UNIT–5 AIR POLLUTANTS FROM AUTOMOBILES

The addition of chemicals released from automobile emissions constituting NO_X, HC's, CO, SPM, SO_2, Pb resulting in deterioration of ambient air is termed as automobile pollution. Five of these are also criteria air pollutants.

SOURCE, EFFECT AND CONTROL OF AUTOMOBILE POLLUTANTS

1] **SO2**.

The formation of Sulphur di Oxide in exhaust gases is caused by the oxidation of the sulphur in the fuel during the combustion process. In the atmosphere however, SO2 combines with moisture to form H2SO4, which then falls as acid rain, and has been linked to environmental damage.The major health concerns associated with exposure to high concentrations of SO2 include effects on breathing (decreased lung function), respiratory illness, alterations in pulmonary defences, and aggravation of existing cardiovascular disease. Children, the elderly, and people with asthma, cardiovascular disease or chronic lung disease (such as bronchitis or emphysema), are most susceptible to adverse health effects associated with exposure to SO2.

2] **Pb**.

Exposure to lead mainly occurs through inhalation of air and ingestion of lead in food, paint, water, soil, or dust. Lead accumulates in the body in blood, bone, and soft tissue. Because it is not readily excreted, lead can also affect the kidneys, liver, nervous system, and other organs. Excessive exposure to lead may cause anemia, kidney disease, reproductive disorders, and neurological impairments such as seizures, mental retardation, and/or behavioral disorders. Even at low doses, lead exposure is associated with changes in fundamental enzymatic, energy transfer, and other processes in the body. Fetuses and children are especially susceptible to low doses of lead, often suffering central nervous system damage or slowed growth. Lead may also contribute to osteoporosis in post-menopausal women.

3] **SPM**.

The composition and properties of particulates varies greatly and is therefore difficult to define. Furthermore, there is not a quantitative relationship between the smoke opacity and the particulate emission. Particle emissions from engines can originate from:

a) agglomeration of very small particles of partly burned fuel;
b) partly burned lub oil;
c) ash content of fuel oil and cylinder lub oil; or
d) sulphates and water.

The smaller particles that are likely responsible for adverse health effects because of their ability to reach the lower regions of the respiratory tract. Major concerns for human health from exposure to PM-10 include: effects on breathing and respiratory systems, damage to lung tissue, cancer, and premature death. The elderly, children, and people with chronic lung disease, influenza, or asthma, are especially sensitive to the effects of particulate matter. Acidic PM-10 can also damage human-made materials and is a major cause of reduced visibility.

The most effect method of reducing particulate emissions is to use lighter distillate fuels however, this leads to added expense. Additional reductions in particulate emissions can be achieved by increasing the fuel injection pressure to ensure that optimum air-fuel mixing is achieved, however, as fuel injection pressure increases, the reliability of the equipment decreases. Much research has also been conducted on cyclone separators, which are effective for particle sizes greater than 0.5μm while electrostatic precipitators are more effective, capable of reduction emissions by up to 99%. Unfortunately, precipitators are expensive, prone to clog and are large in size.

4] **Unburnt Hydrocarbons**.

The emission of unburned hydrocarbons (HC) generally results from fuel, which is unburned as a result of insufficient temperature. This often occurs near the cylinder wall (wall quenching) where the temperature of the air/fuel mixture is significantly less than in the centre of the cylinder. Bulk quenching can also occur as a result of insufficient pressure or temperature within the cylinder itself. Still further, HC production may also be a result of poorly designed fuel injection systems, injector needle bounce, excessive nozzle cavity volumes or fuel jets reaching a quench layer.

Volatile Organic Compounds or VOCs are organic chemicals that easily vaporize at room temperature. VOCs include a very wide range of individual substances, such as hydrocarbons (for example benzene and toluene), halocarbons and oxygenates.

Hydrocarbon VOCs are usually grouped into methane and other non-methane VOCs. Methane is an important component of VOCs, its environmental impact principally related to its contribution to global warming and to the production of ground level or lower atmosphere ozone. Most methane is released to the atmosphere via the leakage of natural gas from distribution systems. Benzene, a non-methane hydrocarbon, is a colourless, clear liquid. It is fairly stable but highly volatile, readily evaporating at room temperature. Since 80% of man-made emissions come from petrol-fuelled vehicles, levels of benzene are higher in urban areas than rural areas. Benzene concentrations are highest along urban roadsides. Evaporation of solvents, used for example in paints, cause a release of hydrocarbons, oxygenates and halocarbons to the atmosphere.

Some VOCs are extremely harmful, including the carcinogens benzene, polycyclic aromatic hydrocarbons (PAHs) and 1,3 butadiene. Benzene may increase susceptibility to leukaemia, if exposure is maintained over a period of time. There are several hundred different forms of PAH, and sources can be both natural and man-made processes. PAHs can cause cancer. Sources of 1,3 butadiene include the manufacturing of synthetic rubbers, petrol driven vehicles and cigarette smoke. There is an apparent correlation between butadiene exposure and a higher risk of cancer.

HC reduction would most likely only be possible using primary and further secondaryoxidation catalysts.

5] **NOx**.

NOx is formed during the combustion process within the burning fuel sprays and is deemed one of the most harmful to the environment and contributes to acidification, formation of ozone, nutrient enrichment and to smog formation, which has become a considerable problem in most major cities world-wide.

The amount of NOx produced is a function the maximum temperature in the cylinder, oxygen concentrations, and residence time. At cylinder temperatures, nitrogen from the intake air and fuel becomes active with the oxygen in the air forming oxides of nitrogen. Increasing the temperature of combustion increases the amount of NOx by as much as 3 fold for every 100oC increase. NO is formed first in the cylinder followed by the formation of NO2 and N2O, typically at concentrations of 5% and 1%; respectively. NO2 is soluble and washed out by rain which increases the acidity level of the soil.

Nitrogen dioxide can irritate the lungs and lower resistance to respiratory infections such as influenza. The effects of short-term exposure are still unclear, but continued or frequent exposure to concentrations that are typically much higher than those normally found in the ambient air may cause increased incidence of acute respiratory illness in children. Nitrogen oxides contribute to ozone formation and can have adverse effects on both terrestrial and aquatic ecosystems. Nitrogen oxides in the air contribute to acid rain and eutrophication. (Eutrophication occurs when a body of water suffers an increase in nutrients that leads to a reduction in the amount of oxygen in the water, producing an environment that is destructive to fish and other animal life.)

The best way to reduce NOx generation, is to reduce peak cylinder temperatures.

6] **CO**.

CO is formed due to the incomplete combustion of organic material where the oxidation process does not have enough time or reactant concentration to occur completely. In engines, the formation of CO is determined by the air/fuel mixture in the combustion chamber and as diesels have a consistently high air to fuel ratio, formation of this toxic gas is minimal. Nevertheless, insufficient combustion can occur if the fuel droplets in a diesel engine are too large or if insufficient turbulence or swirl is created in the combustion chamber.

Carbon monoxide enters the bloodstream and reduces oxygen delivery to the body's organs and tissues. The health threat from exposure to CO is most serious for those who suffer from cardiovascular disease. Healthy individuals are also affected, but only at higher levels of exposure. Exposure to elevated CO levels is associated with visual impairment, reduced work capacity, reduced manual dexterity, poor learning ability, and difficulty in performing complex tasks.

The intensity and frequency of the afore-mentioned impacts essentially depends on several other factors such as age of the vehicle, type of fuel used, condition of engine, type of engine, maintenance and operation mode of vehicle etc.

PETROL ENGINE vs. DIESEL ENGINE

Petrol engine	**Diesel engine**
High CO, HC's concentration in emissions	Lesser HC's concentration i.e., 1/10 CO that of petrol
Less smoke	Major problem odor and smoke, at least 80% SPM than in petrol exhaust
Less SO2, NOX,PM	More NO_X, SO_2, PM/SPM

Inference: The major pollutants in diesel exhaust emissions are a direct result of the diesel combustion process itself. Diesel engines have higher compression ratio than petrol. First air is compressed, then fuel injected, then ignition but in petrol, air fuel mixed first, compressed and the n ignited. HC's concentration is less, because blowby is negligible as only air is present in compression stroke & evaporative emissions. Hydrocarbons are as well low because diesel uses a closed injection fuel system.

SMOKE

When compared to diesel emissions, petrol emissions are more toxic w.r.t. human; while diesel emissions contribute towards environmental impacts. Yet smoke emission from diesel cannot be ignored.

Maximum smoke is produced when vehicle runs at 60% of total power. It is measured in Ringlemann's Scale.

Effects of smoke: Irritation of eye membrane, ear membrane and respiratory tract, soilingof clothes, disfiguring of buildings.

Control means: High A/F ratio, Smokeless fuel – Vehicle maintenance - Lean mixture.

2 STROKE ENGINE vs. 4 STROKE ENGINE

When compared to 4 stroke, 2 stroke engine produces more pollution [HC's, CO, SPM, Smoke] as it burns an oil gasoline mixture, but 2 stroke engine is more powerful, lighter, less expensive. On the contrary, 4 stroke engine gives more mileage, produces less HC's and VOC's [volatile organic carbon] as there is no short circuit of raw fuel.

TYPES OF EMISSIONS

1. **Tailpipe emissions:** This is what most people think of when they think of vehicle air pollution; the products of burning fuel in the vehicle's engine, emitted from the vehicle's exhaust system. The major pollutants emitted include:

Hydrocarbons: This class is made up of unburned or partially burned fuel, and is a major contributor to urban smog, as well as being toxic. They can cause liver damage and even cancer.

Nitrogen oxides (NOx): These are generated when nitrogen in the air reacts with oxygen under the high temperature and pressure conditions inside the engine. NOx emissions contribute to both smog and acid rain.

Carbon monoxide (CO): A product of incomplete combustion, carbon monoxide reduces the blood's ability to carry oxygen and is dangerous to people with heart disease.

Carbon dioxide (CO_2): Emissions of carbon dioxide are considered to pollute because it is a significant greenhouse gas and increasing its levels in the atmosphere contributes to global climate change.

Exhaust emissions contain 100% CO, 100% NO_X, 100% Pb and 60-65% HC's

2. **Blowby/Crankcase emissions:** 20% unburnt HC's mainly due to leakage of oil vapor around Worn-out piston rings.

3. **Evaporative emissions:** These are produced from the evaporation of fuel, and are a large contributor to urban smog, since these heavier molecules stay closer to ground level. Fuel tends to evaporate in these ways:

Gas tank venting: the heating of the vehicle as the temperature rises from the night-time temperature to the hottest temperatures of the day mean that gasoline in the tank evaporates, increasing the pressure inside the tank above atmospheric pressure. This pressure must be relieved, and before emissions control it was simply vented into the atmosphere.

Running losses include the escape of gasoline vapors from the hot engine. **Refueling losses** include these can cause a lot of hydrocarbon vapor emission. The empty space inside a vehicle's tank is filled with hydrocarbon gases, and as the tank is filled, these gases are forced out into the atmosphere. In addition, there is loss from further evaporation and fuel spillage.

Bird view of emission of net pollution

65 % from Exhaust + 15 % from Blowby + 20 % Evaporative = 100%

Bird view of Hydrocarbon emissions [mainly as Benzopyrene]

60 % from Exhaust + 20 % from Blowby + 20 % Evaporative = 100%

Evaporative emissions: 20% HC'S via gas tank venting, refueling & running losses.

Operation w.r.t Emissions

Mode of Operation	Unburnt HC's [ppm]	CO [% by volume]	NO_X [ppm]	A/F RATIO
IDLE	750	5.2	30	11:1-12:1
CRUISING	300	0.8	1500	11:1-13:1
ACCELERATION	400	5.2	3000	13:1-15:1
DECELERATION	4000	4.2	60	11:1-12.5:1

Comparative study

When A/F ratio is high, then less CO, HC's but high NOx When Vehicle decelerates high HC's [hydrocarbon]
When vehicle is idle [engine not switched off during signals] high CO, low NO_X, moderate HC's.
When vehicle accelerates low HC'S , high CO, high CO, and high NOx When vehicle cruises high NOx, low CO, moderate HC's and high CO_2.

Drawbacks

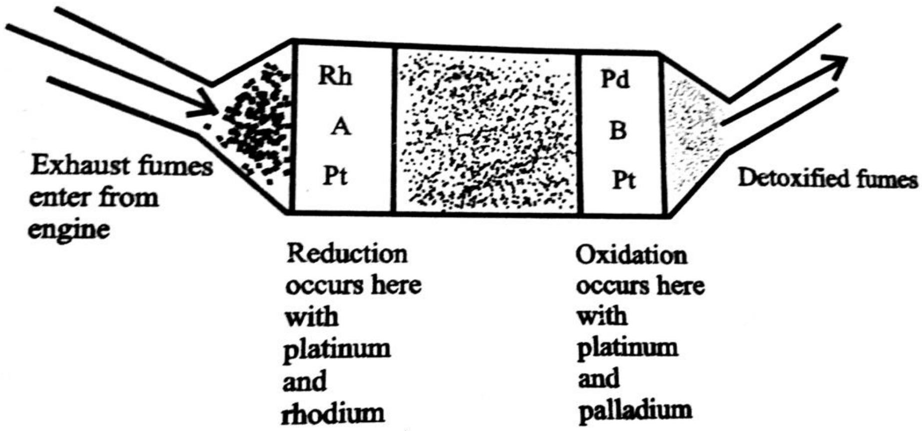
Pb is released from exhaust as lead halides which are a cumulative toxin, a chief environmental pollutant capable of affecting neural development resulting in lower IQ.

Also lead acts as poison for catalytic converter. This resulted in advent of unleaded petrol. The alternative used was MTBE. But it has been found to be non-bio-degradable and possible ground contamination. This resulted in the use of ethanol as anti-knocking agent to boost octane rating. But ethanol causes fuel to absorb moisture from air, over long time it leads to rusting, corrosion in fuel line. Also it is poorly soluble and enhances possibility of bacterial contamination.

TEL now banned in road sector continues to be used in aviation fuel as additive called as AVGAS. The catch is despite using unleaded petrol; the emissions consist of benzene which causes cancer, anemia and blood cancer. The other option w.r.t knocking phenomenon is utilize branched chain alkanes, which results pre ignition, loss of power, lower octane rating.

Catalytic converters

The air fuel ratio must be so high that all CO formed is converted to CO_2, but if ratio is less [lack of O_2], it facilitates formation of CO, Unburnt HC's, NO_X. Also due to higher temperature [2000-2500 ^{0}C], high pressure formation of Nitric oxide takes place.



Basic catalytic converter

Construction

A catalytic converter is simple device that uses basic redox reactions to reduce the pollutants coming out from the exhaust gas. Catalytic converter is composed of a metal housing with a ceramic honey comb like interior with insulating layers.

Working

The exhaust fumes are first allowed to enter into the compartment A, where the reduceable impurities are reduced, then the remaining gases are allowed to pass through the compartment B, where all oxidisable impurities are oxidised.

Functions

1. Reduction of nitrogen oxide into nitrogen and oxygen.

$\mathbf{NO_X \text{---}\!\!\rightarrow N_X + O_X}$

2. Oxidation of CO into CO_2
3. Oxidation of hydrocarbons into CO_2 and H_2O

Nowadays Rhodium, Platinum, Palladium serve the role as 3-way catalyst, once the exhaust heats the converter above 300^{0}C, unwanted molecules bind temporarily to catalyst and are converted. 95% of HC's, CO, NO_X is removed by converter but the presence of Pb in fuel as lead Halide gets coated over surface inactivating them. Catalytic converters have no moving parts, but its limitations include poisoning by lead, deterioration with time and pressure loss.

Indirect Control measures

Car pool system, eco-friendly fuels, hybrid vehicles, use of bio fuels, use of alternate energy such as solar driven, use of unleaded petrol, complying to rules and regulation, frequent periodical emission testing, stringent norms and enforcement on violation,

Minimizing the use of vehicles by walking for small distances, pooling of the vehicles, switching off the vehicles on red lights, maintaining the vehicles in proper order, adopting efficient ways of driving, ban on overloading, better design and maintenance of roads collectively can reduce automobile air pollution.

Direct Control measures

The amount of SO2 formed is a function of the sulphur content of the fuel used and therefore the only effective method of reducing SOx is by reducing the sulphur content of the fuel. Unfortunately, low-sulphur fuels are more expensive to purchase (10 to 20% greater cost, when switching from 3.5% to 1% sulphur) and there is a practical lower sulphur limit desired as desulphurisation of fuel lowers the lubricity of the fuel which can lead to increase wear on fuel pumps and injectors.

proper operation and maintenance of vehicles Using catalytic converter for

HC's, CO, NOx, C_6H_6 Increasing air-fuel ratio for HC's, CO and Benzene

Recycling exhaust gas for NO_x, [15-25%]

In case of SPM, ensure proper maintenance and operation process, such has change air filter regularly, change engine oil as per manufacturer's specification, use moderate acceleration and avoid slowing of engine atop gear.

The industry may be compelled to manufacture the vehicles in such a way, i.e. enforcing the Euro standards, that they produce minimum pollutants.

To maintain the vehicle by its proper servicing (tuning of engine) in such a way that the exhaust emissions are under control.

Control on the quality of fuel. Use unleaded petrol. Sometimes Kerosene is mixed with petrol or diesel (as it is cheaper) than the emissions are more pollutant and are of different nature.

CLIMATE

The average weather of an area.

Causes of climate change

- Presence of green house gases
- Depletion of ozone gases.

Effect of climate change

- Migration of animals
- Upsetting the hydrological cycles results in floods and droughts
- Changes in global pattern of winds.

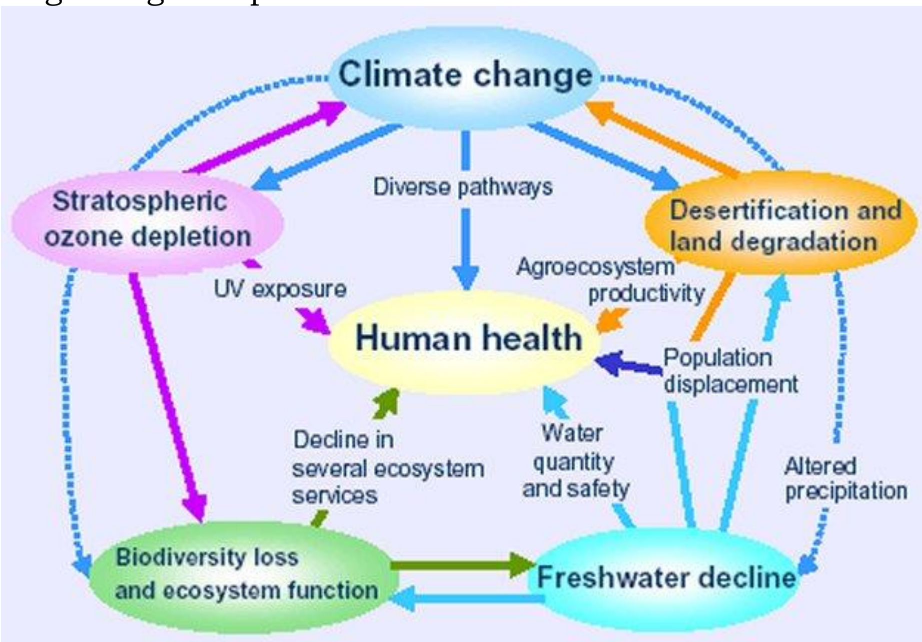


Fig. Climate Changes

Green house effect

The progressive warming of earth surface due to blanketing effect of man made CO_2 in the atmosphere.

Green house gases- causing global warming

CO_2, CH_4, N_2O, CFCs.

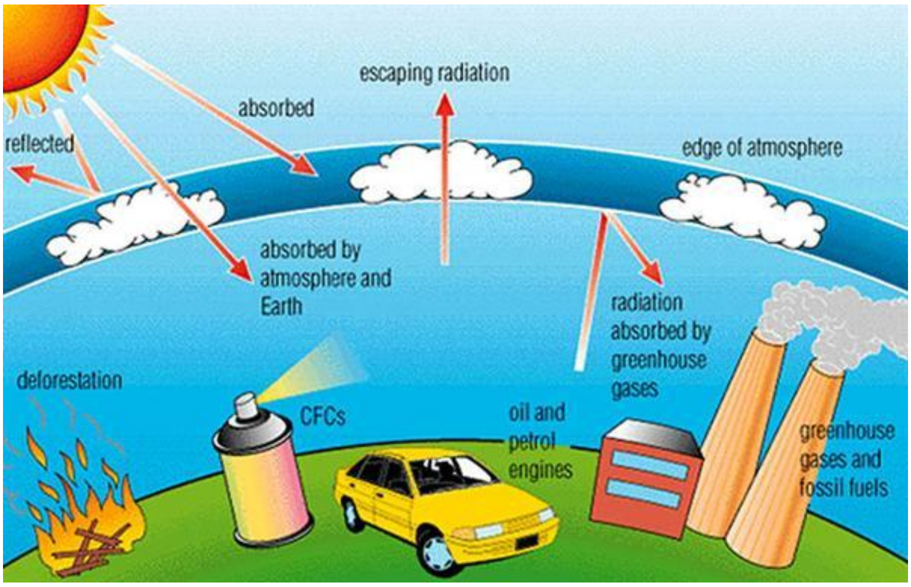


Fig.4.3 Green House effect

4.Effect on global warming

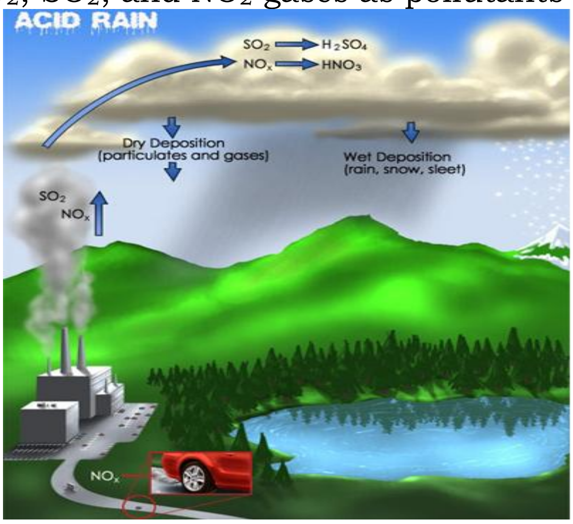
- Sea level
- Agriculture and forestry
- Water resources
- Terrestrial ecosystems
- Human health.

Measures

- ❖ Reducing CO_2 emission
- ❖ Utilizing renewable resources
- ❖ Plant more trees
- ❖ Adopt sustainable agriculture.

ACID RAIN

The precipitation of CO_2, SO_2, and NO_2 gases as pollutants in water.



Acid Rain formation

The principal cause of acid rain is sulfuric and nitrogen compounds from human sources, such as electricity generation, factories and motor vehicles. Coal power plants are one of the most polluting. The gases can be carried hundreds of kilometres in the atmosphere before they are converted to acids and deposited. Factories used to have short funnels to let out smoke, but this caused many problems, so now, factories have longer smoke funnels. The problem with this is those pollutants get carried far off, where it creates more destruction.

Sulfur dioxide contributes to about seventy percent of acid rain while nitrogen oxides provide the remaining thirty percent. The sources of sulfur in the atmosphere include coal combustion, smelting, organic decay, and ocean spray. Approximately ninety percent of atmospheric sulfur results from human activities.

In the atmosphere, sulfur dioxide combines with water vapor to form hydrogen sulfite gas: $SO_2 + H_2O + 1/2O_2 \rightarrow H_2SO_4$

Next, hydrogen sulfite reacts with oxygen to form sulfuric acid, a major component of acid rain: $H_2SO_3 + 1/2O_2 \rightarrow H_2SO_4$

The sources of nitrogen oxides include the combustion of oil, coal and natural gas, forest fires, bacterial action in soil, volcanic gases, and lighting-induced atmospheric reactions.

In the atmosphere, nitrogen monoxide reacts with oxygen gas to form nitrogen dioxide gas: $NO + 1/2O_2 \rightarrow NO_2$

Then, nitrogen dioxide reacts with water vapor in the atmosphere to form hydrogen nitrite and hydrogen nitrate: $2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$

Henceforth, acid rain is a mixture of HNO_3, H_2SO_4 + HCl. however conditions needed to favor formation of these are sunlight, temperature, humidity, hydrocarbons, NO_X, SO_2.

Effects

Both the lower p^H and higher aluminum concentrations in surface water that occur as a result of acid rain can cause damage to fish and other aquatic animals. At p^H lower than 5 most fish eggs will not hatch and lower p^H can kill adult fish. As lakes become more acidic biodiversity is reduced. Soil biology can be seriously damaged by acid rain. Some tropical microbes can quickly consume acids but other microbes are unable to tolerate low p^H and are killed.

Effects of acid rain

1. Human beings

- Destroy life – nervous, respiratory and digestive system
- Causes premature death from heart and lung disorders.

2. On Buildings

Corrosion - Taj Mahal, houses, statues, bridges, metals.

3. On terrestrial and Lake Ecosystem

- Reduces rate of photosynthesis, growth of crops, Fish population.
- And bio mass production.

4.6.2 Control measures

- ✓ Clean combustion technologies
- ✓ Using pollution control equipments
- ✓ Replacement of coal by natural gas
- ✓ Liming of lakes and soils.

OZONE LAYER DEPLETION

Ozone is formed in the stratosphere by photo - chemical reaction.

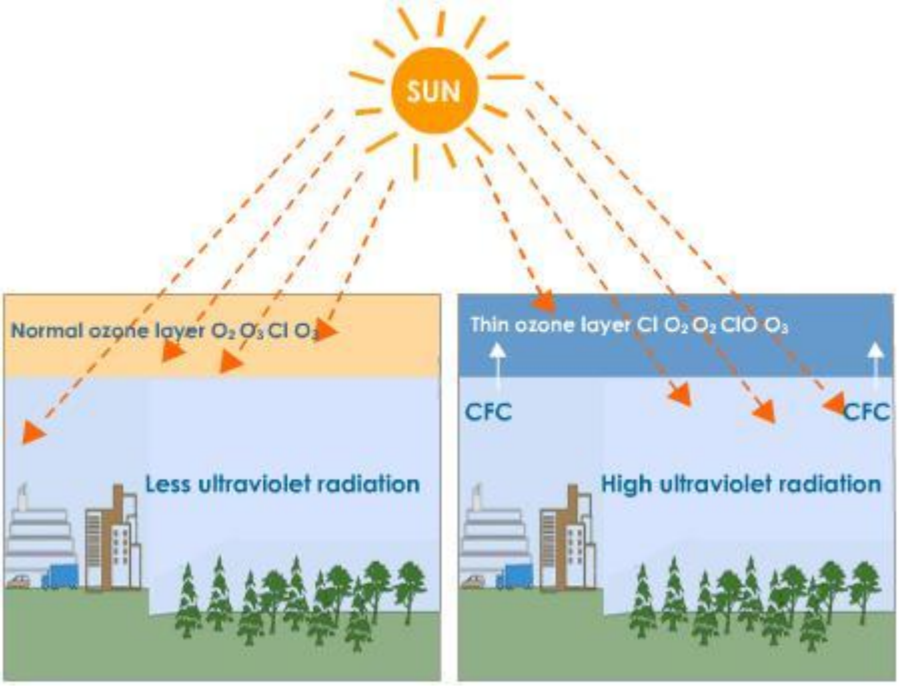


Fig. Depletion of Ozone layer

Ozone layer is an umbrella 24 km [15 miles] from earth surface, an essential component of the stratosphere that absorbs short wavelength ultraviolet radiation from the sun, heating the gases of the stratosphere in the process. World ozone day is celebrated on Sept, 16 of every year.

Stratospheric ozone is measured in Dobson units [DU] named after G.M.B Dobson who pioneered the study; [I Dobson unit = 0.01 mm thickness of stratospheric ozone], Average ozone thickness in stratosphere is 300 DU, & when it falls below 200 DU, it's considered as Ozone hole. It is thinnest around equator and thickest near poles.

Ozone depleting chemicals
Chloro Fluro carbon, Hydro chloro fluoro carbon, Bromo fluoroCarbon.
Causes

Ozone depletion is caused by the release of chlorofluorocarbons (CFC's) and other ozone-depleting substances (ODS), which were used widely as refrigerants, insulating foams, and solvents. The discussion below focuses on CFCs, but is relevant to all ODS [NO, NO_2 (aircraft exhaust), Br^-, UV rays, [O] Atomic oxygen etc].

Although CFCs are heavier than air, they are eventually carried into the stratosphere in a process that can take as long as 2 to 5 years. When CFCs reach the stratosphere, the ultraviolet radiation from the sun causes them to break apart and release chlorine atoms which react with ozone, starting chemical cycles of ozone destruction that deplete the ozone layer. One chlorine atom can break apart more than 100,000 ozone molecules.

Effects

- ❖ On human health – Skin cancer, cataracts, allergies etc.
- ❖ On aquatic systems- phyto plankton, fish
- ❖ On materials- paints, plastics
- ❖ On climate – increasing the average temperature of the earth surface.

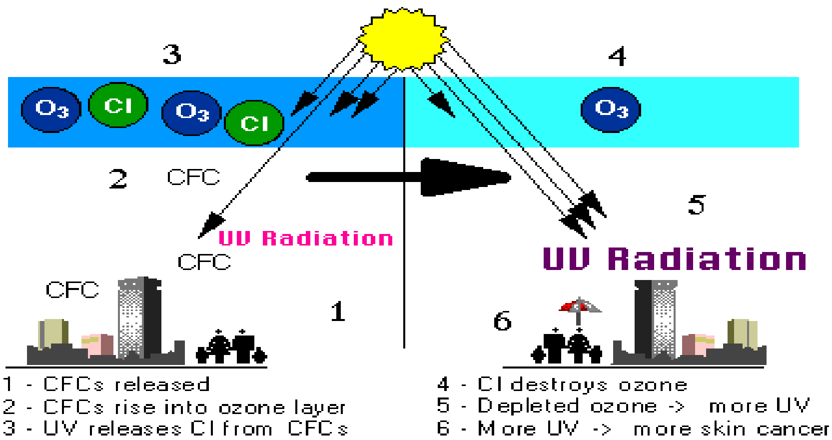


Fig. Causes and Effects of O_3 depletion

Control Measures

- Replacing CFCs
- Use of methyl bromide – crop fumigant.

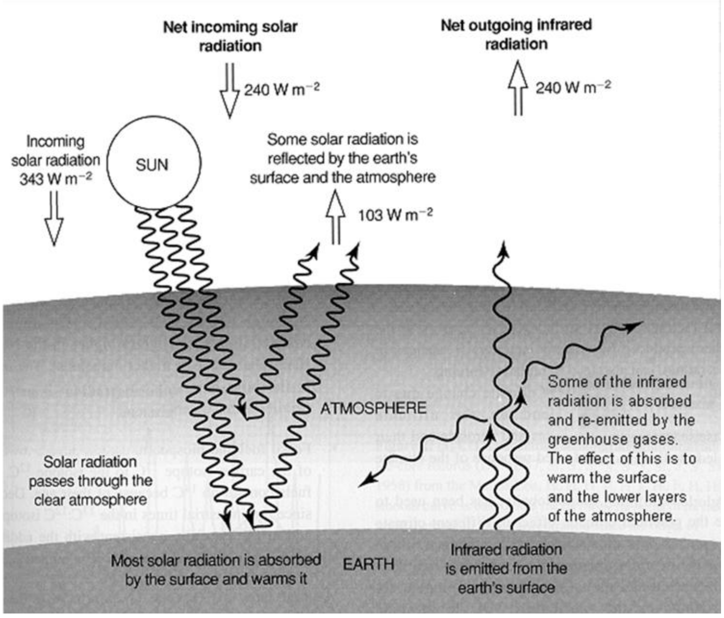
GREEN HOUSE EFFECT

Introduction

Objects that absorb all radiation upon them are called "blackbody" absorbers. The earth is close to being a black body absorber. Gases, on the other hand, are selective in their absorption characteristics. While many gases do not absorb radiation at all some selectively absorb only at certain wavelengths. Those gases that are "selective absorbers" of solar energy are the gases we

know as "Greenhouse Gases."
Definition

The greenhouse effect is a phenomenon that ought to create a condition in the upper atmosphere, causing a trapping of excess heat and leading to increased surface temperatures.



Mechanism

The Earth receives energy from the Sun in the form of radiation. The Earth reflects about 30% of the incident solar flux; the remaining 70% is absorbed, warming the land, atmosphere and oceans. The visible solar radiation heats the surface, not the atmosphere, whereas most of the infrared radiation escaping to space is emitted from the upper atmosphere, not the surface. The infrared photons emitted by the surface are mostly absorbed by the atmosphere and do not escape directly to space. Hence earth's greenhouse effect is a natural phenomenon that helps regulates the temperature of our planet. Simply put, the sun heats the earth and some of this heat, rather than escaping back to space, is trapped in the atmosphere by clouds and greenhouse gases, such as water vapor and carbon di oxide. If all these greenhouse gases were to suddenly disappear, our planet would be 60° F colder and uninhabitable.

GREENHOUSE GASSES – SOURCES

On Earth, the major natural greenhouse gases are water vapor, which causes about 36– 70% of the greenhouse effect (not including clouds); carbon dioxide (CO_2), which causes 9–26%; methane (CH_4), which causes 4–9%; and ozone, which causes 3–7%.

Carbon Dioxide

Sources: Released by the combustion of fossil fuels (oil, coal, and natural gas), flaring of natural gas, changes in land use (deforestation, burning and clearing

land for agricultural purposes), and manufacturing of cement.
Sinks: Photosynthesis and deposition to the ocean.
Significance: Accounts for about half of all warming potential caused by human activity.

Methane

Sources: Landfills, wetlands and bogs, domestic livestock, coal mining, wet rice growing, natural gas pipeline leaks, biomass burning, and termites.
Sinks: Chemical reactions in the atmosphere.
Significance: Molecule for molecule, methane traps heat 20-30 times more efficiently than CO_2. Within 50 years it could become the most significant greenhouse gas.

Nitrous Oxide [296 times potential than CO_2]

Sources: Burning of coal and wood, as well as soil microbes' digestion. Sinks: Chemical reactions in the atmosphere.
Significance: Long-lasting gas that eventually reaches the stratosphere where it participates in ozone destruction.

Ozone

Sources: Not emitted directly, ozone is formed in the atmosphere through photochemical reactions involving nitrogen oxides and hydrocarbons in the presence of sunlight.
Sinks: Deposition to the surface, chemical reactions in the atmosphere.
Significance: In the troposphere ozone is a pollutant. In the stratosphere it absorbs hazardous ultraviolet radiation.

Chlorofluorocarbons (CFCs)

Sources: Used for many years in refrigerators, automobile air conditioners, solvents, aerosol propellants and insulation.
Sinks: Degradation occurs in the upper atmosphere at the expenses of the ozone layer. One CFC molecule can initiate the destruction of as many as 100,000 ozone molecules.
Significance: The most powerful of greenhouse gases — in the atmosphere one molecule of CFC has about 20,000 times the heat trapping power on a molecule of CO_2.

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