NAVODAYA INSTITUTE OF TECHNOLOGY, RAICHUR

DEPARMENT OF COMPUTER SCIENCE & ENGINEERING

Module - 3

1. Introduction

- **Air** is a vital natural resource, essential for respiration, photosynthesis, and maintaining life on Earth.
- **Air pollution**: Presence of one or more harmful substances in the atmosphere in quantities that cause harm to humans, animals, plants, or property.
- Causes: Industrialization, urbanization, automobiles, burning of fossil fuels, deforestation.

2. Composition of Air

- **Nitrogen (N_2): 78%**
- **Oxygen (O_2): 21%**
- **Argon (Ar): 0.93%**
- **Carbon dioxide (CO_2): 0.03–0.04%**
- **Other gases** (Ne, He, CH_4, O_3, etc.): Trace amounts
- **Water vapour**: Varies from 0–4% (important for weather & climate).

3. Sources of Air Pollutants

(a) Natural Sources

- Volcanic eruptions → SO_2, ash
- Forest fires → CO, CO_2, particulates
- Dust storms → suspended particles
- Sea spray → chlorides, sulphates
- Biological decay → methane, hydrogen sulphide

(b) Anthropogenic (Man-made) Sources

- Industries → SO_2, NOx, CO, particulates
- Automobiles → CO, NOx, hydrocarbons, lead
- Thermal power plants → fly ash, SO_2, CO_2
- Domestic fuel burning (wood, coal, LPG)
- Agricultural activities → pesticide sprays, burning of crop residues

4. Classification of Air Pollutants

- **Based on Origin**
  - *Primary pollutants*: Directly emitted (CO, SO_2, NOx, particulates).
  - *Secondary pollutants*: Formed in atmosphere by chemical reactions (O_3, PAN, smog).
- **Based on State**
  - *Particulates*: Dust, smoke, ash, mist, fumes.
  - *Gases*: SO_2, CO, NOx, hydrocarbons.
- **Based on Effect**
  - *Toxic pollutants*: CO, lead, arsenic.
  - *Greenhouse gases*: CO_2, CH_4, N_2O.
  - *Smog-forming pollutants*: NOx + hydrocarbons.

5. National Ambient Air Quality Standards (NAAQS – 2009, CPCB)

Parameters (µg/m³):

Pollutant	Time Weighted Average	Industrial, Residential, Rural & Other Areas	Ecologically Sensitive Areas
SO_2	Annual	50	20
	24 hours	80	80
NO_2	Annual	40	30
	24 hours	80	80
PM_{10}	Annual	60	60
	24 hours	100	100
$PM_{2.5}$	Annual	40	40
	24 hours	60	60
CO	8 hours	2 mg/m³	2 mg/m³

Pollutant	Time Weighted Average	Industrial, Residential, Rural & Other Areas	Ecologically Sensitive Areas
	1 hour	4 mg/m³	4 mg/m³

6. Air Quality Index (AQI)

- AQI = measure to communicate air quality in a single number (0–500).
- Categories:
  - 0–50 → Good
  - 51–100 → Satisfactory
  - 101–200 → Moderate
  - 201–300 → Poor
  - 301–400 → Very Poor
  - 401–500 → Severe

7. Effects of Air Pollution on Human Health

- **CO**: Binds with haemoglobin → reduces oxygen supply → headache, dizziness, death.
- **SO_2**: Irritates lungs, causes bronchitis, asthma.
- **NOx**: Respiratory problems, eye irritation, contributes to smog.
- **Particulates**: Lung diseases, cancer, reduced visibility.
- **Lead**: Affects nervous system, brain damage in children.

8. Economic Effects of Air Pollution

- Damage to crops (ozone & acid rain).
- Corrosion of metals, buildings, and monuments (Taj Mahal → acid rain).
- Reduced efficiency of solar panels.
- Increased healthcare costs.
- Loss of productivity due to worker illness.

9. Control of Air Pollution

(a) By Equipment

- **Cyclone separators** – remove larger dust particles by centrifugal force.

- **Electrostatic precipitators** – use high voltage to collect fine particles (e.g., in thermal power plants).
- **Bag filters** – fabric filters trap dust.
- **Scrubbers** – absorb SO_2, NOx by spraying water/alkaline solution.

(b) Smoke & Its Control

- Smoke = mixture of particulates + gases from incomplete combustion.
- Control measures:
  - Using electrostatic precipitators in industries.
  - Proper maintenance of vehicles (catalytic converters).
  - Using clean fuels (LPG, CNG).

10. Ozone Depletion

- **Ozone layer** protects Earth from harmful UV radiation.
- **Cause**: CFCs (Chlorofluorocarbons), halons, freons → release chlorine radicals → destroy ozone.
- **Impacts**:
  - Skin cancer, cataracts in humans.
  - Reduced crop yield.
  - Marine ecosystem damage (plankton).
- **Photochemical changes**:
  - UV breaks down CFC → releases Cl radical.
  - $Cl + O_3 \rightarrow ClO + O_2$ (ozone destroyed).
  - $ClO + O \rightarrow Cl + O_2$ (chain reaction).

1. Introduction – Air and Air Pollution

Air – A Vital Natural Resource

- **Definition**: Air is the invisible mixture of gases that surrounds the Earth, forming the atmosphere.
- **Importance**:
  - **Respiration**: All living beings (humans, animals) need oxygen (O_2) for respiration to release energy from food.
  - **Photosynthesis**: Plants absorb carbon dioxide (CO_2) from the air and release oxygen during photosynthesis.
  - **Climate regulation**: Air contains water vapour which regulates weather, rainfall, and climate.
  - **Protective function**: The ozone layer in the upper atmosphere absorbs harmful ultraviolet (UV) radiation from the Sun.
  - **Transportation**: Winds help in dispersal of seeds, pollination, and also in the distribution of heat and moisture globally.

Air Pollution

- **Definition**:
  Air pollution is the presence of **undesirable solid, liquid, or gaseous substances** in the atmosphere in concentrations harmful to humans, animals, plants, or property.
- **WHO Definition**: "Air pollution is the presence of materials in the air in such concentration which are harmful to man and his environment."
- **Examples of pollutants**:
  - Gases: Carbon monoxide (CO), Sulphur dioxide (SO_2), Nitrogen oxides (NOx), Hydrocarbons.
  - Particulates: Dust, smoke, mist, fumes, fly ash.
  - Toxic substances: Lead, arsenic, benzene.

Causes of Air Pollution

1. **Industrialization**
   - Factories and power plants burn fossil fuels (coal, oil, gas).
   - Emit SO_2, NOx, CO_2, and particulate matter.
   - Example: Thermal power plants → fly ash and SO_2.
2. **Urbanization**
   - Rapid population growth leads to more energy demand, vehicles, waste burning.
   - Urban heat islands + high traffic increase pollution levels.
   - Example: Delhi → high PM2.5 due to vehicles and construction.

3. **Automobiles**
    - Vehicles release CO, NOx, hydrocarbons, lead (in old engines).
    - Contribute to smog formation and respiratory problems.
    - Example: Metro cities like Bengaluru, Mumbai → high vehicular emissions.
4. **Burning of Fossil Fuels**
    - Coal, petroleum, natural gas used in industries, homes, and transport.
    - Release greenhouse gases (CO_2, CH_4) and SO_2, NOx.
    - Example: Household biomass burning in rural areas causes indoor air pollution.
5. **Deforestation**
    - Fewer trees → less CO_2 absorption → higher CO_2 concentration in atmosphere.
    - Forest fires release CO, CO_2, and smoke particles.
    - Loss of vegetation worsens dust storms and soil erosion.

Conclusion

- Air is an essential resource for sustaining life.
- Human activities (industries, vehicles, urban growth, fuel burning, deforestation) are the **main contributors** to air pollution.
- If unchecked, air pollution leads to **serious health, environmental, and economic consequences**.

2. Composition of Air

Definition

- Air is a **mixture of gases** that surrounds the Earth, forming the atmosphere.
- It is **odorless, colorless, and tasteless** under normal conditions.
- The composition of air is **fairly constant up to about 80 km** above Earth's surface, though water vapour and dust vary with place and time.

Major Components of Air

Gas / Component	Percentage by Volume	Importance
Nitrogen (N_2)	~78%	Inert, dilutes oxygen, essential for protein formation (plants fix N_2 from air).
Oxygen (O_2)	~21%	Required for respiration and combustion.
Argon (Ar)	~0.93%	Inert, used in lighting and welding.
Carbon dioxide (CO_2)	~0.03–0.04%	Essential for photosynthesis, greenhouse gas.
Other trace gases (Ne, He, Kr, Xe, CH_4, O_3, H_2)	<0.1%	Important in special roles (e.g., O_3 shields UV radiation, CH_4 is a greenhouse gas).
Water vapour (H_2O)	0–4% (variable)	Controls humidity, rainfall, climate.
Dust & aerosols	Variable	Influence cloud formation, scattering of light (sunrise/sunset colors).

Variation in Composition

- **Altitude**:
  - Lower atmosphere (troposphere) has more water vapour and dust.
  - Higher layers (stratosphere, mesosphere) → thinner air, contains ozone layer.
- **Location**:
  - Coastal areas → higher water vapour, salt particles.
  - Desert areas → more dust.
  - Industrial/urban areas → pollutants (CO, SO_2, NOx).

Significance of Composition

1. **Nitrogen**: Stabilizes air, prevents fast burning of oxygen.
2. **Oxygen**: Essential for life (respiration) and energy production.
3. **Carbon dioxide**: Maintains Earth's temperature through greenhouse effect, vital for plants.
4. **Ozone (O_3)**: Protects from harmful UV rays.
5. **Water vapour**: Regulates climate and hydrological cycle.
6. **Dust**: Helps in cloud condensation nuclei formation → rainfall.

Conclusion

- The atmosphere is **not just empty space**, but a **balanced mixture of gases, vapour, and particles** that sustain life.
- Even small changes (e.g., increase in CO_2, depletion of O_3, rise in pollutants) disturb this balance → causing **climate change and air pollution problems**.

3. Sources of Air Pollutants

Definition of Air Pollutants

- **Air Pollutants** are undesirable solid, liquid, or gaseous substances present in the atmosphere in **sufficient concentration** and for **sufficient duration** to cause harm to humans, plants, animals, property, or climate.

A. Natural Sources

These are pollutants released into the atmosphere by **natural processes** without human interference.

1. **Volcanic eruptions** → emit ash, dust, SO_2, CO_2.
    - Example: Mt. Pinatubo eruption (1991) increased global SO_2 levels.
2. **Forest fires** (natural lightning) → release CO_2, CO, smoke, hydrocarbons.
3. **Dust storms** (from deserts, dry regions) → increase particulate matter.
4. **Microbial decomposition** (swamps, wetlands) → methane (CH_4), hydrogen sulfide (H_2S).
5. **Pollen grains, spores** → cause allergies, asthma.
6. **Sea spray** → sodium chloride particles.

B. Anthropogenic (Man-Made) Sources

These are pollutants **produced by human activities**, the main cause of modern air pollution.

1. Industrial Sources

- **Thermal power plants** → SO_2, NOx, CO_2, fly ash.
- **Cement, chemical, textile, paper, fertilizer industries** → dust, acids, alkalis, toxic gases.
- **Smelting of ores** → SO_2, heavy metals (Pb, Hg, As).

2. Transportation Sources

- Automobiles (cars, buses, trucks, two-wheelers, aircraft, ships).
- Pollutants:
    - **CO** → incomplete combustion of petrol/diesel.
    - **NOx** → high-temperature combustion.
    - **HC (hydrocarbons)** → unburnt fuel vapors.

- **Particulates** → diesel exhaust (soot, black smoke).
- **Pb** (from leaded petrol – now phased out in India).

3. Agricultural Sources

- **Pesticides, insecticides, herbicides** → volatile organic compounds (VOCs).
- **Stubble burning** → CO, CH_4, particulates.
- **Fertilizer use** → releases ammonia (NH_3), nitrous oxide (N_2O – a greenhouse gas).

4. Domestic Sources

- Household cooking (biomass fuel – wood, cow dung, kerosene).
- Burning of waste → smoke, dioxins, CO.
- Use of ACs/refrigerators → CFCs (chlorofluorocarbons) damaging ozone layer.

5. Miscellaneous

- Mining operations → dust, toxic gases.
- Construction activities → cement dust, silica.
- Wars & explosions → smoke, chemicals, radioactive fallout.

C. Classification Based on Nature of Pollutants

1. **Primary Pollutants** → Directly emitted into atmosphere.
   - Examples: CO, CO_2, SO_2, NO, hydrocarbons, particulates.
2. **Secondary Pollutants** → Formed in atmosphere by chemical reaction of primary pollutants.
   - Examples:
     - **Ozone (O_3)** in lower atmosphere.
     - **PAN (Peroxyacetyl nitrate)** → from HC + NOx + sunlight.
     - **Smog** (photochemical or classical).

Conclusion

- Natural sources are unavoidable, but **human-made sources** are largely responsible for present air pollution problems.
- Understanding the sources is the **first step** in planning effective **air pollution control strategies**.

4. Classification of Air Pollutants

Air pollutants can be classified based on **different criteria**:

A. Based on Origin

1. **Primary Pollutants**
    - Directly emitted from natural or man-made sources.
    - Examples:
        - Carbon monoxide (CO)
        - Carbon dioxide (CO_2)
        - Sulphur dioxide (SO_2)
        - Nitric oxide (NO)
        - Hydrocarbons (HC)
        - Particulate matter (dust, soot, smoke)
2. **Secondary Pollutants**
    - Formed in the atmosphere through **chemical/photochemical reactions** of primary pollutants.
    - Examples:
        - Ozone (O_3) (in troposphere, harmful)
        - Peroxyacetyl nitrate (PAN)
        - Photochemical smog
        - Acid rain (H_2SO_4, HNO_3 formed from SO_2, NOx + water vapor)

B. Based on Physical State

1. **Gaseous Pollutants**
    - CO, CO_2, SO_2, NOx, hydrocarbons, ozone, NH_3, H_2S, CFCs.
2. **Particulate Pollutants**
    - Solid or liquid particles suspended in air.
    - Types:
        - **Dust** – solid particles from crushing, grinding (cement, mining).
        - **Smoke** – fine carbon particles from incomplete combustion.
        - **Fumes** – condensed vapors (metals, plastics).
        - **Mist** – liquid droplets (sulphuric acid mist).
        - **Aerosols** – fine particles suspended (hairsprays, perfumes).

C. Based on Chemical Composition

1. **Oxides** → CO, CO_2, SO_2, NOx.
2. **Hydrocarbons** → methane, benzene, VOCs.
3. **Organic compounds** → aldehydes, ketones.
4. **Inorganic compounds** → NH_3, H_2S, HF.
5. **Particulate matter** → soot, fly ash, asbestos, heavy metals.

D. Based on Duration of Stay in Atmosphere

1. **Short-lived pollutants** → ozone, PAN, SO_2.
2. **Long-lived pollutants** → CO_2, CFCs, methane → contribute to **global warming & climate change**.

E. Based on Source

1. **Natural Pollutants** → volcanic gases, forest fires, pollen, sea spray, dust storms.
2. **Anthropogenic Pollutants** → industrial emissions, vehicular exhaust, household combustion, agricultural activities.

Summary Table

Basis	Types	Examples
Origin	Primary, Secondary	SO_2, CO (primary); O_3, PAN (secondary)
Physical state	Gaseous, Particulate	CO_2, SO_2 (gas); dust, smoke (particulate)
Chemical nature	Oxides, Hydrocarbons, Organics, Inorganics	NOx, CH_4, NH_3, benzene
Duration	Short-lived, Long-lived	O_3 (short); CO_2, CFCs (long)
Source	Natural, Anthropogenic	Volcanoes (natural); vehicles (anthropogenic)

5. National Ambient Air Quality Standards (NAAQS)

Introduction

- To control and monitor air pollution, the **Central Pollution Control Board (CPCB), Govt. of India**, has laid down **NAAQS**.
- These are **permissible limits** of major pollutants in the ambient air (outdoor environment).
- Ensures **public health, vegetation, and property protection**.

A. Major Pollutants Monitored under NAAQS (2009 Revision)

1. **Sulphur dioxide (SO_2)**
2. **Nitrogen dioxide (NO_2)**
3. **Particulate Matter (PM_{10}, $PM_{2.5}$)**
4. **Ozone (O_3)**
5. **Carbon monoxide (CO)**
6. **Ammonia (NH_3)**
7. **Lead (Pb)**
8. **Benzene (C_6H_6)**
9. **Benzo(a)pyrene (BaP) – Particulate phase**
10. **Arsenic (As)**
11. **Nickel (Ni)**

B. NAAQS (CPCB – 2009 Standards)

Pollutant	Time Weighted Avg.	Industrial, Residential, Rural & Other Areas	Ecologically Sensitive Area
SO_2	24 hrs	80 µg/m³	80 µg/m³
	Annual	50 µg/m³	20 µg/m³
NO_2	24 hrs	80 µg/m³	80 µg/m³
	Annual	40 µg/m³	30 µg/m³
PM_{10}	24 hrs	100 µg/m³	100 µg/m³

Pollutant	Time Weighted Avg.	Industrial, Residential, Rural & Other Areas	Ecologically Sensitive Area
	Annual	60 µg/m³	60 µg/m³
$PM_{2.5}$	24 hrs	60 µg/m³	60 µg/m³
	Annual	40 µg/m³	40 µg/m³
O_3	1 hr	180 µg/m³	180 µg/m³
CO	1 hr	4 mg/m³	4 mg/m³
NH_3	Annual	100 µg/m³	100 µg/m³
Pb	Annual	0.50 µg/m³	0.50 µg/m³

(Note: Only main pollutants shown in detail; other heavy metals/organics have specific smaller limits.)

6. Air Quality Index (AQI)

Definition

- A single **composite number** that indicates the overall **air quality status** at a location.
- Developed by **CPCB (2014)** for easy public understanding.

A. Pollutants Considered in AQI

- PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, O_3, NH_3, Pb.

B. AQI Categories (India – CPCB)

AQI Value	Category	Colour Code	Health Impact
0–50	**Good**	Green	Minimal impact

AQI Value	Category	Colour Code	Health Impact
51–100	**Satisfactory**	Light Green	Minor breathing discomfort to sensitive people
101–200	**Moderate**	Yellow	Breathing discomfort to people with lung/asthma/heart disease
201–300	**Poor**	Orange	Breathing discomfort to most people
301–400	**Very Poor**	Red	Respiratory illness on prolonged exposure
401–500	**Severe**	Maroon	Serious health impacts, affects even healthy people

Key Points

- AQI converts **pollutant concentrations** into **public-friendly values**.
- Helps government & citizens take **preventive measures**.
- Used in **cities like Delhi, Bengaluru, Mumbai, Hyderabad** for daily monitoring.

7. Effects of Air Pollution on Human Health

Air pollution has **short-term (acute)** and **long-term (chronic)** effects on human health. It affects the **respiratory system, cardiovascular system, nervous system, and overall wellbeing**.

A. Effects of Major Pollutants on Health

1. Particulate Matter (PM_{10} & $PM_{2.5}$)

- $PM_{2.5}$ → can penetrate deep into lungs, even enter bloodstream.
- **Health impacts**:
  - Asthma, bronchitis, lung cancer.
  - Reduced lung function, breathlessness.
  - Cardiovascular diseases (heart attacks, strokes).

2. Carbon Monoxide (CO)

- Colorless, odorless gas → "silent killer."
- Binds with hemoglobin (Hb) forming **carboxyhemoglobin**, reducing oxygen transport.

- **Health impacts**:
    - Headache, dizziness, fatigue.
    - High exposure → unconsciousness, even death.

3. Sulphur Dioxide (SO_2)

- Irritant gas, soluble in water → forms sulphuric acid in lungs.
- **Health impacts**:
    - Throat irritation, coughing.
    - Worsens asthma & bronchitis.
    - Long-term → lung damage.

4. Nitrogen Oxides (NOx)

- Causes inflammation of airways.
- Contributes to **smog & ozone** formation.
- **Health impacts**:
    - Eye, nose, throat irritation.
    - Reduced lung function.
    - Worsens respiratory infections.

5. Ozone (O_3) – Ground Level

- Good in stratosphere, bad in troposphere.
- **Health impacts**:
    - Chest pain, coughing, throat irritation.
    - Worsens asthma & COPD (Chronic Obstructive Pulmonary Disease).
    - Decreases lung function.

6. Lead (Pb)

- Heavy metal, accumulates in body tissues.
- **Health impacts**:
    - Damage to nervous system, kidneys.
    - Affects children → learning disabilities, reduced IQ, behavioral problems.
    - Anemia.

7. Volatile Organic Compounds (VOCs)

- Benzene, formaldehyde, toluene, etc.
- **Health impacts**:
  - Eye & throat irritation, nausea.
  - Benzene → blood cancer (leukemia).
  - Long exposure → nervous system damage.

8. Ammonia (NH_3) & H_2S

- **NH_3** → irritation of eyes, nose, throat.
- **H_2S** ("rotten egg smell") → affects nervous system, high levels cause death.

B. General Health Effects

- **Respiratory diseases** → asthma, lung cancer, COPD.
- **Cardiovascular diseases** → hypertension, stroke, heart attack.
- **Neurological effects** → headache, fatigue, loss of concentration.
- **Reproductive & developmental issues** → low birth weight, birth defects.
- **Premature deaths** → WHO estimates **7 million deaths per year** worldwide due to air pollution.

C. Vulnerable Groups

- **Children** → lungs still developing, more outdoor activity.
- **Elderly people** → weaker immune & cardiovascular systems.
- **People with pre-existing diseases** (asthma, TB, heart disease).
- **Outdoor workers** → traffic police, construction workers, farmers.

8. Economic Effects of Air Pollution

Air pollution not only affects **human health and environment**, but also causes **huge economic losses** to individuals, industries, and the nation.

A. Effects on Human Productivity

- Increased **healthcare costs** due to respiratory and heart diseases.
- Loss of **working days** because of illness (asthma, flu, lung infections).
- Reduced **life expectancy** → lowers economic productivity of the population.
- WHO & World Bank estimate **billions of dollars lost annually** due to air pollution–related diseases.

B. Effects on Agriculture

- **SO_2, NOx, O_3** → damage crops, reduce photosynthesis.
- Acid rain → damages soil quality, reduces crop yield.
- Dust deposition → blocks sunlight, reduces growth.
- Example: Ozone reduces yield of wheat, rice, cotton.

C. Effects on Industries

- Corrosion of machinery, metals, and buildings due to SO_2, NO_2, acid rain.
- Reduced efficiency of power plants (ash, smoke).
- Higher **maintenance costs** for factories, vehicles, and infrastructure.

D. Effects on Materials & Property

- Buildings and monuments damaged:
  - **Taj Mahal (Agra)** – marble corrosion due to SO_2 ("Marble Cancer").
  - Concrete, limestone, metals corrode faster.
- Paint, textiles, leather deteriorate due to ozone and UV radiation.
- Electronics sensitive to fine particulates suffer reduced lifespan.

E. Impact on National Economy

- Increased **public health expenditure** → burden on government.
- Loss of tourism revenue (damaged heritage sites).
- Reduced agricultural productivity → affects GDP.
- World Bank (2019): Air pollution costs India **~8.5% of its GDP annually**.

Summary

- Air pollution causes **direct costs** (medical treatment, crop losses) and **indirect costs** (loss of productivity, heritage damage).
- Investing in **clean technologies & pollution control** can save billions of rupees in the long run.

9. Control of Air Pollution

Air pollution control aims to **reduce emissions at source**, **treat pollutants before release**, and **adopt clean technologies**.

A. General Approaches to Control

1. **At Source (Prevention)**
    - Use of cleaner fuels (CNG, LPG, ethanol blends).
    - Switching to renewable energy (solar, wind, hydropower).
    - Process modification in industries to reduce emissions.
    - Regular maintenance of vehicles and engines.
2. **Dilution & Dispersion**
    - Use of tall chimneys in industries to disperse pollutants over a wide area.
    - Plantation of trees around industries to act as natural filters.
3. **After-Emission Treatment**
    - Use of air pollution control equipment.
    - Conversion of harmful gases into harmless forms.

B. Air Pollution Control Equipment

1. For Particulate Matter (Dust, Smoke, Fly Ash)

- **Gravity Settling Chamber**
    - Large chamber → air velocity reduced → heavy particles settle down.
    - Removes **larger particles (>50 µm)**.
- **Cyclone Separator**
    - Uses **centrifugal force** to separate dust from air.
    - Medium efficiency, low cost.
- **Fabric Filter (Baghouse Filter)**
    - Polluted air passed through cloth bags → dust trapped.
    - Very efficient (up to **99%**).
- **Electrostatic Precipitator (ESP)**
    - Uses **high voltage electric field** to charge and collect particles.
    - Removes **fine particles (<1 µm)** → widely used in power plants.
- **Wet Scrubbers**
    - Polluted gas passed through **liquid (water/alkali solution)** → particles & gases absorbed.
    - Example: Venturi scrubber.

2. For Gaseous Pollutants (SO_2, NOx, CO, VOCs)

- **Absorption**
  - Pollutant gases absorbed in liquid (e.g., SO_2 absorbed in lime slurry).
- **Adsorption**
  - Pollutant gases adsorbed on solid surfaces (activated carbon, silica gel).
- **Catalytic Converters (in vehicles)**
  - Convert $CO \rightarrow CO_2$,
  - $HC \rightarrow CO_2 + H_2O$,
  - $NOx \rightarrow N_2 + O_2$.
- **Combustion / Incineration**
  - VOCs and hydrocarbons oxidized at high temperature to CO_2 and H_2O.

C. Smoke and Its Control

- **Smoke** = fine carbon particles + unburnt hydrocarbons from incomplete combustion.
- **Control Methods**:
  - Ensure **complete combustion** (use of proper fuel-air ratio).
  - Use of **mechanical collectors** (cyclones, scrubbers, ESPs).
  - **Substitute cleaner fuels** (CNG, LPG, low-sulphur coal).
  - **Green belts** around urban & industrial areas to trap smoke.

D. Administrative Measures

- Enforcing **National Ambient Air Quality Standards (NAAQS)**.
- **Emission norms** for vehicles (BS-VI in India).
- Banning **crop burning** and open waste burning.
- Promoting **public transport & electric vehicles (EVs)**.

10. Ozone Depletion

A. Introduction

- **Ozone (O_3)**: A molecule made of three oxygen atoms.
- **Ozone Layer**: Located in the **stratosphere (15–35 km above Earth)**.
- **Function**: Absorbs harmful **ultraviolet (UV-B) radiation** from the Sun → protects humans, animals, and plants.
- **Ozone Depletion**: Thinning of the ozone layer due to **human-made chemicals**.

B. Causes of Ozone Depletion

1. **Chlorofluorocarbons (CFCs)** – Refrigerants, aerosols, foam production.
2. **Halons** – Fire extinguishers.
3. **Carbon tetrachloride (CCl_4)** – Solvents, industrial processes.
4. **Methyl chloroform** – Cleaning agent.

Mechanism:

- CFCs are stable → reach stratosphere → broken by UV → release chlorine (Cl) radicals.
- Cl radical reacts with O_3 → destroys ozone in a chain reaction.

C. Photochemical Reaction (Ozone Depletion)

1. **UV breaks CFC** → Cl radical formation:

$$CCl_3F + UV \rightarrow CCl_2F + Cl\bullet$$

2. **Ozone destruction**:

$$Cl\bullet + O_3 \rightarrow ClO\bullet + O_2$$

$$ClO\bullet + O \rightarrow Cl\bullet + O_2$$

- **Chain reaction**: 1 Cl radical can destroy **~100,000 O_3 molecules**.

D. Impacts of Ozone Depletion

1. **Human Health**
    - Increased **UV-B exposure** → skin cancer, sunburns, cataracts, immune system suppression.
2. **Environment**
    - **Crops**: Reduced yield (wheat, rice, soy).
    - **Marine life**: Plankton affected → disrupts food chain.
    - **Forests**: Reduced growth, leaf damage.
3. **Materials**
    - Plastics, paints, rubber, wood degrade faster under UV radiation.
4. **Climate Interaction**
    - Ozone depletion interacts with greenhouse gases → impacts **global climate patterns**.

E. Measures to Reduce Ozone Depletion

- **Montreal Protocol (1987)** → global phase-out of CFCs, halons.
- Substitute **CFCs with HFCs (hydrofluorocarbons)** or natural refrigerants (ammonia, CO_2).
- Reduce use of **ozone-depleting substances (ODS)** in industry and households.
- Promote **public awareness** about ozone-friendly products.