

4.2 ABSORPTION

Absorption is a physical or chemical process of removing a pollutant from a gas phase media by dissolving the pollutant into a solvent media. Solvent media is most commonly a liquid phase, but can be a dry bulk solid in certain systems. The material that absorbs is called the solvent, and the gas that is to be absorbed is called the solute. The most common form of absorption is wet scrubbing. A wet scrubber is the generic name of a control device that uses the process of absorption to separate the pollutant from a gas stream

The most common type of wet scrubber is a packed-bed counter flow scrubber (which is what we will be discussing in this technology review). There are other types of scrubbers, such as cross flow, bubble plate and tray scrubbers, and more sophisticated or proprietary designs.

The sketch below provides a very basic flow diagram and points out the common components of a cross flow wet scrubber. The gas stream that contains the pollutants to be removed enters from the bottom of the scrubber and quickly turns upward towards the exhaust at the top of the scrubber. The random packing provides necessary surface area to distribute the liquid solvent and encourage contact between the two medias. The liquid scrubbing media (or solvent) enters near the top of the scrubber and is distributed over the random packing. The liquid adsorbs the pollutants from the gas phase and is collected in the sump of the scrubber. Prior to exiting the scrubber, the gas phase passes over a mist eliminator and exits to the atmosphere.

Water is a very common scrubbing fluid, but there are many processes or pollutants that require different fluids or solvent types. One of the determining factors in calculating the performance capability of a scrubber is understanding the pollutants' solubility in water (the assumed scrubbing fluid in this example). Calculating the relationship of the pollutants' solubility in a scrubbing fluid is called the absorption equilibrium.

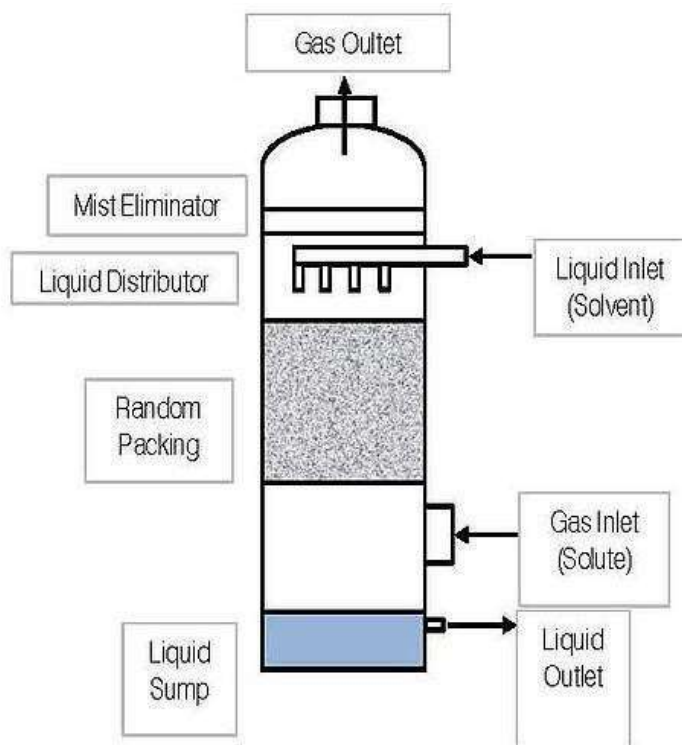


Figure 4.2.1 Absorption

[Source: https://www.cpilink.com/hfs/hubfs/Images/Product_Images/Scrubber.jpg?width=483&name=Scrubber.jpg]

The principle advantages of a wet scrubber for gaseous organic pollution control are low capital and installation costs and simplicity of design. However, there are a number of limitations that should be understood:

1. Pollutant Removal Efficiency:

Depending on the organic pollutant, the absorption equilibrium may not allow enough of the pollutant to be absorbed into the solvent, and the resultant exhaust to the atmosphere may not be adequate to meet EPA clean air act regulations. For a wide variety of VOCs, the maximum removal efficiency may only reach 90%.

2. Scrubbing Liquid:

Water is the most common scrubbing liquid. Water has a relatively low cost, and control loops allow for some degree of recirculation, which helps to lower the fresh water addition to the system. However, if certain pollutants require a modified solvent, additional chemical costs and control systems can quickly increase the total cost of solvent use.

3. Byproducts:

The principle drawback to using a wet scrubber for organic pollutant removal is the transference of an air pollution control problem to a water (liquid) pollution control problem. If the site has a water treatment plant, a study must be conducted to determine if any impact to the plant's operation will be affected by adding the new waste stream. If the liquid waste is discharged directly to the sewer, careful examination must be conducted to insure the downstream municipality is not negatively affected, or additional fees will be incurred.

4. Maintenance:

For most organic pollutants, maintenance impacts will be low. However, if the target gas stream has particulates or biological impurities, these can increase the potential for plugging media, biologic growth, and pump and piping degradation.

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4.3 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
- 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 absorber, the spent carbon is disposed of when it becomes saturated with the pollutant.

Use of Activated carbon is determined by:

- Flow rate
- Pollutant concentration: Higher usage at higher pollutant concentrations. However, the specific load increases; in other words, one needs less activated carbon to collect a particular pollutant quantity.
- Pollutant type
- Gas temperature: Higher temperatures lead to higher usage.
- Gas humidity: Higher humidity level leads to higher usage
- Pressure: Higher pressure leads to lower usage

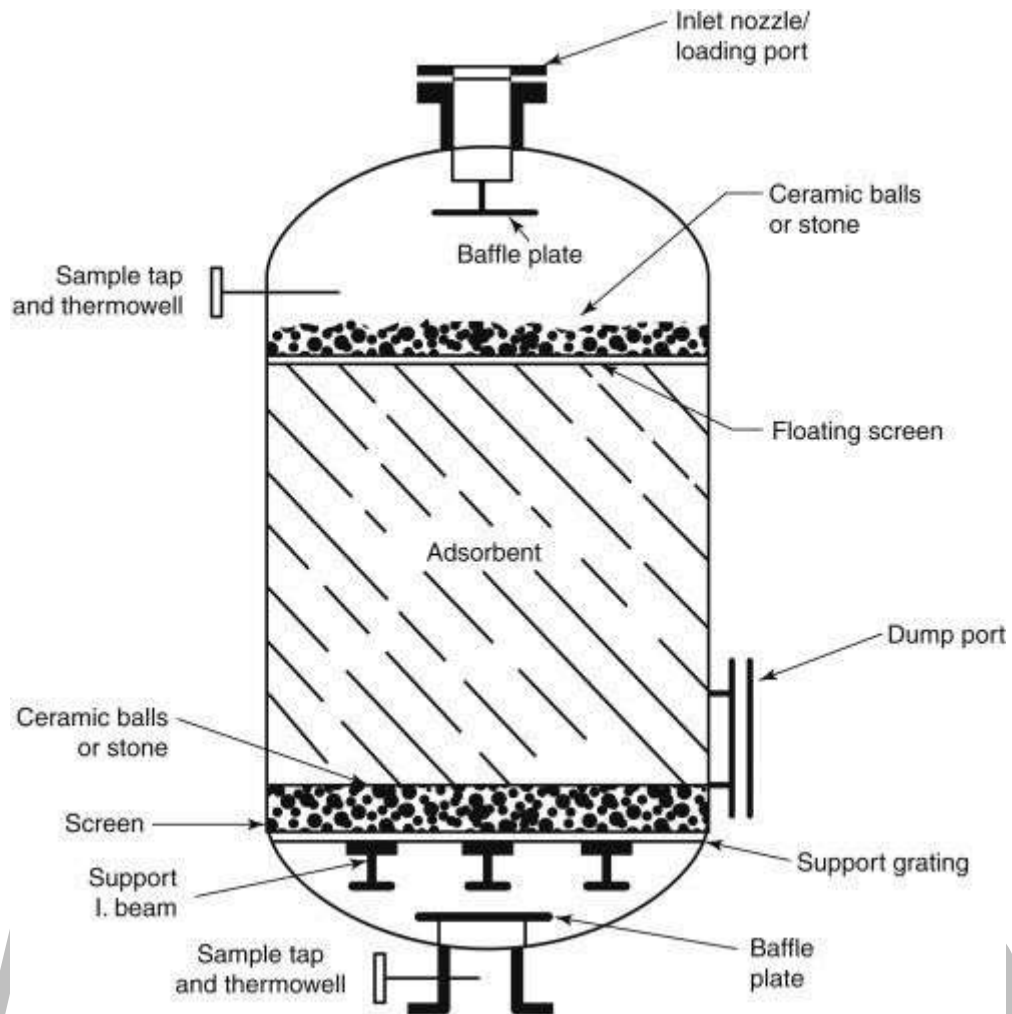


Figure 4.3.1 Adsorption

[Source: https://emis.vito.be/sites/emis/files/data_sheets/migrated/active_carbon_adsorption_2.PNG]

Advantages

- High efficiency in VOC removal
- Simple and robust technology
- Suitable for discontinuous processes
- Easy to maintain
- Easy to place

Disadvantages

- Dust can lead to blockages
- Component mixes may lead to early malfunction
- Not suitable for wet flue gases (less critical for impregnated activated carbon)
- Risk of spontaneous combustion in the bed (ketones, turpentine...)

- Polymerisation risk for unsaturated hydrocarbons on the activated carbon (exothermal and causes blockages)

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4.7 BIO-FILTRATION

- Bio-filtration is a pollution control technique using a bioreactor containing living material to capture and biologically degrade pollutants.
- Common uses include processing waste water, capturing harmful chemicals or silt from surface runoff, and microbiotic oxidation of contaminants in air

Examples of bio-filtration include:

- Bioswales, biostrips, biobags, bioscrubbers, Vermifilters and trickling filters
- Constructed wetlands and natural wetlands
- Slow sand filters
- Treatment ponds
- Green belts
- Green walls
- Riparian zones, riparian forests, bosques
- Bivalve bioaccumulation

Control of Air Pollution using Bio-Filters:

When applied to air filtration and purification, Bio-filters use microorganisms to remove air pollution. The air flows through a packed bed and the pollutant transfers into a thin biofilm on the surface of the packing material. Microorganisms, including bacteria and fungi are immobilized in the biofilm and degrade the pollutant. Trickling filters and bio-scrubbers rely on a biofilm and the bacterial action in their recirculating waters.

- The technology finds greatest application in treating malodorous compounds and water-soluble volatile organic compounds (VOCs).
- Industries employing the technology include:
 - Food and animal products
 - Off-gas from wastewater treatment facilities
 - Pharmaceuticals

- Wood products manufacturing
 - Paint and coatings application
 - Manufacturing and resin manufacturing .
- Compounds treated are typically mixed VOCs and various sulfur compounds, including hydrogen sulfide.
 - Very large airflows may be treated and although a large area (footprint) has typically been required a large biofilter (>200,000 acfm) may occupy as much or more land than a football field this has been one of the principal drawbacks of the technology.
 - Engineered biofilters, designed and built since the early 1990s, have provided significant footprint reductions over the conventional flat-bed, organic media type.
 - One of the main challenges to optimum biofilter operation is maintaining proper moisture throughout the system.
 - The air is normally humidified before it enters the bed with a watering (spray) system, humidification chamber, bio-scrubber, or biotrickling filter.
 - Properly maintained, a natural, organic packing media like peat, vegetable mulch, bark or wood chips may last for several years but engineered, combined natural organic, and synthetic component packing materials will generally last much longer, up to 10 years.
 - A number of companies offer these types or proprietary packing materials and multi-year guarantees, not usually provided with a conventional compost or wood chip bed bio-filter.
 - The scientific community is still unsure of the physical phenomena underpinning bio-filter operation, and information about the microorganisms involved continues to be developed.

A bio-filter/bio-oxidation system is a fairly simple device to construct and operate and offers a cost-effective solution provided the pollutant is biodegradable within a moderate time frame (increasing residence time = increased size and capital costs), at reasonable concentrations (and lb/hr loading rates) and that the airstream is at an organism-viable temperature.

- For large volumes of air, a bio-filter may be the only cost-effective solution.
- There is no secondary pollution (unlike the case of incineration where additional CO₂ and NO_x are produced from burning fuels) and degradation products form additional biomass, carbon dioxide and water.
- Media irrigation water, although many systems recycle part of it to reduce operating costs, has a moderately high biochemical oxygen demand (BOD) and may require treatment before disposal.
- This "blowdown water", necessary for proper maintenance of any bio-oxidation system, is generally accepted by municipal publicly owned treatment works without any pretreatment.
- Bio-filters are being utilized in Columbia Falls, Montana at Plum Creek Timber Company's fiberboard plant.
- The bio-filters decrease the pollution emitted by the manufacturing process and the exhaust emitted is 98% clean.
- The newest, and largest, bio-filter addition to Plum Creek cost \$9.5 million, yet even though this new technology is expensive, in the long run it will cost less overtime than the alternative exhaust-cleaning incinerators fueled by natural gas (which are not as environmentally friendly).

Types of Bio-Filters:

1. Fixed Bed Bio-filters

- Fixed Bed Bio-filters consist of a filter material that may be synthetic or organic, which serves as support for the microorganisms.
- Some of the filter materials that may be used are porous rock, diatomaceous earth, perlite, and ground wood chips as well as different types of compost or organic waste.
- Fixed bed bio-filters operate by passing a humidified gas stream containing the contaminants through the bed where they are degraded by the microorganisms.
- This is recommended for treating contaminants poorly soluble in water due to the absence of the aqueous phase.

- It is important to note that the physical footprint of fixed bed bio-filters is greater than other types of bio-filters.

2. Drained Bed Bio-filters

- Drained Bed Bio-filters consist of a packed column with an inert support where biofilm develops.
- Through the bed, a gaseous stream is fed that contains the substrate to biodegrade in addition to a liquid stream that is continually recycled through the bed.
- This liquid stream has the function of providing nutrients to the biofilm, as well as removing the degradation products of the microorganisms.
- These systems are recommended for water-soluble compounds.
- The recirculation of fluid facilitates the elimination of the reaction products as well as better control over the biological process by pH control and composition of the liquid medium.
- Drained bed bio-filters are the equipment with the smallest physical footprint in addition to being simple to operate.

3. Bio scrubbers

- The compound to be degraded first is absorbed in the liquid phase located in an absorption tower filled with liquid.
- The operation involves making the gas flow in a countercurrent through the liquid where the contaminants and oxygen are absorbed.

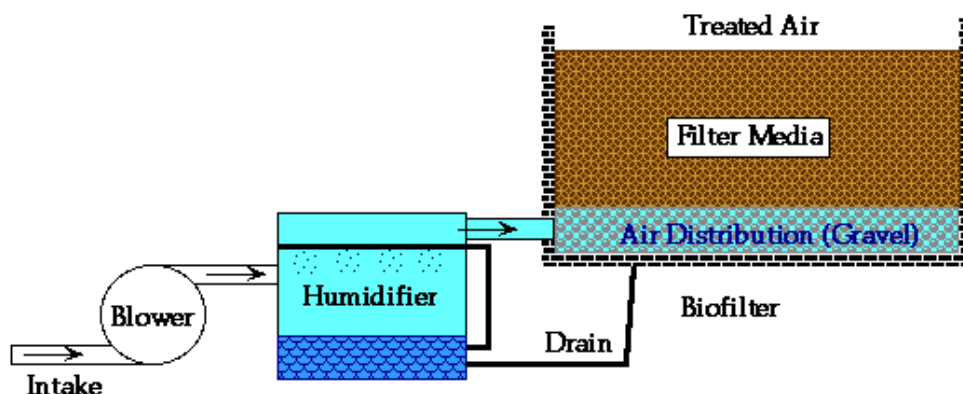


Figure 4.7.1 Biofilter Schematic

[Source: <http://compost.css.cornell.edu/odors/biofilter.gif>]

- The liquid is fed to a reactor packed with an inert material covered with biofilm that is responsible for degrading the pollutant.
- Bio-scrubbers are the most suitable systems for the treatment of highly water-soluble compounds.
- Their advantage in respect to biofilters is that they do not accumulate products that can have harmful effects on the microorganisms.
- They facilitate control of the biological process through the composition of the liquid medium.

However, bio-scrubbers are more costly because they require two systems, one for absorption and one for the biodegradation of the contaminant, therefore making them less economical than drained bed bio-filters.

The selection of the most appropriate system depends on the characteristics of the gas stream being treated, the expected removal efficiency and the costs involved.

Parameters of Bio-Filtration:

The main parameters to consider when designing a Bio-filtration system are:

- The characteristics the gas contaminate (concentration, flow, particulate matter, temperature)
- Selection of filter material
- Moisture content of the filter material
- Microorganisms

4.6 BIOSCRUBBERS

- A bio scrubber couples traditional air pollution control and wastewater treatment technologies and consists of two units:
 - The soluble waste gases and oxygen are continuously absorbed into water in the scrubber.
 - Biological oxidation occurs in the basin unit, which often is the activated sludge basin of a wastewater treatment plant.
- Bio scrubbers are used where the biological degradation products (such as the acids produced during H₂S and NH₃ removal) would harm a biofilter bed.
- In addition to hydrocarbons, bio scrubbers are being used to remove chlorinated organics. Bio scrubbers come in two forms:

1. Activated-sludge scrubber:

- Gaseous pollutants are absorbed by a solvent in a countercurrent packed column tower.
- The absorption solution generally is a water and sludge mixture (1-10 g sludge per liter of water). After absorption in the column, the solution proceeds to a sedimentation tank where biodegradation takes place.
- Clean solution from the sedimentation tank recycles back to the packed column.

2. Trickling-filter scrubbers:

- As with the activated-sludge scrubber, gaseous contaminants are transferred into the liquid phase with a countercurrent scrubber.
- Instead of being fed into an activated sludge pond, however, the pollutant-laden scrubber wastewater is spread over a trickling filter.
- The technology offers greater control than does the activated sludge scrubber.

Applications Biofilters and Bioscrubbers:

- Biofilters and bioscrubbers have different applications, such as VOC treatment, inorganic compounds treatment or odor reduction.

- Biofiltration is a biological process used for the treatment of volatile organic and inorganic compounds.
- Biofiltration application uses microorganisms that subject contaminants contained in air to biological degradation.
- During an air treatment process by biofiltration, polluted air passes through the macro pores of the filter material.
- At this time the contaminants degrade in order to be subsequently transferred to a liquid medium where they are used as carbon and energy sources (organic compounds) or as a source of energy (inorganic compounds).
- Use of biofiltration implies the production of biomass and the partial or total oxidation of the contaminant.
- Biomass, under certain conditions, undergoes oxidation by endogenous respiration.
- Thus, biofiltration processes result in a complete decomposition of the contaminants, creating non-hazardous products.

Advantages of bioscrubbers compared to biofilters:

- Smaller volume of the equipment
 - Better pH control
 - No clogging problems of packing materials
 - Lower occurrence of toxic concentrations in the water phase.

Disadvantages:

- Only cost-effective for pollutants with a dimensionless Henry's law's coefficient below 0.01
- More difficult to attain elimination efficiencies higher than 98%
- More complicated start-up procedure
- Higher operational costs.

4.4 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, absorbers, 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
- 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 Surface condenser Contact condenser.

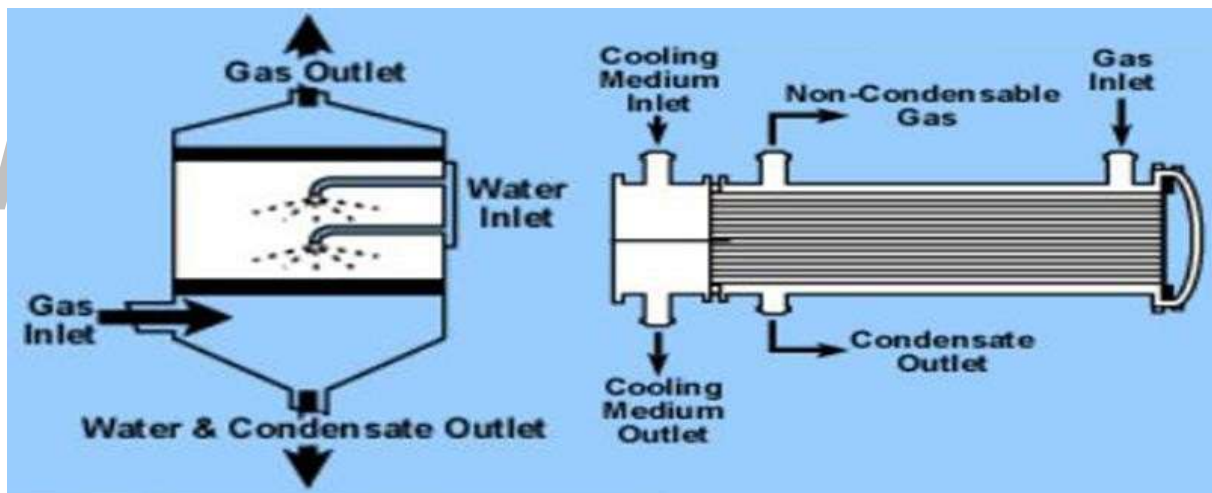


Figure 4.4.1 Contact and Surface Condenser

[Source:<https://www.prakruti.com/images/air-pollution-control-systems/condensation.jpg>]

➤ REFRIGERATED CONDENSER

A refrigerated condenser is a control device that is used to cool an emission stream having organic vapors in it and to change the vapors to a liquid.

A refrigerated condenser condenses organic vapors just as moisture is condensed to water in an air conditioning system.

However, while condensed water from an air conditioning system is disposed of via a drain, condensed organic vapors can be recovered, refined, and might be reused, preventing their release to the ambient air.

➤ **Importance**

Nitrogen oxides (NO_x, the x is used because there are five oxides) and VOC react with each other in ultraviolet (UV) light from the sun to produce tropospheric ozone.

Ozone in the troposphere (the air we breathe in the lower atmosphere) is the principle constituent of smog and is harmful to public health. Refrigerated condensers can reduce VOC emissions, which reduces the ozone generating potential of NO_x. NO_x reduction techniques are discussed in a separate CATC Technical Bulletin.

Many organic compounds have been designated as negligibly reactive with regard to ozone formation and are exempt from VOC regulations. Although some VOC maybe HAP, compounds exempt from VOC regulations also may be HAP and need to be controlled, in addition, stratospheric ozone depleting chemicals are not considered VOC or HAP, but still need to be controlled. Stratospheric ozone protects us from the harmful rays in sunlight.

➤ **Uses:**

A refrigerated condenser works best on emission streams containing high concentrations of volatile organic emissions. They are less effective on dilute streams (i.e., where there is much more air flow than organic vapor flow).

Example:

A paint spray booth requires a substantial amount of air flow through it to protect worker health and safety. As a result, most of the heat removed by a refrigerated condenser would come from air. The organic vapor content in a paint booth emission stream could be recovered by using a refrigerated condenser, but it would be very costly per ton of organic compound recovered. In addition, to reuse the organic compound, moisture condensation would probably need to be removed.

A refrigerated condenser could be a viable control option for any source of evaporative organic emissions if:

- ❖ There is minimal air flow carrying the organic emissions (i.e., the air stream is saturated with the organic compound)
- ❖ The organic vapor containment system limits air flow
- ❖ Required air flow does not overload a refrigeration system with heat
- ❖ Only one organic compound is emitted (or the system is designed for the compound that is the most difficult to control)

Refrigerated condensers often are used in the following applications:

1. Dry Cleaning Industry :

It used to recycle dry cleaning fluid (perchloroethylene or petroleum- base solvent) with virtually no air flow. The vapors are usually condensed without air being used to transport them.

2. Degreasers using VOC or Halogenated Solvents :

Some air is mixed with vapors because the solvent is uncovered (i.e., exposed to the atmosphere). Preparation (degreasing/cleaning) of parts prior to powder coating is one example of this.

- ❖ Transfer of Volatile Organic Liquid (VOL) and Petroleum Products (e.g., bulk plants, bulk terminals, and similar transfer operations).
- ❖ Vapors from Storage Vessels/Tanks

➤ REFRIGERATION

All refrigeration units are basically "heat pumps," absorbing heat on the "cold side" of the system and releasing heat on the "hot side" of the system. All refrigeration systems have a hot side and a cold side. Some have a compressor.

The difference between refrigeration systems is whether the refrigerant is actually liquified within the apparatus and how low a temperature the "cold side" can reach.

Working of the Refrigerated Condensers:

- Each type of refrigeration system chills a heat exchanger surface in a condenser, and organic vapor condenses on the cold heat exchanger (or heat transfer) surface.

- Condensation of organic vapor causes it to lose volume.
- This loss of volume produces a lower concentration of vapor near the heat exchanger (i.e., the condensation) surface.
- This produces a concentration gradient that causes the flow of the emission stream toward the heat exchange surface.
- Condensation is assisted by turbulence in the emission stream that also brings the emission stream close enough for heat transfer and subsequent condensation of the organic vapors.

Only a negligible fraction of a percent escapes this combined action when the condenser is sized large enough and the refrigerant temperature is low enough. A finite vapor pressure is always present that allows some vapor to remain in the exhaust stream at all times.

➤ **Reverse Brayton Cycle Systems**

Reverse Brayton Cycle machines must be externally powered by an electric motor, a gas turbine, or an internal combustion (piston) engine. It is easier to reach the rotational speed of the turbine with either an electric motor or a gas turbine than with a piston engine.

Reverse Brayton Cycle turbines operate inversely from the normal operating cycle for gas turbines. Instead of converting heat to shaft horsepower, the Reverse Brayton Cycle system uses shaft horsepower to remove heat and reject it to the atmosphere.

As shown in Figure, it does this by first compressing the refrigerant air, then rejecting the heat of compression at an elevated temperature, and finally expanding the refrigerant air through a turbine to get useful work from it.

- As a result of the lack of heat input, temperature rise from compression, followed by dissipation of heat, and the work that the refrigerant air flow does on the expansion turbine, exhaust from the expansion turbine is very cold, reaching about -73°C (-100°F).
- The expansion turbine assists the external power source in spinning the compressor turbine.

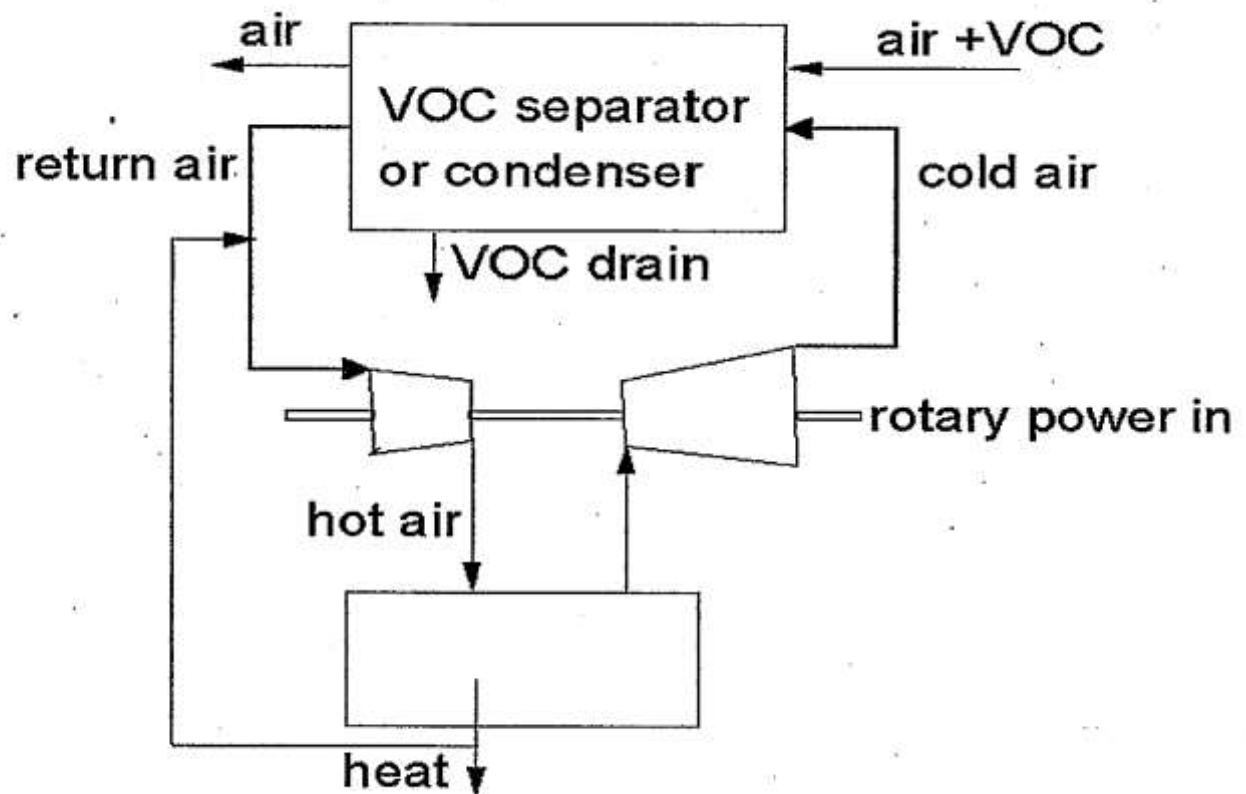


Figure 4.4.2 Reverse Brayton Cycle Refrigeration System

[Source: <https://www.nuclear-power.net/wp-content/uploads/2017/04/reverse-Brayton-cycle-cooling-and-heat-pumps-min-259x300.png?ezimgfmt=ng:webp/ngcb49>]

- The refrigerant air never liquefies in this cycle. Organic vapors may go through the Reverse Brayton Cycle along with the refrigerant air and no heat exchanger surface would then be required.
- Reverse Brayton Cycle machines cool the refrigerant air (and organic vapors if they are contained in the refrigerant air) to a very low temperature in what appears to be a single step, although it may actually be several steps in the expansion turbine.
- All of the vapors condense essentially together.
 - ❖ If the cold refrigerant air is used to chill a heat exchanger (surface condenser) as in Figure, the organic vapor can be condensed without going through the cycle.
 - ❖ When organic vapor is exposed only to a heat exchange surface, the heat exchanger can be like any other refrigerated condenser.
- The refrigerant air in a Reverse Brayton Cycle system does not contaminate the organic

compound, but several organic compounds may be mixed in the vapor state and therefore may be condensed together and mixed in a condensed liquid or slurry.

Reverse Brayton Cycle machines do not have a pre-cooling feature to separate moisture. To the extent that moisture is present in the vapor, it will be present in the condensed organic liquid. Some organic compounds can be separated by skimming, others require fractional distillation for purification.

After completing the Reverse Brayton Cycle, the refrigerant air can be either recycled or exhausted to the atmosphere. Because some organic compounds are actually frozen they should be separated as solid particles. To the extent that the refrigerant air recovers some of its heat before it is again compressed, or for some low melting point compounds, these organic compounds also maybe recovered as a liquid. Multiple filter channels can allow one compound to warm up for recovery, while the other is chilled by cleaning the cold refrigerant air flow. While frozen organic particles must be captured by a filter, organic droplets can be captured by inertia! impact or in a cyclone separator. In both cases the cut-off particle/droplet size depends on the design.

➤ **Cryogenic Cooling**

Cryogenic Cooling uses no power at the plant where it is used for cooling, but the air separation plant that generates liquid nitrogen usually is electrically powered. The truck used to deliver liquid nitrogen to the user's plant will also use fuel. The distribution of liquid nitrogen in a plant is self-powered by the pressure of the gaseous nitrogen that results from heat leakage which causes the liquid nitrogen to boil.

Cryogenic Cooling starts at an air separation plant. Air is compressed, cooled and then expanded to atmospheric pressure. This expansion cools some fraction of the compressed air to make it a liquid. The air that has become liquid is then allowed to boil to give off Argon, Nitrogen, Oxygen, etc. at their respective boiling point temperatures. Each gas is then collected and condensed again by compression and expansion just like the air originally was. This produces relatively pure liquid nitrogen that is used for cryogenic cooling.

Factors Affect The Performance Of Refrigerated Condensers:

Any refrigerant can be used to cool the surface of a heat exchanger. The only requirements are that the temperature is low enough and that the cooling capacity is

sufficient. When organic compounds are recovered along with moisture and other contaminants, an impure organic compound may require too much effort to purify and might be destroyed by burning. However, recovery and recycling of the organic compound is the preferred outcome.

Each organic compound becomes liquid below its dew point, and becomes a solid "frost" below its freezing point. This "frost" must be removed from a condenser periodically, especially in cryogenic condensers because they are so cold, to allow free flow of the emission stream containing organic vapor and to permit heat transfer to occur as designed. The "frost" can be removed by flushing the condenser with the condensed organic compound in its liquid phase. However, the liquid organic compounds are always mixed in the frost and slurry, just as the organic vapors were mixed.

Cryogenic condensers can be the coldest and therefore are capable of the highest DRE. Fluctuations in heat load caused by fluctuations in emission stream flow and organic vapor concentration are offset by a thermostatically controlled valve modulating the nitrogen flow. However, if cryogenic cooling is operated at a temperature well above the boiling point of liquid nitrogen, there will be locations within the condenser that will be somewhat warmer than the thermostat setting because gaseous nitrogen has a low specific heat and is warming up as it passes through the shell of the condenser.

The DRE is limited by the amount of organic vapor that escapes with the exhaust from the condenser. The amount of organic vapor that escapes is determined by both the vapor pressure of the condensed liquid (i.e., the partial pressure of the organic vapors in the emission stream) and the amount of air present in the emission stream. We cannot always eliminate the air from the emission stream, but we can minimize both the amount of air in the emission stream and the vapor pressure of organic compounds. Therefore, condensation technology needs to:

1. Maximize the portion of the organic vapor that is affected by the cold surface in the condenser (i.e., make the residence time large enough and the flow sufficiently turbulent).

2. Minimize the partial pressure of the organic vapor after it comes in contact with the heat exchanger (i.e., make the condenser cold enough and the refrigeration capacity large enough).

3. Reduce the temperature of the organic compounds below the freezing point, if possible, because vapor pressure becomes a minimum when organic compounds are frozen. (This should be done even though frozen organic compounds must be removed periodically.)

4. Minimize the amount of air in the emission stream that contains organic vapors. Heat load is greater when you must chill a lot of air. Minimizing the amount of air mixed with the organic vapors will reduce the heat load and increase the useful cooling (i.e., the cooling available for condensation). Reducing the heat load will reduce the cost of refrigeration. Increasing the useful cooling will improve the DRE.

4.1 FACTORS AFFECTING SELECTION OF CONTROL EQUIPMENT

There are a number of factors to be considered prior to selecting a particular in air pollution control equipment. In general, they can group into three categories.

- Environmental
- Engineering
- Economic

1. Environmental

Equipment location, availability space, ambient conditions, availability of adequate utilities and ancillary system facilities.

- Maximum available emissions (air pollution regulation)
- Contribution of air pollution control system to waste water and solid waste.
- Contribution of air pollution control system to plant noise levels.

2. Engineering

- Design and performance characteristics of the particular control system (size and weight, pressure drop , reliability and dependability, temperature limitation, maintenance requirement)
- Gas stream characteristics (volume, flow rate, temperature, pressure, humidity, composition, viscosity, density, reactivity, corrosiveness and toxicity)
- Contaminant characteristics (physical and chemical properties, concentration, particulate shape and size distribution in the case of particulates)

3. Economic

- Capital cost (equipment, installation, engineering, etc.)
- Operating cost (utilities, maintenance, etc.)
- Expected equipment lifetime and salvage value.

4.5 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

1. 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.

2. Thermal incineration

- 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.

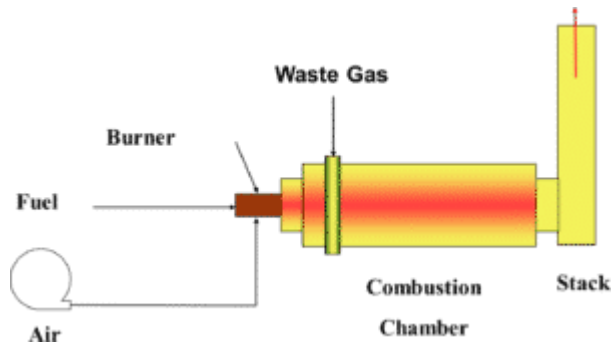


Figure 4.5.1 Thermal incinerator

[Source:<https://mk0pccgroupd070oma36.kinstacdn.com/wp-content/uploads/thermal-oxidizer-graphic-e1555350485609.png>]

3. Catalytic incinerators

- 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.

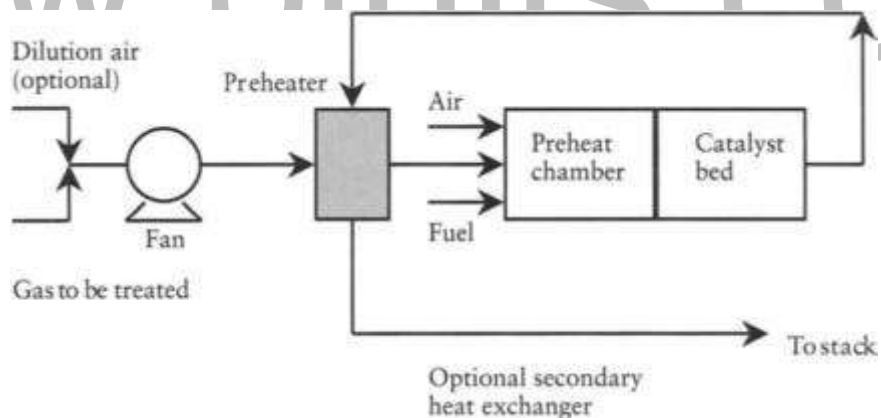


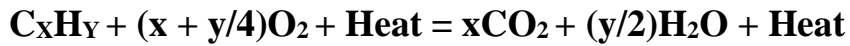
Figure 4.5.2 Catalytic incinerator

[Source:<https://ars.els-cdn.com/content/image/3-s2.0-B9780122896767500163-f13-22-9780122896767.jpg>]

Performance Equations of Incineration or Oxidation:

Oxidation, or combustion as it pertains to the air pollution control industry, can simply be defined as a rapid combination of oxygen with a fuel (in this case, a volatile organic compound, or VOC). This process will result in the release of energy in the form of heat and, if completed correctly in our world, the process will also release carbon dioxide and water.

The basic combustion reaction looks like this:



Where, C_xH_y is any hydrocarbon

O_2 is oxygen

CO_2 is carbon dioxide

H_2O is water

The air pollution control industry typically refers to the equipment which performs this process as oxidizers (i.e. thermal oxidizers, catalytic oxidizers, or regenerative thermal oxidizers).

This is because most processes have excess oxygen (excess air), producing a lean mixture or an oxidizing combustion reaction. This blog will only focus on these type of reactions.

So far, we have talked about the end results of the combustion reaction. These end products are the same for all fuels containing different combinations of hydrogen and carbon within their chemical formulas. However, it should be noted that how these end products are achieved can take many different paths or reaction mechanisms. Therefore, different flames, cold spots, or quenching surfaces can produce many varied and unknown intermediate products.

Example:

Carbon and hydrogen atoms may combine and disassociate to form unstable compounds like carbon monoxide and different types of aldehydes.

The types of compounds formed and the speed of their formation and disassociation depend upon the reaction conditions. Other reaction conditions that can affect the combustion process other than temperature are items like pressure, O_2 levels present, and mixing.

Most oxidizers operate at or near atmospheric pressure, so we will not explore that variable in depth. As discussed above, most oxidizers also operate with excess air,

oxidizing the atmosphere, which means that the combination of the final products is more dependent on temperature and mixing.

The mixing of the VOC is important to the combustion reaction. This reaction needs a minimum temperature to start the process and efficiently proceed to the desired end products of CO_2 and H_2O . Mixing is very important to provide a uniform temperature to start the reaction. This is key to lowering fuel gas costs.

Mixing is also important with regards to the mixture of VOC and O_2 . Every particle of fuel or VOC must contact a particle of oxygen in order for the combustion reaction to take place. Oxygen content and residence time at the combustion temperature is also important.

The reaction rate of the combustion reaction is dependent on temperature; for instance, an increase in temperature actually decreases the amount of time that is needed to convert CO to CO_2 .

- A decrease in O_2 concentration would require better mixing, due to the lack of availability of O_2 for the reaction completion.
- Temperature, oxygen concentration, and residence time to reduce CO actually must be controlled in the opposite direction to reduce the amount of nitrogen oxides (NO_x) emitted, so raising the temperature isn't always the best solution.

Advantage:

- One advantage of thermal incineration is that the energy and heat produced by the process can be recovered and used to power other processes in the facility.

Disadvantages:

- Thermal incinerators are also not generally cost-effective for low-concentration, high-flow organic vapor streams
- Thermal incinerators are not usually as economical, on an annualized basis, as recuperative or regenerative incinerators because they do not recover waste heat energy from the exhaust gases.

4.8 PROCESS CONTROL AND MONITORING

Air pollution control efforts by federal, State, regional, and municipal agencies and by industry have expanded tremendously within the past few years. That this increased effort is a reflection of elevated public understanding of the problem and rising public insistence upon action is inescapable.

Through all media of mass communication, through the efforts of public service organizations, and through the actions and pronouncements of public officials at all levels of government, the popular desire for better control of air pollution is being expressed with mounting frequency and increasing impact.

To generating an unprecedented expansion in control activity, requires that communication between the individuals and agencies responsible for air pollution control and the citizen, to whom this responsibility is owed, be open, comprehensive, and forthright.

Any other response to the need for public information and education concerning the problem of air pollution must in the long run seriously jeopardize the air pollution control effort.

- ✚ There are various air pollution control technologies and land-use planning strategies available to reduce air pollution.
- ✚ At its most basic level, land-use planning is likely to involve zoning and transport infrastructure planning.

Land-use Planning

In most developed countries, land-use planning is an important part of social policy, ensuring that land is used efficiently for the benefit of the wider economy and population, as well as to protect the environment.

- Efforts to reduce pollution from mobile sources includes

1. Primary regulation (many developing countries have permissive regulations),

2. Expanding regulation to new sources (such as cruise and transport ships, farm equipment, and small gas powered equipment such as string trimmers, chainsaws, and snowmobiles),
3. Increased fuel efficiency (such as through the use of hybrid vehicles),
4. Conversion to cleaner fuels (such as bio ethanol, biodiesel, or conversion to electric vehicles).

- Titanium dioxide has been researched for its ability to reduce air pollution.
- Ultraviolet light will release free electrons from material, thereby creating free radicals, which break up VOCs and NO_x gases. One form is super hydrophilic.
- In 2014, Prof. Tony Ryan and Prof. Simon Armitage of University of Sheffield prepared a 10 meter by 20 meter-sized poster coated with microscopic, pollution eating nano particles of titanium dioxide.
- Placed on a building, this giant poster can absorb the toxic emission from around 20 cars each day.

SO_x Control :

General Methods for Control Of So 2 Emissions

➤ Change to Low Sulfur Fuel

- ✚ Natural Gas
- ✚ Liquefied Natural Gas
- ✚ Low Sulfur Oil
- ✚ Low Sulfur Coal

➤ Use Desulfurized Coal and Oil Increase Effective Stack Height

- ✚ Build Tall Stacks
- ✚ Redistribution of Stack Gas Velocity Profile
- ✚ Modification of Plume Buoyancy
- ✚ Use Flue Gas Desulfurization Systems
- ✚ Use Alternative Energy Sources, such as Hydro -Power or Nuclear-Power

Flue Gas Desulfurization

➤ Classification

SO₂ scrubbing, or Flue Gas Desulfurization processes can be classified as: –

- ✚ Throwaway or Regenerative, depending upon whether the recovered sulfur is discarded or recycled.
- ✚ Wet or Dry, depending upon whether the scrubber is a liquid or a solid.

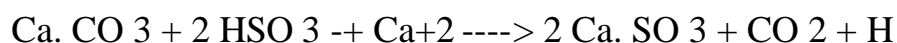
➤ Flue Gas Desulfurization Processes

The major flue gas desulfurization (FGD), processes are :

- ✚ Limestone Scrubbing
- ✚ Lime Scrubbing
- ✚ Dual Alkali Processes
- ✚ Lime Spray Drying
- ✚ Wellman-Lord Process

➤ Limestone Scrubbing

Limestone slurry is sprayed on the incoming flue gas. The sulfur dioxide gets absorbed. The limestone and the sulfur dioxide react as follows :



NO_x Control :

Background on Nitrogen Oxides . There are seven known oxides of nitrogen :



NO and NO₂ are the most common of the seven oxides listed above. NO_x released from stationary sources is of two types .NO_x control can be achieved by:

- ✚ Fuel Denitrogenation
- ✚ Combustion Modification
- ✚ Modification of operating conditions
- ✚ Tail-end control equipment

- + Selective Catalytic Reduction
- + Selective Non - Catalytic Reduction
- + Electron Beam Radiation
- + Staged Combustion

i) Fuel Denitrogenation

- One approach of fuel denitrogenation is to remove a large part of the nitrogen contained in the fuels.
- Nitrogen is removed from liquid fuels by mixing the fuels with hydrogen gas, heating the mixture and using a catalyst to cause nitrogen in the fuel and gaseous hydrogen to unite. This produces ammonia and cleaner fuel.
- This technology can reduce the nitrogen contained in both naturally occurring and synthetic fuels.

ii) Combustion Modification

Combustion control uses one of the following strategies: .

- Reduce peak temperatures of the flame zone. The methods are :
 - + Increase the rate of flame cooling
 - + Decrease the adiabatic flame temperature by dilution
- Reduce residence time in the flame zone. For this we change the shape of the flame zone
- Reduce Oxygen concentration in the flame one. This can be accomplished by:
 - + Decreasing the excess air
 - + Controlled mixing of fuel and air
 - + Using a fuel rich primary flame zone

iii) Modification of Operating Conditions

The operating conditions can be modified to achieve significant reductions in the rate of thermal NO_x production. the various methods are:

- + Low-excess firing

- ✚ Off-stoichiometric combustion (staged combustion) Flue gas recirculation

Reduced air preheat

Reduced firing rates ✚

Water Injection

Carbon Monoxide Control:

Formation Of Carbon Monoxide due to insufficient oxygen

- Factors affecting Carbon monoxide formation:
 - ✚ Fuel-air ratio
 - ✚ Degree of mixing
 - ✚ Temperature
 - ✚ Control carbon monoxide formation.

Note :

CO & NO_x control strategies are in conflict

1. Stationary Sources

- ✚ Proper Design
- ✚ Installation
- ✚ Operation
- ✚ Maintenance

2. Process Industries

- ✚ Burn in furnaces or waste heat boilers.

Carbon Dioxide Control:

1. Sources of Carbon Dioxide

(i) Human-Related Sources

- ✚ Combustion of fossil fuels: Coal, Oil, and Natural Gas in power plants,

automobiles, and industrial facilities

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Use of petroleum-based products

Industrial processes: Iron and steel production, cement, lime, and aluminum manufactures

(ii) Natural Sources

- + Volcanic eruptions
- + Ocean-atmosphere exchange
- + Plant photosynthesis

2. Methods For Control of CO₂ Emissions

- Reducing energy consumption, increasing the efficiency of energy conversion
- Switching to less carbon intensive fuels
- Increasing the use of renewable sources
- Sequestering CO₂ through biological, chemical, or physical processes

Mercury Emissions

- Mercury exists in trace amounts

- + Fossil fuels such as Coal, Oil, and Natural Gas
- + Vegetation
- + Waste products

- Mercury is released to the atmosphere through combustion or natural processes.

- + It creates both human and environmental risks.
- + Fish consumption is the primary pathway for human and wildlife exposure.

United states is the first country in the world to regulate mercury emissions from coal-fired power plants

Control Technologies for Mercury Emissions

Currently installed control devices for SO₂, NOX, and particulates, in a power

plant, remove some of the mercury before releasing from the stack.

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1. Activated Carbon Injection :

Particles of activated carbon are injected into the exit gas flow, downstream of the boiler. The mercury attaches to the carbon particles and is removed in a particle control device

2. Thief process for the removal of mercury from flue gas:

It is a process which extracts partially burned coal from a pulverized coal-fired combustor using a suction pipe, or "thief, " and injects the resulting sorbent into the flue gas to capture the mercury.

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