UNIT IV

1. **Explain the legal provisions in India against air pollution**.

With development and industrialization, environmental preservation has become a serious concern. The rising power, India, has been facing the environmental pollution due to rapid development and lack of proper implementation of environmental pollution control standards. Environment is directly related with article 21 of Constitution of India which deals with right to life of individual. The two main laws that regulate air pollution in India: The Air (Prevention and Control of Pollution) Act, 1981 (Air Act) and Environment (Protection) Act, 1986 (EPA). This article is primarily concerned with critical study of provisions under these two acts.

The term "clean air" means air which is clean, unpolluted and neither harmful for humans nor harmful to the surroundings where we live. To maintain this, various countries in the world have their own laws. A state cannot ignore environment and only concentrate on economic growth. India is having worst environment among 132 countries according to Environment Performance Index. There are several factors degrading air quality of India. Today, it has been a challenge to maintain clean air in most developed countries like China etc. Smog has been common in big cities. In article 48A of the Directive Principles of Constitution of India it has declared that the state endeavors to protect and improve the environment and to safeguard the forest and wildlife of the country whereas article 51A imposes similar fundamental duty to citizens as well. Hence, it is necessary to have good laws and mechanisms.

Air (Prevention and Control of Pollution) Act, 1981

The objective of the Air Act 1981 is to preserve the quality of air and control of air pollution.There are two boards namely Central Board and State Boards. Some of their important functions are to improve the quality of air and to prevent, control or abate air pollution in the country, to advise the Government on any matter concerning the improvement of the quality of air and the prevention, control or abatement of air pollution, to plan and executed a program for the prevention, control or abatement of air pollution, to collect, compile and publish technical and statistical data relating to air pollution and the measures devised for its effective prevention, control or abatement and prepare manuals, codes or guides relating to prevention, control or abatement of air pollution, to lay down standards for the quality of air, to inspect, at all reasonable times, any control equipment, industrial plant or manufacturing process and to give, by order, such directions to such persons as it may consider necessary to take steps for the prevention, control or abatement of air pollution, to inspect air pollution control areas at such intervals as it may think necessary, assess the quality of air therein and take steps for the prevention, control or abatement of air pollution in such areas.The Central Board and State Board work in collaboration of each other. The Central works throughout the nation whereas State Boards work within its state.Likewise, chapter four states about the prevention and control of air pollution. State Government after consultation with State Board can declare any area or areas within the State as air pollution control area or areas for the purposes of this Act, can alter any air pollution control area whether by way of extension or reduction, can declare a new air pollution control area in which may be merged one or more existing air pollution control areas or any part or parts thereof.

Environment Protection Act, 1986

The Environment Protection Act came in 1986. Prior to this act, there was Department of Environment which was established in 1980 in India. In 1985, it converted into Ministry of Environment and Forests. Similarly, The Air (Prevention and Control of Pollution) Act came before this act in 1981. The objective of this act is to take appropriate steps for the protection and improvement of environment and prevention of hazards to human beings, other living creatures, plants and properties.This act has defined “environment pollution” as the presence of any environmental pollutant in the environment and “environment pollutant” as any solid, liquid or gaseous substance present in such concentration as may be, or tend to be injurious to environment. Similarly, chapter two deals with general power of Central government. Central Government shall have power to take all such steps it thinks necessary for the preserving and improving the quality of the environment and preventing and controlling environmental pollution, to prohibit and restrict on the handling of hazardous substance in different areas, to prohibit and restrict on the location of industries and the carrying on of the process and operations in different areas, to carry out and sponsor investigations and research relating to problems of environmental pollution, to safeguard for the prevention of accidents which may cause environmental pollution and for providing for re-medical measures for such accidents etc.

Besides, third chapter talks about the ways of prevention, control and abatement environmental control. It prohibits any person to carry on any industry operation or process shall discharge or emit or permit to be discharged or emitted any environmental pollutant in excess of such standards as may be prescribed and to handle or cause to be handled any hazardous substance expert in accordance with such procedure and after complying with such safeguards may be prescribed. Whoever fails to comply or contravenes will be punished with five years imprisonment or with fine which may extend to one lakh rupees, or both, and in the case of failure or if contravention continues, with additional fine which may extend to five thousand rupees for every day during which such failure or contravention continues after the conviction for the first such failure or contravention. Finally, if it continues more than a year from the date of conviction shall be punishable with imprisonment for the term which may extend to seven years.

Again, if a company commits any offense under this act, every person such as director, manager secretary or another officer of the company who at the time offence was committed, was directly in charge of and was responsible to the company for the conduct of the business of the company, as well as company shall be deemed to guilty of the offence and shall be liable to be proceeded against and punished accordingly.

Bhopal Disaster Case study :

On December 3, 1984, the worst industrial accident in history occurred. Around 40 tons of Methyl Isocyanate (MIC) gas mixed with other poisonous gasses from a chemical plant which is owned and operated by Union Carbide (India) Limited. At least 3,800 people were killed and several were injured in this incident. This incident caused victims throats and eyes to burn, induced nausea because the gases remained low to the ground. Those who were exposed to such toxic gas gave birth to physically and mentally disabled baby even after 30 years.

The Union Carbide Corporation paid a sum of U.S. Dollars 470 millions for full settlement of all claims, rights and liabilities related to and arising out of the Bhopal Gas disaster to the Union of India. The principle of absolute liability was used by the Supreme Court made the Union Carbide Corporation pay compensation.It is relatively small in comparison to the offence which has long term effect in the human existence of that place. Even after this disaster, there has been rapid industrialization in India. While some affirmative changes in policy of government and conducts of a few industries have taken place, there still remain major threats to the environment from rapid and poorly regulated industrial growth. Due to widespread environmental degradation, adverse effect in human health consequences continues to happen all over India.

Role of CPCB and SPCBs

The CPCB and the SPCBs have been given the role to improve the quality of air and to prevent, control or abate air pollution. The various functions and powers of the CPCB and the SPCB are respectively provided under Section 16 and Section 17 of the Air Act. The CPCB is bound by the direction of the Central Government and SPCB is bound by directions of the CPCB and the State Government.

Functions and Power of CPCB :

a) Advice the Central Government on improvement of air quality and prevention, control or abatement of air pollution and to provide training to persons engaged in such programs
b) Prescribe the standards for air quality
c) Execute nation-wide programs for prevention, control or abatement of air pollution and training to persons engaged in such programs
d) Give direction to SPCBs, co-ordinate between SPCBs and provide any technical assistance, guidance and resolve the disputes among SPCBs
e) Collect and publish technical and statistical data relating to air pollution
f) Organize mass media programs for prevention, control or abatement of air pollution.
g) Establish or recognize laboratory (ies) to perform the various functions mentioned under Section 16 of the Air Act

Functions and Power of SPCB :

a) Plan comprehensive program for the prevention, control or abatement of air pollution
b) Advice the State Government on any matter concerning the prevention, control or abatement of air pollution
c) Prescribe the standards for emission of air pollutants into the atmosphere in consultation with CPCB
d) Collaborate with CPCB in providing training to persons engaged in the prevention, control or abatement of air pollution and also to organize mass education programs.
e) Collect and disseminate information regarding air pollution
f) Inspect air pollution control areas, any control equipment, industrial plat or manufacturing

process and assess the quality and further to give order or direction

g) Establish or recognize laboratory(ies) to perform the various functions mentioned under Section 17 of the Air Act

h) To give directions in writing for (a) stoppage or regulation of electricity, water or any other services; or (b) the closure, prohibition or regulation of any industry, operation or process.

Power of State Governments

The State Governments has the power to declare any area as air pollution control area after consultation with the SPCB. The State Government, after consultation with the SPCB, can prohibit use of any fuel, other than approved fuel in any area if it feels that the use of the fuel will pollute the atmosphere. Further, in order to prevent air pollution, the State Governments have the power to prohibit the use of any appliance. If the State Government is of the view that burning of any substance (other than a fuel) may cause or likely to cause air pollution, it can prohibit burning of such material by notification through official gazette. The State Government also has the power to instruct the authority in charge of the Motor Vehicles Act, 1939 to adhere to the standards for emission of air pollutants from automobiles which are stipulated by the SBCB

2. List the objectives of Air pollution monitoring.

- To provide comprehensive data to judge the significance of actual and perceived regional issues
- be related to the issues, objectives and methods of implementation specified in the regional air plan
- supply sufficient data to determine geographical patterns in air quality over various time scales (eg, seasonally)
- lead to an understanding of whether national or regional air quality standards, guidelines, objectives and environmental outcomes are being met, and whether areas of concern are being identified
- develop a picture of representative concentrations in areas of high population density where air quality is known, or suspected, to be poor

- provide sufficient data to determine trends in air quality over time and the background levels of contaminants
- supply enough information to determine the population at risk from exposure to poor air quality in order to evaluate the potential and actual health effects in a region (eg, personal exposure assessments).

- determining the level of contaminants in an airshed to compare with standards and guidelines
- reporting on the state of the environment
- obtaining exploratory data
- conducting air quality research
- obtaining data for air quality modelling
- providing air quality information for policy or strategy development
- assessing the effectiveness of policy based on air quality trends.
- To facilitate the background concentration(s) measurements,
- To monitor current levels as a baseline for assessment
- To check the air quality relative to standards or limit values
- To detect the importance of individual sources
- To enable comparison of the air quality data from different areas and countries,
- To collect data for the air quality management, traffic and land-use planning purposes
- To observe trends (related to emissions),
- To develop abatement strategies,
- To determine the exposure and assess the effects of air pollution on health, vegetation or building materials,
- To inform the public about the air quality and raise the awareness
- To develop warning systems for the prevention of undesired air pollution episodes, to facilitate the source apportionment and identification,
- To supply data for research investigations
- To develop/validate management tools (such as models)
- To develop and test analytical instruments

- To support legislation in relation to the air quality limit values and guidelines.

3. Enumerate the reason for high air pollution in India.

Some of the major causes of air pollution in India are as follows: 1. Industrial chimney wastes 2. Thermal power stations 3. Automobiles.

Air pollution results from gaseous emissions from mainly industry, thermal power stations, automobiles, domestic combustion etc.

1. Industrial chimney wastes:

There are a number of industries which are source of pollution. The chief gases are SO_2 and NO_2. Cement factories emit plenty of dust, which is potential health hazard. Stone crushers and hot mix plants also create a menace. The SPM levels in such areas of stone crushing are more than five times the industrial safety limits. There are many food and fertilizers industries which emit acid vapors in air.

2**. Thermal power stations:**

There are number of power stations and super thermal power stations in the country. The National Thermal Power Corporation (NTPC) is setting up four mammoth coal- powered power stations to augment the energy generation. These are at Singrauli in U.P., Korba in M.P., Ramgundam in Andhra Pradesh and Farakka in W. Bengal. The coal consumption of thermal plants is several million tonnes. The chief pollutants are fly ash, SO_2 and other gases and hydrocarbons..

3. Automobiles:

The Toxic vehicular exhausts are a source of considerable air pollution, next only to thermal power plants. The ever increasing vehicular traffic density has posed continued threat to the ambient air quality. There are over 300 million cars, trucks and buses the world over and their number is increasing rapidly. India is likely to have over 5 million vehicles by 2010 of which more than 65% will be two-wheelers operating on petrol. In all the major cities of the country about 800 to 1000 tonnes of pollutants are being emitted into the air daily, of which 50% come from automobile exhausts.

In the major metropolitan cities, vehicular exhaust accounts for 70% of all CO, 50% of all hydrocarbons, 30-40% of all oxides and 30% of all SPM. It is estimated that a car (without cleaning device) on burning 1000 gallons of petrol after combustion produces 3200 lb. of CO, 2200-2400 lb organic vapours, 20-75 lb of NO_x, 18 lb of aldehydes, 17 lb of sulphur compounds, 2 Ib of organic acids and NH_3 each and 0.3 lb of solid carbons.

Chief sources of emission in automobiles are:

(i) Exhaust system,

(ii) Fuel tank and carburetor and

(iii) Crankcase

The exhaust produces many air pollutants including un-burnt hydrocarbons, CO, NO_x and lead oxides. There are also traces of aldehydes, esters, ethers, peroxides and ketones which are chemically active and combine to form smog (smoke + fog) in presence of light. Evaporation from fuel tank goes on constantly due to volatile nature of petrol, causing emission of hydrocarbons.

The evaporation through carburetor occurs when engine is stopped and heat builds up, and as much as 12 to 40 ml of fuel is lost during each long stop causing emission of hydrocarbons. Some gas vapour escapes between walls and the piston which enters the crankcase and then discharges into atmosphere. This accounts for 25% of the total hydrocarbon emissions of an engine. From the different sources of air pollution, a variety of pollution are released into atmosphere.

The principal air pollutants emitted from these different sources are as follows:

1. Carbon compounds:

These are mainly CO_2 and CO, the former released by complete combustion of fossil fuels and the latter by automobile exhausts.

2. **Sulphur compounds:**

There include SO_2, H_2S and H_2SO_2 mostly released by fossil fuel (Coal etc.) based power generating plants (thermal plants) and industrial units as refineries.

3. Nitrogen oxides:

These include chiefly NO, NO_2, HNO_3, mostly released by automobiles, power plants and industries.

4. Ozone (O_3):

Its level may rise in atmosphere due to human activities.

5. Fluorocarbons:

These come from industries, insecticides spray etc.

6. Hydrocarbons:

These are chiefly benzene, benzphrene etc. which are mostly discharge by automobiles and industries.

7. Metals:

These include chiefly lead, nickel, arsenic beryllium, tin, vanadium, titanium, cadmium etc., present in air as solid particles or liquid droplets or gases. They are produced mostly by metallurgical processes, automobiles, sea pray etc.

8. Photochemical products:

These are the photochemical smog, PAN, etc. released mostly by automobiles.

9. Particulate matter:

These are fly ash, dust, grit and other suspended particulate matter (SPM) released from power plants and industries (stone crushers etc.). There are also bacterial cells, fungal spores and pollens in air as biological particulate pollutants.

10. Toxicants other than heavy metals:

These are complex chemical substances released during manufacture of other goods

4. Explain the working principle of bio-filtration process.

Biofiltration is a relatively new pollution control technology. It is an attractive technique for the elimination of malodorous gas emissions and of low concentrations of volatile organic compounds (VOCs).

The most common style biofilter is just a big box. Some can be as big as a basketball court or as small as one cubic yard. A biofilter's main function is to bring microorganisms into contact with pollutants contained in an air stream. The box that makes up this biofilter contains a filter material, which is the breeding ground for the microorganisms. The microorganisms live in a thin layer of moisture, the "biofilm", which surrounds the particles that make up the filter media. During the biofiltration process, the polluted air stream is slowly pumped through the biofilter and the pollutants are absorbed into the filter media. The contaminated gas is diffused in the biofilter and adsorbed onto the biofilm. This gives microorganisms the opportunity to degrade the pollutants and to produce energy and metabolic byproducts in the form of CO2 and H2O.

This biological degradation process occurs by oxidation, and can be written as follows:

Organic Pollutant + O2 → CO2 + H2O + Heat + Biomass

- The process involved (bio reaction) is a green process.
- Thermal and catalytic control units consume large volumes of expensive fuel.
- Bioreactors only use small amounts of electrical power to drive two or three small motors.
- Normally, bioreactors do not require full-time labor and the only operating supplies needed are small quantities of macronutrients.

Biofiltration utilizes a supported media for microbial growth to remove odors and organic contaminants from air streams. The filter consists of a closed chamber containing contaminant degrading microbes and absorbed water suspended in a filter medium. The filter medial is designed to provide a high capacity for water uptake, have a long working life, and provide a low pressure drop for the gases passing through the media.

The multi layers are called s "Biocubes" were designed by EG&G Biofiltration and are approximately 7 feet high and 6 feet in diameter. This multi-layered system prevents the compaction of the filter media and helps eliminate the risk of channeling by the contaminated air stream. In addition, the stacked discs allow for easy maintenance when it comes time to change the filter media.

In the biofiltration process, contaminated air is moistened by a humidifier and is pumped into the biofilter through a chamber below the filter medium. While the air slowly flows upward through the filter media, the contaminants in the air stream are absorbed and metabolized. The purified air passes out of the top of the biofilter and into the atmosphere. Most biofilters that are in operation today can treat odor and VOCs add efficiencies greater that 90%. However, the drawback to this technology is that it can only handle low concentrations of pollutants (<1000 ppm) and loading rates between 300-500 ft^3/ft^2-hr.

Biofilter media:

The moist filter medium provides physical and chemical conditions appropriate for the transfer of contaminants from the air to the liquid phase and the biodegradation of the contaminants in the biofilm layer. The mechanism of the biofiltration process includes a combination of adsorption, absorption and microbial degradation. Microorganisms contained in the biofilm layer continually metabolize the contaminants, as they are absorbed, converting them ultimately to water, carbon dioxide and salts.

Typical biofilter media material includes compost-based materials, earth, heather, plastic, or wood-product based material. The purpose of the biofilter media is to provide a large surface area for the absorption and adsorption of contaminants. The media also serves as a nutrient source for the microbial population. In fact, some types of media lack proper nutrients and will require the manual addition nutrients (e.g. nitrogen and phosphorous compounds) in order to sustain microbial life. Most biofilters will operate for 5-7 years before it is necessary to renew the filter media.

Major considerations when determining the appropriate filter material include:

- Ability to retain moisture to sustain biofilm layer;
- Large surface area, both for contaminant absorption and microbial growth;
- Ability to retain nutrients and supply them to microbes as required;
- Low resistance to air flow (minimizes pressure drop and blower power requirements);
- Physical characteristics, such as physical stability and ease of handling

The operation and maintenance of the bio filtration system would require weekly site visits during initiation of operations for emiss. However, after acclimation and all system problems are resolved the frequency of site visits could be reduced to the biweekly or monthly.

Advantages of Biofiltration:

- The main advantage of using biofiltration over other more convention control methods are lower capita costs, lower operating costs, low chemical usage, and no combustion source.
- Biofiltration units can be designed to physically fit into any industrial setting. A biofiltration unit can be designed as any shape, size or as an open field with the piping and delivery system underground. In addition, biofilters can be designed with stacked beds to minimize space requirements and multiple units can be run in parallel.
- Biofiltration is versatile enough to treat odors, toxic compounds, and VOCs. The treatment efficiencies of these constituents are above 90% for low concentrations of contaminants (<1000 ppm).

- Different media, microbes and operating conditions can be used to tailor a biofilter system for many emission points.

Disadvantages of Biofiltration:

- Biofiltration cannot successfully treat some organic compounds, which have low adsorption or degradation rates. This is especially true for chlorinated VOCs.
- Contaminant sources with high chemical emissions would require large biofilter units or open areas to install a biofiltration system.
- Sources with emissions that fluctuate severely or produce large spikes can be detrimental to the of a biofilter’s microbial population and overall performance.
- Acclimation periods for the microbial population may take weeks or even months, especially for VOC treatment.

General Requirements for a biofilters:

- Requires continuous air flow.
- Requires consistent loading.
- Requires a humid and warm air stream
- Often requires acclimation period for media.

Commercial Applications

There have been over 50 commercial biofilters using compost-type material installed in the world over the past 15 years.

VOC applications to date have included the following industries:

- Chemical and petrochemical industry
- Oil and gas industry
- Synthetic resins
- Paint and ink
- Pharmaceutical industry
- Waste and wastewater treatment
- Soil and Groundwater remediation

Odor abatement applications to date have included the following industries.

- Sewage treatment
- Slaughter houses
- Rendering

- Gelatin and glue plants
- Agricultural and meat processing
- Tobacco, cocoa and sugar industry
- Flavor and fragrance

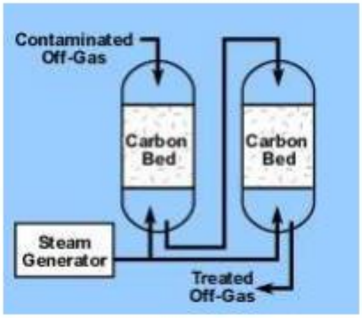
5. Describe the working principle of adsorption

- The process of adsorption involves the molecular attraction of gases or vapors (usually volatile organic compounds (VOCs)) onto the surface of certain solids (usually carbon, molecular sieves, and/or catalysts).
- This attraction may be chemical or physical in nature and is predominantly a surface effect. Activated carbon (charcoal), which possesses the large internal surface area needed to adsorb large quantities of gases within its structure, is often used to remove VOCs from flue gases. After the activated carbon is saturated with VOCs, it is often treated (by heat and/or steam) to strip off the collected VOCs.
- The VOCs are then sent for further treatment, and the carbon is reused in the adsorption reactor. Adsorption is affected by the temperature, flowrate, concentration, and molecular structure of the gas.
- Adsorption is commonly used for removing gases from contaminated soil, oil refineries, municipal wastewater treatment plants, industrial paint shops, and steel mills
- 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. Adsorption is the binding of molecules or particles to a surface. In this phenomenon molecules from a gas or liquid will be attached in a physical way to a surface. The binding to the surface is usually weak and reversible.
- 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. Carbon adsorption uses activated carbon to control and/or recover gaseous pollutant emissions. In carbon adsorption, the gas is

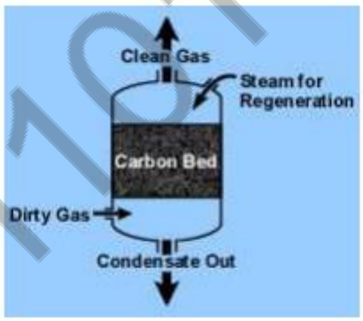
attracted and adheres to the porous surface of the activated carbon. Removal efficiencies of 95 percent to 99 percent can be achieved by using this process.

- Carbon adsorption is used in cases where the recovered organics are valuable. For example, carbon adsorption is often used to recover perchloroethylene, a compound used in the dry cleaning process.
- Carbon adsorption systems are either regenerative or non-regenerative. A regenerative system usually contains more than one carbon bed. As one bed actively removes pollutants, another bed is being regenerated for future use.
- Steam is used to purge captured pollutants from the bed to a pollutant recovery device. By "regenerating" the carbon bed, the same activated carbon particles can be used again and again. Regenerative systems are used when concentration of the pollutant in the gas stream is relatively high. 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. Because of the solid waste problem generated by this type of system, nonregenerative carbon adsorbers are usually used when the pollutant concentration is extremely low.
- 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, in much the same way that sugar is absorbed in a glass of water when stirred. Absorption is commonly used to recover products or to purify gas streams that have high concentrations of organic compounds.
- Absorption equipment is designed to get as much mixing between the gas and liquid as possible. 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 venture scrubbers. The packed column is by far the most commonly used for the absorption of gaseous pollutants.

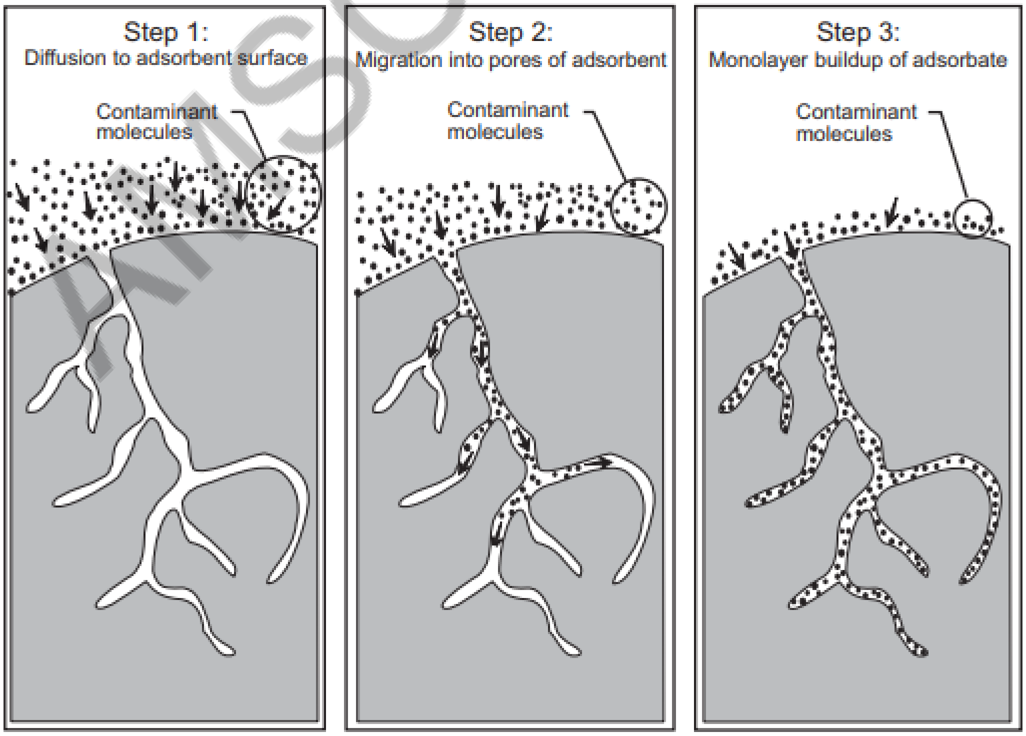
- The packed column absorber has a column filled with an inert (non-reactive) substance, such as plastic or ceramic, which increases the liquid surface area for the liquid/gas interface. The inert material helps to maximize the absorption capability of the column.
- In addition, the introduction of the gas and liquid at opposite ends of the column causes mixing to be more efficient because of the counter-current flow through the column.
- In general, absorbers can achieve removal efficiencies greater 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.



Regenerative Carbon Adsorption System

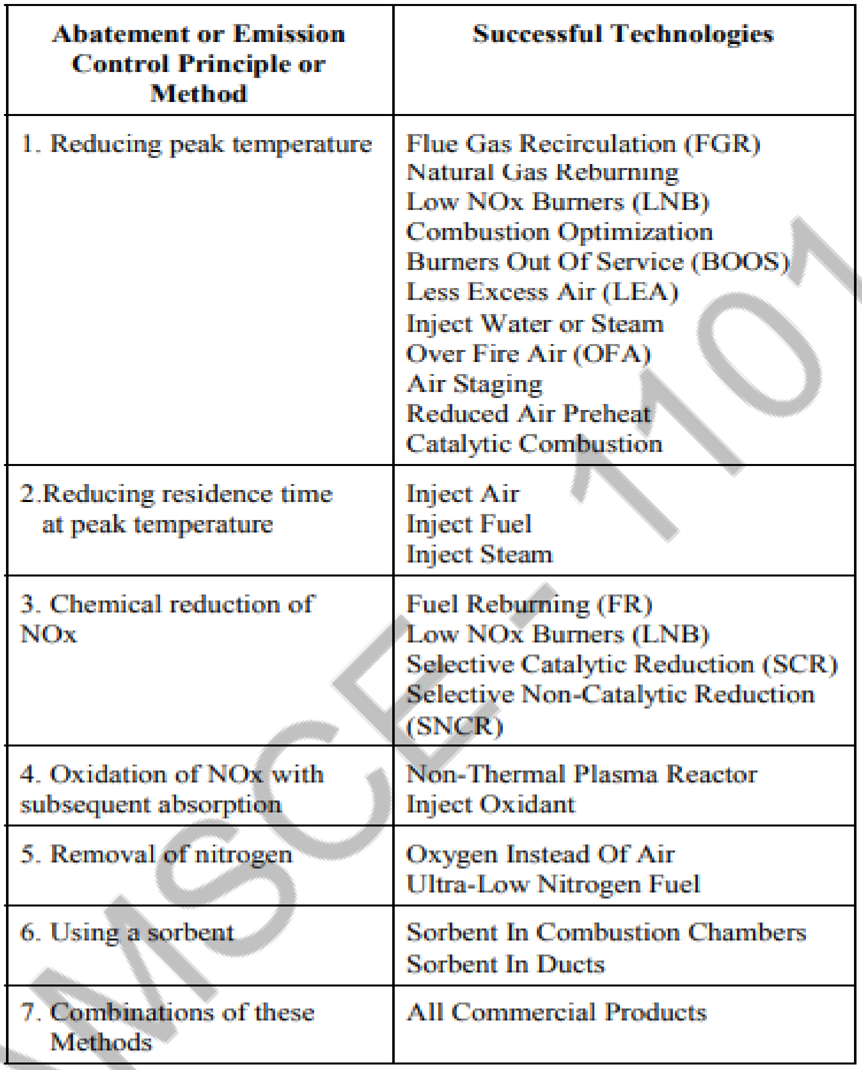


Non-Regenerative Carbon Adsorption System



6. Discuss the approach for controlling Nitrogen Oxides.

- The following methods adopted for controlling NOx



Abatement or Emission Control Principle or Method	Successful Technologies
1. Reducing peak temperature	Flue Gas Recirculation (FGR) Natural Gas Reburning Low NOx Burners (LNB) Combustion Optimization Burners Out Of Service (BOOS) Less Excess Air (LEA) Inject Water or Steam Over Fire Air (OFA) Air Staging Reduced Air Preheat Catalytic Combustion
2.Reducing residence time at peak temperature	Inject Air Inject Fuel Inject Steam
3. Chemical reduction of NOx	Fuel Reburning (FR) Low NOx Burners (LNB) Selective Catalytic Reduction (SCR) Selective Non-Catalytic Reduction (SNCR)
4. Oxidation of NOx with subsequent absorption	Non-Thermal Plasma Reactor Inject Oxidant
5. Removal of nitrogen	Oxygen Instead Of Air Ultra-Low Nitrogen Fuel
6. Using a sorbent	Sorbent In Combustion Chambers Sorbent In Ducts
7. Combinations of these Methods	All Commercial Products

Reducing Temperature

Reducing combustion temperature means avoiding the stoichiometric ratio (the exact ratio of chemicals that enter into reaction). Essentially, this technique dilutes calories with an excess of fuel, air, flue gas, or steam. Combustion controls use different forms of this technique and are different for fuels with high and low nitrogen content.

Control of NOx from combustion of high nitrogen content fuels (e.g., coal) can be understood by the net stoichiometric ratio. Control of the NOx from combustion of low nitrogen fuels (such as gas and oil) can be seen as lean versus rich fuel/air ratios. Either way, this technique avoids the ideal stoichiometric ratio because this is the ratio that produces higher temperatures that generate higher concentrations of thermal NOx.

Combustion temperature may be reduced by:

- using fuel rich mixtures to limit the amount of oxygen available;
- using fuel lean mixtures to limit temperature by diluting energy input;
- injecting cooled oxygen-depleted flue gas into the combustion air to dilute energy;
- injecting cooled flue gas with added fuel; or
- injecting water or steam. Low-NOx burners are based partially on this principle.

The basic technique is to reduce the temperature of combustion products with an excess of fuel, air, flue gas, or steam. This method keeps the vast majority of nitrogen from becoming ionized (i.e., getting a non-zero valence)

Reducing Residence Time

Reducing residence time at high combustion temperatures can be done by ignition or injection timing with internal combustion engines. It can also be done in boilers by restricting the flame to a short region in which the combustion air becomes flue gas.

This is immediately followed by injection of fuel, steam, more combustion air, or recirculating flue gas. This short residence time at peak temperature keeps the vast majority of nitrogen from becoming ionized. This bears no relationship to total residence time of a flue gas in a boiler.

Chemical Reduction of NOx

This technique provides a chemically reducing (i.e., reversal of oxidization) substance to remove oxygen from nitrogen oxides. Examples include Selective Catalytic Reduction (SCR) which uses ammonia, Selective Non-Catalytic Reduction (SNCR) which use ammonia or urea, and Fuel Reburning (FR).

Non-thermal plasma, an emerging technology, when used with a reducing agent, chemically reduces NOx. All of these technologies attempt to chemically reduce the valence level of nitrogen to zero after the valence has become higher.11 Some low-NOx burners also are based partially on this principle.

Oxidation of NOx

This technique intentionally raises the valence of the nitrogen ion to allow water to absorb it (i.e., it is based on the greater solubility of NOx at higher valence). This is accomplished either by using a catalyst, injecting hydrogen peroxide, creating ozone within the air flow, or injecting ozone into the air flow. Non-thermal plasma, when used without a reducing agent, can be used to oxidize NOx.

A scrubber must be added to the process to absorb N2O5 emissions to the atmosphere. Any resultant nitric acid can be either neutralized by the scrubber liquid and then sold (usually as a calcium or ammonia salt), or collected as nitric acid to sell to customers.

Removal of nitrogen from combustion

This is accomplished by removing nitrogen as a reactant either by

- using oxygen instead of air in the combustion process;
- using ultra-low nitrogen content fuel to form less fuel NOx.

Eliminating nitrogen by using oxygen tends to produce a rather intense flame that must be subsequently and suitably diluted. Although Method 2 can lower the temperature quickly to avoid forming excessive NOx, it cannot eliminate nitrogen oxides totally if air is the quench medium. Hot flue gas heats the air that is used to quench it and this heating generates some thermal NOx.

This method also includes reducing the net excess air used in the combustion process because air is 80% nitrogen. Using ultra-low-nitrogen content fuels with oxygen can nearly eliminate fuel and prompt NOx.13

Sorption, both adsorption and absorption –

Treatment of flue gas by injection of sorbents (such as ammonia, powdered limestone, aluminum oxide, or carbon) can remove NOx and other pollutants (principally sulfur). There have been successful efforts to make sorption products a marketable commodity.

This kind of treatment has been applied in the combustion chamber, flue, and baghouse. The use of carbon as an adsorbent has not led to a marketable product, but it is sometimes used to limit NOx emissions in spite of this. The sorption method is often referred to as using a dry sorbent, but slurries also have been used. This method uses either adsorption or absorption followed by filtration and/or electrostatic precipitation to remove the sorbent.

Combinations of these methods

Many of these methods can be combined to achieve a lower NOx concentration than can be achieved alone by any one method. For example, a fuel-rich cyclone burner can be followed by fuel reburn and over-fire air .

This has produced as much as a 70% reduction in NOx. Other control technologies that are intended to primarily reduce concentrations of sulfur also strongly affect the nitrogen oxide concentration.

For example, the SOx-NOx-ROx-Box (SNRB) technology uses a limestone sorbent in the flue gas from the boiler to absorb sulfur. This is followed by ammonia injection and SCR using catalyst fibers in the baghouse filter bags.

The sulfur is recovered from the sorbent and the sorbent regenerated by a Claus process. This has demonstrated removal of up to 90% of the NOx along with 80% of the SOx