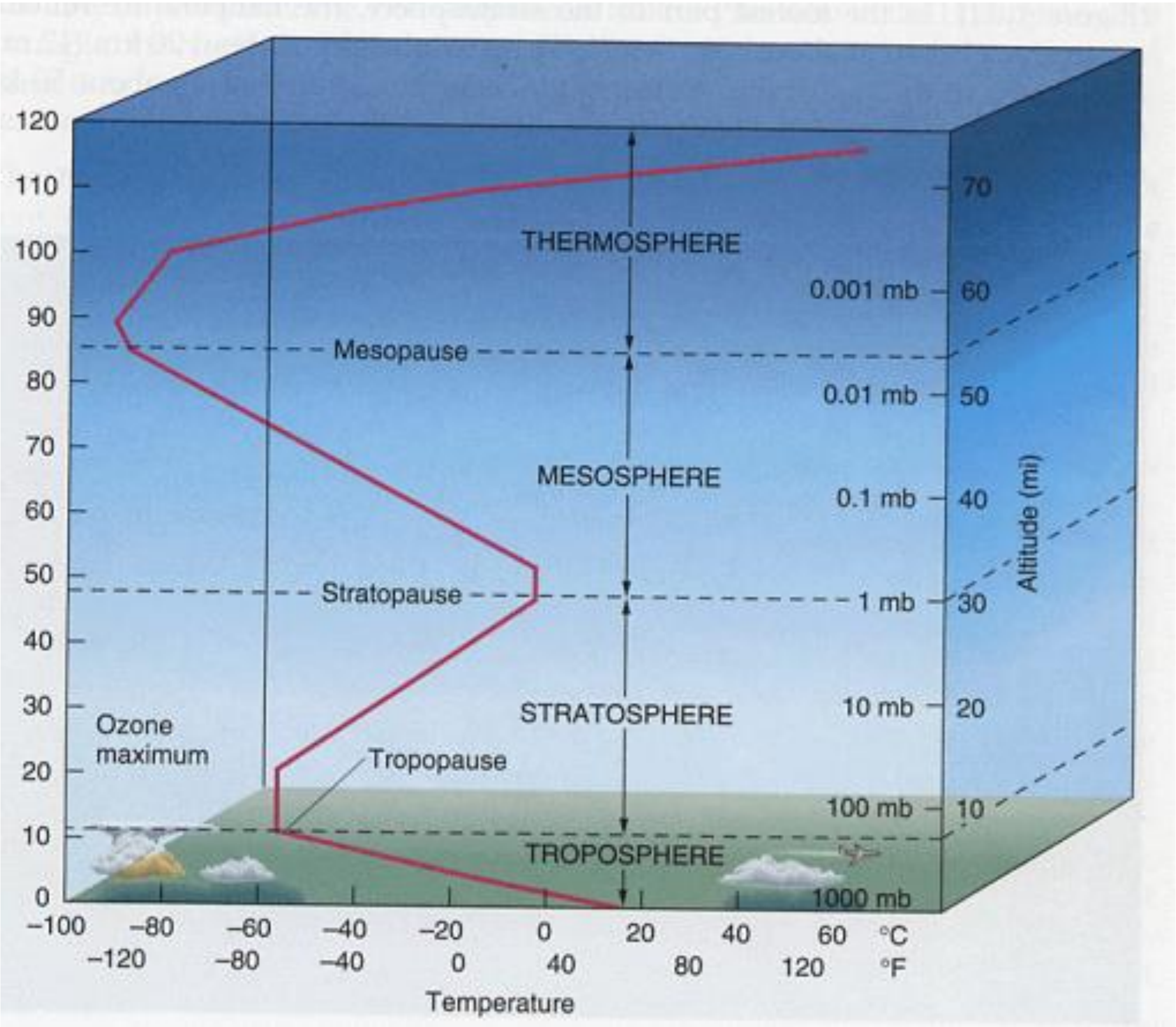
Air Pollution and control

Structure of Atmosphere



- The **troposphere** is the lowest layer extending from the surface up to roughly 18 km above the surface depending on location (varies from as low as 6 km to as high as 20 km).

- The **stratosphere** extends from the tropopause up to about 50 km to 53 km above the Earth's surface

  - **there is almost no water vapor in the stratosphere and**
  - **the stratosphere has nearly 1,000 times more ozone (O_3) than the troposphere.**

- **mesosphere** extends to about 85 km above the Earth's surface. The mesosphere has no ozone molecules and the other gases such as oxygen and nitrogen continue to become less dense with height. As a result, not much ultraviolet and x-ray radiation from the sun is absorbed by molecules in this layer so temperature decreases with altitude.

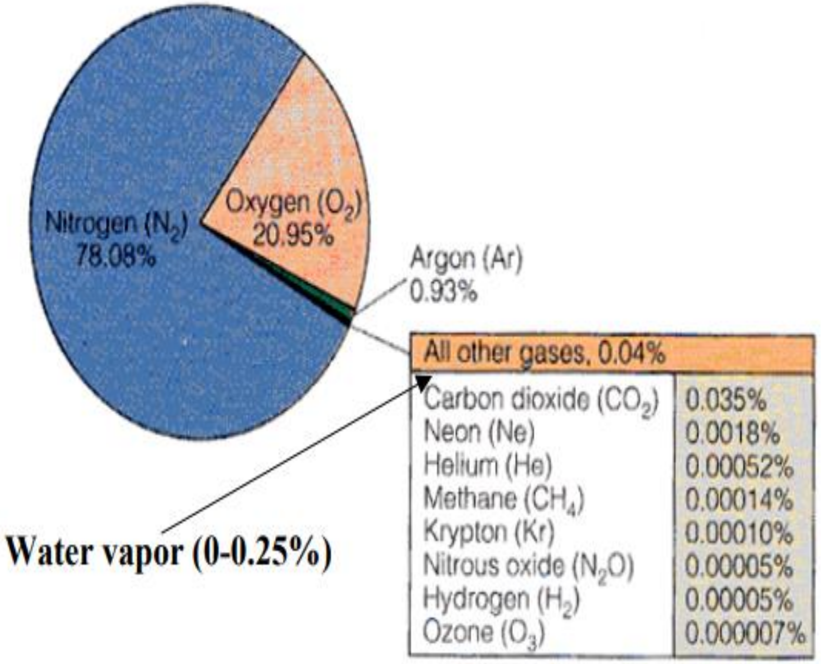
- Between 85 km and 600 km lies the **thermosphere**.
- The gases in this layer readily absorb incoming high energy ultraviolet and x-ray radiation from the sun. Because of this absorption, the temperature in the thermosphere increases with height and can reach as high as 2,000°C (3,600°F) near the top depending on solar activity.

Thickness of the Atmosphere

(from *Meteorology Today*)

- Most of the atmospheric mass is confined in the lowest 100 km above the sea level.
- The thickness of the atmosphere is only about 2% of Earth's thickness (Earth's radius = ~6500km).

Composition of Atmosphere



All other gases, 0.04%	
Carbon dioxide (CO_2)	0.035%
Neon (Ne)	0.0018%
Helium (He)	0.00052%
Methane (CH_4)	0.00014%
Krypton (Kr)	0.00010%
Nitrous oxide (N_2O)	0.00005%
Hydrogen (H_2)	0.00005%
Ozone (O_3)	0.000007%

Figure 12.2 Composition of dry, aerosol-free air in volume percent. Three gases—nitrogen, oxygen, and argon—make up 99.96 percent of the air.

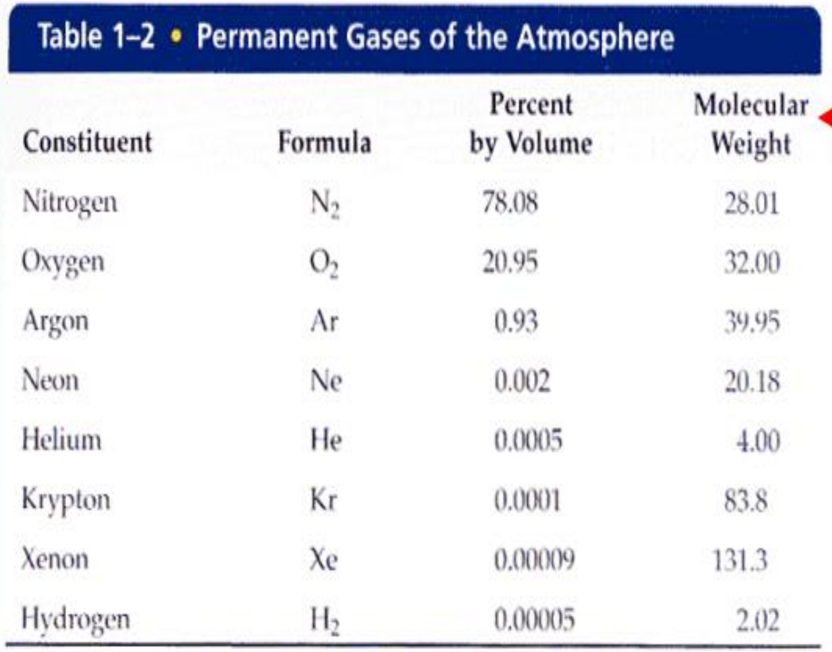


Table 1–2 • Permanent Gases of the Atmosphere

Constituent	Formula	Percent by Volume	Molecular Weight
Nitrogen	N_2	78.08	28.01
Oxygen	O_2	20.95	32.00
Argon	Ar	0.93	39.95
Neon	Ne	0.002	20.18
Helium	He	0.0005	4.00
Krypton	Kr	0.0001	83.8
Xenon	Xe	0.00009	131.3
Hydrogen	H_2	0.00005	2.02

Those gases that form a constant portion of the atmospheric mass.

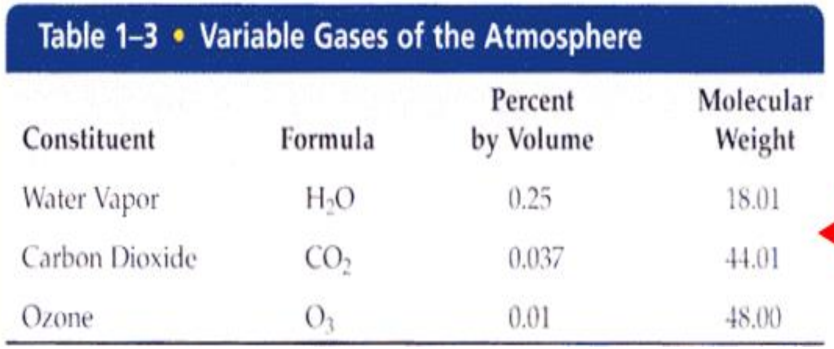


Table 1–3 • Variable Gases of the Atmosphere

Constituent	Formula	Percent by Volume	Molecular Weight
Water Vapor	H_2O	0.25	18.01
Carbon Dioxide	CO_2	0.037	44.01
Ozone	O_3	0.01	48.00

Those gases whose concentrations changes from time to time and from place to place. Some of those gases are important to weather and climate.

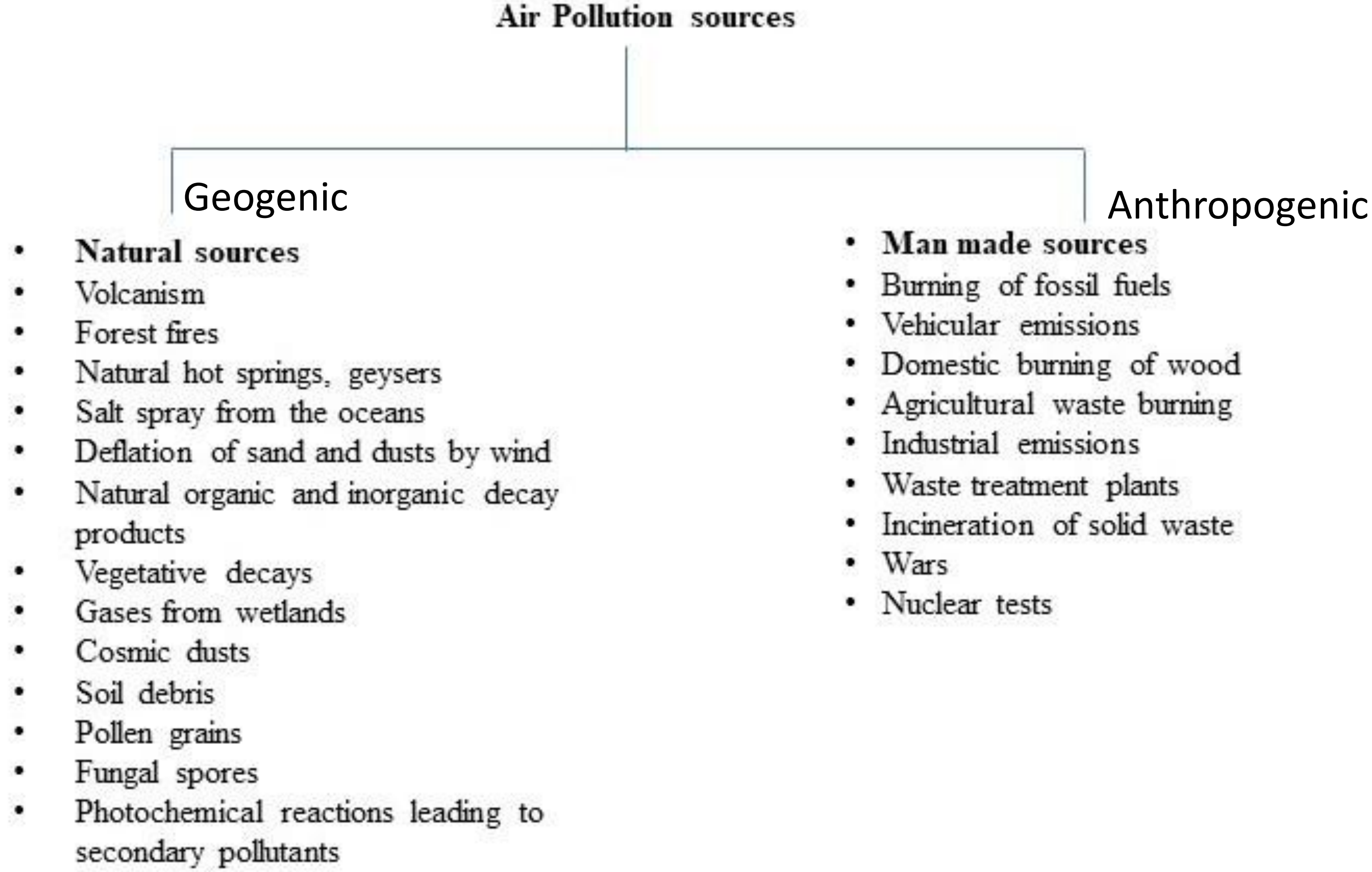
AIR POLLUTION

- **Air pollution is the accumulation in the atmosphere of substances that, in sufficient concentrations, endanger human health or produce other measured effects on living matter and other materials.**

STR APPROACH

- Source
- Transport
- Receptor

Sources



Air Pollution sources

Geogenic

- **Natural sources**
- Volcanism
- Forest fires
- Natural hot springs, geysers
- Salt spray from the oceans
- Deflation of sand and dusts by wind
- Natural organic and inorganic decay products
- Vegetative decays
- Gases from wetlands
- Cosmic dusts
- Soil debris
- Pollen grains
- Fungal spores
- Photochemical reactions leading to secondary pollutants

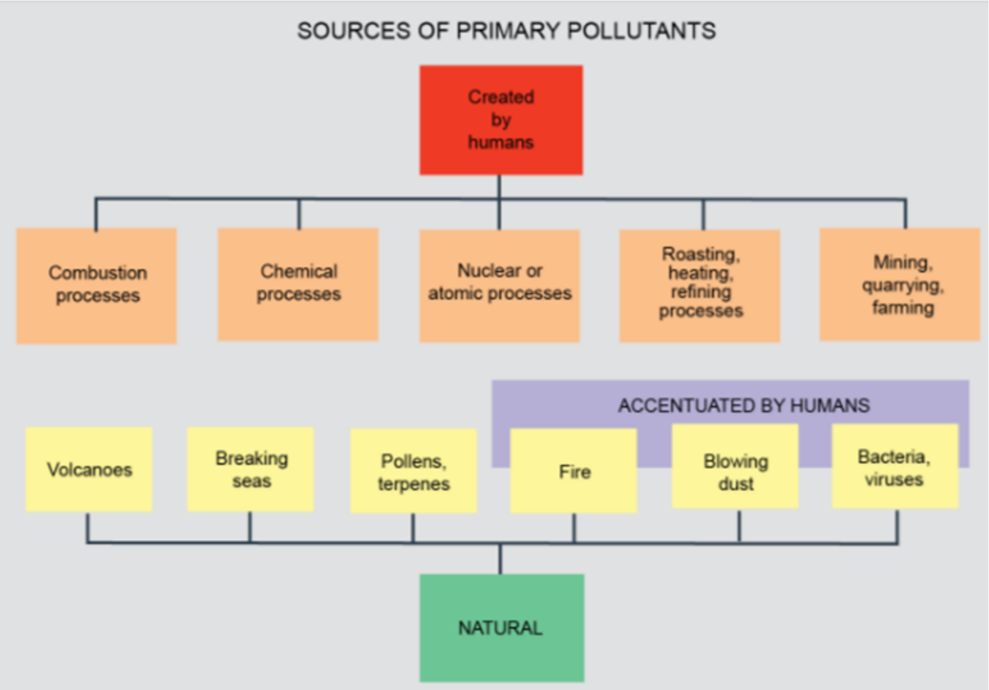
Anthropogenic

- **Man made sources**
- Burning of fossil fuels
- Vehicular emissions
- Domestic burning of wood
- Agricultural waste burning
- Industrial emissions
- Waste treatment plants
- Incineration of solid waste
- Wars
- Nuclear tests

Sources

Total Sources

- **Stationary Sources**
  - **Point**
    1. Industrial processing
    2. Power plants
    3. Fuel combustion (Industrial)
       Coal
       Oil
       Gas
    4. Solid waste disposal
       Municipal incinerators
    5. Misecellaneous
  - **Area Sources**
    1. Residential heating
       Coal
       Oil
       Gas
    2. Institutional & Commercial heating
       Coal
       Oil
       Gas
    3. On site incineration
    4. Open burning
- **Mobile Sources**
  - **Line Sources**
    1. Highway vehicles
    2. Railroad
       Locomotives
    3. Channel vessels
  - **Area Sources**
    1. Motor vehicles
       Light-duty
       Medium-duty
       Heavy-duty
    2. Railyard
       Locomotives
    3. Port vessels
    4. Aircraft (airports)
    5. Miscellaneous



- **Fugitive emissions**

are **emissions** of gases or vapors from pressurized equipment due to leaks and other unintended or irregular releases of gases

These emission are most difficult to take into account or monitor. As they are not emitted from any fixed source there no standards also.

Sources from industries and human activities or anthropogenic sources

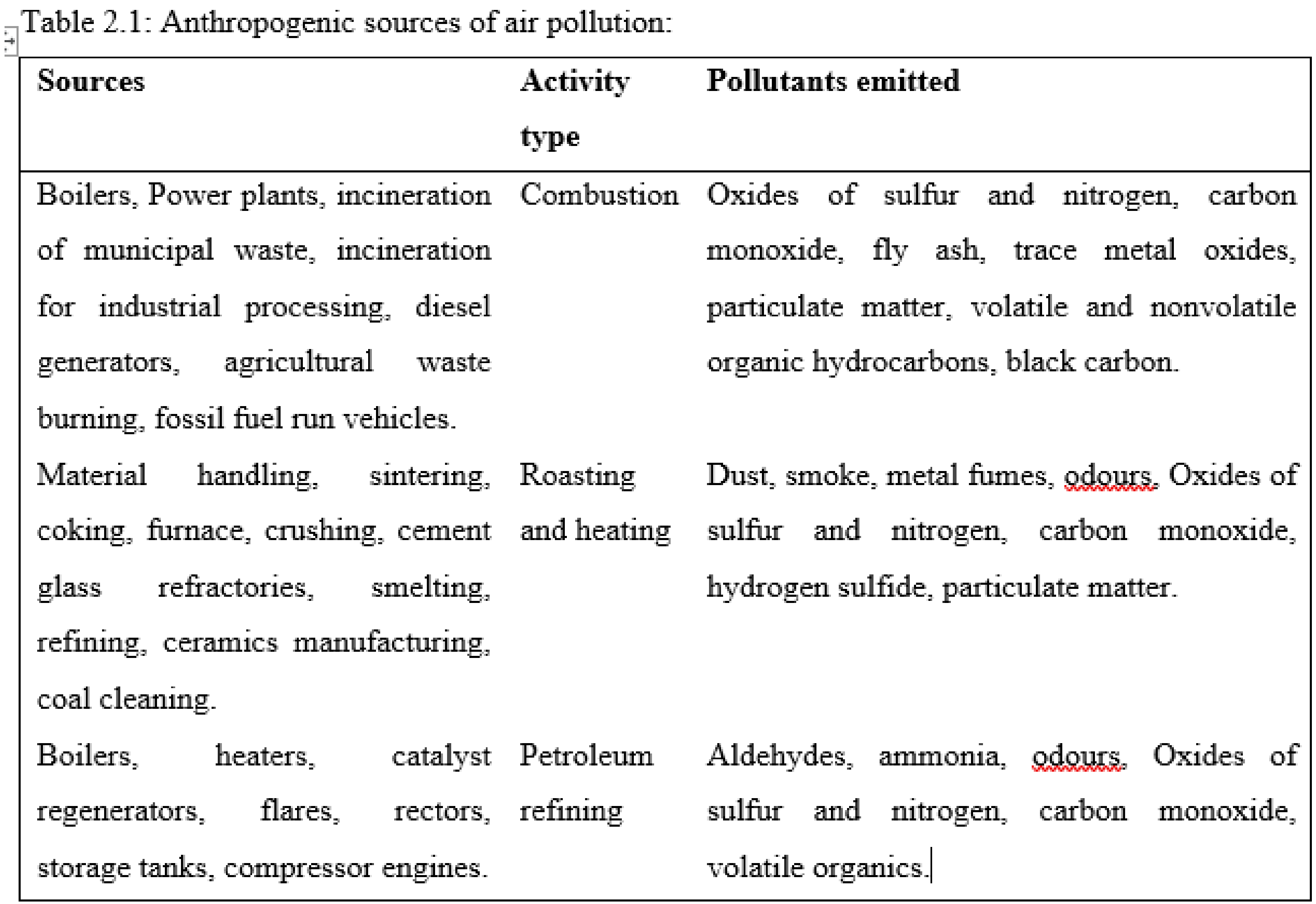
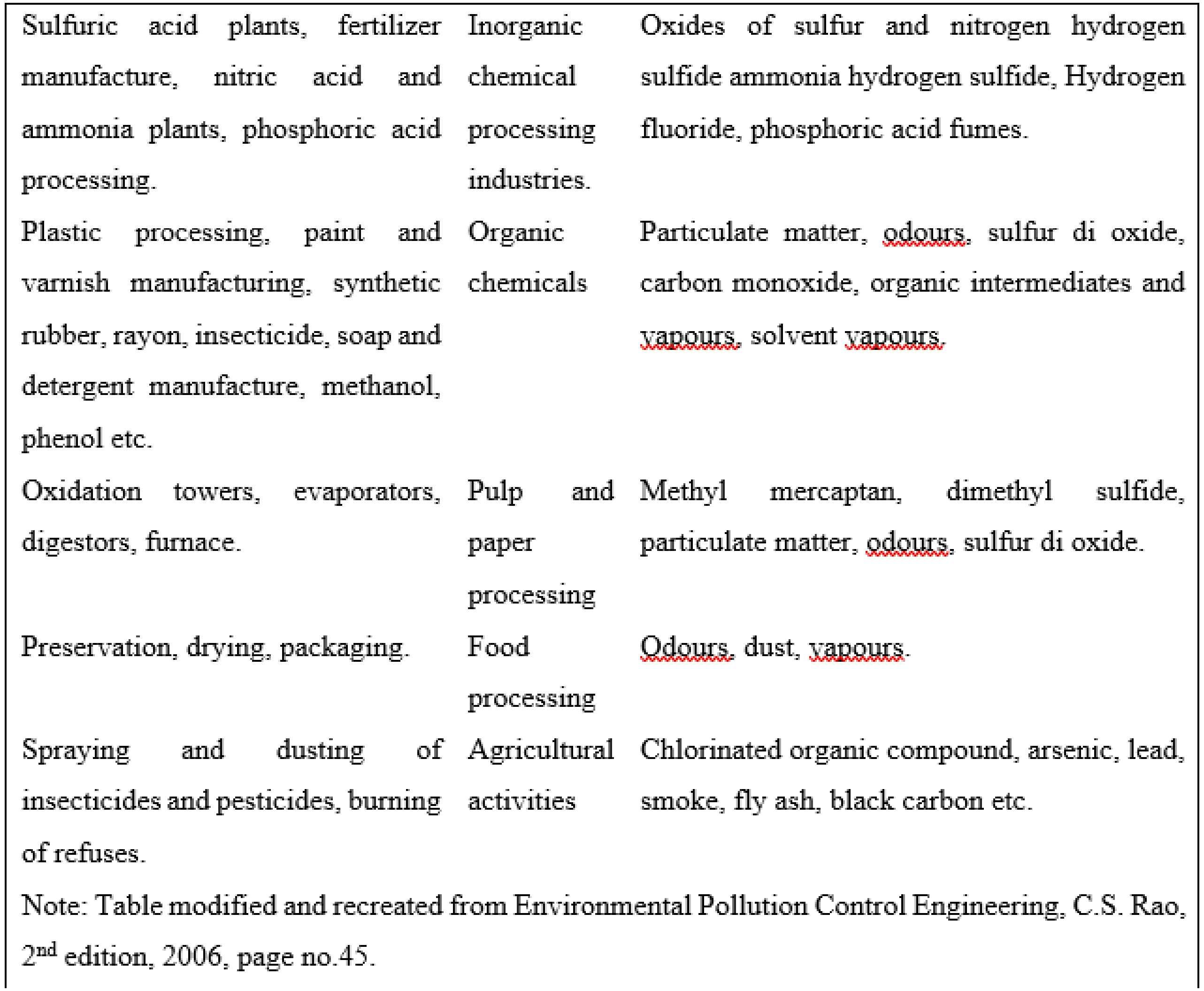


Table 2.1: Anthropogenic sources of air pollution:

Sources	**Activity type**	**Pollutants emitted**
Boilers, Power plants, incineration of municipal waste, incineration for industrial processing, diesel generators, agricultural waste burning, fossil fuel run vehicles.	Combustion	Oxides of sulfur and nitrogen, carbon monoxide, fly ash, trace metal oxides, particulate matter, volatile and nonvolatile organic hydrocarbons, black carbon.
Material handling, sintering, coking, furnace, crushing, cement glass refractories, smelting, refining, ceramics manufacturing, coal cleaning.	Roasting and heating	Dust, smoke, metal fumes, odours, Oxides of sulfur and nitrogen, carbon monoxide, hydrogen sulfide, particulate matter.
Boilers, heaters, catalyst regenerators, flares, rectors, storage tanks, compressor engines.	Petroleum refining	Aldehydes, ammonia, odours, Oxides of sulfur and nitrogen, carbon monoxide, volatile organics.

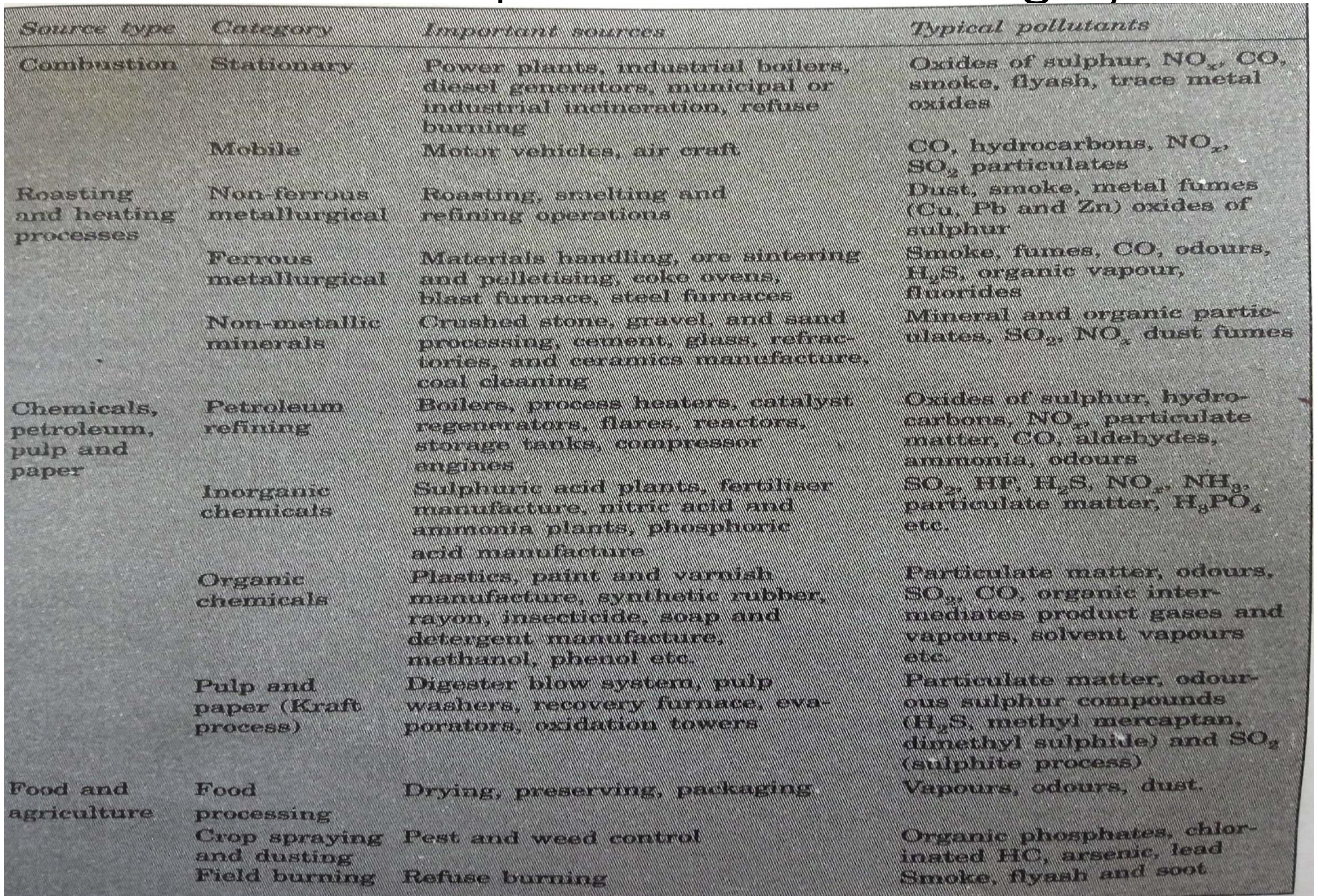
Continued…



Sulfuric acid plants, fertilizer manufacture, nitric acid and ammonia plants, phosphoric acid processing.	Inorganic chemical processing industries.	Oxides of sulfur and nitrogen hydrogen sulfide ammonia hydrogen sulfide, Hydrogen fluoride, phosphoric acid fumes.
Plastic processing, paint and varnish manufacturing, synthetic rubber, rayon, insecticide, soap and detergent manufacture, methanol, phenol etc.	Organic chemicals	Particulate matter, odours, sulfur di oxide, carbon monoxide, organic intermediates and vapours, solvent vapours.
Oxidation towers, evaporators, digestors, furnace.	Pulp and paper processing	Methyl mercaptan, dimethyl sulfide, particulate matter, odours, sulfur di oxide.
Preservation, drying, packaging.	Food processing	Odours, dust, vapours.
Spraying and dusting of insecticides and pesticides, burning of refuses.	Agricultural activities	Chlorinated organic compound, arsenic, lead, smoke, fly ash, black carbon etc.

Note: Table modified and recreated from Environmental Pollution Control Engineering, C.S. Rao, 2^{nd} edition, 2006, page no.45.

Sources of air pollutant emissions from human activities, Source: Environmental pollution control Eng by C.S. Rao



Source type	*Category*	*Important sources*	*Typical pollutants*
Combustion	Stationary	Power plants, industrial boilers, diesel generators, municipal or industrial incineration, refuse burning	Oxides of sulphur, NO_x, CO, smoke, flyash, trace metal oxides
	Mobile	Motor vehicles, air craft	CO, hydrocarbons, NO_x, SO_2 particulates
Roasting and heating processes	Non-ferrous metallurgical	Roasting, smelting and refining operations	Dust, smoke, metal fumes (Cu, Pb and Zn) oxides of sulphur
	Ferrous metallurgical	Materials handling, ore sintering and pelletising, coke ovens, blast furnace, steel furnaces	Smoke, fumes, CO, odours, H_2S, organic vapour, fluorides
	Non-metallic minerals	Crushed stone, gravel, and sand processing, cement, glass, refractories, and ceramics manufacture, coal cleaning	Mineral and organic particulates, SO_2, NO_x dust fumes
Chemicals, petroleum, pulp and paper	Petroleum refining	Boilers, process heaters, catalyst regenerators, flares, reactors, storage tanks, compressor engines	Oxides of sulphur, hydrocarbons, NO_x, particulate matter, CO, aldehydes, ammonia, odours
	Inorganic chemicals	Sulphuric acid plants, fertiliser manufacture, nitric acid and ammonia plants, phosphoric acid manufacture	SO_2, HF, H_2S, NO_x, NH_3, particulate matter, H_3PO_4 etc.
	Organic chemicals	Plastics, paint and varnish manufacture, synthetic rubber, rayon, insecticide, soap and detergent manufacture, methanol, phenol etc.	Particulate matter, odours, SO_2, CO, organic intermediates product gases and vapours, solvent vapours etc.
	Pulp and paper (Kraft process)	Digester blow system, pulp washers, recovery furnace, evaporators, oxidation towers	Particulate matter, odourous sulphur compounds (H_2S, methyl mercaptan, dimethyl sulphide) and SO_2 (sulphite process)
Food and agriculture	Food processing	Drying, preserving, packaging	Vapours, odours, dust.
	Crop spraying and dusting	Pest and weed control	Organic phosphates, chlorinated HC, arsenic, lead
	Field burning	Refuse burning	Smoke, flyash and soot

CE101 module 2. Dr. Tanushree Bhattacharya, BIT Mesra

AIR POLLUTANTS and THEIR SOURCES

- **Sulphur dioxide** produced through the burning of coal, causes acid rain and respiratory problems.

Sources:

- coal-burning power plants and industries,
- industrial boilers and processes
- coal-burning stoves
- refineries
- heaters
- **Nitrogen oxides** from vehicle emissions, combine to form photochemical smog which causes respiratory problems
- Sources:
- vehicles, industrial boilers
- industrial processes, power plants
- commercial and residential heaters
- coal-burning stoves
- natural gas pipelines

- **Carbon monoxide** from vehicle emissions, restricts oxygen uptake, causes drowsiness, headaches, death.
- Sources: vehicles burning gasoline
- indoor sources include kerosene- or wood- burning stoves
- dry cleaners
- **Carbon dioxide** produced during the burning of coal enhances global warming.
- **Chloro Fluoro Carbons** used in aerosols, refrigeration, air-conditioning and foam- blowing industries destroys the ozone layer.
- **Methane** from feedlots and rubbish dumps enhances global warming.
- **Ozone, volatile organic compounds (VOCs) and airborne particles, with radioactive pollutants** probably among the most destructive ones (specifically when produced by nuclear explosions). Volatile Organic Compounds-oil refineries.

Types of air pollution

- Ambient air pollution

Ambient air pollution is a broader term used to describe air pollution in outdoor environments. Poor ambient air quality occurs when pollutants reach high enough concentrations to affect human health and/or the environment.

- Indoor air pollution

Indoor pollution sources that release gases or particles into the air are the primary cause of indoor air quality problems. Inadequate ventilation can increase indoor pollutant levels by not bringing in enough outdoor air to dilute emissions from indoor sources and by not carrying indoor air pollutants out of the area.

Photo: N. Bruce/WHO

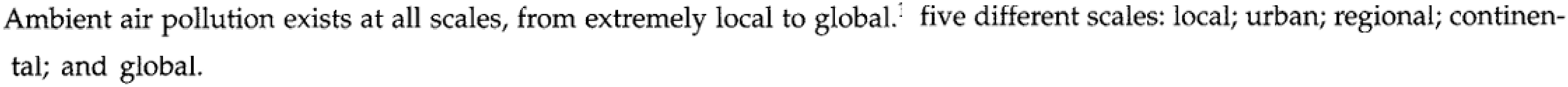
Ambient air pollution facts (source WHO)

- Air pollution is one of the greatest environmental risk to health. By reducing air pollution levels, countries can reduce the burden of disease from stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma.
- In 2019, 99% of the world's population was living in places where the WHO air quality guidelines levels were not met.
- The combined effects of ambient air pollution and household air pollution are associated with 6.7 million premature deaths annually.
- Ambient (outdoor) air pollution is estimated to have caused 4.2 million premature deaths worldwide in 2019.
- Some 89% of those premature deaths occurred in low- and middle-income countries, and the greatest number in the WHO South-East Asia and Western Pacific Regions.
- Policies and investments supporting cleaner transport, energy efficient homes, power generation, industry and better municipal waste management would reduce key sources of outdoor air pollution. Access to clean household energy would also greatly reduce ambient air pollution in some regions.

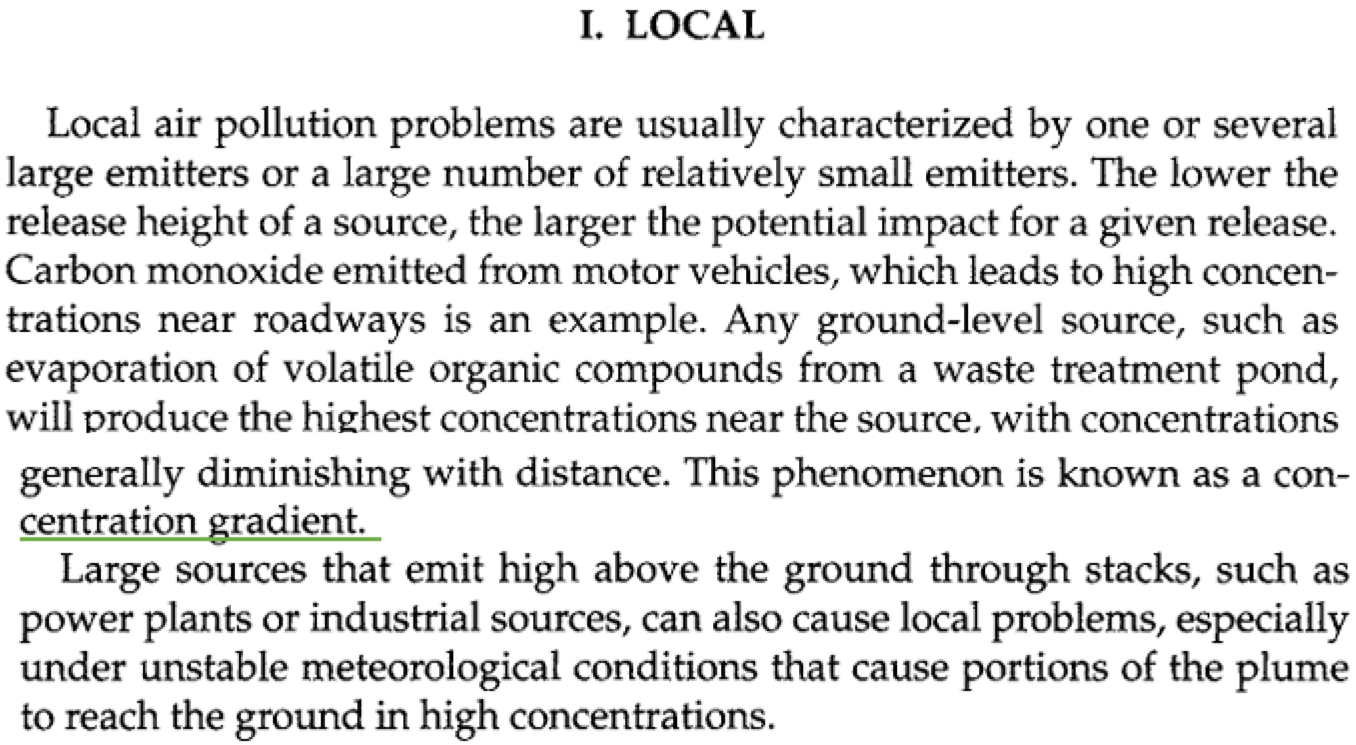
Indoor air pollution facts (WHO, 2023)

- Around 2.3 billion people worldwide (around a third of the global population) cook using open fires or inefficient stoves fueled by kerosene, biomass (wood, animal dung and crop waste) and coal, which generates harmful household air pollution.
- Household air pollution was responsible for an estimated 3.2 million deaths per year in 2020, including over 237 000 deaths of children under the age of 5.
- The combined effects of ambient air pollution and household air pollution are associated with 6.7 million premature deaths annually.
- Household air pollution exposure leads to noncommunicable diseases including stroke, ischaemic heart disease, chronic obstructive pulmonary disease (COPD) and lung cancer.
- Women and children, typically responsible for household chores such as cooking collecting firewood, bear the greatest health burden from the use of polluting fuels and technologies in homes.
- It is essential to expand use of clean fuels and technologies to reduce household air pollution and protect health. These include solar, electricity, biogas, liquefied petroleum gas (LPG), natural gas, alcohol fuels, as well as biomass stoves that meet the emission targets in the WHO Guidelines.

Scales of air pollution



Ambient air pollution exists at all scales, from extremely local to global.[1] five different scales: local; urban; regional; continental; and global.



I. LOCAL

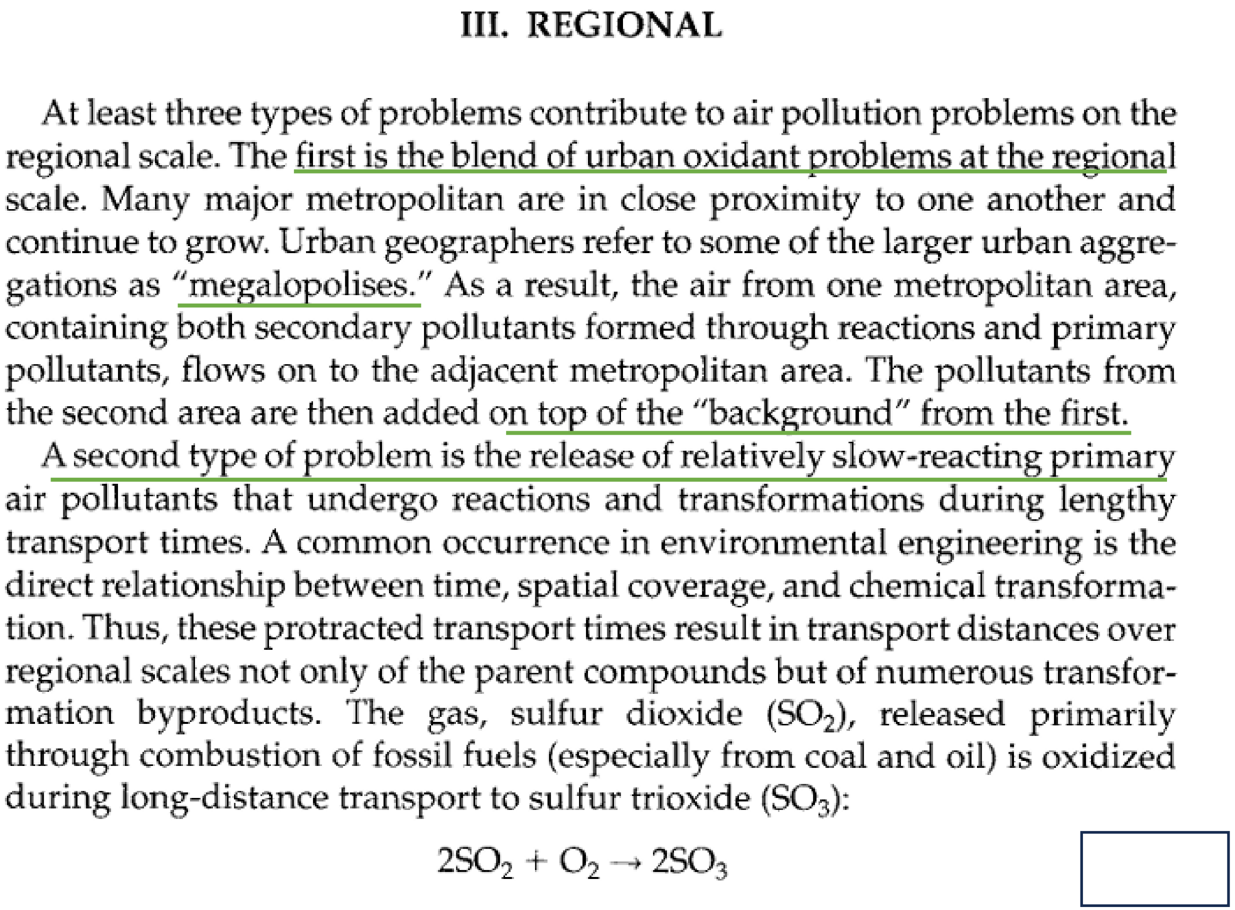
Local air pollution problems are usually characterized by one or several large emitters or a large number of relatively small emitters. The lower the release height of a source, the larger the potential impact for a given release. Carbon monoxide emitted from motor vehicles, which leads to high concentrations near roadways is an example. Any ground-level source, such as evaporation of volatile organic compounds from a waste treatment pond, will produce the highest concentrations near the source, with concentrations generally diminishing with distance. This phenomenon is known as a concentration gradient.

Large sources that emit high above the ground through stacks, such as power plants or industrial sources, can also cause local problems, especially under unstable meteorological conditions that cause portions of the plume to reach the ground in high concentrations.

II. URBAN

Air pollution problems in urban areas generally are of two types. One is the release of primary pollutants (those released directly from sources). The other is the formation of secondary pollutants (those that are formed through chemical reactions of the primary pollutants).

Air pollution problems can be caused by individual sources on the urban scale as well as the local scale. For pollutants that are relatively nonreactive, such as carbon monoxide and particulate matter,[2] or relatively slowly reactive, such as sulfur dioxide, the contributions from individual sources combine to yield high concentrations. Since a major source of carbon monoxide is motor vehicles, "hot spots" of high concentration can occur especially near multilane intersections. The emissions are especially high from idling vehicles. The hot spots are exacerbated if high buildings surround the intersection, since the volume of air in which the pollution is contained is severely restricted. The combination of these factors results in high concentrations.

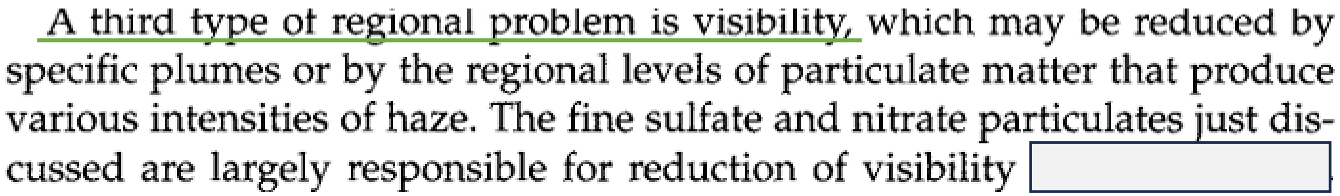


III. REGIONAL

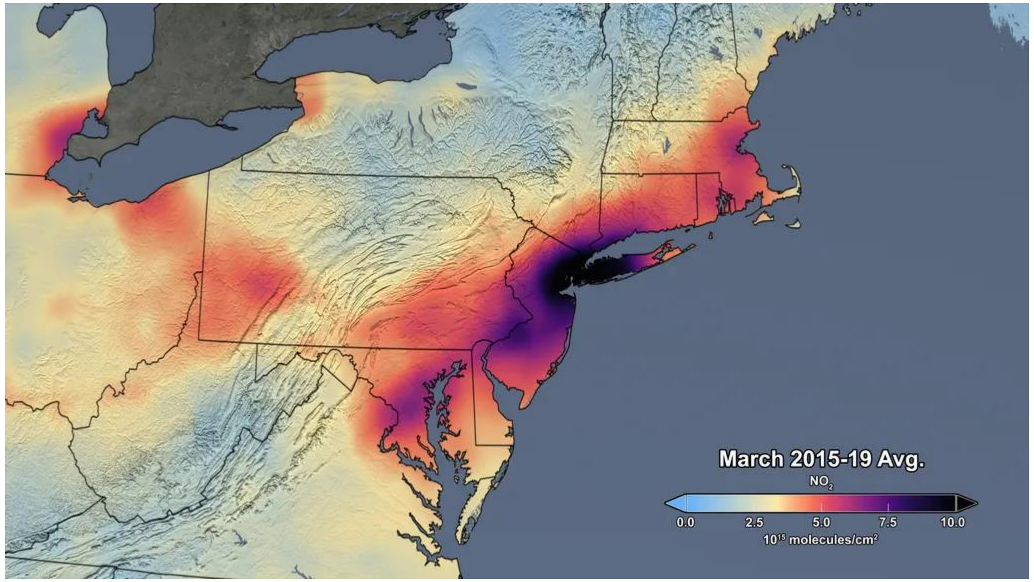
At least three types of problems contribute to air pollution problems on the regional scale. The first is the blend of urban oxidant problems at the regional scale. Many major metropolitan are in close proximity to one another and continue to grow. Urban geographers refer to some of the larger urban aggregations as "megalopolises." As a result, the air from one metropolitan area, containing both secondary pollutants formed through reactions and primary pollutants, flows on to the adjacent metropolitan area. The pollutants from the second area are then added on top of the "background" from the first.

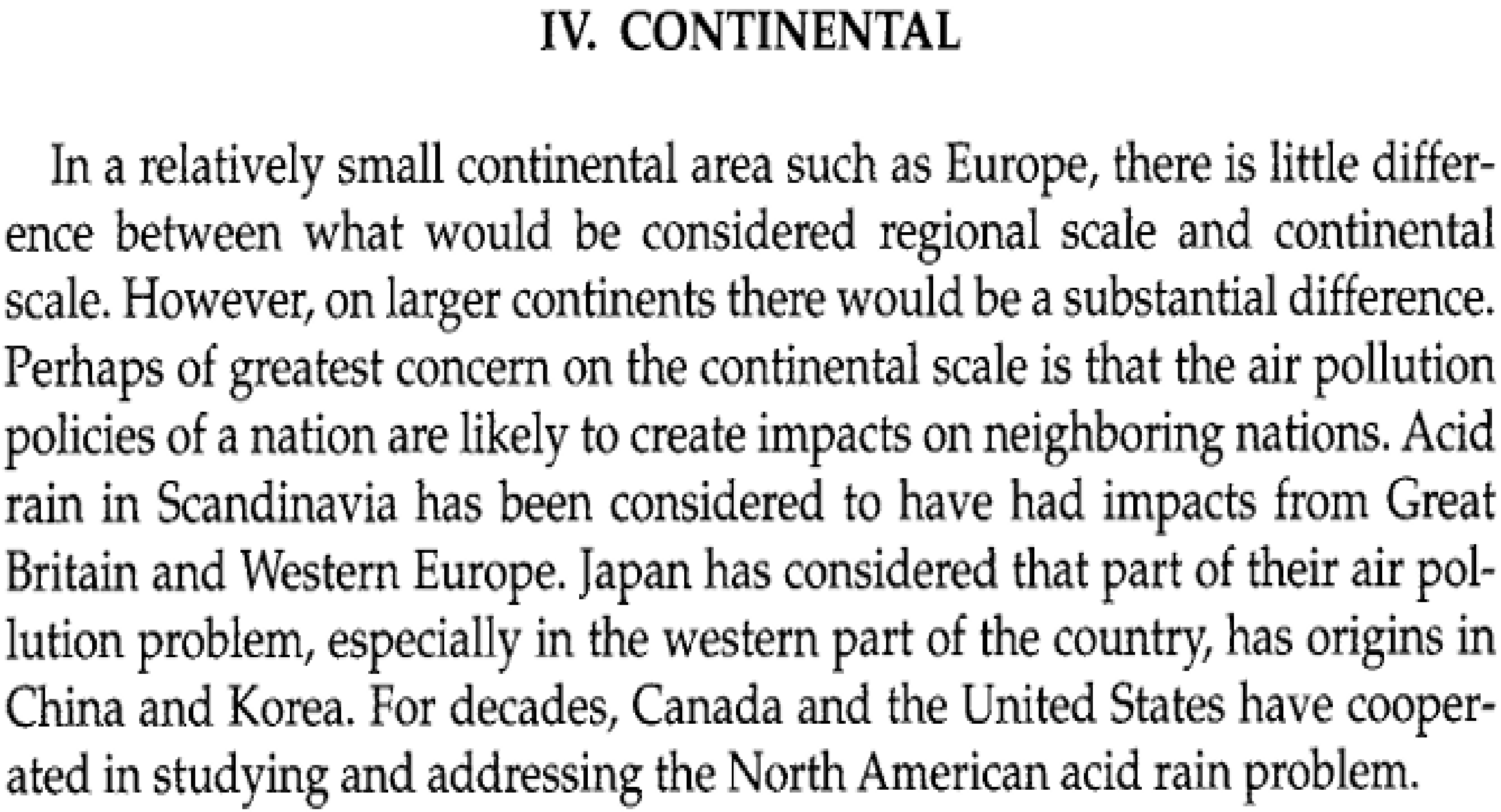
A second type of problem is the release of relatively slow-reacting primary air pollutants that undergo reactions and transformations during lengthy transport times. A common occurrence in environmental engineering is the direct relationship between time, spatial coverage, and chemical transformation. Thus, these protracted transport times result in transport distances over regional scales not only of the parent compounds but of numerous transformation byproducts. The gas, sulfur dioxide (SO_2), released primarily through combustion of fossil fuels (especially from coal and oil) is oxidized during long-distance transport to sulfur trioxide (SO_3):

$$2SO_2 + O_2 \rightarrow 2SO_3$$



A third type of regional problem is visibility, which may be reduced by specific plumes or by the regional levels of particulate matter that produce various intensities of haze. The fine sulfate and nitrate particulates just discussed are largely responsible for reduction of visibility





IV. CONTINENTAL

In a relatively small continental area such as Europe, there is little difference between what would be considered regional scale and continental scale. However, on larger continents there would be a substantial difference. Perhaps of greatest concern on the continental scale is that the air pollution policies of a nation are likely to create impacts on neighboring nations. Acid rain in Scandinavia has been considered to have had impacts from Great Britain and Western Europe. Japan has considered that part of their air pollution problem, especially in the western part of the country, has origins in China and Korea. For decades, Canada and the United States have cooperated in studying and addressing the North American acid rain problem.

Types of Pollutants

Based on origin

1. Primary
2. Secondary

Based on state

1. Suspended matter (Particulate matter)
2. Gaseous (Gases and Volatile Organic Carbons)

Hazardous air pollutants

Criteria Pollutants

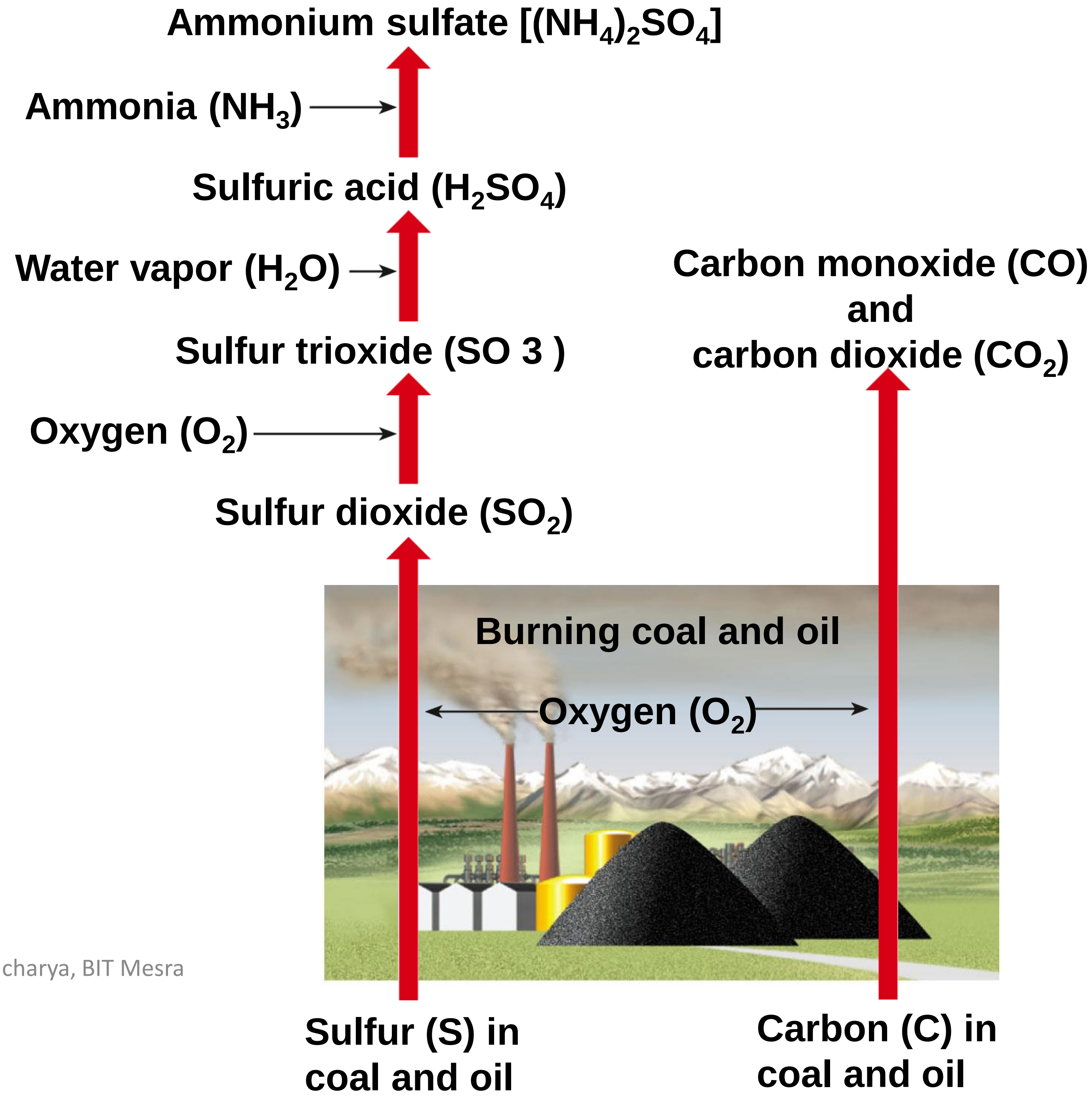
Primary and Secondary Air Pollutants

Primary air pollutants - Materials that when released pose health risks in their unmodified forms or those emitted directly from identifiable sources.

-Carbon monoxide
-Sulfur dioxide
-Nitrogen oxides
-Hydrocarbons
-Particulate matter

Secondary air pollutants - Primary pollutants interact with one another, sunlight, or natural gases to produce new, harmful compounds

Ozone
PAN (peroxy acetyl nitrate)
Photochemical smog
Aerosols and mists (H_2SO_4)



Ammonium sulfate [$(NH_4)_2SO_4$]

Ammonia (NH_3)

Sulfuric acid (H_2SO_4)

Water vapor (H_2O)

Sulfur trioxide (SO 3)

Oxygen (O_2)

Sulfur dioxide (SO_2)

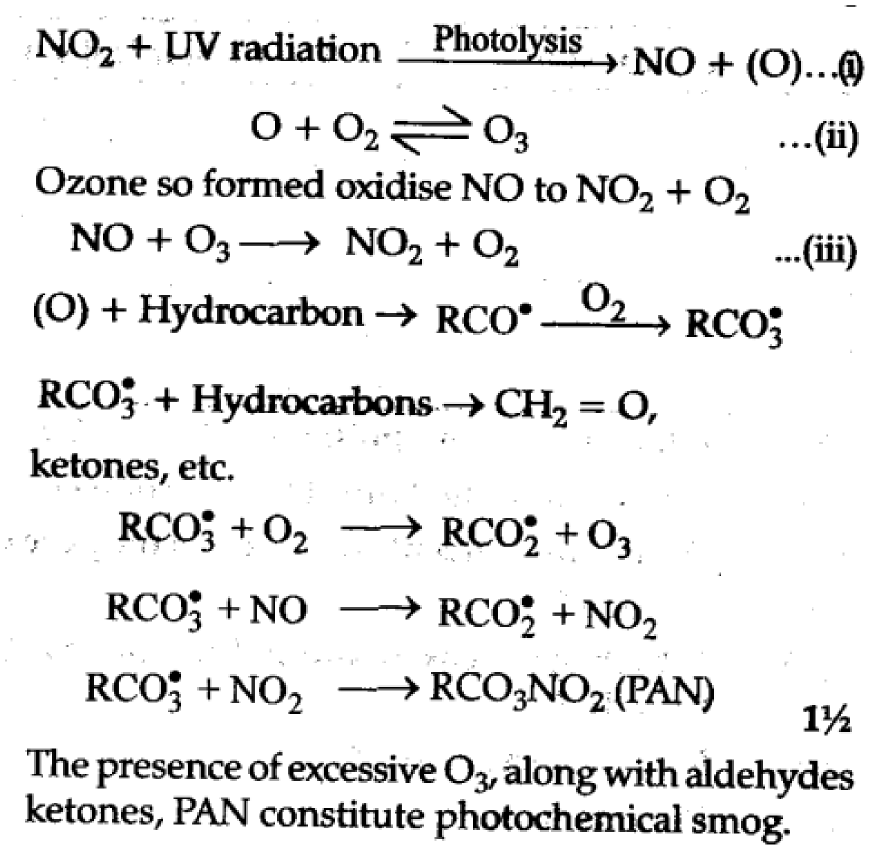
Carbon monoxide (CO)
and
carbon dioxide (CO_2)

Burning coal and oil

Oxygen (O_2)

Sulfur (S) in
coal and oil

Carbon (C) in
coal and oil



NO_2 + UV radiation $\xrightarrow{\text{Photolysis}}$ NO + (O)...(i)

$O + O_2 \rightleftharpoons O_3$ ...(ii)

Ozone so formed oxidise NO to $NO_2 + O_2$

$NO + O_3 \longrightarrow NO_2 + O_2$ ...(iii)

$(O) + \text{Hydrocarbon} \rightarrow RCO^\bullet \xrightarrow{O_2} RCO_3^\bullet$

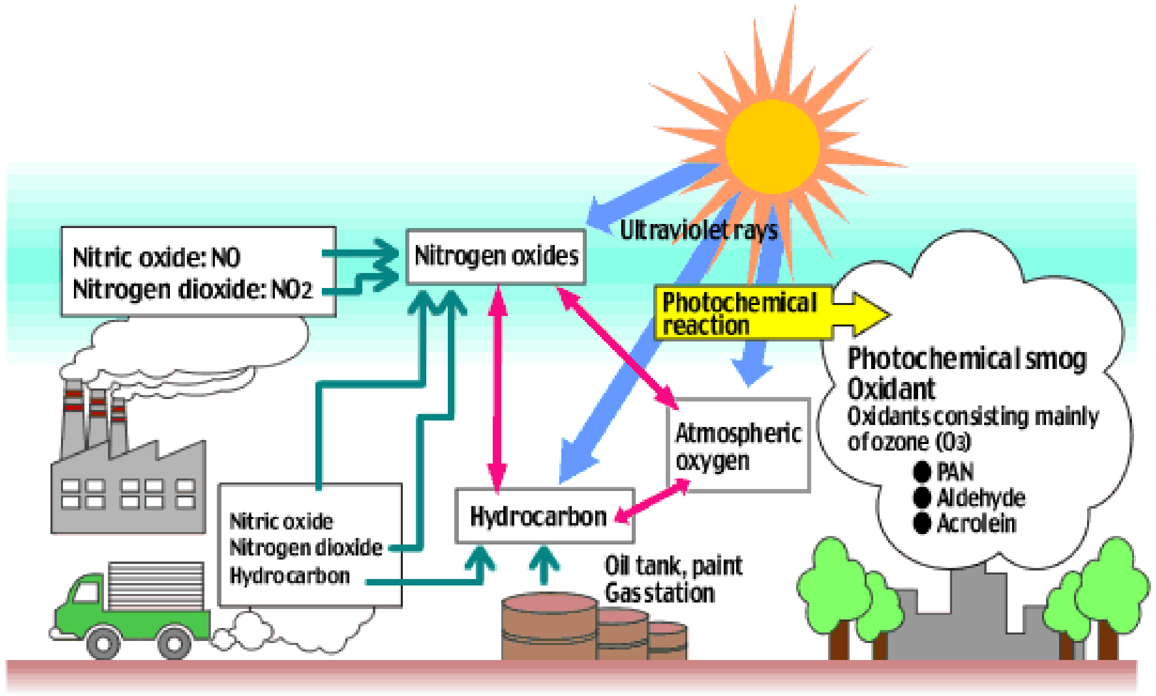
$RCO_3^\bullet + \text{Hydrocarbons} \rightarrow CH_2 = O$, ketones, etc.

$RCO_3^\bullet + O_2 \longrightarrow RCO_2^\bullet + O_3$

$RCO_3^\bullet + NO \longrightarrow RCO_2^\bullet + NO_2$

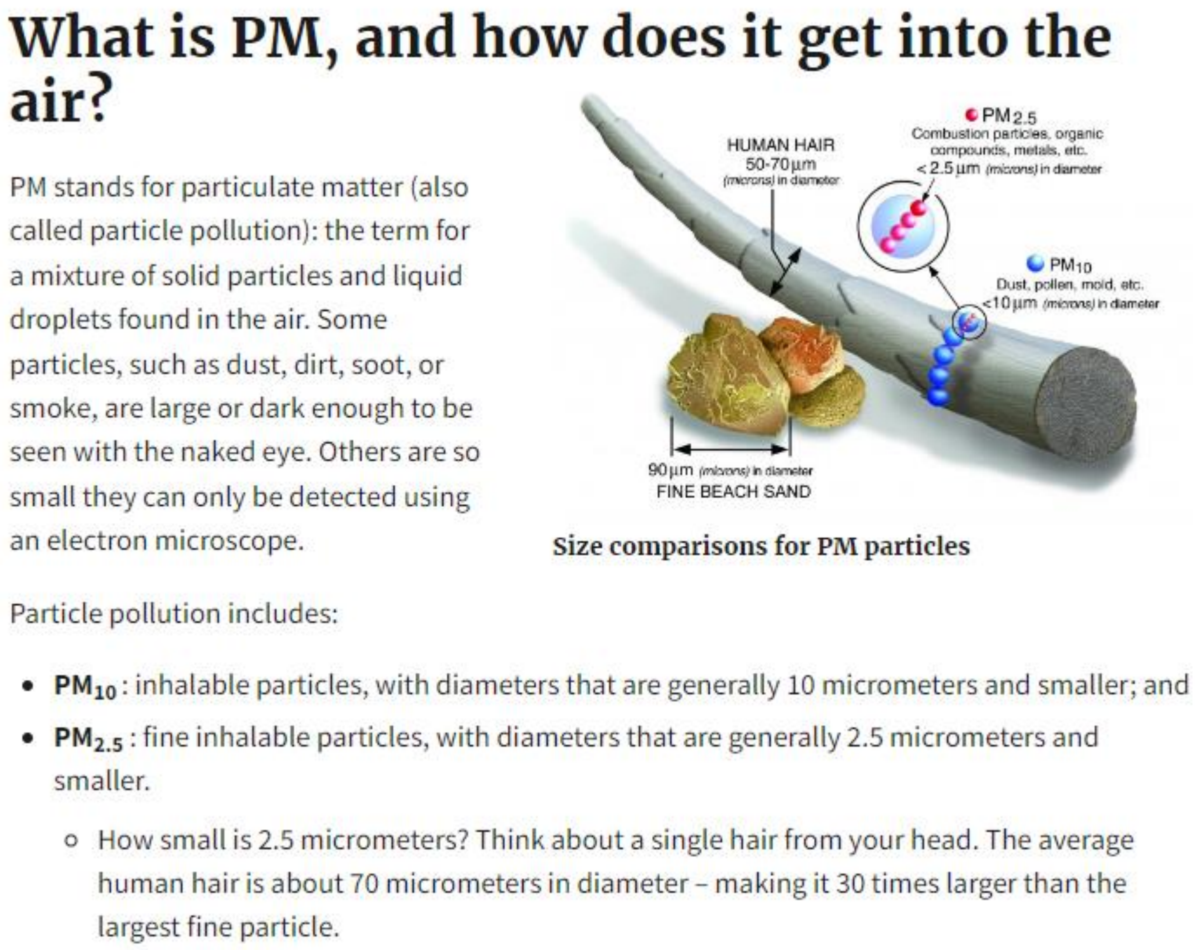
$RCO_3^\bullet + NO_2 \longrightarrow RCO_3NO_2$ (PAN) 1½

The presence of excessive O_3, along with aldehydes ketones, PAN constitute photochemical smog.



Photochemical Smog

Particulate air pollutants



What is PM, and how does it get into the air?

PM stands for particulate matter (also called particle pollution): the term for a mixture of solid particles and liquid droplets found in the air. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye. Others are so small they can only be detected using an electron microscope.

Size comparisons for PM particles

Particle pollution includes:

- **PM$_{10}$** : inhalable particles, with diameters that are generally 10 micrometers and smaller; and
- **PM$_{2.5}$** : fine inhalable particles, with diameters that are generally 2.5 micrometers and smaller.
    - How small is 2.5 micrometers? Think about a single hair from your head. The average human hair is about 70 micrometers in diameter – making it 30 times larger than the largest fine particle.

Atmospheric particulate matter consists of any dispersed matter, solid or liquid, in which the individual aggregates range from molecular clusters of 0.005 micrometers to 100 micrometers.
The solid and liquid particles suspended in our air are called **aerosols**.

Types

Viable Particulate Matter:
These particles incorporate lower living creatures like green growth, microbes, molds, organisms, etc. They are scattered into the air. People are adversely affected by these microorganisms, and they can likewise cause various kinds of infections in plants and animals.

Non-Viable Particulate Matter:
We can group these particles based on size and their inclination.

Smoke
Smoke particulates contain a combination of fluid and solid particles. The burning of any natural matter prompts the development of smoke particles. Models incorporate the arrival of smoke from a cigarette, consuming trash and dry leaves, consuming petroleum products, oil, etc.

Dust
They are solid particles. The size of residue particulates is more than 1 micrometer (µm) in width. Dust particulate matter starts from crushing, pulverizing, and attribution of solid substances. Instances of this kind of particulate emanation include sawdust's arrival during word works, the arrival of sand particles during sandblasting, the crushing of coal, the arrival of fly debris and concrete from processing plants, dust storms, etc.

Mists
Liquid or vapours in the air go through the buildup to frame a fog. The creation of fog is likewise conceivable by particles of splash fluids. For example, herbicides and pesticides are utilized as showers in farming. However, in some cases, it is possible to miss the splash target and enter the environment and structure fogs. One more model is the corrosive sulfuric mist.

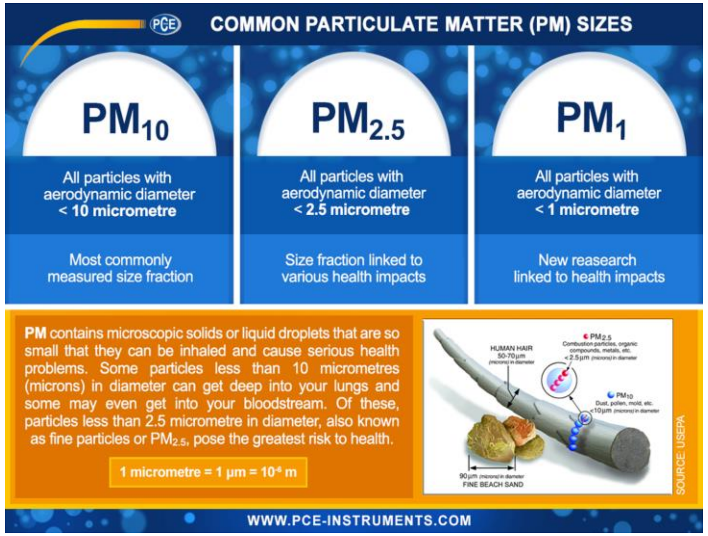
Fumes
They are solid particles formed when vapor condenses. The formation of the exhaust is conceivable by the buildup of fumes during various cycles like bubbling, refining, sublimation, and different sorts of substance responses. Natural solvents, metallic oxides, and metals undergo a synthetic response to produce rage particles.

Smog
Smog, or smoke mist, is a sort of extraordinary air contamination. "Exhaust cloud" was instituted in the mid-twentieth century and is a withdrawal (portmanteau) of the words smoke and mist to allude to smoky mist because of its darkness and smell. The word was then expected to allude to what was now and again known as pea soup haze, a recognizable and significant issue in London from the nineteenth century to the mid-twentieth century. This sort of apparent air contamination is made out of nitrogen oxides, sulfur oxide, ozone, smoke, and different particulates. Artificial brown haze is gotten from coal-burning emanations, vehicular discharges, modern outflows, timberland, farming flames, and photochemical responses of these emissions.

Particulate matter sources

Sources of particulate matter can be manmade or natural.

- Some particulates occur naturally, originating from volcanoes, dust storms, forest and grassland fires, living vegetation, and sea spray.
- Human activities, such as the burning of fossil fuels in vehicles, power plants and various industrial processes also generate significant amounts of aerosols.



COMMON PARTICULATE MATTER (PM) SIZES

PM_{10}	$PM_{2.5}$	PM_1
All particles with aerodynamic diameter **< 10 micrometre**	All particles with aerodynamic diameter **< 2.5 micrometre**	All particles with aerodynamic diameter **< 1 micrometre**
Most commonly measured size fraction	Size fraction linked to various health impacts	New reasearch linked to health impacts

PM contains microscopic solids or liquid droplets that are so small that they can be inhaled and cause serious health problems. Some particles less than 10 micrometres (microns) in diameter can get deep into your lungs and some may even get into your bloodstream. Of these, particles less than 2.5 micrometre in diameter, also known as fine particles or $PM_{2.5}$, pose the greatest risk to health.

1 micrometre = 1 µm = 10^{-6} m

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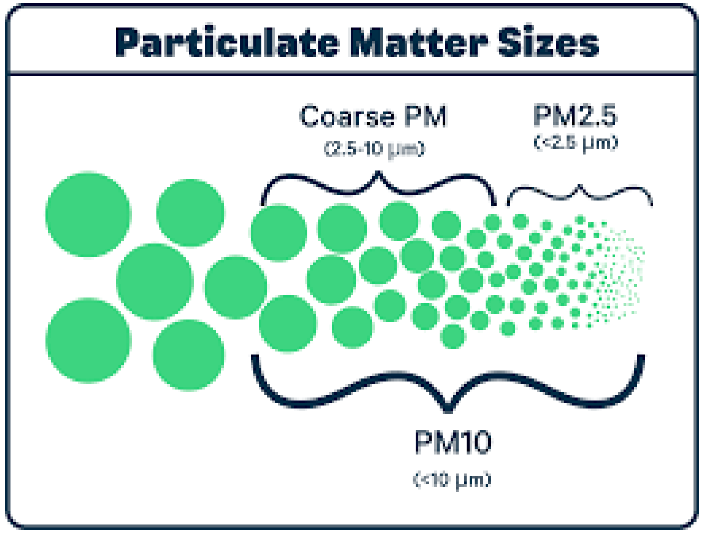
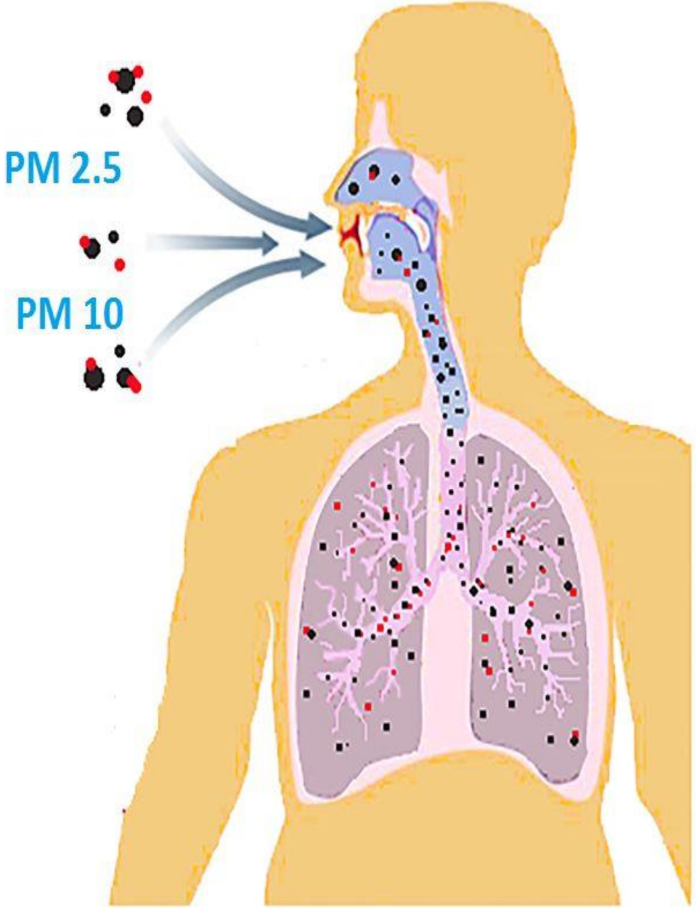
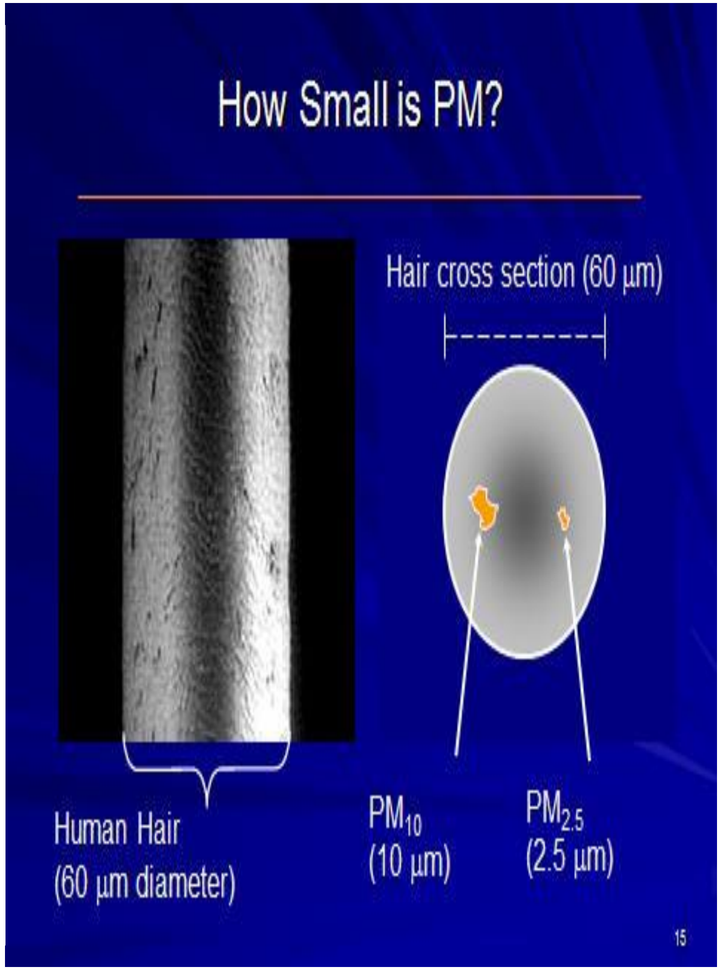


Particulate Matter Sizes





How Small is PM?

Hair cross section (60 µm)

Human Hair (60 µm diameter)

PM_{10} (10 µm)

$PM_{2.5}$ (2.5 µm)

15

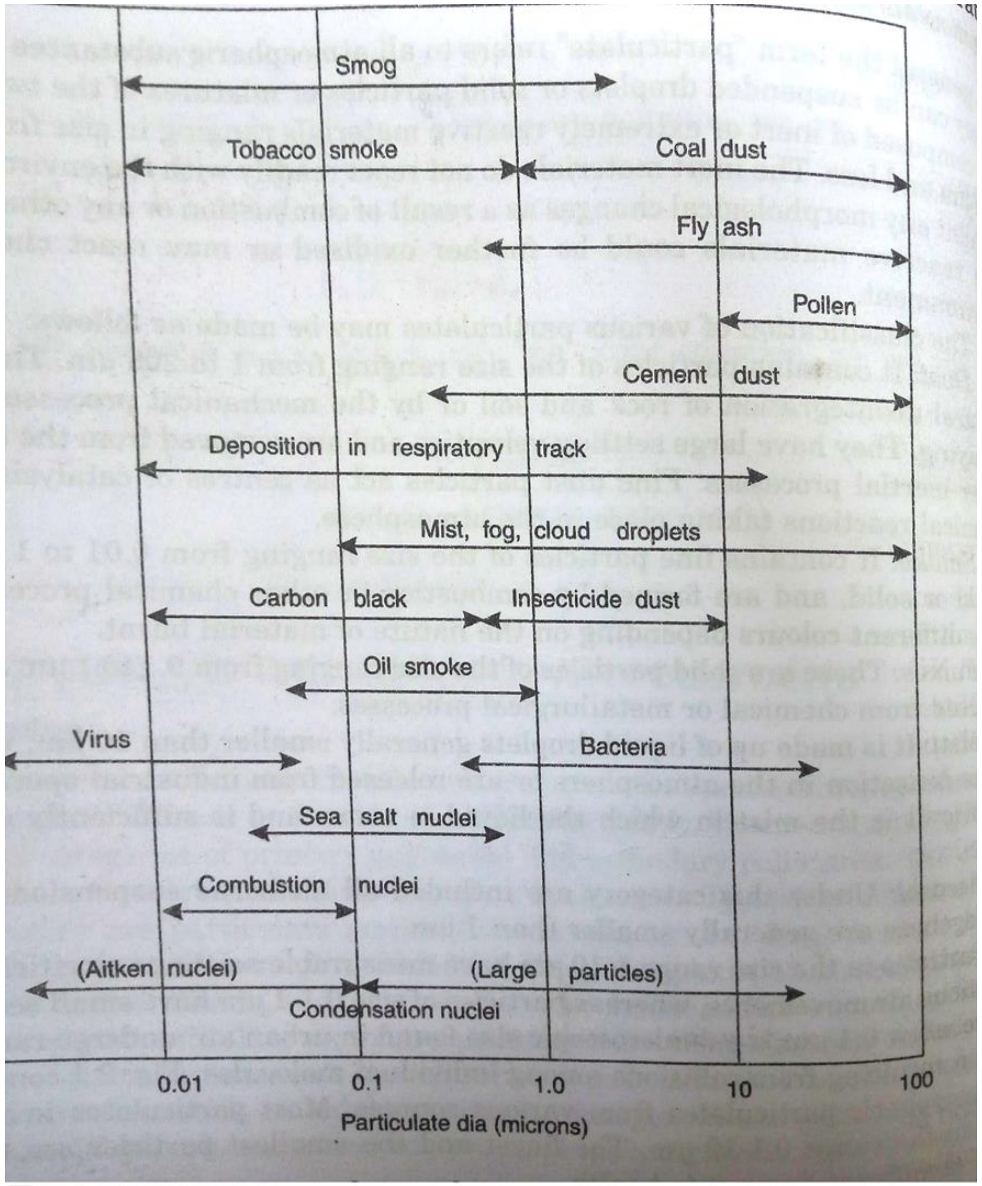
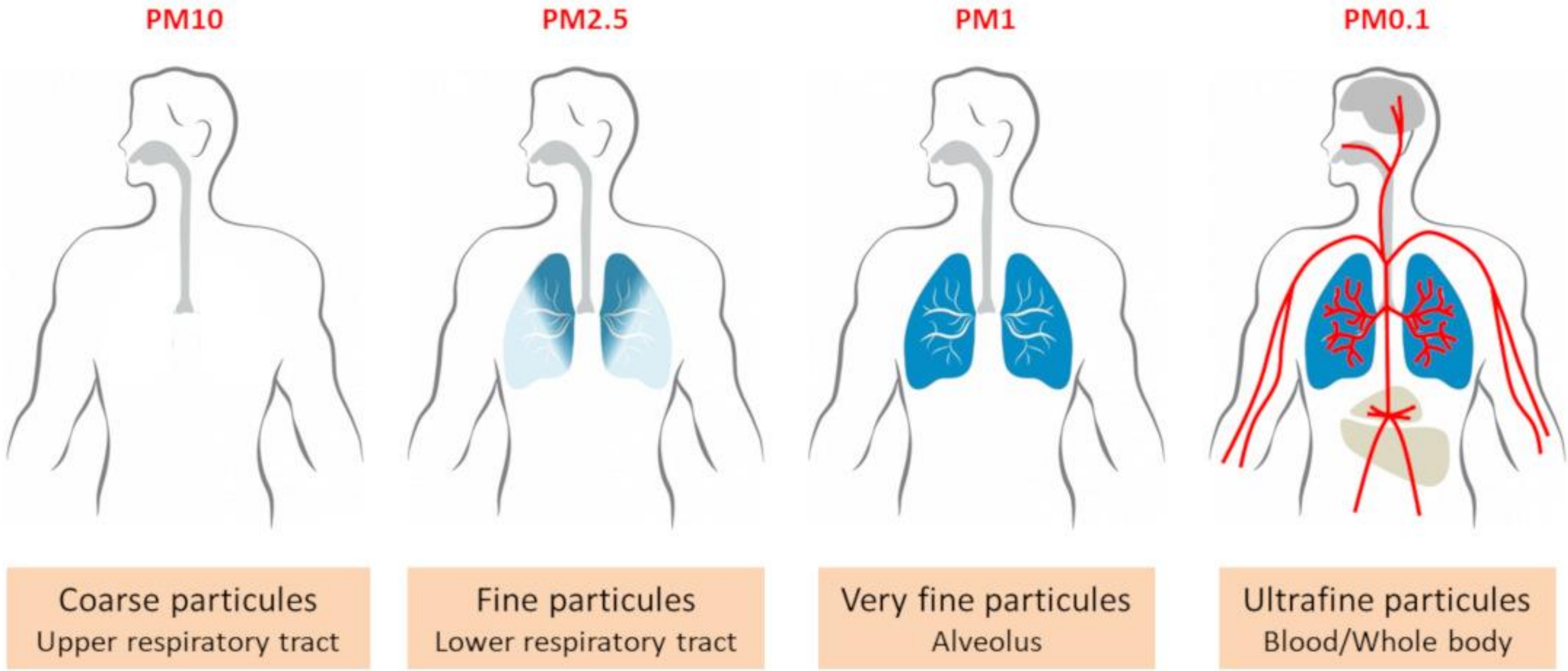
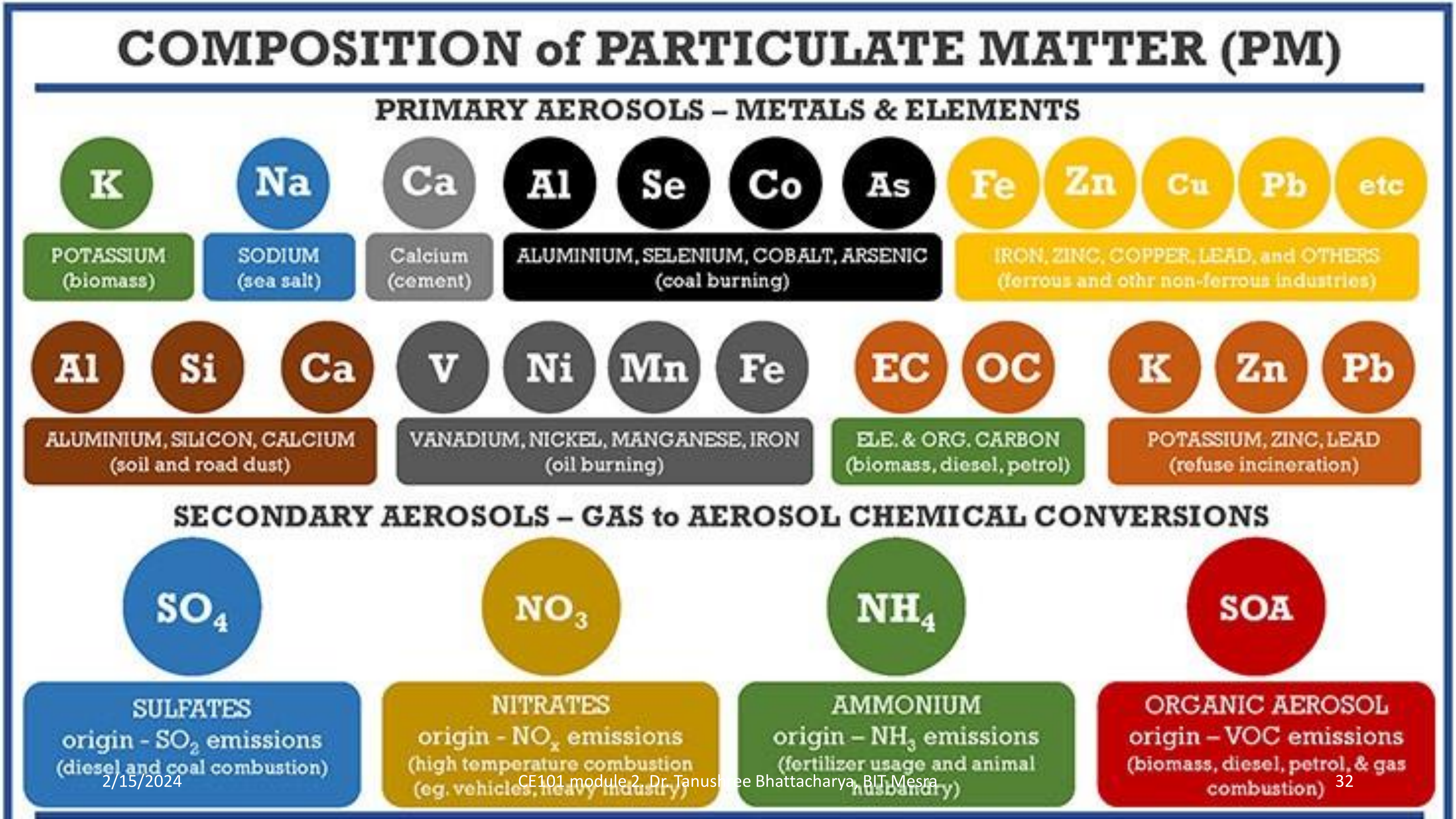


Figure: size range of the particulate matters, Source: Env Pollution Cont. Eng. C.S. Rao

SIZES


PM10
PM2.5
PM1
PM0.1
Coarse particules
Upper respiratory tract
Fine particules
Lower respiratory tract
Very fine particules
Alveolus
Ultrafine particules
Blood/Whole body



COMPOSITION of PARTICULATE MATTER (PM)

PRIMARY AEROSOLS – METALS & ELEMENTS

K
POTASSIUM
(biomass)

Na
SODIUM
(sea salt)

Ca
Calcium
(cement)

Al **Se** **Co** **As**
ALUMINIUM, SELENIUM, COBALT, ARSENIC
(coal burning)

Fe **Zn** **Cu** **Pb** **etc**
IRON, ZINC, COPPER, LEAD, and OTHERS
(ferrous and othr non-ferrous industries)

Al **Si** **Ca**
ALUMINIUM, SILICON, CALCIUM
(soil and road dust)

V **Ni** **Mn** **Fe**
VANADIUM, NICKEL, MANGANESE, IRON
(oil burning)

EC **OC**
ELE. & ORG. CARBON
(biomass, diesel, petrol)

K **Zn** **Pb**
POTASSIUM, ZINC, LEAD
(refuse incineration)

SECONDARY AEROSOLS – GAS to AEROSOL CHEMICAL CONVERSIONS

SO_4
SULFATES
origin - SO_2 emissions
(diesel and coal combustion)

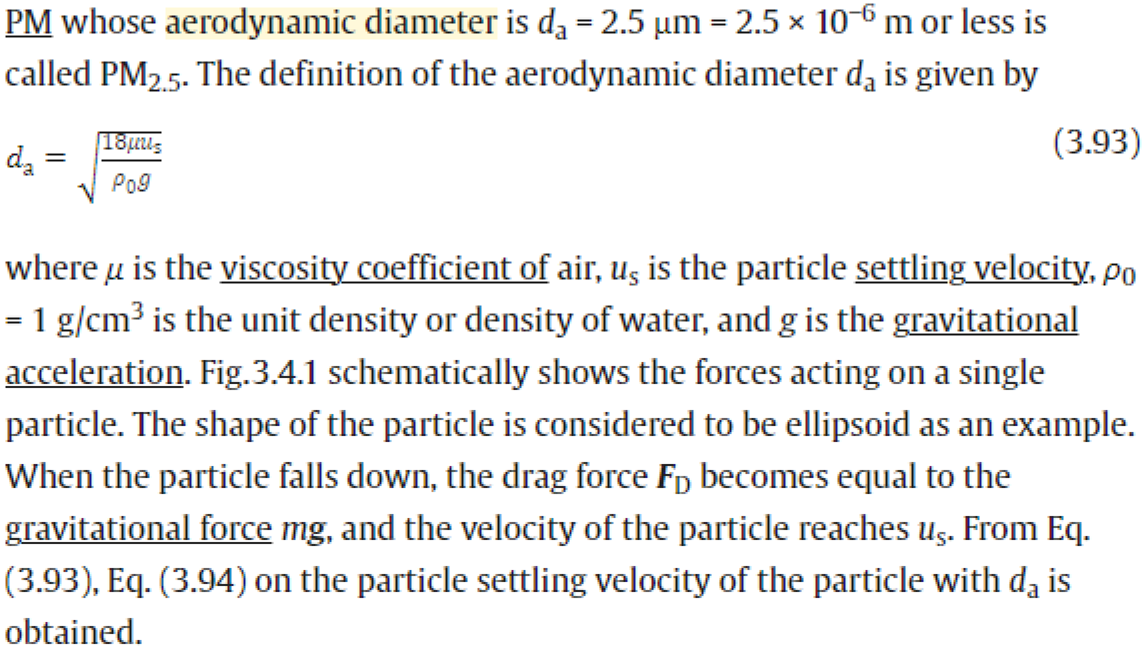
NO_3
NITRATES
origin - NO_x emissions
(high temperature combustion
(eg. vehicles, heavy industry)

NH_4
AMMONIUM
origin – NH_3 emissions
(fertilizer usage and animal
husbandry)

SOA
ORGANIC AEROSOL
origin – VOC emissions
(biomass, diesel, petrol, & gas
combustion)

Aerodynamic diameter

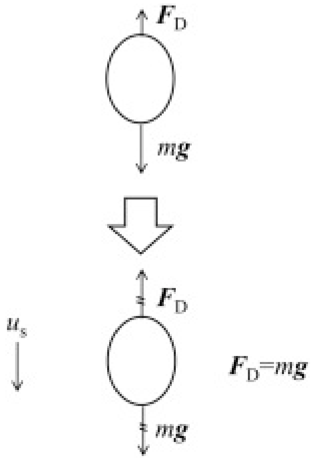
- Aerodynamic diameter of a particle is defined as that of a sphere, whose density is 1g/cm^3, which settles in still air at the same velocity as the particle in question.



PM whose aerodynamic diameter is $d_a = 2.5\ \mu m = 2.5 \times 10^{-6}$ m or less is called PM$_{2.5}$. The definition of the aerodynamic diameter d_a is given by

$$d_a = \sqrt{\frac{18\mu u_s}{\rho_0 g}} \tag{3.93}$$

where μ is the viscosity coefficient of air, u_s is the particle settling velocity, $\rho_0 = 1$ g/cm^3 is the unit density or density of water, and g is the gravitational acceleration. Fig.3.4.1 schematically shows the forces acting on a single particle. The shape of the particle is considered to be ellipsoid as an example. When the particle falls down, the drag force $\boldsymbol{F}_D$ becomes equal to the gravitational force mg, and the velocity of the particle reaches u_s. From Eq. (3.93), Eq. (3.94) on the particle settling velocity of the particle with d_a is obtained.



$$u_s = \frac{d_a^2 \rho_0 g}{18\mu} \tag{3.94}$$

On the other hand, the Stokes diameter d_{St} is defined as Eq. (3.95) and expressed with d_a,

$$d_{St} = \sqrt{\frac{18\mu u_s}{\rho_p g}} = \sqrt{\frac{d_a^2 \rho_0}{\rho_p}} \tag{3.95}$$

where ρ_p is the density of the particle. The maximum settling velocity of $PM_{2.5}$ in the atmosphere is calculated from Eq. (3.94) as

$$u_s = \frac{2.5 \times 10^{-6^2} \times 10^3 \times 9.81}{18 \times 1.822 \times 10^{-5}} = 187 \times 10^{-6}\ \mathrm{m/s} = 187\ \mu\mathrm{m/s}$$

The settling velocity of PM_{10} in the atmosphere is calculated as

$$u_s = 187 \times 4^2 = 2.990\ \mu\mathrm{m/s} = 2.99\ \mathrm{mm/s}$$

The settling velocity of $PM_{2.5}$ is about 0.2 mm/s, which is quite small. Thus, $PM_{2.5}$ is considered as suspended PM.

Gaseous- SO_x

- SO_2 is the component of greatest concern and is used as the indicator for the larger group of gaseous sulfur oxides (SOx). Other gaseous SOx (such as SO_3) are found in the atmosphere at concentrations much lower than SO_2.
- Control measures that reduce SO_2 can generally be expected to reduce people's exposures to all gaseous SOx. This may have the important co-benefit of reducing the formation of particulate sulfur pollutants, such as fine sulfate particles.
- Emissions that lead to high concentrations of SO_2 generally also lead to the formation of other SOx. The largest sources of SO_2 emissions are from fossil fuel combustion at power plants and other industrial facilities.
- **How does SO_2 get in the air?**
- The largest source of SO_2 in the atmosphere is the burning of fossil fuels by power plants and other industrial facilities. Smaller sources of SO_2 emissions include: industrial processes such as extracting metal from ore; natural sources such as volcanoes; and locomotives, ships and other vehicles and heavy equipment that burn fuel with a high sulfur content.

What are the health effects of SO_2?

- Short-term exposures to SO_2 can harm the human respiratory system and make breathing difficult. People with asthma, particularly children, are sensitive to these effects of SO_2.

- SO_2 emissions that lead to high concentrations of SO_2 in the air generally also lead to the formation of other sulfur oxides (SOx). SOx can react with other compounds in the atmosphere to form small particles. These particles contribute to particulate matter (PM) pollution. Small particles may penetrate deeply into the lungs and in sufficient quantity can contribute to health problems.

What are the environmental effects of SO_2 and other sulfur oxides?

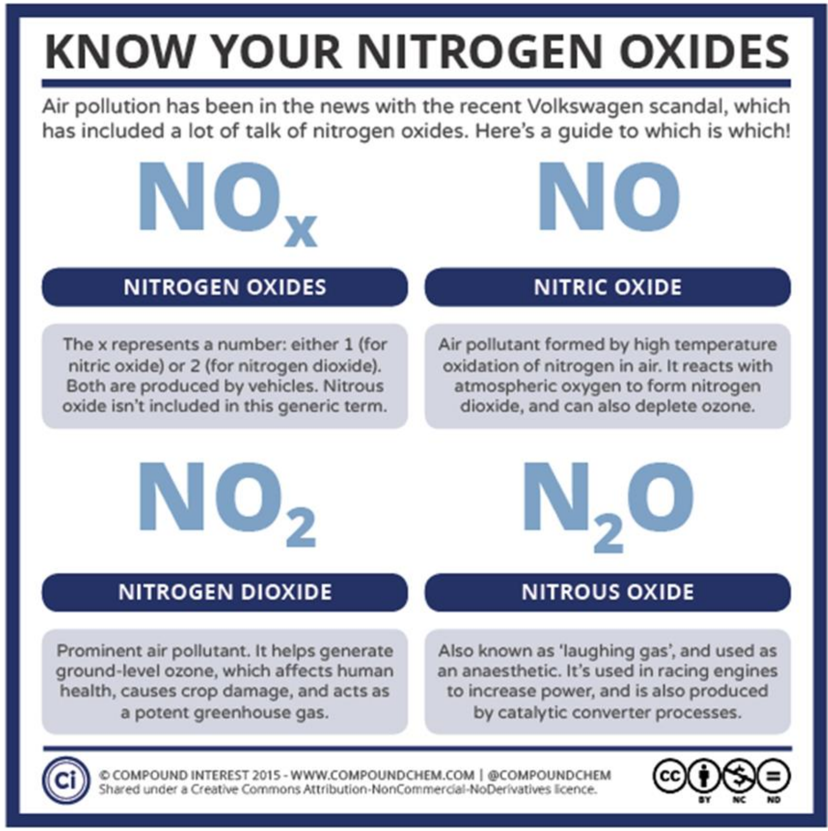
- At high concentrations, gaseous SOx can harm trees and plants by damaging foliage and decreasing growth.

- SO_2 and other sulfur oxides can contribute to acid rain which can harm sensitive ecosystems.
- **Visibility:** SO_2 and other sulfur oxides can react with other compounds in the atmosphere to form fine particles that reduce visibility (haze).
- Deposition of particles can also stain and damage stone and other materials, including culturally important objects such as statues and monuments.

What is NO_2 and how does it get in the air?

- Nitrogen Dioxide (NO_2) is one of a group of highly reactive gases known as oxides of nitrogen or nitrogen oxides (NOx). Other nitrogen oxides include nitrous oxide (N_2O) and nitric oxide (NO). NO_2 is used as the indicator for the larger group of nitrogen oxides.

- NO_2 primarily gets in the air from the burning of fuel. NO_2 forms from emissions from cars, trucks and buses, power plants, and off-road equipment.



KNOW YOUR NITROGEN OXIDES

Air pollution has been in the news with the recent Volkswagen scandal, which has included a lot of talk of nitrogen oxides. Here's a guide to which is which!

NO_x

NITROGEN OXIDES

The x represents a number: either 1 (for nitric oxide) or 2 (for nitrogen dioxide). Both are produced by vehicles. Nitrous oxide isn't included in this generic term.

NO

NITRIC OXIDE

Air pollutant formed by high temperature oxidation of nitrogen in air. It reacts with atmospheric oxygen to form nitrogen dioxide, and can also deplete ozone.

NO_2

NITROGEN DIOXIDE

Prominent air pollutant. It helps generate ground-level ozone, which affects human health, causes crop damage, and acts as a potent greenhouse gas.

N_2O

NITROUS OXIDE

Also known as 'laughing gas', and used as an anaesthetic. It's used in racing engines to increase power, and is also produced by catalytic converter processes.

Types of Nox: Prompt NOx, fuel NOx and thermal NOx

- Fuel NOx
- When nitrogen is chemically bonded to the fuel, essentially all of it converts to NOx in the exhaust. While most gaseous fuels, such as natural gas, are free of fuel bound nitrogen, it is often found in liquid and solid fuels. Untreated fuel oil can contain over 1,000 ppm of fuel bound nitrogen, which can result in over 40 ppm NOx in the exhaust just from this mechanism. Fortunately, refinery processes that remove sulfur also remove fuel bound nitrogen.

Thermal NOx

- Sometimes called Zeldovich NOx, after the Russian physicist who described the mechanisms in his 1939 doctoral dissertation. Thermal NOx only requires nitrogen in the air to combine with O and OH radicals, which are in abundant supply in a flame. $N2 + O \rightarrow NO + N$; $N + O2 \rightarrow NO + O$; $N + OH \rightarrow NO + H$

- The reactions are highly temperature (1000K) dependent, so the hotter the combustion, the more NOx is formed. The NOx formation rate is also pressure and residence time dependent. Decreasing any of these three reduces the NOx, but the exponential dependence on temperature makes reducing combustion temperature the key strategy to low NOx combustion. Fortunately, the thermal NOx formation rates are relatively slow; equilibrium concentrations are never reached in practical combustion devices.

Prompt NOx

- The presence of a second mechanism leading to NOx formation was first proposed by Charles Fenimore and was termed “prompt NOx” in 1971. When thermal and fuel NOx are eliminated, some NOx formation was still observed. Fenimore attributed this to the reaction of atmospheric nitrogen with combustion radicals occurring in the earliest stages of combustion. $CH' + N_2 \rightarrow HCN + N'$ $N' + OH \rightarrow NO + H'$ $N' + O_2 \rightarrow NO + O'$ $HCN + O_2 \rightarrow NO + CO + H'$
- Because this mechanism is not significantly temperature dependent, it becomes more important when other NOx formation mechanisms have been suppressed. Prompt NOx cannot be practically quenched because the length scales are so small. So, prompt NOx must be lived with and focus is normally placed on suppressing the other two main NOx mechanisms.

Effects of NO_2

- **Health effects**
- Breathing air with a high concentration of NO_2 can irritate airways in the human respiratory system. Such exposures over short periods can aggravate respiratory diseases, particularly asthma, leading to respiratory symptoms (such as coughing, wheezing or difficulty breathing), hospital admissions and visits to emergency rooms. Longer exposures to elevated concentrations of NO_2 may contribute to the development of asthma and potentially increase susceptibility to respiratory infections. People with asthma, as well as children and the elderly are generally at greater risk for the health effects of NO_2.
- NO_2 along with other NO_x reacts with other chemicals in the air to form both particulate matter and ozone. Both of these are also harmful when inhaled due to effects on the respiratory system.

Environmental effects

- NO2 and other NOx interact with water, oxygen and other chemicals in the atmosphere to form acid rain. Acid rain harms sensitive ecosystems such as lakes and forests.
- The nitrate particles that result from NOx make the air hazy and difficult to see though. This affects the many national parks that we visit for the view.
- NOx in the atmosphere contributes to nutrient pollution in coastal waters.

What is Acid Rain?

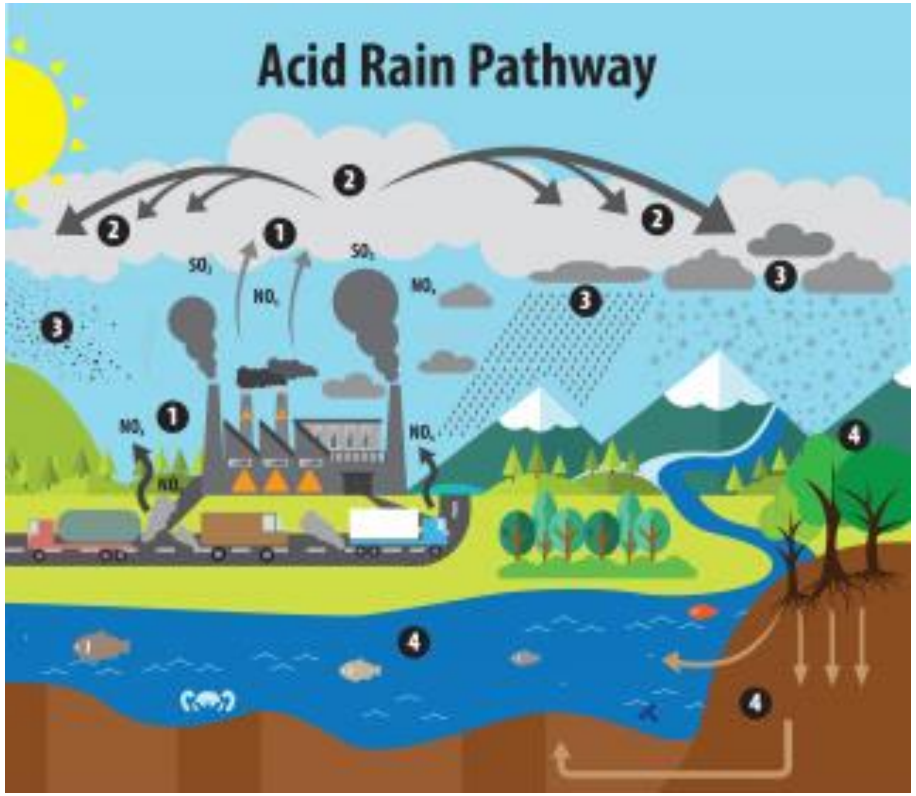
- Acid rain, or acid deposition, is a broad term that includes any form of precipitation with acidic components, such as sulfuric or nitric acid that fall to the ground from the atmosphere in wet or dry forms. This can include rain, snow, fog, hail or even dust that is acidic.

What Causes Acid Rain?

- Acid rain results when sulfur dioxide (SO_2) and nitrogen oxides (NO_X) are emitted into the atmosphere and transported by wind and air currents. The SO_2 and NO_X react with water, oxygen and other chemicals to form sulfuric and nitric acids. These then mix with water and other materials before falling to the ground.

- While a small portion of the SO_2 and NO_X that cause acid rain is from natural sources such as volcanoes, most of it comes from the burning of fossil fuels. The major sources of SO_2 and NO_X in the atmosphere are:

- Burning of fossil fuels to generate electricity. Two thirds of SO_2 and one fourth of NO_X in the atmosphere come from electric power generators.
- Vehicles and heavy equipment.
- Manufacturing, oil refineries and other industries.
- Winds can blow SO_2 and NO_X over long distances and across borders making acid rain a problem for everyone and not just those who live close to these sources.



This image illustrates the pathway for acid rain in our environment: (1) Emissions of SO_2 and NOx are released into the air, where (2) the pollutants are transformed into acid particles that may be transported long distances. (3) These acid particles then fall to the earth as wet and dry deposition (dust, rain, snow, etc.) and (4) may cause harmful effects on soil, forests, streams, and lakes.

Forms of Acid Deposition

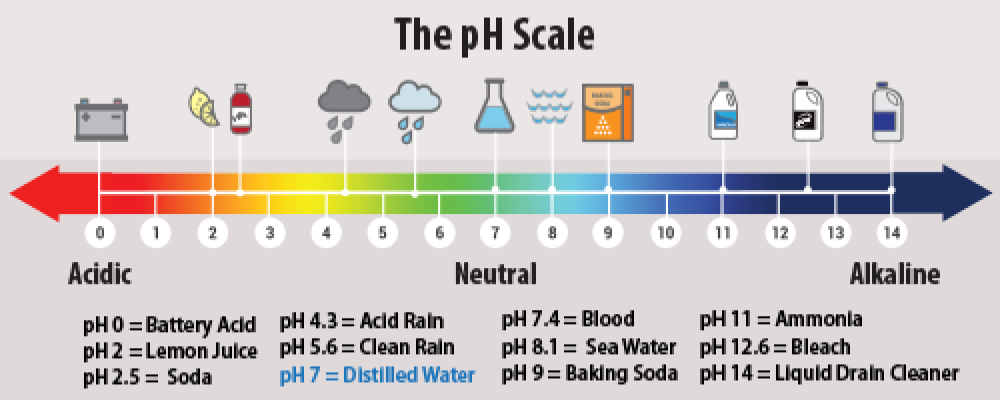
- Wet Deposition
- Wet deposition is what we most commonly think of as acid rain. The sulfuric and nitric acids formed in the atmosphere fall to the ground mixed with rain, snow, fog, or hail.

- Dry Deposition
- Acidic particles and gases can also deposit from the atmosphere in the absence of moisture as dry deposition. The acidic particles and gases may deposit to surfaces (water bodies, vegetation, buildings) quickly or may react during atmospheric transport to form larger particles that can be harmful to human health. When the accumulated acids are washed off a surface by the next rain, this acidic water flows over and through the ground, and can harm plants and wildlife, such as insects and fish.

- The amount of acidity in the atmosphere that deposits to earth through dry deposition depends on the amount of rainfall an area receives. For example, in desert areas the ratio of dry to wet deposition is higher than an area that receives several inches of rain each year.

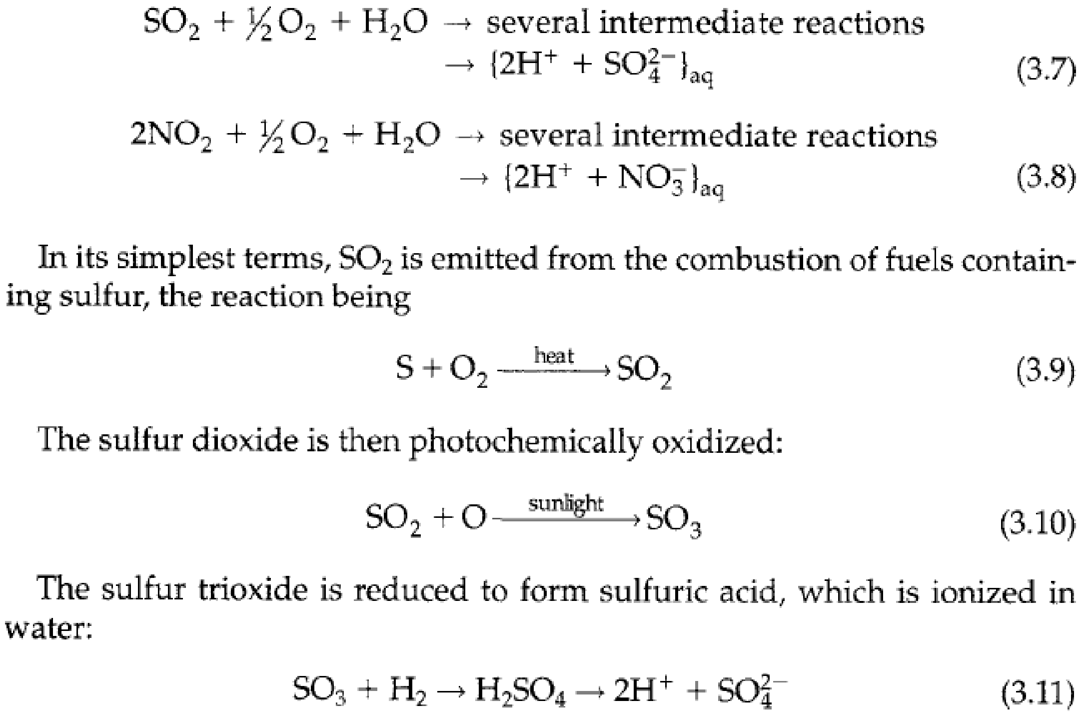
Measuring Acid Rain

- Acidity and alkalinity are measured using a pH scale for which 7.0 is neutral. The lower a substance's pH (less than 7), the more acidic it is; the higher a substance's pH (greater than 7), the more alkaline it is. Normal rain has a pH of about 5.6; it is slightly acidic because carbon dioxide (CO2) dissolves into it forming weak carbonic acid. Acid rain usually has a pH between 4.2 and 4.4.



$$CO_{2(g)} \xleftrightarrow{K_H} CO_{2(aq)} \xleftrightarrow{K_r} H_2CO_{3(aq)} \xleftrightarrow{K_{a1}} HCO^-_{3(aq)} \xleftrightarrow{K_{a2}} CO^{2-}_{3(aq)}$$

Reactions



$$SO_2 + \tfrac{1}{2}O_2 + H_2O \rightarrow \text{several intermediate reactions} \rightarrow \{2H^+ + SO_4^{2-}\}_{aq} \quad (3.7)$$

$$2NO_2 + \tfrac{1}{2}O_2 + H_2O \rightarrow \text{several intermediate reactions} \rightarrow \{2H^+ + NO_3^-\}_{aq} \quad (3.8)$$

In its simplest terms, SO_2 is emitted from the combustion of fuels containing sulfur, the reaction being

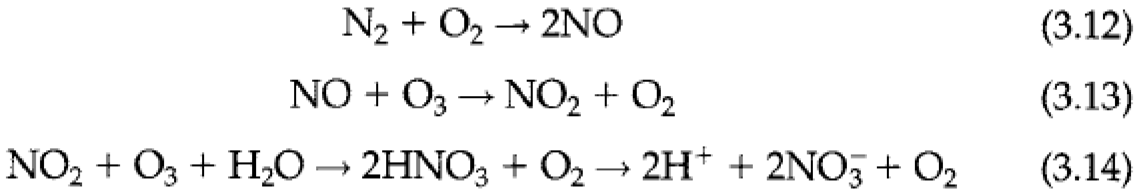
$$S + O_2 \xrightarrow{\text{heat}} SO_2 \quad (3.9)$$

The sulfur dioxide is then photochemically oxidized:

$$SO_2 + O \xrightarrow{\text{sunlight}} SO_3 \quad (3.10)$$

The sulfur trioxide is reduced to form sulfuric acid, which is ionized in water:

$$SO_3 + H_2 \rightarrow H_2SO_4 \rightarrow 2H^+ + SO_4^{2-} \quad (3.11)$$



$$N_2 + O_2 \rightarrow 2NO \quad (3.12)$$

$$NO + O_3 \rightarrow NO_2 + O_2 \quad (3.13)$$

$$NO_2 + O_3 + H_2O \rightarrow 2HNO_3 + O_2 \rightarrow 2H^+ + 2NO_3^- + O_2 \quad (3.14)$$

OZONE O_3

- Tropospheric or ground-level ozone – what we breathe – is formed primarily from photochemical reactions between two major classes of air pollutants, volatile organic compounds (VOC) and nitrogen oxides (NOx). These reactions have traditionally been viewed as depending upon the presence of heat and sunlight, resulting in higher ambient ozone concentrations in summer months. Within the last decade, however, high ozone concentrations have also been observed under specific circumstances in cold months, where a few high elevation areas in the Western U.S. with high levels of local VOC and NOx emissions have formed ozone when snow is on the ground and temperatures are near or below freezing. Ozone contributes to what we typically experience as "smog" or haze, which still occurs most frequently in the summertime, but can occur throughout the year in some southern and mountain regions.

- Although some stratospheric ozone is transported into the troposphere, and some VOC and NOx occur naturally, the majority of ground-level ozone is the result of reactions of man-made VOC and NOx. Significant sources of VOC are chemical plants, gasoline pumps, oil-based paints, autobody shops, and print shops. Nitrogen oxides result primarily from high temperature combustion. Significant sources are power plants, industrial furnaces and boilers, and motor vehicles.

Are high ambient ozone concentrations found only in heavily urbanized areas?

- Many people mistakenly believe that tropospheric ozone concentrations are high only in major urban areas, but high ambient ozone concentrations can and do occur anywhere. Ozone formation is not limited to big cities. It is also formed in smaller cities and it is transported hundreds of miles downwind from where it is created to affect ambient air quality in other urban and rural areas.
- Where ozone is formed, peak concentrations usually occur during afternoon hours, when sunlight is the most intense. However, areas downwind of major sources of VOC and NOx may experience ozone peaks in the afternoon and evening, after wind has carried ozone and its VOC and NOx precursors many miles from their sources. Thus, high ozone concentrations can occur in remote areas and at various times of day, including during the early evening or night.

How does atmospheric ozone affect human health?

- Ozone has two properties of interest to human health. First, it absorbs UV light, reducing human exposure to harmful UV radiation that causes skin cancer and cataracts. Second, when inhaled, it reacts chemically with many biological molecules in the respiratory tract, leading to a number of adverse health effects.
- Breathing ground-level ozone can result in a number of health effects that are observed in broad segments of the population. Some of these effects include:
- Induction of respiratory symptoms
- Decrements in lung function
- Inflammation of airways
- Respiratory symptoms can include:
- Coughing
- Throat irritation
- Pain, burning, or discomfort in the chest when taking a deep breath
- Chest tightness, wheezing, or shortness of breath
- In addition to these effects, evidence from observational studies strongly indicates that higher daily ozone concentrations are associated with increased asthma attacks, increased hospital admissions, increased daily mortality, and other markers of morbidity. The consistency and coherence of the evidence for effects upon asthmatics suggests that ozone can make asthma symptoms worse and can increase sensitivity to asthma triggers.

What is CO?

- CO is a colorless, odorless gas that can be harmful when inhaled in large amounts. CO is released when something is burned. The greatest sources of CO to outdoor air are cars, trucks and other vehicles or machinery that burn fossil fuels. A variety of items in your home such as unvented kerosene and gas space heaters, leaking chimneys and furnaces, and gas stoves also release CO and can affect air quality indoors.

What are the harmful effects of CO?

- Breathing air with a high concentration of CO reduces the amount of oxygen that can be transported in the blood stream to critical organs like the heart and brain.

- At very high levels, which are possible indoors or in other enclosed environments, CO can cause dizziness, confusion, unconsciousness and death.

- Very high levels of CO are not likely to occur outdoors. However, when CO levels are elevated outdoors, they can be of particular concern for people with some types of heart disease. These people already have a reduced ability for getting oxygenated blood to their hearts in situations where the heart needs more oxygen than usual. They are especially vulnerable to the effects of CO when exercising or under increased stress. In these situations, short-term exposure to elevated CO may result in reduced oxygen to the heart accompanied by chest pain also known as angina.

Indoor sources of CO include:

- unvented kerosene and gas space heaters
- leaking chimneys and furnaces
- back-drafting from furnaces, gas water heaters, wood stoves and fireplaces
- gas stoves
- generators and other gasoline powered equipment
- automobile exhaust from attached garages
- tobacco smoke
- auto, truck, or bus exhaust from attached garages, nearby roads, or parking areas
- incomplete oxidation during combustion in gas ranges, and unvented gas or kerosene heaters
- worn or poorly adjusted and maintained combustion devices (e.g., boilers, furnaces)
- if the flue is improperly sized, blocked or disconnected
- if the flue is leaking

Health Effects Associated with Carbon Monoxide

- **At low concentrations:** fatigue in healthy people ,chest pain in people with heart disease,
- **At moderate concentrations**: Angina, impaired vision, reduced brain function
- **At higher concentrations:** impaired vision and coordination, headaches, dizziness, confusion, nausea, flu-like symptoms that clear up after leaving home, fatal at very high concentrations
- Acute effects are due to the formation of **carboxyhemoglobin** in the blood, which inhibits oxygen intake.
- At low concentrations, fatigue in healthy people and chest pain in people with heart disease. At higher concentrations, impaired vision and coordination; headaches; dizziness; confusion; nausea. Can cause flu-like symptoms that clear up after leaving home. Fatal at very high concentrations. Acute effects are due to the formation of carboxyhemoglobin in the blood, which inhibits oxygen intake. At moderate concentrations, angina, impaired vision, and reduced brain function may result. At higher concentrations, CO exposure can be fatal.
- **Levels in Homes**
- Average levels in homes without gas stoves vary from 0.5 to 5 parts per million (ppm). Levels near properly adjusted gas stoves are often 5 to 15 ppm and those near poorly adjusted stoves may be 30 ppm or higher.

Lead –Pb
How does lead get in the air?

- Lead (Pb) is an elemental heavy metal found naturally in the environment as well as in manufactured products. Lead can be released directly into the air, as suspended particles. Historic major sources of lead air emissions were motor vehicles and industrial sources.
- Sources of lead emissions vary from one area to another. At the national level, major sources of lead in the air are ore and metals processing and piston-engine aircraft operating on leaded aviation fuel. Other sources are waste incinerators, utilities, and lead-acid battery manufacturers. The highest air concentrations of lead are usually found near lead smelters.

- As a result of EPA's regulatory efforts including the removal of lead from motor vehicle gasoline, levels of lead in the air decreased by 98 percent between 1980 and 2014.

What are the effects of lead on human health?

- Once taken into the body, lead distributes throughout the body in the blood and is accumulated in the bones. Depending on the level of exposure, lead can adversely affect the nervous system, kidney function, immune system, reproductive and developmental systems and the cardiovascular system. Lead exposure also affects the oxygen carrying capacity of the blood. The lead effects most likely to be encountered in current populations are neurological effects in children. Infants and young children are especially sensitive to lead exposures, which may contribute to behavioral problems, learning deficits and lowered IQ.

What are the effects of lead on ecosystems?

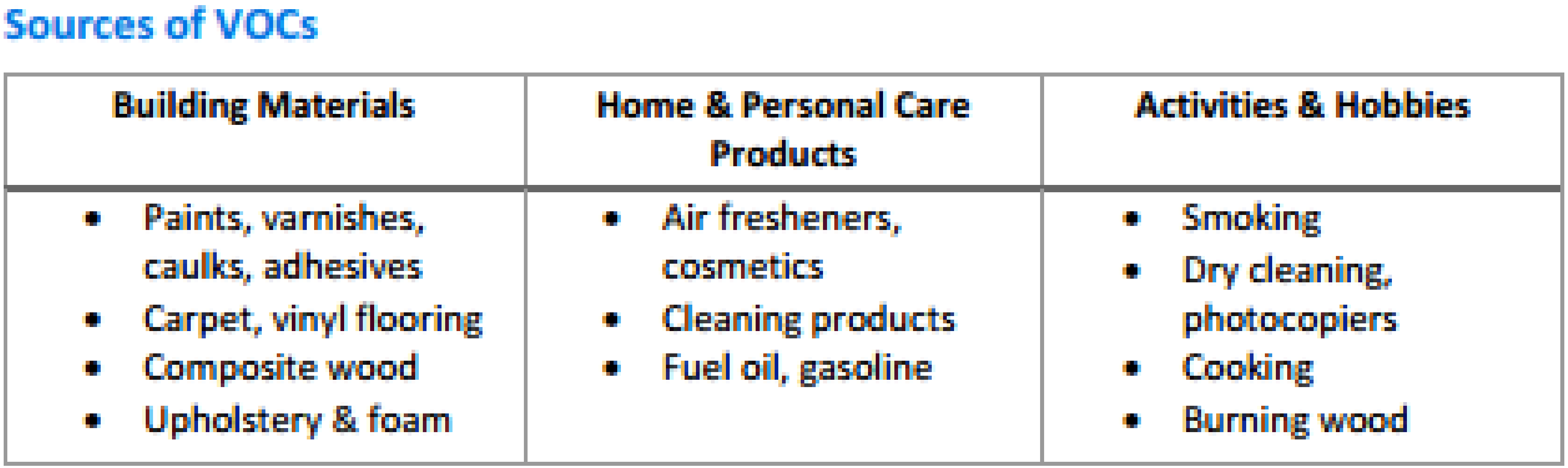
- Lead is persistent in the environment and can be added to soils and sediments through deposition from sources of lead air pollution. Other sources of lead to ecosystems include direct discharge of waste streams to water bodies and mining. Elevated lead in the environment can result in decreased growth and reproduction in plants and animals, and neurological effects in vertebrates.

Volatile organic compounds:

VOCs are often divided into the separate categories of methane (CH_4) and non-methane (NMVOCs).

Methane is an extremely efficient greenhouse gas which contributes to enhanced global warming.

Within the NMVOCs, the aromatic compounds benzene, toluene and xylene and furan, dioxin are suspected carcinogens and may lead to leukemia through prolonged exposure.



Sources of VOCs

Building Materials	Home & Personal Care Products	Activities & Hobbies
• Paints, varnishes, caulks, adhesives • Carpet, vinyl flooring • Composite wood • Upholstery & foam	• Air fresheners, cosmetics • Cleaning products • Fuel oil, gasoline	• Smoking • Dry cleaning, photocopiers • Cooking • Burning wood

Hazardous Air Pollutants

- **Hazardous air pollutants**, also known as **toxic air pollutants** or **air** toxics, are those **pollutants** that cause or may cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental and ecological effects.

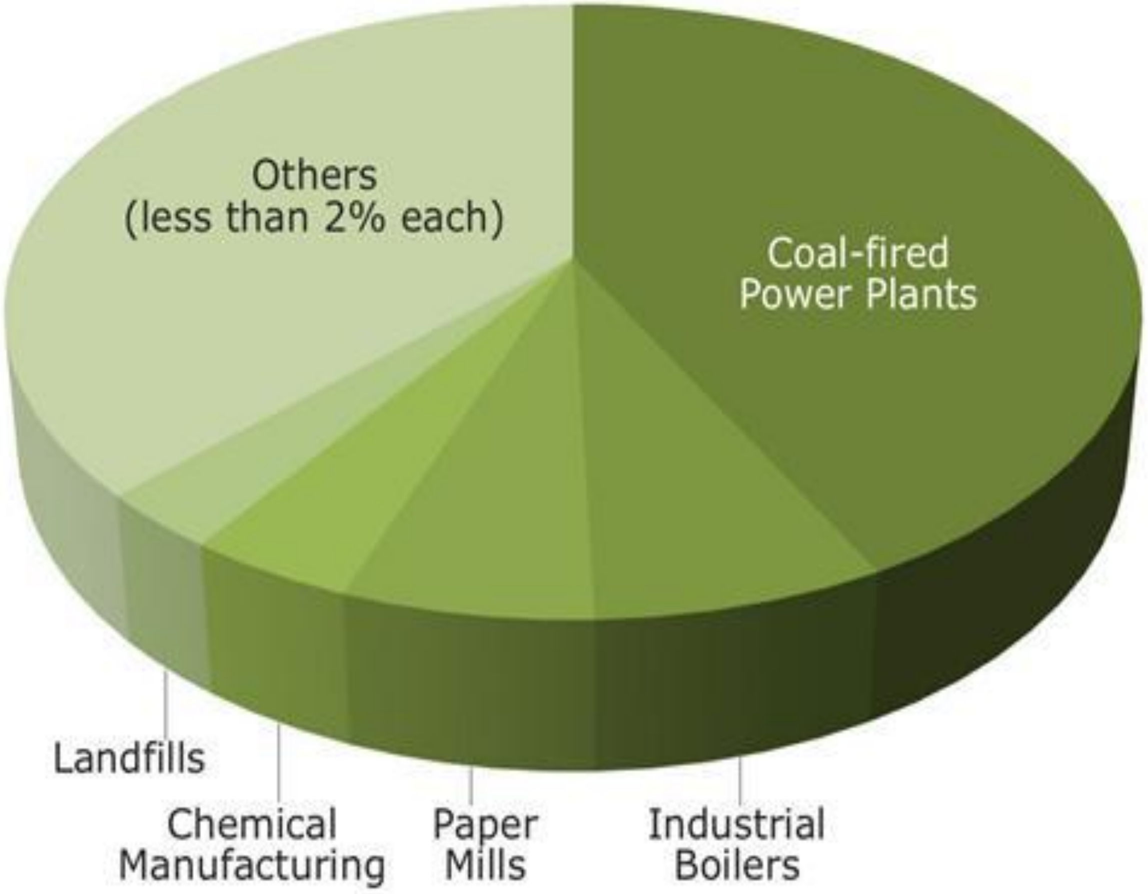
- In addition to exposure from breathing air toxics, some toxic air pollutants such as mercury can deposit onto soils or surface waters, where they are taken up by plants and ingested by animals and are eventually magnified up through the food chain. Like humans, animals may experience health problems if exposed to enough quantities of air toxics over time.

- **Sources**
- Most air toxics originate from human-made sources, including mobile sources (e.g., cars, trucks, buses) and stationary sources (e.g., factories, refineries, power plants), as well as indoor sources (e.g., some building materials and cleaning solvents). Some air toxics are also released from natural sources such as volcanic eruptions and forest fires.
-

- **List of Hazardous Air Pollutants with Modifications**
- Under the Clean Air Act, EPA is required to regulate emissions of hazardous air pollutants. This original list included 189 pollutants. Since 1990, EPA has modified the list through rulemaking to include 187 hazardous air pollutants.
- https://dep.wv.gov/daq/Air%20Toxics/Pages/HazardousAirPollutants(HAPs)List.aspx

Examples of toxic air pollutants include benzene, which is found in gasoline;
perchloroethylene, which is emitted from some dry cleaning facilities; and
methylene chloride, which is used as a solvent and paint stripper by a number of industries.
Examples of other listed air toxics include dioxin, asbestos, toluene, and metals such as cadmium, mercury, chromium, and lead compounds.

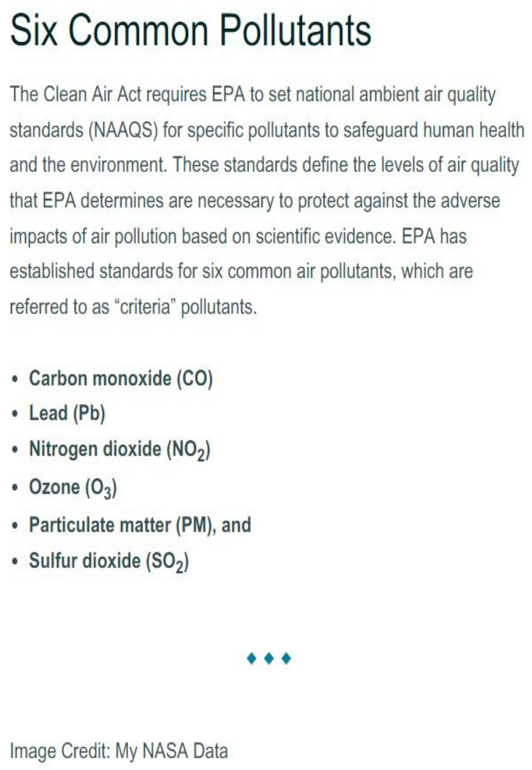
Coal-fired Power Plants are a Major Source of Hazardous Air Pollutant Emissions



Source: U.S. EPA, National Emissions Inventory, 2007[2]

Criteria air pollutants

- Criteria air pollutants are air pollutants for which acceptable levels of exposure can be determined and for which an ambient air quality standard has been set. Examples include: ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, and PM10 and PM2. 5.



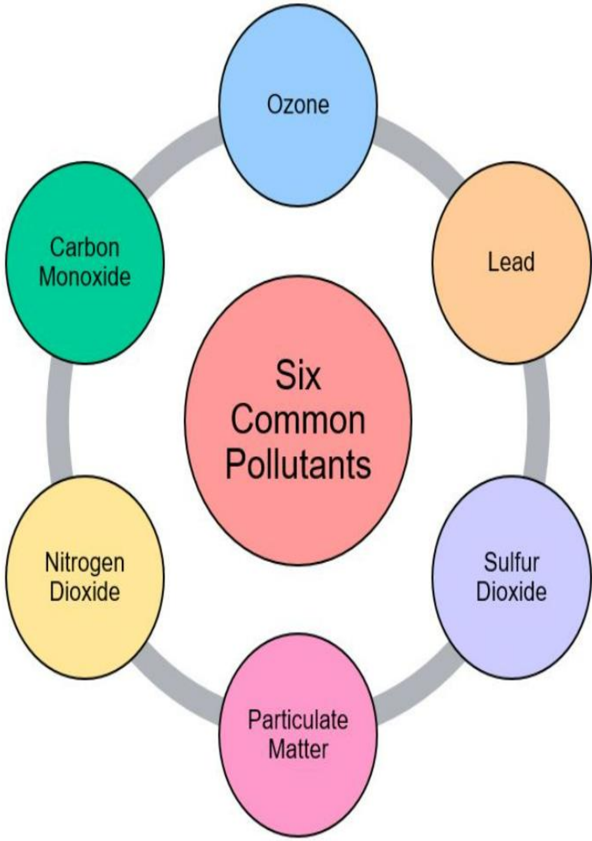
Six Common Pollutants

The Clean Air Act requires EPA to set national ambient air quality standards (NAAQS) for specific pollutants to safeguard human health and the environment. These standards define the levels of air quality that EPA determines are necessary to protect against the adverse impacts of air pollution based on scientific evidence. EPA has established standards for six common air pollutants, which are referred to as "criteria" pollutants.

- **Carbon monoxide (CO)**
- **Lead (Pb)**
- **Nitrogen dioxide (NO_2)**
- **Ozone (O_3)**
- **Particulate matter (PM), and**
- **Sulfur dioxide (SO_2)**

◆ ◆ ◆

Image Credit: My NASA Data



Effects of air pollution

Effects on human health

Effects on vegetation

Effects on materials/properties

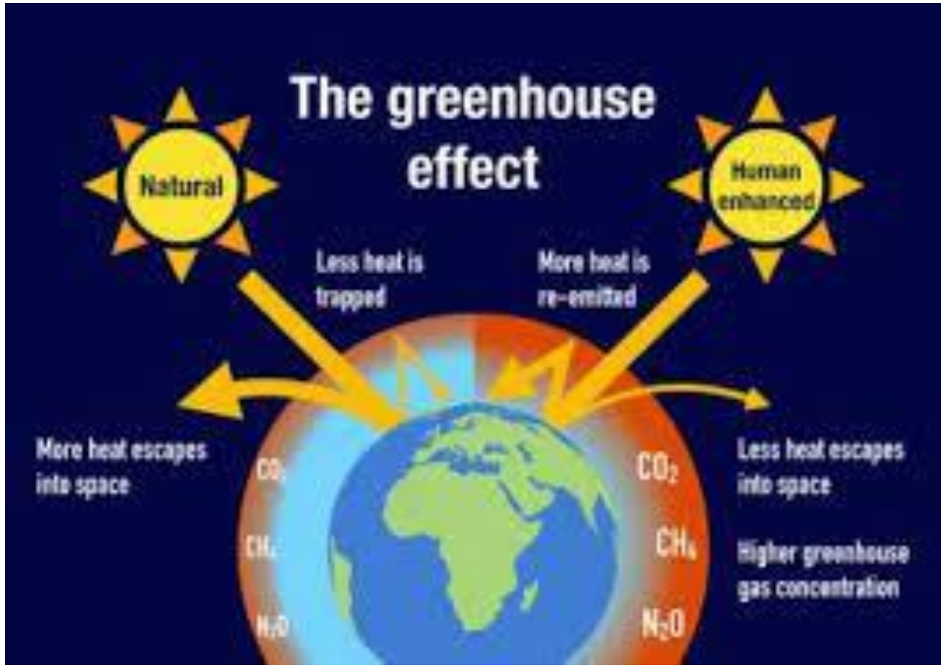
EFFECTS OF AIR POLLUTION

POLLUTANT	SOURCES	EFFECTS			
		Human	Plant	Properties or materials	
Sulphur dioxide	• Coal and oil(fuel) combustion • Chemical and metallurgical industries	• Affects mucous membrane • Bronchospasms • Lungs	• Bleaching • Necrosis • Skeleton-sized leaves	• Acid rain • Surface damage • Leaching -	
Nitrogen dioxide	• Vehicles • Combustion at industries • Chemical industries	• Eye and nasal irritation • Pulmonary problems	• Suppressed growth • Leaf collapse		
Hydrogen sulphide	• Petroleum refineries • Chemical industries • Bituminous fuels	• Nausea • Eye and throat irritation	-	• Odour nuisances • Darkening of surfaces • Dis-colouration	

4	**Carbon monoxide**	**Combustion (coal, gasoline, TPP, automobiles, refuse burning)** **Chemical, Metallurgical and Mineral processing industries**	**Affects CNS** **Heart attack** **Reduces O_2 carrying capacity of blood**	-	-
5	Hydrogen sulphide	Blast furnace Fumigation Chemical Production Metal plating	Affect nerve cells and vision Dry throat Headache	Injures vegetation	-
6	Ammonia	Chemical processes (paper mills, cement, fertilizers etc.) Explosives	Respiratory diseases	Toxic	-
7	Phosgene or Carbonyl chloride	Chemical processes Dye making	Cough Fatal pulmonary edema	Toxic at higher conc.	-
8	Aldehydes, fats, glycerols	Oil combustion Incomplete oxidation of fuels and lubricators	Respiratory and eye problems	Growth retardation Curling Chlorosis	-
9	Arsines	Processes involving metals/acids containing arsenic	Damages RBC Affects kidney Jaundice	-	-

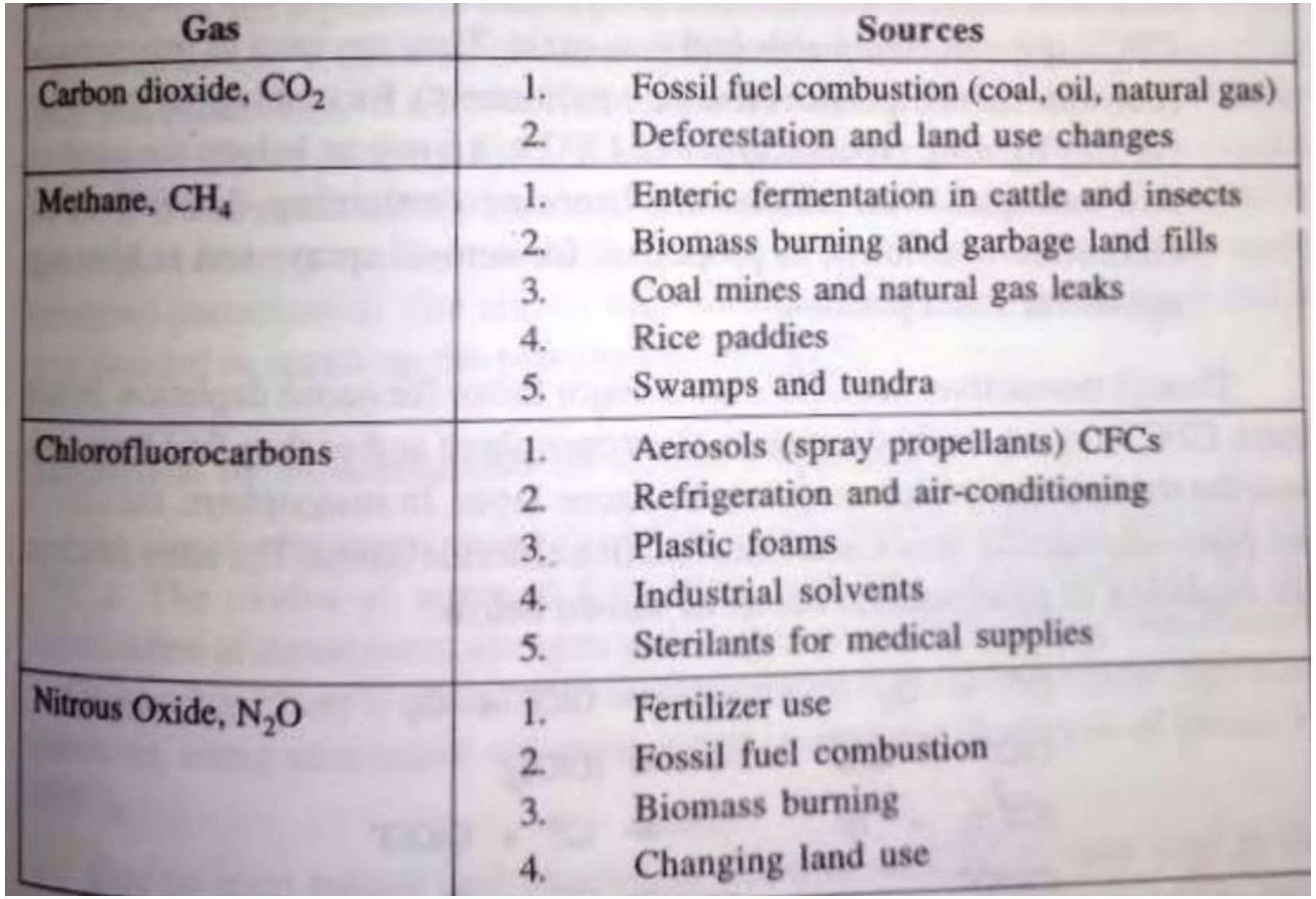
10	**Suspended Particles (ash, smog, soot, smoke etc)**	**All combustion** **Major industries (steel, paper, chemical, cement, all manufacturing process)**	**Asthma** **Heart Diseases** **Lung problems** **Cancer** **Irritation**	**Affects leaf characteristics** **Invisible injuries**	**Corrosion** **Leaching**
11	Lead	Automobiles Smelters	Affects- Gastro-intestine, liver and kidney Fertility and pregnancy, Brain	Toxic	White lead affects surface
12	Ozone	Combustion products + sunlight = Ozone(smog)	Respiratory irritant Aggravates asthma and other heart and lungs problems	Premature aging Suppressed growth Leaf collapse	Fading Cracking Weakening

Global warming

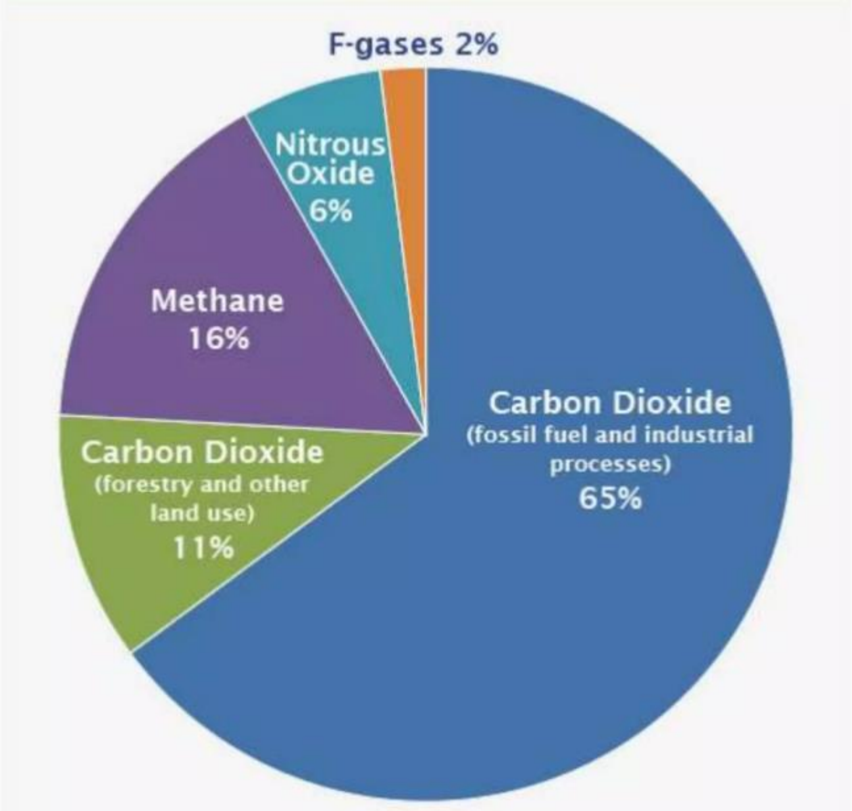


- Without greenhouse gases, the average temperature of Earth's surface would be about **-18°C (0 °F)**, rather than the present average of **15°C**.

Greenhouse gases



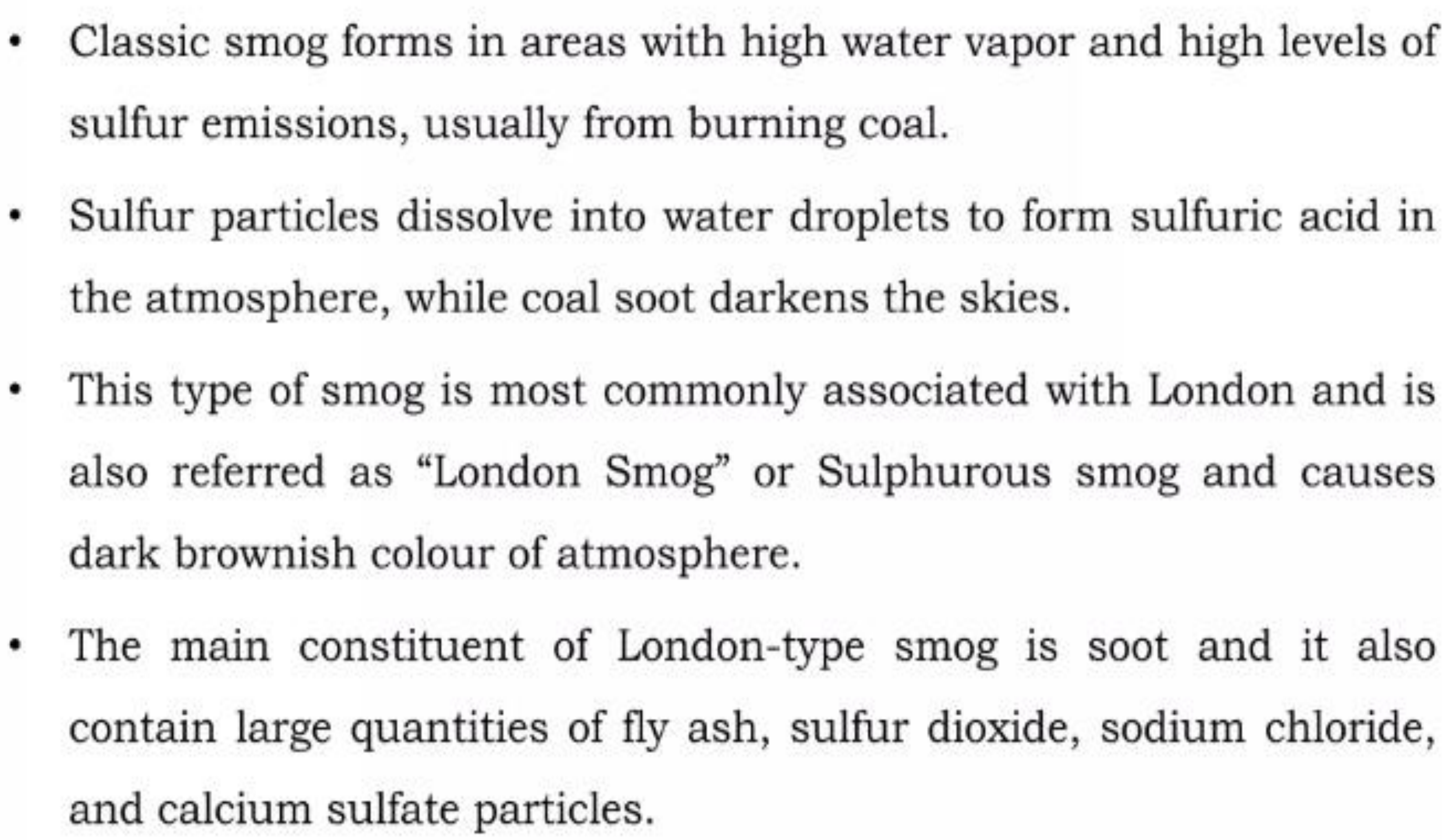
Gas	Sources
Carbon dioxide, CO_2	1. Fossil fuel combustion (coal, oil, natural gas) 2. Deforestation and land use changes
Methane, CH_4	1. Enteric fermentation in cattle and insects 2. Biomass burning and garbage land fills 3. Coal mines and natural gas leaks 4. Rice paddies 5. Swamps and tundra
Chlorofluorocarbons	1. Aerosols (spray propellants) CFCs 2. Refrigeration and air-conditioning 3. Plastic foams 4. Industrial solvents 5. Sterilants for medical supplies
Nitrous Oxide, N_2O	1. Fertilizer use 2. Fossil fuel combustion 3. Biomass burning 4. Changing land use



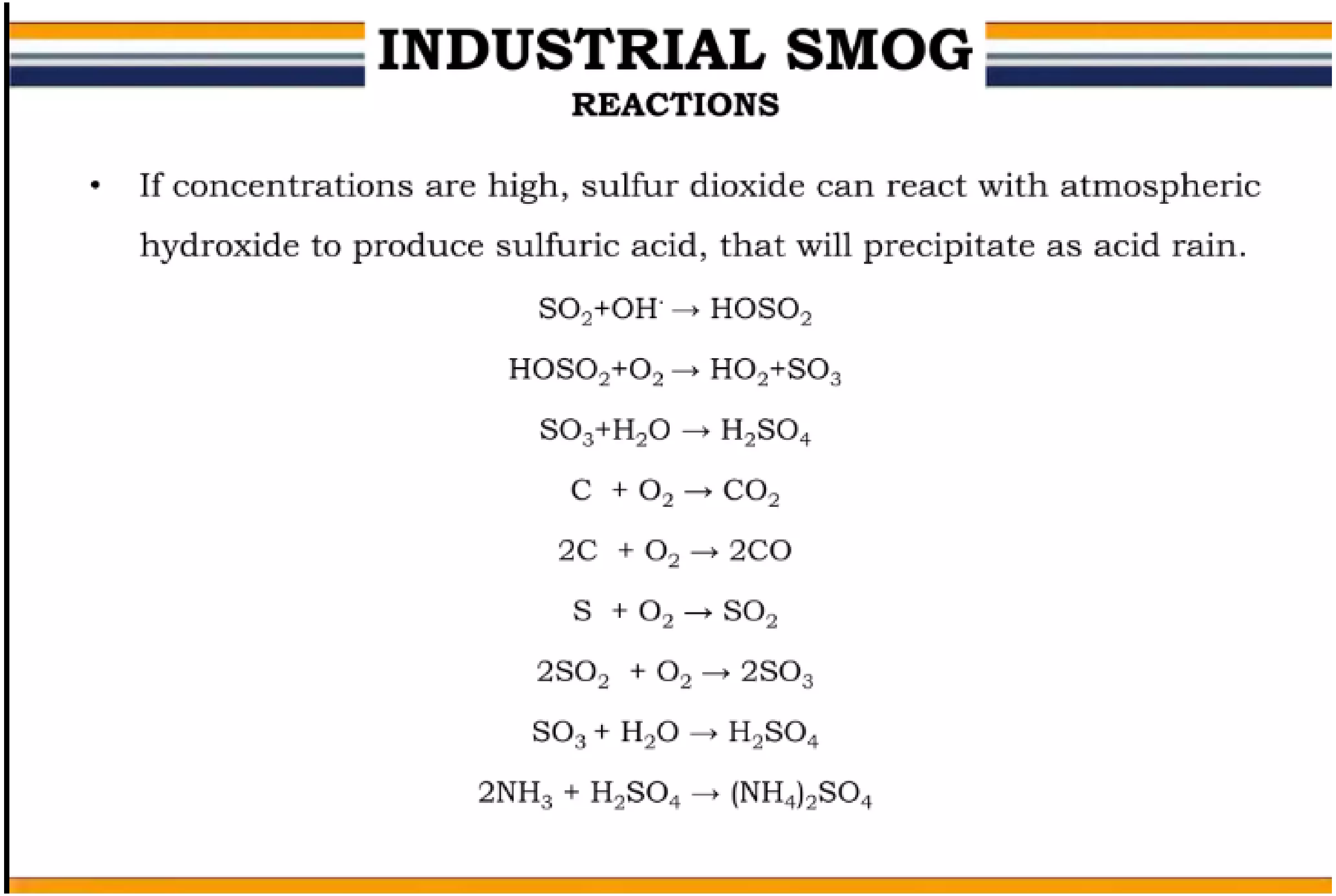
Smog

- PHOTOCHEMICAL SMOG Photochemical smog is a mixture of pollutants that are formed when nitrogen oxides and volatile organic compounds (VOCs) react to sunlight, creating a brown haze above cities. It tends to occur more often in summer, because that is when we have the most sunlight.
-
- REDUCING SMOG or INDUSTRIAL SMOG
-
- Reducing smog refers to air pollution episodes characterized by high concentrations of sulfur dioxide and smoke (or particulate aerosols). Reducing smog is also sometimes called London-type smog, because of famous incidents that occurred in that city during the 1950s.

INDUSTRIAL SMOG



- Classic smog forms in areas with high water vapor and high levels of sulfur emissions, usually from burning coal.
- Sulfur particles dissolve into water droplets to form sulfuric acid in the atmosphere, while coal soot darkens the skies.
- This type of smog is most commonly associated with London and is also referred as “London Smog” or Sulphurous smog and causes dark brownish colour of atmosphere.
- The main constituent of London-type smog is soot and it also contain large quantities of fly ash, sulfur dioxide, sodium chloride, and calcium sulfate particles.



INDUSTRIAL SMOG

REACTIONS

- If concentrations are high, sulfur dioxide can react with atmospheric hydroxide to produce sulfuric acid, that will precipitate as acid rain.

$$SO_2 + OH^{\cdot} \rightarrow HOSO_2$$

$$HOSO_2 + O_2 \rightarrow HO_2 + SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

$$C + O_2 \rightarrow CO_2$$

$$2C + O_2 \rightarrow 2CO$$

$$S + O_2 \rightarrow SO_2$$

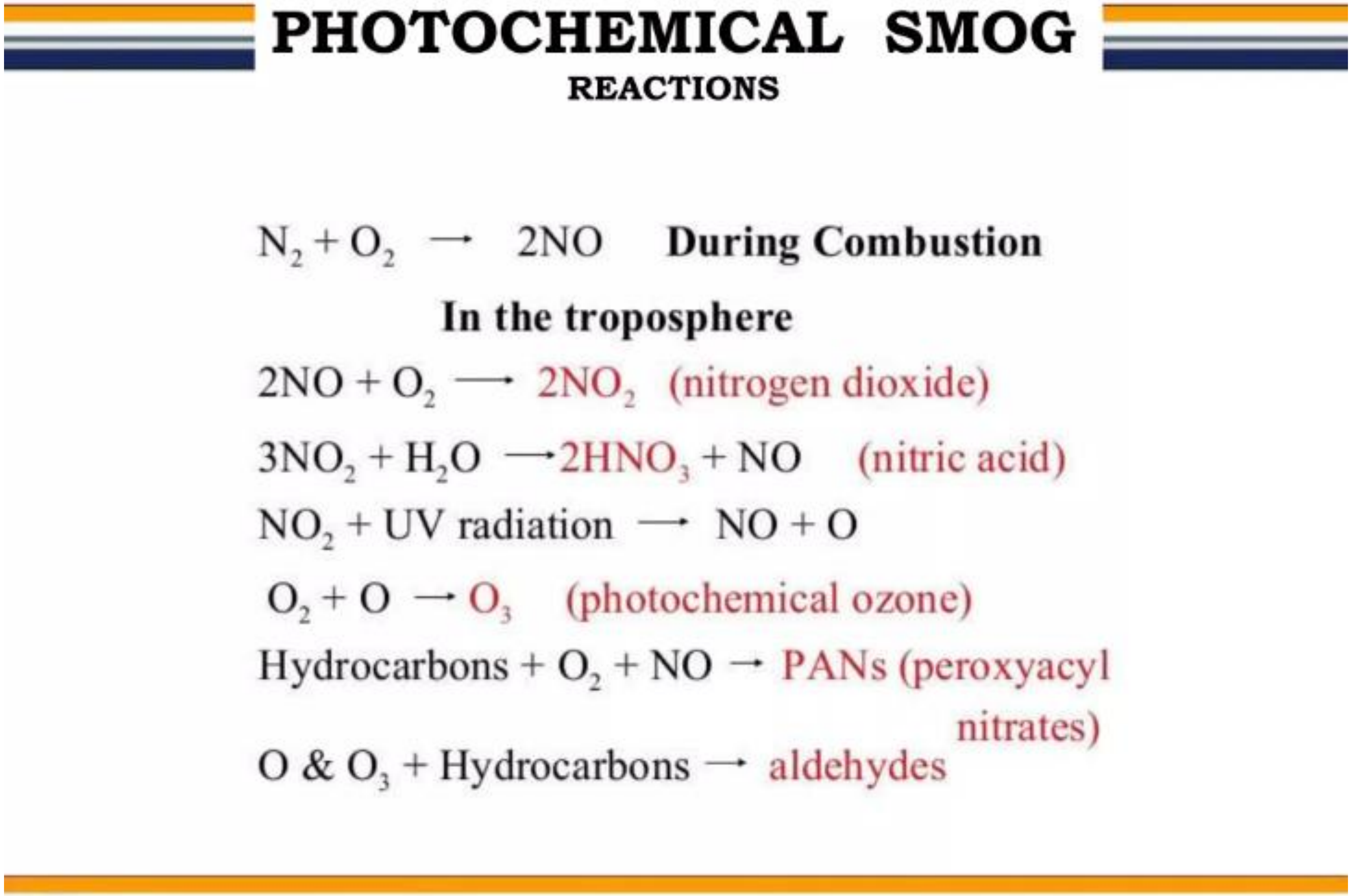
$$2SO_2 + O_2 \rightarrow 2SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

$$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$$

PHOTOCHEMICAL SMOG

- It is the haze created when sunlight reacts with primary pollutants like nitrogen oxides and volatile organic compounds that can be found in fossil fuel emissions from automobiles, factories, and power plants.
- These reactions create secondary pollutants and are characterized by high concentrations of a large variety of pollutants, such as nitrogen oxides, O_3, CO, hydrocarbons, aldehydes (and other materials that are eye irritants), and sometimes sulfuric acid as well.
- Photochemical smog is a problem in large cities around the world and is best exemplified by cities like Los Angeles, Mexico city etc.



PHOTOCHEMICAL SMOG

REACTIONS

$N_2 + O_2 \rightarrow 2NO$ **During Combustion**

In the troposphere

$2NO + O_2 \rightarrow 2NO_2$ (nitrogen dioxide)

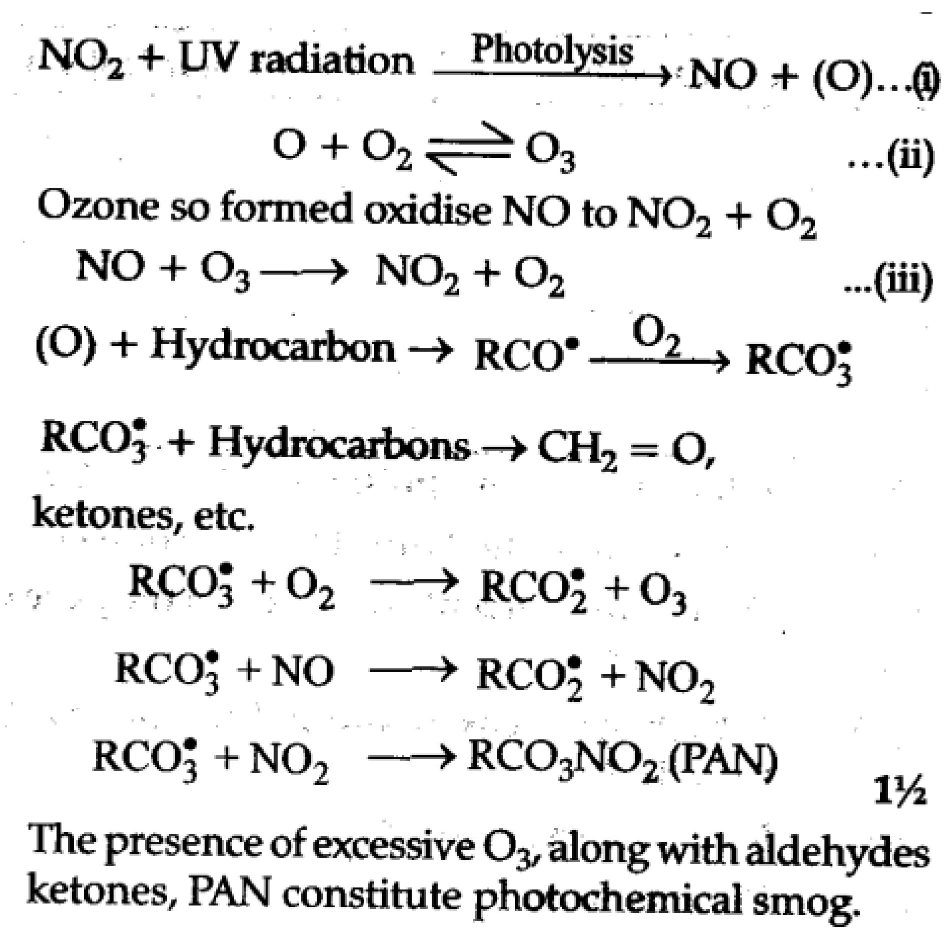
$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$ (nitric acid)

NO_2 + UV radiation $\rightarrow NO + O$

$O_2 + O \rightarrow O_3$ (photochemical ozone)

Hydrocarbons + O_2 + NO → PANs (peroxyacyl nitrates)

O & O_3 + Hydrocarbons → aldehydes



NO_2 + UV radiation $\xrightarrow{\text{Photolysis}}$ NO + (O)…(i)

$O + O_2 \rightleftharpoons O_3$ …(ii)

Ozone so formed oxidise NO to $NO_2 + O_2$

$NO + O_3 \longrightarrow NO_2 + O_2$ ...(iii)

(O) + Hydrocarbon → $RCO^{\bullet} \xrightarrow{O_2} RCO_3^{\bullet}$

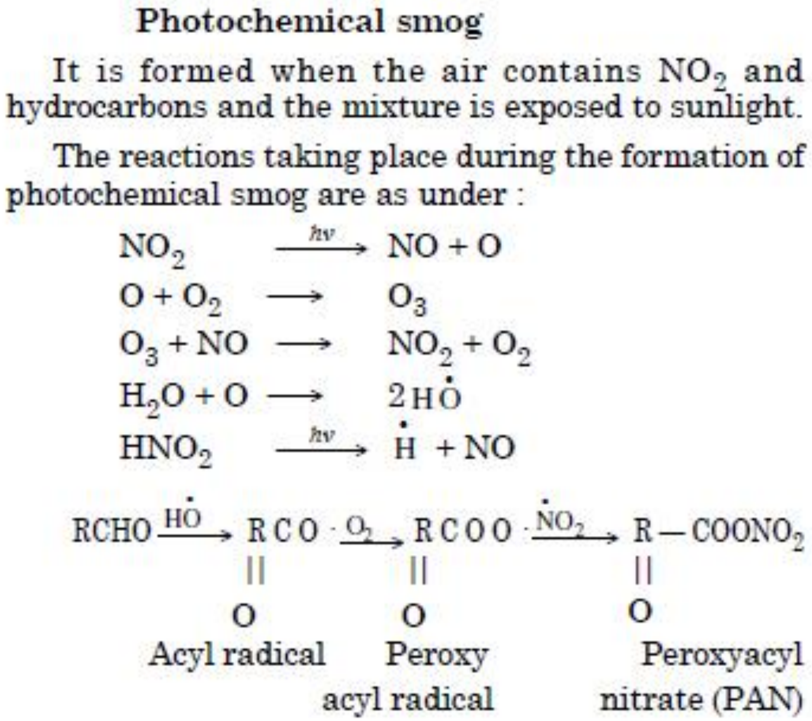
$RCO_3^{\bullet}$ + Hydrocarbons → $CH_2 = O$, ketones, etc.

$RCO_3^{\bullet} + O_2 \longrightarrow RCO_2^{\bullet} + O_3$

$RCO_3^{\bullet} + NO \longrightarrow RCO_2^{\bullet} + NO_2$

$RCO_3^{\bullet} + NO_2 \longrightarrow RCO_3NO_2$ (PAN) 1½

The presence of excessive O_3, along with aldehydes ketones, PAN constitute photochemical smog.



Photochemical smog

It is formed when the air contains NO_2 and hydrocarbons and the mixture is exposed to sunlight.

The reactions taking place during the formation of photochemical smog are as under :

$NO_2 \xrightarrow{h\nu} NO + O$

$O + O_2 \longrightarrow O_3$

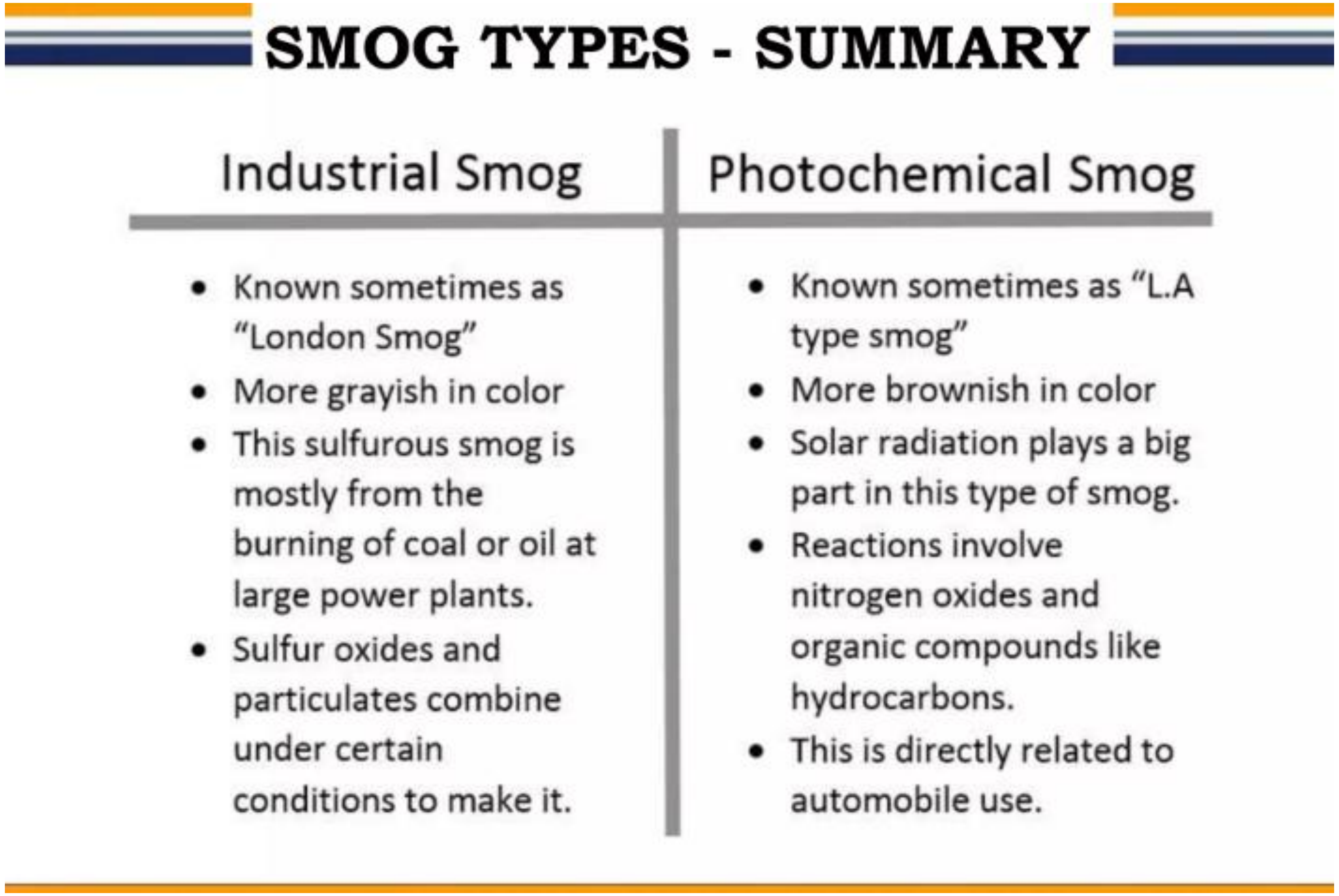
$O_3 + NO \longrightarrow NO_2 + O_2$

$H_2O + O \longrightarrow 2\,H\dot{O}$

$HNO_2 \xrightarrow{h\nu} \dot{H} + NO$

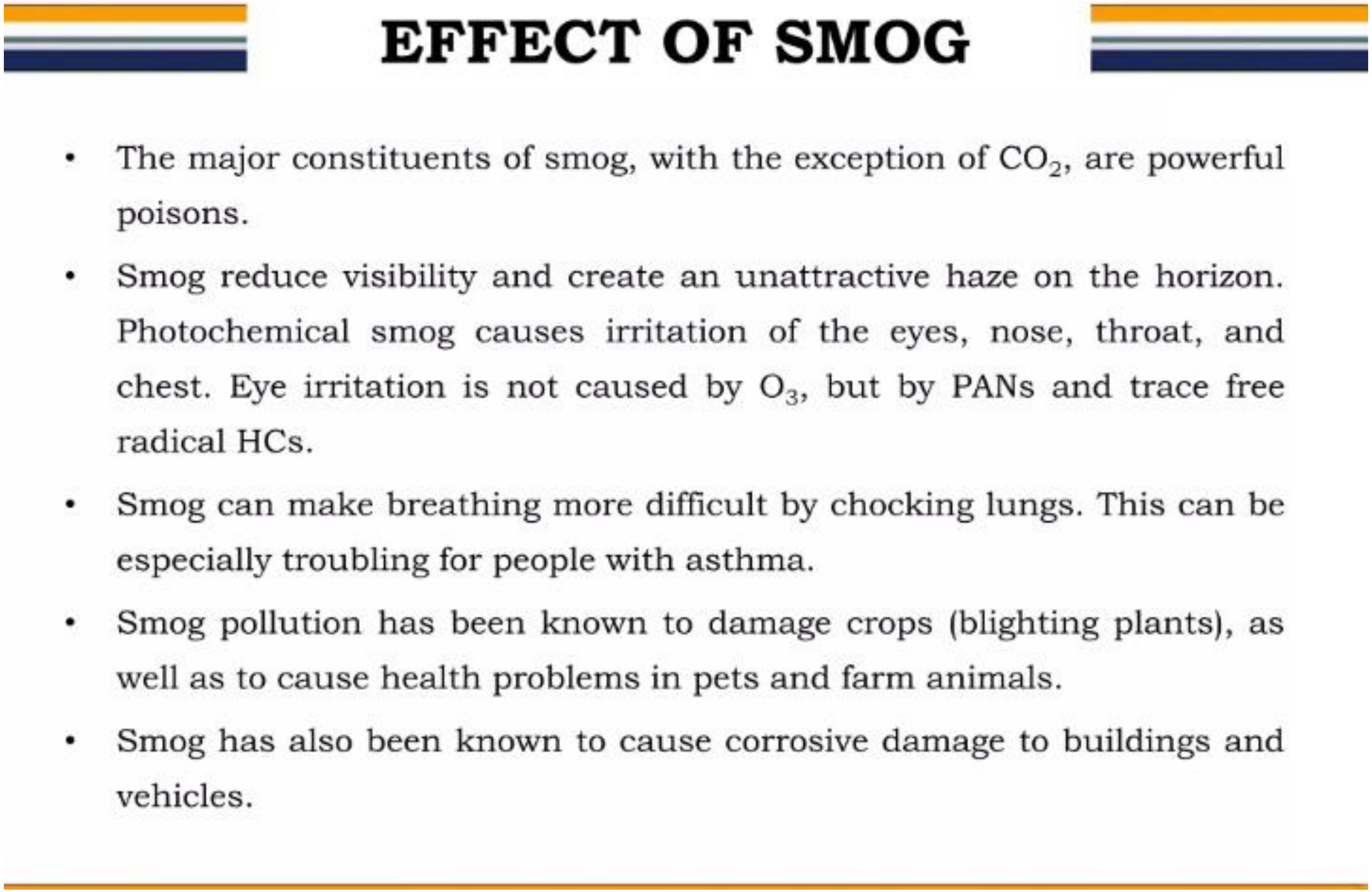
$$RCHO \xrightarrow{H\dot{O}} \underset{\substack{\Vert \\ O}}{RCO}\cdot \xrightarrow{O_2} \underset{\substack{\Vert \\ O}}{RCOO}\cdot \xrightarrow{\dot{N}O_2} \underset{\substack{\Vert \\ O}}{R-COONO_2}$$

Acyl radical — Peroxy acyl radical — Peroxyacyl nitrate (PAN)



SMOG TYPES - SUMMARY

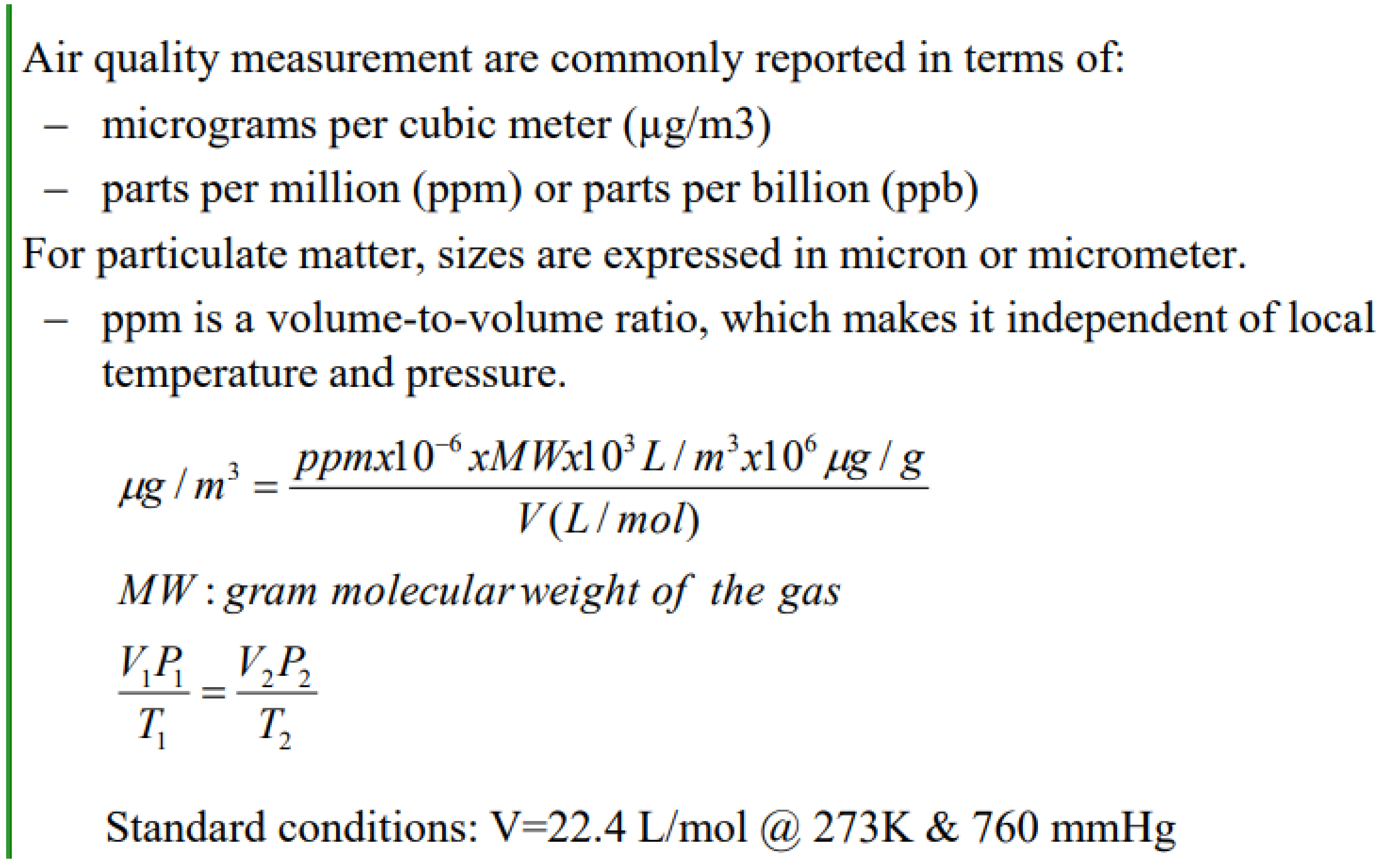
Industrial Smog	Photochemical Smog
• Known sometimes as "London Smog" • More grayish in color • This sulfurous smog is mostly from the burning of coal or oil at large power plants. • Sulfur oxides and particulates combine under certain conditions to make it.	• Known sometimes as "L.A type smog" • More brownish in color • Solar radiation plays a big part in this type of smog. • Reactions involve nitrogen oxides and organic compounds like hydrocarbons. • This is directly related to automobile use.



EFFECT OF SMOG

- The major constituents of smog, with the exception of CO_2, are powerful poisons.
- Smog reduce visibility and create an unattractive haze on the horizon. Photochemical smog causes irritation of the eyes, nose, throat, and chest. Eye irritation is not caused by O_3, but by PANs and trace free radical HCs.
- Smog can make breathing more difficult by chocking lungs. This can be especially troubling for people with asthma.
- Smog pollution has been known to damage crops (blighting plants), as well as to cause health problems in pets and farm animals.
- Smog has also been known to cause corrosive damage to buildings and vehicles.

Units of air pollution



Air quality measurement are commonly reported in terms of:

- micrograms per cubic meter (µg/m3)
- parts per million (ppm) or parts per billion (ppb)

For particulate matter, sizes are expressed in micron or micrometer.

- ppm is a volume-to-volume ratio, which makes it independent of local temperature and pressure.

$$\mu g / m^3 = \frac{ppm x 10^{-6} x MW x 10^3 L / m^3 x 10^6 \mu g / g}{V(L/mol)}$$

$$MW : gram\ molecular weight\ of\ the\ gas$$

$$\frac{V_1 P_1}{T_1} = \frac{V_2 P_2}{T_2}$$

Standard conditions: V=22.4 L/mol @ 273K & 760 mmHg

Converting μg/m^3 ppm

- The conversion between μg/m^3 and ppm is based on the fact that at standard conditions (0^0C and 101.325 kPa), one mole of an ideal gas occupies 22.414 L.
- We may write an equation that converts the mass of the pollutant M_p in grams to its equivalent volume $\cancel{V}_p$ in liters at standard temperature and pressure (STP).

$$\boxed{\cancel{V}_p = \frac{M_p}{GMW} \times 22.414\ \text{L/GM}}$$

GMW = g MW of the pollutant
$\cancel{V}_p$ = equivalent volume
M_p = mass of the pollutant

REMEMBER!!

For readings made at T & P other than standard conditions, the standard volume, 22.414 L/GM must be corrected.

Use Ideal law to make correction

$$22.41 \boxed{} \frac{\text{L}}{\text{GM}} \times \frac{T_2}{273\ \text{K}} \times \frac{101.325\ \text{kPa}}{P_2}$$

T_2 and P_2 (absolute temperature and absolute pressure at which the readings were made.

ppm is a volume ratio, $$\boxed{\text{ppm} = \frac{V_p}{V_a}}$$

Where ~~V~~a = volume of air in cubic meters at T,P of the reading.

- Final equation:

$$\boxed{\text{ppm} = \frac{\frac{M_p}{\text{GMW}} \times 22.414 \times \frac{T_2}{273\ \text{K}} \times \frac{101.325\ \text{kPA}}{P_2}}{\cancel{V}_a \times 1000\ \text{L/m}^3}}$$

Where

GMW = gram MW of the pollutant

$\cancel{V}_p$ = equivalent volume

M_p = mass of the pollutant (μg)

$\cancel{V}_a$ = volume of air in cubic meters at T,P of the reading

T_2 = absolute temperature at which the readings were made

P_2 = absolute pressure at which the readings were made

- Factors converting μg to g and L to million of L to millions of L cancel one another.
- Unless otherwise stated, assumed that $\cancel{V}_a = 1.00\ \text{m}^3$

Example

- A one-cubic-meter sample of air was found to contain 80 μg/m^3 of SO_2. The temperature and pressure were 25◦C and 102.193 kPa when the air sample was taken. What was the SO_2 concentration in ppm?

Given; S = 32.07

O = 16.00

Answer; $SO_2 = 0.03$ ppm

Solution

1. Determine the GMW of SO_2 .

$$\text{GMW of } SO_2 = 32.07 + 2(16.00)$$

2. Convert temp to absolute temp.

$$25^0C + 273K = 298K$$

3. Solve the equation

$$\text{ppm} = \frac{\frac{M_p}{\text{GMW}} \times 22.414 \times \frac{T_2}{273\ \text{K}} \times \frac{101.325\ \text{kPA}}{P_2}}{V_a \times 1000\ \text{L/m}^3}$$

$$\text{ppm} = \frac{\frac{80\mu g}{64.07} \times 22.414 \times \frac{298\ \text{K}}{273\ \text{K}} \times \frac{101.325\ \text{kPA}}{103.193\ \text{kPA}}}{1.00\text{m}^3 \times 1000\ \text{L/m}^3}$$

Answer ; 0.0300 ppm of SO_2

National ambient air quality standards

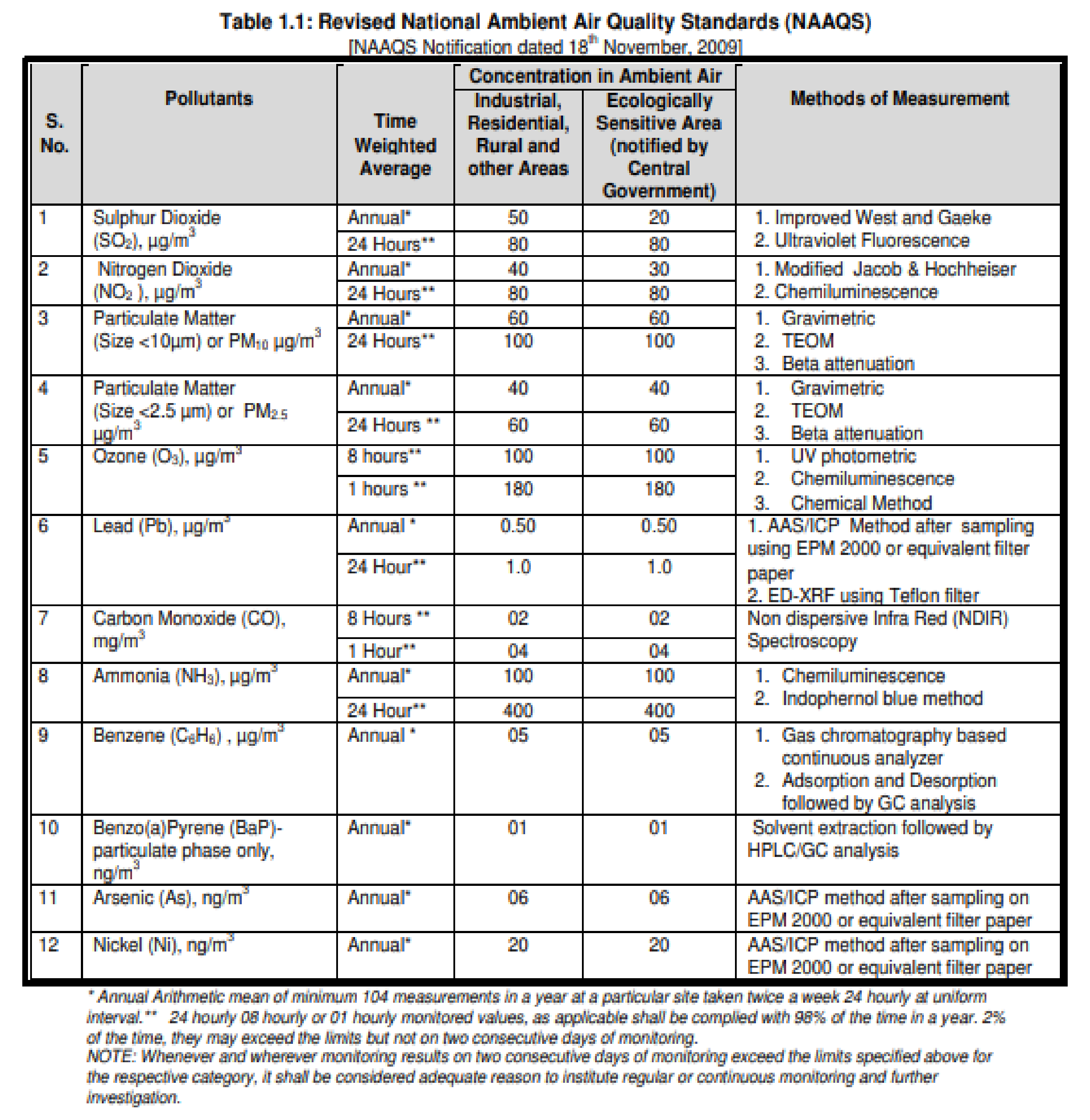


Table 1.1: Revised National Ambient Air Quality Standards (NAAQS)

[NAAQS Notification dated 18th November, 2009]

S. No.	Pollutants	Time Weighted Average	Concentration in Ambient Air		Methods of Measurement
			Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area (notified by Central Government)	
1	Sulphur Dioxide (SO_2), µg/m^3	Annual*	50	20	1. Improved West and Gaeke 2. Ultraviolet Fluorescence
		24 Hours**	80	80	
2	Nitrogen Dioxide (NO_2), µg/m^3	Annual*	40	30	1. Modified Jacob & Hochheiser 2. Chemiluminescence
		24 Hours**	80	80	
3	Particulate Matter (Size <10µm) or PM_{10} µg/m^3	Annual*	60	60	1. Gravimetric 2. TEOM 3. Beta attenuation
		24 Hours**	100	100	
4	Particulate Matter (Size <2.5 µm) or $PM_{2.5}$ µg/m^3	Annual*	40	40	1. Gravimetric 2. TEOM 3. Beta attenuation
		24 Hours **	60	60	
5	Ozone (O_3), µg/m^3	8 hours**	100	100	1. UV photometric 2. Chemiluminescence 3. Chemical Method
		1 hours **	180	180	
6	Lead (Pb), µg/m^3	Annual *	0.50	0.50	1. AAS/ICP Method after sampling using EPM 2000 or equivalent filter paper 2. ED-XRF using Teflon filter
		24 Hour**	1.0	1.0	
7	Carbon Monoxide (CO), mg/m^3	8 Hours **	02	02	Non dispersive Infra Red (NDIR) Spectroscopy
		1 Hour**	04	04	
8	Ammonia (NH_3), µg/m^3	Annual*	100	100	1. Chemiluminescence 2. Indophernol blue method
		24 Hour**	400	400	
9	Benzene (C_6H_6) , µg/m^3	Annual *	05	05	1. Gas chromatography based continuous analyzer 2. Adsorption and Desorption followed by GC analysis
10	Benzo(a)Pyrene (BaP)- particulate phase only, ng/m^3	Annual*	01	01	Solvent extraction followed by HPLC/GC analysis
11	Arsenic (As), ng/m^3	Annual*	06	06	AAS/ICP method after sampling on EPM 2000 or equivalent filter paper
12	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 interval.** 24 hourly 08 hourly or 01 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 investigation.

Air quality index (AQI)

- A number used by government agencies to communicate to the public how polluted the air currently is or how polluted it is forecast to become.

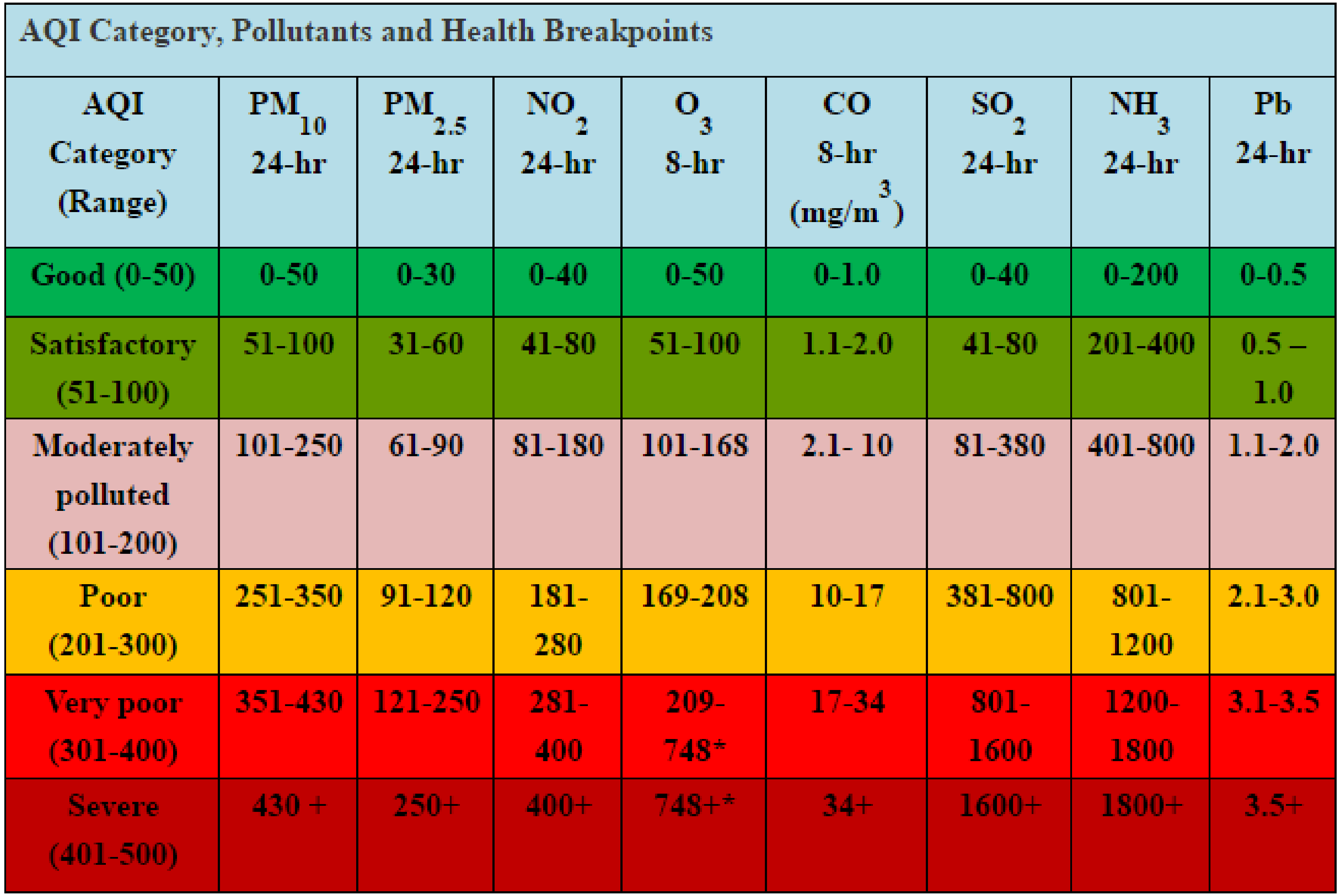
- Different countries have their own air quality indices, corresponding to different national air quality standards. Some of these are the Air Quality Health Index (Canada), the Air Pollution Index (Malaysia), and the Pollutant Standards Index (Singapore).

National Air Quality Index (AQI) launched by the Environment Minister AQI is a huge initiative under ‘Swachh Bharat’ in October, 2014 envisioned by the Hon’ble Prime Minister Shri Narendra Modi..

AQI to act as ‘One Number- One Colour-One Description’ to judge the Air Quality for Common Man: Shri Prakash Javadekar.

The Minister for Environment, Forests & Climate Change Shri Prakash Javadekar launched ‘The National Air Quality Index’ (AQI) in New Delhi. Speaking on the occasion, Shri Javadekar outlined the AQI, as ‘One Number- One Colour-One Description’ for the common man to judge the air quality within his vicinity.

The proposed AQI will consider eight pollutants (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3, and Pb) for which short-term (up to 24-hourly averaging period) National Ambient Air Quality Standards are prescribed.



AQI Category, Pollutants and Health Breakpoints

AQI Category (Range)	PM$_{10}$ 24-hr	PM$_{2.5}$ 24-hr	NO$_2$ 24-hr	O$_3$ 8-hr	CO 8-hr (mg/m^3)	SO$_2$ 24-hr	NH$_3$ 24-hr	Pb 24-hr
Good (0-50)	0-50	0-30	0-40	0-50	0-1.0	0-40	0-200	0-0.5
Satisfactory (51-100)	51-100	31-60	41-80	51-100	1.1-2.0	41-80	201-400	0.5 – 1.0
Moderately polluted (101-200)	101-250	61-90	81-180	101-168	2.1- 10	81-380	401-800	1.1-2.0
Poor (201-300)	251-350	91-120	181-280	169-208	10-17	381-800	801-1200	2.1-3.0
Very poor (301-400)	351-430	121-250	281-400	209-748*	17-34	801-1600	1200-1800	3.1-3.5
Severe (401-500)	430 +	250+	400+	748+*	34+	1600+	1800+	3.5+

**One hourly monitoring (for mathematical calculations only)*

How to calculate Air Quality Index?

The formula to calculate AQI is the same as per the Indian CPCB and US-EPA. The AQI is calculated using the equations separately for parameters. For example, if you wish to calculate AQI on the basis of four parameters, use the equation four times, and the worst sub-index communicates the AQI.

A subindex is a linear function (two different yet related notions) of the concentration of pollutants.

The Indian AQI range differs from that of US-EPA. To calculate AQI, a minimum of three parameters should be taken out of which one must be either PM10 or PM2.5.

$$\mathbf{AQI_p = [I_{Hi} – I_{Lo} / C_{Hi} – C_{Lo}] (C_p – C_{Lo}) + I_{Lo}}$$

Where,

AQI = index of pollutant p

C_p = truncated concentration of pollutant p

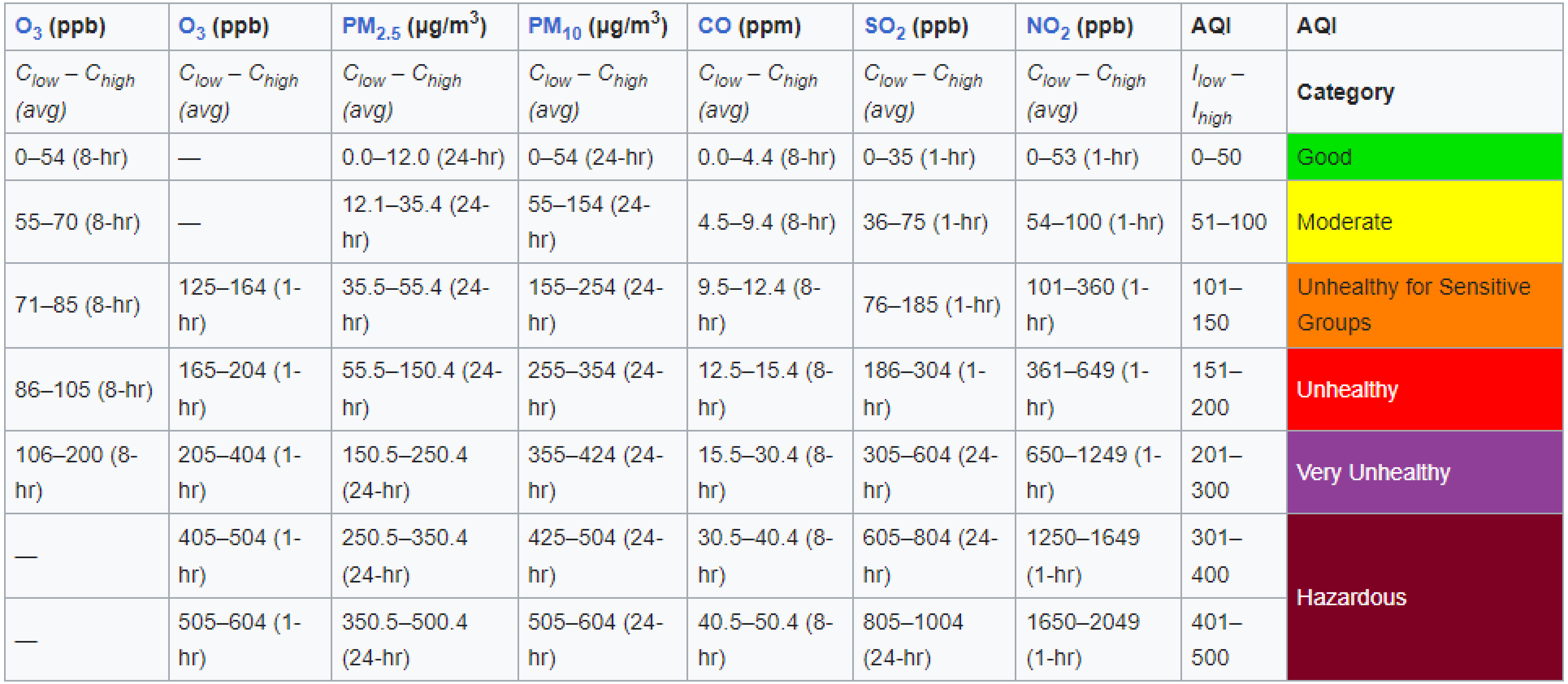
C_{Hi} = concentration breakpoint i.e. greater than or equal to Cp

C_{Lo} = concentration breakpoint i.e. less than or equal to Cp

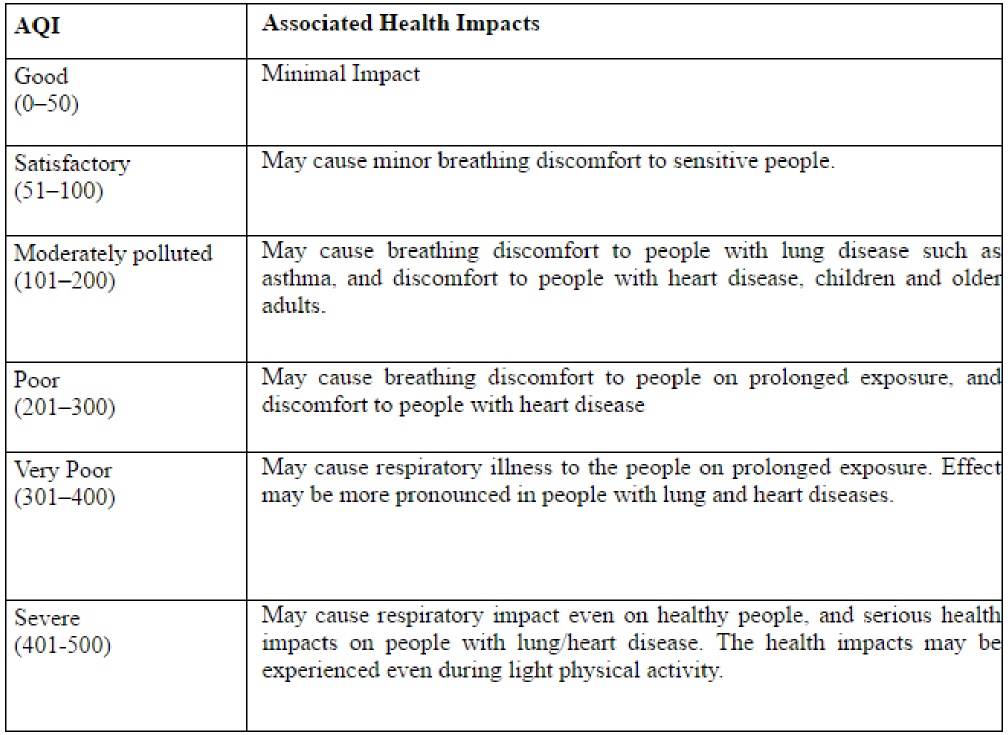
I_{Hi} = AQI value corresponding to CHi

I_{Lo} = AQI value corresponding to CLo

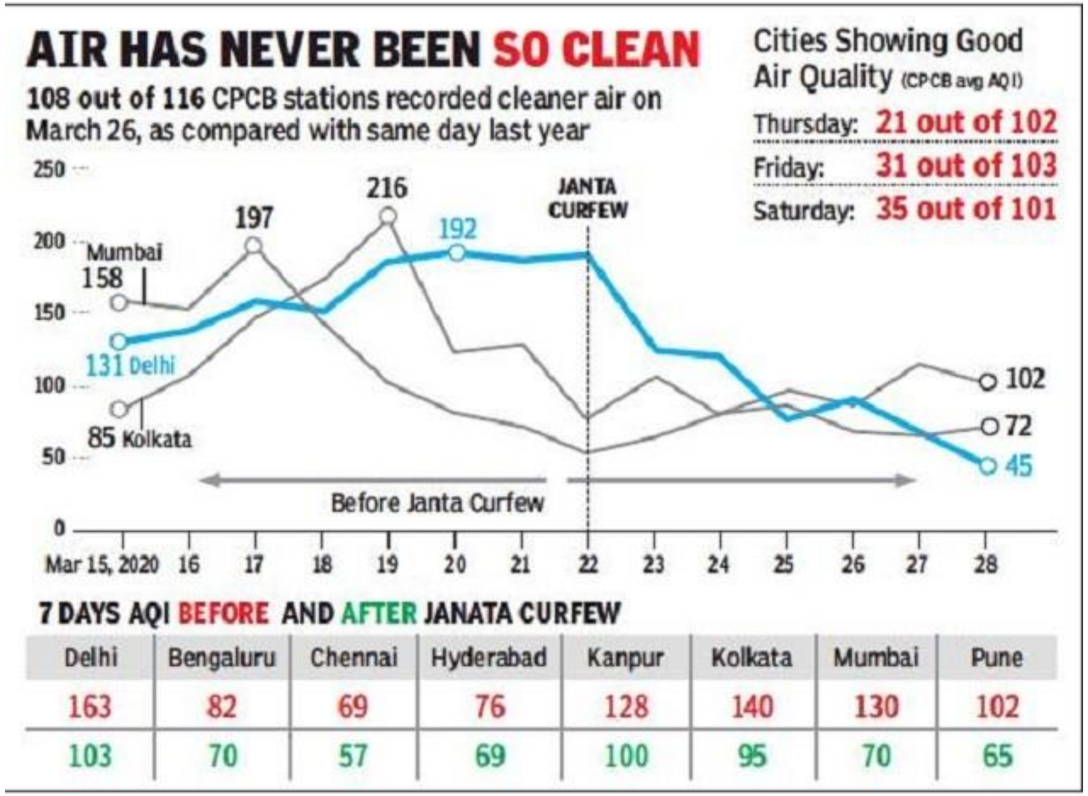
AQIp = [IHi – ILo / CHi – CLo] (Cp –CLo) + ILo
Where,
AQI = index of pollutant p
Cp = truncated concentration of pollutant p
CHi = concentration breakpoint i.e. greater than or equal to Cp
CLo = concentration breakpoint i.e. less than or equal to Cp
IHi = AQI value corresponding to CHi
ILo = AQI value corresponding to CLo



O_3 (ppb)	O_3 (ppb)	$PM_{2.5}$ (μg/m^3)	PM_{10} (μg/m^3)	CO (ppm)	SO_2 (ppb)	NO_2 (ppb)	AQI	AQI
$C_{low} – C_{high}$ (avg)	$C_{low} – C_{high}$ (avg)	$C_{low} – C_{high}$ (avg)	$C_{low} – C_{high}$ (avg)	$C_{low} – C_{high}$ (avg)	$C_{low} – C_{high}$ (avg)	$C_{low} – C_{high}$ (avg)	$I_{low} – I_{high}$	Category
0–54 (8-hr)	—	0.0–12.0 (24-hr)	0–54 (24-hr)	0.0–4.4 (8-hr)	0–35 (1-hr)	0–53 (1-hr)	0–50	Good
55–70 (8-hr)	—	12.1–35.4 (24-hr)	55–154 (24-hr)	4.5–9.4 (8-hr)	36–75 (1-hr)	54–100 (1-hr)	51–100	Moderate
71–85 (8-hr)	125–164 (1-hr)	35.5–55.4 (24-hr)	155–254 (24-hr)	9.5–12.4 (8-hr)	76–185 (1-hr)	101–360 (1-hr)	101–150	Unhealthy for Sensitive Groups
86–105 (8-hr)	165–204 (1-hr)	55.5–150.4 (24-hr)	255–354 (24-hr)	12.5–15.4 (8-hr)	186–304 (1-hr)	361–649 (1-hr)	151–200	Unhealthy
106–200 (8-hr)	205–404 (1-hr)	150.5–250.4 (24-hr)	355–424 (24-hr)	15.5–30.4 (8-hr)	305–604 (24-hr)	650–1249 (1-hr)	201–300	Very Unhealthy
—	405–504 (1-hr)	250.5–350.4 (24-hr)	425–504 (24-hr)	30.5–40.4 (8-hr)	605–804 (24-hr)	1250–1649 (1-hr)	301–400	Hazardous
—	505–604 (1-hr)	350.5–500.4 (24-hr)	505–604 (24-hr)	40.5–50.4 (8-hr)	805–1004 (24-hr)	1650–2049 (1-hr)	401–500	



AQI	Associated Health Impacts
Good (0–50)	Minimal Impact
Satisfactory (51–100)	May cause minor breathing discomfort to sensitive people.
Moderately polluted (101–200)	May cause breathing discomfort to 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
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 impact even on healthy people, and serious health impacts on people with lung/heart disease. The health impacts may be experienced even during light physical activity.



AIR HAS NEVER BEEN SO CLEAN

108 out of 116 CPCB stations recorded cleaner air on March 26, as compared with same day last year

Cities Showing Good Air Quality (CPCB avg AQI)

Thursday: 21 out of 102
Friday: 31 out of 103
Saturday: 35 out of 101

7 DAYS AQI BEFORE AND AFTER JANATA CURFEW

Delhi	Bengaluru	Chennai	Hyderabad	Kanpur	Kolkata	Mumbai	Pune
163	82	69	76	128	140	130	102
103	70	57	69	100	95	70	65

What is the major cause of air pollution according to this data?

Problem

Calculate the AQI of a given city where,
24 hr average of PM10 is 150 µg/m^3
24 hr average of PM2.5 is 60 µg/m^3
24 hr average of SO2 is 35 µg/m^3
24 hr average of NO2 is 22 µg/m^3

Hint:
Step 1 : calculate sub index for each pollutant
Step 2: worst value will be the AQI

Indoor Air Pollution

© Brooks/Cole, Cengage Learning

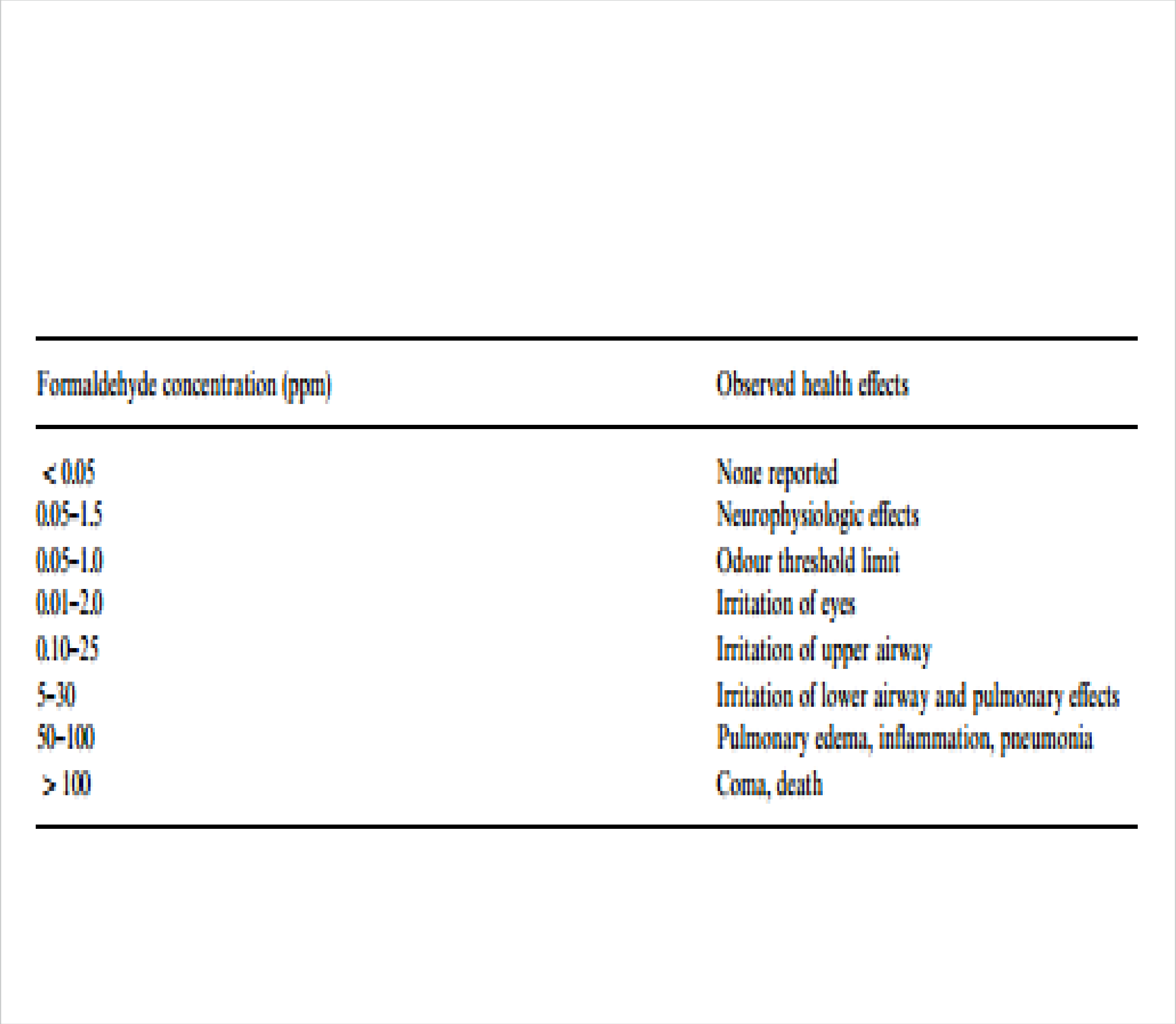
Indoor Air Pollution Problems?

- *The most threatening indoor air pollutants are smoke and soot from wood and coal cooking fires (a hazard found mostly in developing countries) and chemicals used in building materials and products.*

Who are at greatest risk from indoor air pollution?

- Children under 5 and the elderly
- Sick
- Pregnant women
- People with respiratory disorders or heart problems
- Smokers
- Factory workers

- **Formaldehyde** is the most widespread aldehyde found in the environment.
- Particle-board, medium-density fiber board, plywood, resins, adhesives, and carpeting.
- Insulation in existing buildings



Formaldehyde concentration (ppm)	Observed health effects
< 0.05	None reported
0.05–1.5	Neurophysiologic effects
0.05–1.0	Odour threshold limit
0.01–2.0	Irritation of eyes
0.10–25	Irritation of upper airway
5–30	Irritation of lower airway and pulmonary effects
50–100	Pulmonary edema, inflammation, pneumonia
> 100	Coma, death

BIOMASS BURNING

- RESPIRABLE FINE PARTICLES
- Burning of wood.
- Constituents of the smoke.
- Are around 6~7μm less in diameter.
- Mix of organic and inorganic substances including aromatic hydrocarbon compounds, trace metals, nitrates, and sulphates.

CO, CO_2, NO_2, SO_2, VOC's, HAPs and other carcinogenic substances, particulates are released.

Biomass burning

- Around 2.4 billion people worldwide (around a third of the global population) cook using open fires or inefficient stoves fuelled by kerosene, biomass (wood, animal dung and crop waste) and coal, which generates harmful household air pollution.
- Household air pollution was responsible for an estimated 3.2 million deaths per year in 2020, including over 237 000 deaths of children under the age of 5.
- The combined effects of ambient air pollution and household air pollution are associated with 6.7 million premature deaths annually.
- Household air pollution exposure leads to noncommunicable diseases including stroke, ischaemic heart disease, chronic obstructive pulmonary disease (COPD) and lung cancer.
- Women and children, typically responsible for household chores such as cooking collecting firewood, bear the greatest health burden from the use of polluting fuels and technologies in homes.
- It is essential to expand use of clean fuels and technologies to reduce household air pollution and protect health. These include solar, electricity, biogas, liquefied petroleum gas (LPG), natural gas, alcohol fuels, as well as biomass stoves that meet the emission targets in the WHO Guidelines.

FACTS

- Most of these people are poor and live in low- and middle-income countries. There is a large discrepancy in access to cleaner cooking alternatives between urban and rural areas: in 2020, only 14% of people in urban areas relied on polluting fuels and technologies, compared with 52% of the global rural population.

- Household air pollution is generated by the use of inefficient and polluting fuels and technologies in and around the home that contains a range of health-damaging pollutants, including small particles that penetrate deep into the lungs and enter the bloodstream. In poorly ventilated dwellings, indoor smoke can have levels of fine particles 100 times higher than acceptable. Exposure is particularly high among women and children, who spend the most time near the domestic hearth. Reliance on polluting fuels and technologies also require significant time for cooking on an inefficient device, and gathering and preparing fuel.

Impacts on health

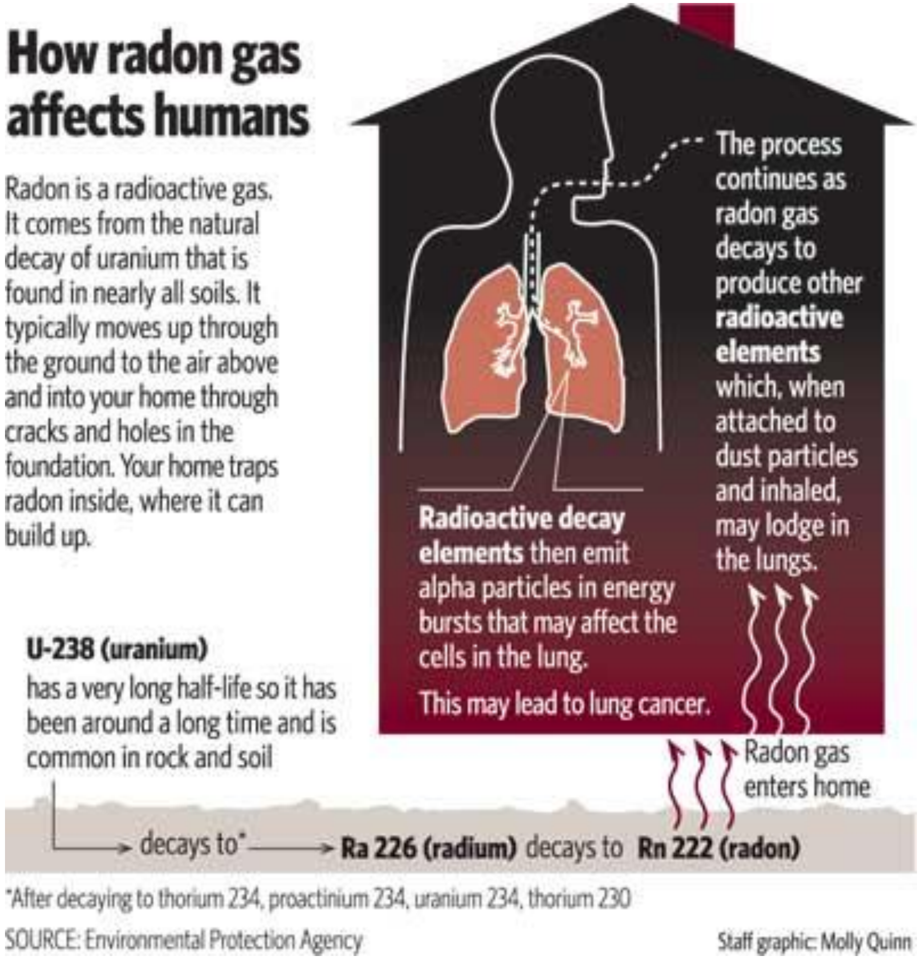
- Among these 3.2 million deaths from household air pollution exposure:

- 32% are from ischaemic heart disease: 12% of all deaths due to ischaemic heart disease, accounting for over a million premature deaths annually, can be attributed to exposure to household air pollution;
- 23% are from stroke: approximately 12% of all deaths due to stroke can be attributed to the daily exposure to household air pollution arising from using solid fuels and kerosene at home;
- 21% are due to lower respiratory infection: exposure to household air pollution almost doubles the risk for childhood LRI and is responsible for 44% of all pneumonia deaths in children less than 5 years old. Household air pollution is a risk for acute lower respiratory infections in adults and contributes to 22% of all adult deaths due to pneumonia;
- 19% are from chronic obstructive pulmonary disease (COPD): 23% of all deaths from chronic obstructive pulmonary disease (COPD) in adults in low- and middle-income countries are due to exposure to household air pollution; and
- 6% are from lung cancer: approximately 11% of lung cancer deaths in adults are attributable to exposure to carcinogens from household air pollution caused by using kerosene or solid fuels like wood, charcoal or coal for household energy needs.

- Radon is an inert radioactive gas that arises directly from the decay of radium-226 contained in various minerals.
- It has a half-life of 3.82 d.
- Once inhaled, they tend to remain in the lungs, where they may eventually cause cancer.

RADON

1. Cracks in solid floors
2. Construction Joints
3. Cracks in walls
4. Gaps in suspended floors
5. Water supply service pipes



How radon gas affects humans

Radon is a radioactive gas. It comes from the natural decay of uranium that is found in nearly all soils. It typically moves up through the ground to the air above and into your home through cracks and holes in the foundation. Your home traps radon inside, where it can build up.

The process continues as radon gas decays to produce other **radioactive elements** which, when attached to dust particles and inhaled, may lodge in the lungs.

Radioactive decay elements then emit alpha particles in energy bursts that may affect the cells in the lung.

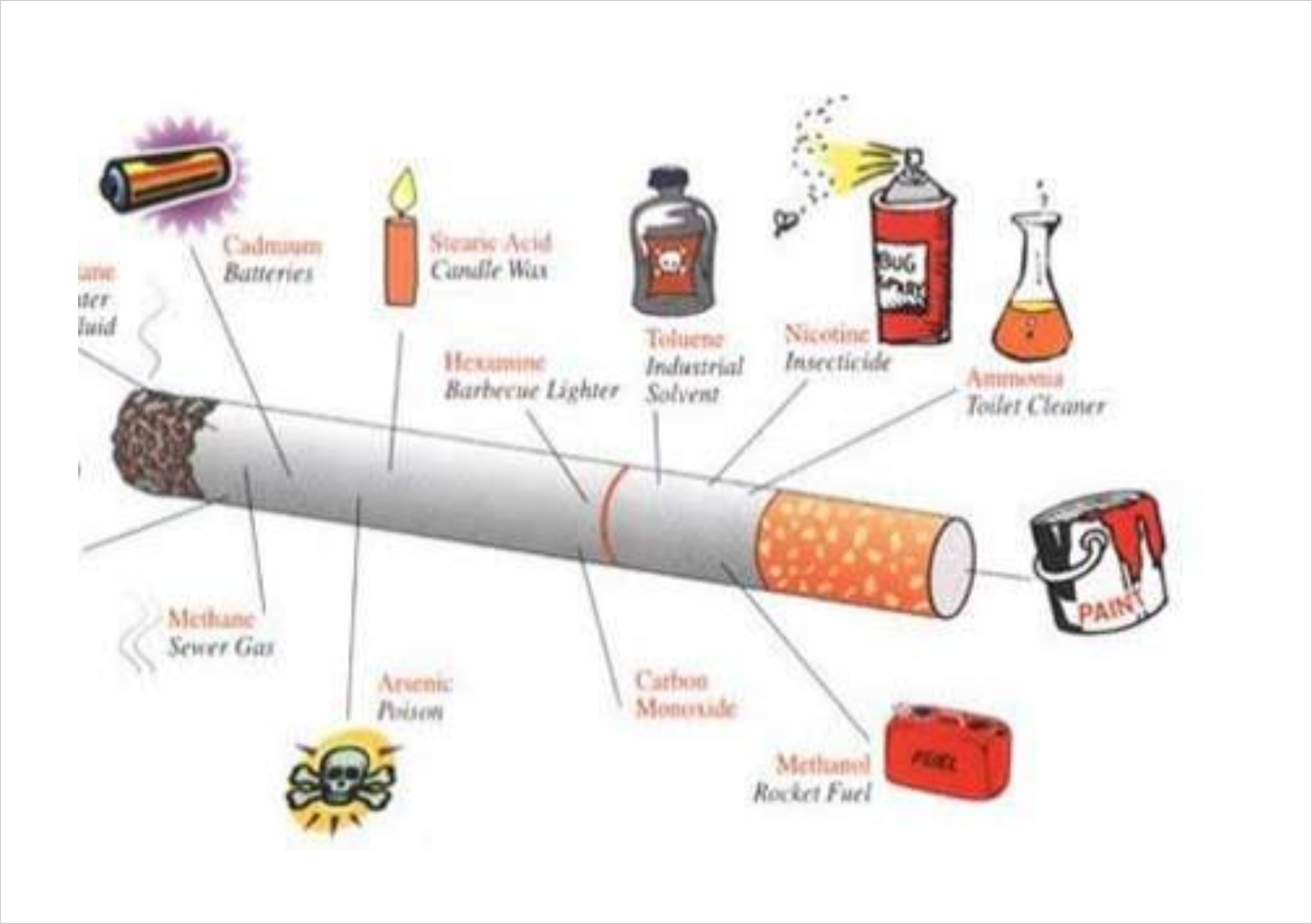
This may lead to lung cancer.

U-238 (uranium) has a very long half-life so it has been around a long time and is common in rock and soil

*After decaying to thorium 234, proactinium 234, uranium 234, thorium 230

SOURCE: Environmental Protection Agency

Staff graphic: Molly Quinn

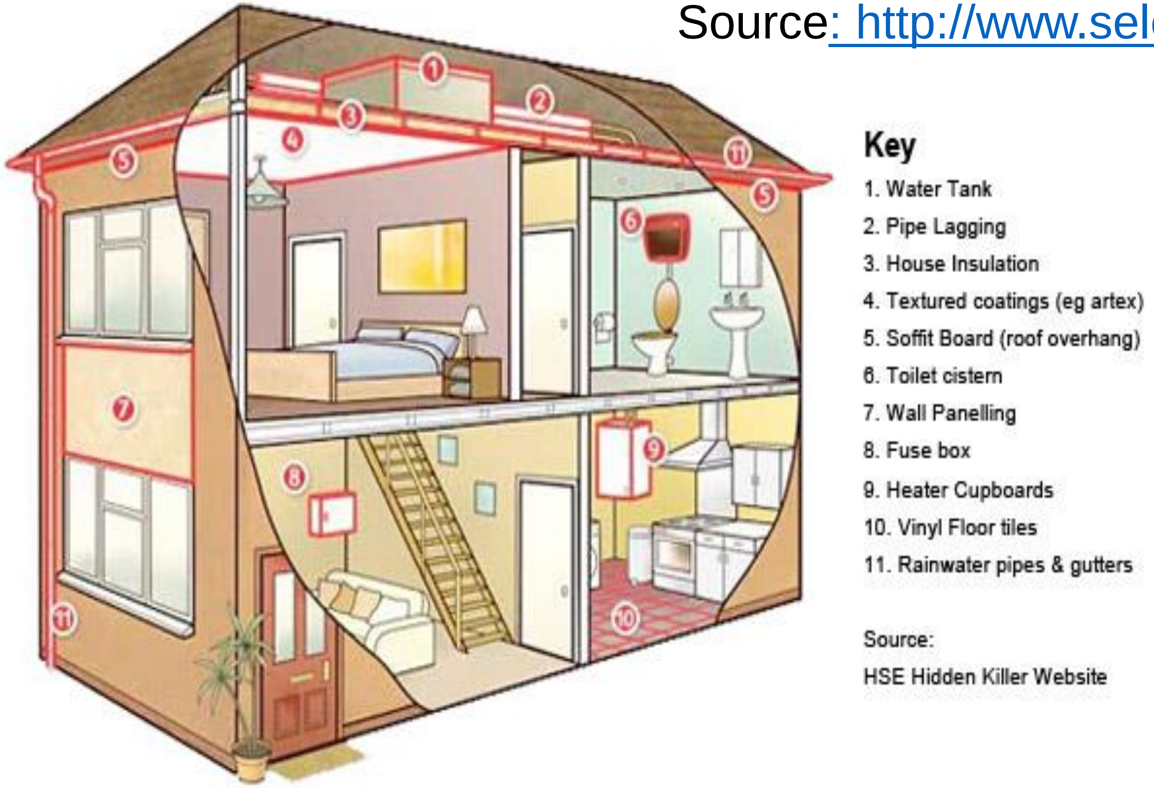


Tobacco smoke

Asbestos

- Hydrated silicate minerals which occur in various forms and are incombustible and separates into filaments.
- Asbestos is a naturally occurring mineral resistant to heat, chemicals, electricity, and physical forces. It cannot be destroyed but can be made into various forms such as rope, cloth, sheets, blocks, and many others. Therefore, it has several applications, especially in industries which deal with high temperature, strong chemical or physical forces, for example, boilers, brake-linings, insulators, and cement.
- It was particularly valued for its electrical and thermal insulating properties, and was heavily utilized in pipe and boiler insulation, cement-board, thermal tiles, paint, and wallpaper and covering roof tops

Source: http://www.selectselect.net/asbestos.php



Humans can get exposed to asbestos exposure in several ways. Primary exposure is the direct exposure to individuals while directly handling asbestos or its products as in mining, milling, and occupations such as ship breaking, pipe, and boiler insulation and repair. Secondary exposure is indirect exposure to the family members of those exposed primarily through their contaminated body and clothes (also known as "take-home" exposures). Environmental exposure is through the local physical environment where air, soil, and water have got polluted due to asbestos which typically happens around the asbestos mines or factories processing it.

Heath effects

- Mesothelioma
- Asbestos-related lung cancer
- Asbestosis
- Pleural thickening:

The hazardous health effects of asbestos were identified as early as 1899. International Agency on Research on Cancer concluded by 1977 that asbestos is a strong carcinogen and classified it as “Group-1” carcinogen. Apart from causing mesothelioma and cancers of lungs, larynx, pharynx, and ovary, it is also capable of causing a disabling fibrotic lung disease called asbestosis as well as pleural plaques and benign fibrous skin lesions, collectively referred to as asbestos-related diseases (ARDs). Most of the ARDs have a very long latent period ranging from 20 to 35 years, and all of these are progressive incurable diseases. Due to long latency periods and slow progression, these diseases are frequently not identified as asbestos related.

Asbestos in India

- On 21 January 2011, the Indian Supreme court refused to ban usage of Asbestos in India, though its mining is banned.
- Despite asbestos being a health hazard, its market has grown because it serves the poor.
- The World Health Organization (WHO) estimates that globally 125 million people are currently exposed to asbestos at work, and every year around 107,000 people die due to ARDs by just occupational (primary) exposure alone.

Other possible indoor air pollutants

- Pesticide residue
- Pb particles
- VOCs
- PAH
- Asbestos, minerals and synthetic fibres
- Hg
- Living organisms and their excrements
    - E.g., Dust mites and cockroach droppings
- Airborne spores of molds and mildews

Sick-building syndrome

Magnified View of a Household Dust Mite in a Dust Ball

The sick building syndrome

- The sick building syndrome (SBS) is used to describe a situation in which the occupants of a building experience acute health- or comfort-related effects that seem to be linked directly to the time spent in the building. No specific illness or cause can be identified. The complainants may be localized in a particular room or zone or may be widespread throughout the building.

- The health conditions associated with buildings are commonly classified as:

1. SBS or Tight building syndrome .

2. Building-related disease, when the symptoms of diagnosable illness are identified and attributed directly to airborne building contaminants.

3. Building-associated symptoms.

Signs and symptoms of the sick building syndrome are as follows

- Headache, dizziness, nausea, eye, nose or throat irritation, dry cough, dry or itching skin, difficulty in concentration, fatigue, sensitivity to odours, hoarseness of voice, allergies, cold, flu-like symptoms, increased incidence of asthma attacks and personality changes.
- The cause of the symptoms is not known. It reduces work efficiency and increases absenteeism. Most of the complainants report relief soon after leaving the building, although lingering effects of neurotoxins can occur.
- **Signs and symptoms of the building-related disease are as follows**
- Cough, chest pain, shortness of breath on mild exertion, edema, palpitations, nosebleeds, cancers, pregnancy problems and miscarriages. Extrinsic allergic alveolitis, Legionnaire's disease, humidifier fever, pneumonia and occupational asthma are also known to occur.
- Legionnaire's disease is due to contamination of cooling towers by legionella organisms. Legionella is also responsible for Pontiac fever. Legionnaire's disease occurs predominantly in the middle aged and elderly adults whereas Pontiac fever occurs in young healthy adults and has a very high secondary attack rate.
- Humidifier fever is caused by breathing in water droplets from humidifiers heavily contaminated with microorganisms causing respiratory infections, asthma and extrinsic allergic alveolitis. The disease is noninfective in nature. The patient may have flu-like symptoms. It is sometimes called Monday Fever. Permanent lung damage does not occur.
- The symptoms can be clinically defined and have clearly identifiable causes. The complainants may require prolonged recovery time after leaving the building.
- It is important to note that complaints may also result from other cause like a preexisting illness or other allergies, job-related stress or dissatisfaction and psychosocial factors.

PREVENTION AND CONTROL

- Increase the ventilation rates and air distribution.
- Removal or modification of the pollutant source can be carried out by a routine maintenance.
- Air cleaning can be a useful addition to control air pollution. Air cleaning can be performed by ensuring uncongested interiors with open office designs, use of frosted glass and skylights that give access to natural light, terrace gardens, community spaces and indoor plants that absorb carbon monoxide and formaldehyde from the air. Air filters are also effective in removing some if not all of the pollutants.

- Education and communication are important parts of any air quality management programme so as to work more effectively and efficiently to prevent and solve the health problems.

- Legislation: Banning of smoking in the workplace or restricting smoking to designated well-ventilated areas away from the work stations and creating no-smoking zones with the help of laws. In some European countries, workers have a statutory right to be involved with the employer's plans for changes in the work place.

Air pollution sampling and monitoring

Ambient air sampling-High volume of air is needed

Indoor air sampling-low volume of air

Stack sampling-low volume of air

Vehicular exhaust sampling-low volume of air

Measurement of air quality

- Measurements of air quality generally fall into three classes:
- – **Measurements of Emissions - also called source sampling** - when a particular emission source is measured, generally by on the spot tests
- – **Meteorological Measurement** – Measures meteorological factors that show how pollutants are transferred from source to recipient
- – **Ambient Air Quality** - Measures the quality of all the air in a particular place. Almost all the evidence of health effects is based on these measurements.
- **Industrial Hygiene sampling** - for testing the air quality inside of factories and places of work
- – **Residential Indoor sampling -** to evaluate the quality of air in living spaces

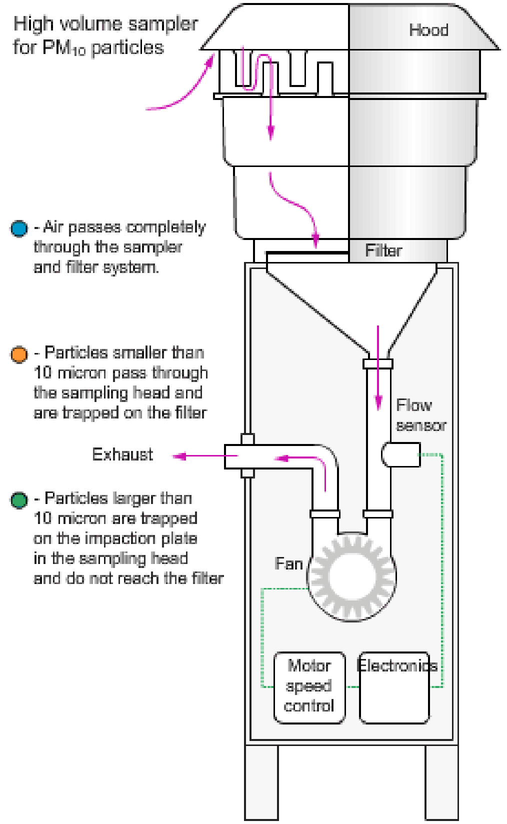
Air Sampling Techniques

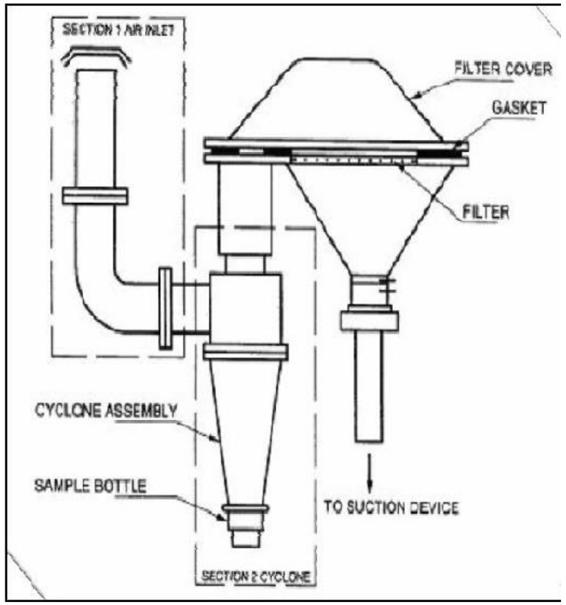
- Most air pollution monitoring equipment performs the act of sampling and analysis in one action = real time measurement
- older equipment = intermittent sampling (time lag between when the sample was obtained and when data was available)
- Almost all gaseous pollutants are monitored by real time analysis
- - Particulate pollutants are still mostly monitored by intermittent sampling, even though real time methods are available
- When obtaining a sample for air pollution analysis – should be sufficient sample for analysis. Most pollutants ,very low levels and require a large volume of gas for accurate measurement
- – pollutants in very small quantities are easy to contaminate. Take care to purge sampling containers if grab samples are used
- – Collection and analysis limitations may require collection over extended periods means data may only be a 24 hr avg.
- – real time produces so much data - are often set to give hourly avg. to make data more understandable
- Remote sensing can also be an useful tool to measure air pollution.

Real time analysers or continuous ambient air quality monitoring systems (CAAQMS)

Air Sampling Systems

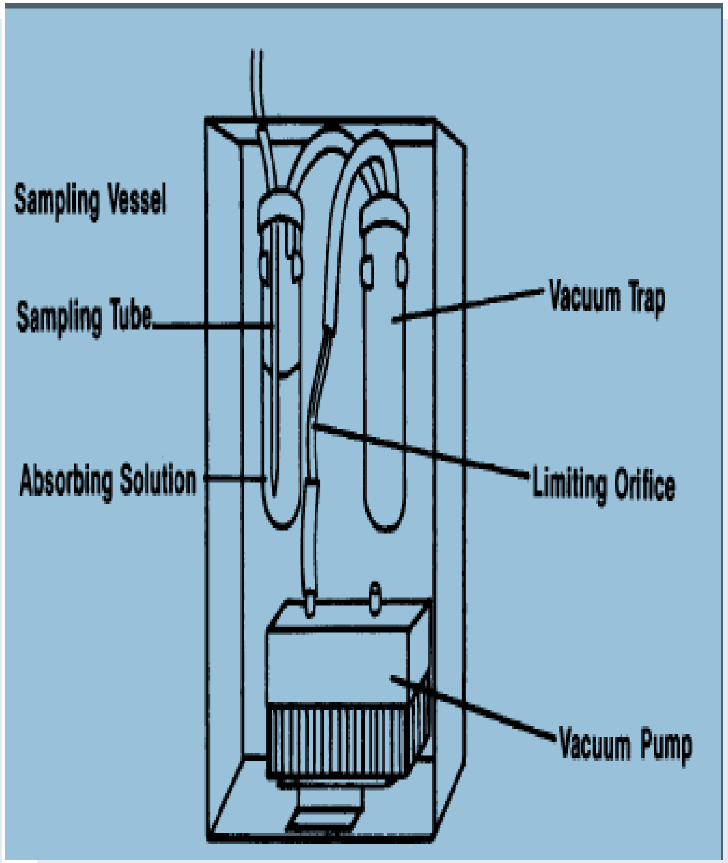
- Require gases or particles to be drawn to the surface of a collecting medium or a sensor
- Sampling trains, which may include a vacuum pump, vacuum trap, a flow regulator and a collecting device or sensing unit
- Sampling trains for gases may also utilize filters to prevent particles from entering the collection Unit
- **Site Selection**
- • **General Requirements for Site Selection**
- – purpose of monitoring
- – number and type of instruments required
- – duration of measurements
- – best available general guide comes from AS2922
- – should be easily accessible
- **Meteorological Monitoring**
- • changing weather conditions can produce dramatic
- changes in air quality and ambient pollution levels
- • Factors such as:
- – wind dispersion rates (velocity and direction)
- – temperature
- – rain
- -cloud cover
- -atm pressure





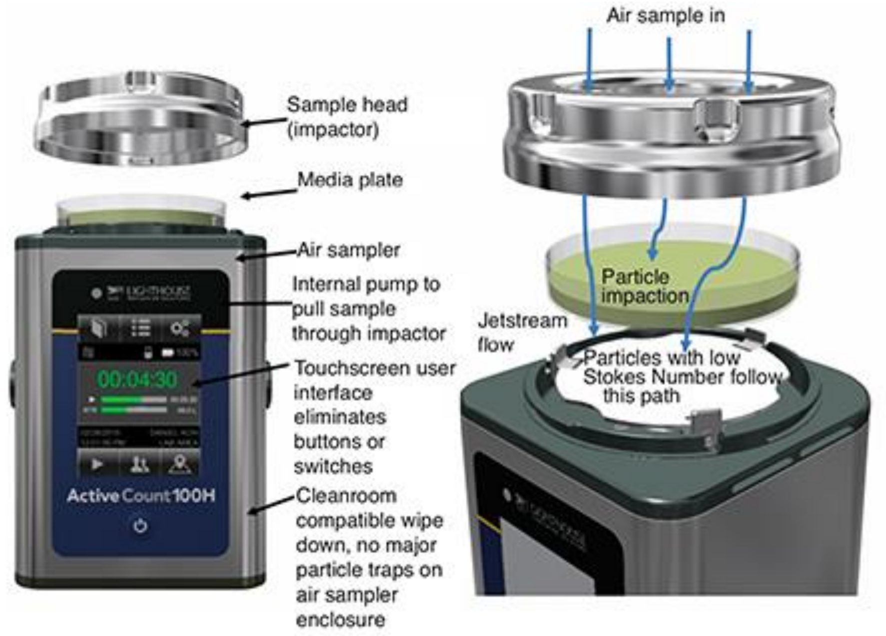
High volume samplers

Gaseous sampling of ambient air

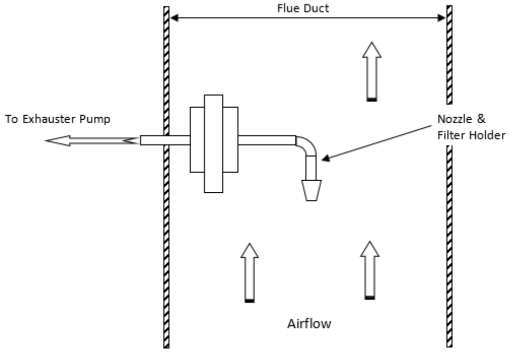


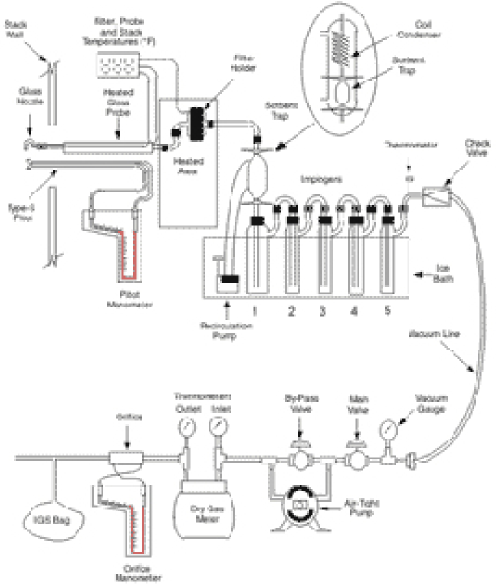
- Air Sampling Systems
- Impingers

Indoor samplers

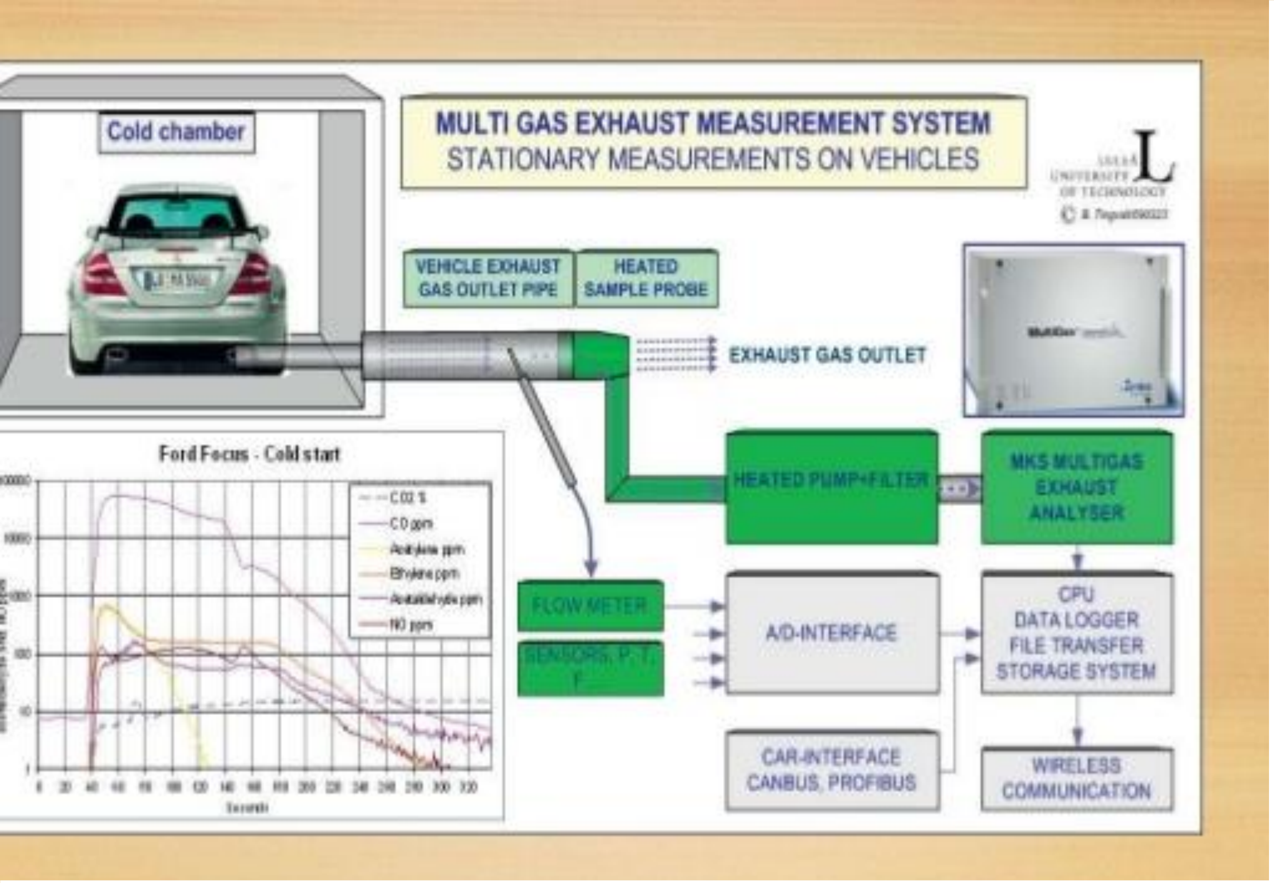


Microbial air sampler





Stack sampling



Vehicular exhaust monitoring

Bharat stage emission standards (BSES)

- To regulate the pollution emitted by cars and two-wheelers, the government of Asian nation has placed forth regulations known as Bharat Stage Emission Standards (BSES). The Central government has mandated that every vehicle manufacturer, each two-wheels and four-wheels, ought to manufacture, sell and register solely BS6 (BSVI) vehicles from 1 April 2020.
- Both BSIV and BSVI area unit emission norms that set the most permissible levels for pollutants emitting from an automotive or a two-wheeler exhaust. Compared to the BS4, BS6 emission standards area unit stricter, whereas makers use this variation to update their vehicles with new options and safety standards, the largest or the numerous modification comes within the type of stricter permissible emission norms.
- The below table offers Associate in Nursing insight into the modification within the permissible emission levels of BS6 vehicles compared to BS4 vehicles:

Fuel Type	Pollutant Gases	BS6 (BSVI)	BS4 (BSIV)
Petroleum Distillate Vehicle	Nitrogen Oxide (NOx) Limit	60mg	80mg
	Particulate Matter (PM) Limit	4.5mg/km	-
Diesel Fuel Vehicle	Nitrogen Oxide (NOx) Limit	80mg	250mg
	Particulate Matter (PM) Limit	4.5mg/km	25mg
	HC + NOx	170mg/km	300mg

BSES….

Table 2: Indian emission standards (2- and 3-wheeled vehicles)

Standard	Reference	Date
Bharat Stage II	Euro 2	1 April 2000
Bharat Stage III	Euro 3	1 April 2010
Bharat Stage IV	Euro 4	1 April 2017
Bharat Stage VI	Euro 6	April 2020 with mandate (proposed)

Table 3: Emission standards for diesel truck and bus engines, g/kWh

Year	Reference		Test	CO	HC
	NOx	PM			
1992	–	ECE R49	17.3–32.6		2.7–3.7
	–	–			
1996	–	ECE R49	11.20	2.40	14.4
	–				
2000	Euro I	ECE R49	4.5	1.1	8.0
	0.36*				
2005†	Euro II	ECE R49	4.0	1.1	7.0
	0.15				
2010†	Euro III	ESC	2.1	0.66	5.0
	0.10				
ETC	5.45	0.78	5.0	0.16	
2010‡	Euro IV	ESC	1.5	0.46	3.5
	0.02				
ETC	4.0	0.55	3.5	0.03	

* 0.612 for engines below 85 kW

† Earlier introduction in selected regions, see Table 1. ‡ Only in selected regions, see Table 1.

Air Pollution Control Module 2

Control methods

- Source Correction Methods Precautionary Approach
- Raw material changes (using purer grade)
- - use of purer grade raw material
  - Fuel desulphurisation

- Process changes through modified techniques.
- E.g in petroleum refining industries VOCs are condensed.
- Equipment modification or replacement.

- Cleaning of Pollutants once formed (end of the pipe treatment-through pollution control equipments)
  - Particulates
  - Gaseous pollutants

EQUIPMENTS FOR AIR POLLUTANTS CONTROL PARTICULATE MATTER

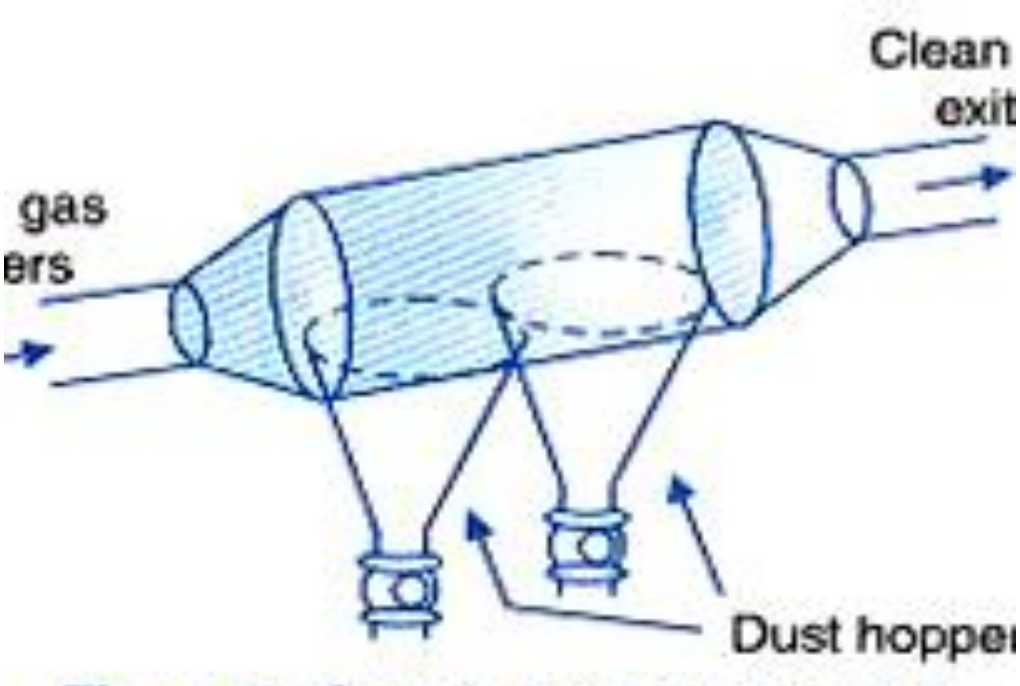


Fig. 5.3. Gravity settling chamber

- Gravitational Settling Chambers :Settling chambers use the force of gravity to remove solid particles.
- The gas stream enters a chamber where the velocity of the gas is reduced allowing sufficient time for the particles to settle.
- Large particles drop out of the gas and are recollected in hoppers. Because settling chambers are effective in removing only larger particles, they are used in conjunction with a more efficient control device.
- Gas velocity less than about 3 m/s for particles above 50 μm

Cyclones separators

- The general principle of inertia separation is that the particulate-laden gas is forced to change direction. As gas changes direction, the inertia of the particles causes them to continue in the original direction and be separated from the gas stream.
- The walls of the cyclone narrow toward the bottom of the unit, allowing the particles to be collected in a hopper.
- The cleaner air leaves the cyclone through the top of the chamber, flowing upward in a spiral vortex, formed within a downward moving spiral.
- Cyclones are efficient in removing large particles but are not as efficient with smaller particles. For this reason, they are used with other particulate control devices.

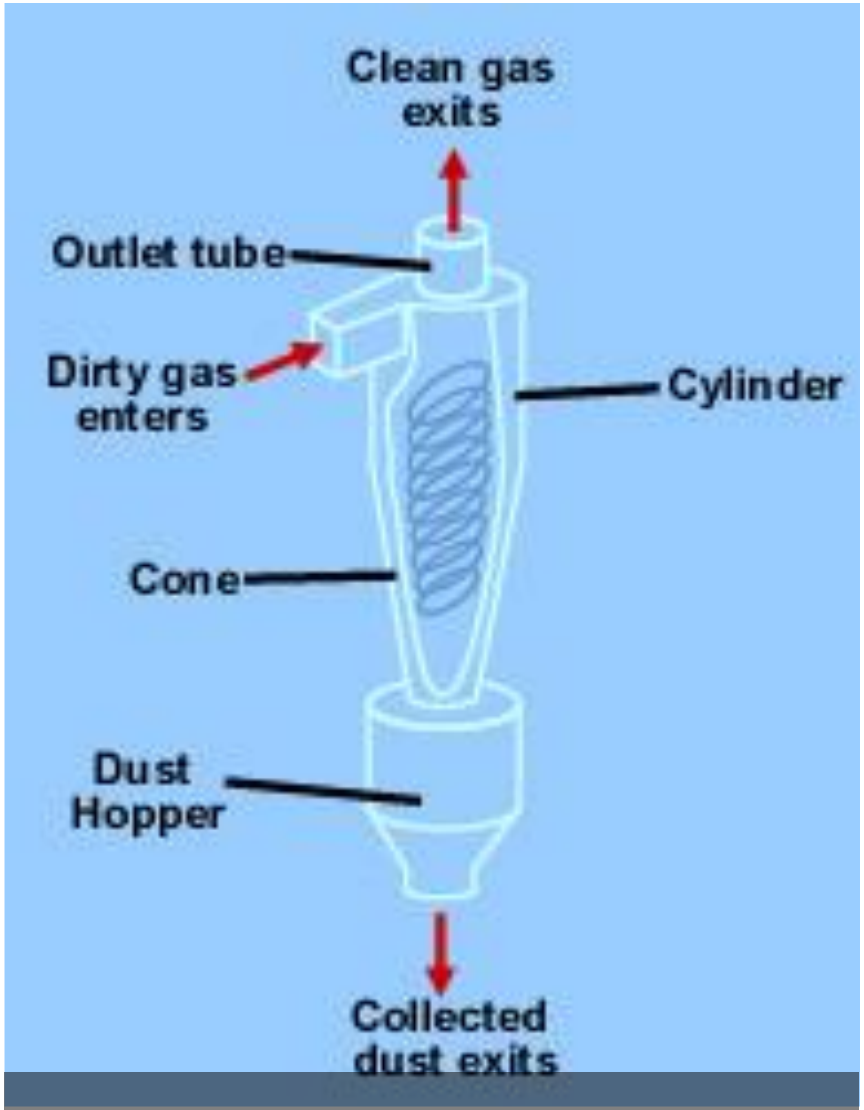
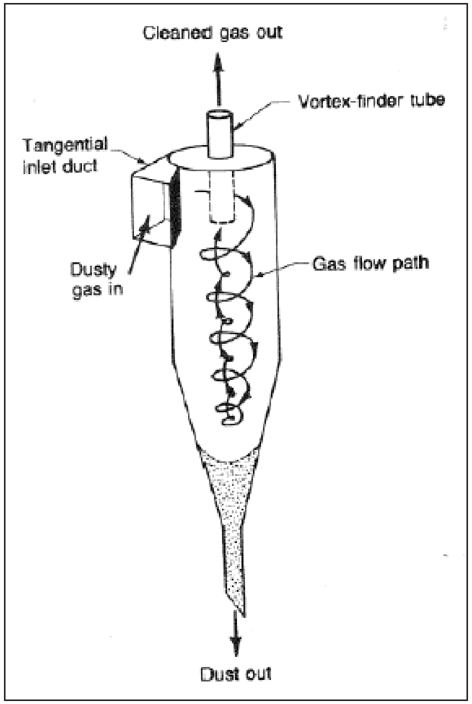


Figure: Cyclone Collector

CYCLONES

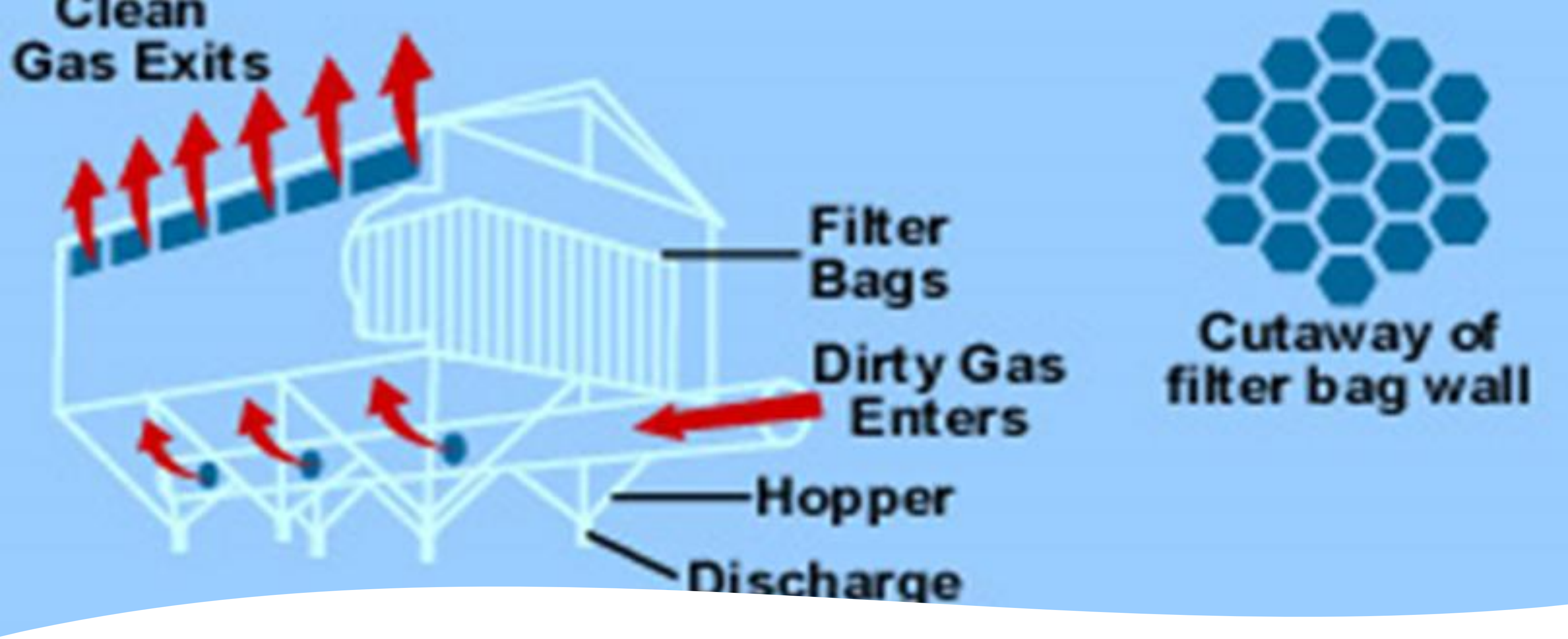
Dust-laden gas is whirled rapidly inside a collector shaped like a cylinder where, the swirling motion creates centrifugal forces that cause the particles to be thrown against the walls of the cylinder and drop into a hopper below. The gas left in the middle of the cylinder after the dust particles have been removed moves upward and exits the cylinder.



Centrifugal force (F) = mv^2/R (N)

m: particle mass (kg)
V: particle velocity (m/ s)
R: cyclone radius (m)

[Centrifugal]

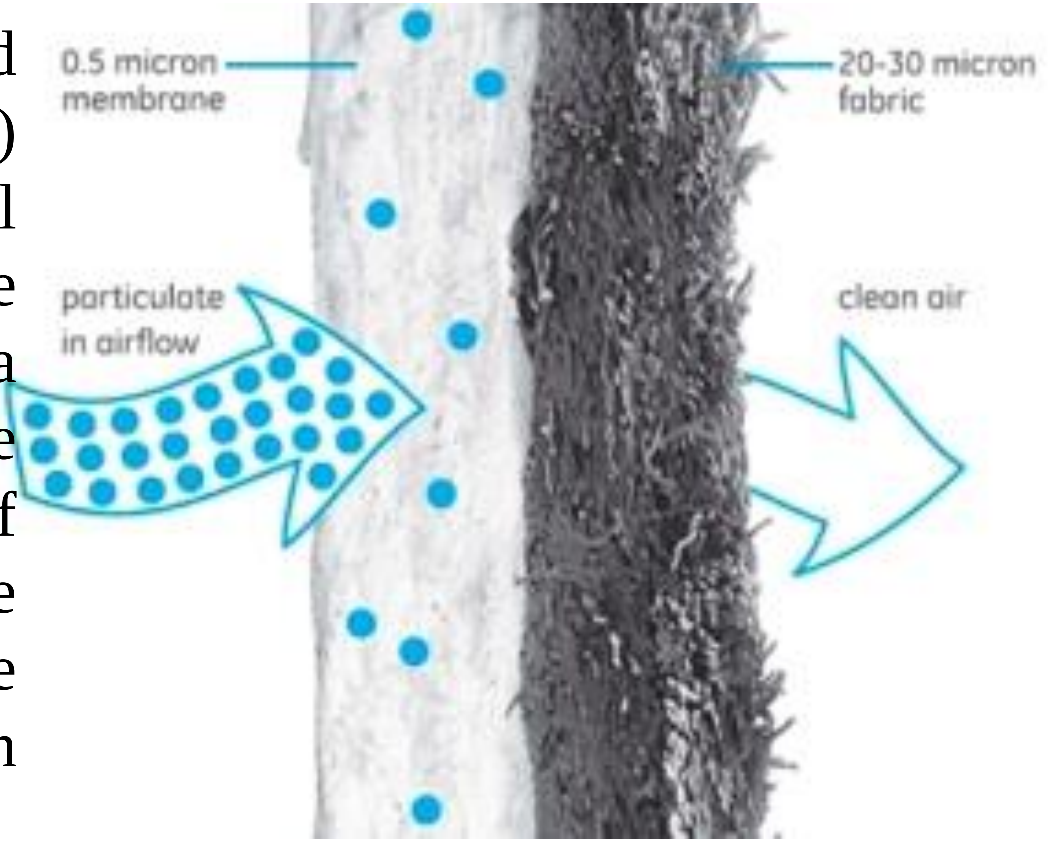


Fabric Filters

- Fabric filters, or baghouses, remove dust from a gas stream by passing the stream through a porous fabric. The fabric filter is efficient at removing fine particles and can exceed efficiencies of 99 percent in most applications.

Figure: Fabric filter (baghouse) components

- **Fabric Filters** (also called baghouses and bagfilters) are air pollution control devices that remove particulate matter from a gas stream by passing the dirty air through a layer of cloth. The particulate matter deposits on the cloth surface and the clean air passes through.



Conti…..

- The selection of the fiber material and fabric construction is important to baghouse performance.

- The fiber material from which the fabric is made must have adequate strength characteristics at the maximum gas temperature expected and adequate chemical compatibility with both the gas and the collected dust.

- One disadvantage of the fabric filter is that high-temperature gases often have to be cooled before contacting the filter medium.

- **Fabric and Fibre Characteristics:**
- Fabric filter may be classified according to filtering media:

- **Woven fabric or felt cloth.**
- Woven fabrics have a definite long range repeating pattern and have considerable porosity in the direction of gas flow.
- Felted cloth consists of randomly oriented fibres, compressed into a mat and needled to some loosely woven backing material to improve mechanical strength.
- **Cotton cloth**
- Cotton is the least expensive fibre, and is preferably used in low temperature dust collection service. Silicon coated glass fibre cloth is commonly employed in high temperature applications.
- **Glass fibre**
- The glass fibre must be lubricated to prevent abrasion. All fibre may be applied to the manufacture of woven and felt type fabrics.

- **HEPA**
- High-efficiency particulate arrestance (HEPA), originally called high-efficiency particulate absorber but also sometimes called high-efficiency particulate arresting or high-efficiency particulate air, is a type of air filter. To qualify as HEPA an air filter must remove (from the air that passes through) 99.97% of particles that have a size of 0.3 µm.

Electrostatic Precipitators (ESPs)

- An ESP is a particle control device that uses electrical forces to move the particles out of the flowing gas stream and onto collector plates.
- The ESP places electrical charges on the particles, causing them to be attracted to oppositely charged metal plates located in the precipitator.

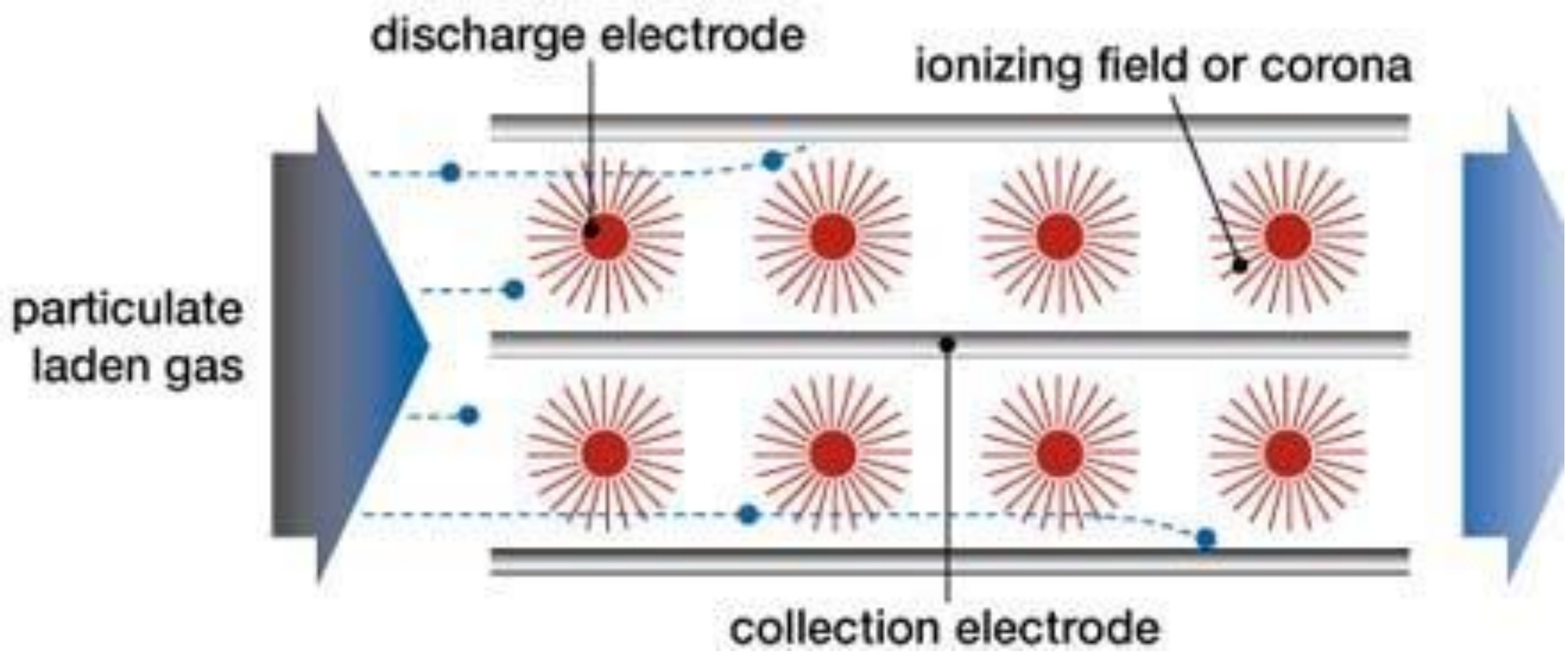
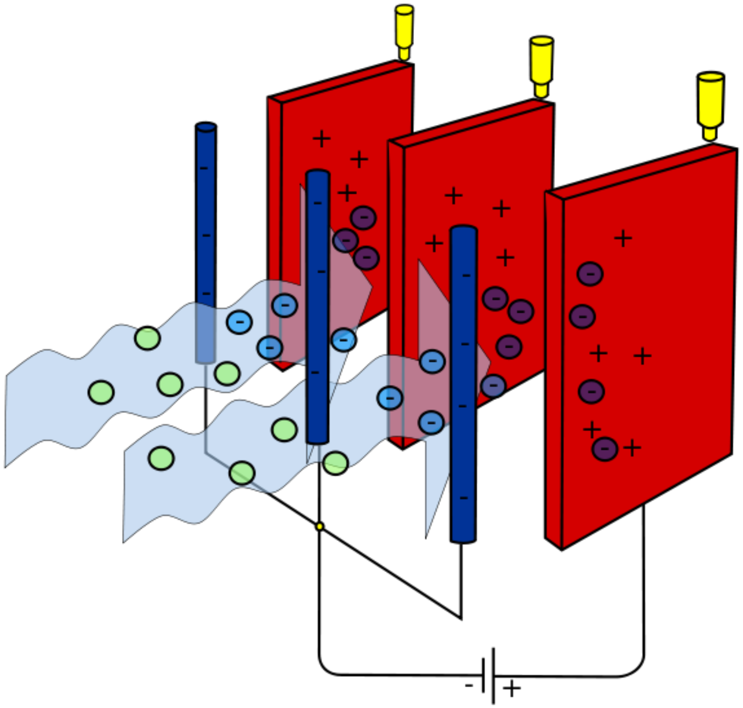
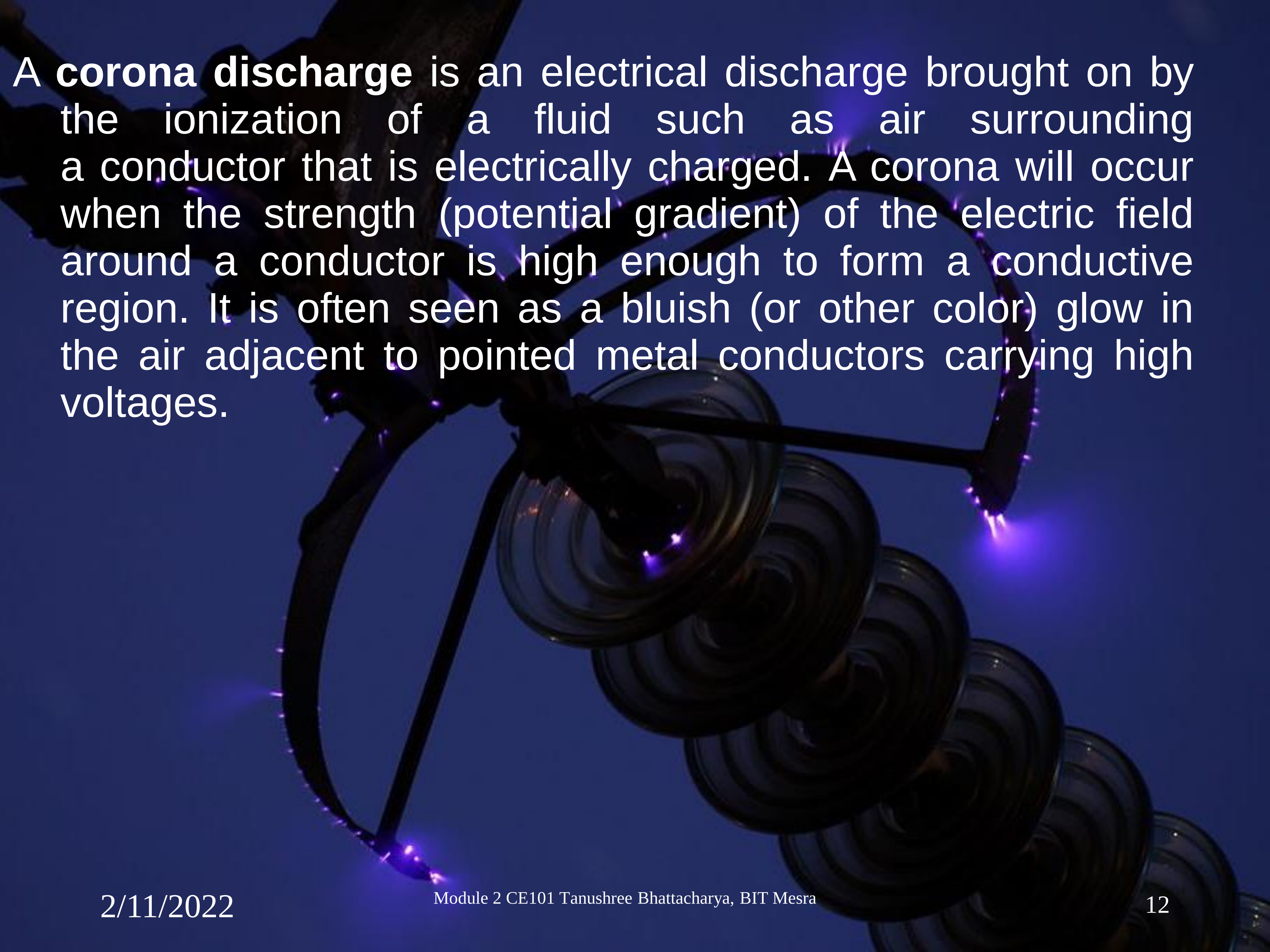


Figure: Electrostatic precipitator components

ESP….



- The most basic precipitator contains a row of thin vertical wires, followed by a stack of large flat metal plates oriented vertically, with the plates typically spaced about 1 cm to 18 cm apart, depending on the application. The air stream flows horizontally through the spaces between the wires, and then passes through the stack of plates.
- A negative voltage of several thousand volts is applied between wire and plate. If the applied voltage is high enough, an electric corona discharge ionizes the air around the electrodes, which then ionizes the particles in the air stream.
- The ionized particles, due to the electrostatic force, are diverted towards the grounded plates. Particles build up on the collection plates and are removed from the air stream



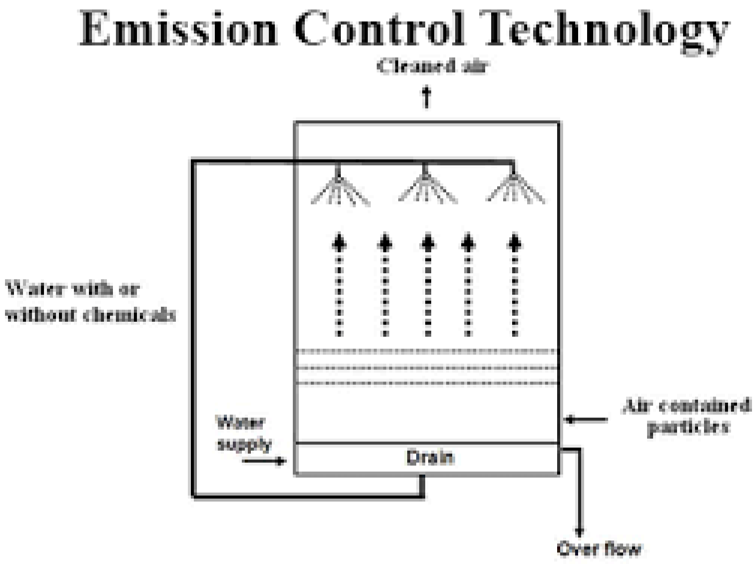
A **corona discharge** is an electrical discharge brought on by the ionization of a fluid such as air surrounding a conductor that is electrically charged. A corona will occur when the strength (potential gradient) of the electric field around a conductor is high enough to form a conductive region. It is often seen as a bluish (or other color) glow in the air adjacent to pointed metal conductors carrying high voltages.

Conti….

- The particles are removed from the plates by "rapping" and collected in a hopper located below the unit.
- The removal efficiencies for ESPs are highly variable; however, for very small particles alone, the removal efficiency is about 99 percent.
- Electrostatic precipitators are not only used in utility applications but also other industries (for other exhaust gas particles) such as cement (dust), pulp & paper (salt cake & lime dust), petrochemicals (sulfuric acid mist), and steel (dust & fumes).

Scrubbers

- Scrubbers are air pollution control devices that use liquid to remove particulate matter or gases from an industrial exhaust or flue gas stream. This atomized liquid (typically water) entrains particles and pollutant gases in order to effectively wash them out of the gas flow.



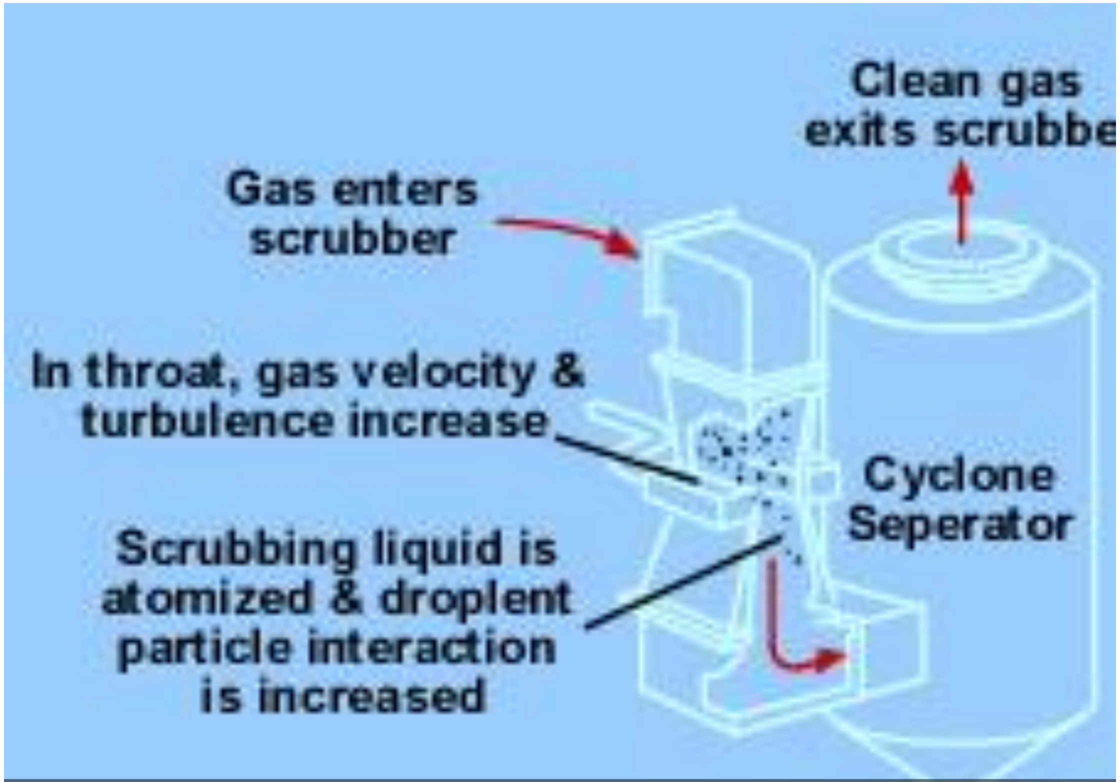


Figure: Venturi scrubber components

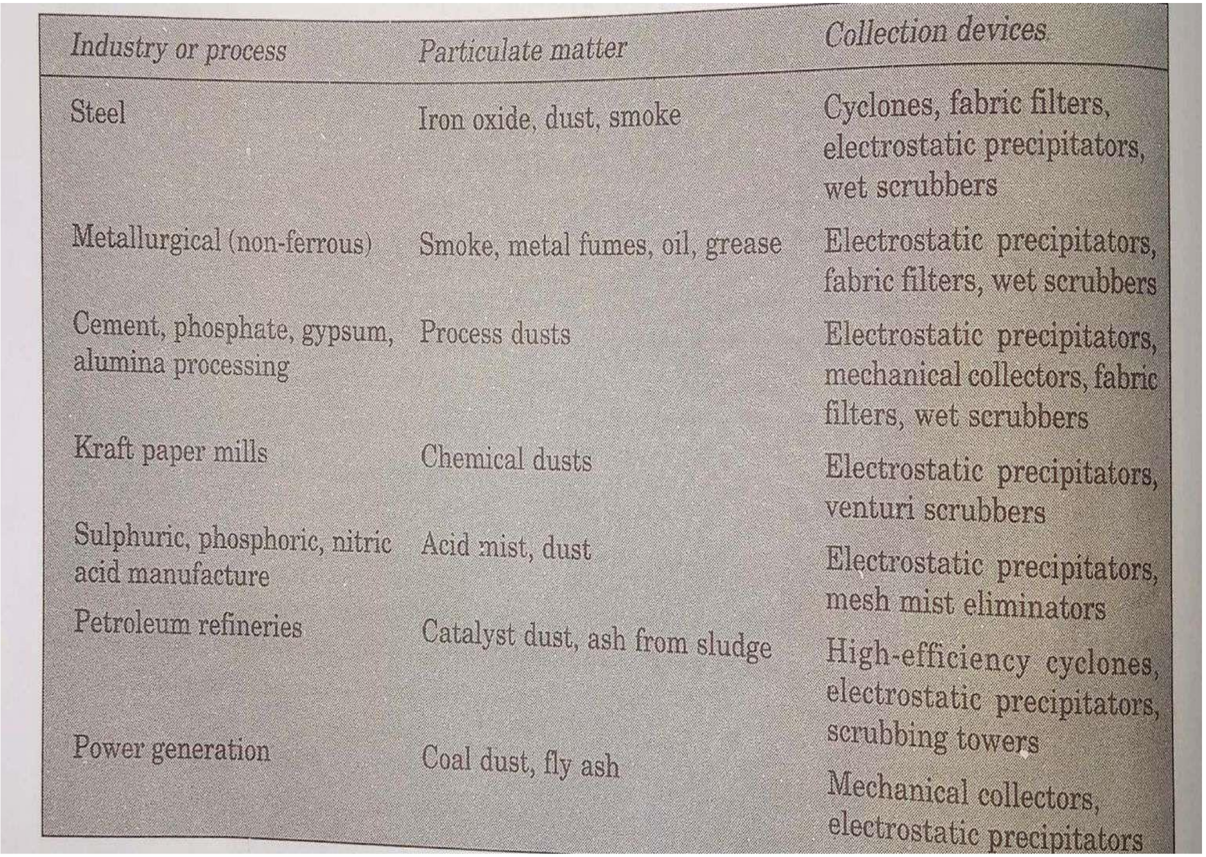
Venturi Scrubbers

- Venturi scrubbers use a liquid stream to remove solid particles.
- In the venturi scrubber, gas laden with particulate matter passes through a short tube with flared ends and a constricted middle.
- This constriction causes the gas stream to speed up when the pressure is increased.

Conti….

- The difference in velocity and pressure resulting from the constriction causes the particles and water to mix and combine.
- The reduced velocity at the expanded section of the throat allows the droplets of water containing the particles to drop out of the gas stream.
- Venturi scrubbers are effective in removing small particles, with removal efficiencies of up to 99 percent.
- One drawback of this device, however, is the production of wastewater.

Particulate collectors in industry



Industry or process	*Particulate matter*	*Collection devices*
Steel	Iron oxide, dust, smoke	Cyclones, fabric filters, electrostatic precipitators, wet scrubbers
Metallurgical (non-ferrous)	Smoke, metal fumes, oil, grease	Electrostatic precipitators, fabric filters, wet scrubbers
Cement, phosphate, gypsum, alumina processing	Process dusts	Electrostatic precipitators, mechanical collectors, fabric filters, wet scrubbers
Kraft paper mills	Chemical dusts	Electrostatic precipitators, venturi scrubbers
Sulphuric, phosphoric, nitric acid manufacture	Acid mist, dust	Electrostatic precipitators, mesh mist eliminators
Petroleum refineries	Catalyst dust, ash from sludge	High-efficiency cyclones, electrostatic precipitators, scrubbing towers
Power generation	Coal dust, fly ash	Mechanical collectors, electrostatic precipitators

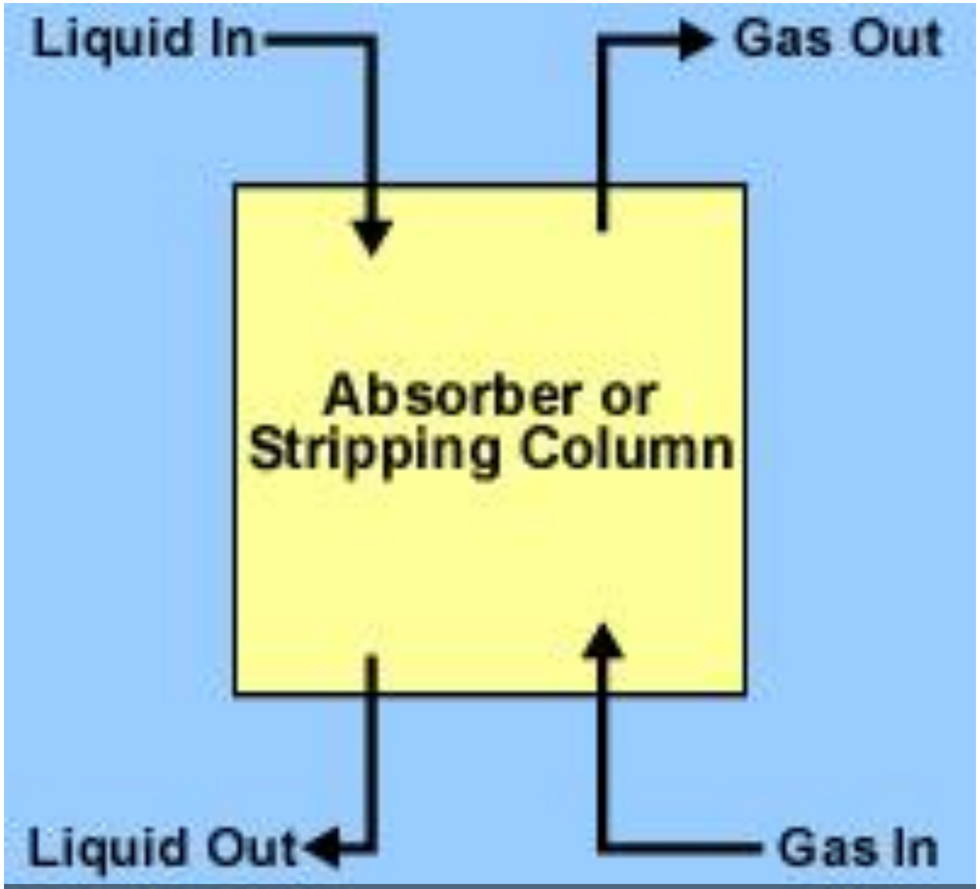
- Source: Environmental Engineering by C S Rao

Control of gaseous pollutants from stationary sources

- The most common method for controlling gaseous pollutants is the addition of add-on control devices to recover or destroy a pollutant.
- There are four commonly used control technologies for gaseous pollutants:
  - Absorption,
  - Adsorption,
  - Condensation, and
  - Incineration (combustion)

Absorption

- The removal of one or more selected components from a gas mixture by absorption is probably the most important operation in the control of gaseous pollutant emissions.
- Absorption is a process in which a gaseous pollutant is dissolved in a liquid.
- Water is the most commonly used absorbent liquid.
- As the gas stream passes through the liquid, the liquid absorbs the gas.



Typical Packed Column Diagram

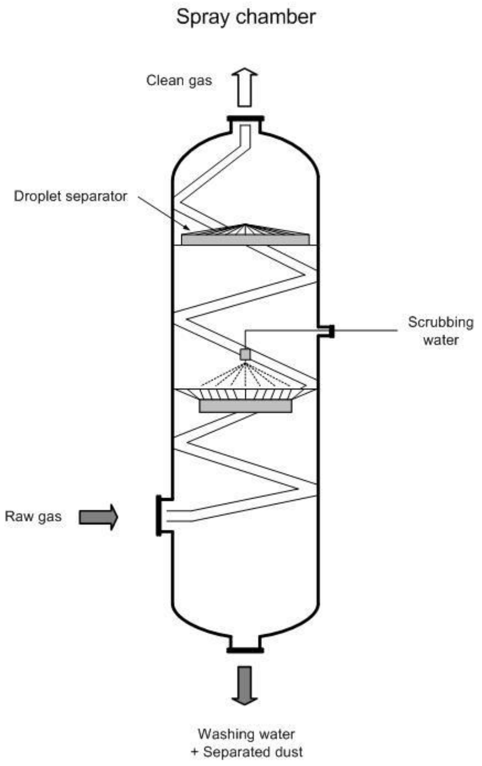
Conti….

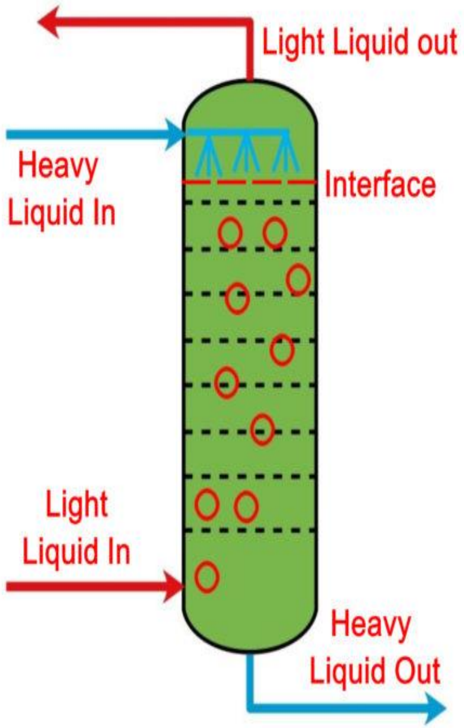
- Absorbers are often referred to as scrubbers, and there are various types of absorption equipment.

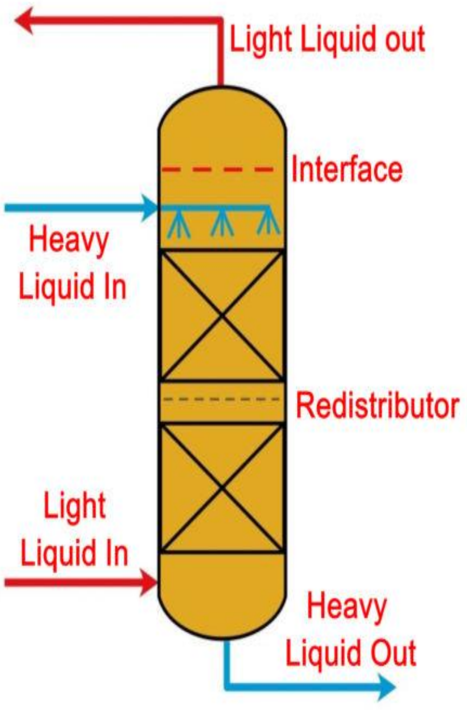
- The principal types of gas absorption equipment include spray towers, packed columns, spray chambers, and venturi scrubbers.

- In general, absorbers can achieve removal efficiencies grater than 95 percent. One potential problem with absorption is the generation of waste-water, which converts an air pollution problem to a water pollution problem.

Spray towers, spray chambers

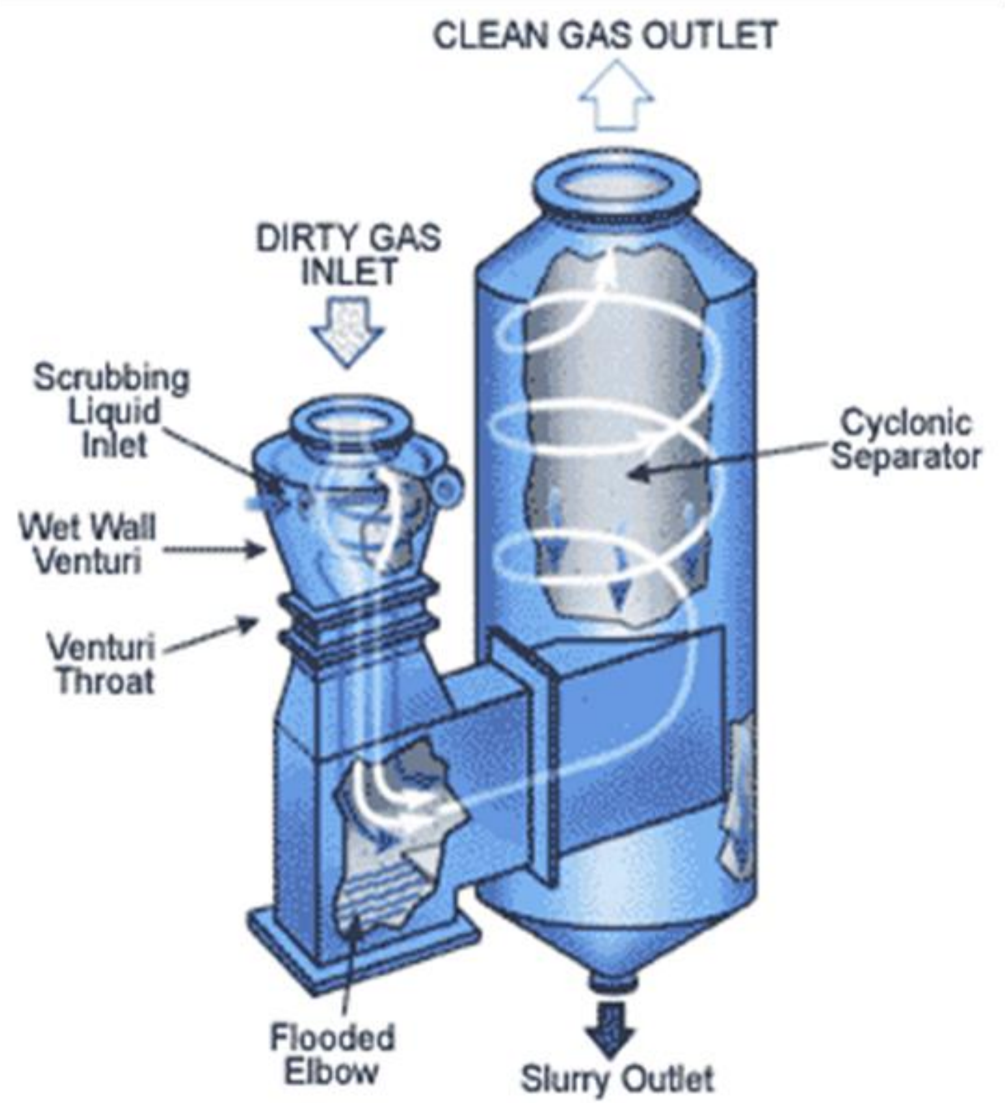




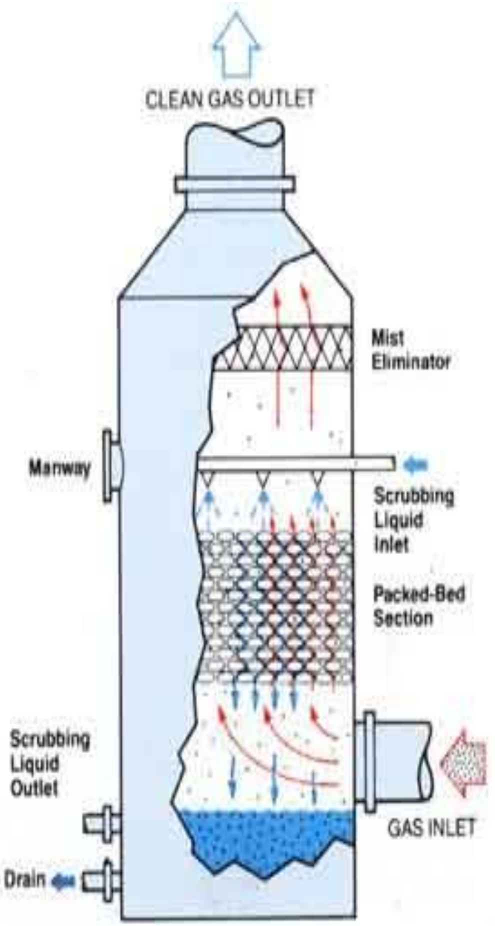


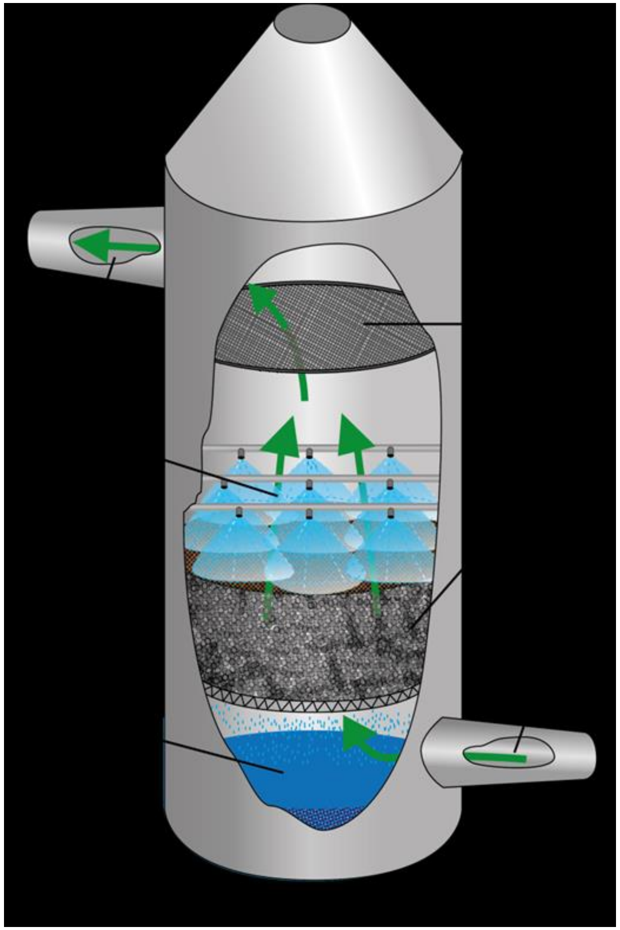
Spray tower

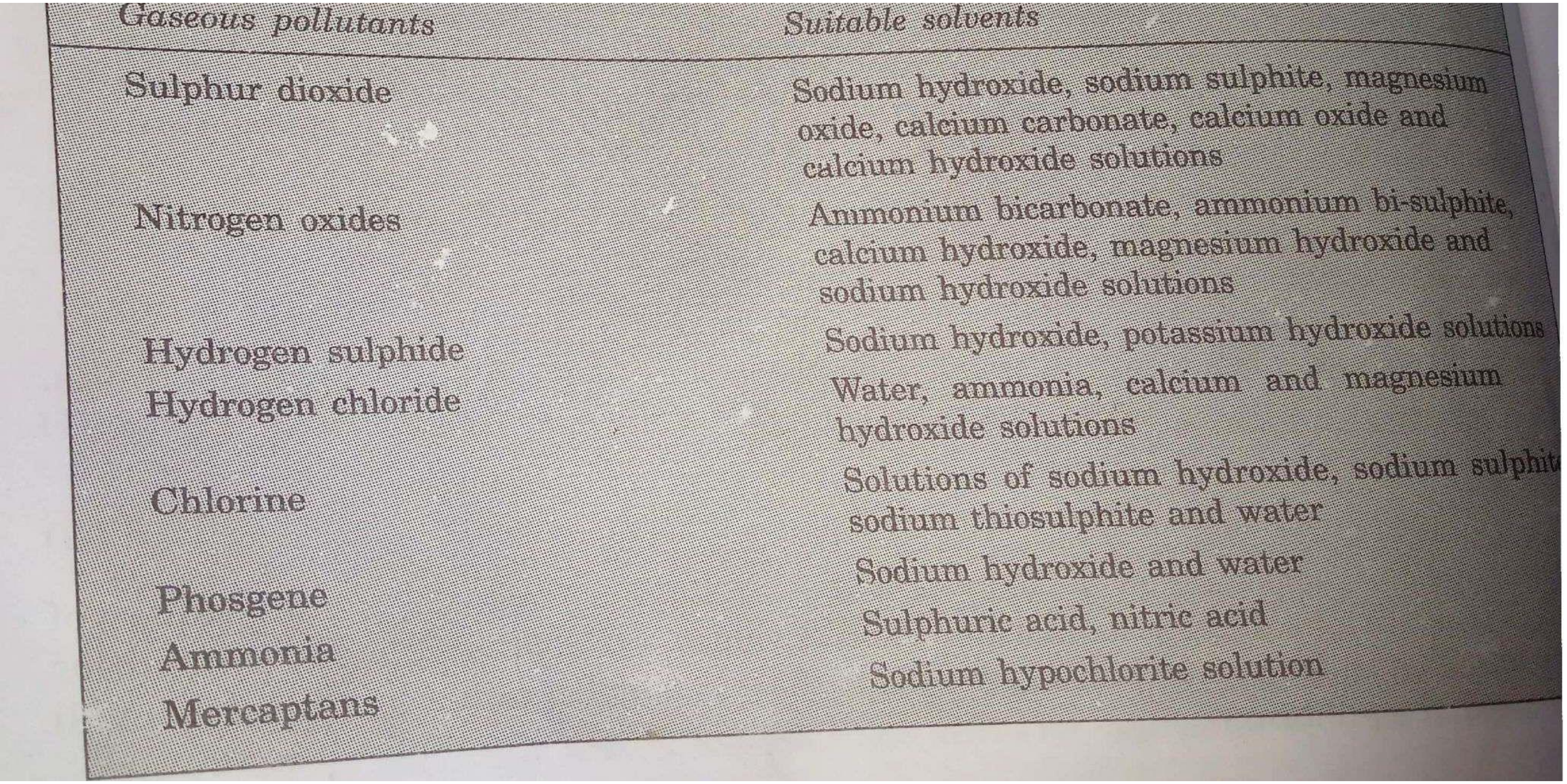
Venturi scrubbers



Packed scrubber







Gaseous pollutants	Suitable solvents
Sulphur dioxide	Sodium hydroxide, sodium sulphite, magnesium oxide, calcium carbonate, calcium oxide and calcium hydroxide solutions
Nitrogen oxides	Ammonium bicarbonate, ammonium bi-sulphite, calcium hydroxide, magnesium hydroxide and sodium hydroxide solutions
Hydrogen sulphide	Sodium hydroxide, potassium hydroxide solutions
Hydrogen chloride	Water, ammonia, calcium and magnesium hydroxide solutions
Chlorine	Solutions of sodium hydroxide, sodium sulphit sodium thiosulphite and water
Phosgene	Sodium hydroxide and water
Ammonia	Sulphuric acid, nitric acid
Mercaptans	Sodium hypochlorite solution

Suitable solvents for various gaseous pollutants

- Source: Environmental Engineering by C S Rao

Adsorption

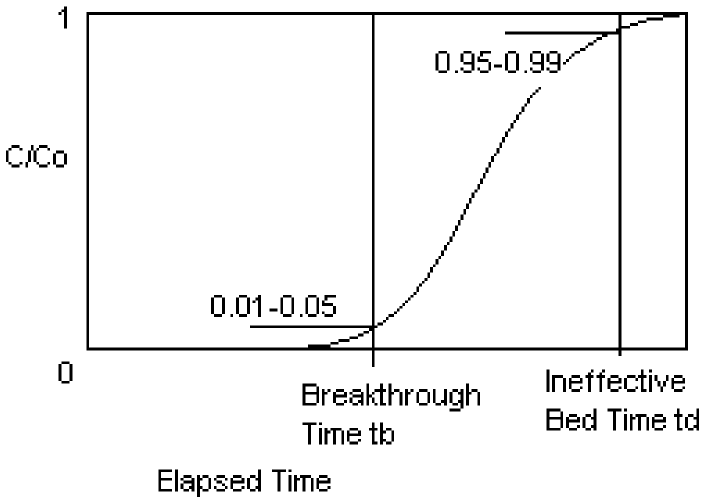
When a gas or vapor is brought into contact with a solid, part of it is taken up by the solid. The molecules that disappear from the gas either enter the inside of the solid or remain on the outside attached to the surface. The former phenomenon is termed absorption (or dissolution) and the latter adsorption.

The most common industrial adsorbents are activated carbon, silica gel, and alumina, because they have enormous surface areas per unit weight.

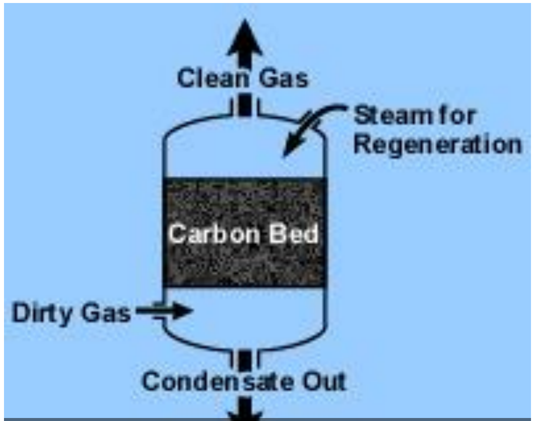
Activated carbon is the universal standard for purification and removal of trace organic contaminants from liquid and vapor streams.

Adsorption

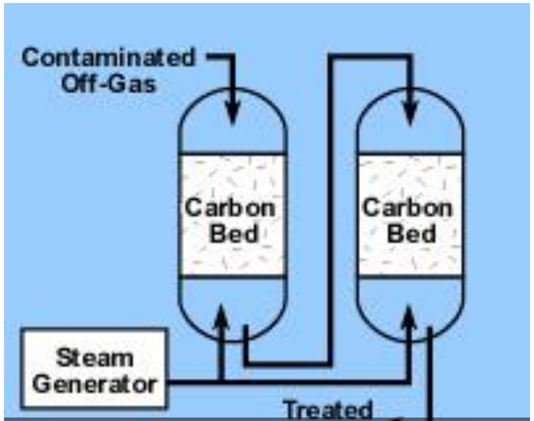
- Physi-sorption
- Chemisorption
- Break through curve



- Carbon adsorption systems are either regenerative or non-regenerative.
  - **Regenerative system** usually contains more than one carbon bed. As one bed actively removes pollutants, another bed is being regenerated for future use.
  - **Non-regenerative systems** have thinner beds of activated carbon. In a non-regenerative adsorber, the spent carbon is disposed of when it becomes saturated with the pollutant.



Non-Regenerative Carbon Adsorption System



Regenerative Carbon Adsorption System

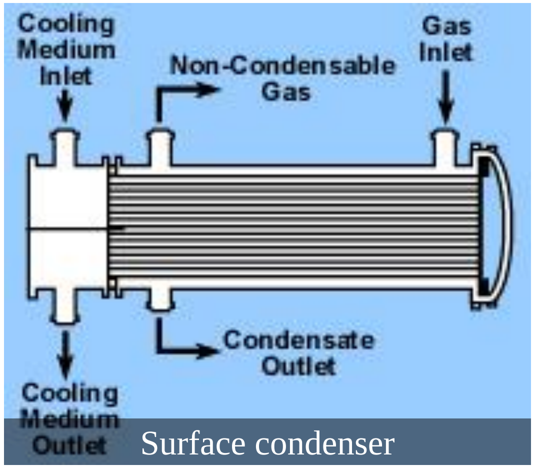
Condensation

- Condensation is the process of converting a gas or vapor to liquid. Any gas can be reduced to a liquid by lowering its temperature and/or increasing its pressure.

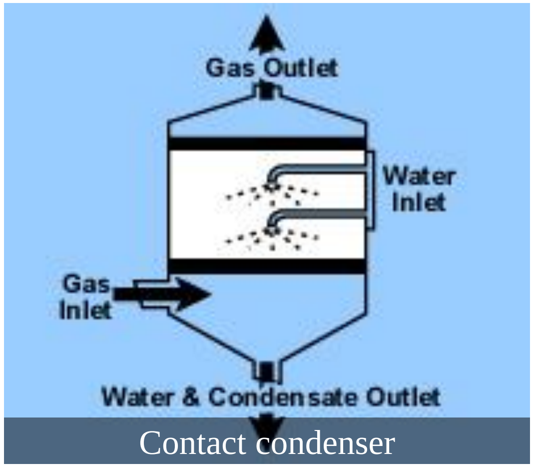
- Condensers are typically used as pretreatment devices. They can be used ahead of absorbers, adsorbers, and incinerators to reduce the total gas volume to be treated by more expensive control equipment. Condensers used for pollution control are contact condensers and surface condensers.

Types of condensers

- **In a contact condenser**, the gas comes into contact with cold liquid.
- In a **surface condenser**, the gas contacts a cooled surface in which cooled liquid or gas is circulated, such as the outside of the tube.
- Removal efficiencies of condensers typically range from 50 percent to more than 95 percent, depending on design and applications.



Surface condenser



Contact condenser

Incineration

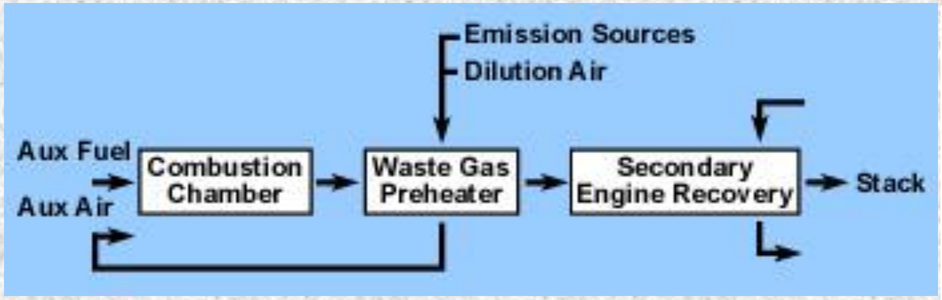
- Incineration, also known as combustion, is most used to control the emissions of organic compounds from process industries.
- This control technique refers to the rapid oxidation of a substance through the combination of oxygen with a combustible material in the presence of heat.
- When combustion is complete, the gaseous stream is converted to carbon dioxide and water vapor.
- Equipment used to control waste gases by combustion can be divided in three categories:
  - Direct combustion or flaring,
  - Thermal incineration and
  - Catalytic incineration.

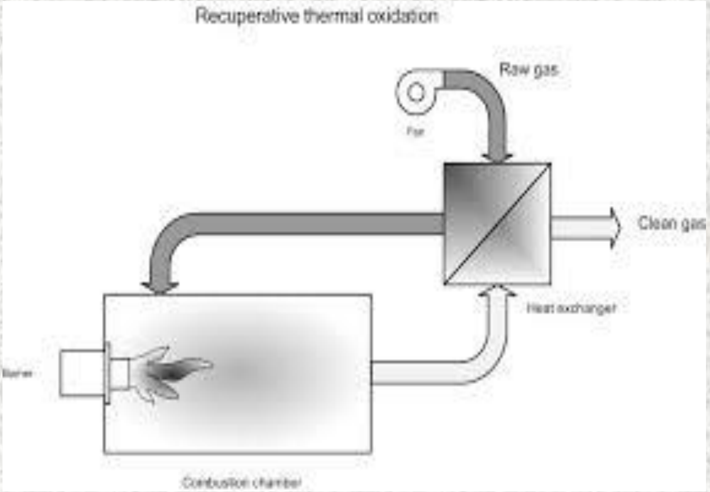
Direct combustor

- **Direct combustor** is a device in which air and all the combustible waste gases react at the burner. Complete combustion must occur instantaneously since there is no residence chamber.
- A flare can be used to control almost any emission stream containing volatile organic compounds. Studies conducted by EPA have shown that the destruction efficiency of a flare is about 98 percent.

In **thermal incinerators** the combustible waste gases pass over or around a burner flame into a residence chamber where oxidation of the waste gases is completed.

Thermal incinerators can destroy gaseous pollutants at efficiencies of greater than 99 percent when operated correctly.

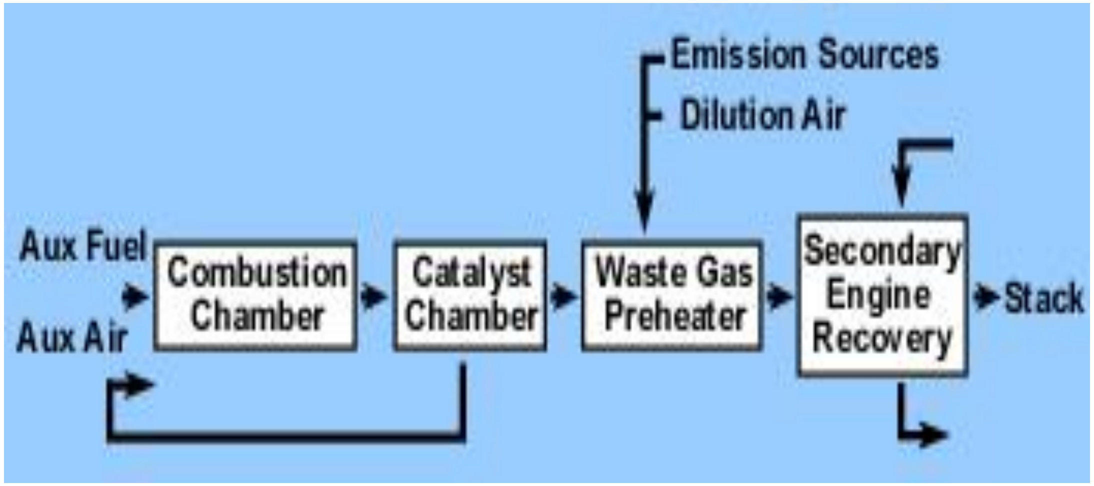




Catalytic incinerators are very similar to thermal incinerators. The main difference is that after passing through the flame area, the gases pass over a catalyst bed.

A catalyst promotes oxidation at lower temperatures, thereby reducing fuel costs. Destruction efficiencies greater than 95 percent are possible using a catalytic incinerator.

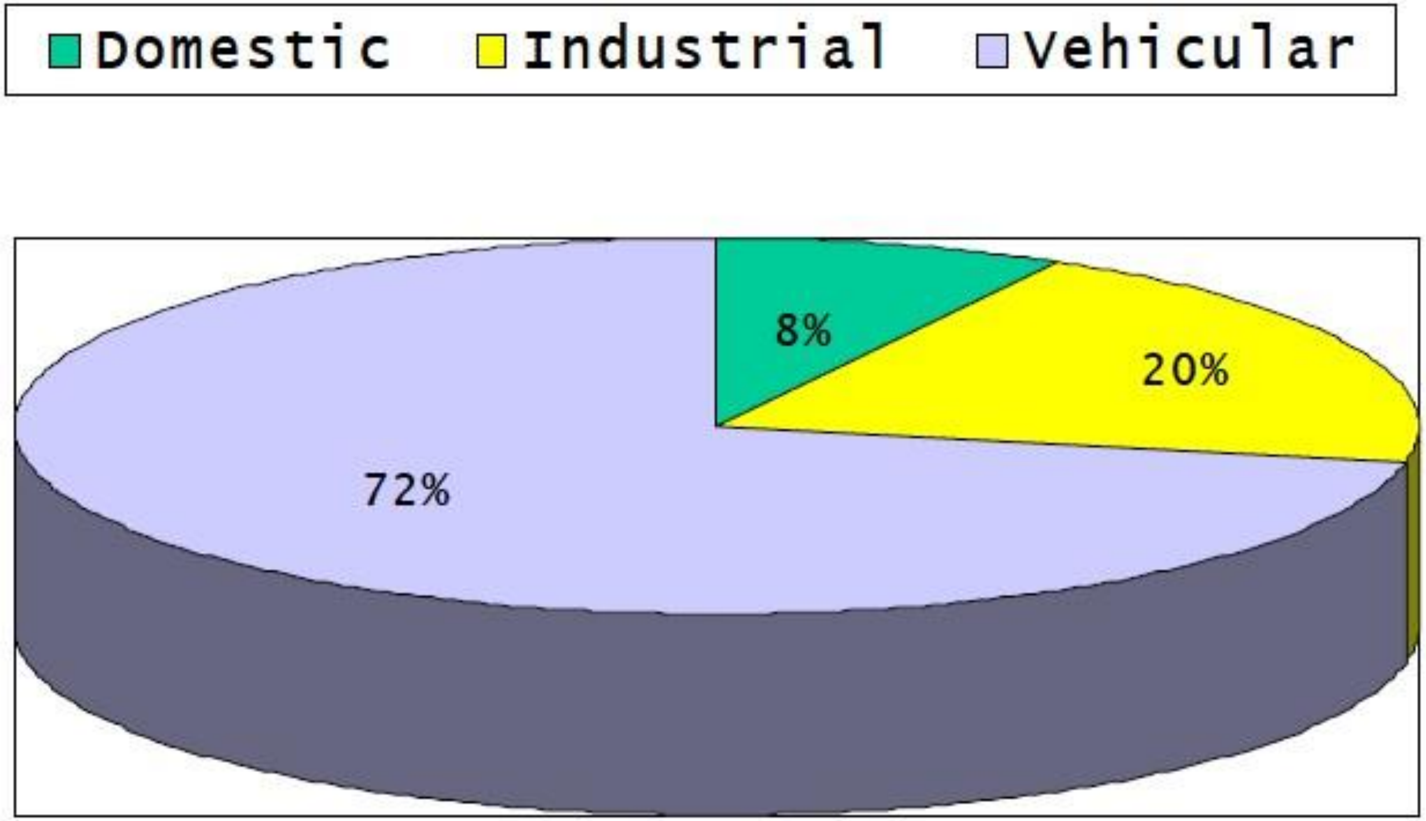
- Catalytic incinerator



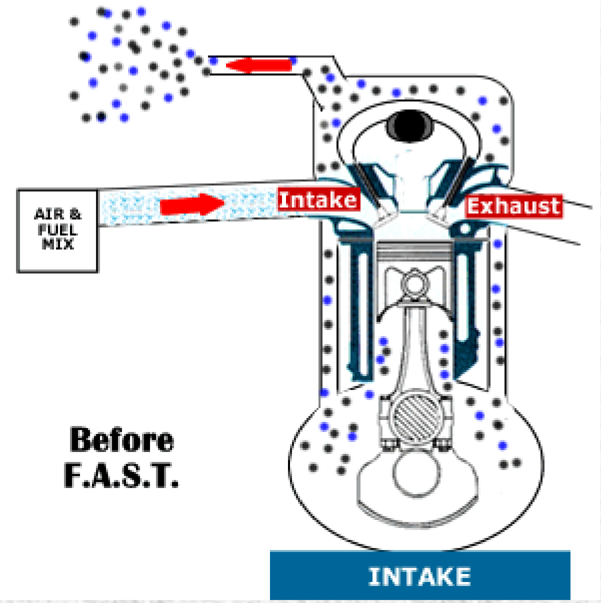
Vehicular emission control

- Phasing out of tetra ethyle lead as anti knocking compound.
- Engines can be made more efficient so that they can ensure more complete combustion. E.g four stroke engines
- Proper fuel and air ratio should be maintained by the engines and ignition system, which will ensure complete combustion.
- Filters and catalytic converters should be used in the emission system.
- Efficient carburetor system.
- Recirculation of the exhaust gas.
- Use of cleaner fuel.
- Non emitting vehicles.
- Biodisel/ biofuels.

CONTRIBUTION OF VARIOUS SECTORS TO AMBIENT AIR QUALITY IN MAJOR CITIES



Engine Modification Related to Emission Control



Lower Compression Ratios

- Use of unleaded gasoline that permits use of catalytic converters and burns completely to lower **HC** emissions.
- Lower combustion temperature = Lower **NOx** emissions.

Smaller Combustion Chamber Surface Volume

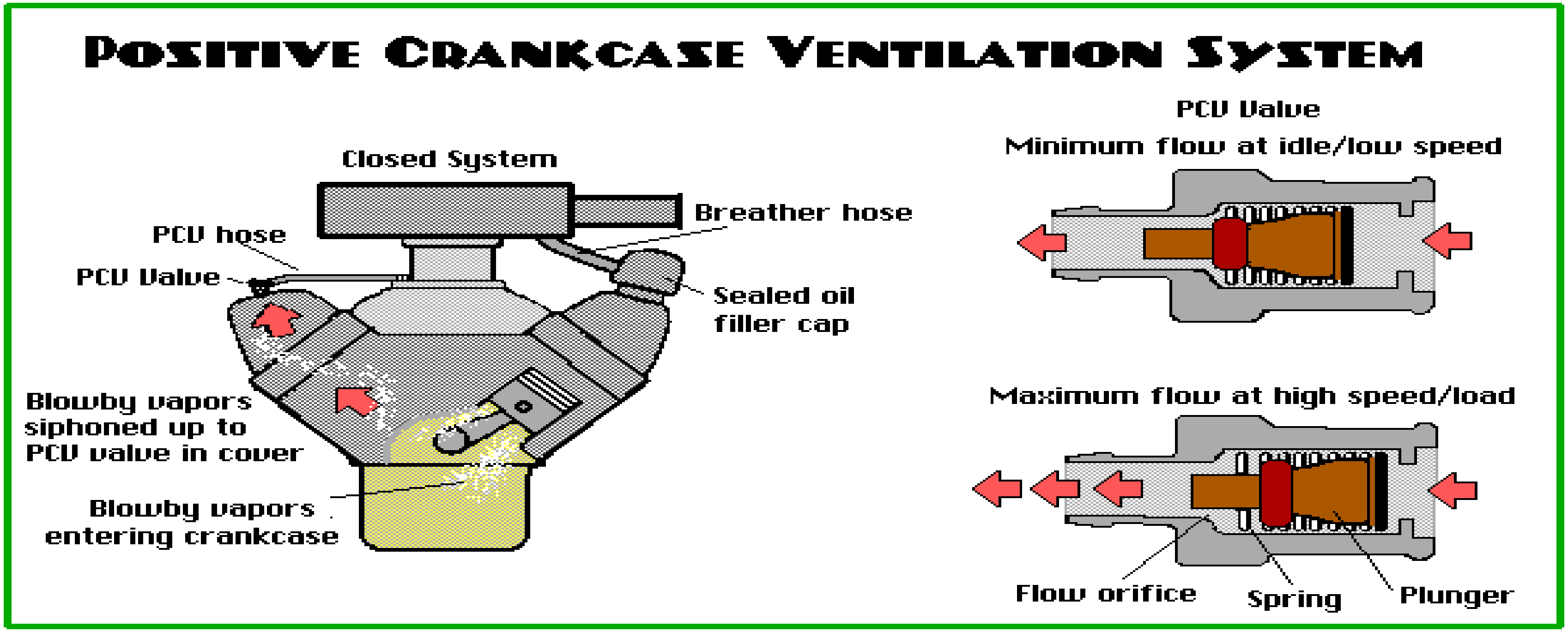
- Reduce **HC** emissions.
- Lowers the amount of heat dissipation out of the fuel mixture.
- Reduce the chance of fuel condensation.

Reduce Quench Areas in the Combustion Chambers

- Lower **HC** and **CO** emissions.
- *Quench areas-* movement of piston too close to the cylinder head.
- If too close, it tends to quench *(put out)* combustion and increase emissions due to unburned fuel.

Vehicle Emission Control System

PCV (Positive Crankcase Ventilation System)



- Uses engine vacuum to draw blow-by gases into the intake manifold for reburning in the combustion chamber.
- Vacuum or electronic controlled, mounted on the valve cover.

Vehicle Emission Control System

Evaporative Emission Control Systems (EVAP)

- Prevents toxic fuel system vapours from entering the atmosphere.

Parts

- **Non-vented fuel tank cap** – prevents fuel vapours from entering the atmosphere.

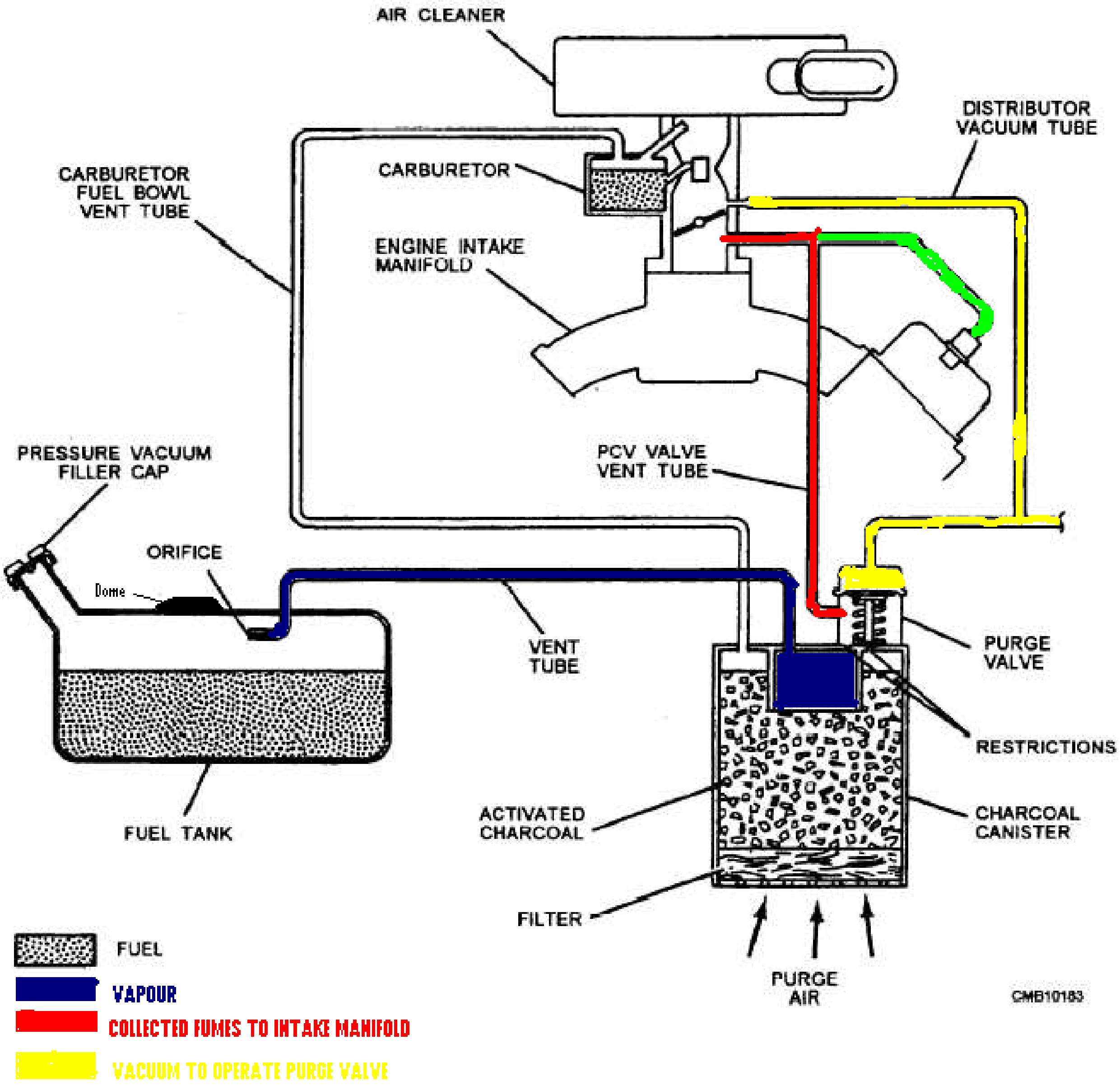
- **Air Dome** – hump formed at the top of the tank for fuel expansion.

- **Charcoal Canister** – stores vapours when the engine is not running.
  - filled with active charcoal granules.
  - charcoal is capable of absorbing fuel vapours.

- **Purge Line/Valve** – controls the flow of vapours from the canister to the intake manifold.
  - allows flow when engine reaches operating temperature and is operating above idle speed.

Clean canister filter time to time.

Evaporative Emission Control Systems (EVAP)

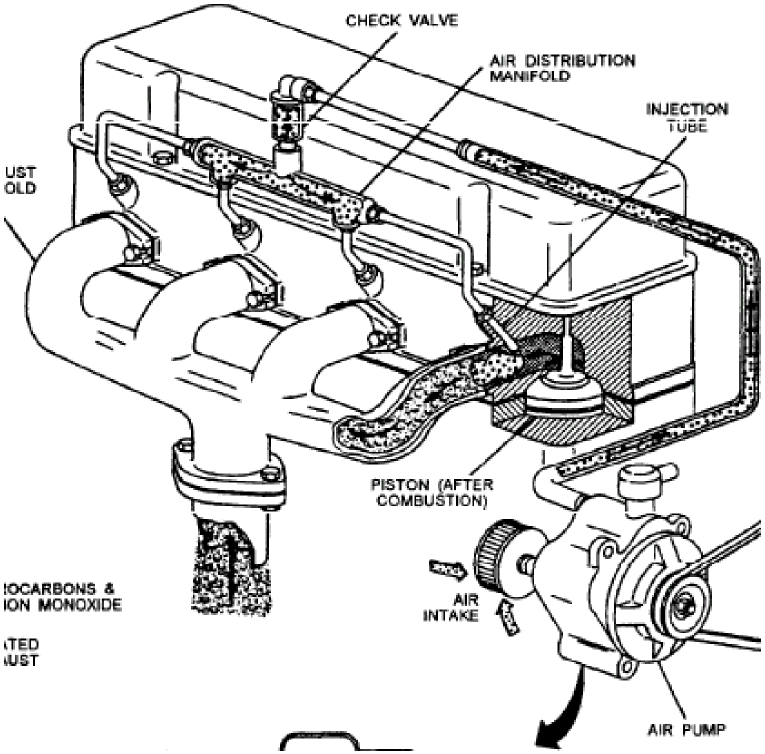


Vehicle Emission Control System

- **Exhaust Gas Recirculation (EGR)**
  - Allows burned gases to enter the engine intake manifold to help reduce **NOx**
  - When exhaust gases are added to air-fuel mixture, they decrease peak
  - combustion temperatures.

Vehicle Emission Control System

- **Air Injection System**
    - Forces fresh air into the exhaust ports or catalytic converter to reduce **HC/CO**.
    - Oxygen from the air injection system causes the unburned fuel to burn in the
    - exhaust system or the catalytic converter.



Catalytic Converters

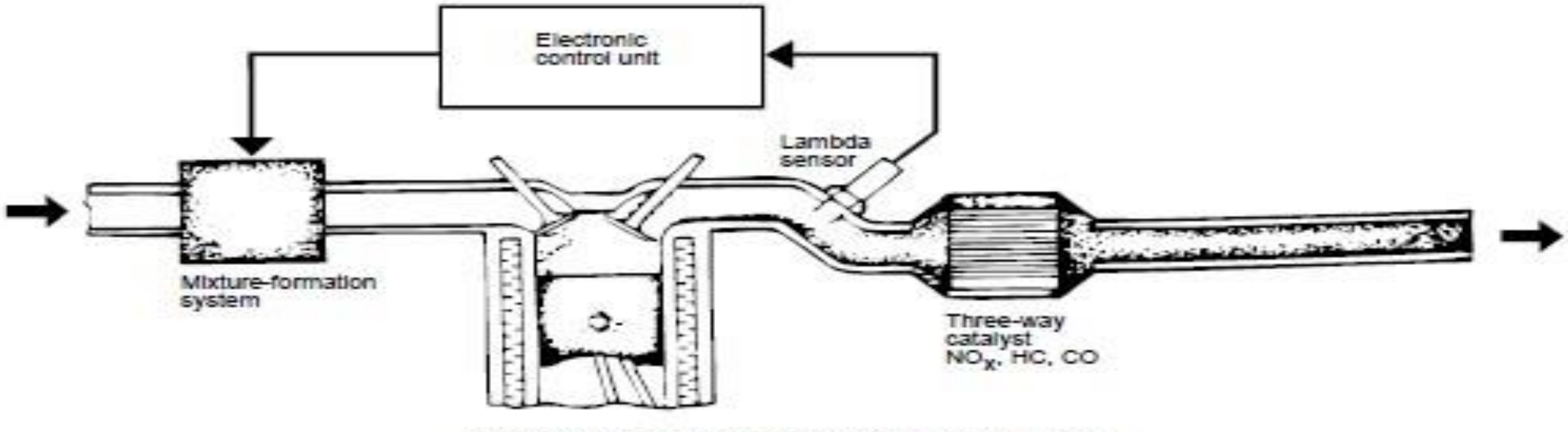
- catalytic converter processes exhaust to remove pollutants, achieving considerably lower emissions than is possible with in-cylinder techniques
- **Reduction catalyst** is the **FIRST STAGE**

$$2NO \Rightarrow N_2 + O_2 \quad \text{or} \quad 2NO_2 \Rightarrow N_2 + 2O_2$$

- **Oxidation catalyst** is the **SECOND STAGE**

$$2CO + O_2 \Rightarrow 2CO_2$$

- **THIRD STAGE** of conversion is a control system that monitors the exhaust stream, and uses this information to control the fuel injection system



SINGLE BED THREE-WAY CATALYTIC CONVERTER

Fuel Quality

- Adulterated fuel increases tailpipe emissions of hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x) and particulate matter (PM).

In order to take preventive measures:

- Introduce early policies to lower sulfur levels to 50ppm for diesel and 150 ppm for petrol
- Encourage to use advanced control technologies for diesel vehicles.
- Increase the use of bio fuels and alternative fuels
- Biodiesel
- Ethanol
- Biogas
- LPG

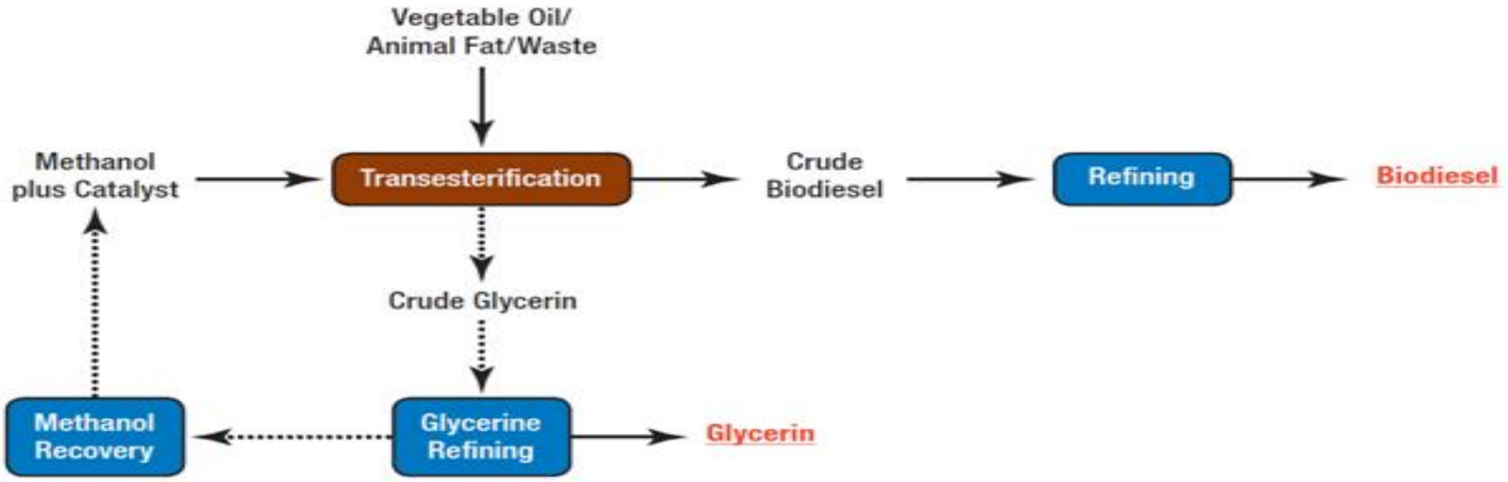
BIODIESEL

- Produced from oils or fats using transesterification
- usually used as a diesel additive to reduce levels of particulates, carbon monoxide, and hydrocarbons from diesel-powered vehicles

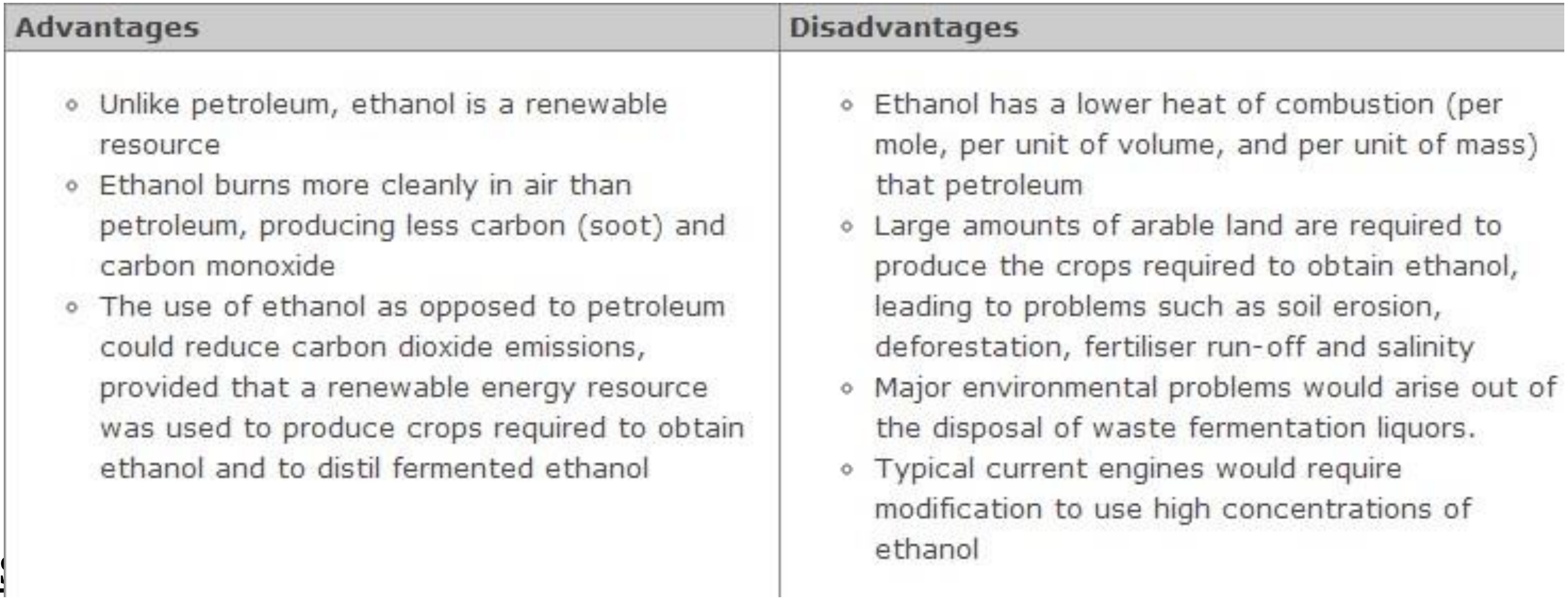
BENEFITS

- **Greater lubricity**, or smoothness, reduces friction
- **Reduced emissions** improve living and working environments
- M

Schematic of Biodiesel Production Path



ETHANOL



Advantages	Disadvantages
◦ Unlike petroleum, ethanol is a renewable resource ◦ Ethanol burns more cleanly in air than petroleum, producing less carbon (soot) and carbon monoxide ◦ The use of ethanol as opposed to petroleum could reduce carbon dioxide emissions, provided that a renewable energy resource was used to produce crops required to obtain ethanol and to distil fermented ethanol	◦ Ethanol has a lower heat of combustion (per mole, per unit of volume, and per unit of mass) that petroleum ◦ Large amounts of arable land are required to produce the crops required to obtain ethanol, leading to problems such as soil erosion, deforestation, fertiliser run-off and salinity ◦ Major environmental problems would arise out of the disposal of waste fermentation liquors. ◦ Typical current engines would require modification to use high concentrations of ethanol

BIOGAS

Produced by anaerobic digestion with anaerobic bacteria or fermentation of biodegradable materials

- Increased energy security
- Fewer emissions
- Better economics
- Cleaner environment

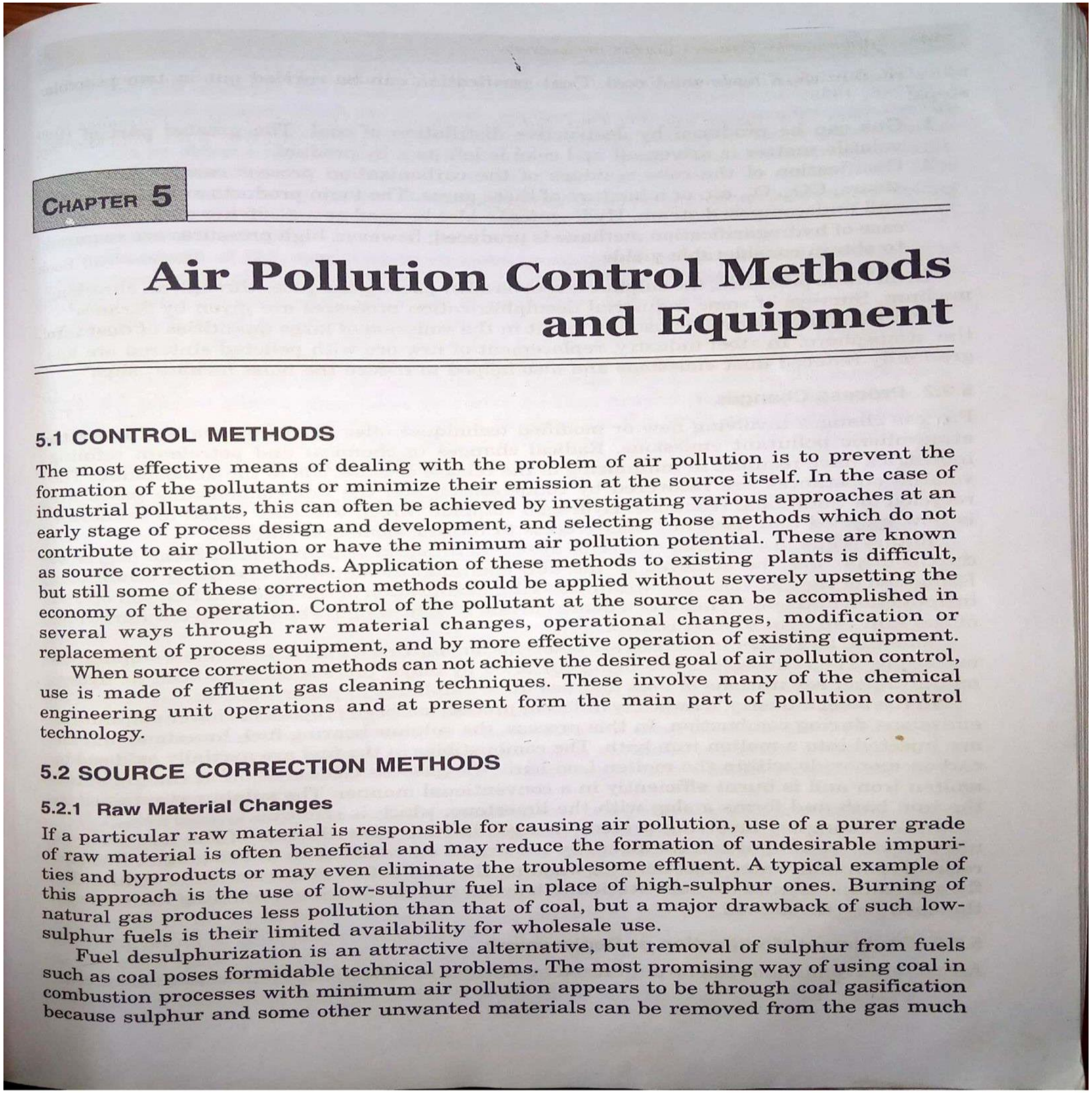
Zero-Emission Vehicles

- A zero-emissions vehicle, or ZEV, is a vehicle that emits no tailpipe pollutants from the onboard source of power

EXAMPLES

- Muscle-powered vehicles such as bicycles
- battery electric vehicles
- fuel cell vehicles powered by hydrogen

Reading material



CHAPTER 5

Air Pollution Control Methods and Equipment

5.1 CONTROL METHODS

The most effective means of dealing with the problem of air pollution is to prevent the formation of the pollutants or minimize their emission at the source itself. In the case of industrial pollutants, this can often be achieved by investigating various approaches at an early stage of process design and development, and selecting those methods which do not contribute to air pollution or have the minimum air pollution potential. These are known as source correction methods. Application of these methods to existing plants is difficult, but still some of these correction methods could be applied without severely upsetting the economy of the operation. Control of the pollutant at the source can be accomplished in several ways through raw material changes, operational changes, modification or replacement of process equipment, and by more effective operation of existing equipment.

When source correction methods can not achieve the desired goal of air pollution control, use is made of effluent gas cleaning techniques. These involve many of the chemical engineering unit operations and at present form the main part of pollution control technology.

5.2 SOURCE CORRECTION METHODS

5.2.1 Raw Material Changes

If a particular raw material is responsible for causing air pollution, use of a purer grade of raw material is often beneficial and may reduce the formation of undesirable impurities and byproducts or may even eliminate the troublesome effluent. A typical example of this approach is the use of low-sulphur fuel in place of high-sulphur ones. Burning of natural gas produces less pollution than that of coal, but a major drawback of such low-sulphur fuels is their limited availability for wholesale use.

Fuel desulphurization is an attractive alternative, but removal of sulphur from fuels such as coal poses formidable technical problems. The most promising way of using coal in combustion processes with minimum air pollution appears to be through coal gasification because sulphur and some other unwanted materials can be removed from the gas much more readily than from solid coal. Coal gasification can be carried out in two possible steps:

1. Gas can be produced by destructive distillation of coal. The greater part of the volatile matter is driven off and coke is left as a by-product.
2. Gasification of the coke residues of the carbonisation process can be done with steam, CO_2, O_2, air, or a mixture of these gases. The main products are H_2, CO, CO_2 and undecomposed steam. Hydrogen can also be used as a gasifying medium. In the case of hydrogasification methane is produced; however, high pressures are required to obtain considerable yields.

In all these processes, the sulphur is recovered by passing the gases through an absorbing medium. Surveys of some industrial desulphurization processes are given by Strauss[1].

Ore handling operations usually result in the emission of large quantities of dust into the atmosphere. In steel industry, replacement of raw ore with pelleted sintered ore has gradually reduced dust emissions and also helped to reduce the blast furnace "slips".

5.2.2 Process Changes

Process changes involving new or modified techniques offer important ways of lowering atmospheric pollutant emissions. Radical changes in chemical and petroleum refining industries have resulted in minimizing of the release of materials to the atmosphere. The volatile substances are recovered by condensation and the non-condensable gases are recycled for additional reactions. Hydrogen sulphide, which was once flared in refineries, is now recycled and used in Claus process to recover elemental sulphur.

Rotary kilns are a major source of dust generation in cement plants. Some degree of dust control may be achieved in the kiln operation by adjusting operating conditions. Reduction of the gas velocities within the kiln, modification of the rate and location of feed introduction and employment of a dense curtain of light-weight chain at the discharge end of the kiln can lead to dust control.

Smelting and paper industries are notorious for emitting highly objectionable sulphurous materials. These emissions are being curtailed by major process changes such as hydro-metallurgical separations of ores and use of no sulphides in paper making.

In the steel industry, a radically different process has been proposed to lower sulphurous emissions during combustion. In this process, the sulphur bearing fuel, limestone and air are injected into a molten iron bath. The combustibles in the fuel are partially oxidised to carbon monoxide within the molten iron bath; the gaseous CO comes off at the top of the molten iron and is burnt efficiently in a conventional manner. The sulphur is retained in the iron bath and forms a slag with the limestone, which is removed.

Other examples involving process changes include: (1) reduction of the formation of nitric oxides in combustion chambers by low excess air combustion in two stages, flue gas recirculation and water injection, (2) washing the coal before pulverization to reduce the fly ash emissions, and (3) substitution of bauxite flux for fluorine containing fluorspar in the open hearth method.

5.2.3 Equipment Modification or Replacement

Air pollutant emissions can be minimized by suitable modification or replacement of process equipment. For example, the unburnt carbon monoxide and hydrocarbons in the cylinders of an automobile engine, which are otherwise emitted into the atmosphere through the tail pipe, can be burnt by injecting air into the hot exhaust manifold of the engine. Similar results can be obtained by suitable modifications in the carburation and ignition systems.

In petroleum refineries, hydrocarbon vapours are released into the atmosphere from storage tanks due to temperature changes, direct evaporation, and displacement during filling. These losses can be minimized by designing the tanks with floating roof covers or by pressurising the tanks.

Replacement of the open hearth furnace by oxygen furnace in steel industry and development of an alternative power source for automobiles in place of the internal combustion engine are additional examples of equipment alteration.

In addition to the above mentioned source correction methods, air pollutant emissions from industrial operations can be reduced by proper equipment maintenance, housekeeping and cleanliness in the facilities and premises. Often changes in the design of local exhaust hood and proper installation can minimize the emission of pollutants to the atmosphere. Chemical process plants often have excessive leakage around ducts, piping, valves and pumps. Many such leaks can be prevented by checking the seals and gaskets routinely. Floors, decks, storage bins and silos, loading areas, and material transfer conveyors must be kept clean to reduce dust pollution.

5.3 CLEANING OF GASEOUS EFFLUENTS

The technology for the removal of gaseous pollutant emissions after their formation has probably received the maximum attention. The cleaning techniques are applied to those cases where emissions of pollutants can not be prevented and pollution control equipment is necessary to remove them from the main gas stream. Normally, it is more economical to install the control equipment at the source where the pollutants are present in the smallest possible volume in relatively high concentrations rather than at some point away from the source where the pollutants are diluted by other process gases or air. The size of the equipment is directly related to the volume being treated, and equipment costs can be drastically reduced by decreasing the exhaust volume. At the same time, the equipment is more efficient for the handling of higher concentrations of pollutants. Gas cleaning techniques used alone, or in conjunction with source correction methods form the basis of present-day air resource management concepts. The methods are often integrated into chemical processes, which eliminate pollutant discharges and conserve materials in the same unit operation.

Emission control equipment may be classified into two general types: particulate control type, and gases and odours control type. For gaseous pollutants, essentially two alternative classes or methods are available. The first class comprises the wet absorption and dry adsorption methods, and the second class includes methods depending on the chemical alteration of the pollutant, usually through combustion or catalytic incineration. The basic mechanism in all these is the diffusion of the particular gas either to the surface of an absorbing liquid or adsorbing solid or catalyst, or to the reaction zone of a chemical reaction. On the other hand, the removal of particles relies only partly on their diffusion from the gas stream to a collecting surface or space, and other mechanisms which take special advantage of the nature and properties of particulate matter play a more important role.