

Module 3-AIR

Air is a non-homogeneous mixture of different gases in the atmosphere & it is the invisible mixture of gases that surrounds Earth. Air is the most important component for the survival of life on Earth. We breathe in air. The oxygen present in air is required for respiration of living beings. The carbon dioxide present in air is essential for the green plants to manufacture their own food by the process of photosynthesis.

The composition of air refers to the chemical composition of the troposphere. The troposphere is the lowest layer of the atmosphere, extending from the surface to about 12 km or 39000 ft. The troposphere contains about 80% of the mass of the Earth's atmosphere. Nearly all of the atmosphere's water vapor exists in this layer. Just three gases account for 99% of dry air: nitrogen, oxygen, and argon.

Air pollution is the world's largest environmental threat to human health and one of the major preventable causes of death and disease. According to WHO, the ambient and household air pollution together account for 7 million premature deaths globally every year, making it more deadly than a combination of malaria, tuberculosis, and AIDS. In particular, an estimated 4.2 million people die prematurely around the world due to ambient air pollution, mostly from heart disease, stroke, chronic obstructive pulmonary disease, lung cancer, and acute respiratory infections in children. It disproportionately affects women, children, and the elderly in developing nations, who are frequently exposed to ambient and indoor air pollution.

Air pollution may be defined as the,

Presence in the air (outdoor atmosphere) of one or more contaminants or combinations thereof in such quantities and of such durations as may be or tend to be injurious to human, animal or plant life, or property, or which unreasonably interferes with the comfortable enjoyment of life or property or conduct of business. Air pollutants come in the form of gases and finely divided solid and liquid aerosols. Aerosols are loosely defined as "any solid or liquid particles suspended in the air".

A pollutant can be solid (large or sub-molecular), liquid or gas. It may originate from a natural or anthropogenic source (or both). It is estimated that anthropogenic sources have changed the composition of global air by less than 0.01%.

Examples of “natural” air pollution include:

Ash,
salt particles,
pollen and spores,
smoke and
windblown dust

DEFINITION OF TERMS AND SCALE CONVERSION

1. Air pollution: - concentration of foreign matter in air in excessive quantity which is harmful to the health of man.
2. Indoor air pollutions: - Pollutions from the housing made materials and living and working activities of the house, such as: natural radiation-radon, domestic combustion-coal gas, and human habits tobacco smoking.
3. Outdoor air pollution: - Pollutions from out door services and environmental mixings, such as transportation-automobiles, industries-refineries, atomic energy plant-nuclear, and community activities-cleaning of streets.
4. Acute effects: - with in twenty-four hours of sudden exposure to polluted air illness would occur.
5. Delayed effect: - The cause-and-effect relationship of air pollution and chronic effects on health is in a way difficult to prove due to long time contact and accumulation effect.
6. Aerosols: - Small solid or liquid particles (fine drops or droplets) that are suspended in air.
7. Dust: - aerosols consist of particles in the solid phase.
8. Smoke: - aerosols consist of particles in the solid and sometimes also liquid-phase and the associated gases that result from combustion. 1.4.9. Ash: - aerosols of the solid phase of smoke, particularly after it settles into a fine dust.
9. Particulates: - Small particles, that travel in air and settles or lands on something.
10. Fumes: - are polydispersed fine aerosols consisting of solid particles that often aggregate together, so that many little particulates may form one big particle.
11. Mist: - A cloud or dense collection of droplets suspended in air.
12. Vapour: - The evaporated compound in the gas phase.
13. Troposphere: - The first and lowest of the atmospheric layers is called the “troposphere”

- 14. Stratosphere: - The second layer of air is called the “stratosphere”.
- 15. Ionosphere: - Above the stratosphere is the “ionosphere” the top of which is the border line space.
- 16. Thermosphere: - This is a region of highly ionized gases, extending to about 1600 km.
- 17. Mesosphere: - Above the stratosphere, or the middle layer.

Air pollution due to natural sources

Forest fires (which often start naturally) can produce huge swathes of smoke that drift for miles over neighboring cities, countries, or continents. Giant volcanic eruptions can spew so much dust into the atmosphere that they block out significant amounts of sunlight and cause the entire planet to cool down for a year or more. Radioactive rocks can release a gas called radon when they decay, which can build up in the basements of buildings with serious effects on people's health.

All these things are examples of serious air pollution that happen without any human activity; although we can adapt to natural air pollution, and try to reduce the disruption it causes, we can never stop it happening completely.

However, since Earth's atmosphere is very turbulent the natural air pollution will often disperse relatively quickly.

Air pollution due to anthropogenic activities

Today most of the natural resources are polluted due to increased pace of anthropogenic activities. The increase in population and transportation and industrial development has resulted in the release of all kinds of air pollutants into the environment. The natural capacity of the environment to tolerate and sustain development has dwindled in the face of the ever-increasing discharge of air pollutants.

The assessment of air quality and control of air pollution are difficult tasks facing an environmental manager. Both soil and water can be confined and gathered at one place while air cannot be gathered and confined in one place. Hence air quality assessment, air pollution prevention strategies and control technologies are of great importance in air quality management.

Top-ten gases in anthropogenic air pollution

Any gas could qualify as pollutant if it reaches a high enough concentration to do harm. Theoretically, that means there are dozens of different pollution gases. In practice, about ten different substances cause most concern:

Sulfur dioxide: Coal, petroleum, and other fuels are often impure and contain sulfur as well as organic (carbon-based) compounds. When sulfur (spelled "sulphur" in some countries) burns with oxygen from the air, sulfur dioxide (SO_2) is produced. Coal-fired power plants are the world's biggest source of sulfur-dioxide air pollution, which contributes to smog, acid rain, and health problems that include lung disease.

Carbon monoxide: This highly dangerous gas forms when fuels have too little oxygen to burn completely. It spews out in car exhausts and it can also build up to dangerous levels inside a home if you have a poorly maintained gas boiler, stove, or fuel-burning appliance.

Carbon dioxide: This gas is central to everyday life and isn't normally considered a pollutant: we all produce it when we breathe out and plants such as crops and trees need to "breathe" it in to grow. However, carbon dioxide is also a greenhouse gas released by engines and power plants. Since the beginning of the Industrial Revolution, it's been building up in Earth's atmosphere and contributing to the problem of global warming and climate change.

Nitrogen oxides: Nitrogen dioxide (NO_2) and nitrogen oxide (NO) are pollutants produced as an indirect result of combustion, when nitrogen and oxygen from the air react together. Nitrogen oxide pollution comes from vehicle engines and power plants, and plays an important role in the formation of acid rain, ozone and smog. Nitrogen oxides are also "indirect greenhouse gases" (they contribute to global warming by producing ozone, which is a greenhouse gas).

Volatile Organic Compounds (VOCs): These carbon-based (organic) chemicals evaporate easily at ordinary temperatures and pressures, so they readily become gases. That's precisely why they're used as solvents in many different household chemicals such as paints, waxes, and varnishes. Unfortunately, they're also a form of air pollution: they're believed to have long-term (chronic) effects on people's health and they also play a role in the formation of

ozone and smog.

Particulates: These are the sooty deposits in air pollution that blacken buildings and cause breathing difficulties. Particulates of different sizes are often referred to by the letters PM followed by a number, so PM10 means soot particles of less than 10 microns (10 millionths of a meter or $10\mu\text{m}$ in diameter). In cities, most particulates come from traffic fumes.

Ozone: Also called trioxygen, this is a type of oxygen gas whose molecules are made from three oxygen atoms joined together (so it has the chemical formula O_3), instead of just the two atoms in conventional oxygen (O_2). In the stratosphere (upper atmosphere), a band of ozone ("the ozone layer") protects us by screening out harmful ultraviolet radiation (high-energy blue light) beaming down from the Sun. At ground level, it's a toxic pollutant that can damage health. It forms when sunlight strikes a cocktail of other pollution and is a key ingredient of smog (see box below).

Chlorofluorocarbons (CFCs): Once thought to be harmless, these gases were widely used in refrigerators and aerosol cans until it was discovered that they damaged Earth's ozone layer. We discuss this in more detail down below.

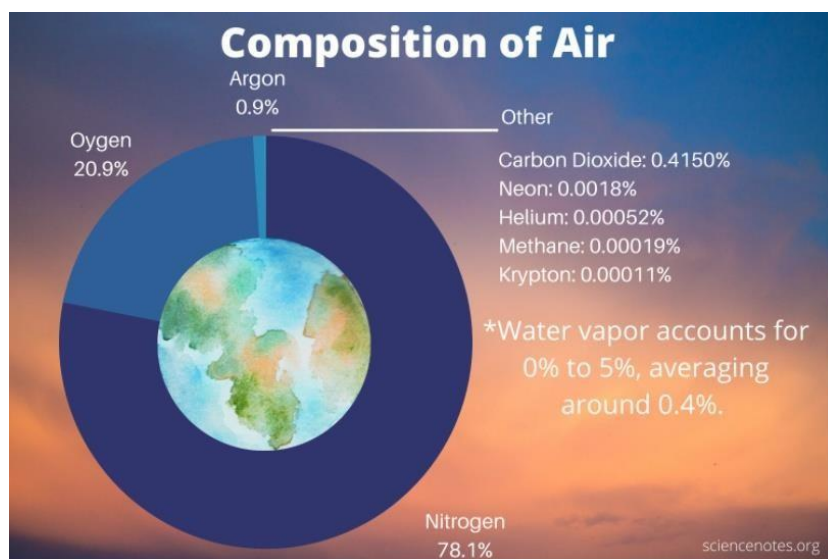
Unburned hydrocarbons: Petroleum and other fuels are made of organic compounds based on chains of carbon and hydrogen atoms. When they burn properly, they're completely converted into harmless carbon dioxide and water; when they burn incompletely, they can release carbon monoxide or float into the air in their unburned form, contributing to smog.

Lead and heavy metals: Lead and other toxic "heavy metals" can be spread into the air either as toxic compounds or as aerosols (when solids or liquids are dispersed through gases and carried through the air by them) in such things as exhaust fumes and the fly ash (contaminated waste dust) from incinerator smokestacks.

Composition of air

Air constitutes 80% of man's daily intake of materials by weight. We breathe 22,000 times a day on the average, inhaling 16 kg of air. The earth's atmosphere is an envelope of gases extending to a height of 200 km from the earth's surface. The atmosphere is a protective cover which sustains life and protects it from the unfriendly environment of outer space. The lower atmosphere, i.e, the troposphere contains about 70% of the mass of the atmosphere. It has mainly three categories of gaseous components: major, minor, and trace (Table 1.1). For

major gases, like N_2 and O_2 , the concentrations vary but to a very little extent with time, while for trace gases, the values tend to converge as the averaging time lengthens. Oceans as well as vegetation are the most important **sinks** for most atmospheric gases. A **sink** is a medium which is capable of retaining and interacting with a long-lived pollutant, though not necessarily indefinitely.



Average composition of clean dry air near sea level (ppm by volume)

Components	Average conc. (ppm)	Concentration in volume percent	Estimated residence time
Major			
Nitrogen, N_2	78.09×10^4	78.09	Continuous
Oxygen, O_2	20.94×10^4	20.94	Continuous
Minor			
Argon, Ar	93×10^2	0.93	Continuous
Carbon dioxide, CO_2	32×10^2	0.0318	2 to 4 years
Trace			
Neon, Ne	18	0.0018	Continuous
Helium, He	5.2	0.00052	– 2 million years
Methane, CH_4	1.3	0.00013	4 to 7 years
Krypton, Kr	1.0	0.0001	Continuous
Hydrogen, H_2	0.5	0.00005	Little is known about residence time
Carbon monoxide, CO	0.1	0.00001	0.5 year
Ozone, O_3	0.02	0.000002	– 60 days
Ammonia, NH_3	0.01	0.000001	7 days
Nitrogen dioxide, NO_2	0.001	0.0000001	5 days
Sulphur dioxide, SO_2	0.0002	0.0000002	4 days
Hydrogen sulphide, H_2S	0.002	0.0000002	2 days

Xenon, Xe	0.081	-	Continuous
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UNIT OF MEASUREMENT:

Concentrations of air pollutants are commonly expressed as the mass of pollutant per Unit volume of air mixture, as mg/m³, µg/m³, ng /m³. Concentration of gaseous pollutants may also be expressed as volume of pollutant per million volumes of the air plus pollutant mixture (ppm) where 1ppm= 0.0001 % by volume. It is sometimes necessary to convert from volumetric units to mass per unit volume and vice versa.

The relationship between ppm and mg/m³ depends on the gas density, which in turn depends on:

TMTemperature

TMPressure

TMMolecular weight of the pollutant

The following expression can be uses to convert of between ppm and mg/m³ at any temperature or pressure.

$$\text{mg/m}^3 = \frac{273 \times \text{PPM} \times \text{molecular wt.} \times \text{pressure}}{22.4 \times \text{temperature}}$$

Simply multiply the calculated value of mg/m³ by 1000 to obtain µg/m³. The constant 22.4 is the volume in liter occupied by 1 mole of an ideal gas at standard concentration (0 0 c and 1 atm.). One mole of any substance is a quantity of that substance whose mass in grams numerically equals its molecular weight.

SOURCES AND CLASSIFICATION OF AIR POLLUTION

As clean air in the troposphere moves across the earth's surface, it collects the products of both natural events (dust storms and volcanic eruptions) and human activities (emissions from sources like transportation, fuel combustion, industrial operations, solid waste disposal and various other activities). These potential pollutants, called, **primary pollutants** which are emitted directly from the source, mix with the churning air in the troposphere. Some primary pollutants may react with one another or with the basic components of the atmosphere in chemical and photochemical reactions to form new pollutants which are called **secondary pollutants**. The reaction mechanisms and various steps involved in the

process are influenced by many factors such as concentrations of reactants, the amount of moisture in the atmosphere, degree of photo-activation, meteorological forces, and local topography (Fig shown below). Long-lived pollutants travel far before they return to the earth as particles, droplets, or chemicals dissolved in precipitation.

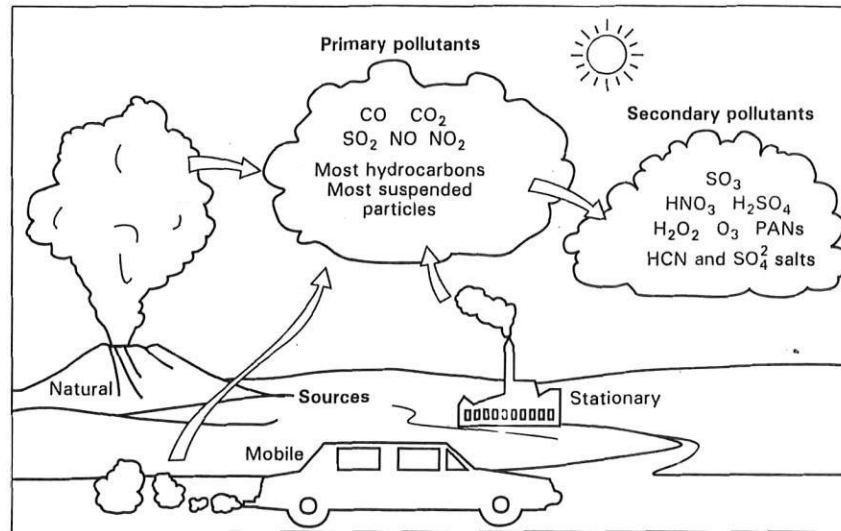


Fig. Primary and secondary air pollutants

ACCORDING TO ORIGIN:

Primary pollutants:

The pollutants that are emitted directly from identifiable sources produced by natural events (eg: dust storms and volcanic eruptions) and human activities (eg: emissions from vehicles, industries etc.) are called primary pollutants. Eg: smoke, dust, oxides of Sulphur & nitrogen, hydrocarbons and particulate matter etc.

Secondary pollutants:

The pollutants that are formed in the atmosphere by chemical interactions between primary pollutants and atmospheric constituents are known as secondary pollutants. Eg. Sulphur trioxide, ozone, ketones, sulphuric acid, nitric acid, carbonic acid etc.

ACCORDING TO STATE OF MATTER:

Gaseous air pollutants:

These pollutants exist in a gaseous state at normal temperature and pressure. They are carbon dioxide, nitrogen dioxide, sulphur oxides etc.

Particulate air pollutants:

These are not gaseous substances. They are suspended droplets, solid particles or mixtures of the two.

ACCORDING TO SOURCES:**Natural sources:**

These include volcanic eruptions, deflation of sand and dust, forest or wild fires of natural vegetation, sulphur springs, natural geysers, organic and inorganic decays, vegetative decays, marsh gases, cosmic dust, pollen grains of flowers, photochemical reactions, soil debris etc.

Wild animals in their natural habitat are also considered natural sources of pollution – decomposition gases, waste

Man-made sources:

These include human activities such as industries, factories, urban centers, aircraft, nuclear experiments, automobiles, agriculture, domestic burning of wood and burning of fossil fuels, deforestation, mining, waste treatment plants and power plants.

STATIONARY SOURCES

A stationary source of air pollution refers to an emission source that does not move (i.e., power plants, chemical and manufacturing industries). Often stationary sources are defined as large emitters who release relatively consistent qualities and quantities of pollutants

There are two types:

Point Source: industrial and nonindustrial stationary equipment or processes.

Area Sources: locomotives operating within a railyard, Multiple flue gas stacks within a single industrial plant, Open burning and forest fires, Evaporation losses from large spills of volatile liquids.

Emission from Stationary Sources:

CO: As the incomplete combustion of carbon fuel emits CO, power plants (e.g. coal-, gas-, and oil-fired) are the key source of CO emission. Other industrial processes, including petroleum refinery, metal production, and chemical production, also emit CO.

GHGs: According to the IPCC, the industry (e.g. burning of fossil fuels at facilities), production of electricity and heat (e.g. coal, natural gas, and oil burning), and other energy production processes (e.g. refining, processing, and transporting of energy) combined

accounted for 56% of the global greenhouse gas emission in 2010. The production of electricity and heat is the single largest contributor to GHGs emissions by accounting for 25%.

NOX: Fuel combustion in stationary sources accounts for the greatest portion of NOX emission. There are two mechanisms in which NOX is produced in the combustion process, namely fuel NOX and thermal NOX. Fuel NOX is caused when nitrogen in fuel is burnt and thermal NOX is attributable to the high-temperature oxidation process that converts the atmospheric N₂ to NOX.

PM: Combustion of fossil fuel from stationary sources emits black carbon and organic aerosol. Moreover, the oxidation of NOX and SOX forms nitrate and sulfate aerosol species that can constitute secondary PM.

SOX: Fossil fuel combustion is a major contributor to SOX. Of the fossil fuel combustion, about 90% is originated from the burning of coal in a stationary source (e.g. power plants and kilns). Compared to natural gas (trace amount) and oil (0.1-1%), coal (0.5-4%) contains significantly high sulfur content, which emits a greater amount of SOX.

MOBILE SOURCES

"Mobile Sources" is a term used to describe a variety of vehicles, engines, and equipment that generate air pollution and that move, or can be moved, from place to place. They are either classified as on-road (e.g. passenger cars, trucks, buses, motorcycles) or non-road (construction equipment, lawn & garden equipment, locomotives, and marine vessels).

- On-Road Motor Vehicles consist of passenger cars, motorcycles, trucks, and buses.
- Other Mobile Sources consist of ships, planes, trains, and off-road equipment.

**Emission from Mobile Sources:**

CO: CO is formed during an incomplete combustion process. Mobile sources, including both on-road (e.g. cars, trucks, buses, and motorcycles) and off-road (lawnmowers, boats, ships, aircraft), are responsible for emitting the majority of CO. According to the U.S. EPA, in urban areas, for instance, 95 percent of CO emission is attributable to vehicle exhaust.

GHGs: According to the IPCC, the transportation sector (on-road and non-road combined) accounted for 14 percent of the 2010 global greenhouse gas emission. It is attributable to the fact that CO₂ is the major by-product of the burning of petroleum-based fuels (e.g. gasoline and diesel).

NOX: The combustion process of gasoline and diesel fuels in mobile sources releases NOX to the atmosphere. In the urban city, mobile and stationary sources are responsible for the majority of NOX emissions. Indeed, the urban-suburban has a boundary-layer NOX mixing ratio of 10-1000 ppb, whereas the remote rural area has 0.2-10 ppb. It represents that the fossil fuel combustion process is the major source of NOX.

NMVOCs: A mobile source emits the NMVOCs through tailpipe emissions, refueling process, and evaporative loss process. Examples of evaporative loss processes include gasoline vapors release resulting from temperature change, hot soak, losses during running, and permeation. Among these NMVOCs include air toxics (e.g. benzene, acetaldehyde, aldehyde, butadiene, etc.).

PM: Both primary and secondary PMs are emitted from mobile sources. The primary PM

includes diesel PM that originates from diesel engine emissions and black carbon from fossil fuel combustion. NO_x and SO_x that are released to the atmosphere due to mobile sources undergo chemical reactions to form nitrate and sulfate, which constitute fine PM. SO_x: Mobile sources are responsible for SO_x emission as it requires the combustion of fuel for mobile objects to operate. In particular, diesel combustion emits more SO_x than gasoline (< 300ppm) by containing more sulfur content (0.1%).

1.2.1 Emission sources of air pollutants

The various emission sources of air pollutants can be classified into natural and man-made sources as presented in Fig below.

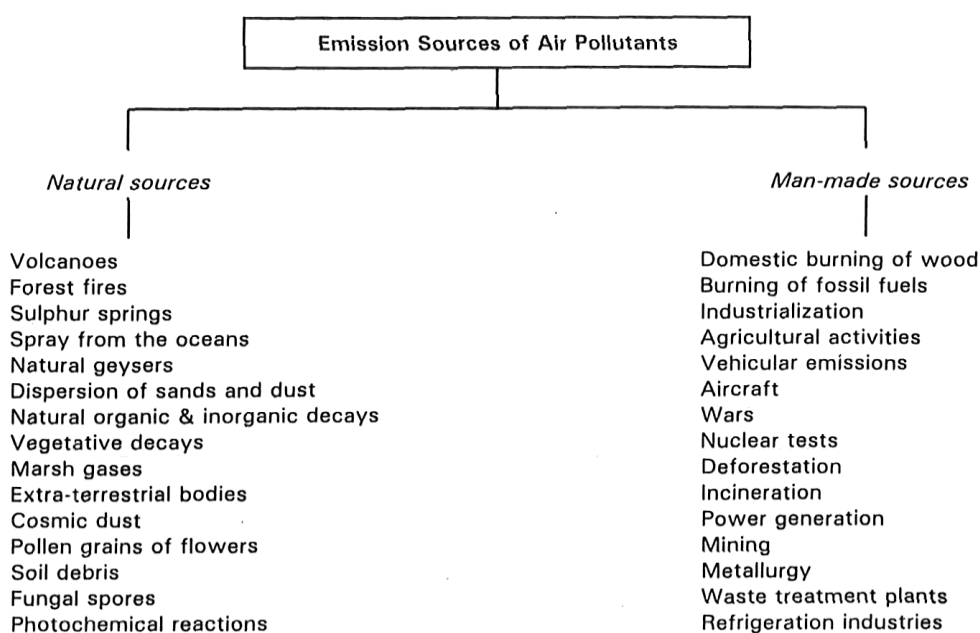


Fig. Emission sources of air pollutants

Classification of anthropogenic or man-made air pollution sources

Source type	Category	Important sources	Typical pollutants
Combustion	Stationary	Power plants, industrial boilers, diesel generators, municipal or industrial incineration	SO _x , NO _x , CO, smoke fly ash
	Refuse burning Mobile	Trace metal oxides Motor vehicles, aircraft	CO, HC, NO _x , SO _x , particulates

Roasting and heating processes	Non-ferrous metallurgical Ferrous metallurgical	Roasting, smelting and refining operations Material handling, ore sintering and pelletising, coke ovens, blast furnaces, steel furnaces	Dust, smoke, metal fumes (Cu, Zn, and Pb), oxides of sulphur Smoke, fumes, CO, odours, H ₂ S, organic vapour, fluorides
	Non-metallic minerals	Crushed stone, cement, glass, refractories, ceramic manufacture, coal cleaning	Mineral and organic particulates
Food and agriculture	Food processing crop spraying and dusting. Field burning	Drying, preserving, packaging Pest and weed control Refuse burning	Vapour, odour, and dust Organic phosphates, chlorinated HC, organic, lead Smoke, fly ash and soot
petroleum, chemicals, pulp and paper	Petroleum refining	Boilers, process heaters, catalyst regenerators, flares, storage tanks, compressor engines	So _x , HC, NO _x , particulate matter, CO, aldehyde, ammonia, odours
	Inorganic chemicals	Sulphuric acid plants, fertilizer manufacture, nitric acid and ammonia plants, phosphoric acid manufacture	So _x , HF, H ₂ S, NO _x , NH ₃ , particulate matter, H ₃ PO ₄ , etc.
	Organic chemicals	Plastics, paint and varnish manufacture, synthetic rubber, rayon, insecticides, soap and detergent manufacture, methanol, phenol, etc.	Particulate matter, odours, SO ₂ , CO, organic intermediates, solvent vapours
	Pulp and paper	Digester blow oxidation towers	Mercaptans, dimethyl sulphide, SO ₂

AMBIENT AIR QUALITY:

Ambient air quality refers to the quality of outdoor air in our surrounding environment. It is typically measured near ground level, away from direct sources of pollution. Good air quality refers to clean, clear, unpolluted air. Clean air is essential to maintaining the delicate balance of life on this planet — not just for humans, but wildlife, vegetation, water and soil. Poor air quality is a result of a number of factors, including emissions from various sources, both natural and “human-caused.” Poor air quality occurs when pollutants reach high enough concentrations to endanger human health and/or the environment. Our everyday choices, such as driving cars and burning wood, can have a significant impact on air quality. Pollutants are measured in one of two ways: either through continuous (real-time) or noncontinuous (discrete) monitoring. In continuous monitoring, air is constantly measured and the data is automatically transmitted to a central database. In noncontinuous monitoring, pollutants collect on a filter or canister over a specified period of time (such as one, three or six days). Then a technician collects the filter or canister and sends it to a certified laboratory for measurement and analysis.

NATIONAL AMBIENT AIR QUALITY STANDARDS (NAAQS)

NATIONAL AMBIENT AIR QUALITY STANDARDS (2009)

Pollutants	Time Weighted Average	Concentration in Ambient Air		Methods of Measurement
		Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area (Notified by Central Government)	
Sulphur Dioxide (SO ₂), µg/m ³	Annual * 24 Hours **	50 80	20 80	-Improved West and Gaeke Method -Ultraviolet Fluorescence
Nitrogen Dioxide (NO ₂), µg/m ³	Annual * 24 Hours **	40 80	30 80	-Jacob & Hochheiser modified (NaOH-NaAsO ₂) Method -Gas Phase Chemiluminescence
Particulate Matter (Size less than 10µm) or PM ₁₀ , µg/m ³	Annual * 24 Hours **	60 100	60 100	-Gravimetric -TEOM -Beta attenuation
Particulate Matter (Size less than 2.5µm) or PM _{2.5} , µg/m ³	Annual * 24 Hours **	40 60	40 60	-Gravimetric -TEOM -Beta attenuation
Ozone (O ₃), µg/m ³	8 Hours * 1 Hour **	100 180	100 180	-UV Photometric -Chemiluminescence -Chemical Method
Lead (Pb), µg/m ³	Annual * 24 Hours **	0.50 1.0	0.50 1.0	-AAS/ICP Method after sampling on EPM 2000 or equivalent filter paper -ED-XRF using Teflon filter
Carbon Monoxide (CO), mg/m ³	8 Hours ** 1 Hour **	02 04	02 04	-Non dispersive Infrared (NDIR) Spectroscopy
Ammonia (NH ₃), µg/m ³	Annual * 24 Hours **	100 400	100 400	-Chemiluminescence -Indophenol blue method
Benzene (C ₆ H ₆), µg/m ³	Annual *	05	05	-Gas Chromatography (GC) based continuous analyzer -Adsorption and desorption followed by GC analysis
Benzo(a)Pyrene (BaP) Particulate phase only, ng/m ³	Annual *	01	01	-Solvent extraction followed by HPLC/GC analysis
Arsenic (As), ng/m ³	Annual *	06	06	-AAS/ICP Method after sampling on EPM 2000 or equivalent filter paper
Nickel (Ni), ng/m ³	Annual *	20	20	-AAS/ICP Method after sampling on EPM 2000 or equivalent filter paper
* Annual Arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals. ** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring. NOTE: Whenever and wherever monitoring results on two consecutive days of monitoring exceed the limits specified above for the respective category, it shall be considered adequate reason to institute regular or continuous monitoring and further investigations.				

Major objectives of NAAQS are:

1. To indicate necessary air quality levels and appropriate margins required to ensure the protection of vegetation, health, and property.
2. To provide a uniform yardstick for the assessment of air quality at the national level.
3. To indicate the extent and need of the monitoring programme.

Annual standards are basically the annual arithmetic mean of a minimum 104 measurements in a year, at a particular site taken twice a week, at a uniform 24-hourly interval and at either a 24 hourly, 8 hourly, or 1 hourly monitored value, as applicable, shall be complied with 98% of the time in a year. However, there is a 2% chance of exceeding the limits but not on two consecutive days of monitoring.

AIR QUALITY INDEX

The AQI was launched by the Prime Minister in April, 2015 starting with 14 cities and now extended to 71 cities in 17 states. The AQI is a tool for the effective communication of air quality status to people in terms, which are easy to understand. It transforms complex air quality data of various pollutants into a single number (index value), nomenclature and colour.

There are six AQI categories, namely, **good, satisfactory, moderately polluted, poor, very poor, and severe**. Each of these categories is decided based on the ambient concentration values of air pollutants and their likely health impacts (known as health breakpoints).

The AQ sub-index and health breakpoints are evolved for eight pollutants (PM₁₀, PM_{2.5}, NO₂, SO₂, CO, O₃, NH₃, and Lead (Pb)) for which short-term (upto 24-hours) .

TABLE 3: AQI CATEGORIES AND HEALTH BREAKPOINTS

AQI	Associated Health Impacts
Good (0-50)	Minimal Impact
Satisfactory (51-100)	May cause minor breathing discomfort to sensitive people
Moderate (101-200)	May cause breathing discomfort to the people with lung disease such as asthma and discomfort to people with heart disease, children and older adults
Poor (201-300)	May cause breathing discomfort to people on prolonged exposure and discomfort to people with heart disease with short exposure
Very Poor (301-400)	May cause respiratory illness to the people on prolonged exposure. Effect may be more pronounced in people with lung and heart diseases.
Severe (401-500)	May cause respiratory effects even on healthy people and serious health impacts on people with lung/heart diseases. The health impacts may be experienced even during light physical activity

EFFECTS OF AIR POLLUTION ON HUMAN HEALTH

According to the Institute for Health Metrics and Evaluation (IHME), outdoor and indoor air pollution combined was the 4th leading risk factor to the number of deaths across all age groups in 2017, causing 4.9 million premature deaths annually.

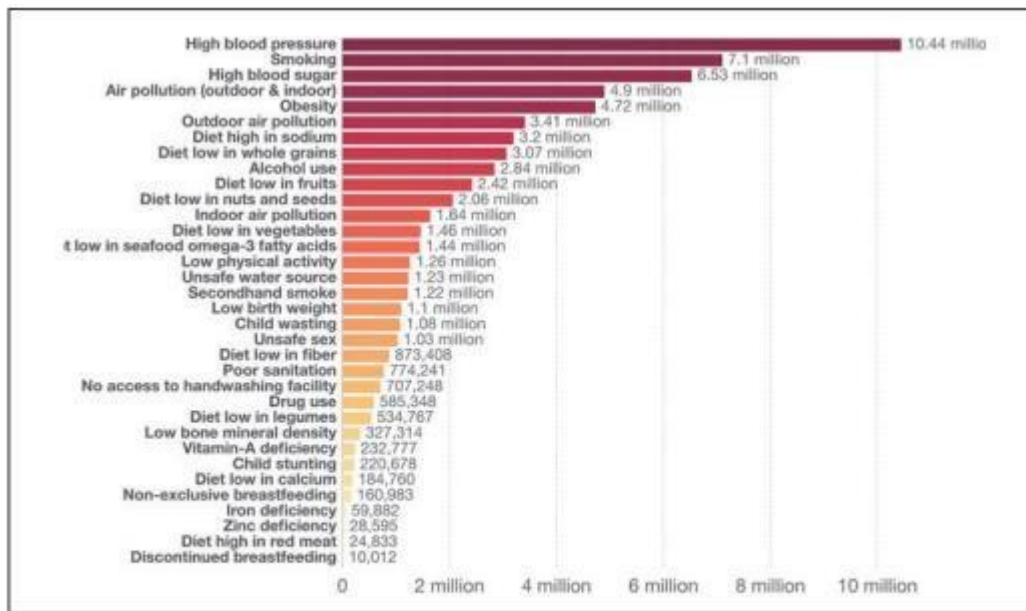


Figure 4.1. Global Number of Deaths Categorized and Ranked by Risk Factor as of 2017 as Provided by Global Burden of Diseases from IHME.
(Graph Source: Ritchie, 2018)

The estimate of WHO is slightly higher than that of the IHME. According to WHO, household air pollution accounts for some 3.8 million premature deaths and outdoor air pollution causes an estimated 4.2 million premature deaths, together accounting for 7 million deaths every year globally. Low-income and middle-income countries are more heavily affected by air pollution by accounting for 90% of 4.2 million deaths (outdoor air pollution). As children with developing lungs, people with pre-existing health complications, and the elderly are more heavily affected by air pollution than other populations, more care is needed to protect those groups of people in the event of high air pollution. The WHO also summarizes how much the proportion of each disease is attributable to outdoor air pollution.

Lung cancer (deaths & disease): 9%

Acute Lower respiratory infection (deaths & disease): 17%

Stroke (deaths): 24%

Ischemic heart disease (deaths & disease): 25%

Chronic obstructive pulmonary disease (deaths & disease): 43%

AIR POLLUTANTS AND THEIR RESPECTIVE HEALTH COMPLICATIONS

Organ	Air Pollutant	Health Complication
Respiratory System	SO ₂ , NO ₂	• Asthma • Nose irritation, throat irritation, eye irritation • Lung inflammation: coughing, wheezing, mucous secretion • For asthmatic individuals: bronchoconstriction, dyspnea
	PM, O ₃	• Asthma • Lung inflammation • Reduction in lung functionality • Lung cancer • Worse lung inflammation for individuals with pre-existing lung diseases
Cardiovascular System	CO	• Binding to hemoglobin and interfering with oxygen transfer ultimately affecting brain and heart functionality • Confusion, lack of concentration, slow reflexes
	PM	• Blood coagulation
Nervous System	PM	• Increase in ischemic stroke • Increase in stroke mortality

EFFECTS ON ECONOMY

Overview of Air Pollution Impact on Economy:

According to the OECD's report on the relationship between outdoor air pollution and the economy, the global healthcare cost generated from the outdoor air pollution is predicted to reach 176 billion US dollars (USD) by 2060, compared to 21 billion USD in 2015. Also, premature deaths attributable to outdoor air pollution are predicted to be 6 to 9 million people by 2060, compared to 3 million people in 2010. About an eightfold increase in global healthcare expenditure is expected due to the global Non-market Costs Associated with Air Pollution (Welfare Costs). The non-market costs are costs that cannot be readily observed as monetary values but affect the quality of life. The willing-to-pay (WTP) is the maximum amount of money that one will pay to procure the desired product or service, and it is used to

convert the non-markets costs into monetary values. According to the OECD report (“The economic consequences of outdoor air pollution”), there are two major nonmarket costs associated with air pollution. The first factor is a decrease in the quality of life due to illnesses associated with air pollution such as hospital admission, pain, and inability to continue regular activity (morbidity). The OECD report predicts that the global WTP for morbidity rising trend of air pollution emission from economic growth and increasing energy demand worldwide. Market Costs Associated with Air Pollution. There are three major market costs linked to air pollution, namely health spending, labor productivity, and crop yield. Exacerbated air pollution conditions will increase hospital admission, which will increase health expenditure and decrease labor productivity. Air pollutants such as O₃ decrease the crop yield, which all have adverse impacts on the economy. The OECD expects the combined market cost from health spending, labor productivity, and crop yield to take up 1.0% of global GDP by 2060 compared to 0.3% in 2015 due to the globally increased air pollution trend will increase to 2.2 trillion USD by 2060, compared to 280 billion USD in 2015. The second factor is an increase in premature deaths caused by air pollution. The WTP is much higher for premature death as compared to the morbidity since the global WTP for premature death is expected to reach 18-25 trillion USD by 2060 as compared to 3.2 trillion USD in 2015. Such a six-fold to eightfold increase in WTP between those two time frames is attributed to a projected increase in premature deaths. The OECD report used the value of statistical life (VSL) metric to calculate the WTP and adjusted each country by its income to calculate the global average WTP. More details about WTP related to air pollution can be found in the OECD report.

Air pollution already affects human health, agriculture and leads to a range of other impacts. These impacts are projected to become much more severe in the coming decades. Rising emissions of air pollutants are projected to lead to higher concentrations of particulate matter (PM_{2.5}) and ground level ozone. In several regions of the world, average concentrations of PM_{2.5} and ozone are already well above the levels recommended by the WHO Air quality guidelines. The market impacts of outdoor air pollution, which include impacts on **labour productivity, health expenditures and agricultural crop yields**, are projected to lead to global economic costs that gradually increase to 1% of global GDP by 2060.

Global air pollution-related healthcare costs are projected to increase from **USD 21 billion**

(using constant 2010 USD and PPP exchange rates) in 2015 to **USD 176 billion** in 2060.

By 2060, the annual number of lost working days, which affect labour productivity, are projected to reach **3.7 billion** (currently around 1.2 billion) at the global level. The most dangerous consequences from **outdoor air pollution** are related to the **number of premature deaths**. This report projects an increase in the number of premature deaths due to outdoor air pollution from approximately 3 million people in 2010, in line with the latest global burden of disease estimates, to 6-9 million annually in 2060.

A large number of deaths occur in densely populated regions with high concentrations of PM_{2.5} and ozone, especially China and India, and in regions with aging populations such as China and Eastern Europe.

Other effects are corrosion of metals, soiling and eroding of building surfaces, fading of dyed materials rubber cracking, spoiling or destruction of vegetation effects on animals, as well as interference with production and services

Building materials are corroded and disfigured by air pollutants. Smoke and aerosols adhere to stone, brick, and other building surfaces to produce unsightly coatings. Sulphur dioxide and sulphur trioxide in the presence of moisture can react with limestone (CaCO_3) to form calcium sulphate (CaSO_4) and gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). This acid converts limestone into a water-soluble bicarbonate, which is then leached away. Staining of building stone by sulphur compounds and particulars requires additional cleaning expense.

Paints

Areas of high pollution require more frequent painting. Air pollutants may damage the protective coating and by exposing the underlying surface to attack.

Textiles

Sulphur oxides cause deterioration of natural and some synthetic textile fibres. The most common form of permanent damage to textiles has been the deterioration of nylon hose.

Rubber

The main affected areas are the side walls of tyres and various forms of electrical insulation. This type of damage is caused by ozone.

Leather

Sulphur dioxide causes leather to lose much of its strength and ultimately disintegrate.

Paper

The small amounts of metallic impurities in 'modern' paper accelerate the conversion of absorbed sulphur dioxide to sulphuric acid, in the presence of moisture.

Glass and Ceramics

During a long exposure for three years, porcelain enamels showed a change in their surface appearance. Moisture and atmospheric pollution by acidic substances seems to have played a major role in surface degradation.

Electronics Industry

Air pollutants cause thin insulating film to develop on contacts resulting in open circuits and malfunctioning of the equipment.

Vegetation

Damage to vegetation as a result of air pollution is a very important aspect of economic loss due to air pollution.

Intangible Loss

Another very important economic repercussion of air pollution is the intangible loss due to great damage to art objects throughout the world including our country. For example, effects on the Taj Mahal (Agra), Sri Channakeshava Temple (Belur), and Parthenon (Athens).

Harmful effects of air pollutants on materials

Material	Effects	Principal air pollutants
Stone and concrete	Surface erosion, discoloration, soiling	Sulphur dioxide, sulphuric acid, nitric acid, particulate matter
Metals	Corrosion, tarnishing, loss of strength	Sulphur dioxide, sulphuric acid, nitric acid and particulate matter
Ceramics and glass	Surface erosion	Hydrogen fluoride, particulate matter
Paints	Surface erosion, discoloration, soiling	Sulphur dioxide, hydrogen sulphide, ozone, particulate matter
Paper	Embrittlement, discoloration	Sulphur dioxide
Rubber	Cracking, loss of strength	Ozone
Leather	Surface deterioration, loss of strength	Sulphur dioxide
Textile	Deterioration, fading, soiling	Sulphur dioxide, nitrogen dioxide, ozone, particulate matter

SPM (SUSPENDED PARTICULATE MATTER):

Suspended matter consists of **dust, fumes, mist and smoke**. The main chemical component of SPM that is of major concern is **lead**, others being **nickel, arsenic**, and those present in diesel exhaust. These particles when breathe in, lodge in our lung tissues and cause lung damage and respiratory problems.

The importance of SPM as a major pollutant needs special emphasis as,

- a) It affects more people globally than any other pollutant on a continuing basis.
- b) There is more monitoring data available on this than any other pollutant.
- c) More epidemiological evidence has been collected on the exposure to this than to any other pollutant.

CAUSES OF AIR POLLUTION**Burning of Fossil Fuels**

The combustion of fossil fuels emits a large amount of sulphur dioxide. Carbon monoxide released by incomplete combustion of fossil fuels also results in air pollution.

Automobiles

The gases emitted from vehicles such as jeeps, trucks, cars, buses, etc. pollute the environment. These are the major sources of greenhouse gases and also result in diseases among individuals.

Agricultural Activities

Ammonia is one of the most hazardous gases emitted during agricultural activities. The insecticides, pesticides and fertilisers emit harmful chemicals in the atmosphere and contaminate it.

Factories and Industries

Factories and industries are the main source of carbon monoxide, organic compounds, hydrocarbons and chemicals. These are released into the air, degrading its quality.

Mining Activities

In the mining process, the minerals below the earth are extracted using large pieces of equipment. The dust and chemicals released during the process not only pollute the air, but also deteriorate the health of the workers and people living in the nearby areas.

Domestic Sources

The household cleaning products and paints contain toxic chemicals that are released in the air. The smell from the newly painted walls is the smell of the chemicals present in the paints. It not only pollutes the air but also affects breathing.

AIR POLLUTION CONTROL MEASURES

1. By minimizing and reducing the use of fire and fire products.
2. Since industrial emissions are one of the major causes of air pollution, the pollutants can be controlled or treated at the source itself to reduce its effects. For example, if the reactions of a certain raw material yield a pollutant, then the raw materials can be substituted with other less polluting materials.
3. Fuel substitution is another way of controlling air pollution. In many parts of India, petrol and diesel are being replaced by CNG – Compressed Natural Gas fueled vehicles. These are mostly adopted by vehicles that aren't fully operating with ideal emission engines.
4. Although there are many practices in India, which focus on repairing the quality of air, most of them are either forgotten or not being enforced properly. There are still a lot of vehicles on roads which haven't been tested for vehicle emissions.
5. Another way of controlling air pollution caused by industries is to modify and maintain existing pieces of equipment so that the emission of pollutants is minimised.
6. Sometimes controlling pollutants at the source is not possible. In that case, we can have process control equipment to control the pollution.
7. A very effective way of controlling air pollution is by diluting the air pollutants.
8. The last and the best way of reducing the ill effects of air pollution is tree plantation. Plants and trees reduce a large number of pollutants in the air. Ideally, planting trees in areas of high pollution levels will be extremely effective.

AIR POLLUTION CONTROL DEVICES

Air pollution control devices are a series of devices that work to prevent a variety of different pollutants, both gaseous and solid, from entering atmosphere primarily out of industrial smokestacks. These control devices can be separated into two broad categories - devices that control the amount of particulate matter escaping into the environment and devices that control acidic gas emissions. It is important to understand that the extraction methods for each specific type of pollutant can differ, so the only the major methods are discussed.

Although complex, these devices have shown to be effective in the past with the overall levels of emissions for many pollutants dropping with the implementation of these control devices.

CONTROL OF PARTICULATE MATTER

Specific machinery is used to remove particulate matter from flue gases. Much of this separation uses physical means of separation and not chemical separation techniques simply because particulate matter is large enough to be "caught" in this manner.

Below are some of the basic ways that particulate matter can be extracted.

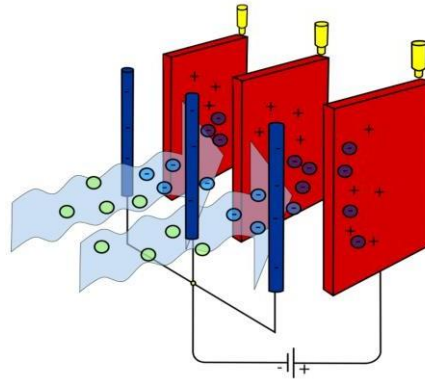
- Electrostatic Precipitators
- Cyclone Separators
- Fabric Filters

ELECTROSTATIC PRECIPITATORS:

An electrostatic precipitator is a type of filter that uses static electricity to remove soot and ash from exhaust fumes before they exit the smokestacks. Unburned particles of carbon in smoke are pulled out of the smoke by using static electricity in the precipitators, leaving clean, hot air to escape the smokestacks. It is vital to remove this unreacted carbon from the smoke, as it can damage buildings and harm human health - especially respiratory health.

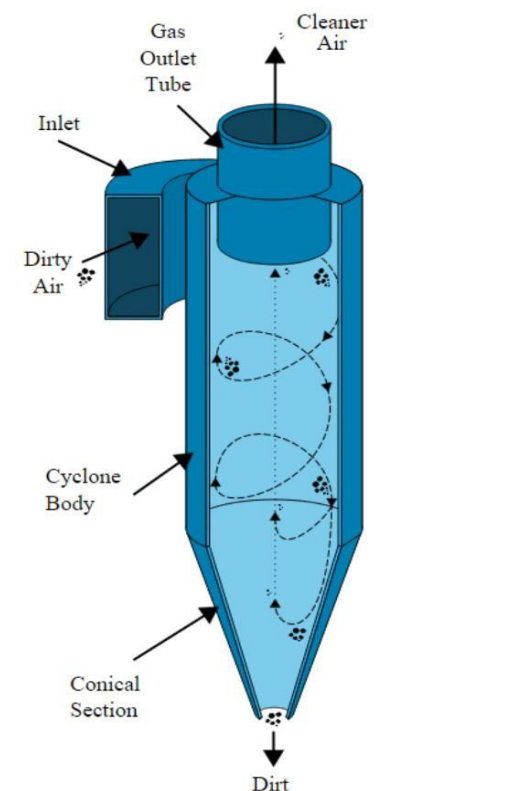
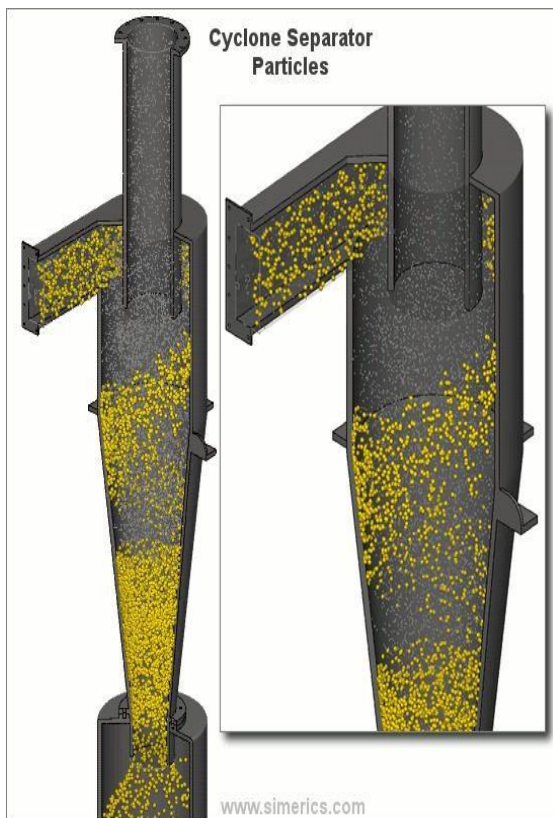


A model of an electrostatic precipitator using metal wires as the negative electrodes and large plates as the positive electrodes



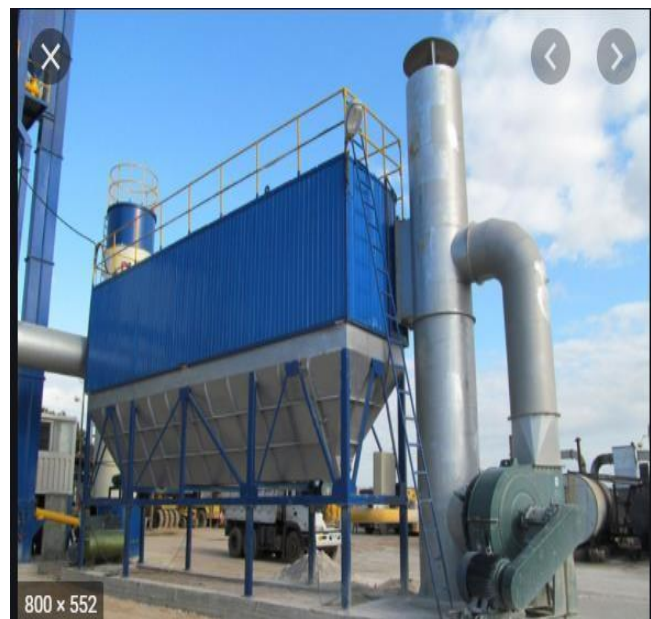
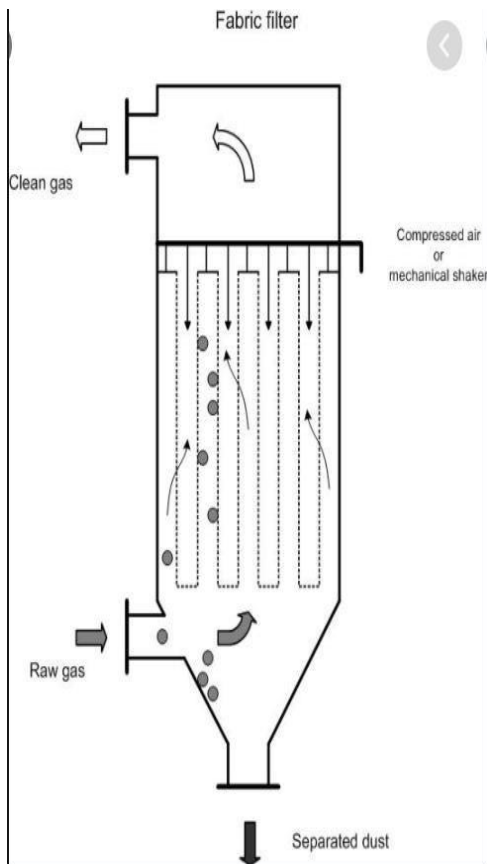
CYCLONE SEPARATORS

A cyclone separator is a separation device that uses the principle of inertia to remove particulate matter from flue gases. In these separators, dirty flue gas enters a chamber containing a vortex, similar to a tornado. Because of the difference in inertia of gas particles and larger particulate matter, the gas particles move up the cylinder while larger particles hit the inside wall and drop down. This separates the particulate matter from the flue gas, leaving cleaned flue gas.



FABRIC FILTERS

Fabric filters are one fairly simple method that can be used to remove dust from flue gases. In some gases they can also remove acidic gases if they utilize basic compounds. This method simply uses some sort of fabric - generally felt is used as a woven cloth would allow dust to make its way through - is placed so that flue gasses must pass through it before exiting the smokestacks. When the gas passes through, dust particles are trapped in the cloth.



GAS CONTROL

More intense chemical methods of separation are generally required to separate polluting gases from the flue gas. However, this extraction is important as many acidic gases in flue gas contribute to acid rain. Below are some of the basic ways that gases can be extracted.

1. Scrubbers
2. Incineration
3. Carbon Capture

SCRUBBERS

Scrubbers are a type of system that is used to remove harmful materials from industrial exhaust gases before they are released into the environment. These pollutants are generally gaseous, and when scrubbers are used to specifically remove SO_x it is referred to as flue gas desulfurization.

There are two main types of scrubbers, wet scrubbers and dry scrubbers.

The main difference is in the type of material used to remove the gases. By removing acidic gases from the exhaust before it is released into the sky, scrubbers help prevent the formation of acid rain.

There are two main ways to scrub pollutants out of exhaust, and they are:

Wet Scrubbing: The removal of harmful components of exhausted flue gases by spraying a liquid substance through the gas.

Dry Scrubbing: The removal of harmful components of exhausted flue gases by introducing a solid substance to the gas - generally in powdered form.

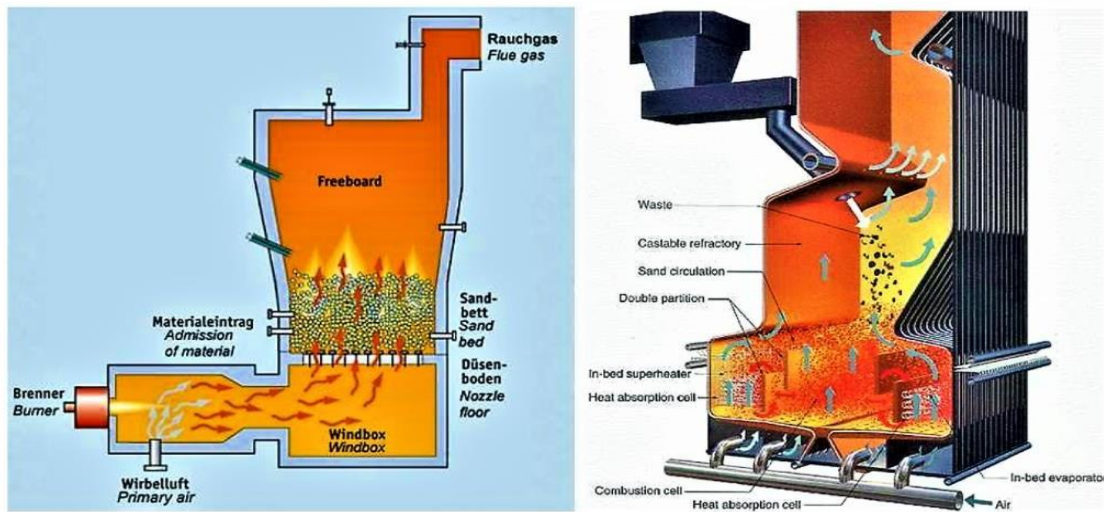


Figure 1. A chemical scrubber.^[1]

INCINERATION

Incineration is used to convert VOC emissions into carbon dioxide and water through combustion. The incineration generally takes place in a specialized piece of equipment known as an afterburner, which is built to create the conditions necessary for complete combustion (such as sufficient burn time and a high temperature). Additionally,

the incinerated gas must be mixed to ensure complete combustion.



The scheme of a fluidised-bed incinerator. There are two types of technologies: bubbling bed (left) and circulating bed (right) technology Source: EISENMANN (n.y.) and GEC (n.y.)

CARBON CAPTURE

Carbon dioxide can theoretically also be captured and stored underground or in forests and oceans to prevent it from entering the atmosphere. Carbon capture and storage refers to the process of capturing this carbon dioxide and storing it below ground, pumping it into geologic layers. This process is rarely being used, but is talked about extensively as a way to limit greenhouse gas emissions leading to climate change.

OZONE

Ozone (O_3) is a reactive oxidant gas produced naturally in trace amounts in the Earth's atmosphere. Ozone is a relatively colorless gas at typical mixing ratios. It appears faintly purple when its mixing ratios are high because it weakly absorbs green wavelengths of visible light and transmits red and blue, which combine to form purple. Ozone exhibits an odor when its mixing ratios exceed 0.02 ppmv. Ozone is considered an air pollutant in the boundary layer (lower troposphere) because of the harm that it does to humans, animals, plants, and materials. In India, it is one of the criteria air pollutants that require control under NAAQS. In the stratosphere, ozone's absorption of UV radiation provides a protective shield for life on Earth. Although ozone is considered to be "good" in the stratosphere and "bad" in the boundary layer, ozone molecules are the same in both cases. The increase in ozone is a concern because ozone

present in the upper troposphere acts as a GHG, absorbing some of the infrared energy emitted by the earth. The radiative forcing of tropospheric ozone is about 25% that of carbon dioxide (IPCC Third Assessment Report). The annual global warming potential of tropospheric ozone is between 918-1022 tons carbon dioxide equivalent / tons tropospheric ozone. This means on a per-molecule basis, ozone in the troposphere has a radiative forcing effect roughly 1,000 times as strong as carbon dioxide. However, tropospheric ozone is a short-lived greenhouse gas, which decays in the atmosphere much more quickly than carbon dioxide. This means that over a 20 year horizon, the global warming potential of tropospheric ozone is much less, roughly 62 to 69 tons carbon dioxide equivalent / tons tropospheric ozone. Ozone plays a controlling role in the oxidizing capacity of the troposphere.

SOURCES OF TROPOSPHERIC OR GROUND-LEVEL OZONE

Ozone is not directly emitted into the atmosphere. Ozone is a secondary pollutant formed in the atmosphere by sunlight driven chemical reactions between the O₃ precursor gases: VOC, CO, NO_x, and CH₄. Emissions of O₃ precursor gases arise from a wide range of sources that are either natural in origin or driven by human activities. Energy generation, transport, agriculture, industrial processes, biomass burning and land use changes such as deforestation are significant sources of O₃ precursor gases. In addition small amounts of stratospheric ozone, which occasionally migrate down to the earth's surface also, contribute. With increasing populations, more automobiles, and more industry, there is more ozone in the lower atmosphere. Since 1900 the amount of ozone near the earth's surface has more than doubled. When referring to ground-level O₃, a distinction is usually drawn between baseline, hemispheric background, or peak/episodic O₃ concentrations. Background O₃ in the Northern Hemisphere is now in the range of 35–40 ppb. High O₃ concentrations occur episodically throughout the year depending on the weather. During such episodes, O₃ concentrations can reach as high as 200 ppb. Even larger values, of up to 400 ppb, can be observed during the smog episodes. In urban areas in the Northern Hemisphere, high ozone levels usually occur during the warm, sunny summer months (from May through September). Typically, ozone levels reach their peak in mid to late afternoon, after the sun has had time to react fully with the exhaust fumes from the morning rush hours. A hot, sunny, still day is the perfect environment for ozone pollution production. In early evening, the sunlight's intensity decreases and the photochemical production process that forms ground level ozone begins to subside. Stratosphere-Troposphere Exchange accounts for

about 18% of Ozone in the troposphere (with a range of 8-44% -- large amount of error!). Although photochemistry in the lower troposphere is the major source of tropospheric ozone, the stratosphere-troposphere transport of ozone is important to the overall climatology, budget and long-term trends of tropospheric ozone.

OZONE DEPLETION

Ozone layer is an umbrella 24 km [15 miles] from earth surface, an essential component of the stratosphere that absorbs short wavelength ultraviolet radiation from the sun, heating the gases of the stratosphere in the process. This is the reason temperatures rise with increasing altitude in the stratosphere, and also the reason life was able to move out of the oceans and on to the land, evolving into the diverse biosphere we know today.

World ozone day is celebrated on Sept 16th of every year. Stratospheric ozone is measured in Dobson units [DU] named after G.M.B Dobson who pioneered the study;

[1 Dobson unit = 0.01 mm thickness of stratospheric ozone]

Its role:

Solar radiation: 55% IR; 40% visible light; 5% UV.

Acts as a UV protective blanket (layer).

UV radiation includes three bands: UVA (400-320nm);

UVB (320-280nm); UVC (280-200nm), far UV (< 50nm).

It blocks nearly all UVC, half UVB, and small part UV

Mechanism for UV blocking:

Equilibrium in nature between destruction and production of O₃.

$O_2 \rightarrow O+O$ (energized by UVC)

$10+O_2 \rightarrow O_3 + IR$ (production of Ozone)

$O_3 + UV \rightarrow O_2+O$: (destruction of Ozone as energized by UVB).

What causes Ozone depletion?

Human activity: release of halogenated hydrocarbons: CFCs; CCl₄;

- Are used as refrigerants, propellants, solvents, foam production, etc.
- Are stable under normal conditions in the troposphere. These volatile chemicals become active with the presence of UV to react with O₃.

The reaction:

1. $\text{CCl}_2\text{F}_2 + \text{UV} \rightarrow \text{CClF}_2 + \text{Cl}^\cdot$
2. $\text{Cl}^\cdot + \text{O}_3 \rightarrow \text{ClO} + \text{O}_2$
3. $\text{ClO} + \text{O} \rightarrow \text{Cl}^\cdot + \text{O}_2$
4. Net: $\text{O}_3 + \text{O} \rightarrow 2\text{O}_2$ (Chlorine atom acts as a catalyst).

EFFECTS OF OZONE DEPLETION

Direct effect:

1. Skin damage and cancer:
 - Acute exposure: thermal extremes due to UV: sun burn; skin lesions;
 - Cumulative (chronic) exposure: skin cancer in fair skinned humans;
 - UNEP estimates: 5% skin cancer increase during 2070's (extra 100 cases of skin cancer per million population per year) in Europeans living at around latitude 45 degrees N)
2. Effects on eye: by UVB; cornea, lens, and retina: cataract (snow blindness): UNEP estimates: 1.75 million additional cataract cases worldwide each year due to 10% loss of ozone.
3. Effects on immune system
 - Skin sensitivity; animal tests; possible effects.

Indirect effects:

- Effects on plants: impairs photosynthesis & UVB; farm productivity declining
- Effects on aquatic system: Phytoplankton & UVB; aquatic farm productivity declining. CO₂ take up will be diminished.

OZONE DEPLETION

- Average ozone thickness in stratosphere is 300 DU, & when it falls below 200 DU, it's considered as Ozone hole. It is thinnest around equator and thickest near poles.
- Ozone depletion is caused by the release of chlorofluorocarbons (CFC's) and other ozone-depleting substances (ODS), which were used widely as refrigerants, insulating foams, and solvents.
- Although CFCs are heavier than air, they are eventually carried into the stratosphere in a process that can take as long as 2 to 5 years.
- When CFCs reach the stratosphere, the ultraviolet radiation from the sun causes them to break apart and release chlorine atoms which react with ozone, starting chemical cycles of ozone destruction that deplete the ozone layer.
- One chlorine atom can break apart more than 100,000 ozone molecules.

The atmosphere is made up of a layer of gases that includes nitrogen, oxygen, carbon dioxide, argon, and many other minor gases. It is made up of 78 per cent nitrogen, 21 per cent oxygen, 0.93 per cent argon, and 0.04 per cent carbon dioxide.

There are four layers in the atmosphere:

1. Troposphere: All biological activities take place in the troposphere. It is the lowest layer, just above the Earth's surface. Carbon dioxide and water vapours are produced as a result of the reaction in the troposphere. When sunlight passes through the troposphere, the carbon dioxide molecule absorbs a large amount of energy, causing excitation.

2. Stratosphere: The formation of ozone is the primary reaction occurring in the stratosphere. Ozone is created in two stages:

Step 1: Oxygen gas dissociation in oxygen atoms.

Step 2: These oxygen atoms combine with additional dioxygen to form ozone.

- ☐ A chemical reaction is taking place in the mesosphere. As a result of photochemical reactions, free ions and electrons are formed in these reactions.
- ☐ Some of the atom and ion forming reactions that occur with increasing frequency as

altitude increases are as follows:

- i) Dioxygen ion and electron are formed when oxygen gas decomposes
- ii) Nitrogen gas is broken down into dinitrogen ion and electron.

Chemical and photochemical reaction in the atmosphere

- ❑ Photochemistry is the branch of chemistry that is primarily concerned with the rates and mechanisms of reactions that occur when reactants are exposed to light radiations.
- ❑ The photochemical reaction is, in fact, the thermal reaction of the molecule's electronically excited state, whereas the dark reaction is the thermal reaction of the molecule's ground state.
- ❑ "The photochemical reaction is nothing more than a chemical reaction that begins with the absorption of light as a form of energy."
- ❑ The various chemical and photochemical reactions that occur in the atmosphere are primarily determined by the temperature, composition, humidity, and intensity of sunlight.
- ❑ The absorption of solar radiation in the ultraviolet region causes photochemical reactions in the atmosphere.
- ❑ The ozone layer in the earth's stratosphere is formed by the photochemical dissociation of molecular oxygen into oxygen atoms, which then react with oxygen molecules to form ozone.
- ❑ Photochemical reactions produce ultraviolet (UV) rays that are harmful to human DNA and cause skin cancer. Photochemical reactions and their peak states have a significant impact on a variety of commercial processes and devices.

EFFECTS

- Effect of ozone hole include cataract, genetic mutation, constriction of blood vessels, reduced crop yield, leukemia, breast cancer, damage to crop, aqua culture, etc.,
- The higher energy UV radiation absorbed by ozone is generally accepted to be a contributory factor to skin cancer. In addition, increased surface UV leads to increased tropospheric ozone, which is a health risk to humans. The increased surface UV also represents an increase in the vitamin D synthetic capacity of the sunlight.

- It should be deduced that the above impacts are not due to exposure of Ozone but due to the UV rays that have reached the earth surface through the ozone holes. One important health hazard is Snow Blindness [photo keratosis], i.e., inflammation of cornea (outer coating of eyeball).
- The most common forms of skin cancer in humans, basal and squamous cell carcinomas have been strongly linked to UVB exposure. Another form of skin cancer, malignant melanoma, is much less common but far more dangerous, being lethal in about 15% - 20% of the cases diagnosed.

CAUSES OF OZONE LAYER DEPLETION

Chlorofluorocarbons:

- Chlorofluorocarbons or CFCs are the main cause of ozone layer depletion. These are released by solvents, spray aerosols, refrigerators, air-conditioners, etc.
- The molecules of chlorofluorocarbons in the stratosphere are broken down by ultraviolet radiations and release chlorine atoms. These atoms react with ozone and destroy it.

Unregulated Rocket Launches:

- Researchers say that the unregulated launching of rockets results in much more depletion of the ozone layer than the CFCs do. If not controlled, this might result in a huge loss of the ozone layer by the year 2050

Nitrogenous Compounds:

- The nitrogenous compounds such as NO₂, NO, N₂O are highly responsible for the depletion of the ozone layer.

Natural Causes:

- The ozone layer has been found to be depleted by certain natural processes such as Sun-spots and stratospheric winds. But it does not cause more than 1-2% of the ozone layer depletion.
- The volcanic eruptions are also responsible for the depletion of the ozone layer.

Ozone-Depleting Substances	Sources
Chlorofluorocarbons (CFCs)	Refrigerators, air-conditioners, solvents, dry-cleaning agents, etc.
Halons	Fire-extinguishers
Carbon tetrachloride	Fire extinguishers, solvents
Methyl chloroform	Adhesives, aerosols
Hydrofluorocarbons	fire extinguishers, air-conditioners, solvents

SOLUTIONS TO OZONE LAYER DEPLETION

The depletion of the ozone layer is a serious issue and various programmes have been launched by the government of various countries to prevent it. However, steps should be taken at the individual level as well to prevent the depletion of the ozone layer.

Avoid Using ODS

Reduce the use of ozone depleting substances. E.g. avoid the use of CFCs in refrigerators and air conditioners, replacing the halon based fire extinguishers, etc.

Minimise the Use of Vehicles

The vehicles emit a large amount of greenhouse gases that lead to global warming as well as ozone depletion. Therefore, the use of vehicles should be minimized as much as possible.

Use Eco-friendly Cleaning Products

Most of the cleaning products have chlorine and bromine releasing chemicals that find a way into the atmosphere and affect the ozone layer. These should be substituted with natural products to protect the environment.

Use of Nitrous Oxide should be Prohibited

The government should take actions and prohibit the use of harmful nitrous oxide that is adversely affecting the ozone layer. People should be made aware of the harmful effects of nitrous oxide and the products emitting the gas so that its use is minimised at the individual level as well.

OZONE AND PHOTOCHEMICAL SMOG

Ozone is a major component of photochemical smog – the brownish haze that covers many urban areas during the hot, sunny days of summer. Ozone is produced by chemical reactions between hydrocarbons and nitrogen oxides in the presence of sunlight – so the products of these reactions are called photochemical smog. The greater the intensity of sunlight and the warmer the day, the larger the amount of ozone produced. Since hydrocarbons and oxides of nitrogen are mainly generated by automobiles, the ozone levels gradually rise in the morning and peak between noon and 4 pm. On cloudy days, ozone production is reduced; after sunset, it stops altogether.

Photochemical smog has in addition to ozone, peroxyacetyl nitrates which are excellent oxidizing agents that readily react with many other compounds, including those found in living things, causing destructive changes. The general scheme for the formation of photochemical smog is shown in Fig.

