Lecture Notes

on

Environmental Engineering (MCMC3001)

3rd Year Civil, Electrical, Mechanical, Computer Science Engineering

Module III: Air

By

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Module-III

Air

Air is a gaseous mixture that surrounds the Earth, composed primarily of about 78% nitrogen, 21% oxygen and 1% other gases like argon, carbon dioxide, and water vapour.

Composition of Air

Air is a mixture of several gases, the most abundant of which are:

- **Nitrogen (N_2):**

Approximately 78% of air. It is essential for plants and is converted by soil bacteria into a usable form.

- **Oxygen (O_2):**

About 21% of the air, vital for respiration by living organisms.

- **Other Gases (1%):**

This category includes trace amounts of gases like:

- **Argon (Ar):** The third most abundant gas.
- **Carbon Dioxide (CO_2):** A small but important component for photosynthesis in plants and also known for trapping heat in the atmosphere.
- **Water Vapour:** The amount of water vapor varies significantly from one location to another, with drier regions having less moisture than wetlands.
- **Trace Gases:** Other gases such as neon, helium, ozone, and methane are present in minute quantities.

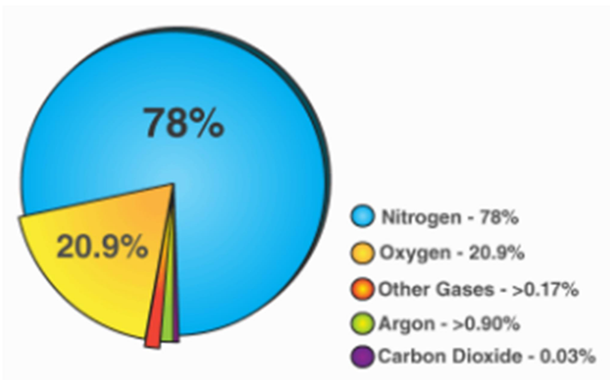
Dust Particles & Aerosols:

Air also contains minute particles of dust, pollen, smoke, and other aerosols.

Properties of Air

- **Colourless and Odourless:** Pure air lacks any distinct color or smell.
- **Invisible:** Air is invisible to the naked eye.
- **Occupies Space and has Mass:** Air exerts pressure and takes up volume, demonstrating it has mass.

- **Supports Life:** It is essential for the survival of living organisms, providing oxygen for breathing and for plants to use carbon dioxide in photosynthesis.
- **Medium for Sound and Light:** Air allows for the diffusion of light and the transmission of sound.
- **Temperature and Moisture Variation:** The amount of moisture air can hold is dependent on temperature, meaning its moisture content changes from place to place and with temperature fluctuations.



Quantification of air pollutants involves measuring specific atmospheric components using techniques like continuous monitoring with electronic sensors or noncontinuous sampling for laboratory analysis, often focusing on pollutants like PM2.5, PM10, ozone, and gases such as CO, NO2, and SO2. Results are expressed in units like micrograms per cubic meter and are often summarized by the Air Quality Index (AQI), which provides a scale to understand overall pollution levels.

Methods for Quantification

- **Continuous Monitoring:**

  Electronic sensors are used to measure pollutants in real-time, with data automatically collected and transmitted to a central database.

- **Non-continuous Sampling:**

  Pollutants are collected on filters or in canisters over a specific period, then sent to a laboratory for detailed measurement and analysis.

- **Remote Sensing:**

  Satellite or aerial observations are used to measure pollutants from a distance, offering broad spatial coverage.

- **In-situ Measurement:**

  Direct measurement of pollutants at their location using specialized devices and techniques for high accuracy.

Key Pollutants Measured

- **Particulate Matter (PM):** Includes PM2.5 (particles < 2.5 microns) and PM10 (particles < 10 microns), measured in micrograms per cubic meter.
- **Gases:** Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Sulfur Dioxide (SO2), and Ozone (O3) are frequently monitored.
- **Volatile Organic Compounds (VOCs):** Measured using sensors for comprehensive air quality data.

Units of Measurement & Indices

- **Concentration Units:**

  Pollutants are often quantified in units like micrograms per cubic meter ($\mu g/m^3$).

- **Air Quality Index (AQI):**

  A scale (typically 0-500) that translates the concentrations of various pollutants into an easily understandable numerical value representing the overall air quality.

Purpose of Quantification

- **Health Impact Assessment:** To understand the health risks associated with different levels of air pollution.
- **Regulatory Compliance:** To ensure that air pollutant levels meet government standards and regulations.
- **Trend Analysis:** To track changes in air quality over time and identify pollution sources.

Monitoring air pollutants

Monitoring air pollutants is the process of collecting and measuring air samples to determine the presence and concentration of harmful substances like particulate matter (PM2.5, PM10), sulfur dioxide (SO_2), oxides of nitrogen (NO_2).

This monitoring is crucial for identifying

- pollution sources
- assessing public health risks
- creating strategies to improve air quality

Methods include using ground-based sensors and sampling stations, as well as remote sensing techniques.

Key pollutants monitored

- Particulate Matter (PM) includes fine (PM2.5) and respirable (PM10) suspended particles which can be inhaled deep into the lungs.
- Gases:
    - Sulfur Dioxide (SO_2)
    - Oxides of Nitrogen (NO_2)
    - Carbon Monoxide (CO)
    - Ozone (O_3)
    - Methane (CH_4)

Methods of monitoring

Ground-based monitoring:

Traditional methods involve manual air sampling and analysis using equipment at fixed stations, often coordinated by government agencies like the Central Pollution Control Board.

Sensors:

Modern air sensors, sometimes cloud-based, provide real-time data and can be used for continuous monitoring of gas concentrations and environmental factors.

Remote sensing:

Techniques that use satellite imagery to monitor pollutants like sulfur dioxide (SO_2), oxides of nitrogen (NO_2) etc.

Biological monitoring:

Using plants to indicate air quality, as they can show visible damage from specific pollutants (from damage symptoms on plant leaves, accumulation of pollutants over time on Lichens and mosses).

Importance of monitoring of air pollutants

- **Public health:**

  Identifying pollution levels to protect human health from respiratory illnesses and other health effects.

- **Regulatory compliance:**

  Ensuring compliance with air quality standards, such as the National Ambient Air Quality Standards (NAAQS).

- **Policy and urban planning:**

  Providing data to inform policies and guide decisions for sustainable development and pollution control measures.

- **Environmental research:**

  Monitoring climate change and other environmental impacts of pollution.

Air pollution- Occupational hazards

- Occupational hazards are risks associated with a particular job that can lead to accidents, injuries or illness.
- In the context of air pollution, occupational hazards refer to the health risks that arise from exposure to airborne contaminants in the workplace.
- These hazards involve higher concentrations of pollutants that can cause acute or long-term health problems for employees.
- Workplace air pollution can originate from industrial processes, vehicles, or even poorly ventilated offices.

Occupational hazards from air pollution include:

- respiratory diseases like asthma,
- chronic obstructive pulmonary disease (COPD)
- lung cancer

- cardiovascular problems such as heart attacks and strokes
- Eye irritation
- other issues like silicosis and skin irritation.

Workers in industries like mining, cement manufacturing, and construction are particularly at risk due to exposure to dust, fumes, and gases like silica, carbon monoxide, nitrogen dioxide, and particulate matter.

Urban air pollution automobile pollution


- Urban air pollution is heavily influenced by automobile emissions, as vehicle exhaust releases pollutants like carbon monoxide (CO), particulate matter (PM2.5, PM10), sulfur dioxide (SO_2), oxides of nitrogen (NO_2)

Sources

- Transportation
- Domestic use of fossil fuels
- Industrialization
- Power generation

Transportation

The use of private vehicles (predominantly older, diesel models) is the major source of urban air pollution. The US Environmental Protection Agency estimates that around 75% of VOC emissions (by weight) come from transportation. Approximately one-quarter of particulate matter in the air is due to vehicles.

Domestic use of fossil fuels

Around half of the world population still relies on solid fuels for cooking and heating. These fuels, including wood, coal and charcoal are burned in inefficient stoves that release large quantities of health-damaging particulate matter and climate warming pollutants into the nearby environment. In addition, it is estimated that 1.2 billion people light their home with kerosene lamps additionally contributing to air pollution and increasing risk of respiratory and cardiovascular diseases.

Industrialization

Industrialization is considered as a major contributor to urban air pollution as the area having industries particularly show poor air quality. Factories release many toxic gases due to the burning of fossil fuels and the use of chemicals. These gases react with each other and with other atmospheric constituents. It is estimated that around 80 different toxins can be found in the air emitted by factories i.e. from asbestos and dioxin to lead and chromium.

Power generation

With increased population, there is an increased demand of energy. To fulfill that demand, fossil fuels are tremendously being used to generate energy as they are cheap and readily available. The coal powered power plants are a major source of urban air pollution.

Combustion and agriculture

Combustion of material is an activity that releases various toxic gases in the atmosphere and contributes to urban air pollution. Combustion releases CO_2 and incomplete combustion releases CO. Both of these gases lead to urban air pollution. Agriculture activities also release various other gases in the atmosphere such as NO_2 and Methane (CH_4).

Beauty Products

A recent study suggests that use of beauty products also contributes to urban air pollution. Most of the cosmetics and perfumes contain VOCs, which are released during their use and contribute to urban air pollution. With more population, the use of these beauty products is increasing and so the pollution.

Air Pollutants

The quality of urban air is indicated by the quantity of certain pollutants in the air, i.e. Particulate Matter (PM_{10}, $PM_{2.5}$), Ozone (O_3), Sulfur Oxides (SO_x), Nitrogen Oxides (NO_x), Carbon monoxide (CO) and Volatile Organic Compounds (VOCs).

Particulate matter (PM10, PM2.5)

PM_{10} are fine particles having an aerodynamic diameter smaller than 10 µm and $PM_{2.5}$ are fine particles having an aerodynamic diameter smaller than 2.5 µm. If inhaled, PM particles penetrate deep into lungs and enter the bloodstream. The concentration of PM_{10} and $PM_{2.5}$ is a metric most often used to indicate the quality of air in urban environments. PM is associated with major health effects like respiratory diseases, cardiovascular functions and lung cancer.

Ozone (O_3)

Ground level ozone, a pollutant considered harmful for human health, is not directly emitted to the atmosphere, but rather formed as a result of chemical reaction between nitrogen oxides (NO_x) and volatile organic compounds (VOCs) under the stimulation from sunlight. In other words, pollutants emitted by cars, power plants and burning of materials interact with sunlight to create ozone. Ozone forms smog and makes air difficult to breathe.

Sulphur oxides (SO_x)

Sulphur oxides are colourless gases found in the lower atmosphere. Depending on the concentration these gases can be detected by smell and taste. The main source of these pollutants is burning of fossil fuels that contain sulphur. In particular, the thermal power plants that burn coal with high sulphur content are known to be the main sources of anthropogenic sulphur dioxide emissions worldwide. Emissions from domestic coal burning and from vehicles can also contribute to high local ambient concentrations of sulphur dioxide. Sulphur oxides also react with rainwater to produce sulphuric acid (which causes acid rain).

Nitrogen oxides (NO_x)

Nitrogen is found as a compound in fossil fuel and nitrogen oxides are obtained as a result of combustion processes of fuels. Nitrogen oxides have a deteriorating impact on the respiratory system and cause inflammation of the airways at high levels. Long term exposure, on the other hand, can decrease lung function and increases the response to allergens. NO_x are the majority of the anthropogenic emissions in Europe. These compounds are mostly emitted by power stations, vehicles, and industrial and domestic combustion processes. In the cities the road transport is the major cause. In addition, NO_x contributes to the formation of PM and ground level ozone.

Carbon monoxide (CO)

Carbon monoxide is a highly toxic, colourless, odourless and tasteless air pollutant. CO is produced in the incomplete combustion of fossil fuels such as gasoline, natural gas, oil, coal, and wood. The largest anthropogenic source of CO is vehicle emissions.

Volatile Organic Compounds (VOCs)

VOCs are the compounds that have low boiling point and can evaporate at room temperatures. These compounds are harmful to human health. Sources of VOCs include paints, varnishes, waxes, oil-dissolving solvents, cleansers, fuels, disinfecting, cosmetics and glues. They can be also produced from smoking and burning of fuel. VOCs additionally contribute to the formation of ozone.

Air Quality Standards

- Air quality standards are regulations that set limits on the concentration of pollutants in the atmosphere to protect public health and the environment.
- They are established by governmental bodies like the U.S. Environmental Protection Agency (EPA) and are based on factors like the health effects of pollutants, which include smog, acid rain and other hazards.
- India's air quality standards are defined by the National Ambient Air Quality Standards (NAAQS) notified in 2009, which regulate 12 pollutants with limits set for different areas and time periods.
- The standards include annual and 24-hour averages for pollutants like Sulfur Dioxide, Nitrogen Dioxide and Particulate Matter, with specific limits for industrial and ecologically sensitive areas.
- The Central Pollution Control Board (CPCB) is responsible for setting and enforcing these standards under the Air Act, 1981.

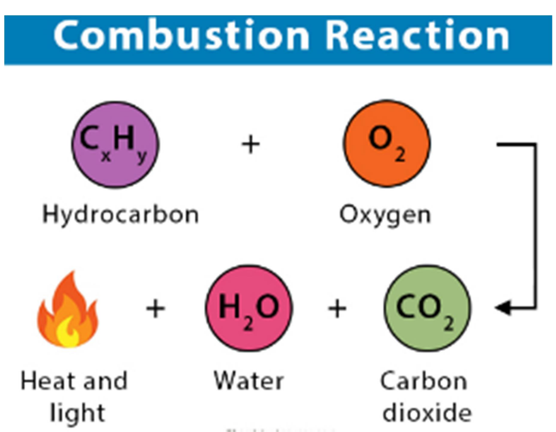
Pollutant	Time Period	Industrial/Residential/Rural/Other Areas	Ecologically Sensitive Areas
SO_2	Annual	50 $\mu g/m^3$	20 $\mu g/m^3$
SO_2	24-hour	80 $\mu g/m^3$	80 $\mu g/m^3$
NO_2	Annual	40 $\mu g/m^3$	30 $\mu g/m^3$
NO_2	24-hour	80 $\mu g/m^3$	80 $\mu g/m^3$
PM_{10}	Annual	60 $\mu g/m^3$	60 $\mu g/m^3$
$PM_{2.5}$	Annual	40 $\mu g/m^3$	40 $\mu g/m^3$
Ozone (O_3)	8-hour average	100 $\mu g/m^3$	100 $\mu g/m^3$
Ozone (O_3)	1-hour average	180 $\mu g/m^3$	180 $\mu g/m^3$
Carbon Monoxide (CO)	8-hour average	2 mg/m^3	2 mg/m^3

Chemistry of combustion

- Combustion is a high-temperature exothermic chemical reaction between a fuel and an oxidant (usually oxygen) that releases energy as heat and light.
- The general equation for complete combustion of a hydrocarbon fuel is

Fuel + O2→ CO2+$H2O$

It involves the breaking of chemical bonds and the formation of new, more stable bonds.



Key aspects of combustion chemistry

Reactants:

- A fuel and an oxidant are required.
- **Fuel:** The substance that burns, which can be a solid, liquid, or gas (e.g., methane, wood, gasoline).
- **Oxidant:** Usually oxygen from the air.

Reaction conditions:

- A trigger is needed to initiate the reaction, typically by heating the fuel to its ignition temperature.

Products:

- The products are typically oxides, such as carbon dioxide and water in the complete combustion of hydrocarbons.

Energy release:

- Combustion is an exothermic process, meaning it releases a significant amount of energy in the form of heat and light.

Complete and Incomplete Combustion

- Complete combustion reactions, also known as clean combustion reactions, is the complete oxidation of the fuel. Such reactions often liberate only water and carbon dioxide as the products, apart from heat and light. An example could be the combustion of propane in the presence of oxygen.
- Incomplete combustion reactions are the combustion reactions that involve the formation of by-products such as ash and soot. This reaction happens when the supply of oxygen is inadequate, and carbon and carbon monoxide are produced. An example could be the combustion of propane in an environment where the oxygen is deficient

Automobile Engines

- Automobile engines are machines that convert fuel into mechanical energy to power a vehicle
- The most common type of Automobile engines:
    - internal combustion engines (ICE)

- electric motors
- hybrid engines

- ICEs use the combustion of gasoline or diesel to move pistons, while electric motors are powered by batteries (these are found in Battery Electric Vehicles (BEVs)).
- hybrid engines Combines an internal combustion engine with an electric motor to improve fuel economy.

Quality of fuel

- Fuel quality refers to its composition and purity, which impact engine performance, efficiency, and emissions.
- High-quality fuel is clean, meets specific standards, and contains fewer impurities, while low-quality fuel can contain contaminants that damage an engine over time.
- Key indicators of fuel quality include octane rating for gasoline (higher is better) and cetane number for diesel, which are measured to ensure the fuel is suitable for a particular engine.

Operating conditions and interrelationship

- The key operating conditions of air include temperature, pressure, humidity and density, all of which are intrinsically linked and affect one another.
- Changes in any one of these properties will alter the others and influence everything from weather patterns to human health.

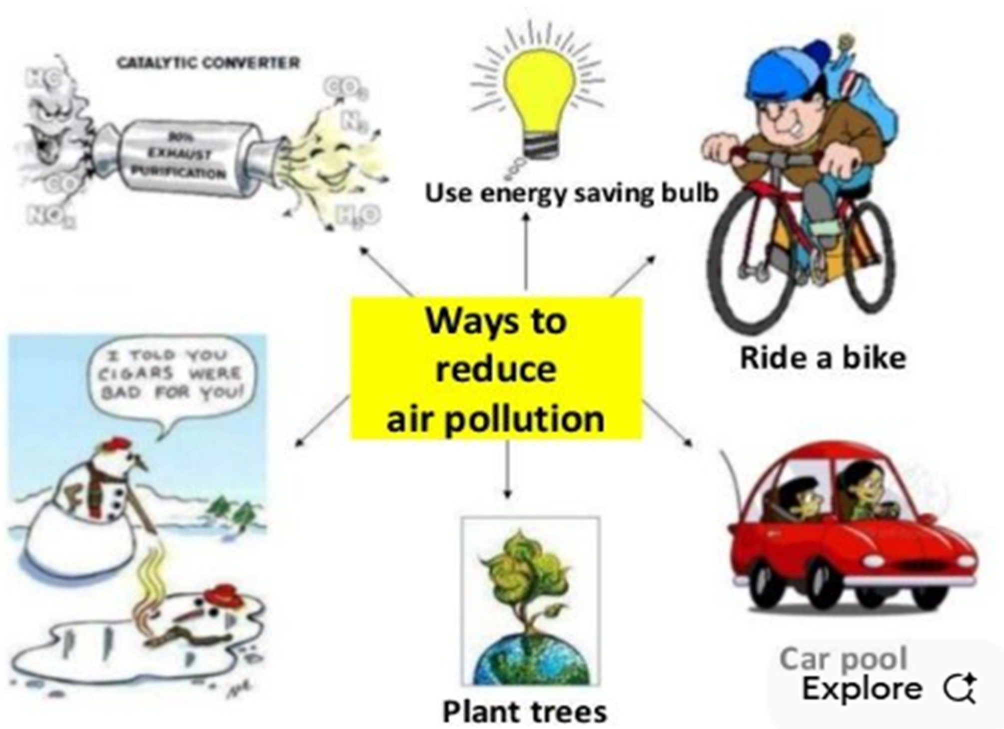
Effect of altitude on air's operating conditions

- **Pressure:** As altitude increases, atmospheric pressure decreases significantly because there is less weight from the column of air above.
- **Temperature:** In the troposphere (the lowest layer of the atmosphere), air temperature generally decreases with increasing altitude. This is a result of the lower air pressure, which causes the air to expand and cool.
- **Density:** Both reduced pressure and lower temperatures cause air density to decrease at higher altitudes. This "thinner" air has critical implications for aviation, as it reduces engine power and the lift on an aircraft's wings.

- **Humidity:** While the maximum moisture-holding capacity of air decreases with altitude due to lower temperatures, localized conditions such as air expansion can still lead to increased humidity and condensation.

Control measures for Air pollution

- To control air pollution, individuals can reduce vehicle emissions by using
  - public transport or carpooling
  - conserving energy at home
  - avoiding burning waste.
- On a larger scale, industries can implement cleaner technologies like scrubbers and filters, governments can enforce stricter emission norms, and communities can increase green cover through tree planting initiatives.



public transport

Energy Efficient Vehicles Like Electric

Going Green

use of Solar Energy

Construction and limitations

- Construction is the process of building structures, from houses to large infrastructure projects.
- Construction contributes to air pollution through the release of
  - dust (PM 2.5)-from activities like demolition, excavation, and vehicle movement
  - gaseous pollutants (NO2, CO)-from heavy-duty diesel engines
- Current limitations include a lack of clear, enforceable standards for construction site pollution