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Emission Control Technology

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1. Introduction

The chapter presents various promising methods to control air pollution emissions. Although several previously published books have examined this field [1-6], most of them presented only the methods to control air pollutants generated from stationary sources. These days, however, mobile sources are also important sources contributing to air pollution. Among the six air criteria pollutants listed by the United States Environmental Protection Agency (EPA), including CO, particulate matter (PM), SO₂, NO₂, O₃, and Pb, mobile sources can contribute to 81% of all CO emissions, 37% of PM, 4% of SO₂, 45% of NO₂, 47% of volatile organic compounds (VOCs are precursors of O₃, their estimate is a surrogate of the O₃ concentration), and 72% of Pb [6]. Therefore, promising methods to control the emission of air pollutants generated from mobile sources should be included in the chapter to provide the readers with innovative ideas about the emission control of air pollution. Because of the variety of mobile sources and their mobility from one location to another, the methods applied to control the emission of air pollutants generated from stationary sources may not be useful for controlling air pollutants generated from mobile sources. Therefore, in this chapter, upstream control strategies, which try to control air pollutants from upstream emission processes, will be presented as promising methods to control the emission of air pollutants generated from mobile sources. Policies and regulations applying to control air pollutants emitted from transportation activities, agricultural activities, and construction fields will be presented as the main strategies to air pollution from upstream processes.

On the other hand, the chapter also presents downstream technologies to control air pollutants emitted from stationary sources. Based on the characteristics of target pollutants, the downstream control technologies will be classified into two categories: particulate matter and gaseous pollutant control technologies. The technologies of cyclone, wet scrubber, electrostatic

precipitators, and fabric filter will be introduced in the chapter as methods to control particulate matter pollutants. To control gaseous pollutants, the chapter will present methods such as adsorption, absorption, condensation, incineration, applications of biological system, and photocatalyst. Each technology will be presented in detail from definition to principle and applications. The advantages and disadvantages of each technology will be described and compared in the chapter.

2. Upstream control strategies

2.1. Control transportation activities

Strategies to control air pollutants emitted from transportation activities include regulations to control precursor pollutants in raw materials; the application of catalytic converters to reduce NO_x , CO, and hydrocarbon emissions; the control of lubricant consumption; the reduction of motorized transportation demand; and the improvements to road quality and traffic flow.

2.1.1. Raw materials

Air pollutants can be controlled based on regulations that control precursor pollutants in raw materials such as sulfur and lead. Sulfur oxides (SO_x) in aerosol are formed during the combustion process of sulfur in fossil fuels such as gasoline and diesel. Therefore, the use of low-sulfur-content fuels can be considered as a control strategy to reduce SO_2 emissions. Many regulations have been issued to reduce the sulfur content in all transportation fuels. For example, Figure 1 presents a selection of a few of the gasoline and diesel sulfur specifications in major countries and the regulatory timetable associated with the introduction of these specifications [7].

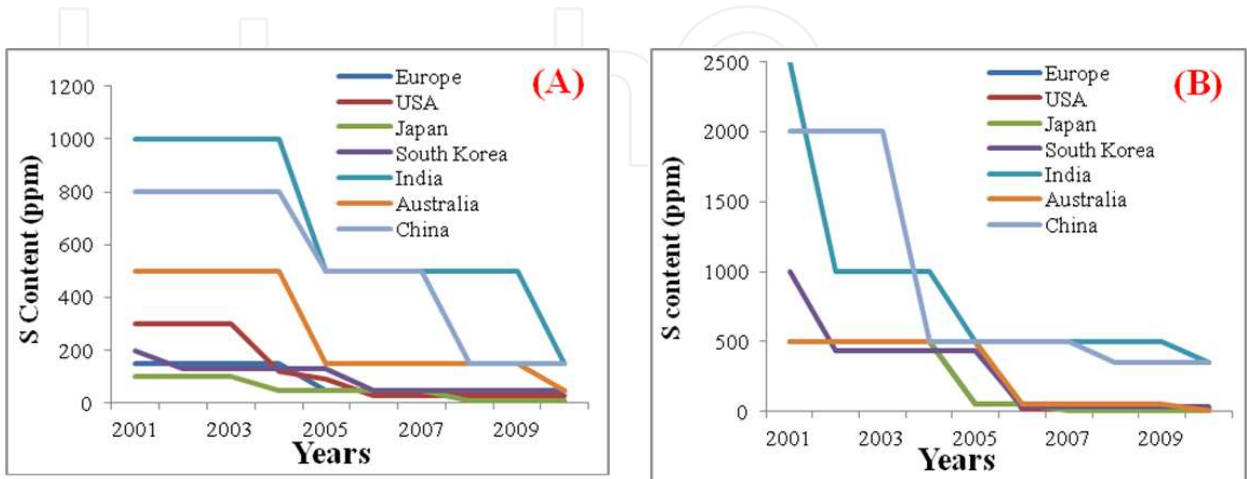


Figure 1. Regulations and regulatory timetable for sulfur content in gasoline (A) and diesel (B) in several countries.

In the 1920s, refiners started adding lead compounds to gasoline in order to increase octane levels and improve engine performance by reducing engine “knock” and allowing higher engine compression. However, the burning of leaded fuel introduced massive quantities of atmospheric lead leading to many adverse effects on human health. Therefore, regulations to eliminate lead from leaded fuel began to be issued worldwide from the 1970s. For example, the US EPA scheduled performance standards requiring refineries to decrease the average lead content of all fuels beginning in 1975, but these were postponed until 1979 through a series of regulatory adjustments. By the early 1980s, the lead content in fuels had declined by about 80% due to both the regulations and the fleet turnover [8]. In August 1984, the US EPA proposed a further reduction of lead to 0.1 grams per liter gallon (gplg) by January 1, 1986. However, several refineries were not able to achieve this time scale, so the US EPA postponed the deadline until January 1, 1988. Lead was banned as a fuel additive in the United States beginning in 1996. Figure 2 shows the decline over time in the lead content of leaded fuel in the United States [9].

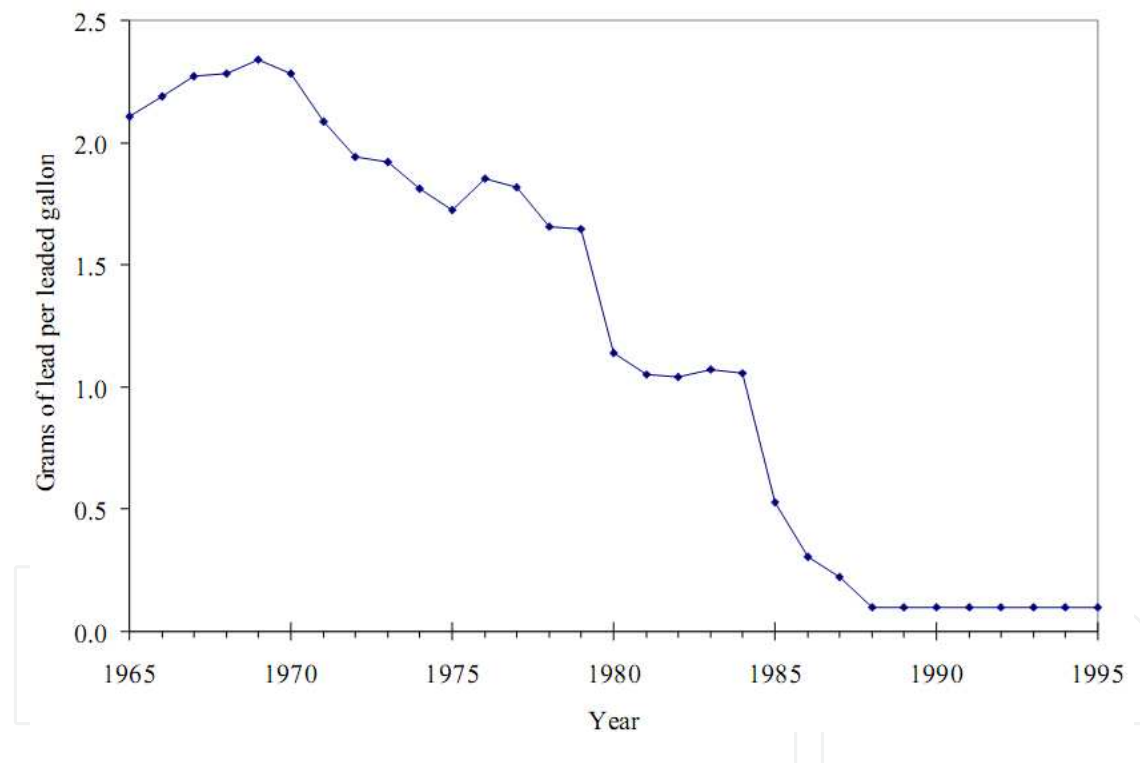


Figure 2. Temporal lead content in leaded fuel in the United States.

Regulations concerning oxygenated gasoline and reformulated gasoline were also issued in the United States in 1990 to reduce the vehicular emissions of CO and VOCs. The oxygenated gasoline regulation required a higher oxygen content in gasoline in order to ensure more complete burning of the gasoline and thereby reduce harmful tailpipe emissions from motor vehicles. In this respect, oxygen dilutes or displaces the precursor pollutant components in gasoline such as aromatics (e.g., benzene) and sulfur and thus decreases their content in gasoline. The reformulated gasoline regulation is specially blended gasoline. Therefore, the

gasoline can be burned more cleanly and can be prevented from evaporating as quickly as conventional gasoline, thereby reducing the emission of smog-forming and toxic pollutants. To reduce the emission of benzene (VOCs) into an aerosol, the US EPA required all refiners to meet an annual average gasoline benzene content standard of 0.62% by volume (vol %) in all their gasoline, both reformulated and conventional, nationwide, from 2011.

In addition, the use of new-generation fuels such as biofuels and natural gas can be a valuable strategy to reduce air pollutant emission. Feedstocks for biofuels, mostly plants, are much more environmental-friendly and evenly distributed around the world than the feedstocks for traditional fuels such as oil and gas. Two of the most commonly used biofuels are ethanol and biodiesel. Biodiesel fuels are oxygenated organic compounds of methyl or ethyl esters derived from a variety of renewable sources such as vegetable oil, animal fat, and cooking oil. Therefore, the use of biofuels for transportation activities can significantly reduce the atmospheric emissions of CO, hydrocarbon, and lead.

2.1.2. Catalytic converters

A catalytic converter is a vehicle emission control device that converts toxic pollutants in exhaust gas to less-toxic pollutants by catalyzing a redox reaction (oxidation or reduction). A catalytic converter comprised usually of the following three main parts is used in internal combustion engines: substrate, washcoat, and catalytic materials. The substrate material is usually a ceramic monolith with a honeycomb structure. A washcoat, usually aluminum oxide, titanium dioxide, silicon dioxide, or a mixture of silica and alumina, is used as a carrier for the catalytic materials. The catalytic material is often a mix of precious metals such as platinum, palladium, and rhodium. The catalytic converter can reduce oxides of nitrogen (NO_x) into nitrogen gas (N_2), combine or oxidize carbon monoxide (CO) with/or unburned hydrocarbons (HC) to produce carbon dioxide (CO_2) and water (H_2O). A schematic diagram illustrating the role of the catalytic converter in reducing air pollutants is shown in Figure 3.

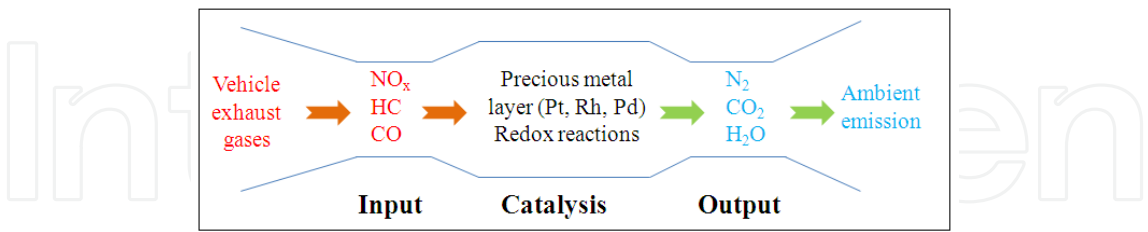


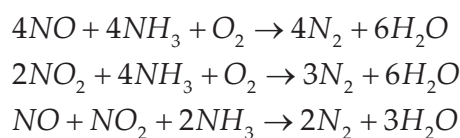
Figure 3. A schematic diagram of a catalytic converter.

The relevant catalysts applied to reduce the pollutants emitted from specific engines are listed in Table 1 [10].

To reduce NO_x , a controlled amount of the reactive chemical reductant such as anhydrous ammonia, aqueous ammonia, and urea is added to a stream of fuel or exhaust gas and adsorbed onto the catalyst. Due to the role of the catalysts, NO_x can react with the reductant to produce nitrogen gas and water according to the following reactions:

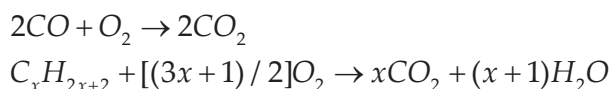
Engines	Pollutants	Catalysts
Gasoline engines	Nitrogen oxides (NO _x), Hydrocarbons (HC _s), and Carbon monoxide (CO)	Pt/Pd/Rh/Ce _x Zr _{1-x} O ₂ /(La, Ba)-Al ₂ O ₃ on ceramic and metallic monoliths
Diesel engines (light vehicles, truck, and bus)	NO _x , HC _s , CO	Pt/Pd/Rh/BaO/Al ₂ O ₃ on ceramic and metallic monoliths
Diesel engines	Particulate matter	V ₂ O ₅ /TiO ₂ on ceramic monolith Cerium and iron oxides Pt/Al ₂ O ₃ Cu, V- and K-based catalysts

Table 1. The relevant catalysts for specific engines



The reaction typically takes places at an optimal temperature range between 630 and 720 K, but can operate from 500 to 720 K with longer residence times. To operate an effective process, the engine requires an external urea tank and dosing system. The specific NO_x/ammonia and ammonia/catalyst ratios can be designed to optimize a specific application. At optimal conditions, the application of a catalyst in the downstream of engine can reduce NO_x emissions from vehicles by 70–90%.

The reactions to oxidize carbon monoxide and unburned hydrocarbon are described by the following reactions:



2.1.3. Lubricant consumption

Lubricants are composed of a base fluid and additives. The base fluid is the major part of the lubricant formulation and is mainly made from petroleum-based oils. The additives are used to obtain desirable properties. Lubricants are very important substances for reducing the wear and tear of machine parts. Lubricants also reduce friction, which in turn reduces heat loss. The worldwide consumption of lubricants is more than 41 million tones [11]. They have a soluble organic fraction of 60%, which contributed between 20% and 90% of the total particulates in air that were generated from engine lubricant consumption. Therefore, the particulate emission rate can be significantly reduced by controlling engine lubricant consumption. The strategies to control engine lubricant consumption include changing the piston-ring design and manipulating the operation conditions of the engine such as intake air pressure. The use of biolubricants is also a valuable strategy to reduce the adverse effects of traditional lubricants

to the atmospheric emissions of particulate matter. Biolubricants are described in many ways such as eco-friendly lubricants, green lubricants, biodegradable lubricants, recyclable, nontoxic, and reusable.

2.1.4. Reduce motorized transportation demand

Strategies applied to encourage the use of nonmotorized transport, discourage nonessential trips, shorten trip lengths, and restrain the use of private cars can reduce the overall demand for motorized transport and thus minimize the emission of air pollutants from transportation activities. The strategies could be instigated based on the following regulations:

- Provide safe and comfortable conditions for walking and other forms of nonmotorized transport
- Improve public transportation quality and efficiency
- Increase fuel taxes
- Increase parking charges
- Increase road pricing
- Compact design of retail and entertainment centers with workers and public transport
- Limit use of private vehicles both by pricing and by administrative regulation

2.1.5. Road quality and traffic flow

Road quality also directly affects the air pollutants emitted from transportation activities. For example, the operation of vehicles on unpaved roads can introduce a significant amount of atmospheric particulate matter. Therefore, road qualities need to be improved to reduce air pollutant emission. The strategies to improve road quality include:

- Try to pave unpaved roads
- Sweep roads frequently (can reduce concentrations of PM up to 20%)
- Flush roads with water in the dry season
- Investigate new types of asphalt and concrete, which are cheap and environmental-friendly
- Cover operating trucks

Strategies to improve traffic flow and thereby minimize unnecessary braking and reduce congestion can result in high efficiency of vehicle operation and reduce undesired pollutant emissions. These strategies can be obtained based on the following methods:

- Control traffic signals
- Design road systems by use of ring roads and bypasses
- Increase infrastructure capacity
- Reduce congestion by congestion charging
- Reduce vehicle speeds because fast moving vehicles stir up dust (a reduction in speed from 40 miles per hour (m/h) to 20 (m/h) reduces dust emissions by 65%)

2.2. Control agricultural activities

Air pollutants emitted from the agricultural sector are mainly methane (CH₄), nitrous oxide (N₂O), and ammonia (NH₃). Agriculture is also a major source of PM, both primary and secondary in origin [12]. Agricultural pollutants are mainly generated from livestock production and the application of fertilizers and pesticides. Therefore, strategies to control air pollutants emitted from agriculture activities are strongly linked to the activities including strategies to control livestock feeding, animal housing systems, manure storage systems, application of manure for crops, and application of fertilizers and pesticides.

2.2.1. Livestock feeding

Because the quantity of nitro compounds, such as ammonia and nitrous oxide excreted from animal feces and urine, is linearly dependent on the intake of nitrogen in food (protein), the strategies to reduce the oversupply of protein in animal feedstock can reduce nitrogen excretions and thus decrease the emissions of nitrogen-containing compounds [13]. Such strategies involve adapting the amount of proteins in the food to the needs of the animals. For instance, young animals and high-productive animals require more protein than older and less-productive animals. On average, this measure leads to a NH₃ emission reduction of 10% for a 1% reduction in the mean protein content in the diet, but efficiencies depend strongly on the animal categories. It has no implications on animal health as long as the requirements for all amino acids are ensured. It is most applicable to housed animals while the practical applicability of feeding strategies to grazing animals is limited.

2.2.2. Animal housing systems

The available strategies to reduce NH₃ emissions from animal housing systems have been well known for decades and apply one or more of the following principles [13]:

Principles	NH ₃ emission reduction
· Decrease the surface area fouled by manure	15–25% in pig housing
· Rapid removal of urine and rapid separation of feces and urine	25–46%
· Reduce pH of the manure	up to 20%
· Reduce temperature of the manure	up to 60% in pig and cattle housing systems
· Dry the manure (e.g., poultry litter)	45–75%
· Scrubbing ammonia from exhaust air	up to 70%
· Decrease housing time by increasing grazing time	70–95%
	10–50%, but some emission swapping

2.2.3. Manure storage

The strategies to eliminate air pollutants emitted from manure storage can be based on the following principles:

- Decreasing the surface area where emissions can take place, i.e., by covering the storage, encouraging crusting, and increasing the storage depth
- Reducing the pH and temperature of the manure
- Minimizing disturbances such as aeration

2.2.4. Manure used for crops

The application of manure for crops can emit a significant amount of atmospheric pollutants. The strategies or application techniques to control the emissions can be based on the following principles:

- Decrease the exposed surface area of slurries applied to surface soil through band application, injection, and incorporation
- Decrease the time that emissions can take place, i.e., bury the slurry or solid manures through injection or incorporation into the soil
- Decrease the source strength of the emitting surface, i.e., through lowering the pH and NH_4 concentration of the manure (through dilution)

2.2.5. Fertilizer application

The strategies to reduce emissions of pollutants from the application of fertilizers are based on one or more principles including:

- Decrease emission sites by decreasing the surface area via band application, injection, and incorporation
- Decrease the emission periods of pollutant via rapid incorporation of fertilizers into the soil or via irrigation
- Decrease the emitting source surface strength via urea inhibitors and blending
- Ban use of pollutant precursors such as ammonium (bi) carbonate

For example, the techniques for the application of urea and ammonium-based fertilizers can reduce levels of ammonia emission as follows [13]:

Fertilizer type	Application techniques	Emission reduction %
Urea	Injection	>80
	Urea inhibitors	>30
	Incorporation following surface application	>50
	Surface spreading with irrigation	>40
	Ban	~100
	Injection	>80
Ammonium carbonate	Incorporation following surface application	>50
Ammonium-based fertilizers	Surface spreading with irrigation	>40

2.3. Control construction fields

The strategies to control air pollutants emitted from construction fields can be classified into four categories: control of site planning, construction traffic, demolition works, and site activities [14].

2.3.1. Site planning

Regulations applied to control air pollutants emitted from site planning include:

- Erect effective barriers around dusty activities or entire site boundary
- Do not burn any material in entire site planning
- All site personnel to be fully trained
- Trained and responsible manager on site during working times to maintain logbook and carry out site inspections
- Hard surface all major haul routes through the site (e.g., use recycled rubber blocks, concrete blocks or tarmac)
- Use nearby rail or waterways for transportation to/from site

2.3.2. Construction traffic

Regulations applied to control air pollutants emitted from construction traffic activities include:

- No vehicles or plant will be left idling unnecessarily
- Wash or clean all vehicles effectively before leaving the site
- All loads entering and leaving site should to be covered
- On-road vehicles comply to emission standards
- Use ultra-low sulfur tax-exempt diesel for all nonroad mobile machineries
- Should minimize construction traffic activity around site
- Cover the haul routes with hard surface combining with frequently cleaning the surface and give an appropriate control of speed limit around site

2.3.3. Demolition works

Regulations applied to control air pollutants emitted from demolition works include:

- Use water as dust suppressant during demolition works
- Use enclosed chutes and covered skips
- Wrap building(s) before demolition works
- Bag and remove any biological debris or damp down before demolition
- Avoid explosive blasting where possible and consider using appropriate manual or mechanical alternatives

2.3.4. Site activities

Regulations applied to control air pollutants emitted from site activities include:

- Minimize dust-generating activities. For example, when a worker cuts concrete slabs or bricks with a power tool without extraction or suppression, a second worker can pour water from a plastic bottle over the material leading to reduce the great amount of generated dust.
- Use water as a dust suppressant where applicable
- Cover, seed, or fence stockpiles to prevent wind whipping
- Re-vegetate earthworks and exposed areas
- If applicable, ensure the concrete crusher or concrete batcher has a permit to operate
- Minimize drop heights to control the fall of materials

2.4. Miscellaneous

Coal, the most abundant solid fuel and widely used for power plant and other industrial activities, is the largest source of air pollutant emissions. Coal combustion produces a significant amount of air pollutants such as SO_x , heavy metals, and PM. For example, sulfur in coal occurs both as inorganic minerals (mainly pyrite and marcassite) and organic compounds incorporated in the combustible part of coal. The sulfur content can be converted into SO_x during the coal combustion. Therefore, reducing the sulfur content in coal before the combustion processes is a great strategy to reduce SO_x emissions from the upstream coal combustion process. Inorganic sulfur in coal can be removed by coal washing and the organic sulfur by using chemical hydrogenation and gasification processes.

Mining activities can produce significant air pollutants such as heavy metals (in PM form), SO_x and NO_x . Strategies to reduce air pollutants emitted from mining activities from the upstream process include enclosure or cover mine, mining area, and transfer areas; water spraying mining area; and stabilizing unpaved traffic areas.

Indoor activities can also be a significant source of air pollution. Strategies to reduce air pollutants emitted from indoor activities include improvement of cooking devices, use of alternative fuels for cooking and reducing the need for fire. Strategies to improve cooking devices include stabilization of stove materials and improvement of stove chimneys, in particular, biomass stoves. Uses of alternative fuels for cooking including charcoal, biogas, liquid petroleum gas, and electricity can significantly reduce air pollutant emissions. For example, the transition from wood to charcoal for cooking can reduce PM10 emissions by more than 80% (although the wider environmental impacts of charcoal production must be considered). The need for fire can be reduced based on the use of solar heating or electric devices.

The change of building materials from high-polluting materials such as paint, linoleum, and gypsum to low-polluting materials such as PVC and polyolefin can also control air pollutants from upstream emissions.

3. Downstream control

3.1. Particulate matter control

3.1.1. Cyclone

The cyclone is a well-known device used primarily for the collection of medium-sized and coarse particles. The cyclone works by forcing a gaseous suspension downward. The particles move outward by centrifugal force and collide with the outer wall and then slide downward to the bottom of the cyclone. At the bottom of the cyclone, the gas reverses its downward spiral and moves upward in a smaller, inner spiral. The cleaned air exits from the top of the cyclone and the particles are expelled from the bottom of the cyclone through a pipe sealed by a spring-loaded flapper valve or a rotary valve. The cyclone collector is shown schematically in Figure 4.

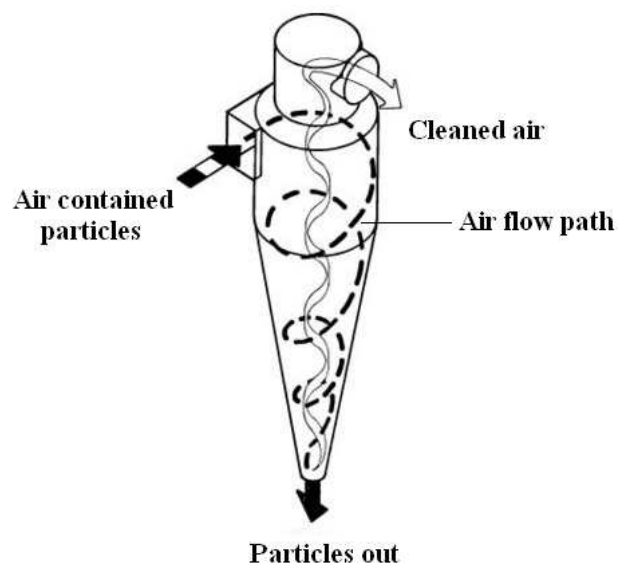


Figure 4. Schematic diagram of a cyclone.

Cyclones have a wide range of industrial applications in gaseous cleaning and product recovery. They are relatively inexpensive, easy to set up and maintain, and can work at high temperature and pressure. They can be used as a precollector for removing larger particles before next treatment. When well designed, the cyclone can collect particles larger than $10\ \mu\text{m}$ with an efficiency of more than 90%. For smaller particles, however, the well-designed cyclone would have a considerable pressure drop with relatively lower collection efficiency [15]. In addition, the cyclone method cannot be used for removing sticky particles with high moisture content.

3.1.2. Wet scrubber

A wet scrubber system can be used to control fumes, mists, acid gasses, heavy metals, trace organics, and suspended dusts. An individual wet scrubber can usually be used to control a

targeted pollutant. Therefore, a well-designed wet scrubber system often contains two or more single scrubbers leading to a multistage wet scrubber, which affords higher total removal efficiencies than that of a single-stage scrubber [1]. A schematic diagram of a wet scrubber is shown in Figure 5.

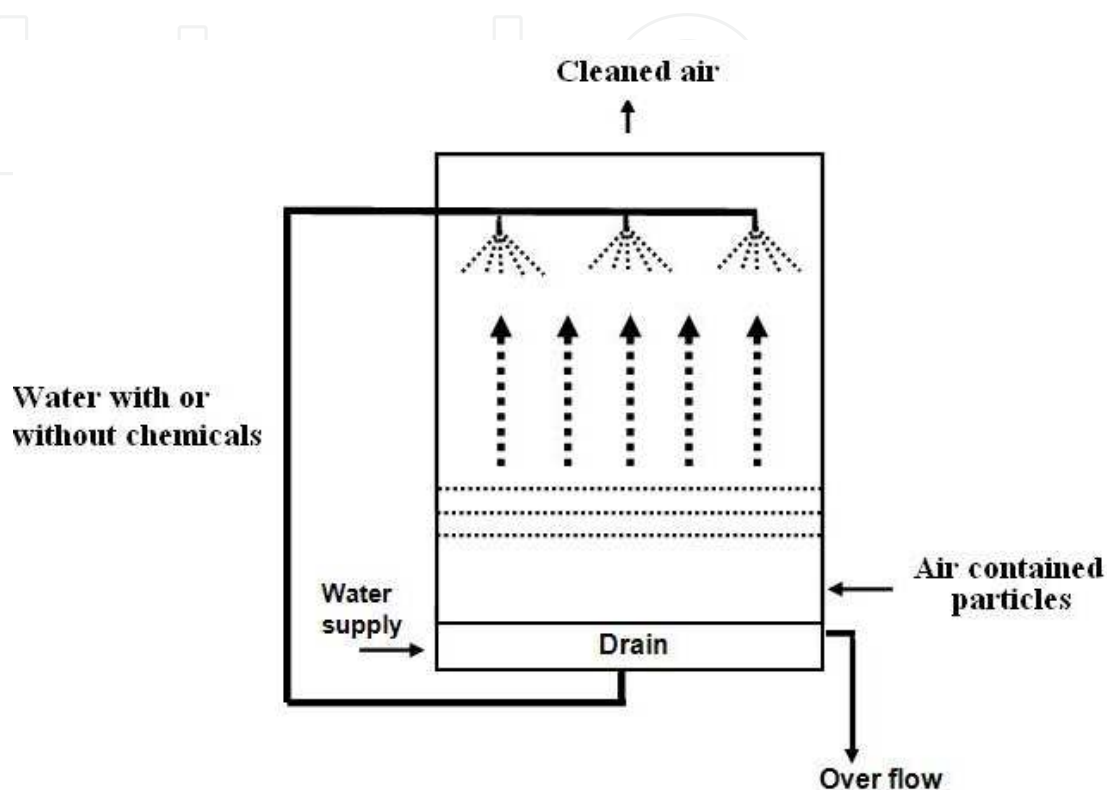


Figure 5. Schematic diagram of a wet scrubber chamber.

The wet scrubber system works based on direct interaction between the adsorbent liquid and the particles. The adsorbent liquid is usually water; however, several chemicals are also added to water to increase the adsorption ability of the liquid phase with the particles. Based on the interaction between the particles and the liquid phase, the particles can diffuse out of the gas phase and be absorbed in the liquid phase and the particle-loaded air can be cleaned. The absorption of particles into the liquid phase can be both physical and chemical absorption, depending on the particle and liquid phase and gaseous properties. The particle removal efficiency depends on:

- The solubility of the pollutant in the chosen scrubbing liquor
- Pollutant concentration in the gas phase being treated
- Flow rate of the gas and liquid phases
- Gas–liquid phase contact surfaces

- Stripping efficiency of the liquor and recycling of the solvent
- The ability to increase gas–liquid phase contact surfaces will result in higher absorption efficiency in a wet scrubber system. The reduced temperature and increased liquid-to-air ratio improve the absorption efficiency of a wet scrubber system.
- The pH of the scrubbing liquid is an important factor directly affecting the purification efficiency. The pH of the liquid may need to be low for ammonia scrubbing, while a neutral or high pH liquid is required for acid gas scrubbing. When scrubbing trace organics, a wet scrubber with alkaline pH is often used.

3.1.3. Electrostatic precipitators

Electrostatic precipitation (ESP), which is one of the most popular and efficient particle control systems in the United States, is defined as a particle control method that uses electrical forces to move the particles out of the flowing gas stream and onto collector plates [16]. The ESP processes include:

1. The ionization of particles, which can be dry dusts or liquid droplets, in contaminated air (particle charging)
2. The charged particles are deposited on an oppositely charged plate
3. The removal of the deposited particles from the plates

The particles are charged when the particles in the air stream pass through a corona, a region of gaseous ions flow. In the corona, the ions bombard the surface of the particles leading to charging particles. When these charged particles pass through the surface of the collecting electrodes, oppositely charged plates, they are trapped on the collected electrodes by the electrostatic field. The charged particles are accelerated toward the collecting electrodes by Coulomb forces, but inertial and viscous forces can resist the motion. When the plates (electrodes) collected a certain particle amount, the collected particles must be removed from the plates to prevent their re-entrainment into the gas stream. The plates could be knocked to let the collected layer of particles to slide down into a hopper from which they are evacuated [16]. The plates could also be continuously washed with water to remove the collected particles. A schematic diagram of an electrostatic precipitator is shown in Figure 6.

The principal difference between the ESP and other scrubbing methods are that in the ESP, the separation forces are electrical and are applied directly to the particles or droplets themselves while in others the separation forces are usually applied indirectly through the contaminated air system [17]. Therefore, the ESP could remove small particles or liquid droplets at a high efficiency with low energy consumption or low cost and small pressure drop through the gas cleaning system [17]. ESPs are built in either single-stage or two-stage versions. In the single-stage precipitator, the ionization and collection of particles or liquid droplets are achieved in a single stage and the corona discharge and precipitating field extend over the full length of the device. In the two-stage precipitator, the ionization of particles or liquid droplets is carried out in the first stage confined to the region around the corona discharge wires, followed by

the particle collection in the second stage which provides an electrostatic field whereby the previously charged particles migrate onto the surface of the collecting electrodes [2].

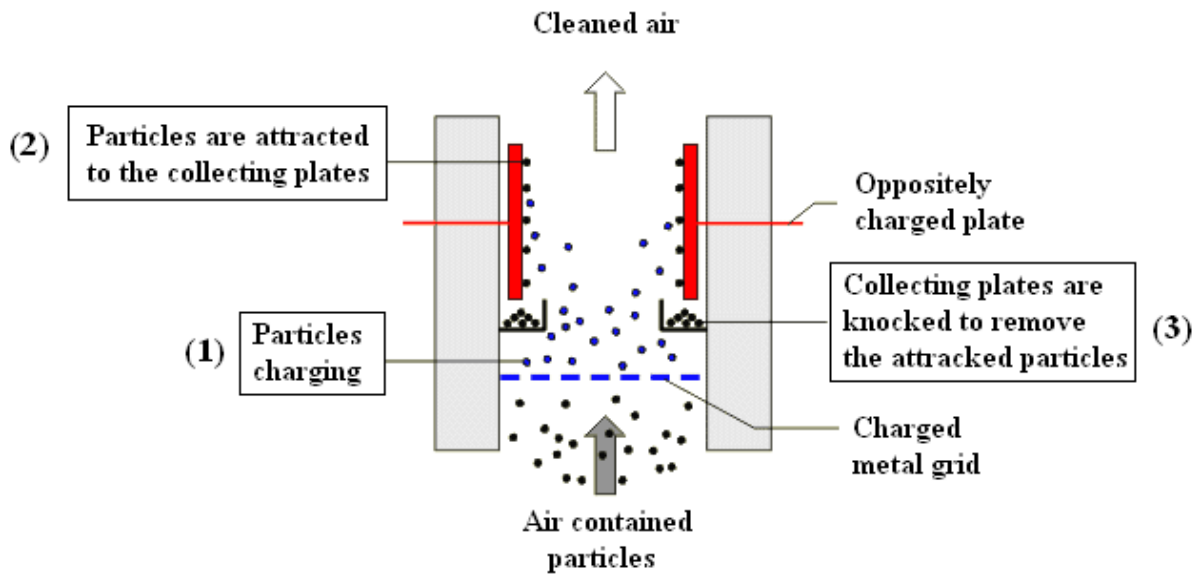


Figure 6. Schematic diagram of an electrostatic precipitator.

3.1.4. Fabric filtration

Fabric filtration is a well known and accepted physical technique in which a gas stream containing mainly solids passes through a porous fabric medium which retains the solids. This process may operate in a batch or semicontinuous mode for removing the retained solid particles from the filter medium. Filtration systems may also be designed to operate in a continuous manner.

In air fabric filtration, the contaminated gas flows into and passes through a number of filter bags placed in parallel, leaving the solid particles retained by the fabric filter. The fabric filter can be classified into two basic groups, depending on the fabric properties: felt and woven. Felt media are normally used in high-energy cleaning systems, while woven media are used in low-energy systems. Felt fabrics are tighter in construction and they can be considered to be more of a true filter medium and should be kept as clean as possible to perform satisfactorily as a filter. The woven fabric is merely a site upon which the true filtering occurs as the dust layer builds up, through which the actual filtering takes place.

Particles are collected on the fabric surface through four mechanisms including:

- Inertial collection – the fibers, which are placed perpendicular to the gas flow direction, could collect the particles in the stream without changing gas flow direction.
- Interception – particles are trapped in the filter matrix.

- Brownian movement – submicron particles are collected on the surface of the filter.
- Electrostatic forces – the particles on the gas stream were captured because of electrostatic interaction between the particles and the filter.

The particles were captured on the filter leading to formation of a dust cake on the filter. The formation of the dust cake could increase the resistance to gas flow. Therefore, the filter containing the dust cake must be frequently cleaned.

Fabric filters are extremely efficient solid removal devices and operate at nearly 100% efficiency. The efficiency depends on several factors including:

- Particle properties
 - Size: Particles between 0.1 and 1.0 μm in diameter may be more difficult to capture.
 - Seepage characteristics: Small, spherical solid particles tend to escape.
 - Inlet dust concentration: The deposit is likely to seal over sooner at high concentrations.
- Fabric properties
 - Surface depth: Shallow surfaces form a sealant dust cake sooner than napped surfaces do.
 - Weave thickness: Fabrics with high permeability, when clean, show lower efficiencies.
 - Electrostatics: Particles, fabrics, and gas can all be influenced electrostatically and proper combination.
- Dust cake properties
 - Residual weight: The heavier the residual loading, the sooner the filter is apt to seal over.
 - Residual particle size: The smaller the base particles, the smaller (and fewer) are the particles likely to escape.
- Air properties
 - Humidity: With some dusts and fabrics, 60% relative humidity is much more effective than 20% relative humidity. Increased humidity or moisture level can be a frequent cause of clogging pores of the filter medium and increasing filter pressure drop.
- Operational variables
 - Velocity: Increased velocity usually lowers the efficiency, but this can be reversed depending on the collection mechanisms, for example, impaction and infusion.
 - Pressure: Probably not a factor, except that an increase in pressure after the dust cake has been formed can fracture the filter medium and greatly reduce efficiency until the cake reseals.
 - Cleaning: Without frequent or periodical cleaning, the air filtration system cannot be operated.

The advantages and disadvantages of methods to control particulate matter including cyclone, wet scrubber, ESP, and fabric filtration are summarized in Table 2.

Advantages	Disadvantages
Cyclone	
<ul style="list-style-type: none"> · Low capital cost · Simple and insignificant maintenance problems · Ability to operate at high temperature · Require small spaces 	<ul style="list-style-type: none"> · Relatively low efficiencies for collection particles which are smaller than 10 mm · Could not use for sticky materials
Wet scrubber	
<ul style="list-style-type: none"> · No secondary production · Require small space · Operation to collect both gases and sticky particles · Operation at high-temperature as well as high-humidity gas streams · Low capital cost · Operation with flammable and explosive dust with little risk · High effective to collect fine particles 	<ul style="list-style-type: none"> · Treatment issue concerning with water disposal/effluent · Corrosion problems · High pressure drop problems · Solid buildup problems at the wet–dry interface · Relatively high maintenance costs
Electrostatic precipitation (ESP)	
<ul style="list-style-type: none"> · Very high collection efficiencies of coarse as well as fine particulates with low energy consumption · Collection dry dust · Low pressure drop · Relatively low operation and maintenance costs · Operation capability at high temperatures as well as high pressure or under vacuum · High collect capacity 	<ul style="list-style-type: none"> · High capital cost · High sensitivity to fluctuations in gas stream · Problems with particles, with extremely high or low resistivity · Require large space for installation · Produce ozone as by-product · Require highly trained maintenance personnel
Fabric filtration	
<ul style="list-style-type: none"> · Very high collection efficiencies of coarse as well as fine particulates · Relative insensitivity to gas stream fluctuations and large changes in inlet dust loadings · Recirculation of filter outlet air · No corrosion issues · Simple maintenance, flammable dust collection · High collection efficiency of submicron smoke and gaseous contaminants · Many application types · Simple operation 	<ul style="list-style-type: none"> · Difficult to operate at high temperature · Need for fabric treatment after removal process · Require high maintenance costs · Explosion problems · Shortened fabric life at elevated temperatures and in the presence of acid or alkaline particulate or gas · Respiratory protection requirement for fabric replacement · Medium pressure-drop requirements
Source: Bounicore and Davis 1992 [18]	

Table 2. Advantages and disadvantages of particulate control methods

3.2. Gaseous pollutants control

3.2.1. Adsorption

Adsorption is the phenomenon via which molecules of a fluid adhere to the surface of a solid material (adsorbent). Gas adsorption is used for industrial applications such as odor control, recovery of volatile solvents such as benzene, toluene, and chlorofluorocarbon, and drying of process gas streams. During this process, the molecules or particles (adsorbate) in airstream gases and liquids can be selectively removed or captured despite being at low concentrations. There are two distinct adsorption mechanisms: physisorption and chemisorption. Physisorption or physical adsorption, also called van der Waals adsorption, involves a weak bonding of gas molecules with the adsorbent. The bond energy is similar to the attraction forces between molecules in the stream. The adsorption process is exothermic and the heat of adsorption is slightly higher than the heat of the vaporization of the adsorbate. The forces holding the adsorbate to the adsorbent are easily overcome by either the application of heat or the reduction of pressure, which are methods that can be used to regenerate the adsorbent. Chemisorption or chemical adsorption involves an actual chemical bonding by reaction of the adsorbate with the adsorbent, leading to new chemical bonds such as covalent bonding generated at the adsorbent surface.

When a stream comes into contact with an adsorbent, one or several components of the stream are adsorbed by the adsorbent. At all adsorbent interfaces, adsorption can occur, but often at a low level unless the adsorbent is highly porous and possesses fine capillaries. For an effective solid adsorbent, it should have a large surface-to-volume ratio, and a preferential affinity for the individual component of concern. The adsorption occurs by a series of steps. In the first step, the adsorbate diffuses from the stream to the external surface of the adsorbent. In the second step, the adsorbate molecule migrates from the relatively small area of the external surface to the pores within each adsorbent. The bulk of the adsorption occurs in these pores because of the majority of available surface area. In the final step, the adsorbate adheres to the surface in the pores of the adsorbent [19].

Most industrial adsorbents could be divided into three classes including:

- Oxygen-containing compounds such as silica gel and zeolite
- Carbon-based compounds such as graphite or activated carbon materials
- Polymer-based compounds, which include functional groups in a porous polymer matrix

Silica gel, which is usually prepared by the reaction between sodium silicate and acetic acid, is a chemically inert, nontoxic, polar, and dimensionally stable amorphous form of SiO_2 . It is used for the drying of processed air and the adsorption of polar hydrocarbons from natural gas.

Zeolites are natural or synthetic crystalline aluminosilicates, which have a repeating pore network and release water at high temperature. Zeolites are applied in the drying of processed air, CO_2 removal from natural gas, CO removal from reforming gas, air separation, catalytic cracking, and catalytic synthesis and reforming.

Activated carbon is a highly porous, amorphous solid consisting of microcrystallines with a graphite lattice, usually prepared in small pellets or a powder. It is nonpolar and cheap. Activated carbon is used for the adsorption of organic substances and nonpolar adsorbate. Activated carbon is also usually used for waste gas (and waste water) treatment. It is the most widely used adsorbent because its chemical and physical properties such as surface groups, pore size distribution, and surface area can be tuned as required. Its usefulness also derives from its large microspore (and sometimes mesoporous) volume and the resulting high surface area.

3.2.2. Absorption

Absorption is a physical or chemical process in which atoms, molecules, or ions enter some bulk phase – gas, liquid, or solid material. As compared to the adsorption process, in which the molecules are adhered on the surface of the adsorbent, the absorption process takes place when the volume takes up molecules.

Gas absorption is the removal of one or more pollutants from a contaminated gas stream when the gas stream passes through a gas–liquid interface and ultimate dispersion in the liquid. Absorption is a process that may be chemical (reactive) or physical (nonreactive). Physical absorption is formed based on the interaction of two phases of matter including a liquid absorbs a gas or a solid absorbs a liquid. When a liquid solvent absorbs a part or all of a gas mixture, the gas mass could move into the liquid volume. The mass transfer could take place at the interface between the gas and the liquid. The mass transfer rate depends on both the liquid and the gas properties. The solubility of gases, the pressure and the temperature are the main factors affecting to this type of absorption. In addition, the absorption rate also depends on the surface area of the interface and its duration in time. When a solid absorbs a part or all of a liquid mixture, the liquid mass could move into the solid volume. The mass transfer could take place at the interface between the liquid and the solid. The mass transfer rate depends on both the solid and the liquid properties. Chemical absorption or reactive absorption is a chemical reaction between the absorbed and the absorbing substances. Sometimes, it is combined with physical absorption. This type of absorption depends upon the stoichiometry of the reaction and the concentration of its reactants.

Gas absorption is usually carried out in packed towers. The contaminated gas stream enters the bottom of the column and passes upward through a wetted packed bed. The absorbing liquid enters from the top of the column and is distributed over the column packing. The column packing may have one or more commercially available geometric shapes designed to maximize the gas–liquid contact and minimize the gas–phase pressure drop [20]. The requirements for the packing column include high wetted area per unit volume, minimal weight, sufficient chemical resistance, low liquid holdup, and low pressure drop.

3.2.3. Condensation

Condensation is a separation process to convert one or more volatile components of a vapor mixture to a liquid through saturation process. Any volatile components can be converted to

liquids by sufficiently lowering their temperature and increasing their pressure. The most common process is reducing the temperature of the vapor because increasing the vapor pressure is expensive. The condensation process is primarily used to remove VOCs from gas streams prior to other control methods, but sometimes it can be used alone to reduce emissions from high-VOCs concentration gas streams [2, 21].

The simple and relatively inexpensive condenser uses water or air to cool and condense the vapor stream to the liquid. Since these devices are not required to reach or capable of reaching low temperature, high removal efficiencies of most vapor pollutants cannot be obtained unless the vapor will condense at high temperature. That is why condensers are typically used as a pretreatment device. They can be used together with adsorption, absorption, and incinerators to reduce the gas volume to be treated by other expensive methods.

A typical condenser device includes condenser, refrigeration system, storage tanks, and pumps. The condensation process includes:

- The contaminated gas stream is compressed as it passes through the blower.
- The existing hot gas stream flows to an after-cooler, which is constructed of copper tubes with external aluminum fins. Air is passed over the fins to maximize the cooling effect. Some condensation occurs at this step.
- The gas stream continues to cool in an air-to-air heat exchanger.
- The condenser cools the gas to below the condensing temperature in an air-to-refrigerant heat exchanger.
- Finally, the cold gas passes to a centrifugal separator where the liquid is removed to the collecting vessel. The gas stream typically requires further treatment before being emitted to the atmosphere.

A condensing system usually contains either a contact condenser or a surface condenser. Contact condensing systems cool the contaminated gas stream by spraying ambient or chilled liquid directly into the gas stream. A packed column is usually used to maximize the surface area and contact time. The direct mixing of the coolant and contaminant necessitates separation or extraction before coolant reuse. This separation process may lead to a disposal problem or secondary emissions. Contact condensers usually remove more contaminated air as a result of greater condensate dilution. In the surface condensing systems, the coolant does not mix with the gas stream, but flows on one side of a tube or plate in the surface condensing systems. The condensing vapor contacts the other side, forms a film on the cooled surface, and drains into a collection vessel for storage, reuse, or disposal. Surface condensers require less water and generate 10–20 times less condensation than contact condensers do.

The advantages of the condensation method include lower installation cost, little required auxiliary equipment, and less maintenance requirement. However, the remaining disadvantages of the method include problems of water disposal, low efficiencies, and the need for further treatment.

3.2.4. Incineration

Incineration or thermal oxidation is a broadly used method to control air pollutants such as VOCs, using oxidation at high temperature. Incineration is considered as an ultimate disposal technique in which VOCs are converted to carbon dioxide, water, and other inorganic gases. The two popular incineration methods are thermal incineration and catalytic incineration.

In thermal incineration, organic compounds in the contaminated gas are burned or oxidized at a high temperature with air in the presence of oxygen [22]. The thermal oxidizer involves specifying a temperature of operation along with a desired residence time and then optimum sizing the device to achieve the desired residence time and temperature with proper flow velocity. Selection of the proper piece of equipment depends on the mode of operation, oxygen content, and concentration of the organic gases. They are very important when trying to minimize the overall cost of the incineration and reduce the volume of the gas stream to be treated as much as possible. Depending on the types of heat recovery, incinerators can be classified into two categories: recuperative and regenerative. The recuperative incinerator uses a shell and tube heat exchanger to transfer the heat generated by the incinerator to the preheat of the feed stream. The recuperative incinerator can recover about 70% of the waste heat from the exhaust gases [21]. The regenerative incinerator includes a flame-based combustion chamber that connects two or three fixed beds containing ceramic or other inert packing. The input gas enters over these beds where it is preheated before passing into the combustion chamber and being burned. Then, the hot flue gases pass through the packed beds where the heat generated during incineration is recovered and stored. The packed beds keep the heat during one cycle and release it as the beds preheat the input organic gases in the second cycle. This regenerative incinerator method can recover up to 95% of the energy from the flue gas [23].

In catalytic incineration, the organic compounds in the contaminated gas are converted into carbon dioxide and water by using a catalyst that facilitates incineration at low temperature. Thus, the requirement incineration temperature can be decreased by hundreds of degrees. Therefore, the application of catalyst incineration can save a large amount of energy to heat up the gas stream containing pollutants for combustion. The contaminated gases are heated by a small auxiliary burner, and then the gases passed through the catalyst bed. The space requirement for operation of catalytic incineration is much smaller than that of thermal incineration. Thanks to the catalytic activity, the degree of oxidation of the pollutants is greatly increased compared with that in the incineration system without any catalyst. The catalyst activity refers to the degree of the chemical reaction rate. The catalyst can also be selective with higher activity for some compounds. Such activity and selectivity enable a lower operating temperature while still achieving the desired destruction efficiencies. In air pollution control, the catalyst is usually a noble metal (Pd, Pt, Cr, Mn, Cu, Co, and Ni) deposited on an alumina support in a configuration to minimize the pressure drop, which is often critical for incinerator designs [23, 24].

3.2.5. Biological system

The biological system for controlling air pollutants such as VOCs and odor uses microbes or microorganisms, immobilized on a biologically active solid support, to treat the gas pollutants.

The principle of the method is that the gaseous pollutants are used by the microbes as a food or energy source and thus destroyed and converted into innocuous metabolic end products such as carbon dioxide and water. The processes via which microbes destroy or convert pollutants contain:

- First, the pollutant gas must be absorbed into the liquid film in which the microbes are growing.
- The pollutant is absorbed into the cells of the microbes and metabolized.
- Finally, the end products (mainly CO₂) must be expelled from the cell and diffuse outward through the liquid film.

The process requires careful attention to design and operation in order to ensure firstly good contact between the contaminated gases and the microbes contained on the solid support; and secondly, that the microbe population is sustained and maintained in a healthy state. The key concerns in the design and operation of a biological system to control air pollutants contain [25]:

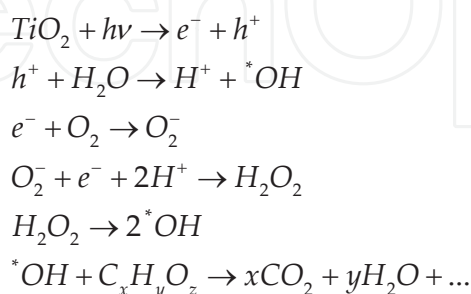
- Identify the type of the contaminant and its concentration in the air stream
- Find the suitable microbial population and combining with a compatible medium
- Maintain sufficient moisture
- Design the bed to ensure suitable residence time for a given airflow rate
- Control the bed conditions including pH, nutrient levels, and temperature

The biological technology is most suitable for high volumetric flow rate air streams containing low pollutant concentrations. The two most common biological systems are biofilter and bioscrubber. Biofilter is a biological system which uses an organic or synthetic media to host and nourish the microorganism without the requirement for an aqueous flush system. Bioscrubber is a biological system which uses an inorganic or synthetic media to provide a structural base for physically hosting the microorganisms requiring a continuous water flush or an intermittent containing carbon nutrient that supports the microorganism. The use of a biological system to control air pollutant offers several advantages including effective removal of compounds, little or no by-product pollutants, uncomplicated installations, and low costs. However, the method retains several disadvantages including a reduced suitability to high concentration streams, large area requirement for installation, need for careful attention to moisture control, and the possibility of becoming clogged by particulate matter or biomass growth.

3.2.6. Application of photocatalyst

An alternative technology, which offers a number of advantages over the above-mentioned technologies, for controlling organic air pollutants is to use photocatalysts. The use of a photocatalyst supports the operation of a low- or room-temperature photocatalytic oxidation process that can degrade a broad range of organic contaminants into innocuous final products such as CO₂ and H₂O without significant energy input. When the photocatalyst, for example, TiO₂, is irradiated with ultraviolet (UV) radiation that has energy higher than the band gap

energy of the TiO_2 , an electron could be excited from the valence band to the conduction band of TiO_2 , leaving holes behind on the TiO_2 surface. The leaved holes could react with surrounding H_2O to produce hydroxyl radicals ($^*\text{OH}$), while the excited electrons could react with O_2 to produce superoxide radical anions (O_2^-). These oxy radical species can participate in the oxidation reaction to destroy many organic contaminants ($\text{C}_x\text{H}_y\text{O}_z$) completely [26]. The photocatalytic process mainly follows the following reactions:



The three common reactor types designed to use a photocatalyst for air purification purposes are the honeycomb monolith, fluidized-bed, and annular reactors [27]. A honeycomb monolith reactor contains a certain number of channels, each of which typically has an internal dimension of the order of 1 mm. The cross-sectional shapes of the channels are square or circular. The photocatalyst is coated onto the walls of channels in a very thin wash coat. Fluidized-bed reactors are designed to treat a high gas feed rates directly passing through the catalyst bed. Based on reactor design, the solid photocatalyst could directly contact with the UV irradiation as well as gaseous reactants. The fluidized-bed reactors generally consisted of two concentric cylinders, which form an annular region with a certain gap. The photocatalyst is deposited onto the interior wall of the outer cylinder. The light source is usually located at the center. The thickness of the deposited photocatalyst film is sufficiently thin ensuring that all of the photocatalyst could be illuminated by UV irradiation [28].

The applications of the photocatalyst for photocatalytic oxidation processes to reduce air pollutants have been considered as alternatives to conventional air pollution control technologies. However, they have yet to overcome the problems of low energy efficiency and poor cost competitiveness. Therefore, numerous methods for modifying photocatalysts have been developed and investigated to accelerate the photo-conversion, enable the absorption of visible light, or alter the reaction mechanism to control the products and intermediates [29]. In this regard, metals or nonmetals were used as doping agents to implant or coprecipitate on the surface or in the lattice of TiO_2 . Electron donors or hole scavengers have been added to such photocatalytic systems. In addition, another semiconductor was integrated with TiO_2 to establish a suitable two-semiconductor system [29]. The modifications not only change the mechanism and kinetics of the photocatalytic processes under UV irradiation but also enhance the photocatalytic activities of the photocatalyst, thereby enabling the photocatalytic oxidation processes to proceed even under visible light [30].

4. Strategies to control climate change

Global climate change, also called global warming or the greenhouse effect, may be the most significant problem ever faced by humankind. Global climate change is caused by adding certain gases including carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and many chlorofluorocarbons (CFCs). The added gases absorbed infrared radiation leading to excess thermal energy within the earth's biosphere. The largest driver of global warming is carbon dioxide (CO₂) emissions from fossil fuel combustion, cement production, and land use changes such as deforestation. Therefore, the strategies to control CO₂ emission are also the main strategies to control global climate change.

4.1. Upstream control

Upstream strategies to control CO₂ emission include energy conservation, alternative and renewable fuels, and oxy-fuel combustion.

4.1.1. Energy conservation and efficiency use

Energy conservation refers to reducing energy consumption through using less of an energy service. The strategies concerned to energy conservation include energy taxes, building design, transportation, and consumer products.

- Energy taxes

Some countries employ energy or carbon taxes to motivate energy users to reduce their consumption.

- Building design

Energy conservation in building could be improved by using of an energy audit, which is an inspection and analysis of energy use and flows in the building, process, or system to reduce the amount of energy input into the system without negatively affecting the output(s). In addition, a passive solar building design in which windows, walls, and floors are made to collect, store, and distribute solar energy in the form of light or heat in the winter and reject solar heat in the summer. The design, leading to decreased use of mechanical and electrical devices, is also a solution for energy conservation.

- Transportation

The zoning reform and designs for walking and bicycling could allow greater urban density leading to reduce energy consumption concerning to transportation. The application of telecommuting is also a sufficient opportunity to conserve energy. For example, with people who work in service jobs, they could work at home instead of commuting to work each day.

- Consumer products

Because the consumers usually lack the information concerning to saving by energy-efficient products, we must inform the consumer in understanding the problems. For example, many

consumers choose cheap incandescent bulbs, failing to take into account their higher energy costs and lower lifespan. However, as compared to modern compact fluorescent and LED bulbs, these products have a higher upfront cost, with their long lifespan and low energy.

4.1.2. *Alternative and renewable fuels*

Use of alternative energy sources could prevent CO₂ emission from fossil fuel. The alternative energy sources include wind, solar, hydropower, biomass, and geothermal energy.

- Wind energy

Airflows can be used to run wind turbines to produce electric energy. Globally, the long-term technical potential of wind energy is believed to be five times total current global energy production, or 40 times current electricity demand.

- Solar energy

Solar energy, radiant light and heat from the sun, is harnessed using a range of ever-evolving technologies such as solar heating, photo-voltaic, concentrated solar power, solar architecture, and artificial photosynthesis.

- Hydropower

Hydropower is the power derived from the energy of falling water and running water, which may be harnessed for useful purposes. Hydropower could be also captured from ocean surface waves and tidal power.

- Biomass

Biomass is the biological material derived from living or recently living organisms. Biomass could be used as energy source by either used directly via combustion to produce heat or indirectly after converting it to various forms of biofuels.

- Geothermal energy

Geothermal energy could be generated from thermal energy, which is stored in the earth. Because of the difference between temperature of the core of the planet and its surface, it drives a continuous conduction of thermal energy in the form of heat from the core to the surface.

4.1.3. *Oxy-fuel combustion*

When burning coal or other fossil fuel using ambient air, the air contains a huge amount of nitrogen as well as the oxygen needed for combustion (4:1). Raising the temperature of the nitrogen to the combustion temperature requires a great deal of heat. Therefore, reducing nitrogen content in the air input could be a good strategy to reduce fuel consumption, leading to reduced CO₂ emission. In the strategy, oxy-fuel combustion, a process of burning a fuel using pure oxygen instead of air as the primary oxidant, is applied. There are several researches being done in firing fossil-fueled power plants with an oxygen-enriched gas mixture instead of air. Almost all of the nitrogen is removed from input air, yielding a stream that is approximately 95% oxygen.

4.2. Downstream control

Technologies to downstream control CO₂ or remove CO₂ from atmospheric include biological capture, wet scrubbing, CO₂ absorption, and mineral carbonation.

4.2.1. Biological capture

Biological capture of CO₂ is a process in which photosynthetic organisms are used to absorb the CO₂ gas from air and convert it into a solid carbonaceous compound. The strategies to conduct for biological capture of CO₂ include:

- Reforestation

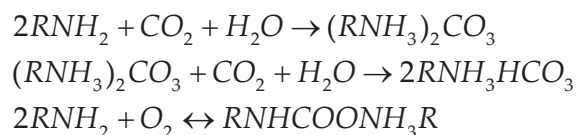
Reforestation means that tree could be replanted on marginal crop and pasturelands leading to incorporate atmospheric carbon (CO₂) into biomass. For a successful process, the incorporated carbon could not return to the atmosphere from burning or rotting when the trees die. Finally, the trees grow in perpetuity or the wood from them must itself be sequestered in the forms of biochar or bio-energy with carbon storage or landfill.

- Agriculture

Agricultural activity to capture CO₂ is also called as “capture” energy of the sun. Under solar light, the artificial plants could capture and convert the CO₂ in atmosphere into biomass, which can be storage or used as food or also used as raw material to make biofuels to replace the use of fossil fuel. Land-based plants such as corn and soybeans can be grown as energy crops, in particular to make biodiesel. Because of the limitations of land-based plants, there has been much interest over the years in developing systems that utilize microalgae for engineered biological CO₂ capture systems. Microalgae can fix CO₂ up to ten times faster than trees, and utilize sunlight much more efficiently than the land-based energy crops.

4.2.2. Wet scrubbing of CO₂

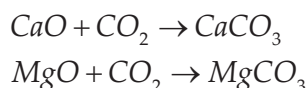
A carbon dioxide scrubber, which uses various amines such as monoethanolamine as absorbents, could absorb CO₂ to capture them from the atmosphere. The design and principle of wet scrubber have been presented in Section 3.2.2. Amines could be used as absorbents to absorb CO₂ based on following reactions:



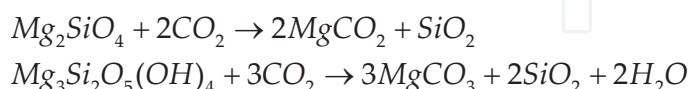
4.2.3. Mineral carbonation

Many chemical processes, known as carbon sequestration by mineral carbonation or mineral sequestration, could capture and store CO₂ from the atmosphere in stable carbonate mineral

forms. In the process, CO_2 could react with abundantly available metal oxides such as MgO or CaO to form stable carbonates. These reactions are mostly exothermic and occur naturally.



CO_2 could also react with calcium and magnesium silicates including forsterite and serpentine by the following the reactions:



These reactions are slightly more favorable at low temperatures. This process occurs naturally over geologic time frames and is responsible for much of the earth's surface limestone.

5. Conclusion

In the chapter, we described the current and emerging technologies and strategies that are being used or proposed to control air pollutants. Control technologies and strategies could be classified into upstream and downstream controls. Upstream technologies and strategies are usually being used to control air pollution emitted from mobile sources such as transportation, agriculture, and construction activities. Downstream technologies are usually applied to control particulate matter and gaseous pollutants emitted from stationary sources. The upstream control exhibited more advantages concerning to cost and efficiency than the downstream control.

The air pollutants including SO_x and Pb emitted from transportation activities could be significantly reduced by controlling the precursor pollutants in raw materials. The NO_x , CO , and hydrocarbon emissions from transportation activity could be reduced by the application of catalytic converters and the control of lubricant consumption. The strategies to reduce motorized transportation demand and improve the road quality and traffic flow decrease the energy consumption demand, leading to decrease in air pollution emission. The strategies to control livestock feeding, animal housing systems, manure storage systems, application of manure for crops and application of fertilizers and pesticides significantly reduced the emission of methane (CH_4), nitrous oxide (N_2O), and ammonia (NH_3). The strategies to control construction activities including control of site planning, construction traffic, demolition works, and site activities significantly reduced the emission of particulate matter.

To control particulate matter pollutants, the technologies including cyclone, wet scrubber, electrostatic precipitators, and fabric filter have been efficiency applied. Among them, electrostatic precipitator is the most advantageous method and widely applied in the United

States. The traditional methods such as adsorption, absorption, condensation, incineration to control air pollutants emitted from stationary sources exhibited many certain disadvantages including high cost and efficiency. Therefore, they should to be modified, enhanced, or replaced by modern technologies such as biological and photocatalytic technologies.

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