the surrounding air, they lose velocity and cool by mixing.
- Finally, they level off when they come to the same temperature as the atmosphere.
- We employ plume rise calculations to estimate the value a of Δh and hence of H to use in Gaussian plume and other more complex pollutant concentration calculations.



Plume rise

. Holland's formula for plume rise is

$$\Delta h = V_s D/ \mu \left[1.5 + 2.68 \times 10^{-3} PD \left(T_s - T_a\right) T_s\right] \text{---------------------} (2)$$

Where, Δh = plume rise in m

V_s = stack exit velocity in m/s

D = stack diameter in m

μ = wind speed in m/s

P = pressure in millibars

T_s = stack gas temperature in K

T_a = atmospheric temperature in K

Plume Behavior

1. The mixing of ambient air into the plume is called entrainment. As the plume entrains air into it, the plume diameter grows as it travels downwind.
2. A combination of the gases' momentum and buoyancy causes the gases to rise. This is referred to as plume rise and allows air pollutants emitted in this gas stream to be lofted higher in the atmosphere.
3. The final height of the plume, referred to as the effective stack height (H), is the sum of the physical stack height (h_s) and the plume rise (Δh).
4. Plume rise is actually calculated as the distance to the imaginary centerline of the plume rather than to the upper or lower edge of the plume

Plume Stability

Shapes of plumes depend upon atmospheric stability conditions which depend on Environmental Lapse rate (ELR) and Dry Adiabatic Lapse Rate (DALR).

The stability conditions based on ELR and DALR is as follows,

- ELR > DALR, atmosphere is stable
- ELR >>DALR, very stable atmosphere
- ELR = DALR, atmosphere is neutral ELR

Problem: Estimate the plume rise for a 3m diameter stack whose exit gas has a velocity of 20m/s when the wind velocity is 2m/s, pressure is 1 atm. & the stack and surrounding temperature are 373 and 288 K , respectively.

Solution

Step I Given Data

a) Stack exist velocity (Vs) – 20m/s
b) Stack diameter (D) – 3m
c) Wind speed (µ) – 2m/s
d) Pressure in mill bars (P) – 1013 (1 atm. = 1013 mb)
e) Stack gas temperature (T_s) -373K
f) Atmospheric temperature (T_a) – 288K

Step II Formula

$$\Delta h = V_s D/ \mu \, [1.5 + 2.68 \times 10^{-3} PD (T_s - T_a) T_s]$$

Δh - Plume rise in m

Step III Calculation

$$\Delta h = 20 * 3/2 [1.5 + 2.68 \times 10^{-3} *1013 *3* (373 - 288) 288$$

$$= 101m$$

Step IV Result

Plume rise for the given data is 101m

Gaussian Diffusion Model

- Most widely accepted model
- Plume originates at height (h) and rises additional height (Δh)
- Applies standard deviations
- Plume shape and standard deviation varies according to meteorological condition.
- Two single distribution are multiplied to give double Gaussian distribution,

Assumptions (Gaussian plume dispersion Model)

- Steady state conditions,
  Which imply that the rate of emission from the point source is constant
- Homogeneous flow,
  Which implies that the wind speed is constant both in time ad with height (wind direction shear is not considered)
- Pollutant is conservative and no gravity fallout
- Perfect reflection of the plume at the under lying surface (i.e no ground absorption)
- Turbulent diffusion in X – direction is neglected relative to advection in the transport direction, which implies, that the models should be applied for average wind speeds of more than 1 m/s (>1m/s)
- Co-ordinate system is directed with its X – axis into the direction of the flow, and the V (lateral) and W (vertical) components of the time averaged wind vector are set to zero.
- Terrain underlying the plume is flat
- All variables are ensemble averaged, which implies long-term averaging with stationary conditions.

I Plume contaminant concentration at a point in space

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

II Plume contaminant concentration at ground level

$$C(x,y,0)=\frac{Q}{\pi u\sigma_y\sigma_z}e^{-\frac{y^2}{2\sigma_y^2}}e^{-\frac{H^2}{2\sigma_z^2}}$$

III contaminant concentration at ground level along the plume centerline

$$C(x,0,0)=\frac{Q}{\pi u\sigma_y\sigma_z}e^{-\frac{H^2}{2\sigma_z^2}}$$

IV contaminant concentration at ground level along the plume centerline when the emission source is at ground level

$$C(x,0,0)=\frac{Q}{\pi u\sigma_y\sigma_z}$$

Where,

C = downwind concentration , g/m^3

Q = pollution source emission rate, g/s

U = average wind speed, m/s

σ_y = y direction plume standard deviation(horizontal distribution of plume concentration)

σ_z= z direction plume standard deviation (vertical distribution of plume concentration)

x = position in the x direction or downwind distance , m

y = position in the y direction or cross wind distance, m

z = position in the z direction (receptor height above ground , m)

H = effectivestack height, m