الجامعة التكنولوجية

قسم الهندسة الكيمياوية

المرحلة الثانية

مباديء هندسة البيئة

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Fundemental in Enviromental Engineering:

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Introduction:

Definition of pollution, Literature surveys, Environmental pollution, problems.

Types of pollutants:

Measuring device, Allowable level of pollutants

Environment: is the physical and biotic habitat which surrounds us. Environment these surroundings include all; physical, mental and spiritual conditions. The human beings are so complex in nature that it is a combined effect of everything, which exists, far or near them, affects their life (mental, physical and spiritual). The gravitational forces of distant planets affect each other and these movement or rotation is based on the balance between them.

Physical or abiotic environment

It consists of physical factors Land (minerals, toxic elements, and nutrients), sky (sink of various things, noise) and air (useful and other gases). Anciently, we have realized this combination as " Ksiti (Earth), Jal (Water), Pavak (Fire), Gagan (Sky), Sameera (Air): the five basic elements (Panch Tatva) which influence life.

Living or biotic environment

It consists of plants, animals (including human beings) and micro-organisms. Life in the form of micro-organisms is very strange and subtle (strong). Fungus is available up to 3 Kms. Below the earth. Thus the earth is not made for human beings alone. All these constituents of environment are referred to as the environmental factors or an ecological factor, which is defined as an ecological condition, which directly or indirectly affects the life of an organism. These biotic and abiotic components are in a dynamic state i.e. they constantly depend and affect each other and cannot be dealt in isolation with each other. This is the fundamental of Environmental Science or Engineering. Wherever we have not considered this interdependence and interrelation, knowingly or unknowingly, we have destroyed the very structure of a factor. This unthoughtful use of a resource, dealt in isolation, pollutes the other environmental factor, which in turn affects the polluting one, as all of them are interrelated and interdependent. This is the fundamental of environmental pollution.

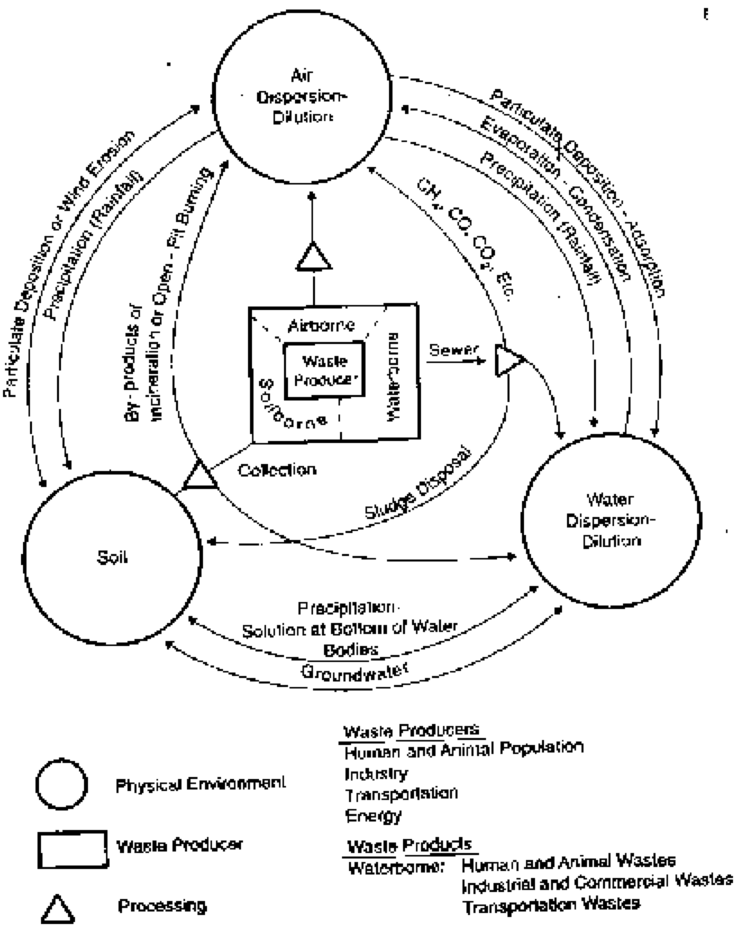
- **Pollution:** an undesirable change in the physical, chemical or biological characteristic of the air, water or land that can harmfully affect the health, survival or activities of human or other living organisms.
- **Particles:** any distinct portion of solid, liquid, or gaseous matter larger than a single small molecules, water, air or solid wastes.

Common names of dispersions:

Dispersed phase	**medium**	**common name**
solid	liquid	suspension
liquid	liquid	emulsion
gas	liquid	foam
solid	gas	smoke
liquid	gas	fog

- Colloidal dispersions: consist of very small particles ranging in size from 1 to 400 nm.

Figure 1 illustrate the waste disposal cycle for industrialized society note that all wastes discharge in to environment and thus our water air and land system



Waste Producers
Human and Animal Population
Industry
Transportation
Energy

Waste Products

Waterborne:	Human and Animal Wastes Industrial and Commercial Wastes Transportation Wastes
Airborne:	Domestic and Industrial Combustion Products Open Burning Emissions Industrial Gases and Particulates Transportation Wastes
Soilborne:	Domestic and Industrial Refuse Sludges Hazardous Wastes

(1)
Figure 1 - Waste cycle in an industrialized society.

Climate change and greenhouse effect:

Our earth is surrounded by a gaseous cover of mainly N2 , O2 and many other gases in small concentration including H2O and CO2 . This atmosphere provides the vital O2 to the living beings maintain heat balance of the earth and protect us from the harmful radiation this phenomenon termed as troposphere heating effect or greenhouse effect which maintains the average temperature of the world and governs all life process. The sea level is maintained and polar ice caps remain intact.

The average temperature should remain constant .however it has been noted for the past hundred years that the earth is gradually getting warmer.

The sea level is maintained and polar ice caps remain intact. The average temperature should remain constant and the earth is gradually gating warmer.

Major greenhouse gases:

1. CO_2 : it is rising at a rate of 0.5 % per year

2. CH_4: produced by organic matter decay under anaerobic conditions, it is rising at a rate of 0.1% per year. at

3. N_2O: it is rising a rate of 0.3 % per year and concentration 315 ppb.

4. Water vapor: 14000 cubic meter of water is present in atmosphere as vapor.

5.Chlorofluorocarbons(CFCs):there concentration. has increase to a very high level at a rate 1ppm.

6. Ozone (O_3):increasing the use of (CFCs) is causing a depleting in the ozone layer but it concentration Increase in the lower layer of the atmospheres.

Effects of greenhouses gas build up:

Carbon dioxide emits and absorbs radiation at wave length typical of the earth and atmosphere. It is conc. Increases, the atmosphere offers resistance to the necessary escape of radiation to space.

Effects of global warming

1. Varying effect on agriculture in different areas by decreasing agricultural yield
2. Increased pests diseases
3. Changes in forest types density and location increasing frequency of the loss to wild life.
4. Extreme climate prolonged heat waves and droughts.

5. Heavy rainfall in some areas, more droughts in other areas.
6. Decreased availability of water, and decline in water quality.
7. Disruption of eco system.

Controlling global warming:

1. Reduce deforestation and develop way to sustainable agriculture.
2. Use of technologies to absorb carbon dioxide from emission
3. Increased absorption of carbon dioxide by planting more trees.
4. Sequester carbon dioxide in the deep ocean.
5. Increased dependence on renewable energy sources.
6. Changed and more environmentally compatible life style.

International action to reduce greenhouse effects:

As period years from 1997, 38 developing countries are to cut greenhouse emissions to an average to 5.2% below 1990 level. By 2012 because they are responsible for 36 %of the world CO_2 emissions.

Ozone layer depletion:

our earth is surrounded by a layer of ozone about 15-40 km above the surface, which keeps about 95% of the sun harmful UV radiation from reaching the earth surface.

Short wave length UV radiations in the range of 1800 A^o to 2200 A^o are absorbed by molecular oxygen which splits up in to constituent atoms these atoms combine with molecular oxygen to produce ozone.

$$O_2 \rightarrow O + O$$

$$O_2 + O \rightarrow O_3$$

Another photochemical reaction which breaks down ozone molecules due to absorption

$O_3 \rightarrow O_2 + O$

$3\ O + O \rightarrow 2O_2$

These 2 reactions balance each other and ultimately result in effective absorption of short wave length UV radiation in the stratospheric region

Causes of ozone depletion:

1. use of chlorofluro carbon: As explained above CFCS are responsible for maximum damage to ozone layer.

2. Nitrogenous fertilizers: Microbial action on it produces nitrous oxide which effect on ozone layer.

3. Supersonic transport, rockets and space shuttle: supersonic 3.jetliners discharge various oxides of N_2 , C, S, , hydrocarbons and particulate material.

4. Nuclear test :explosions release high quantity of various gases and other materials which damage the ozone layer.

International action to protect ozone layer depletion:

Montreal protocol is an international agreement was signed in Montreal city of Canada in 1987, its goal was to cut emission of CFCS in to atmosphere by about 35% between 1989 and 2000.

Acid rain:

Acid rain refers to the presence of strong mineral acids like sulphuric acid , nitric acid , and in some locations HCl , HF , which bring down the PH in the atmospheric precipitation.

Where the quantities of SO_2 , Nox , react with atmospheric moisture to form H_2SO_4 and HNO_3**.**

Effect of acid deposition :

The harmful effect caused by the acid deposition can be categories under many effects:-

1- Effect on water bodies: one of the most sever and problems of acid rain is acidification of lakes and rivers.

2- Effect on soil and soils with low buffer capacity are the most sensitive soil to the acid deposition which frequently lose their fertility by acidification due to accelerated leaching nutrients like K,P,Mg,and Ca.

3- Effect on materials: on of important consequence of acid deposition is the physical damage to building bridges and other structures by corrosion, where sulfate forming a hard surface skin which blisters and scale off.

4- 4. Health effect: human health can also be affected by acidification of air , water , and food while the consumption of low PH water in itself is dangerous it can also release heavy metals from the pipes of the distribution systems in to portable water supply.

Mechanism of acid formation in atmosphere :

H_2SO_4 in the air formed from SO_2 in a no. of ways depending upon the level of air pollution and environmental conditions of lights and humidity:

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

$$SO_2 + O_3 \rightarrow SO_3 + O_2$$

$$SO_2 + ROO \rightarrow SO_3 + RO$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

$$SO_2 + H_2O \rightarrow H_2SO_3$$

HNO_3 can be formed by direct oxidation and catalytic oxidation

$$4 NO_2 + O_2 + 2 H_2O \rightarrow 4 HNO_3$$

$$NO_2 + O_3 \rightarrow NO_3 + O_2$$

$NO_3 + NO_2 \rightarrow N_2O_5$

$N_2O_5 + H_2O \rightarrow 2\ HNO_3$

$NO + NO_2 + H_2O \rightarrow 2\ HNO_3$

Control strategies for acid rain:

1. The use of low sulphur coal or substitution of coal by other fuels.
2. Alternative methods for power generation instead of thermal power plants such as hydropower facilities or nuclear power.
3. Installation of flue-gas desulphurization systems in large power plants can reduce emission of SO_2.
4. Use different new technology like electron beam technology , which converts SO_2 , and Nox in to ammonium sulphate { $(NH_4)_2SO_4$} and ammonium nitrate { NH_4SO_4} . The process involved the reaction of ammonia which is injected from outside in to the flue gas , with SO_2 , Nox in a process vessel under the influence of electrons produced by an electron beam gun. It is possible to remove 95% of SO_2 and 80% of Nox simultaneously from the flue gas under normal operating conditions by this process.

Sample of questions:

Q1 : explain the major greenhouse gases and its allowable levels.

Q2: explain the pollutant that cause a depletion of ozone layer .

Q3 : explain the harmful effects caused by acid rain deposition.

Contin…

1. What do you mean by air pollution?
2. Tabulate the composition of air.
3. Discuss the problem of air pollution.
4. Enlist the major air pollution disasters.
5. Describe the classification of air pollutants.

6. Describe the aerosols as air pollutants.
7. Describe the various air polluting gases.
8. What are the primary and secondary air pollutants?
9. Describe the classification of air pollution based on position of the source.
10. Enlist the allowable limit of the air pollutants in air.
11. Tabulate the harmful impacts of air pollution on human beings by vehicular emissions.
12. Tabulate the harmful impacts of different air pollutants on human beings.
13. Tabulate the harmful impacts of different air pollutants on materials.
14. Discuss the methods of controlling the air pollution.

15. Discuss the methods of controlling the automobile pollution.
16. Describe the catalytic converter.
17. What is greenhouse effect?
18. What is global warming and its effects?
19. Describe acid rain, its formation, the harmful effect and control strategies.
20. Describe ozone depletion, its harmful effects and causes of ozone depletion and its prevention.

Air pollution: Air pollutants

The phenomenon of air pollution involves a sequence of events: the generation of pollutants at and their release from a source; their transport and transfonnation in and removal from the atmosphere; and their effects on human beings, materials, and ecosystems. Because it is generally either economically infeasible or technically impossible to design processes for absolutely zero emissions of air pollutants, we seek to control the emissions to a level such that effects are either nonexistent or minimized. We can divide the study of air pollution into three obviously overlapping but somewhat distinct areas:

1. The generation and control of air pollutants at their source. This first area involves everything that occurs before the pollutant is released "up the stack" or "out the

2. The transport, dispersion, chemical transfonnation in, and removal of species from the atmosphere. This second area thus includes all the chemical and physical processes that take place between the point of emission and ultimate removal from the atmosphere.

3. The effects of air pollutants on human beings, animals, materials, vegetation, crops, and forest and aquatic ecosystems, including the measurement of gaseous and particulate species.

An air pollution control strategy for a region is a specification of the allowable levels of pollutant emissions from sources. To fonnulate such a strategy it is necessary to be able to estimate the atmospheric fate of the emissions, and thus the ambient concentrations, so that these concentrations can be compared with those considered to give rise to adverse effects. The ultimate mix of control actions and devices employed to achieve the allowable levels might then be decided on an economic basis. Therefore, the formulation of an air pollution control strategy for a region involves a critical feedback from area 3 to area 1. Consequently, all three of the areas above are important in air pollution abatement planning.

AIR POLLUTANTS

Particulate matter SO2, CO, NO, -----sources and affect Control treatment methods, Design of some equipment: Centrifugal, cyclone, scrubber, and chimney design.

Table 1.1 summarizes species classified as air pollutants.

Natural Contaminants: Pollen is important natural contaminant because of its peculiar properties of irritation and allergy sometimes leading to bronchitis, asthma and dermatitis. Pollen grains are the male gametophytes of gymnosperms and angiosperms and they are discharged into the atmosphere from plants etc. The air transported pollen grains range mainly between 10 and 50 microns.

Aerosols: Aerosols refer to the dispersion of solid or liquid particles of microscopic size in the air. It can also be defined as a colloidal system in which the dispersion medium is gas and the dispersed phase is solid or liquid. The term aerosol is applicable until it is in suspension and after settlement due to its own weight or by addition with other particles (agglomeration) it is no longer an air pollutant. The diameter of the aerosol may range from 0.01 (or less) micron to 100 micron. The various aerosols are as follows:-

(i) **Dust:** Dust is produced by the crushing, grinding and natural sources like windstorms. Generally the dust particles are over 20 micron in diameter. They do not flocculate but settle under gravity, but smaller particles like 5 micron form stable suspensions.

(ii) **Smoke**: Smoke is made up of finely divided particles produced by incomplete combustion. Generally it consists of carbon particles of size less than 1.0 micron.

(iii) **Mists**: Mist is a light dispersion of minute water droplets suspended in the atmosphere ranging from 40 to 400 micron in size.

(iv) **Fog:** Fog is made up of dispersion of water or ice near the earth's surface reducing visibility to less than 500 m. In natural fog the size of particles range from 1.0 to 40 micron.

(v) **Fumes**: Fumes are solid particles generated by condensation from the gaseous state after volatilization from melted substances. Fumes flocculate and sometimes coalesce.

(IV) Gases: Following are the main air pollutant gases

(i) **Sulphur dioxide**: It is a major air pollutant gas produced by the combustion of fuels like coal. The main source of electricity production is by burning of fossil fuels in India and the whole world. The sulphur content of the coal varies from 1 to 4% and fortunately the Indian coal is low in sulphur content. SO2 is also produced in the metallurgical operations.

(ii) **Oxides of nitrogen:** Oxides of nitrogen are produced either in the production of nitric acid or in the automobile exhausts and as the effluent of power plants. Out of the seven oxides of Nitrogen (N2O, NO, NO2, NO3, N2O3, N2O4, N2O5) only nitric oxide and nitrogen dioxide are classified as the main pollutants. All the oxides of nitrogen are collectively known as NOX.

(iii) **Carbon monoxide**: It is produced because of the incomplete combustion of coal and other petroleum products. It is produced in the exhaust of automobiles. In the pollution check of vehicles mainly CO and unburnt hydrocarbons are measured.

(iv) **Hydrogen sulphide**: Hydrogen Suphide is an obnoxious (bad smelling) gas. It is produced mainly by the anaerobic (in absence of air) decomposition of organic matter. Other air polluting sulfur compounds are methyl mercaptane (CH3 SH) and dimethyle sulphide (CH3 S CH3) etc.

(v) **Hydrogen fluoride**: It is an important pollutant even in very low concentrations. It is produced in the manufacturing of phosphate fertilizers.

(vi) **Chlorine and hydrogen chloride**: It is mixed in the air either from the leakages from water treatment plants or other industries where it is produced or used. Hydrogen chloride is also evolved in various industrial chemical processes. The main effect of chlorine is respiratory irritation which may be fatal.

(vii) **Ozone:** It is a desirable gas in the upper layers of atmosphere as it absorbs the UV radiation of sunlight. But near the earth surface it is a poisonous gas. It makes poisonous chemicals by photochemical reactions.

(viii**) Aldehydes**: They are produced by the incomplete oxidation of motor fuels and lubricating oil. They may also be formed because of photochemical reactions. Formaldehydes are irritating to the eyes.

Oxides of Nitrogen

Nitric oxide (NO) and nitrogen dioxide ($N0_2$) are the two most important nitrogen oxide air pollutants. They are frequently lumped together under the designation NOx , although analytical techniques can distinguish clearly between them. Of the two, $N0_2$ is the more toxic and irritating compound.

Nitric oxide is a principal by-product of combustion processes, arising from the high-temperature reaction between N2 and O2 in the combustion air and from the oxidation of organically bound nitrogen in certain fuels such as coal and oil. The oxidation of N_2 by the O_2 in combustion air occurs primarily through the two reactions Known as the Zeldovich mechanism.

$$N_2 + O \longrightarrow NO + N$$

$$N + O_2 \longrightarrow NO + O$$

Sulfur Oxides

Sulfur dioxide (S02) is formed from the oxidation of sulfur contained in fuel as well as from certain industrial processes that utilize sulfur-containing compounds. Anthropogenic emissions of S02 result almost exclusively from stationary point sources. A small fraction of sulfur oxides is emitted as primary sulfates, gaseous sulfur trioxide (S03), and sulfuric acid (H2S04), It is estimated that, by volume, over 90% of the total U.S. sulfur oxide emissions are in the form of S02, with primary sulfates accounting for the other 10%. Stationary fuel combustion (primarily utility and industrial) and industrial processes (primarily smelting) are the main S02 sources. Stationary fuel combustion includes all boilers, heaters, and furnaces found in utilities, industry, and commercial! institutional and residential establishments. Coal combustion has traditionally been the largest stationary fuel combustion source, although industrial and residential coal use has declined. Increased coal use by electric utilities, however, has offset this decrease. S02 emissions from electric utilities account for more than half of the U. S. total.

Organic Compounds

Organic air pollutants are sometimes divided according to volatile organic compounds (VOCs) and particulate organic compounds (POCs), although there are some species that will actually be distributed between the gaseous and particulate phases. The emission of unburned or partially burned fuel from combustion processes and escape of organic vapors from industrial operations are the major anthropogenic sources of organic air pollutants. A major source of airborne organic compounds is the emissions from motor vehicle.

TABLE 1.1 AIR POLLUTANTS

	Physical properties	Concentration levels[a]	Anthropogenic sources	Natural sources
SO_2	Colorless gas with irritating, pungent odor; detectable by taste at levels of 0.3 to 1 ppm; highly soluble in water (10.5 g/100 cm^3 at 293 K)	Global background concentration levels in the range 0.04 to 6 ppb; hourly averaged maximum concentrations in urban areas have occasionally exceeded 1 ppm	Fuel combustion in stationary sources; industrial process emissions; metal and petroleum refining	Atmospheric oxidation of organic sulfides
H_2S	Colorless, flammable gas; highly toxic; characteristic rotten egg odor	Global background about 3 $\mu g\ m^{-3}$; urban levels have been observed as large as 390 $\mu g\ m^{-3}$	Kraft pulp mills; natural gas and petroleum refining; rayon and nylon manufacture; coke ovens	Biological decay processes; volcanoes and geothermal activities
NO	Colorless, odorless gas; nonflammable and slightly soluble in water; toxic	Global background level from 10 to 100 ppt; urban levels have been observed as large as 500 ppb	Combustion	Bacterial action; natural combustion processes; lightning
NO_2	Reddish-orange-brown gas with sharp, pungent odor; toxic and highly corrosive; absorbs light over much of the visible spectrum	Global background level from 10 to 500 ppt; urban concentrations have reached values exceeding 500 ppb	Combustion	
NH_3	Colorless gas with pungent odor; detectable at concentrations exceeding 500 ppm; highly soluble in water	Global background level of 1 ppb; urban concentrations in range of 5 ppb	Combustion	Bacterial decomposition of amino acids in organic waste
CO_2	Colorless, odorless, nontoxic gas moderately soluble in water	Global background concentration has increased from 290 ppm in 1900 to about 345 ppm in 1985	Combustion of fossil fuels	

CO	Colorless, odorless, flammable, toxic gas, slightly soluble in water	Global average concentration of 0.09 ppm; concentrations in northern hemisphere are about twice those in southern hemisphere; urban levels in the vicinity of heavily traveled roadways can exceed 100 ppm	Combustion of fossil fuels	Atmospheric oxidation of methane and other biogenic hydrocarbons
O_3	Colorless, toxic gas, slightly soluble in water	Global background concentrations range from 20 to 60 ppb; polluted urban levels range from 100 to 500 ppb	No primary sources; formed as a secondary pollutant from atmospheric reactions involving hydrocarbons and oxides of nitrogen	Natural tropospheric chemistry; transport from stratosphere to troposphere
Nonmethane hydrocarbons (see Table 1.2)		Global background concentrations range from 10 to 20 ppb; polluted urban levels range from 500 to 1200 ppb	Incomplete combustion; industrial sources	Vegetation

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[a] Two concentration units that are commonly used in reporting atmospheric species abundances are $\mu g\ m^{-3}$ and parts per million by volume (ppm). Parts per million by volume is not really a concentration but a dimensionless volume fraction, although it is widely referred to as a "concentration." Parts per million by volume may be expressed as

$$\text{"concentration" of species } i \text{ in ppm} = \frac{c_i}{c} \times 10^6$$

where c_i and c are moles/volume of species i and air, respectively, at p and T. Given a pollutant mass concentration m_i expressed in $\mu g\ m^{-3}$

$$c_i = \frac{10^{-6}\, m_i}{M_i}$$

where M_i is the molecular weight of species i and $c = p/RT$. Thus the "concentration" of a species in ppm is related to that in $\mu g\ m^{-3}$ by

$$\text{"concentration" of species } i \text{ in ppm} = \frac{RT}{pM_i} \times \text{concentration in } \mu g\ m^{-3}$$

Parts per billion by volume (ppb) is just $(c_i/c) \times 10^9$.

3.2 Air Pollutants with their Sources

S. No.	*Air pollutant*	*Source*
1	Particulate Dust, SPM, RSPM etc.	Abrasion, quarrying (stone mining), soil erosion fuel combustion in automobiles, building and other civil construction, Industrial effluents, mining, power station, etc.
2	Oxides of sulphur (SO_x)	Power houses, smelters, coal and other fossil fuels combustion, sulphuric acid plant, automobiles etc.
3	Oxides of nitrogen	Combustion, automobiles, acid manufacturing
4	Hydrogen sulphide	Petroleum industry, wastewater treatment, tanneries, oil refineries etc.
5	Carbon monoxide	Metabolic activity, fuel combustion, automobile exhaust
6	Ozone	Photochemical reactions
7	Lead	Automobile exhaust
8	Organic solvents	Solvent use, paints, pesticides, cooking, cosmetics etc.
9	Mercury	Pesticides, paints, laboratories
10	Fluorides (HF)	Glass and ceramics, cement factories, aluminum industry, fertilizer industry etc.

Particulate Matter

Particulate matter refers to everything emitted in the form of a condensed (liquid or solid) phase. Industrial use, coal and, to a lesser extent, oil combustion contribute most of the particulate (and sulfur oxides) emissions. Coal is a slow-burning fuel with a relatively high ash (incombustible inorganic) content. Coal combustion particles consist primarily of carbon, silica (Si02), alumina (AI20 3), and iron oxide (FeO and Fez0 3). In contrast to coal, oil is a fast-burning, low-ash fuel. The low ash content results in formation of less particulate matter, but the sizes of particles formed in oil combustion are generally smaller than those of particles from coal combustion. Oil combustion particulate matter contains cadmium, cobalt, copper, nickel, and vanadium. Major industrial process sources of particulate matter include the metals, mineral products, petroleum, and chemicals industries. Iron and steel and primary smelting operations are the most significant emission sources in the metals industry. The iron and steel industry involves coke, iron, and steel production, each of which is a source of particulate emissions. The primary metals industry includes the smelting of copper, lead, and zinc, along with aluminum production. Sulfur in unprocessed ores is converted to S02 during smelting, with a relatively small portion emitted as particulate sulfate and sulfuric acid. Emissions from the mineral products industry result from the production of Portland cement, asphalt, crushed rock, lime, glass, gypsum, brick, fiberglass, phosphate rock, and potash. The particles emitted from crushing, screening, conveying, grinding, and loading operations tend to be larger than 15 p.m.

ATMOSPHERIC CONCENTRATION UNITS

We note that two concentration units that are commonly used in reporting atmospheric species abundance are JLg m-3 and parts per million by volume (ppm). Parts per million by volume is just

$$\frac{c_i}{c} \times 10^6$$

where ci and c are moles per volume of species i and air, respectively, at pressure p and temperature T. Note that in spite of the widespread reference to it as a concentration, parts per million by volume is not really a concentration but a dimensionless volume fraction.

Given a pollutant mass concentration m_i expressed in $\mu g\ m^{-3}$,

$$c_i = \frac{10^{-6}\, m_i}{M_i}$$

where M_i is the molecular weight of species i and $c = p/RT$. Thus

$$\text{concentration of species } i \text{ in ppm} = \frac{RT}{pM_i} \times \text{concentration in } \mu g\ m^{-3}$$

If T is in kelvin and p in pascal, then (see Table 1.15 for the value of the gas law constant R)

$$\text{concentration of species } i \text{ in ppm} = \frac{8.314T}{pM_i} \times \text{concentration in } \mu g\ m^{-3}$$

Example 1.1 ***Conversion between Parts per Million and Micrograms per Cubic Meter***

Confirm the relation between ppm and $\mu g\ m^{-3}$ for ozone given in Table 1.9 at $T = 298$ K and $p = 1$ atm (1.0133×10^5 Pa)

$$\begin{aligned} \text{concentration in } \mu g\ m^{-3} &= \frac{pM_i}{8.314T} \times \text{concentration in ppm} \\ &= \frac{(1.0133 \times 10^5)(48)}{8.314(298)} \times 0.12 \\ &= 235.6\ \mu g\ m^{-3} \end{aligned}$$

The 24-hour SO_2 NAAQS is 365 $\mu g\ m^{-3}$. Convert this to ppm at the same temperature and pressure.

$$\begin{aligned} \text{concentration in ppm} &= \frac{(8.314)(298)}{(1.0133 \times 10^5)(64)} \times 365 \\ &= 0.139 \text{ ppm} \end{aligned}$$

industrial emissions are also an important source of air pollution. burning.

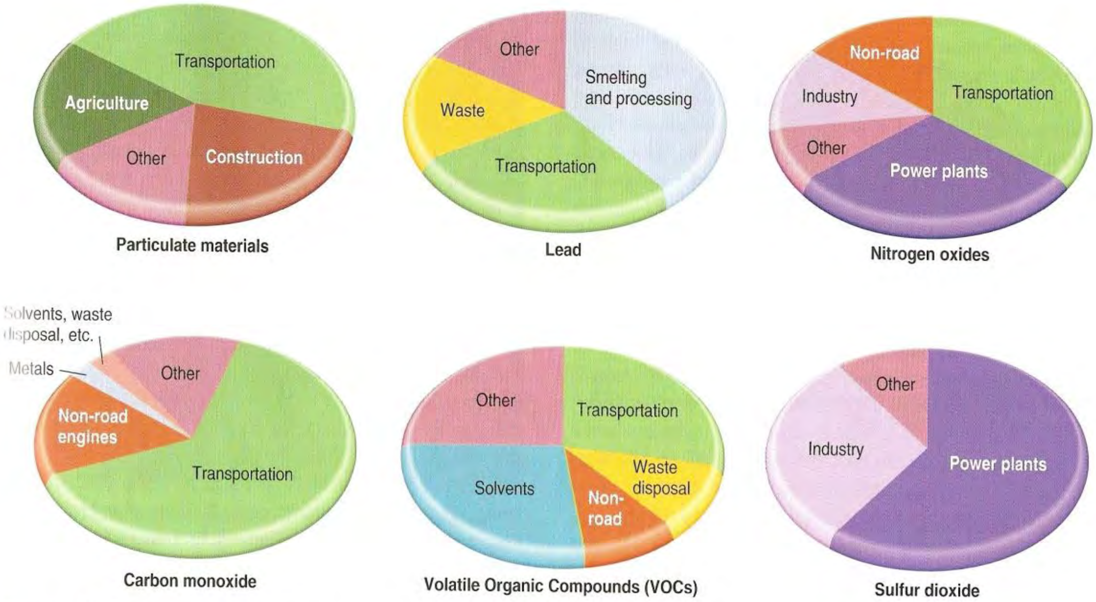
TABLE 16.1

Estimated Fluxes of Pollutants and Trace Gases to the Atmosphere

Species	Sources	Approximate Annual Flux (Millions of Metric Tons/Yr)	
		Natural	Anthropogenic
CO_2 (carbon dioxide)	Respiration, fossil fuel burning, land clearing, industrial processes	370,000	29,600*
CH_4 (methane)	Rice paddies and wetlands, gas drilling, landfills, animals, termites	155	350
CO (carbon monoxide)	Incomplete combustion, CH_4 oxidation, biomass burning, plant metabolism	1,580	930
NMHC (nonmethane hydrocarbons)	Fossil fuels, industrial uses, plant isoprenes and other biogenics	860	92
NO_x (nitrogen oxides)	Fossil fuel burning, lightning, biomass burning, soil microbes	90	140
SO_x (sulfur oxides)	Fossil fuel burning, industry, biomass burning, volcanoes, oceans	35	79
SPM (suspended particulate materials)	Biomass burning, dust, sea salt, biogenic aerosols, gas-to-particle conversion	583	362

**Only 27.3 percent of this amount—or 8 billion tons—is carbon.*

Source: UNEP, 1999.



Particulate materials

Lead

Nitrogen oxides

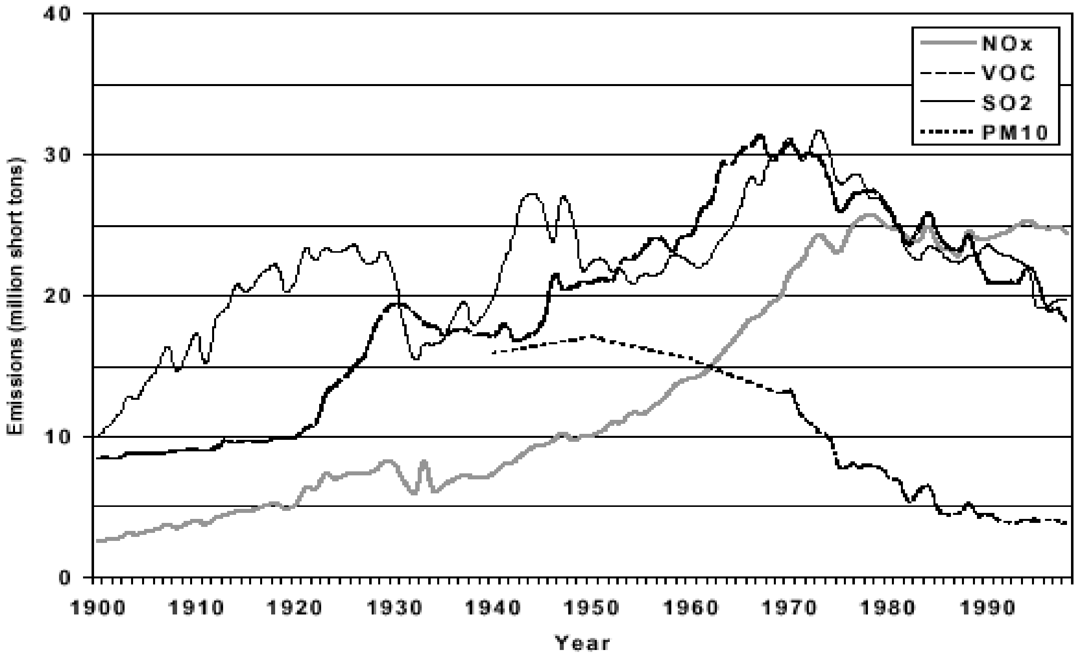
Carbon monoxide

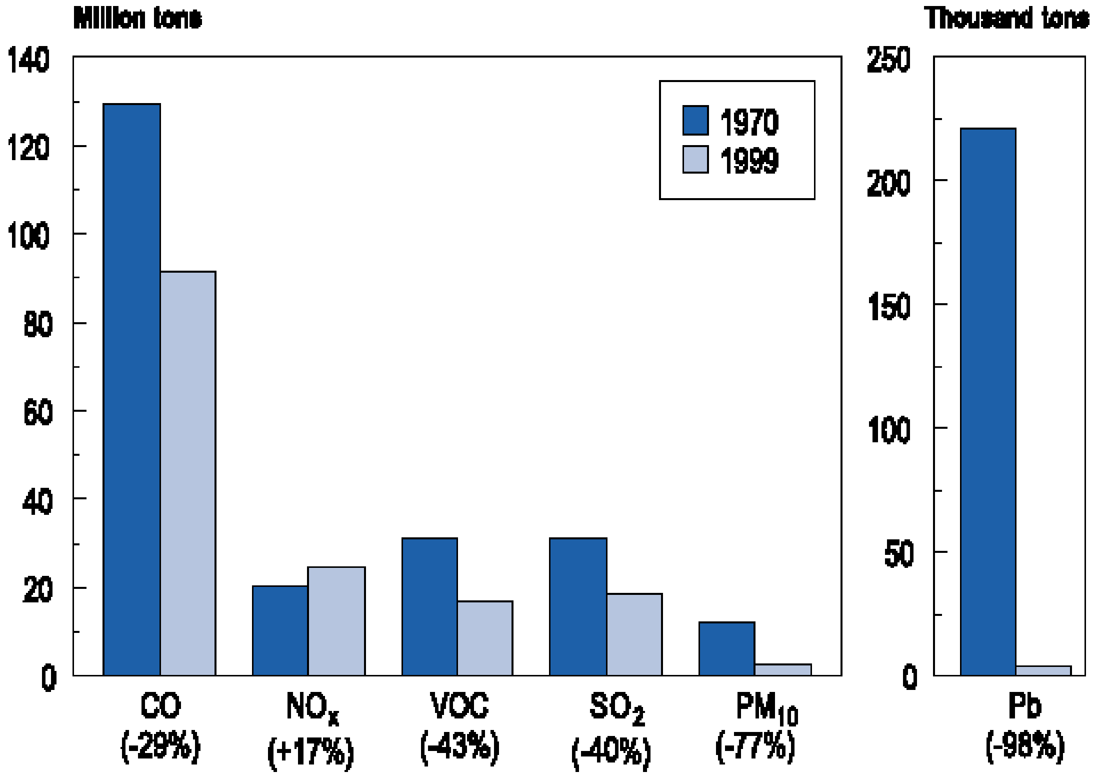
Volatile Organic Compounds (VOCs)

Sulfur dioxide

Figure 16.5 Anthropogenic sources of six of the primary "criteria" air pollutants in the United States. *Source: UNEP, 1999.*

Figure ES-1. Trend in National Emissions, NITROGEN OXIDES, VOLATILE ORGANIC COMPOUNDS, SULFUR DIOXIDE (1900 to 1998), and Directly Emitted PARTICULATE MATTER (PM_{10} [nonfugitive dust sources]; 1940 to 1998)





Percent Change in Emissions

	1980–1999	1990–1999
CO	-22	-7
Pb	-95	-23
NO_x	+1	+2
VOC	-33	-15
PM_{10}	-55	-16
SO_2	-28	-21

Percent Change in Air Quality

	1980–1999	1990–1999
CO	-57	-36
Pb	-94	-60
NO_2	-25	-10
O_3 1-hr	-20	-4
8-hr	-12	no change
PM_{10}	—	-18
SO_2	-50	-36

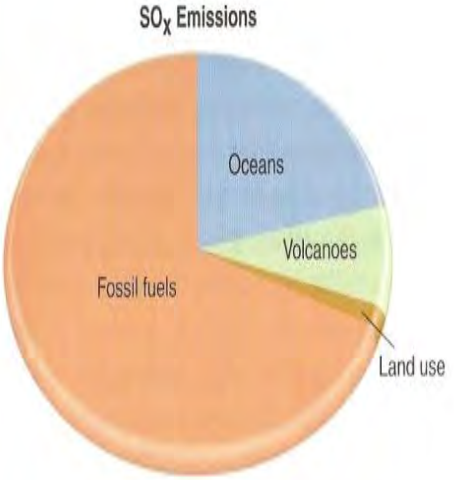


Figure 16.6 Sulfur fluxes into the atmosphere. *Source: UNEP, 1999.*

Sulfur dioxide is a colorless corrosive gas that is directly damaging to both plants and animals. Once in the atmosphere, it can be further oxidized to sulfur trioxide (SO_3), which reacts with water vapor or dissolves in water droplets to form sulfuric acid (H_2SO_4), a major component of acid rain. Very small solid particles or liquid droplets can transport the acidic sulfate ion (SO_4^{-2}) long distances through the air or deep into the lungs where it is very damaging. Sulfur dioxide and sulfate ions are probably second only to smoking as causes of air pollution-related health damage. Sulfate particles and droplets reduce visibility in the United States as much as 80 percent. Some of the smelliest and most obnoxious air pollutants are sulfur compounds, such as hydrogen sulfide from pig manure lagoons or mercaptans (organosulfur thiols) from papermills (fig. 16.7).

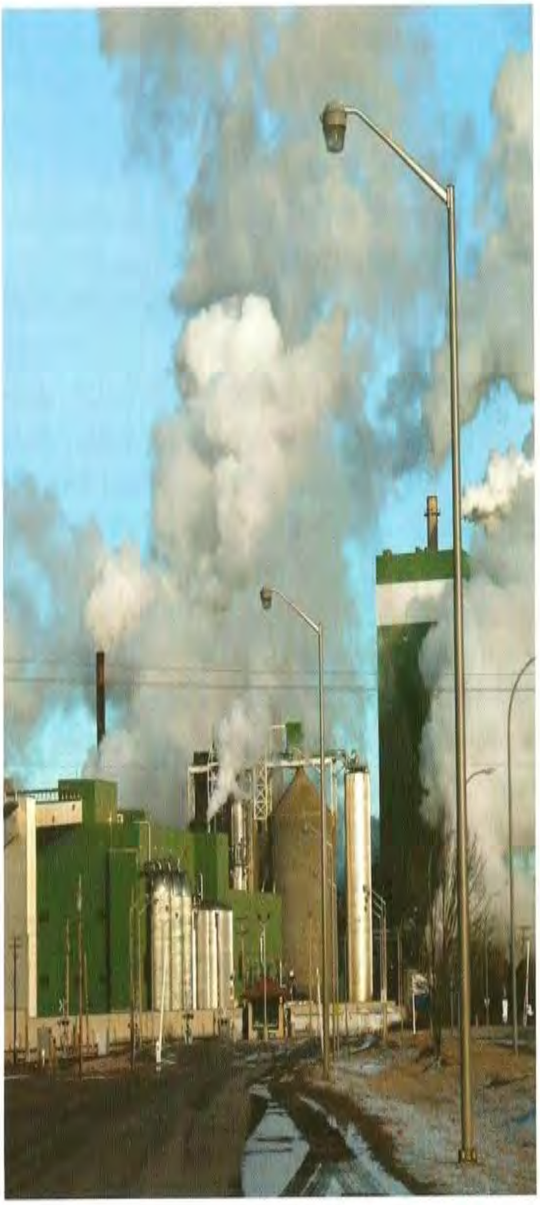


Figure 16.7 The most annoying pollutants from this paper mill are pungent organosulfur thiols and sulfides. Chlorine bleaching can also produce extremely dangerous organochlorines, such as dioxins.

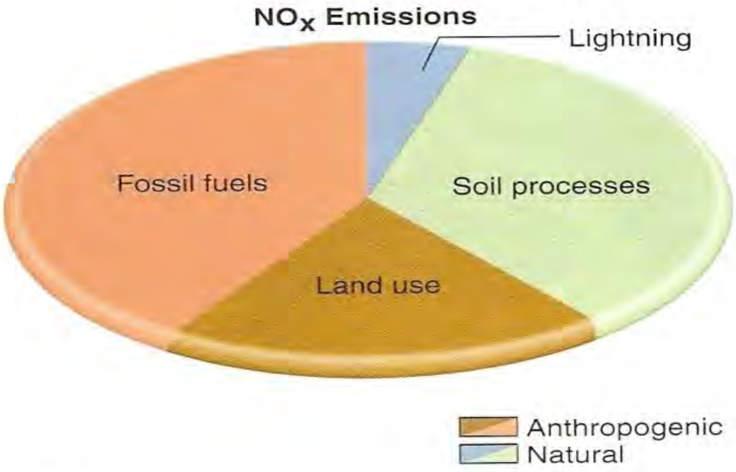


Figure 16.8 Worldwide sources of reactive nitrogen gases in the atmosphere. *Source: UNEP, 1999.*

Nitrogen Compounds **Nitrogen oxides** are highly reactive gases formed when nitrogen in fuel or combustion air is heated to temperatures above 650°C (1,200°F) in the presence of oxygen, or when bacteria in soil or water oxidize nitrogen-containing compounds. The initial product, nitric oxide (NO), oxidizes further in the atmosphere to nitrogen dioxide (NO_2), a reddish brown gas that gives photochemical smog its distinctive color. Because of their interconvertibility, the general term NO_x is used to describe these gases. Nitrogen oxides combine with water to make nitric acid (HNO_3), which is also a major component of atmospheric acidification.

The total annual emissions of reactive nitrogen compounds into the air are about 230 million metric tons worldwide (see table 16.1). Anthropogenic sources account for 60 percent of these emissions (fig. 16.8). About 95 percent of all human-caused NO_x in the United States is produced by fuel combustion in transportation and electric power generation. Nitrous oxide (N_2O) is an intermediate in soil denitrification that absorbs ultraviolet light and plays an important role in climate modification (chapter 15). Excess nitrogen is causing fertilization and eutrophication of inland waters and coastal seas. It also may be adversely affecting terrestrial plants both by excess fertilization and by encouraging growth of weedy species that crowd out native varieties.

Carbon Oxides The predominant form of carbon in the air is car-

Carbon Oxides The predominant form of carbon in the air is carbon dioxide (CO_2). It is usually considered nontoxic and innocuous, but increasing atmospheric levels (about 0.5 percent per year) due to human activities appear to be causing a global climate warming that may have disastrous effects on both human and natural communities. As table 16.1 shows, more than 90 percent of the CO_2 emitted each year is from respiration (oxidation of organic compounds by plant and animal cells). These releases are usually balanced, however, by an equal uptake by photosynthesis in green plants.

Anthropogenic (human-caused) CO_2 releases are difficult to quantify because they spread across global scales. The best current estimate from the Intergovernmental Panel on Climate Change (IPCC) is that between 7 and 8 billion tons of carbon (in the form of CO_2) are released each year by fossil fuel combustion and that another 1 to 2 billion tons are released by forest and grass fires, cement manufacturing, and other human activities. Typically, terrestrial ecosystems take up about 3 billion tons of this excess carbon every year, while oceanic processes take up another 2 billion tons. This leaves an average of at least 3 billion tons to accumulate in the atmosphere. The actual releases and uptakes vary greatly, however, from year to year. Some years almost all anthropogenic CO_2 is reabsorbed; in other years, almost none of it is. The ecological processes that sequester CO_2 depend strongly on temperature, nutrient availability, and other environmental factors.

United States negotiators at the Global Climate meetings claim that forests and soils in North America act as carbon sinks—that is, they take up more carbon than is released by other activities. Over the past decade, CO_2 levels in air coming ashore on the U.S. West Coast have averaged about 2 ppm higher than air leaving from the East Coast. If we assume that there isn't a major inflow of CO_2-depleted air entering from Canada or Mexico, this would mean that somewhere between 1.6 and 2.2 billion tons of CO_2 are being taken up every year than are being released in the United States. Other countries doubt these measurements, however, and refuse to give the United States credit for this large carbon sequestration.

Carbon monoxide (CO) is a colorless, odorless, nonirritating but highly toxic gas produced by incomplete combustion of fuel (coal, oil, charcoal, or gas), incineration of biomass or solid waste, or partially anaerobic decomposition of organic material. CO inhibits respiration in animals by binding irreversibly to hemoglobin. About 1 billion metric tons of CO are released to the atmosphere each year, half of that from human activities. In the United States, two-thirds of the CO emissions are created by internal combustion engines in transportation. Land-clearing fires and cooking fires also are major sources. About 90 percent of the CO in the air is consumed in photochemical reactions that produce ozone.

Particulate Material An **aerosol** is any system of solid particles or liquid droplets suspended in a gaseous medium. For convenience, we generally describe all atmospheric aerosols, whether solid or liquid, as **particulate material.** This includes dust, ash, soot, lint, smoke, pollen, spores, algal cells, and many other suspended materials. Anthropogenic particulate emissions amount to about 362 million metric tons per year worldwide. Wind-blown dust, volcanic ash, and other natural materials may contribute considerably more suspended particulate material.

Particulates often are the most apparent form of air pollution since they reduce visibility and leave dirty deposits on windows, painted surfaces, and textiles. Respirable particles smaller than 2.5 micrometers are among the most dangerous of this group because they can be drawn into the lungs, where they damage respiratory tissues. Asbestos fibers and cigarette smoke are among the most dangerous respirable particles in urban and indoor air because they are carcinogenic.

Diesel fumes also are highly toxic because they contain both fine particulates and chemicals such as benzene, dioxins, and mercury. The EPA has proposed new rules to require low-sulfur fuel and antipollution devices, particularly for off-road engines such as bulldozers, tractors, pumps, and generators. Epidemiologists estimate that these new standards will prevent more than 360,000 asthma

Metals and Halogens Many toxic metals are mined and used in manufacturing processes or occur as trace elements in fuels, especially coal. These metals are released to the air in the form of metal fumes or suspended particulates by fuel combustion, ore smelting, and disposal of wastes. Worldwide atmospheric lead emissions amount to about 2 million metric tons per year, or two-thirds of all metallic air pollution. Most of this lead is from leaded gasoline. Lead is a metabolic poison and a neurotoxin that binds to essential enzymes and cellular components and inactivates them.

Banning leaded gasoline is one of the most successful pollution-control measures in American history. Since 1986, when the ban was enforced, children's average blood lead levels have dropped 90 percent and average IQs have risen three points. Now, 50 nations have renounced leaded gasoline. The global economic benefit of this step is estimated to be more than $200 billion per year.

As the opening case study for this chapter shows, mercury is another dangerous neurotoxin that is widespread in the environment, and whose control is highly contentious. A long-awaited plan from the Bush administration promises to reduce mercury deposition in the United States 70 percent by 2018. But critics contend that the proposed market mechanisms are merely a way to allow utilities to continue to avoid expensive pollution controls and to contaminate our air for decades. The EPA's own inspector general and the nonpartisan Government Accounting Office charge

Volatile Organic Compounds **Volatile organic compounds (VOCs)** are organic chemicals that exist as gases in the air. Plants are the largest source of VOCs, releasing an estimated 350 million tons of isoprene (C_5H_8) and 450 million tons of terpenes ($C_{10}H_{15}$) each year (fig. 16.10). About 400 million tons of methane (CH_4) are produced by natural wetlands and rice paddies and by bacteria in the guts of termites and ruminant animals. These volatile hydrocarbons are generally oxidized to CO and CO_2 in the atmosphere.

In addition to these natural VOCs, a large number of other synthetic organic chemicals, such as benzene, toluene, formaldehyde, vinyl chloride, phenols, chloroform, and trichloroethylene, are released into the air by human activities. About 28 million tons of these compounds are emitted each year in the United States, mainly unburned or partially burned hydrocarbons from transportation, power plants, chemical plants, and petroleum refineries. These chemicals play an important role in the formation of photochemical oxidants.

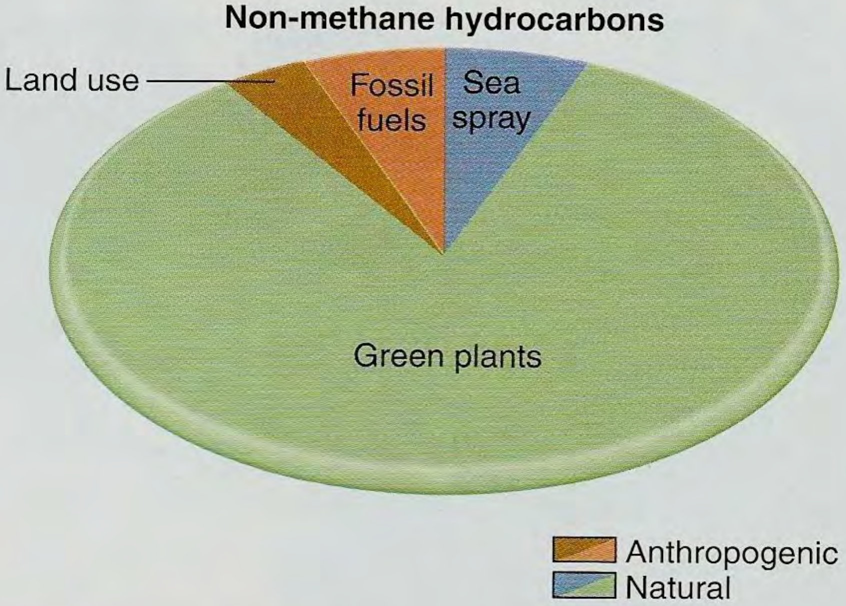


Figure 16.10 Sources of non-methane hydrocarbons in the atmosphere. *Source: UNEP, 1999.*

CONTROL OF AIR POLLUTION

Prevention is always better than cure. So one should try to prevent the air pollution by changing the raw material, the process conditions, procedure and by having the preventive maintenance one can prevent the air pollution. For this purpose some of the examples are as follows:-

(i) Controlling the spread of coal dust by sprinkling water on it before handling in a thermal power plant.

(ii) Preventive maintenance by repairing leaky valves in advance so as to prevent the leakages of the harmful gases in air.

(iii) Applying zoning to distribute the impact of air pollution in a community.

(iv) Selection of proper material. For example using low sulfur coal reduces the SO2 problem.

In addition to the preventive measures one has to have control technologies as follows. Depending upon the situation different control technologies are adopted. For dealing with the particulate matter the following control technologies are used,

- Settling chambers
- Cyclone separators
- Fabric filters
- Electrostatic precipitators
- Wet collector (scrubbers)

The first two of the above are used for coarse particulates where as the other three are used for fine particulates.

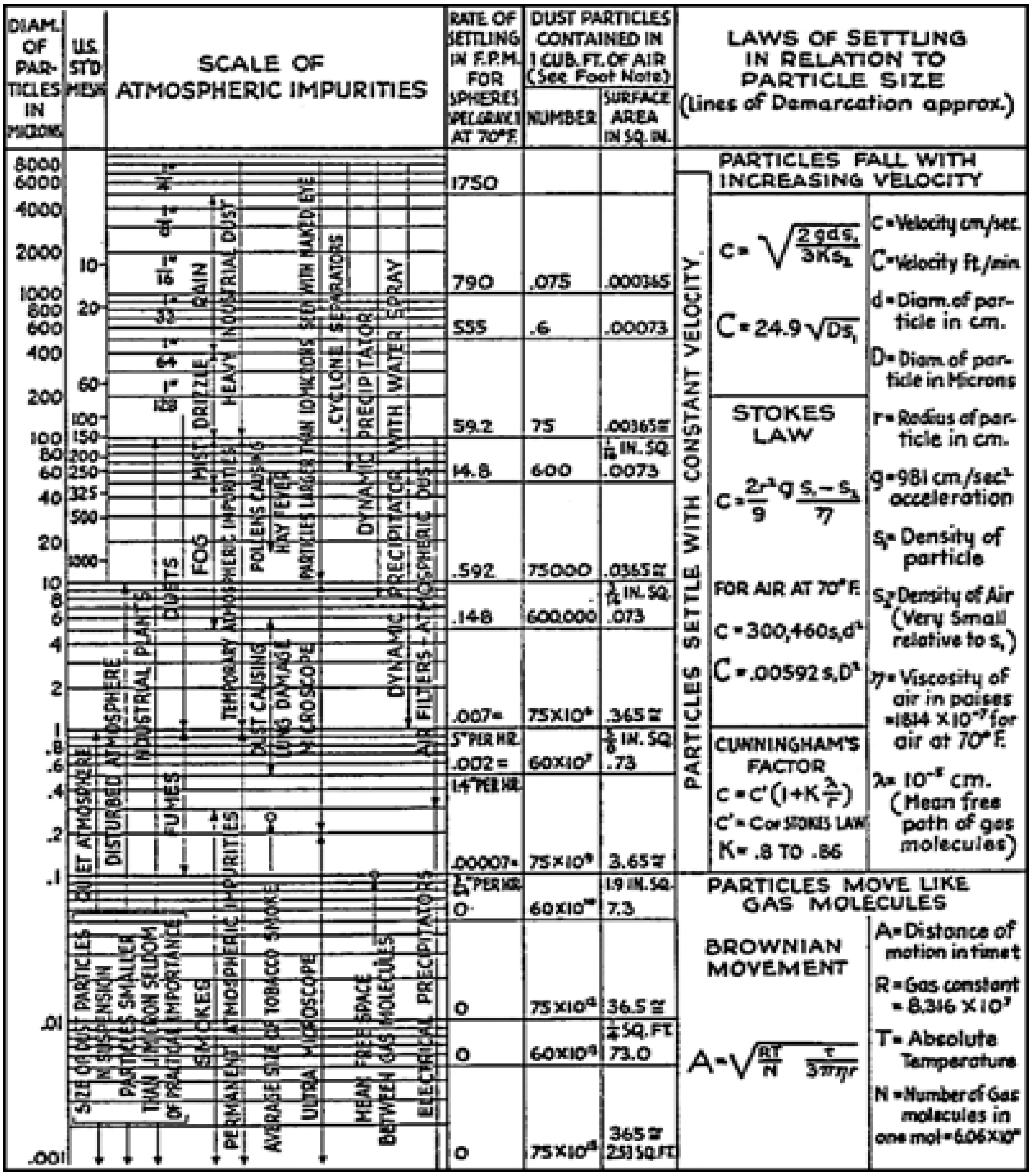
For gaseous pollutants the following control technologies are used.

- Condensation
- Absorption
- Adsorption
- Combustion For the control of gases such as NO2 and SO2 produced in combustion, wet and dry scrubbers are used.

Control treatment methods:

Air Filter: The following chart shows common particulate sizes and the general types of collection mechanisms and devices used for their control. The pollutants are grouped by their settling characteristics. Larger particles (above about 2μm aerodynamic diameter) generally follow Stokes law regarding settling velocities.

Below about 2µm, a correction factor (Cunningham’s correction factor) is needed to adjust Stokes for the longer settling times for these size particles.



Methods of treatment:

In general, particles greater than 20µm in aerodynamic diameter can be controlled using low energy wet-type devices. These are knock out chambers (traps or settling chambers), cyclone collectors, mechanically aided wet scrubbers, educators, fluidized bed scrubbers, spray scrubbers, impactor scrubbers, and venturi scrubbers (low energy). For particles in the 5µm aerodynamic diameter and above, the Venturi scrubbers (moderate energy) are the most common type devices in use. Some vendors have improved the performance of low energy devices sufficiently to span the gap between those capable of removing 20+ and 5+µm pollutants. Some mechanically aided wet scrubbers also bridge this gap at higher energy input. For lower concentrations of particles in this size range, enhanced scrubbers such as air/steam atomized spray scrubbers, and some proprietary designs are used.

For dry type separation devices such as fabric filter collectors (baghouses) and electrostatic precipitators, the energy input is fairly constant regardless of the particle size. Even among these designs, however, increases in energy input yield increases in the collection of finer pollutants. Baghouses are often precoated with a fine material to reduce the permeability of the collecting filter cake and improve fine particulate capture. This cake adds to the pressure drop which mandates, in turn, an increase in energy input. Precipitators are often increased in field size to remove finer particulate thereby requiring greater power input. These dry devices, in general, use less total power input than equivalent wet devices when removing particulate.

Particles less than approximately 2µm diameter tend to be influenced by gas molecules, temperature and density gradients, and other subtle forces and do not follow predictable trajectories. These are the “givens” in the wet scrubber design equation. Nearly all wet separation devices use the same three capture mechanisms.

there are:

- Impaction
- Interception
- Diffusion

Figure 1.3 shows a target droplet being impacted by a particle. The particle has sufficient inertia to follow a predicted course into the droplet. Once inside the droplet, the combined particle/droplet size is aerodynamically much larger, therefore the separation task becomes easier. Simply separate the droplet from the gas stream (more on that later) and one removes the particle(s).

Figure 1.4 shows a particle, perhaps a bit smaller, moving along the gas stream lines and being intercepted at the droplet surface. The particle in this case comes close enough to the droplet surface that it is attracted to that surface and is combined with the droplet. Again, once the particles are intercepted, the bigger droplet is easier to remove.

Figure 1.3 Impaction (Bionomic Industries Inc.).

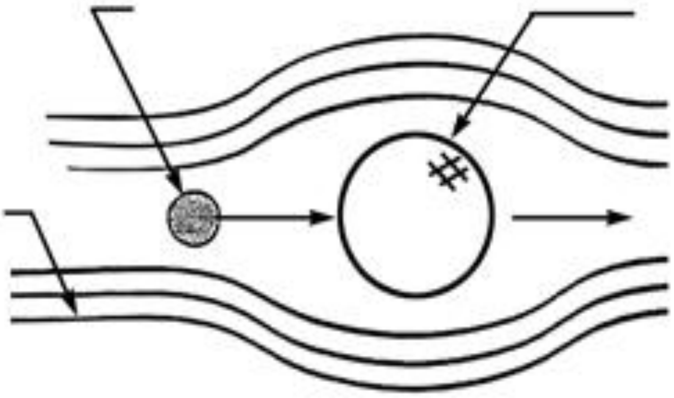


Figure 1.4 Interceptions (Bionomic Industries Inc.

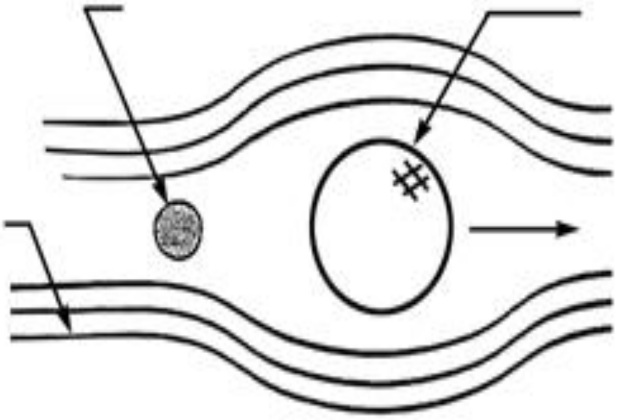


Figure 1.5 Diffusion (Bionomic Industries Inc.)

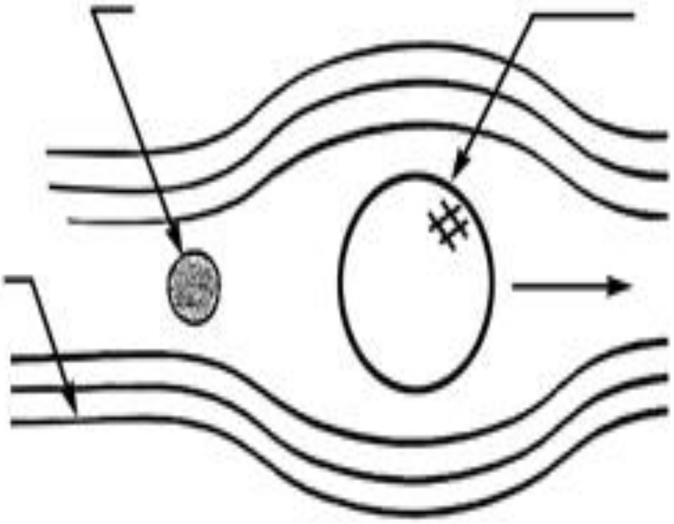


Figure 1.5 depicts an even tinier particle that is so small it bounces around in the moving air stream buffeted by water and gas molecules. In this case the particle *diffuses* over to the droplet and, by chance, is absorbed into the droplet. Obviously, to increase the chances of capture by diffusion, increase the number of droplets per unit volume.

Figure 1.6, we see a Venturi scrubber (left) connected to a typical cyclonic type separator. This device separates the droplets using centrifugal force. The centrifugal force pushes the droplets toward the vessel wall where they form a compressed film, agglomerate, accumulate, and drain by gravity out of the air stream.

Sometimes chevron type droplet eliminators are used. These place a waveform in the path of the droplet (Figure 1.7). The same thing occurs. The droplets build up, drain, and carry their particulate cargo out of the gas stream.

Figure 1.6 Venturi scrubber and cyclonic separator.

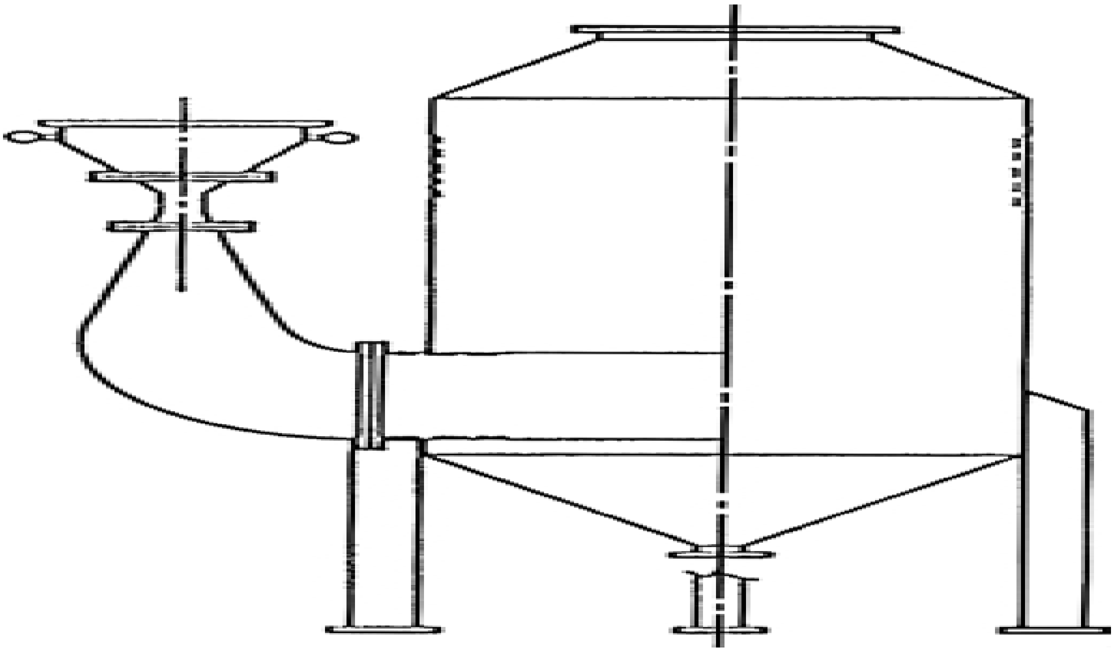


Figure 1.7 Chevron droplet eliminator (Munters Corp.).

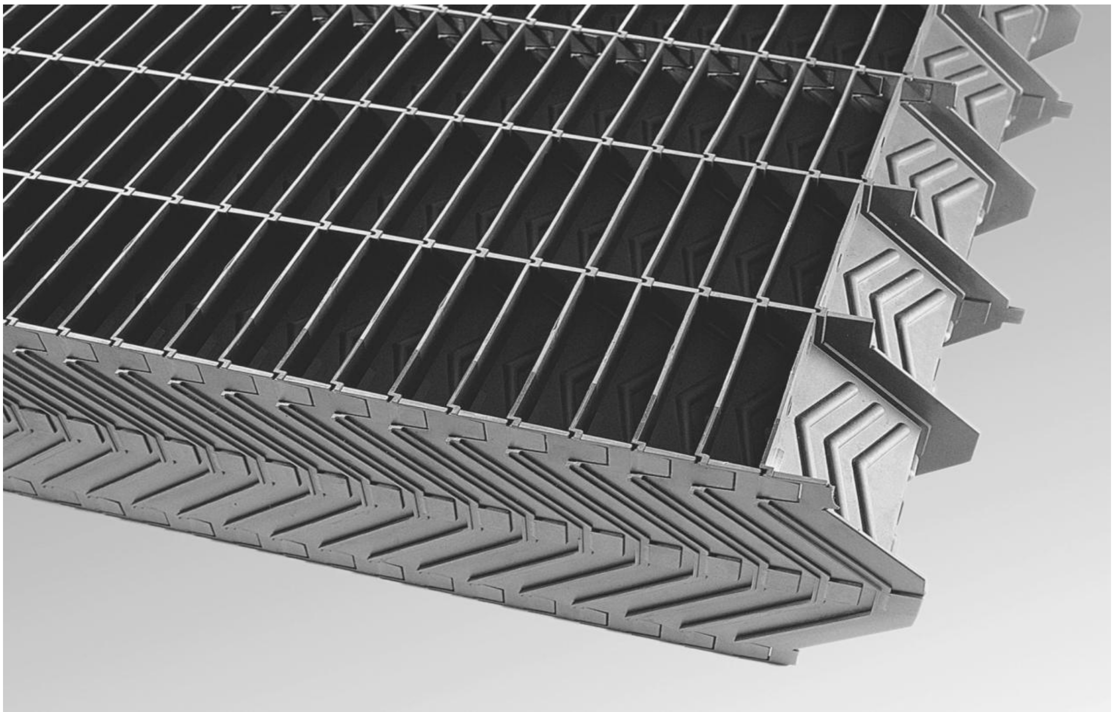
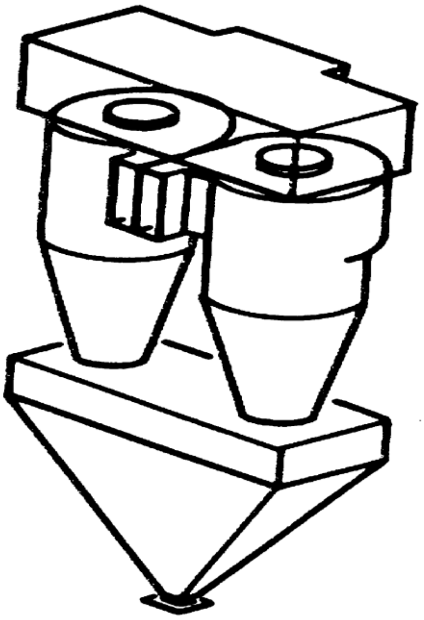


Figure 1.8 **Cyclone collector (Bionomic Industries Inc.).**



dry cyclone collectors (Figure 1.8) could be used to separate the particulate in a dry form. These devices are commonly used to separate particles in excess of 5µm diameter because these particles exhibit the inertia effects mentioned previously. In general, the smaller the cyclone diameter, the smaller the particle that can be removed (because the radius of turn is greater).

In the separation of contaminant gases from carrier gases, we help Mother Nature. Figure 1.9 shows a condensing wet scrubbing system. The processes involved in the separation of contaminant gases from a carrier gas include:

1. Condensation

2. Absorption

3. Adsorption

4. Gas phase destruction (thermal or chemical)

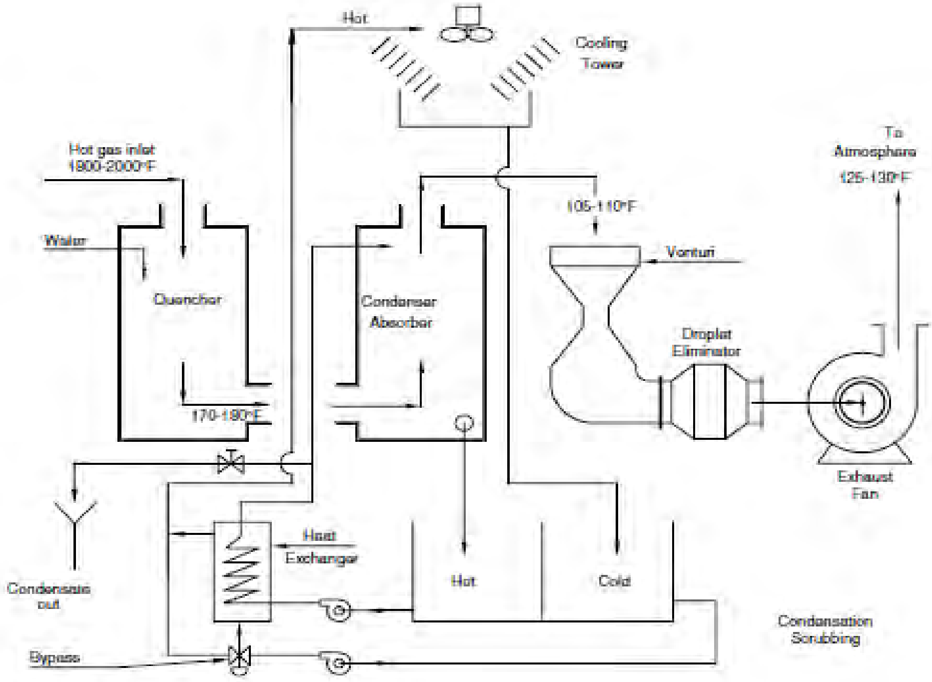


Figure 1.9 Condensation scrubbing system components.

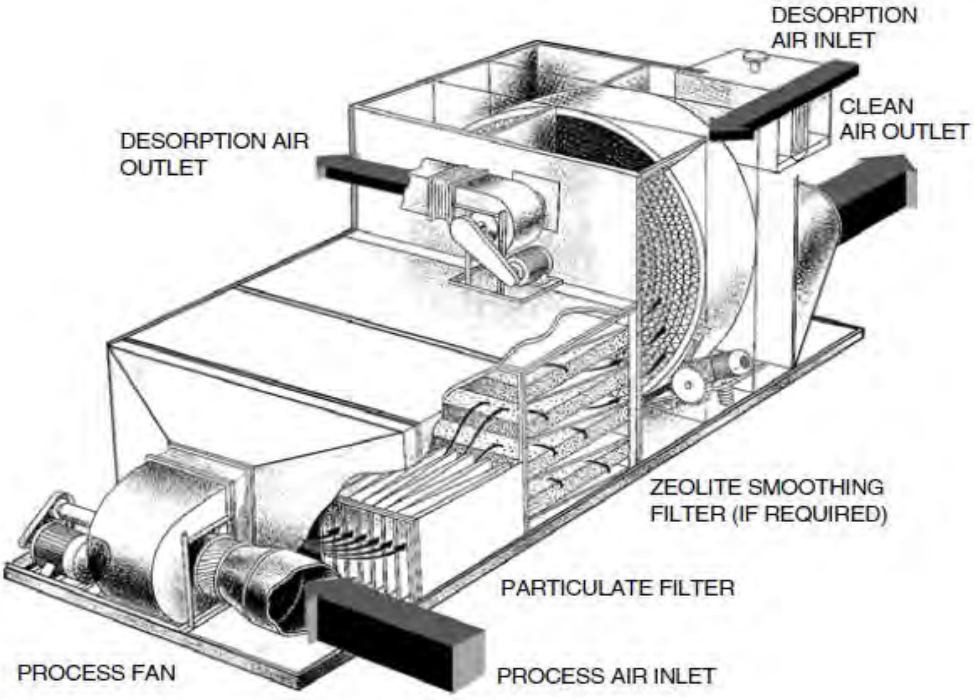


Figure 1.11 Rotary concentrator (Munters Corp.).

Figure 1.11, we see a wheel-shaped accumulator (concentrator) device that is charged with zeolite. The wheel gradually rotates so that one section adsorbs the contaminant and the other section is thermally desorbed. The contaminant, in this case a hydrocarbon that has some heating value, is thermally oxidized in a separate section and this heat is used to perform the desorption.

Sample of questions

Q1 :define primary and secondary air pollutants.

Q2 :how many more hazardous air toxins have been founds.

Q3 :what is long-range air pollution transport? Give two examples.

Q4: explain briefly the methods of treatment for air pollution.

Electrostatic precipitators:

Operating principles, Primary *mechanisms used Design basics*, *Resistivity of dust*.

Operating principles:

The basic principle of an electrostatic precipitator is to attract charged dust particles to the collecting plates where they can be removed from the gas stream. the dust particles are driven toward the collecting plates by the electromagnetic force created by the voltage potential applied to the discharge electrodes. An electrostatic precipitator contains multiple mechanical fields located in series and parallel to the direction of gas flow. Each mechanical field is comprised of a group of collecting plates that define a series of parallel gas passages. These passages run in the direction of gas flow. Bisecting the gas passage are a series of discharge electrodes, also running in the direction of gas flow.

Primary mechanisms used:

As indicated, dust must be charged to be attracted to the collecting plates. This charging occurs between the collecting plates where the discharge electrodes are located. The presence of charge in the gas passage is a function of the secondary voltage applied to the electrical field.

Design basics:

The relationship between operating parameters and collection efficiency is defined by the Deutsch Anderson equation. There are several modifications to the original formula, but the basic equation is:

$\text{Efficiency} = e-(A/V)*W$

where:

$W = (EoEPa/2\pi\eta($

Efficiency = Fractional percentage collected from gas stream

A = Total collecting plate area

V = Volumetric flow rate in actual terms

W = Migration velocity of dust towards collecting plates

Eo= Charging field strength

Ep= Collecting field strength

a = Particle radius

η= Gas viscosity

π= Pi

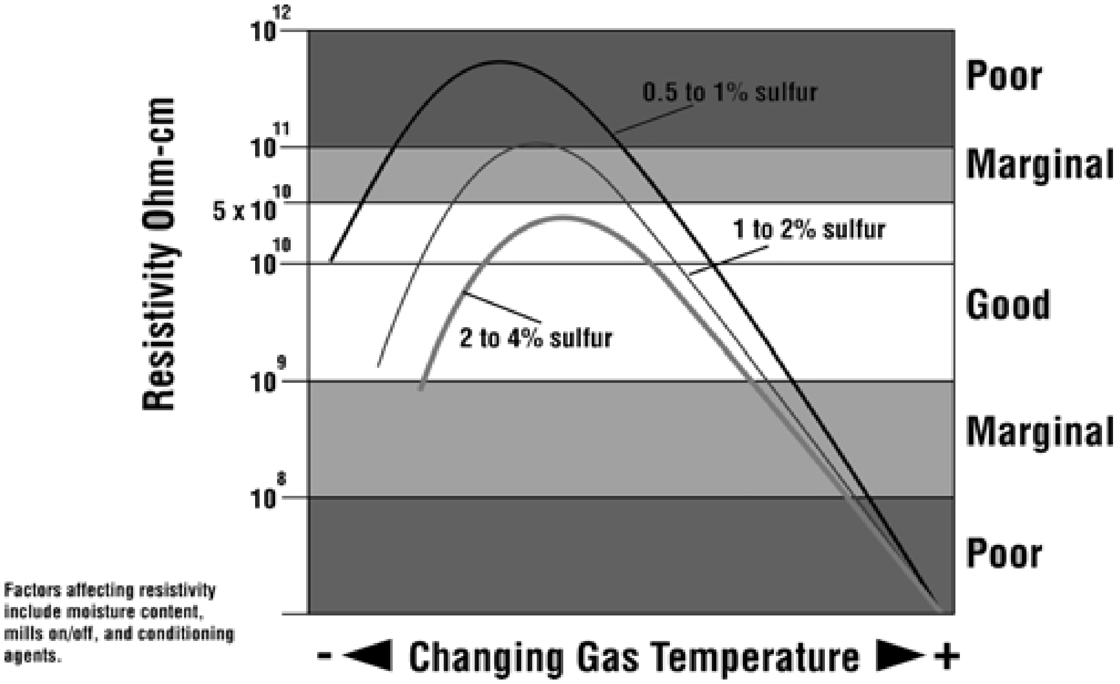
The simple explanation of the Deutsch Anderson equation is that the precipitator collection efficiency is defined by the speed of the dust toward the collecting plates and the amount of collecting plate area relative to the total gas volume.

Resistivity of dust:

There are two types of conduction characterized in dust: surface conduction and volume conduction. Dust resistivity plays a major role in defining electrostatic precipitator collection efficiency. It is generally accepted that electrostatic precipitators operate most effectively when dust resistivity is in the range of 5x10^9 to 5x10^10 ohm-cm. the high resistivity dust deposits on the collecting plates, charge does not dissipate. In fact, charge continues to accumulate due to the constant corona emanating from the discharge electrodes. As a result, high resistivity dust is very difficult to remove from the collecting plates. It is not uncommon for high resistivity dust applications to require periodic manual cleaning to restore precipitator performance

Figure 5.6 indicates relative dust resistivity for varying sulfur content of coal. Similar relationships exist between resistivity and process gas moisture content.

Figure 5.6 Average ash resistivity vs. gas temperature (BHA Group, Inc.).



Settling chambers:

One of the simplest (and oldest) air pollution control devices is the *settling chamber*. These are also sometimes called *knock out boxes* or *drop out boxes* .The equipment is in the form of a large chamber, which allows reduction of the gas velocity to a point where the particulate it carries simply drops out. Today, settling chambers are used for coarse removal of large particulate in advance of higher efficiency particulate control equipment. They are rarely, if ever, used as the final gas cleaning device.

Typical applications and uses:

Settling chambers are primarily used to reduce the loading of particulate from sources such as kilns, calciners, and mills or grinders that inherently produce high particulate concentrations. If the particulate is valuable in a dry form, the settling chamber usually is designed to settle out the smallest size particle that can economically be separated. If the product is not valuable or further downstream particulate separation is to be used (such as a cyclone, scrubber, or fabric filter collector), the chamber is usually sized to afford some basic separation at low cost.

Operating principles:

A settling chamber operates on the principle that if you slow a gas stream down sufficiently, the solid particulate contained within that gas stream will settle out by gravity. In general, the larger the particle, the faster the settling rate. In addition, larger particles will settle out faster in a given moving gas stream than smaller particles. The settling velocity for particulate was explored extensively in the mid-1800s by a scientist named Stokes. His equation for the terminal settling velocity of particulate is used to this day. It is called Stokes Law:

$Vg = (D^{2}(dp-dg)g)/ 18V$

Where

Vg= terminal settling velocity (ft/sec)

D = particle diameter in feet

dp= density of particle, lbsm/ft^3

dg= density of gas, lbsm/ft^3

g = acceleration of gravity, ft/sec^2

v = gas viscosity, lbm/ft/sec

The settling relationship is only accurately applied for particles of about 2µ m and greater aerodynamic diameter. Usually, for calculations involving air at ambient conditions, the density of the gas is ignored because it is minor when compared to the particle density. What this equation shows is that the greater the particle diameter and density, the higher the particle’s settling velocity. Resisting this settling, the higher the viscosity of the gas, the lower the particle’s terminal settling velocity.

Design basics:

Settling chamber design is predicated on the particle size, its density, the gas viscosity and velocity, and space considerations. An infinitely large settling chamber would, in theory at least, settle out all particulate. Economics, however, limit the size of the chamber. Stokes, in turn, limits the size of the particle that can be economically separated.

If the chamber is used for valuable product recovery, the smallest particle that would be worthwhile collecting dry is the common target. The design focus then needs to answer the question, “Is there enough space?” An iterative design then follows. As mentioned earlier, Stokes Law defines the settling velocity and the velocity dictates the size of the equipment. This usually results in a design particle size in excess of 50 to 100µm; otherwise, the chamber becomes excessively large. If the 50- to 100-µm particle is not worth collecting, the designer would size the chamber to capture much larger particles thereby at least economically lowering the loading of particles requiring further control but letting the smaller particles pass through.

Chamber (or can) velocities of 5 to 7 ft/sec or lower are common. Baffles can sometimes be used to provide beneficial changes of direction as long as the particles do not stick to the baffles. Curtains of chains can be used to in effect divert the gas flow but allow some measure of self-cleaning. Given the low gas velocity, the pressure drop is usually under 1 inch water column.

Figure 13.1 from Fan *Engineering* (Buffalo Forge, Co., New York) shows a general diagram of a cross flow settling chamber. Note the hoppers used to remove the collected solids. Gas flow is left to right. The vector diagram depicts the primary forces on the particle, which influences the trajectory and, therefore, the length of the settling chamber. Even given a dispersion of particulate above 100 µm, the efficiency of a settling chamber is quite low. Typically only 25 to 50% of the particulate of that range or larger actually drops out. Settling chambers are often, therefore, called "rock boxes" in the industry because they only remove the "boulders." In doing so, however, they can serve a valuable purpose in reducing the total loading of particulate that must be removed by downstream devices.

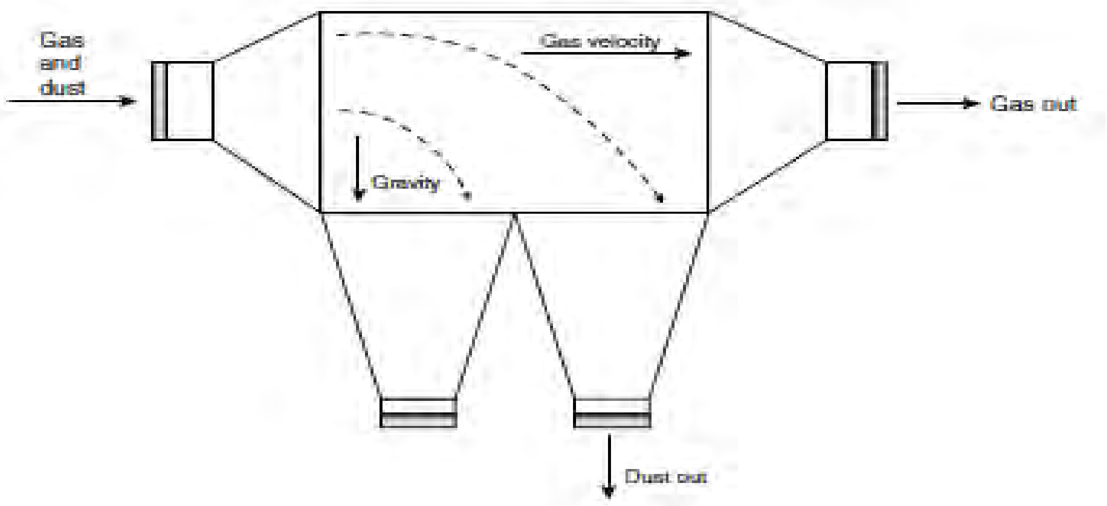


Figure 13.1 Settling chamber

Design basics:

Settling chambers should not be used where the particulate is sticky or can bridge or build up. In those cases, quite the opposite design is used. The ductwork is sized to be above the conveying velocity of the target particulate and that velocity is maintained until the articulate reaches a suitable gas cleaning device.

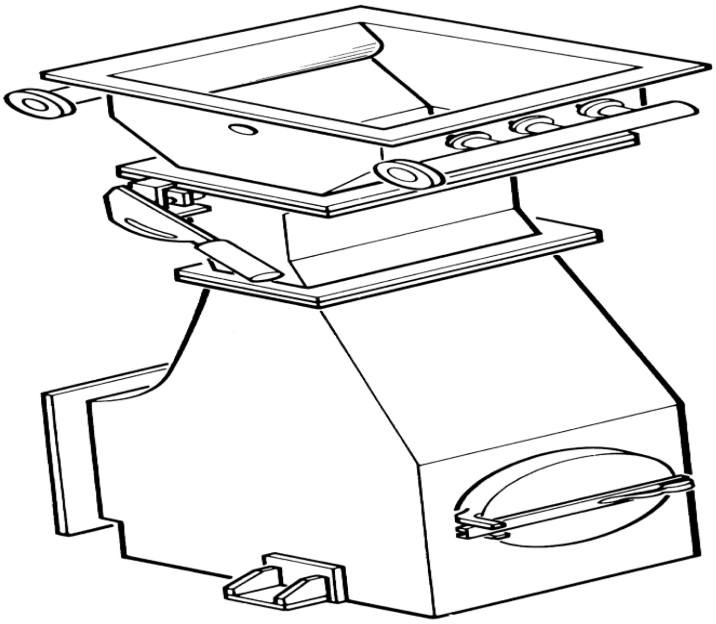
Venturi scrubbers:

Typical applications*:* *Venturi* scrubbers are best used to remove particulate 0.6 µm aerodynamic diameter and larger where the gas flow is from 1 to 500,000 acfm if the particles are 10µm and larger, and from 1 to 50,000 acfm if the particles are 0.6 µm and larger. They have been successfully used, however, to remove submicron particulate at pressure drops of up to about 60 inches water column.

Typical applications:

There are literally hundreds of applications, however, in which the particulate is 1 to 20µm diameter where the Venturi scrubber provides excellent results. The result is that thousands of Venturi scrubbers are in daily use throughout the world.

Figure 19.1 Venturi scrubber (Bionomic Industries Inc.).



Annular Venturi scrubbers are used when the gas volume exceeds about 25,000 acfm. The reason for this is that designers like to maintain a throat width of 4 to 6 inches maximum. Sometimes a rectangular throat of this size would be too long to suit the gas inlet. The throat is therefore wrapped around to form the annular type. These designs are often seen on waste burning boilers, larger kilns and calciners, and large capacity dryers.

Design basics:

Typical Venturi scrubber types are:

1. Rectangular throat designs, both fixed throat and adjustable.

2. Annular type designs wherein the throat zone is an annular gap. This gap can be adjusted by moving the center body plumb-bob up and down to vary the open area and, therefore, the pressure drop.

3. Eductor Venturis wherein the momentum of pressurized liquid introduced into the device both provides mass transfer and provides motive force to the gas.

4. Reverse jet designs wherein the liquid is injected countercurrent to the gas flow. These designs force the particle into a nearly head-on collision with the liquid spray to enhance the application of the spray energy.

5. Collision type designs split the gas streams and impacts them nearly head-on to enhance momentum transfer from gas to particle.

6. Some Venturi scrubbers are made from parallel tubes or pipes as in the multi-Venturi (see below). These pipes may be oriented horizontally, vertically or on an inclined angle. The scrubbing liquid is usually sprayed on the tubes or pipes. The slots formed between the pipes for the Venturi shape.

Gas inlet velocities for all of these designs are generally the same as the ductwork conveying velocities, that is, 45 to 60 ft/sec. The Venturi section outlet duct is usually sized for a similar velocity to reduce pressure losses through velocity changes.

The liquid rate for gas velocity atomized Venturis (using fans) is 5 to 30 gpm/1000 acfm treated with 5 to 10 gallons/1000 acfm being common. The liquid-to-gas ratio is increased as the inlet dust loading is increased. Liquid pressures are under 15 psig with 5 to 10 psig being common. Hydraulically pressurized (spray nozzle type) Venturi scrubbers may use lower liquid rates; however, it is the dust loading that truly dictates the liquid rate. The greater the particulate loading, the higher the liquid rate. Lime kilns, with inlet dust loadings of over 20 grs/dscf, may use 15 to 20 gallons/1000 acfm, whereas a dryer equipped with a product recovery cyclone may use only 4 to 8 gallons/1000 acfm. Figure 19.3 shows the manner in which the L/G increases with increasing dust loading.

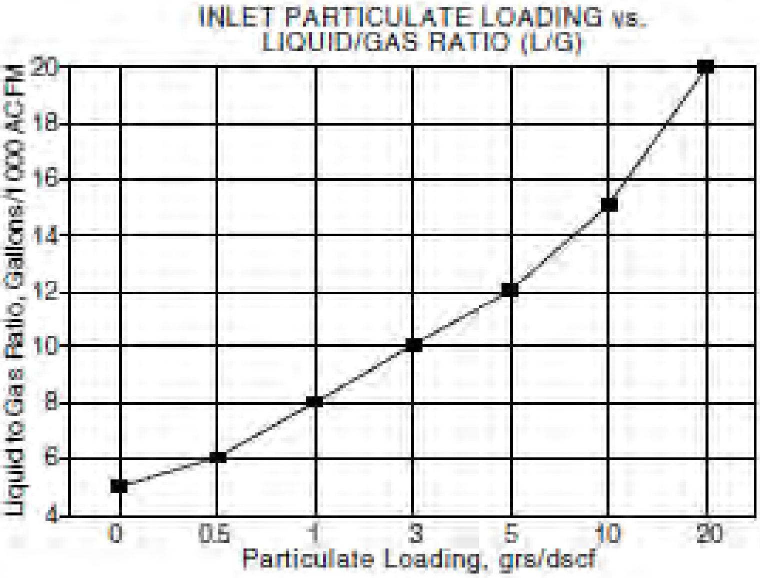


Figure 19.3 Liquid to gas ratio (L/G) vs. loading.

Dry cyclone collectors:

Typical applications and uses: Cyclone collectors are used for product recovery of dry dusts and powders and as primary collectors on high dust loading (more than 2 to 5 grs/dscf) air pollution control applications.

A common application is the rotary dryer. Used to dehydrate various products from grain to manure, direct or indirect fired rotary dryers often use cyclone collectors to capture the entrained dust prior to a secondary collector (such as a Venturi scrubber). The rotating action of the dryer entrains a portion of the product as the product tumbles through the hot, drying air. This product is often valuable in dry form so the cyclone is used to disengage the dust from the gas stream and be recovered. The residual dust is air-conveyed to the downstream device.

As the gas spins (Figure 4.2), the higher specific gravity dust is thrown outward toward the containing vessel wall where it accumulates and slides down the wall surface into a receiving chamber, usually a hopper or other essentially quiescent zone, where the dust accumulates out of the moving gas stream. The dust is usually discharged through a trickle valve or motorized lock/feeder that prevents air leakage or infiltration while allowing the dust to exit.

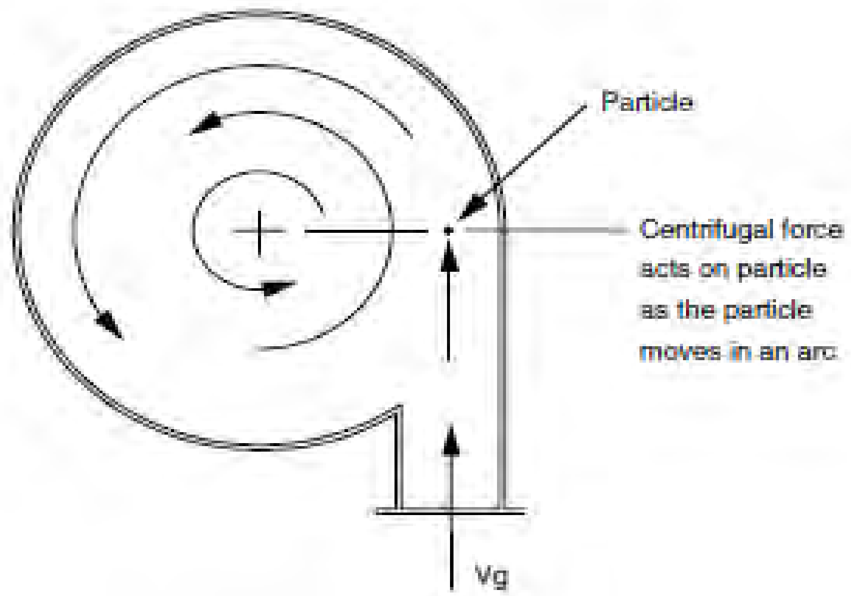


Figure 4.2 Cyclonic separation.

The typical cyclone includes the following components as seen in Figure 4.3. A tangential gas inlet is used (sometimes incorporating a curved “involute” section) to gradually direct the gas stream for smooth tangential release into the cyclone body. The cyclone body itself is typically a vertical walled cylinder. The tapered hopper and disengaging section are used to accumulate and separate the dust.

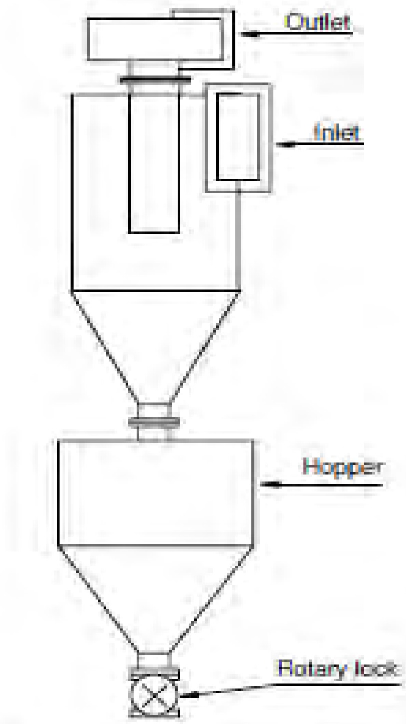


Figure 4.3 Basic cyclone collector components

Design basics:

The gas inlet velocity is usually at or above the conveying velocity of the particular dust being separated. Velocities of 40 to 65 ft/sec are common. The inlet is often rectangular in shape so that the gas enters in wedge form at the tangent line of the cyclone. The width of the inlet is approximately one half the height of the inlet. If the dust is highly friable or abrasive, a velocity toward the lower velocity range is used. If the dust is both heavy and abrasive, a higher velocity must be maintained so wear plates or even refractory linings are suggested at the gas inlet. The cylindrical body tube length in part dictates the number of turns and the turning radius (tube diameter) controls the centrifugal force created at a given gas velocity. The higher the gas tangential velocity, the greater the number of turns, the higher the centrifugal force and the greater the separation.

The cylindrical body length is usually two to three times the body diameter. The gas outlet velocity is usually 55 to 65 ft/sec and sometimes higher. This vortex finder or outlet tube usually extends down into the cylindrical body portion far enough to prevent dust from short-circuiting from the gas inlet to the outlet tube. An ascending vortex is formed in this tube that turns opposite in direction to the inlet spiral. On cyclones with high tangential inlet velocities (greater than 100 ft/sec), the outlet tube can also be equipped with turning vanes that control the gas swirl. The gas outlet diameter is often approximately one half the cylindrical vessel diameter. Care is taken to avoid having the outlet tube extend down too far into or near the conical section of the collector. If it does, dust near the wall will be drawn back up the outlet tube lowering the efficiency. The outlet tube length is usually about 1.2 to 1.5 times the height of the gas inlet.

The gas outlet tube is sized for the expected dust flow rate and allows for a dust velocity of about 4 to 8 ft/sec. Multicyclone collectors are sized in a similar manner; however, a series of standard tubes are used. Each tube is designed for a given cubic feet per minute of gas flow, then multiple rows are used to accommodate the design gas flow. Tube volumes of 500 to 1000 acfm each are common. This results in tubes of 9- to 12-inch inside diameter for many applications.

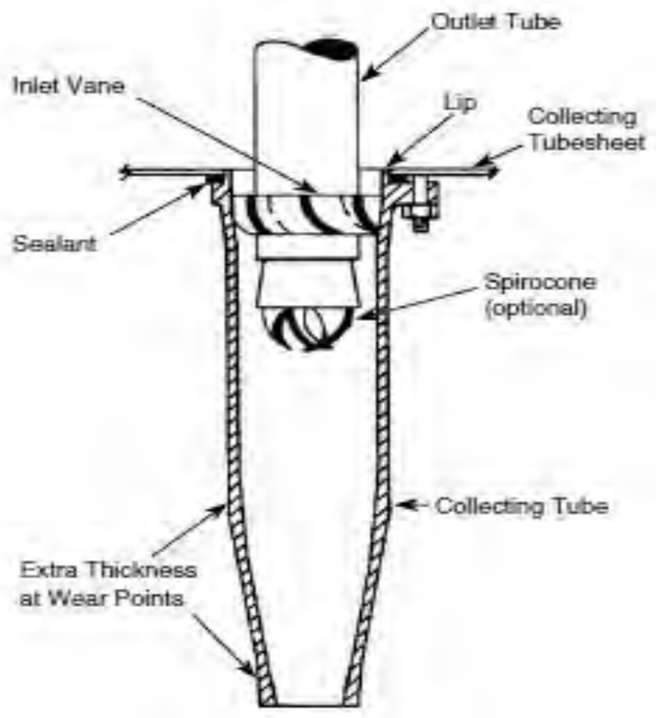


Figure 4.6 Components of typical tube (Allen-Sherman-Hoff).

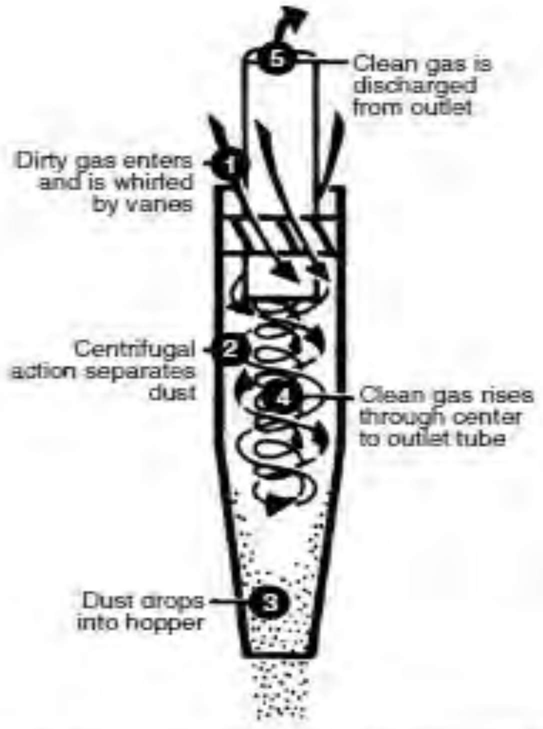


Figure 4.7 How a multiple cyclone works (Allen-Sherman-Hoff).

Sample of questions:

Q1 : explain the major selection parameters to select suitable cyclone.

Q2 :explain the size of pollutant particles that separated by the use of settling chamber.

Q3 : explain the steps of selection a suitable scrubber.