2.3 ATMOSPHERIC STABILITY AND TURBULENCE

Stability:

- The ability of the atmosphere to enhance or to resist atmospheric motions.
- Influences the vertical movement of air.
  - If the air parcels tend to sink back to their initial level after the lifting exerted on them stops, the atmosphere is stable.
  - If the air parcels tend to rise vertically on their own, even when the lifting exerted on them stops, the atmosphere is unstable.
  - If the air parcels tend to remain where they are after lifting stops, the atmosphere is neutral.
- The stability depends on the ratio of suppression to the generation of turbulence.
- The stability at any given time will depend upon:
  - Static stability (related to changes in temperature with height)
  - Thermal turbulence (caused by solar heating)
  - Mechanical turbulence (A function of wind speed and surface roughness)
- Stability classified into 6 classes (A-F)

A	Strongly	Unstable
B	Moderately	Unstable
C	Slightly	Unstable
D	Slightly	Neutral
E	Slightly	Stable
F	Moderately	Stable

Table 2.3.1 Classification of stability

- Atmospheric stability can be determined using adiabatic lapse rate..

$\Gamma > \Gamma_d$	Unstable
$\Gamma = \Gamma_d$	Neutral
$\Gamma < \Gamma_d$	Stable

Table 2.3.2 Condition of lapse rate

Where,

Γ is environmental lapse rate

Γ_d is the dry adiabatic lapse rate (1°C/100 m)

$dT/dZ = -1°C/100$ m

Turbulence:

- Fluctuations in wind flow, which have a frequency of more than 2 cycles/hr.
- In fluid dynamics, turbulence or turbulent flow is fluid motion characterized by chaotic changes in pressure and flow velocity.
- It is in contrast to a laminar flow, which occurs when a fluid flows in parallel layers, with no disruption between those layers.
- Turbulence is commonly observed in everyday phenomena such as surf, fast flowing rivers, billowing storm clouds, or smoke from a chimney, and most fluid flows occurring in nature or created in engineering applications are turbulent.
- Turbulence is caused by excessive kinetic energy in parts of a fluid flow.
    - Which overcomes the damping effect of the fluid's viscosity.
    - For this reason turbulence is commonly realized in low viscosity fluids.
- In general terms, in turbulent flow, unsteady vortices appear of many sizes which interact with each other, consequently drag due to friction effects increases.
- Turbulence can be exploited.

Example:

By devices such as aerodynamic on aircraft that "spoil" the laminar flow to increase drag and reduce lift.

Types of Turbulence:

1. Mechanical turbulence:

It occurs because friction slows the wind in the lowest layers causing the air to turn over in turbulent eddies which can cause fluctuations in winds and vertical velocities.

2. Convective Turbulence:

Turbulence occurring in convective storms, particularly thunderstorms, that is felt by aircraft. The turbulence is caused by strong updrafts and downdrafts.

3. Clear- Air Turbulence (CAT):

Clear-air turbulence is the turbulent movement of air masses in the absence of any visual clues, such as clouds, and is caused when bodies of air moving at widely different speeds meet.

4. Wake Turbulence:

Wake turbulence is a disturbance in the atmosphere that forms behind an aircraft as it passes through the air. Wake turbulence can impose rolling moments exceeding the roll-control authority of encountering aircraft, causing possible injury to occupants and damage to aircraft.

5. Thermal Turbulence:

Thermal turbulence is caused by solar heating of the surface, which in turn heats the lower atmosphere resulting in uneven convective currents, which lead to turbulence.

These thermals act as obstructions to the normal air flow similar to mountainous terrain.

6. Temperature inversion turbulence:

An inversion occurs when the normal temperature (warm air below, cold air above) profile is reversed, creating a stable configuration of dense, cold air sitting below lighter, warm air.

7. Frontal Turbulence:

Frontal turbulence is caused by lifting of warm air, a frontal surface leading to instability, or the abrupt wind shift between the warm and cold air masses. The most severe cases of frontal turbulence are generally associated with fast-moving cold fronts.

8. Mountain Wave Turbulence:

It is as air flows over the tops of mountains, traveling down the leeward side, a standing mountain wave is formed and air currents oscillate between altitudes. Mountain waves and turbulence can extend for hundreds of miles downwind of the mountain range.

2.4 INVERSION

- Inversion is defined as increase in temperature with respect to altitude. It is also known as negative lapse rate.
- An inversion is an extreme sub-adiabatic condition, and thus the vertical air movement within the inversion is almost nil.
- The two most common kinds of inversion are subsidence inversion and radiation inversion.
- The base of the subsidence inversion lies some distance above the earth's surface.
- This type of inversion is formed due to adiabatic compression and warming of sinking air mass to a lower altitude in the region of a high pressure centre.
- In the case of radiation inversion, the surface layers of a atmosphere during the day receive heat by conduction, convection and radiation from the earth's surface and are warmed.
- This results in a temperature profile in the lower atmosphere, which is represented by a negative temperature gradient.
- On a clear night, the ground surface radiates heat and quickly cools.

Types of inversion:

1. Subsidence Inversion
2. Radiation Inversion
3. Combination of subsidence and radiation

1. Subsidence Inversion

- It occurs high above emission sources.
- Associated with high-pressure systems Inversion layer is formed aloft Covers hundreds of thousands of square kms contributes to long term air pollution problems.
- Persists for several days and greatly contribute to long term accumulation of pollutants.
- Gets broken by strong winds at that altitude.

- Elevation of base of inversion varies from about 200m to around 1000m.

2. Radiation Inversion

• Surface layers of the atmosphere during the day receive heat by conduction, convection and radiation from the earth's surface and are warmed.

• This results in temperature profile in the lower atmosphere that is represented by a negative lapse rate.

• These types of inversions are intensified in river valleys.

• Cause pollutants to be "trapped".

• Breakup after sunrise.

• Occurs in winter season in India.

• Most likely to occur during windless and cloudless nights.

3. Combination of radiation and Subsidence inversion

• It is possible for subsidence and radiation inversions to appear in the atmosphere at the same time.

• Joint occurrence of these two types of inversions leads to a special phenomena called 'Trapping of plume'.

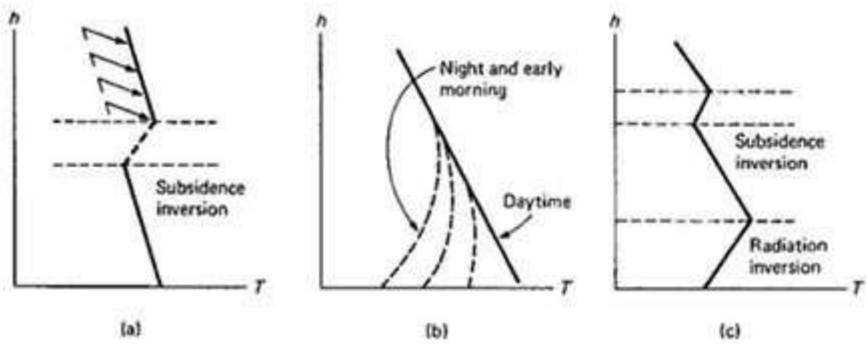

Figure 2.4.1 Illustrations of a) subsidence inversion, b)radiation inversion and c)combination of subsidence and radiation inversion

[Source:https://images.app.goo.gl/Tc18ZmMKU6yUj27d7]

2.1 METEOROLOGY

Meteorology is a branch of the atmospheric sciences which includes atmospheric chemistry and atmospheric physics, with a major focus on weather forecasting.

EFFECTS OF METEOROLOGY ON AIR POLLUTION

Air movements influence the fate of air pollutants. So any study of air pollution should include a study of the local weather patterns (meteorology). If the air is calm arid pollutants cannot disperse, then the concentration of these pollutants will build up. On the other hand, when strong, turbulent winds blows, pollutants disperse quickly, resulting in lower pollutant concentrations.

Meteorological data helps to:

- Identify the source of pollutants.
- Predict air pollution events such as inversions and high-pollutant concentration days.
- Simulate and predict air quality using computer models.

When studying air quality, it is important to measure the following factors as they can help understand the chemical reactions that occur in the atmosphere:

- Wind speed and direction
- Temperature
- Humidity
- Rainfall
- Solar radiation

1. Wind Speed and Direction:

- When high pollutant concentrations occur at a monitoring station, wind data records can determine the general direction and area of the emissions.

- Identifying the sources means planning to reduce the impacts on air quality can take place.
- An instrument called anemometer measures wind speed. At our monitoring stations, the type anemometer we use is a sonic anemometer.
- A sonic anemometer operates on the principle that the speed of wind affects the time it takes for sound to travel from one point to another.
- Sound travelling with the wind will take less time than sound travelling into the wind.
- By measuring sound wave speeds in 2 different directions at the same time, sonic anemometers can measure both wind speed and direction.

2. Temperature:

- Measuring temperature supports air quality assessment, air quality modelling and forecasting activities.
- Temperature and sunlight (solar radiation) play an important role in the chemical reactions that occur in the atmosphere to form photochemical smog from other pollutants.
- Favourable conditions can lead to increased concentrations of smog.
- The most common way of measuring temperature is to use a material with a resistance that changes with temperature, such as platinum wire. A sensor measures this change and converts it into a temperature reading.

3. Humidity:

- Like temperature and solar radiation, water vapour plays an important role in many thermal and photochemical reactions in the atmosphere.
- As water molecules are small and highly polar, they can bind strongly to many substances.

- Is attached to particles suspended in the air they can significantly increase the amount of light scattered by the particles (monitoring aerosols).
- If the water molecules attach to corrosive gases, such as sulphur dioxide, the gas will dissolve in the water and form an acid solution that can damage health and property.
- Eporting of the water vapour content of air is as a percentage of the saturation vapour pressure of water at a given temperature.
- This is the relative humidity. The amount of water vapour in the atmosphere is highly variable.
- Relative humidity is generally higher during summer when temperature and rainfall area also at their highest.
- Measuring humidity uses the absorption properties of a polymer film.
- The film either absorbs or loses water vapour as the relative humidity of the ambient air changes.
- A sensor measures these changes and converts them into a humidity reading.

4. Rainfall:

- Rain has a ‘scavenging’ effect when it washes particulate matter out of the atmosphere and dissolves gaseous pollutants.
- Removing particles improves visibility. When there is frequent high rainfall, the quality is generally better.
- If the rain dissolves gaseous pollutants, such as sulphur dioxide, it can form acid rain resulting in potential damage to materials or vegetation.
- A common method to measure rainfall is to use a tipping bucket rain gauge see illustration.
- The gauge registers rainfall by counting small amounts of rain collected.

- When rain falls into the funnel, it runs into a container (the tripping bucket) divides into 2 equal compartments by a partition.
- The design of the tipping bucket makes one compartment tilt downward and rest against a stop when it is empty, positioning the other compartment under the funnel ready to receive rain water.
- The collected water then empties out and the other compartment starts to fill.

Figure 2.1.1 Tipping bucket Rain gauge

[Source:https://www.qld.gov.au/]

6. Solar radiation:

- It is important to monitor solar radiation for use in modeling photochemical smog events, as the intensity of sunlight has an important influence on the rate of the chemical reactions that produce the smog.
- The cloudiness of the sky, time of day and geographic location all affect sunlight intensity.
- An instrument called a pyranometer measures solar radiation from the output of a type of silicon cell sensor.

2.5 WIND PROFILES AND STACK PLUME PATTERNS/PLUME RISE

- The moving air is called wind, such a movement caused by the unequal distribution of temperature and pressure on earth surface.
- A critical relationship exists between atmospheric stability and pollutant concentrations.
- Pollutants that cannot be transported or dispersed into the upper atmosphere quickly become trapped at ground level and pose a significant risk to human health and the environment.
- This relationship can be visualized in the behaviour of emission plumes from industrial smoke stacks.

Plume:

The dispersion of emitted gases from the source of their production is known as plume and the source is known as stack.

Plume rise:

It is defined as the distance of the hot plume from the stack into the atmosphere, due to the buoyancy and momentum.

Types of Plume rise:

Six types of air pollution plumes illustrate the relationship between atmospheric stability and pollutant emissions:

- Looping plumes
- Fanning plumes
- Coning plumes
- Lofting plumes
- Fumigating plumes

- Trapping plumes.

1. Looping plumes:

- Pollution that is released into an unstable atmosphere forms looping plumes.
- Rapid changes in temperature and pressure may result in plumes that appear billowing and puffy.
- While unstable conditions are usually favorable for pollutant dispersion, high concentrations of air pollution forced down by cooling air can be harmful if trapped at ground level.
- This can occur on sunny days with light to moderate winds, which combine with rising and sinking air to cause the stack gases to move up and down in a wavy pattern producing a looping plume (Godish, 1997).

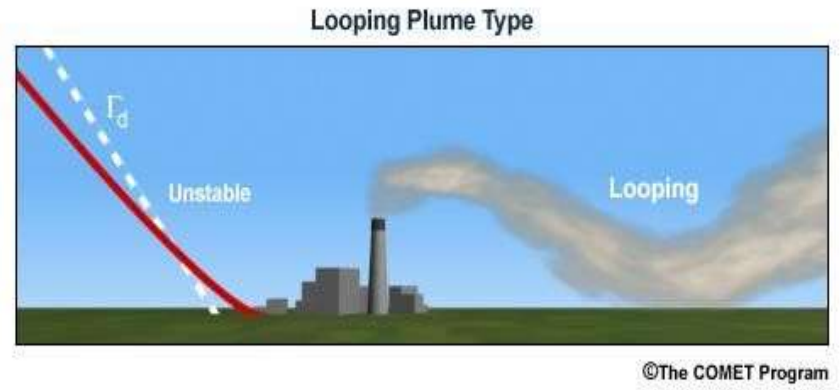

Figure 2.5.1 Looping plumes

[Source:http://stream1.cmatc.cn/pub/comet/EmergencyManagement/afwa_dis/comet/dispersion/afwa/txt/sect3.htm#classic]

2. Fanning plumes:

- A fanning plume occurs during stable conditions and is characterized by long, flat streams of pollutant emissions.
- Because atmospheric pressure is stable, there is neither a tendency for emissions to raise nor descend permitting (horizontal) wind velocity to transport and disperse the pollutant.

- Fanning plumes are usually seen during the early morning hours just before the sun begins to warm the atmosphere and winds are light (Godish, 1997).

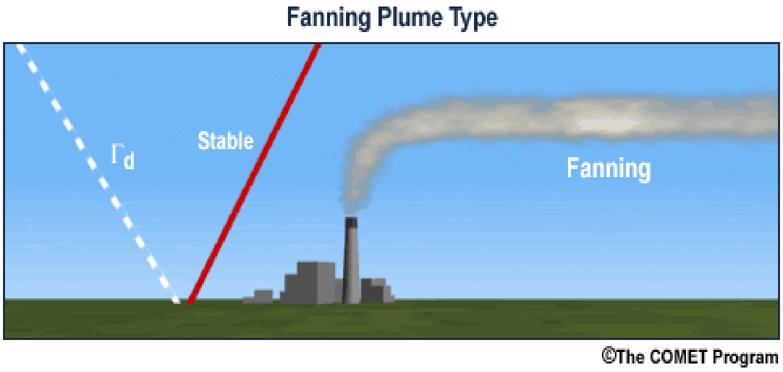

Figure2.5.2 Fanning Plume

[Source:http://stream1.cmatc.cn/pub/comet/EmergencyManagement/afwa_dis/comet/dispersion/afwa/media/graphics/classic1.gif]

3. Coning plumes:

- Neutral or slightly unstable conditions create a coning plume that is distinguished by large billows or puffs of pollutants.
- Coning plumes are typically formed on partly cloudy days when there is an alternate warming and cooling of the atmosphere.
- Warm gases released into cool, ambient air mix, expand, and rise into the upper atmosphere (Godish, 1977).

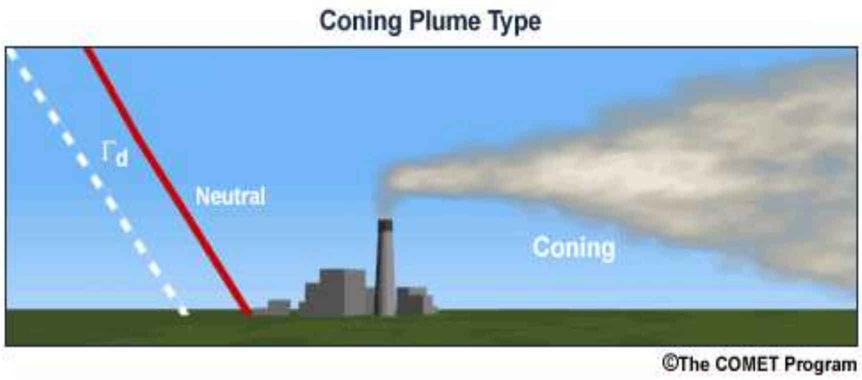

Figure 2.5.3 coning Plume

[Source:http://stream1.cmatc.cn/pub/comet/EmergencyManagement/afwa_dis/comet/dispersion/afwa/media/graphics/classic4.gif]

4. Lofting plumes:

- When the atmosphere is relatively stable, warm air remains above cool air and creates an inversion layer.
- Pollutants released below the inversion layer will remain trapped at ground level and, in the absence of any atmospheric instability, prevent the upward transport of the pollutant.
- When there is little or no vertical mixing, pollutants tend to form in high concentrations at ground level.
- When conditions are unstable or neutral above the inversion layer, stack gases above that level form a lofting plume that can effectively disperse the pollutant into the upper atmosphere (Godish, 1997).

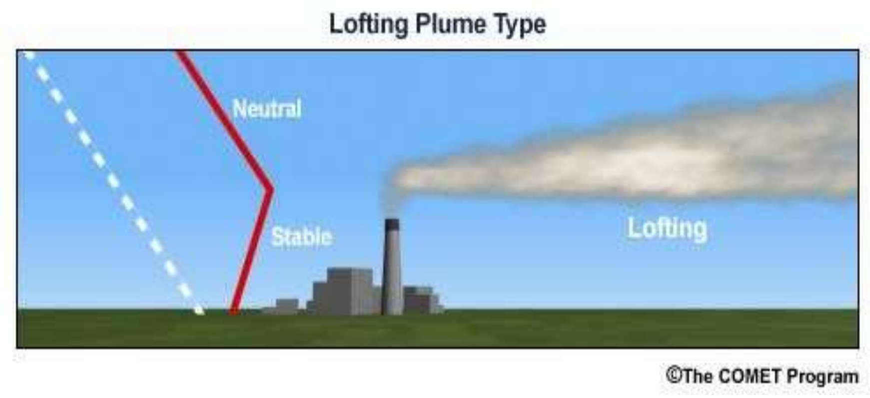

Figure 2.5.4 Lofting Plume

[Source:http://stream1.cmatc.cn/pub/comet/EmergencyManagement/afwa_dis/comet/dispersion/afwa/media/graphics/classic2.jpg]

5. Fumigating plumes:

- In the early morning, if the plume is released just below the inversion layer, a very serious air pollution episode could develop.
- When pollutants are released below the inversion layer, gaseous emissions quickly cool and descend to ground level.

- This condition is known as fumigation and results in a high concentration of pollution that can be damaging to both humans and the environment alike.

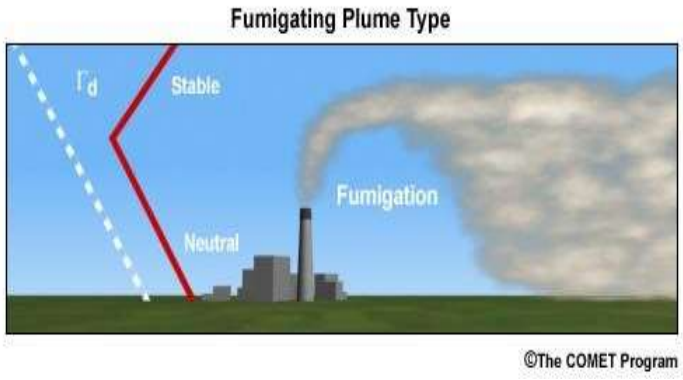

Figure 2.5.5 Fumigating Plume

[Source:http://stream1.cmatc.cn/pub/comet/EmergencyManagement/afwa_dis/comet/dispersion/afwa/media/graphics/classic2.jpg]

6. Trapping plumes:

- Lapse rates and atmospheric stability weak lapse rate below, Inversion aloft(Trapping)
- Radiation inversion at ground level, subsidence inversion at higher altitude (evening-night)

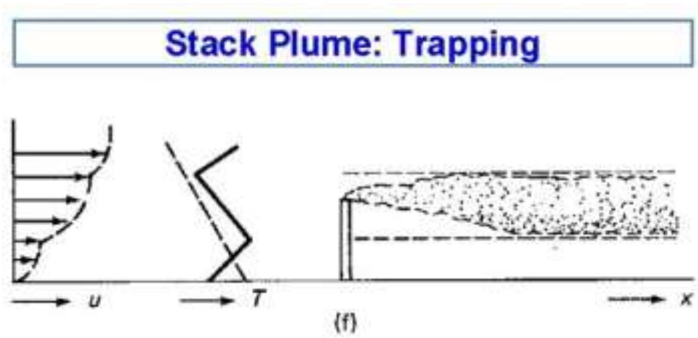

Figure 2.5.6 Trapping Plume

[Source:http://stream1.cmatc.cn/pub/comet/EmergencyManagement/afwa_dis/comet/dispersion/afwa/media/graphics/classic2.jpg]