

# الجامعة التكنولوجية

## قسم الهندسة الكيميائية

### المرحلة الثانية

### مبادئ هندسة البيئة

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## **Fundamental in Environmental 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.

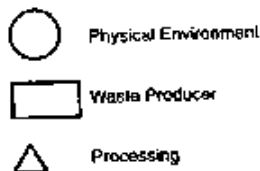
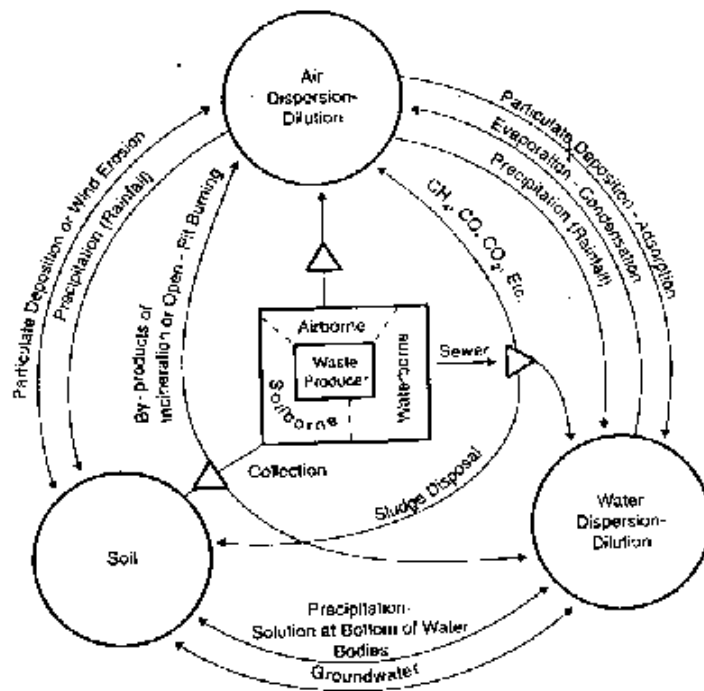
- **Pollution:** an undesirable change in the physical, chemical or biological characteristic of the air, water or land that can harmfully affect the health, survival or activities of human or other living organisms.
- **Particles:** any distinct portion of solid, liquid, or gaseous matter larger than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

Figure 1 Waste cycle in an industrialized society.

### Climate change and greenhouse effect:

Our earth is surrounded by a gaseous cover of mainly  $N_2$ ,  $O_2$  and many other gases in small concentration including  $H_2O$  and  $CO_2$ . This atmosphere provides the vital  $O_2$  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 getting warmer.

#### **Major greenhouse gases:**

1. CO<sub>2</sub> : it is rising at a rate of 0.5 % per year
2. CH<sub>4</sub>: produced by organic matter decay under anaerobic conditions, it is rising at a rate of 0.1% per year. at
3. N<sub>2</sub>O: 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<sub>3</sub>):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.

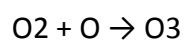
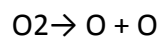
**International action to reduce greenhouse effects:**

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<sub>2</sub> emissions.

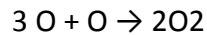
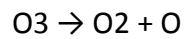
**Ozone layer depletion:**

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 Å<sup>0</sup> to 2200 Å<sup>0</sup> are absorbed by molecular oxygen which splits up in to constituent atoms these atoms combine with molecular oxygen to produce ozone.



Another photochemical reaction which breaks down ozone molecules due to absorption



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 chlorofluoro 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<sub>2</sub> , 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<sub>2</sub> , Nox , react with atmospheric moisture to form H<sub>2</sub>SO<sub>4</sub> and HNO<sub>3</sub>.

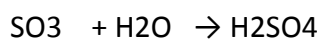
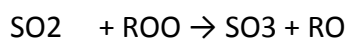
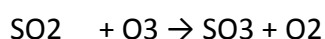
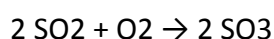
**Effect of acid deposition :**

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

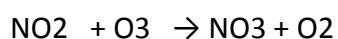
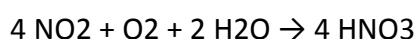
- 1- Effect on water bodies: one of the most severe problems of acid rain is acidification of lakes and rivers.
- 2- Effect on soil and soils with low buffer capacity are the most sensitive soil to the acid deposition which frequently lose their fertility by acidification due to accelerated leaching of nutrients like K,P,Mg, and Ca.
- 3- Effect on materials: one of the important consequences of acid deposition is the physical damage to buildings, bridges and other structures by corrosion, where sulfate forms a hard surface skin which blisters and scales 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 into the portable water supply.

#### **Mechanism of acid formation in atmosphere :**

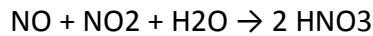
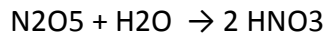
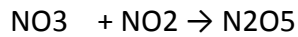
H<sub>2</sub>SO<sub>4</sub> in the air is formed from SO<sub>2</sub> in a number of ways depending upon the level of air pollution and environmental conditions of light and humidity:



HNO<sub>3</sub> can be formed by direct oxidation and catalytic oxidation







**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  $\text{SO}_2$ .
4. Use different new technology like electron beam technology , which converts  $\text{SO}_2$  , and  $\text{NO}_x$  in to ammonium sulphate {  $(\text{NH}_4)_2\text{SO}_4$  } and ammonium nitrate {  $\text{NH}_4\text{NO}_3$  } . The process involved the reaction of ammonia which is injected from outside in to the flue gas , with  $\text{SO}_2$  ,  $\text{NO}_x$  in a process vessel under the influence of electrons produced by an electron beam gun. It is possible to remove 95% of  $\text{SO}_2$  and 80% of  $\text{NO}_x$  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 transformation 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 transformation 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 formulate 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 SO<sub>2</sub>, 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. SO<sub>2</sub> 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 (N<sub>2</sub>O, NO, NO<sub>2</sub>, NO<sub>3</sub>, N<sub>2</sub>O<sub>3</sub>, N<sub>2</sub>O<sub>4</sub>, N<sub>2</sub>O<sub>5</sub>) only nitric oxide and nitrogen dioxide are classified as the main pollutants. All the oxides of nitrogen are collectively known as NO<sub>x</sub>.

(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 Sulphide 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 (CH<sub>3</sub> SH) and dimethyl sulphide (CH<sub>3</sub> S CH<sub>3</sub>) 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.

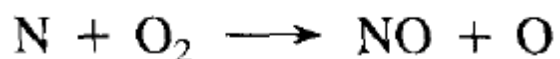
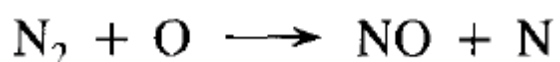
(vii) **Ozone:** It is a desirable gas in the upper layers of atmosphere as it absorbs the UV radiation of sunlight. But near the earth surface it is a poisonous gas. It makes poisonous chemicals by photochemical reactions.

(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 (NO<sub>2</sub>) are the two most important nitrogen oxide air pollutants. They are frequently lumped together under the designation NO<sub>x</sub>, although analytical techniques can distinguish clearly between them. Of the two, NO<sub>2</sub> is the more toxic and irritating compound.

Nitric oxide is a principal by-product of combustion processes, arising from the high-temperature reaction between N<sub>2</sub> and O<sub>2</sub> in the combustion air and from the oxidation of organically bound nitrogen in certain fuels such as coal and oil. The oxidation of N<sub>2</sub> by the O<sub>2</sub> in combustion air occurs primarily through the two reactions known as the Zeldovich mechanism.



### **Sulfur Oxides**

Sulfur dioxide (SO<sub>2</sub>) 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 SO<sub>2</sub> result almost exclusively from stationary point sources. A small fraction of sulfur oxides is emitted as primary sulfates, gaseous

sulfur trioxide (SO<sub>3</sub>), and sulfuric acid (H<sub>2</sub>SO<sub>4</sub>). It is estimated that, by volume, over 90% of the total U.S. sulfur oxide emissions are in the form of SO<sub>2</sub>, with primary sulfates accounting for the other 10%. Stationary fuel combustion (primarily utility and industrial) and industrial processes (primarily smelting) are the main SO<sub>2</sub> 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. SO<sub>2</sub> 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 <sup>a</sup>	Anthropogenic sources	Natural sources
SO <sub>2</sub>	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 <sup>3</sup> 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 <sub>2</sub> S	Colorless, flammable gas; highly toxic; characteristic rotten egg odor	Global background about 3 µg m <sup>-3</sup> ; urban levels have been observed as large as 390 µg m <sup>-3</sup>	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 <sub>2</sub>	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 <sub>3</sub>	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 <sub>2</sub>	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 <sub>3</sub>	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

<sup>a</sup>Two concentration units that are commonly used in reporting atmospheric species abundances are  $\mu\text{g m}^{-3}$  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  $\mu\text{g m}^{-3}$

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

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  $\mu\text{g m}^{-3}$  by

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

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 <sub>x</sub> )	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 ( $\text{SiO}_2$ ), alumina ( $\text{Al}_2\text{O}_3$ ), and iron oxide ( $\text{FeO}$  and  $\text{Fe}_2\text{O}_3$ ). 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  $\text{SO}_2$  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  $\mu\text{m}$ .

## ATMOSPHERIC CONCENTRATION UNITS

We note that two concentration units that are commonly used in reporting atmospheric species abundance are  $\mu\text{g m}^{-3}$  and parts per million by volume (ppm). Parts per million by volume is just

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

where  $c_i$  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  $\mu\text{g m}^{-3}$ ,

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

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

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

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

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

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

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

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

The 24-hour  $\text{SO}_2$  NAAQS is  $365 \mu\text{g m}^{-3}$ . Convert this to ppm at the same temperature and pressure.

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

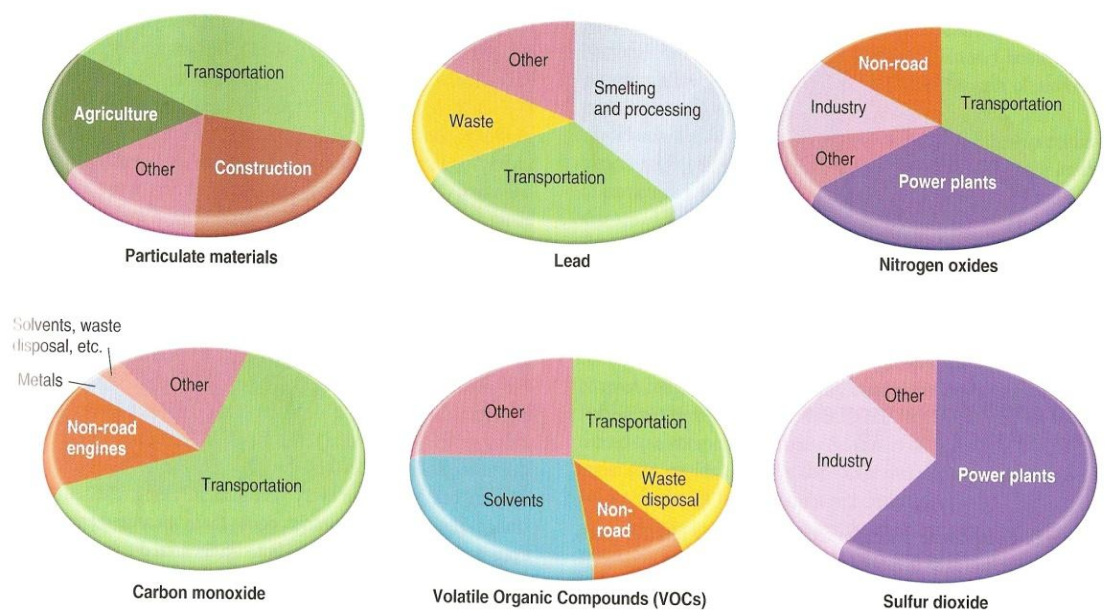
industrial emissions are also an important source of air pollution. burning.

**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 <sub>2</sub> (carbon dioxide)	Respiration, fossil fuel burning, land clearing, industrial processes	370,000	29,600*
CH <sub>4</sub> (methane)	Rice paddies and wetlands, gas drilling, landfills, animals, termites	155	350
CO (carbon monoxide)	Incomplete combustion, CH <sub>4</sub> oxidation, biomass burning, plant metabolism	1,580	930
NMHC (nonmethane hydrocarbons)	Fossil fuels, industrial uses, plant isoprenes and other biogenics	860	92
NO <sub>x</sub> (nitrogen oxides)	Fossil fuel burning, lightning, biomass burning, soil microbes	90	140
SO <sub>x</sub> (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

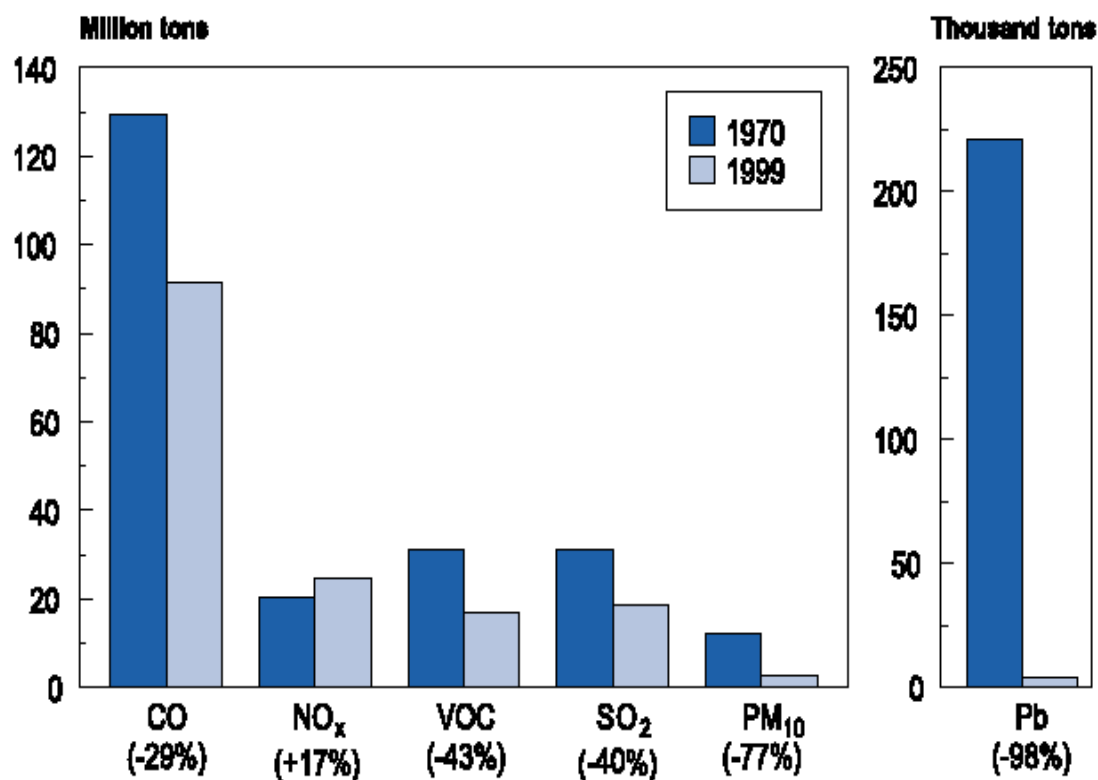
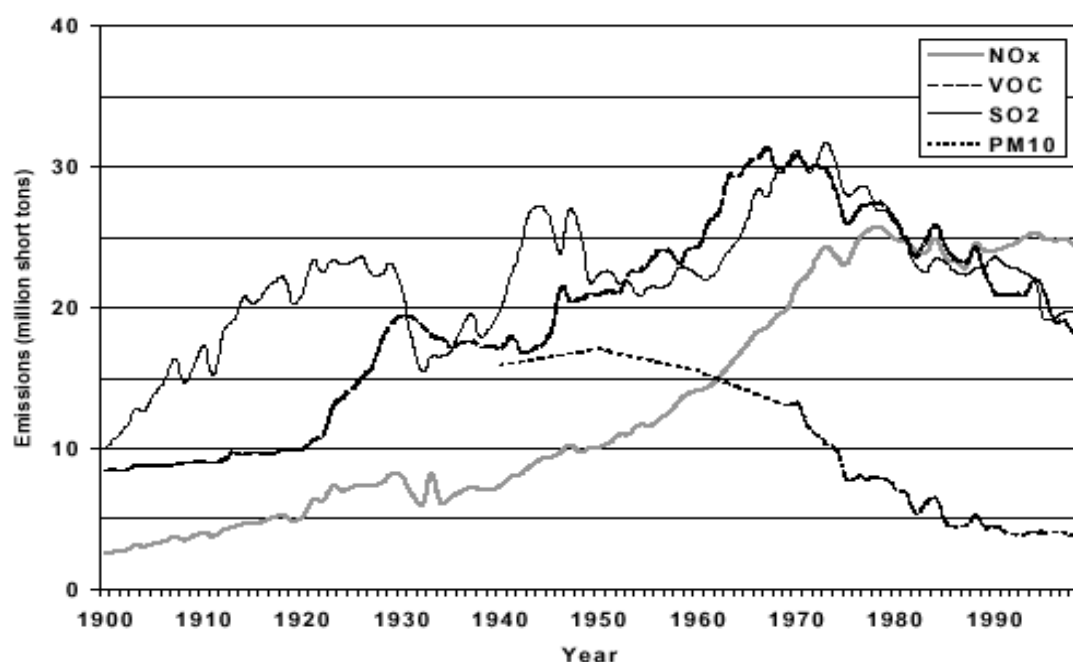
\*Only 27.3 percent of this amount—or 8 billion tons—is carbon.

Source: UNEP, 1999.



**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<sub>10</sub> [nonfugitive dust sources]; 1940 to 1998)**

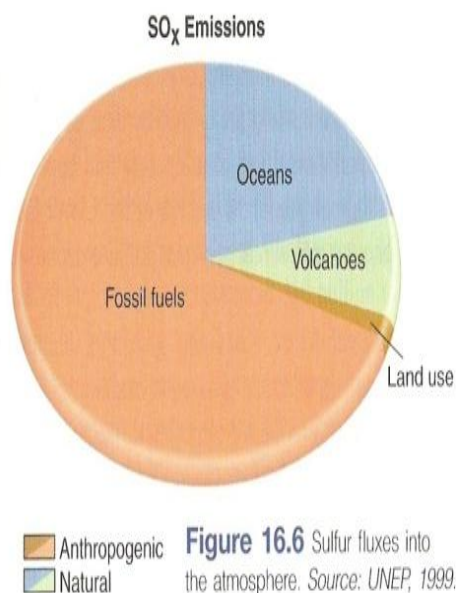


**Percent Change in Emissions**  
**1980–1999    1990–1999**

CO	-22	-7
Pb	-95	-23
NO <sub>x</sub>	+1	+2
VOC	-33	-15
PM <sub>10</sub>	-55	-16
SO <sub>2</sub>	-28	-21

**Percent Change in Air Quality**  
**1980–1999    1990–1999**

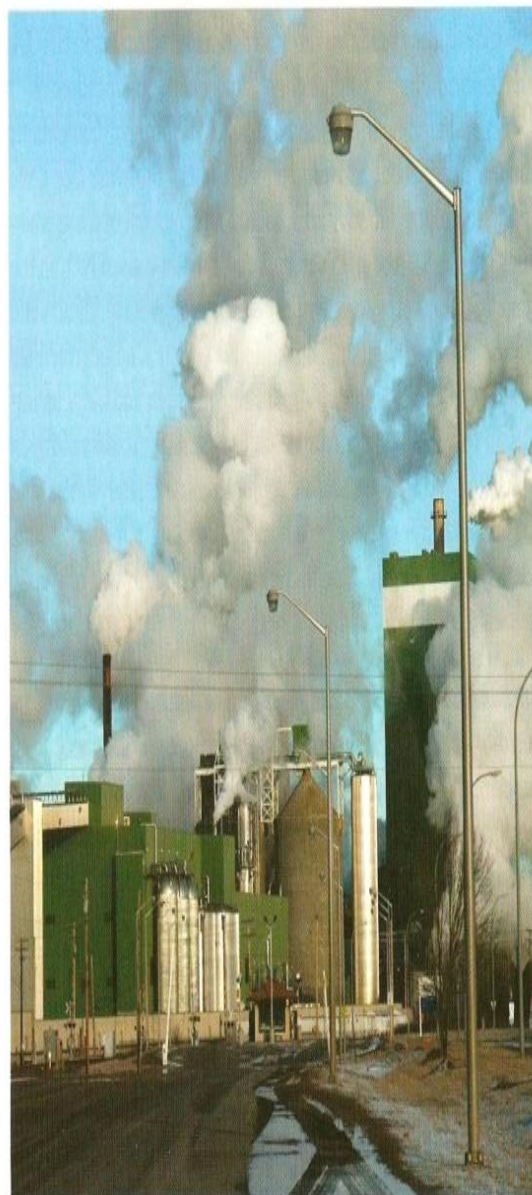
CO	-57	-36
Pb	-94	-60
NO <sub>2</sub>	-25	-10
O <sub>3</sub> 1-hr	-20	-4
8-hr	-12	no change
PM <sub>10</sub>	—	-18
SO <sub>2</sub>	-50	-36



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

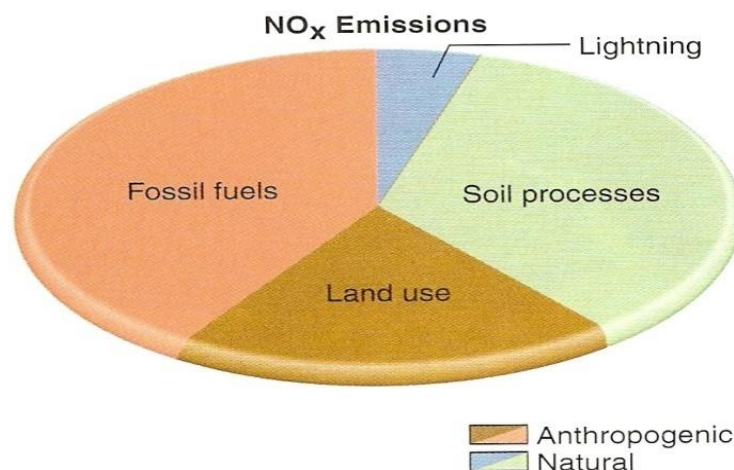
**Sulfur dioxide** is a colorless corrosive gas that is directly damaging to both plants and animals. Once in the atmosphere, it can be further oxidized to sulfur trioxide (SO<sub>3</sub>), which reacts with water vapor or dissolves in water droplets to form sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), a major component of acid rain. Very small solid particles or liquid droplets can transport the acidic sulfate ion (SO<sub>4</sub><sup>2-</sup>) 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).

[www.mhhe.com/cunningham9e](http://www.mhhe.com/cunningham9e)



**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<sub>2</sub>), a reddish brown gas that gives photochemical smog its distinctive color. Because of their interconvertibility, the general term NO<sub>x</sub> is used to describe these gases. Nitrogen oxides combine with water to make nitric acid (HNO<sub>3</sub>), 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<sub>x</sub> in the United States is produced by fuel combustion in transportation and electric power generation. Nitrous oxide (N<sub>2</sub>O) 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 ( $\text{CO}_2$ ). 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  $\text{CO}_2$  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)  $\text{CO}_2$  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  $\text{CO}_2$ ) 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  $\text{CO}_2$  is reabsorbed; in other years, almost none of it is. The ecological processes that sequester  $\text{CO}_2$  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,  $\text{CO}_2$  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  $\text{CO}_2$ -depleted air entering from Canada or Mexico, this would mean that somewhere between 1.6 and 2.2 billion tons of  $\text{CO}_2$  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.

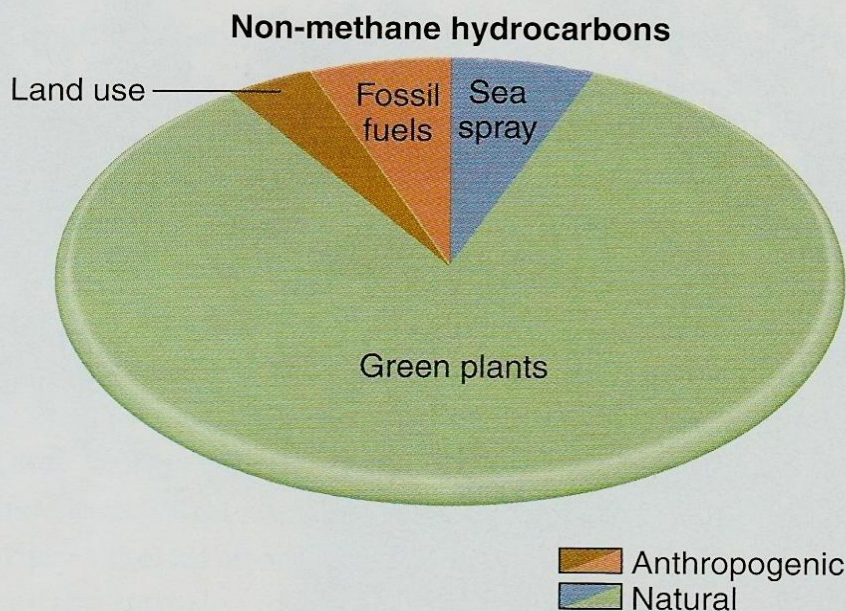
Banning leaded gasoline is one of the most successful pollution-control measures in American history. Since 1986, when the ban was enforced, children's average blood lead levels have dropped 90 percent and average IQs have risen three points. Now, 50 nations have renounced leaded gasoline. The global 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 SO<sub>2</sub> 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.

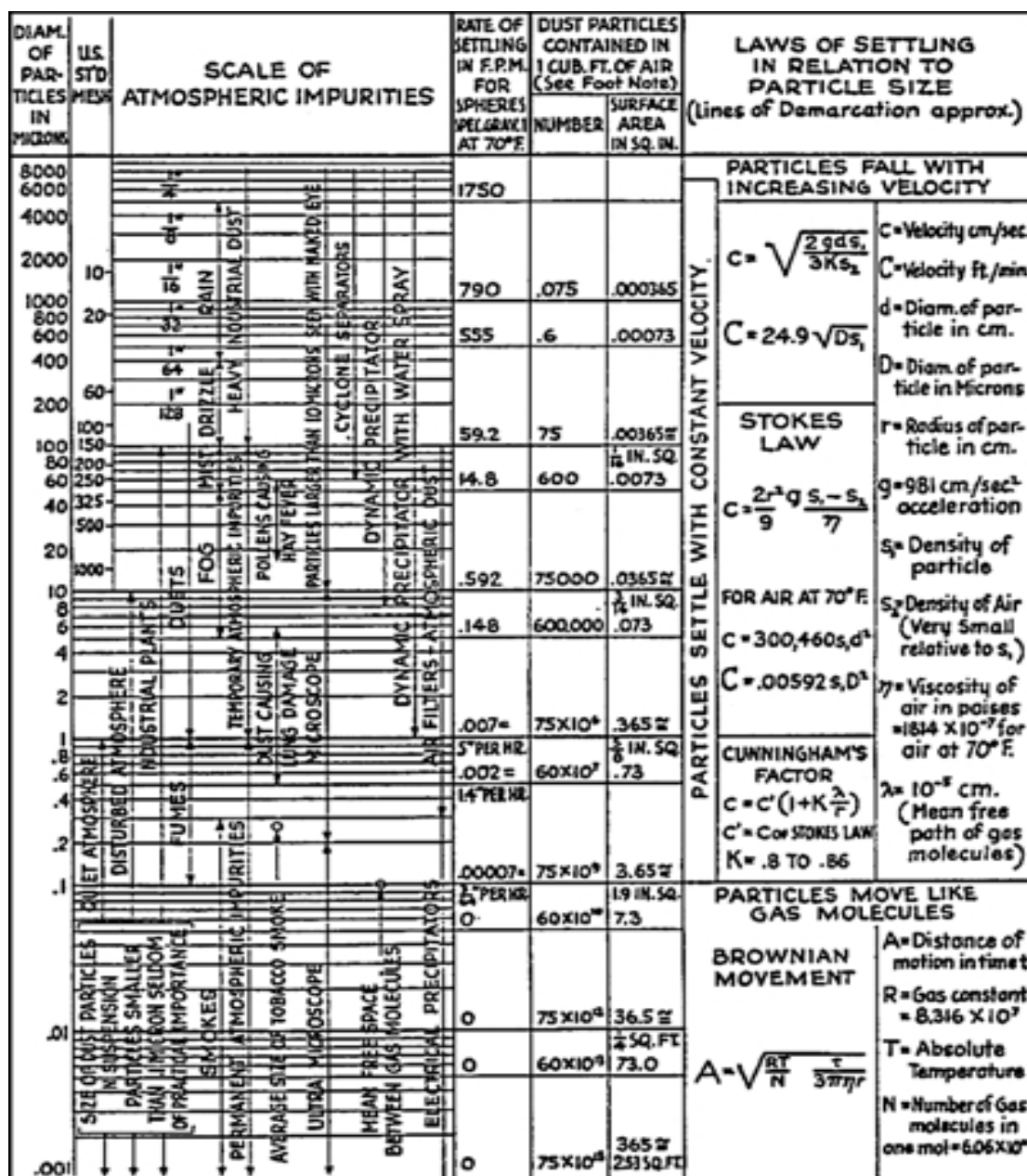
For gaseous pollutants the following control technologies are used.

- Condensation
- Absorption
- Adsorption
- Combustion For the control of gases such as NO<sub>2</sub> and SO<sub>2</sub> 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 2 $\mu$ m 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:

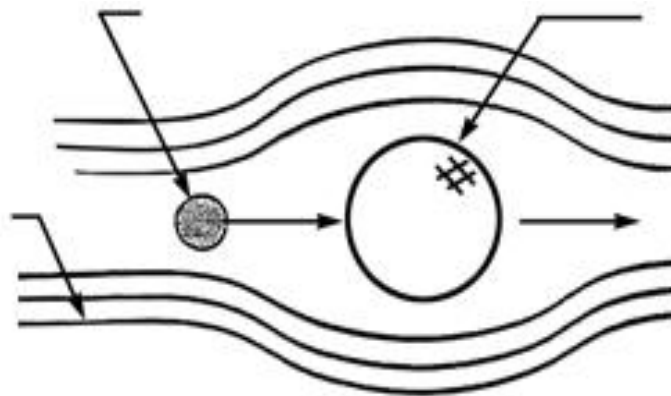
- Impaction
- Interception
- Diffusion

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,

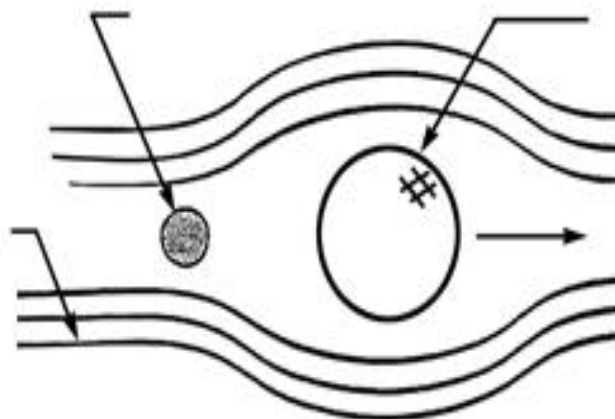
therefore the separation task becomes easier. Simply separate the droplet from the gas stream (more on that later) and one removes the particle(s).

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.)

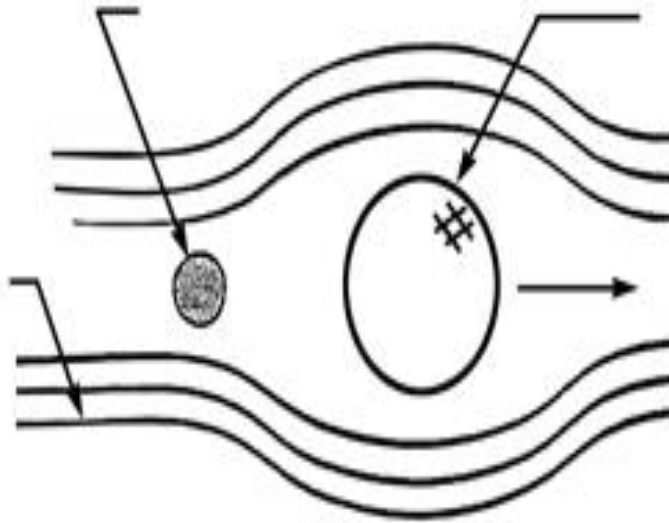
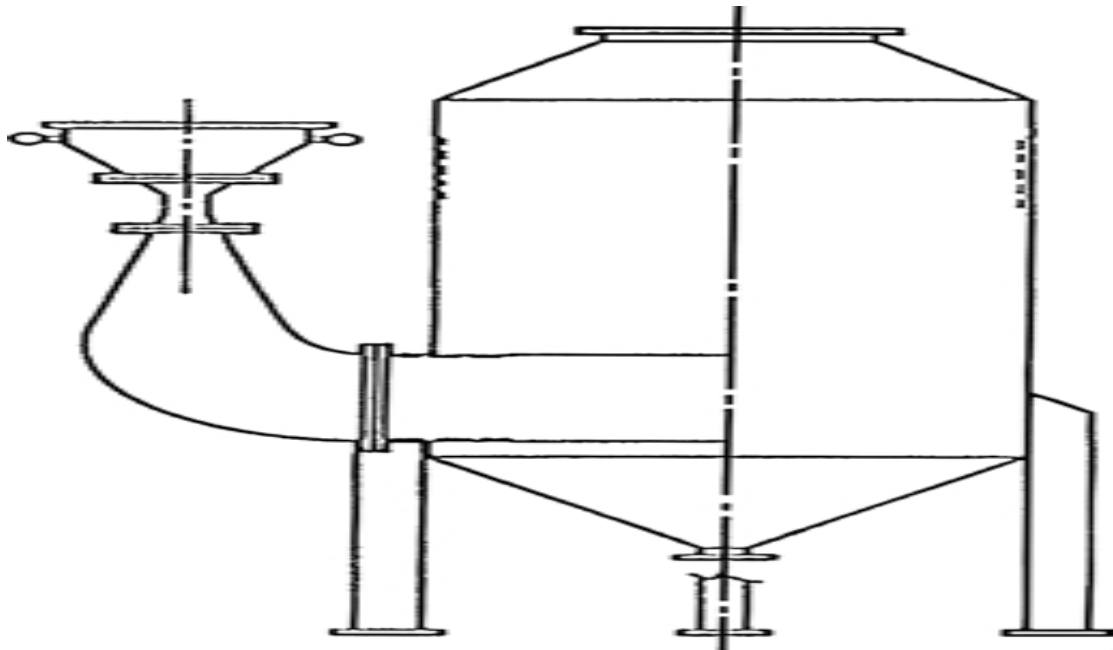


Figure 1.5 depicts an even tinier particle that is so small it bounces around in the moving air stream buffeted by water and gas molecules. In this case the particle *diffuses* over to the droplet and, by chance, is absorbed into the droplet. Obviously, to increase the chances of capture by diffusion,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

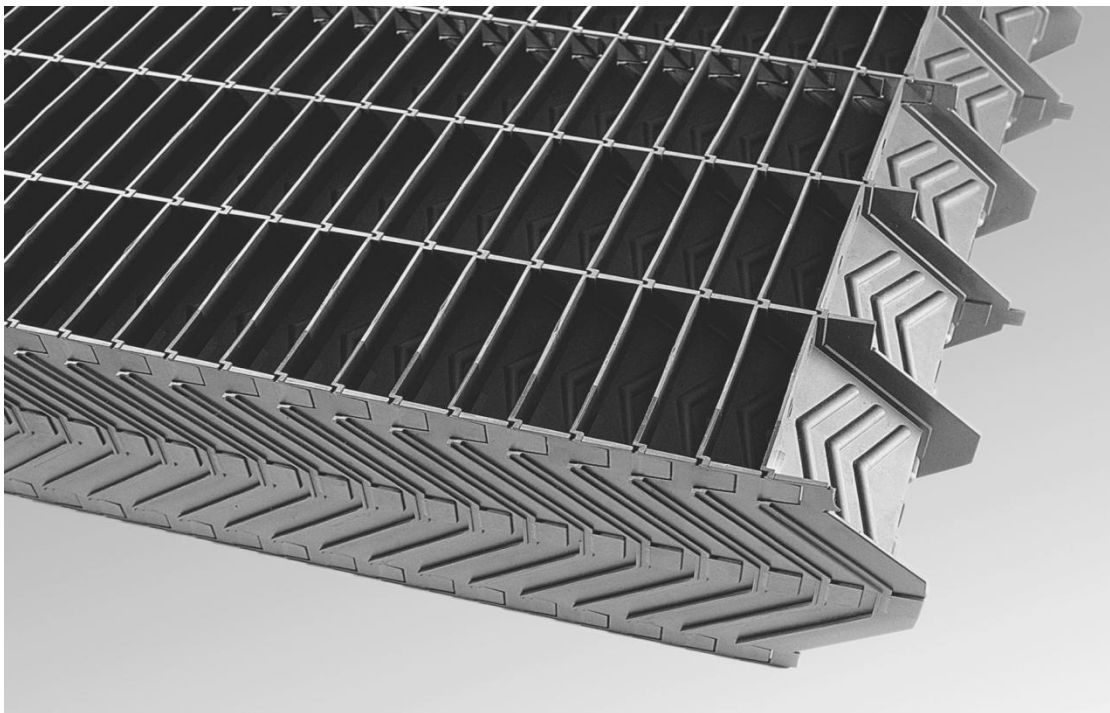
Figure 1.6, we see a Venturi scrubber (left) connected to a typical cyclonic type separator. This device separates the droplets using centrifugal force. The centrifugal force pushes the droplets toward the vessel wall where they form a compressed film, agglomerate, accumulate, and drain by gravity out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

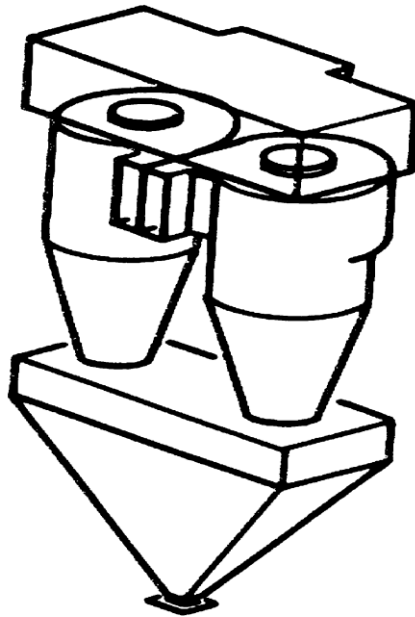
**Figure 1.6 Venturi scrubber and cyclonic separator.**



**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  $5\mu\text{m}$  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)

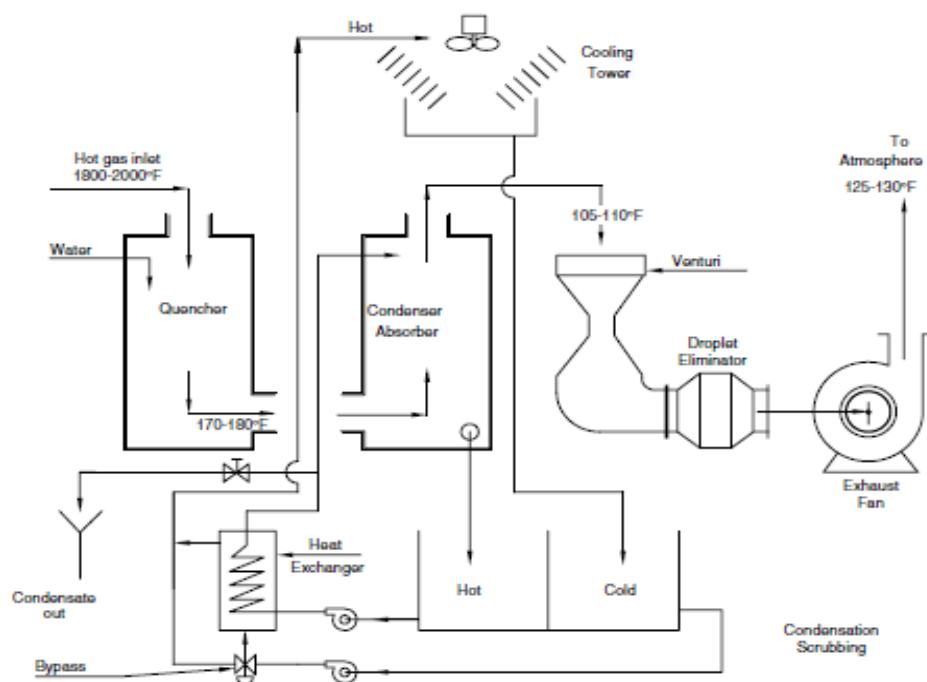


Figure 1.9 Condensation scrubbing system components.

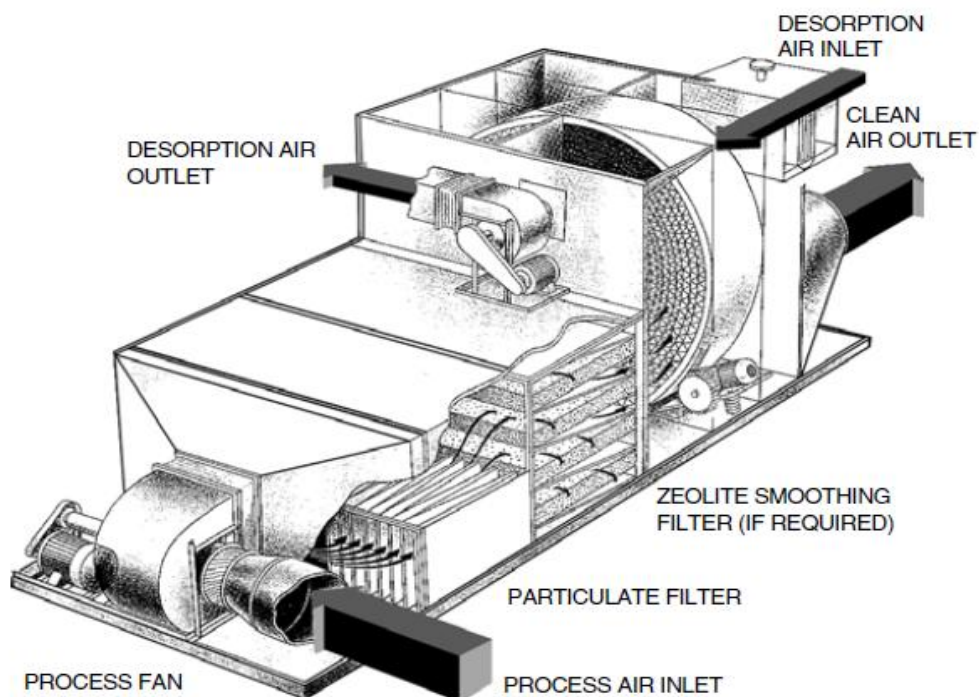


Figure 1.11 Rotary concentrator (Munters Corp.).

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:

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

where:

$$W = (E_o E_p a / 2\pi\eta)$$

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

E<sub>o</sub> = Charging field strength

E<sub>p</sub> = 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.

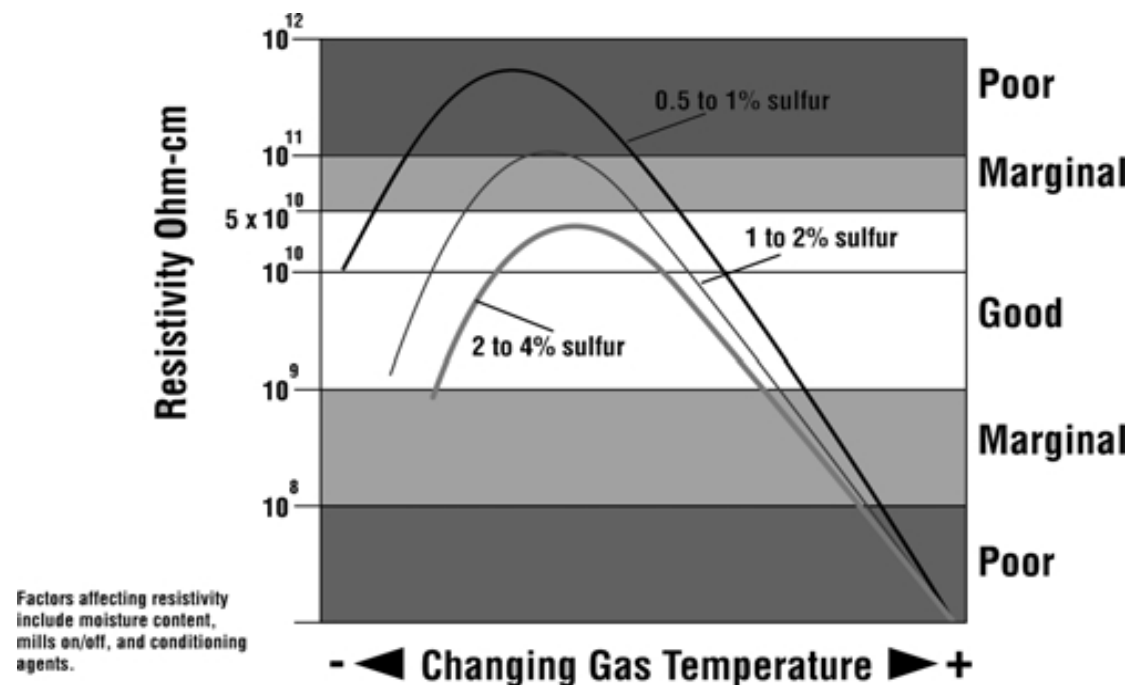
***Resistivity of dust:***

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  $5 \times 10^9$

to  $5 \times 10^{10}$  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:

$$V_g = (D^2(dp - dg)g) / 18V$$

Where

$V_g$  = terminal settling velocity (ft/sec)

$D$  = particle diameter in feet

$dp$  = density of particle, lbfm/ft<sup>3</sup>

$dg$  = density of gas, lbfm/ft<sup>3</sup>

$g$  = acceleration of gravity, ft/sec<sup>2</sup>

$v$  = gas viscosity, lbfm/ft/sec



The settling relationship is only accurately applied for particles of about  $2\mu\text{m}$  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  $100\mu\text{m}$ ; otherwise, the chamber becomes excessively large. If the 50- to  $100\mu\text{m}$  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  $\mu\text{m}$ , 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.

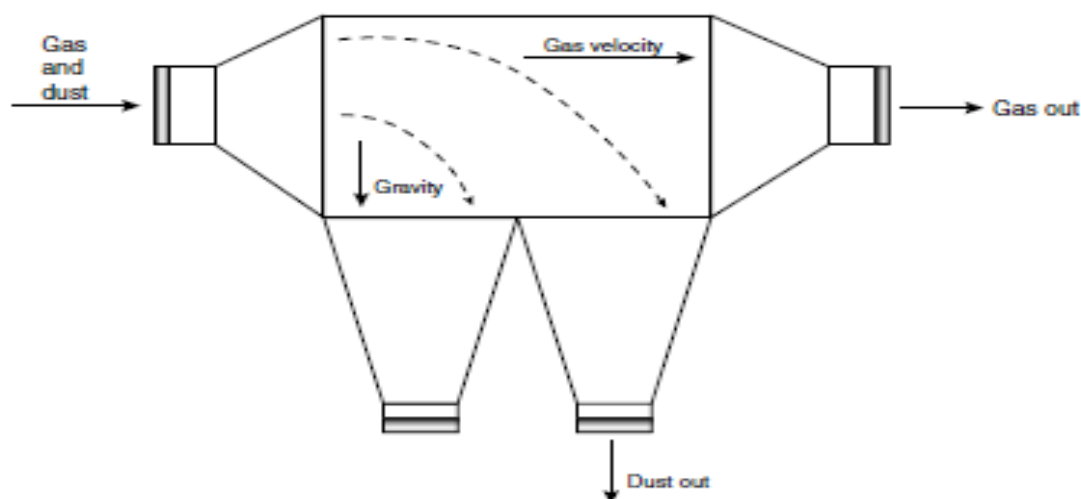


Figure 13.1 Settling chamber.

#### **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 particulate reaches a suitable gas cleaning device.

#### **Venturi scrubbers:**

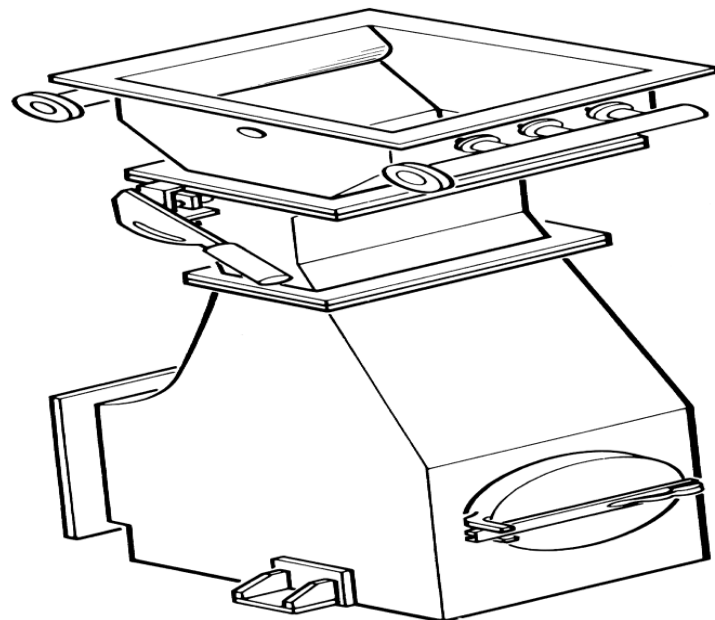
**Typical applications:** Venturi scrubbers are best used to remove particulate 0.6  $\mu\text{m}$  aerodynamic diameter and larger where the gas flow is from 1 to 500,000 acfm if the

particles are  $10\mu\text{m}$  and larger, and from 1 to 50,000 acfm if the particles are  $0.6\mu\text{m}$  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  $20\mu\text{m}$  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.

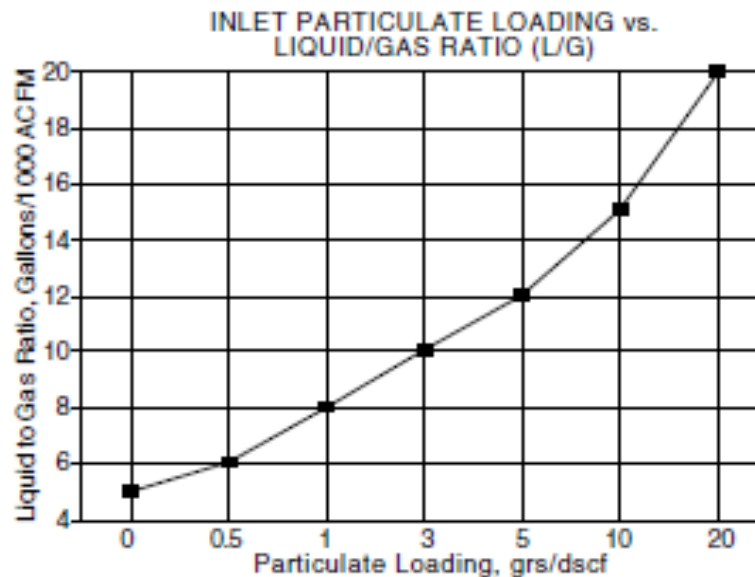


Figure 19.3 Liquid to gas ratio (L/G) vs. loading.

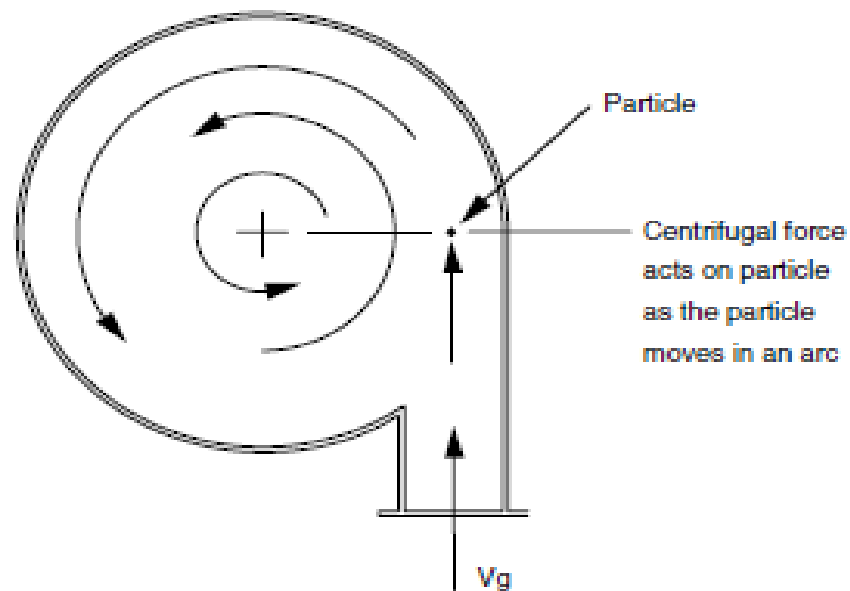
#### **Dry cyclone collectors:**

*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.

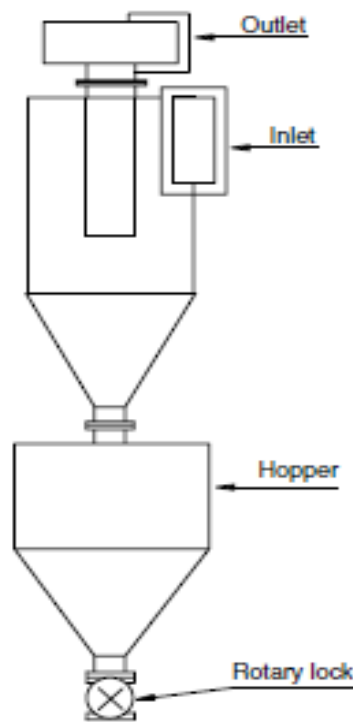
As the gas spins (Figure 4.2), the higher specific gravity dust is thrown outward toward the containing vessel wall where it accumulates and slides down the wall surface into a receiving chamber, usually a hopper or other essentially quiescent

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.*

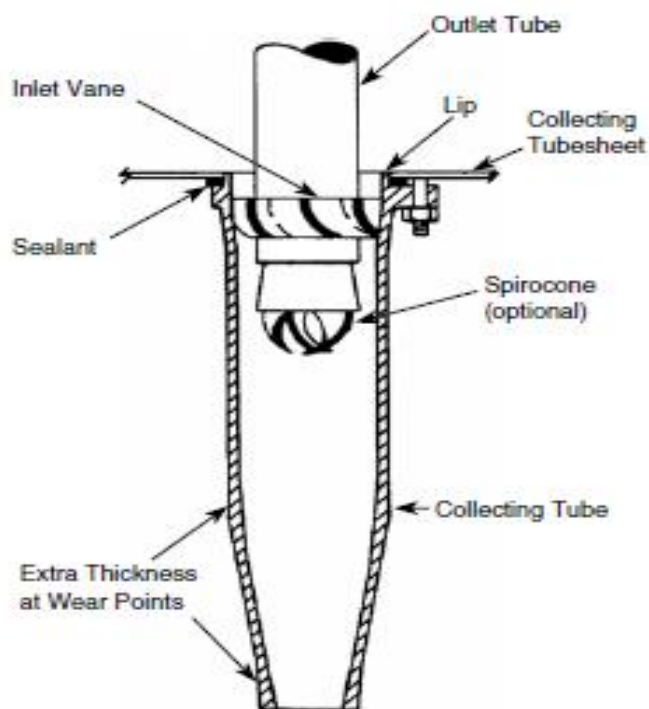
### ***Design basics:***

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

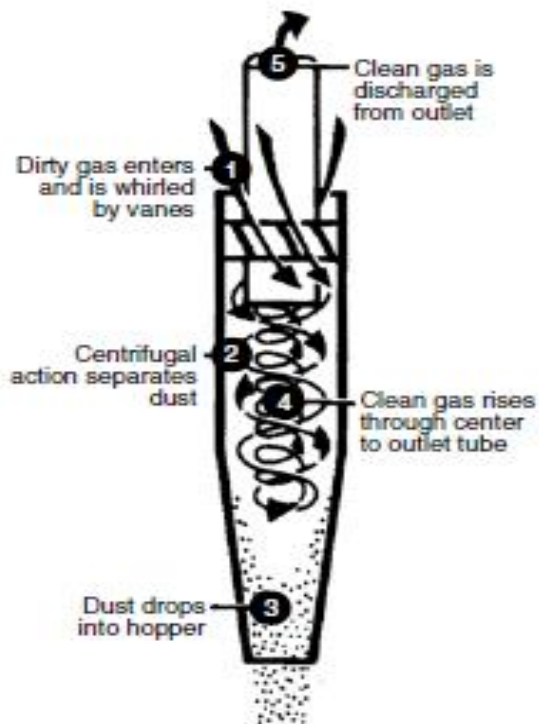
prevent dust from short-circuiting from the gas inlet to the outlet tube. An ascending vortex is formed in this tube that turns opposite in direction to the inlet spiral. On cyclones with high tangential inlet velocities (greater than 100 ft/sec), the outlet tube can also be equipped with turning vanes 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.

**Water pollution:**

INTRODUCTION, Epidemiology, Communicable Disease ,Contamination ,

Disinfection

**Communicable Disease:**

An illness due to a specific infectious agent or its toxic products arises through transmission of that agent or its products from an infected person, animal, or inanimate reservoir to a susceptible host, either directly or indirectly through an intermediate plant or animal host, vector, or the inanimate environment. Illness may be caused by pathogenic bacteria, bacterial toxins, viruses, protozoa, parasitic worms , poisonous plants and animals, chemical poisons, and fungi, including yeasts and molds. Communicable diseases are grouped and discussed under respiratory diseases, waterborne diseases, food borne diseases, zoonoses, and miscellaneous diseases.

The communicable diseases (malaria, yellow fever, pneumonia, tuberculosis, cholera, schistosomiasis, onchocerciasis, trachoma, intestinal parasitosis, and diarrheal diseases) and malnutrition are considered the core health problems of developing countries, many of which are aggravated by contaminated drinking water, unhygienic housing, and poor sanitation.

**Contamination:**

The presence of an infectious agent on a body surface; also on or in clothes, bedding, toys, surgical instruments or dressings, or other inanimate articles or substances, including water and food. *Pollution* is distinct from contamination and implies the presence of offensive, but not necessarily infectious.

**Disinfection:**

The application of microbicidal chemicals to materials (surfaces as well as water), which come into contact with or are ingested b humans and animals, for the purpose

of killing pathogenic microorganisms. Disinfection may not be totally effective against all pathogens.

### **Water pollution:**

#### ***Why treat water and wastewater?***

- *Reasons for treating:*
- Protect surface-water quality
- Protect public health
- Meet legal requirements.

Water is considered polluted if some substance or condition is present to such degree that water cannot be used for a specific purpose.

#### ***Types and source of water pollution:***

1. Domestic swage
2. Disease causing agents (bacteria, virus)
3. Inorganic chemicals and minerals
4. Synthetic organic chemical and oil
5. Nutrients (Nitrates, Phosphate)
6. Radioactive substance
7. Heat from industrial and power plants.

#### ***Domestic swage:***

These wastes are usually destroyed by bacteria if there is sufficient oxygen dissolved in the water. However, if lakes or slow moving rivers are overloaded with these wastes, then the oxygen caused in decomposing them depletes the overall dissolved oxygen content until many of forms of plant and animal life are killed or forced to

migrate to other areas. More sophisticated and expensive secondary and tertiary treatment sewage treatment plants are the major way to solving this problem.

**Disease causing agents:**

*Disease causing agents are the infections organisms such as bacteria and viruses carried into surface and ground water. This form of pollution will require continual vigilance and expensive research to find method for removing bacteria and virus.*

**Inorganic chemicals and minerals:**

*Inorganic chemicals and minerals are the vast arrays of acids, salts and metals compounds that may increase the acidity, salinity and toxicity of water. They reach our waters from industrial activities, irrigation and oil fields. These substances can be controlled by removing them through waste treatment and preventing some chemicals (for example, mercury) from reaching water supplies.*

**Synthetic organic chemicals:**

*Synthetic organic chemicals include pesticides, plastics, detergents, industrial chemicals and oil. The analysis of polluted waters shows the*

*presence of wide variety of these compounds. These compounds can be controlled by removing them through different type of waste treatment.*

**Nutrients:**

*Nutrients include nitrogen, phosphorus and other substances that support and stimulate the growth of aquatic plant such as algae. They are contributed from fertilizer, detergents and effluents from industrial waste and sewage treatment plants. In excess they can cause algae blooms producing odor and taste. Agriculture runoff is difficult to control because the sources are diffuse. Phosphate from sewage and industrial waste can be removed at considerable cost and removal of nitrate is difficult.*

**Radioactive:**

*Radioactive waste includes radium, strontium and uranium. Pollution can be result from mining, testing and using nuclear weapons, poorly designed and operated nuclear power plant, the use of radioactive materials in medicine and research. Because of their harmful effects must be prevent them from reaching out water air and soil.*

#### **Heated water:**

*Heated water is being returned in large quantities to streams, lakes and oceans by power and industrial plants. Excess heat reduces the amount of dissolved oxygen, lowering the capacity of a water system to degrade oxygen demanding waste, decrease the survival changes of some forms of aquatic life. It can be minimized by addition of expensive cooling towers and holding ponds.*

#### **(Water Quality Standards):**

High water quality is defined as water that contains no pathogenic organisms and free from biological forms that may be aesthetically objectionable. It is clear and colorless and has no objectionable taste or odor. It does not contain concentration of chemicals that may be physiological harmful, aesthetically objectionable or economically damaging. It also is not corrosive, nor does it leave excessive or undesirable deposits on water-conveying structures, including pipes, tanks, and plumbing fixtures. Any country can evaluate its positive and negative implications in terms of water quality, health status and environmental conditions, which will lead to the establishment of standards that are really appropriate to local conditions

#### **Iraqi Drinking Water Standards:**

It is essential that each country undertake a review of its needs and capacity for drinking-water standards. Iraqi Central Organization for Standardization and Quality Control (ICSQC, 2001) set down standards for Drinking Water. These are shown in Table

Constituent Or Characteristic	Unit	Drinking Water	
		Iraqi 2001	WHO 2004
<b><u>Physical:</u></b>			
Color	C.U	10	15
Turbidity	NTU	5	5
<b><u>Microbiological:</u></b>			
Colioform organ.	MPN	0.	0
Fecal Coliform	/100ml	0.	0
<b><u>Inorgan. Chemicals:</u></b>			
Aluminum(Al)	mg/L	0.2	0.2
Arsenic(As)	mg/L	0.01	0.01
Cadmium(Cd)	mg/L	0.003	0.003
Chloride(Cl)	mg/L	200	250
Chlorine(Res.Cl)	mg/L	0.5-2	0.6-1
Chromium(Cr <sup>+6</sup> )	mg/L	0.05	0.05
Copper(Cu)	mg/L	1.0	2.0
Fluoride(F)	mg/L	1.0	1.5
Iron(Fe)	mg/L	0.3	0.3
Lead(Pb)	mg/L	0.05	0.05
Manganese (Mn)	mg/L	0.1	0.05
Mercury(Hg)	mg/L	0.001	.....
pH(range)	.....	6.5 - 8.5	6.5 - 8.5
Sulfate(SO <sub>4</sub> )	mg/L	200	250
Zinc(Zn)	mg/L	0.5	5

### World Health Organization Guidelines:

The aim of general drinking water guidelines, such as those set by the World Health Organization, is the ultimate protection of public health. They are intended to be used as the basis for the development of national standards and the development of risk management strategies in the context of environmental, social, economic and cultural conditions for the different countries of the world. (*World Health Organization, WHO, 2004*) set down *Guidelines for Drinking Water Quality*. The guideline values are shown in table

### Most important indicator in water treatment:

#### 1. Turbidity: *Potential health effects:*

Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (e.g., whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of Disease-causing microorganisms such as viruses, parasites, and some bacteria.

- *Sources:* Soil runoff

## **2. Total Coliforms: *Potential health effects:***

Not a health threat in itself; it is used to indicate whether other potentially harmful bacteria may be present

*Sources:*

- Coliforms are naturally present in the environment
- **3. Chlorine: *Potential health effects:***

Eye/nose irritation; stomach discomfort

- *Sources:*

Water additive used to control microbes

## **(POPULATION ESTIMATES):**

Prior to the design of a water treatment plant, it is necessary to forecast the future population of the communities to be served. The plant should be sufficient generally for 25 to 30 years. It is difficult to estimate the population growth due to economic and social factors involved. However, a few methods have been used for forecasting population.

### **1. Arithmetic Method:**

This method of forecasting is based upon the hypothesis that the rate of increase is constant. It may be expressed as follows:



$$\frac{dp}{dt} = k_a$$

where

$p$  = population

$t$  = time, yr

$k_a$  = arithmetic growth rate constant

Rearrange and integrate the above equation,  $p_1$  and  $p_2$  are the populations at time  $t_1$  and  $t_2$  respectively.

$$p_2 - p_1 = k_a(t_2 - t_1)$$

$$k_a = \frac{p_2 - p_1}{t_2 - t_1} = \frac{\Delta p}{\Delta t}$$

$$p_t = p_0 + k_a t$$

$p_t$  = population at future time

$p_0$  = present population, usually use  $p_1$

## 2. Constant Percentage Growth Rate Method:

The hypothesis of constant percentage or geometric growth rate assumes that the rate increase is proportional to population. It can be written as:

Mechanism of acid formation in atmosphere:

$$\frac{dp}{dt} = k_p p$$

Integrating this equation yields

$$\ln p_2 - \ln p_1 = k_p (t_2 - t_1)$$

$$k_p = \frac{\ln p_2 - \ln p_1}{t_2 - t_1}$$

The geometric estimate of population is given by

$$\ln p = \ln p_2 + k_p (t - t_2)$$

### 3. Declining Growth Method

This is a decreasing rate of increase on the basis that the growth rate is a function of its population deficit. Mathematically it is given as

$$\frac{dp}{dt} = k_d (p_s - p)$$

Where

$p_s$  = saturation population, assume value

Integration of the above equation gives

Control strategies for acid rain:

$$\int_{p_1}^{p_2} \frac{dp}{p_s - p} = k_d \int_{t_1}^{t_2} dt$$

$$-\ln \frac{p_s - p_2}{p_s - p_1} = k_d (t_2 - t_1)$$

Rearranging

$$k_d = -\frac{1}{t_2 - t_1} \ln \frac{p_s - p_2}{p_s - p_1}$$

The future population  $P$  is

$$P = P_0 + (P_s - P_0)(1 - e^{-kt})$$

**EXAMPLE: A mid-size city recorded populations of 113,000 and 129,000 in the April 1980 and April 1990 census, respectively. Estimate the population in January 1999 by comparing (a) arithmetic method, (b) constant percentage method, and (c) declining growth method.**

*Solution:*

Step1. Solve with the arithmetic method Let  $t_1$  and  $t_2$  for April 1980 and April 1990, respectively

$$\Delta t = t_2 - t_1 = 10 \text{ yr}$$

$$K_a = \frac{P_2 - P_1}{t_2 - t_1} = \frac{129,000 - 113,000}{10} = 1600$$

Predict  $p_t$  for January 1999 from  $t_2$

$$\begin{aligned} t &= 8.75 \text{ yr} \\ P_t &= P_2 + K_a t \\ &= 129,000 + 1600 \times 8.75 \\ &= 143,000 \end{aligned}$$

Step2. Solve with constant percentage method

$$\begin{aligned} k_p &= \frac{\ln P_2 - \ln P_1}{t_2 - t_1} = \frac{\ln 129,000 - \ln 113,000}{10} \\ &= 0.013243 \end{aligned}$$

$$\begin{aligned} \ln P &= \ln P_2 + k_p (t - t_2) \\ &= \ln 129,000 + 0.013243 \times 8.75 \\ &= 11.8834 \\ P &= 144,800 \end{aligned}$$

Solve with declining growth method Assuming

$$p_s = 200,000$$

$$\begin{aligned} k_d &= -\frac{1}{t_2 - t_1} \ln \frac{p_s - p_2}{p_s - p_1} \\ &= -\frac{1}{10} \ln \frac{200,000 - 129,000}{200,000 - 113,000} \\ &= 0.02032 \end{aligned}$$

$$\begin{aligned} P &= P_0 + (P_s - P_0)(1 - e^{-k_d t}) \\ &= 129,000 + (200,000 - 129,000)(1 - e^{-0.02032 \times 8.75}) \\ &= 129,000 + 71,000 \times 0.163 \\ &= 140,600 \end{aligned}$$

## SUBSURFACE OR UNDERGROUND SOURCES

The rainwater that gets infiltrated and percolated inside the earth to form a uniform water surface is known as the ground water. This water is comparatively pure because of the natural filtration as it passes through the soil. Many impurities are retained by the soil through the actions like screening, sedimentation, adsorption etc. But it dissolves many soluble salts as it passes through the soil containing those salts. So the total dissolved solids of the underground water are much more than the surface water. The flow of rain water from surface of earth to the underground depends upon the porosity of the soil, the rate of water loss by evaporation, seepage to surface sources and withdrawal by us.

### Porosity

The porosity of a stratum (soil or rock) is a quantitative measurement of the interstices of the voids present in a given volume.

Mathematically porosity = Volume of voids/total volume

So the porosity  $| = V_v/V \times 100$  (per cent)

Where  $V_v$  = Volume of voids

$V$  = total volume

Porosity depends upon shape and arrangement (packing) of the solid particles. Uniformly graded (same size and shape) particles are more porous whereas those with different size and shape are well packed and thus have poor porosity. Sands may have 30 to 40% porosity whereas the slate or granite may have 1 to 4% porosity only.

## Permeability

The permeability is defined as the ability of rock or soil stratum to transmit or pass water through itself. Water enters in the pores (voids) of the rocks, and is stored there until it is drained off. The 'porosity' of the rock thus defines the maximum amount of water that can be stored in the rock. The porosity in itself does not ensure the storage of underground water. Actually the water can enter into a rock (with any porosity) only if the rock permits the flow of water through it, i.e. it depends upon whether the rock is permeable or not. So a rock that is porous may not be permeable. For example shale is a porous rock but not permeable. Its pore spaces are so minute and not well connected to each other that the shale is impermeable. The permeability is defined in terms of coefficient of permeability  $k$  (m/sec.). It has been well defined by the Darcy's law. Darcy's Law:- Scientist H. Darcy demonstrated on the basis of experiments that for the laminar flow conditions ( Reynolds number  $< 1$ ) the discharge, passing through a soil is proportional to the head loss  $\Delta H$  and the area of cross section  $A$  of the soil and inversely proportional to the length ( $L$ )

So  $Q \propto \Delta H/L \cdot A$  ( $\Delta H/L$  can be designated as hydraulic gradient  $i$ )

or  $Q \propto i A$

or  $Q = k i A$

The above equation gives the dimensions of  $k$  as m/sec. That is the unit of velocity.

One more term is transmissibility. Scientist This defined transmissibility as the rate of flow of water through a vertical strip of water bearing stratum (aquifer) of unit width and full depth ( $d$ ) under a unit hydraulic gradient and a temperature of 60o F.

Thesis'  $T = k d$

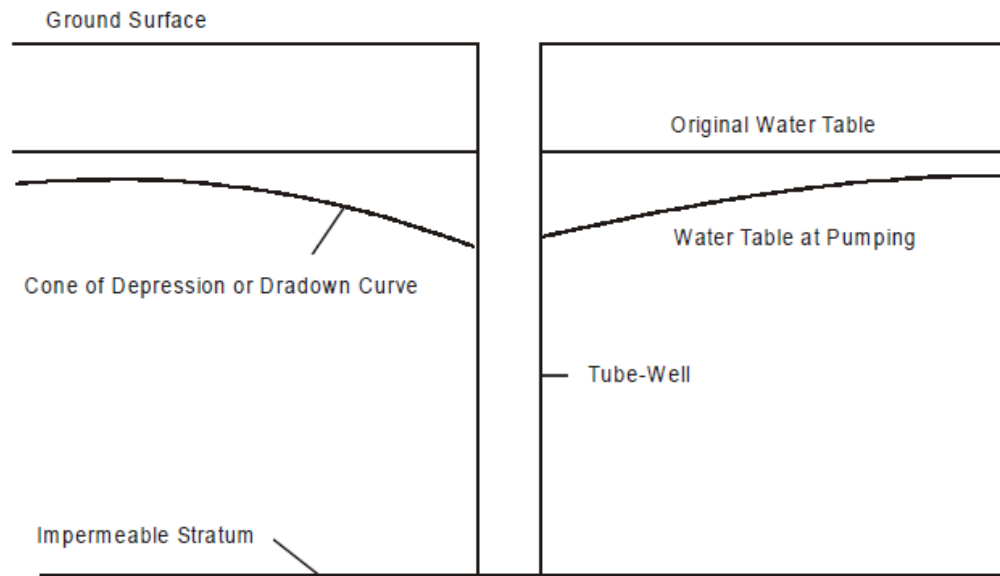
The following table gives the porosity and permeability of some of the formations

**Table 2.1 Porosity and Permeability of Some Soils**

<b>S. No.</b>	<b>Type of formation</b>	<b>Porosity</b>	<b>Permeability</b>
1	Granite, Quartzite	1.5%	
2	Slate, Shale	4%	
3	Limestone	5 to 10%	
4	Sandstone	10 to 15%	
5	Gravel	25%	1.0 or more
6	Sand and gravel	20 to 30%	1-0.1
7	Only fine sand	35%	0.05-0.001
8	Silty sand	-	0.002-0.0001
9	Silt	-	0.0005-0.00001
10	Clay	45%	0.000001 or lesser

## **GROUND WATER YIELD**

The ground water is present in the water bearing stratum. Those soil formations through which it can be easily and economically extracted is known as aquifers. The top layer of ground water is known as water table. The ground water may come out by itself either through springs or sometimes as artisan wells, but generally extracted out through the wells. Larger diameter wells are known as open wells whereas the smaller diameter wells (30 cm or so) are known as tube-wells. Tube-wells are drilled by machines and fitted with blank or perforated pipes (strainers to draw water). Different type of pumps is installed in the wells to get the water on ground surface. These days generally submersible pumps are lowered in the tube-wells and open wells capable of drawing water for various heads and discharges. As soon as the pumping is started the ground water table goes down and a cone of depression is formed as shown below



After sometime the equilibrium is achieved, depending upon the yield (capacity to provide water) and the withdrawal capacity of the pump set. If the yield of the aquifer is more than the capacity of the pump installed we get continuous supply of water, but if the pump has larger withdrawal capacity than the yield, then the supply of water shall stop. The supply shall start again after sometime after further accumulation of water from distant places in the aquifer. So the yield is known as the quantity of ground water that can be extracted from a saturated (all voids filled up with water) water bearing stratum. The ratio of this volume of water to the total volume of the stratum is known as the specific yield. It is expressed in percentage that this much per cent of water may be extracted from the soil economically. The water that cannot be extracted is known as the specific retention or field capacity.

This specific retention is the amount of water held between the grains due to molecular attraction. This film of water is thus held by molecular adhesion on the walls of the intrices. Therefore the amount of this water will depend upon the total interstitial surface in the rock. If the total interstitial surface is more, the specific retention will be more and vice-versa. In soils like clay as the specific area is more, the specific retention would be more and hence it will result in a small specific yield. Similarly in large particle soil like coarse gravels, the specific retention would be smaller and it will give large specific yields.

After drilling the tube-wells by drilling machines the hydro-geologists make a log chart of the stratum and then decide the position of blank and perforated pipes depending upon the rock formation (aquifer). Tube-wells may be shallow or deep

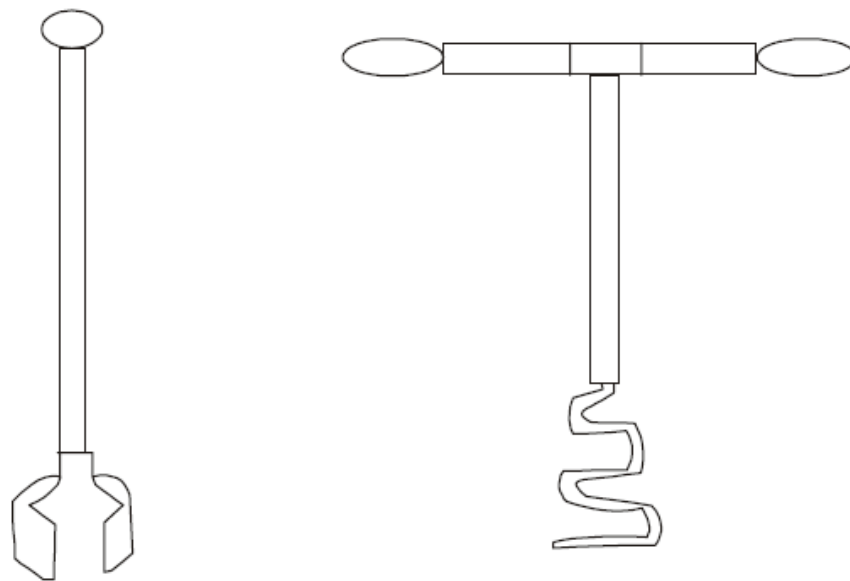


depending upon the depth of water table, yield of the aquifer and the requirement of water. The drilling operation of the well depends upon the expected soil structure.

## 1 Drilling of Tube-Wells

Tube-wells can be drilled by following methods:

(i) Auger Drilling (upto 15 m) For smaller depths and smaller diameters auger drilling can be used in clay silt or sand. The auger may be hand operated or power operated. Some of them are as shown below.



This type of drilling is possible only in soft soils. To support the soft soil casing pipe are lowered simultaneously.

(ii) Water jet or Wash Boring In water jet boring method, a drill bit with nozzles is attached to the drill pipe at its bottom. Water under high pressure is pumped into the drill pipe. The force of water jet coming out of the nozzle loosens the subsurface soil. The returning water flow through the annular space between the borehole and the drill pipe carries the cuttings along with it to the ground surface. Here also the soft soil is supported by the casing pipe to avoid collapsing in. The method is not suitable for hard soils.

(iii) Core Drilling This method is used for hard soil. In this method a core cutter with steel teeth (drill bit) attached to a drill rod rotates and thus cuts the hard soil. As the

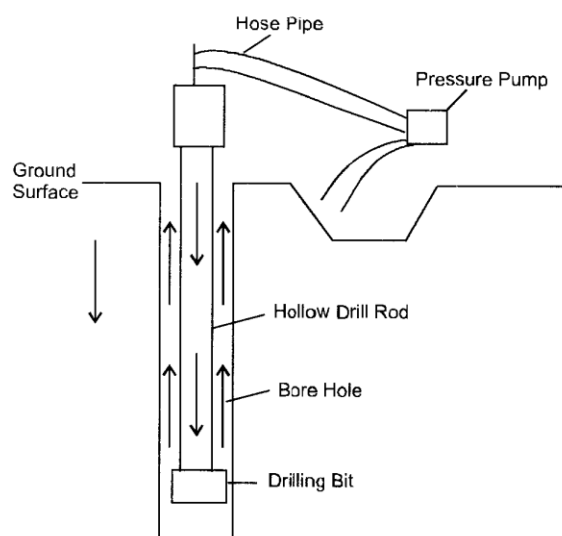
soil is cut and the hole is formed water supplied through the drill rod removes the cuttings. For extremely hard and strong soils diamond bits are used.

(iv) **Percussion Drilling** In this method a drill tool string constituting of a drill bit, a drill stem, and a drill jar is lifted up and dropped down by connecting it to a diesel engine and a winch. The cable tool bit acts as a mini crusher that chops the

consolidated formations. After the bit has chopped the formation for 1 to 1.5 m it is taken out of the hole and a bailer is inserted to remove the cuttings. Water makes slurry with pulverized materials that is bailed out. As the bailer is lifted, the flap valve closes and it brings with it the cuttings to the ground. Casing is used simultaneously in soft (unconsolidated) formation. The method is suitable for drilling holes 20 to 50 cm in diameter and upto 150 m deep.

**(v) Rotary Drilling**

This method is suitable for unconsolidated clay and sand formations as well as coarse gravel and boulders including soft rocks. In this method the rotating drill bit makes the bore hole. The mud slurry, generally bentonite is pumped down through the drill pipe as the drilling proceeds. This mud rises to the ground surface along the walls of the hole and carries with it the cuttings. The mud also strengthens the walls of the hole to prevent falling in. The following figure shows the schematic diagram of the Rotary drilling.



**(vi) Down the Hole Hammer Drilling (DTH)**

In this method of drilling a pneumatically (by air pressure) operated hammer is used at the lower end of the drill pipe. Thus it combines the percussion effect of the cable tool method and the rotary action of the rotary drilling. As the drilling proceeds the hammer crushes the rock into small chips. A flush pump is used to flush out the hole and bringing the cuttings to the ground surface through the annular (circular) space between the bore hole and the drill pipe. Small diameter holes upto 30 cm can be successfully drilled in medium to hard

soil by this method. After drilling the hole and taking samples of the cuttings (removed soil) at regular intervals the pipe assembly is designed for blank and

perforated pipes. Specially designed perforated pipes are known as strainers. They are designed to allow water to come inside the hole and the soil is prevented to get inside it by their special shape. That is why they are costlier than the blank pipes, so they are placed only in water bearing and yielding stratum (aquifer). There are many type of strainers like Cook Strainer, Ashford Strainer, Legget Strainer, Phoenix Strainer etc.

## **2 Lowering of Pipes and Gravel Packing**

The pipe assembly consisting of blind pipes (without hole) and strainers (with well-designed holes) are lowered in the drilled hole to a depth as designed by the hydro geologist. The design of assembly is based on the depth of static water table, expected Draw-down (lowering of water table in a conical shape), expected yield and the requirement of water. The diameter of the drilled hole is bigger than this pipe assembly and thus some space is left between the walls of the hole and the tube-well pipe. This space is filled up with gravel of suitable size. The casing pipe to retain the hole is taken out simultaneously. The process of filling gravel (to stop entry of fine particles at pumping) is known as shrouding. This also increases the effective well diameter and hence the yield of the well. After shrouding the well is developed for use.

## **3 Development of Tube-wells**

Development of a tube-well is the process of removing fine material from the aquifer surrounding the strainer pipe so that it does not cause choking at the time of pumping. It increases the yield from a tube-well and increases the useful life of the well. Following methods may be used for developing a tube-well:-

### **(i) Pumping Method**

In this method the fine particles surrounding the well are agitated by the working of a variable discharge pump that gives jerks by its irregular motion. Slowly the speed of the pump is increased until no more fine particles come out with water.

### **(ii) Surging Method**

In this method a hollow surge block or a bailer moves down the hole, already filled up with Calgon (Sodium hexa meta phosphate) a dispersing agent, forces it to the holes of the soil. When the bailer is moved upwards, a suction pressure is developed and the water calgon solution brings with it fine particles into the well. The surge block (bailer) is connected to a hollow pipe through which the water charged with fine particles is pumped out. This operation is repeated till clear water comes out from the well.

### (iii) Compressed Air Method

In this method, the development of the tube-well is done with an air compressor discharge pipe and an air pipe. The air pipe is placed in the discharge pipe such that its lower end projects out of it by a small length. This assembly is lowered into the well till it reaches the bottom of the strainer pipe. After building a high pressure of air in the compressor ( $800 \text{ kN/m}^2$ ) the air valve is opened suddenly to release the air with high pressure. This loosens the fine particles in the formation surrounding the slots. When the air valve is closed the pressure decreases and water enters the well alongwith the loosened fine particles. This water is pumped out of the well. The same operation is repeated at different levels along the strainer sections of the tube-well so that the whole well is fully developed.

### (iv) Dry Ice Method (Chemical Method)

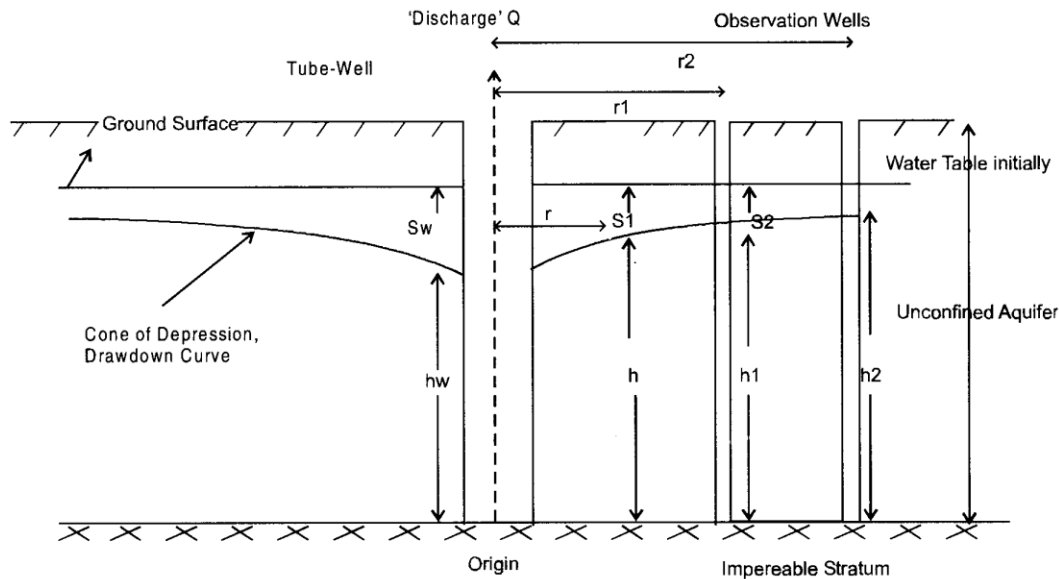
In this method sodium dioxide (dry ice) and hydrochloric acid are used. First of all HCl is poured in the well and the well is closed from the top. Compressed air is supplied which pushes the HCl into the voids of the soil. The top plug is then removed and dry ice blocks are dropped which sublimate to release  $\text{CO}_2$  which builds up a high pressure. This high pressure gas comes out of the tube-well with pressure followed by the water mixed with mud in the form of a jet. This way the fine material; are removed and the well starts giving clean water.

## **4 Yield of a Tube-Well**

The yield (discharge) of a tube-well depends upon the depth and capacity of aquifer (water bearing stratum) and the drawdown. As the water comes to the tube-well from all directions the Dupuit- Theim equations can be used to obtain the yield from it. There are two cases, first in which the water bearing stratum has no upper impermeable layer (confining it to some limited depth), and there is only one impermeable layer at the bottom of the aquifer. This type is known as the unconfined aquifer. In the second case there are two impermeable layers, one at the top and other at the bottom of the aquifer, known as confined aquifer.

### **1 Yield of a tube-well in an unconfined aquifer**

Let there be a well of radius  $r_w$  fully penetrating an unconfined aquifer of thickness  $H$  below the water table (top surface of ground water) that is horizontal in the beginning. As soon as the water is pumped out of the well the water level near the tube-well goes down and this horizontal surface is converted into a conical curved surface as shown below.



When the water is pumped through the well at a constant rate  $Q$  for sometime, the lowering of water table near the tube-well (drawdown) comes to some final constant level, depending upon the capacity of supplying water by the soil and the power of the pump to draw water (discharge). Higher is the withdrawal capacity (discharge) of the pump and lesser is the supplying capacity of aquifer more will be the depth of the drawdown. In extreme case if this drawdown curve reaches the bottom of the aquifer means the demand is more than supply, water will stop coming out of the tube-well until it again gets filled up by resuming water from far places. Keeping this in mind the submersible pump should be lowered at a depth which is more than the worst expected drawdown. This is the reason that sometimes water mixed with air comes out from tube-wells and hand pumps (a type of small diameter tube-well operated manually). Or in extreme cases only air comes out. Here lies the necessity of recharging the aquifer by rain water. The over exploitation of underground water without, or less, recharging by rainwater has converted the good aquifers into dark zones. Presently we are drawing more and more water with tube-wells for irrigation and drinking purposes as the demand is growing exponentially. Nobody cares about the penetration of rainwater (runoff) through the soil to the under ground water. We have made houses, roads and other pucca structures which increases the flow of water (runoff) to the rivers from which most of it goes to sea and gets converted into useless saline, brackish water. Otherwise if it is collected in ponds or reservoirs it gets evaporated easily as it is exposed to atmosphere i.e. about 1.7 m/year in northern India. Had it been stored below the ground as underground water there would have not been any evaporation etc. In this

case it would have been away from the surface pollution and rather it would have been automatically purified due to the natural filtration process. So it is wise to conserve rain water under the ground and use it only in a calculative, judicious manner. Unfortunately in most of the areas in India the underground water is either going deep and deep or has become so polluted to be useless for human consumption.

Actually we have to spent much more electricity if the water is to be lifted from a greater depth. The horse power of the pump that is directly related to the electric consumption (1H.P. = 0.746 kW) is based upon the discharge and head (depth of water) as follows:-

$$\text{Horse Power} = \frac{Q H}{75 \times \eta}$$

Where Q = discharge in liters per second

H = head in meters

$\eta$  = efficiency of the pump

So deeper is the water higher is the head and there is a larger requirement of the HP of the pump. As 1 HP = 0.746 kW and when 1 kW motor runs for one hour it consumes 1 kWh. i.e. one unit of electricity, the consumption of electricity increases directly with depth of water.

Now let us derive a mathematical expression for the estimation of discharge from a tube-well. For this derivation let us consider a cylindrical soil mass around the well (the wells are circular for the ease in construction and stability). Let the origin of the cylindrical co-ordinates (r,  $\theta$  and h) be at the center of the bottom of the well. Let P be a point on the drawdown curve at a radial distance of r and at a height h above the impermeable stratum. Water flows to the vertical sides of the tube well passing through the point P. The area of flow  $A = 2\pi rh$

Darcy's law gives the velocity of flow  $V = ki = kdh/dr$

Where k is the co-efficient of permeability

And I is the hydraulic gradient

$$\begin{aligned} \text{Discharge } Q &= A \cdot V \\ &= 2\pi rhkdh/dr \end{aligned}$$

$$\text{or } h \, dh = \frac{Q}{2\pi k} \frac{dr}{r}$$

Integrating between limits  $r = r_1$  and  $h = h_1$  to  $r = r_2$  and  $h = h_2$

$$\int_{h_1}^{h_2} h \, dh = \frac{Q}{2\pi k} \int_{r_1}^{r_2} \frac{dr}{r}$$

$$\text{or } (h_2^2 - h_1^2)/2 = \frac{Q}{2\pi k} \log_e(r_2/r_1)$$

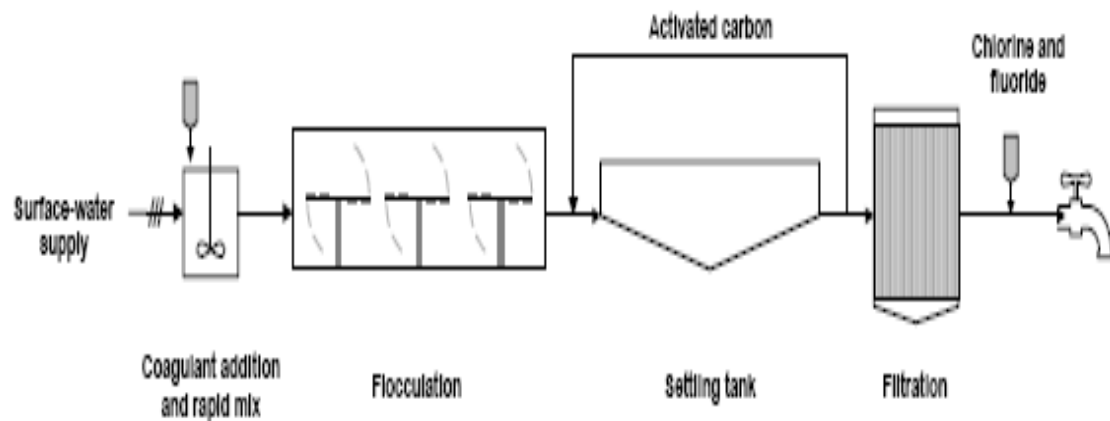
$$\text{So } Q = \frac{\pi k(h_2^2 - h_1^2)}{\log_e(r_2/r_1)}$$

$$\text{or} \quad Q = \frac{\pi k(h_2^2 - h_1^2)}{2.303 \log_{10}(r_2/r_1)}$$

$$\text{or} \quad Q = \frac{1.36k(h_2^2 - h_1^2)}{\log_{10}(r_2/r_1)}$$

### **(WATER TREATMENT):**

As the raw surface water comes to the treatment plant, physical screening is the first step to remove coarse material and debris. Thereafter, following the basic treatment process of clarification, it would include coagulation, flocculation, and sedimentation prior to filtration, then disinfection (mostly by the use of chlorination). With a good quality source, the conventional treatment processes may be modified by removing the sedimentation process and to just have the coagulation and flocculation processes followed by filtration.



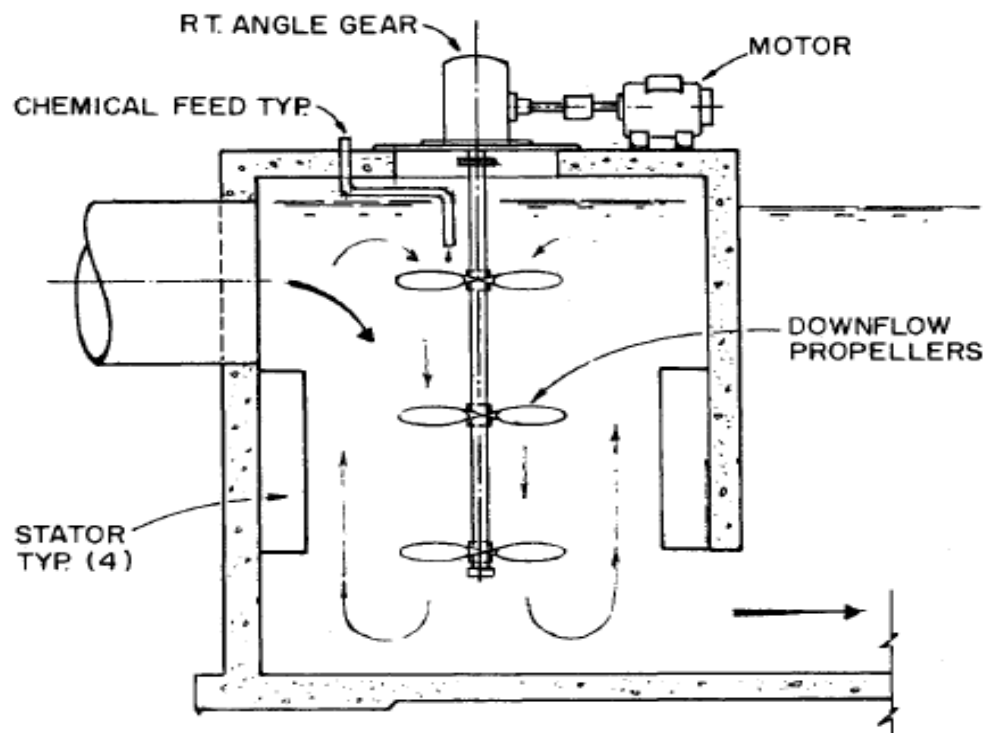
### **COAGULATION:**

Coagulation is a chemical process to remove turbidity and color producing material that is mostly colloidal particles (1 to 200 mill microns, m) such as algae, bacteria, organic and inorganic substances, and clay particles.



**Mixing:**

Mixing is an important operation for the coagulation process. In practice, rapid mixing provides complete and uniform dispersion of a chemical added to the water. Then follows a slow mixing for flocculation (particle aggregation). The time required for rapid mixing is usually 10 to 20 s.

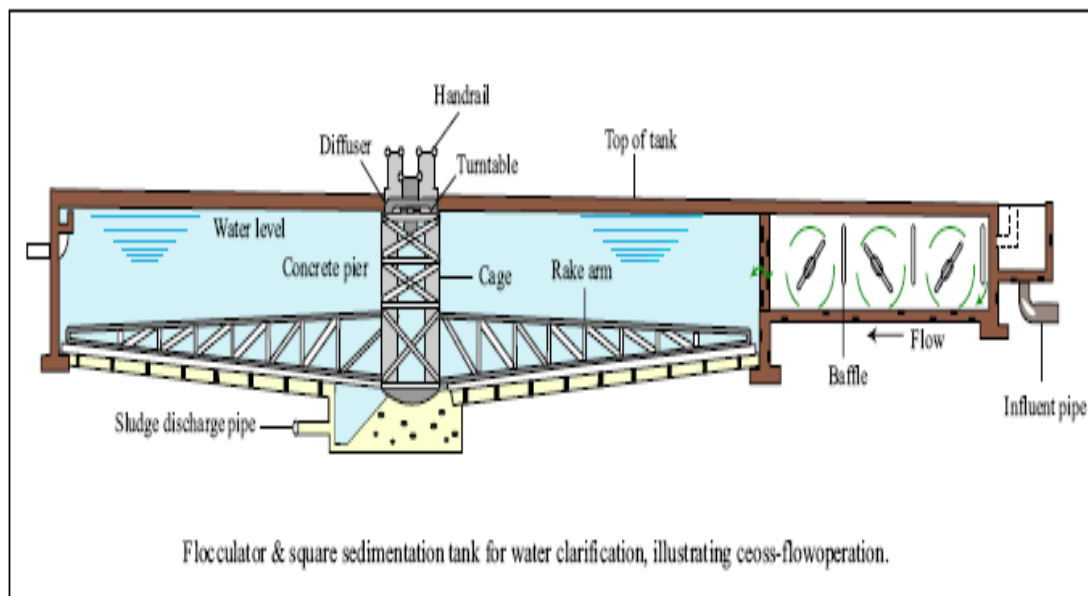
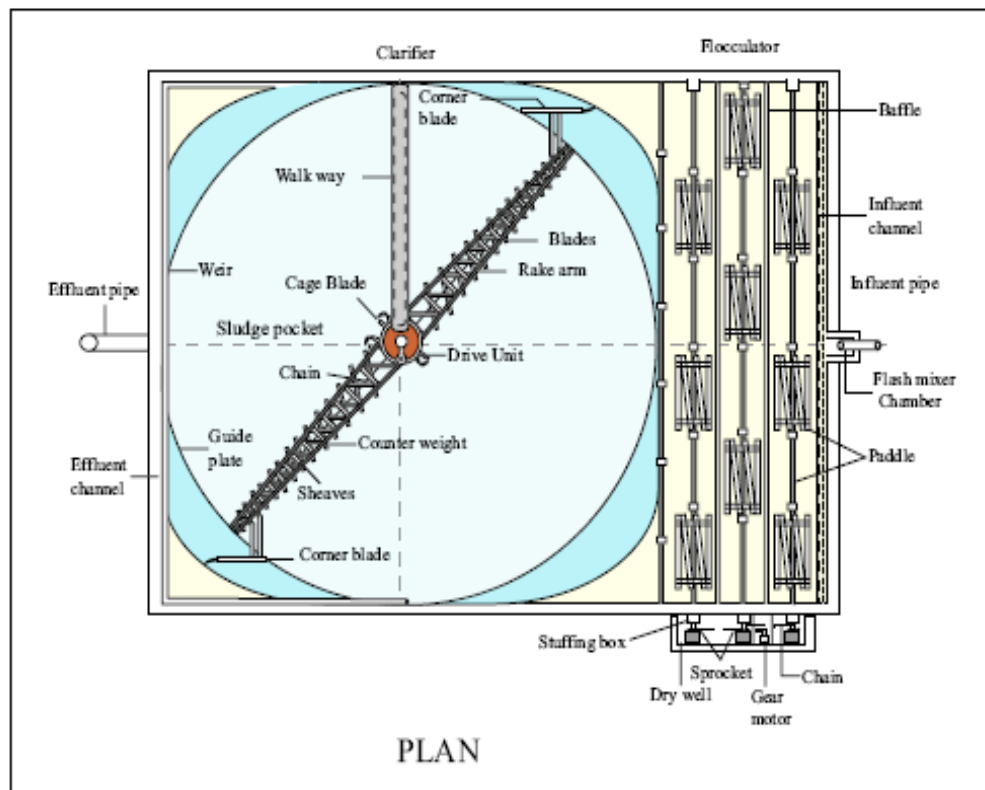
**FLOCCULATION:**

After rapid mixing, the water is passed through the flocculation basin. It is intended to mix the water to permit agglomeration of turbidity settled particles (solid capture) into larger flocs.

**SEDIMENTATION:**

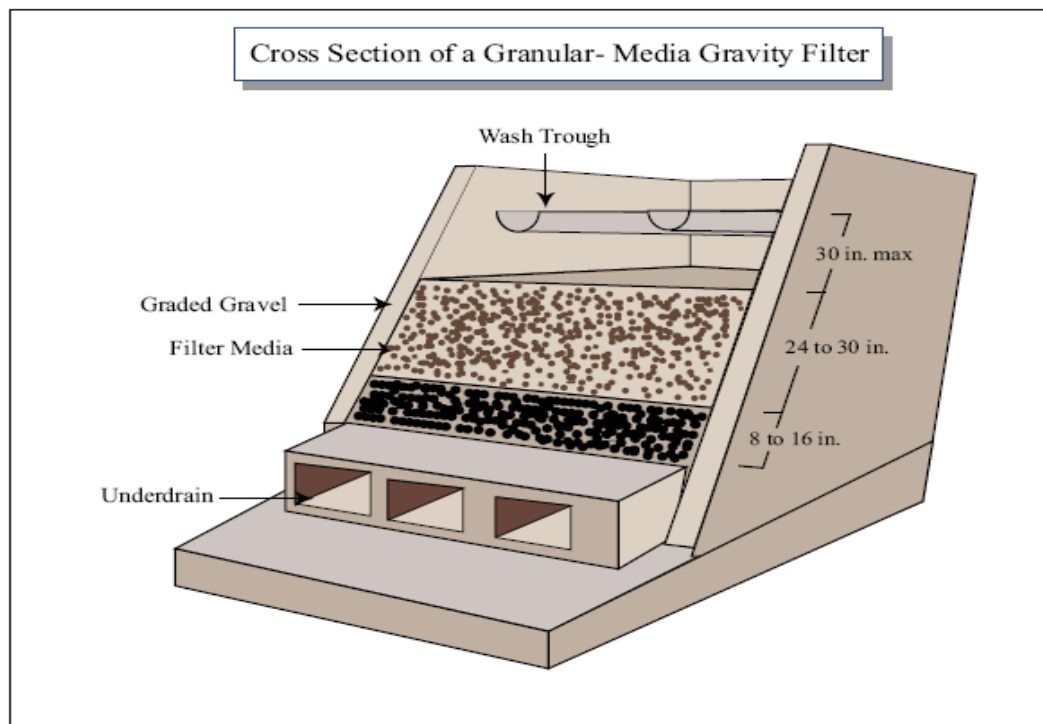
Sedimentation is one of the most basic processes of water treatment. sedimentation tank (or basin) following coagulation—flocculation, is most commonly used in water treatment facilities. Sedimentation is a solid–liquid separation by gravitational settling. There are four types of sedimentation: discrete particle settling (type 1);

flocculants settling (type 2); hindered settling (type 3); and compression settling (type 4).



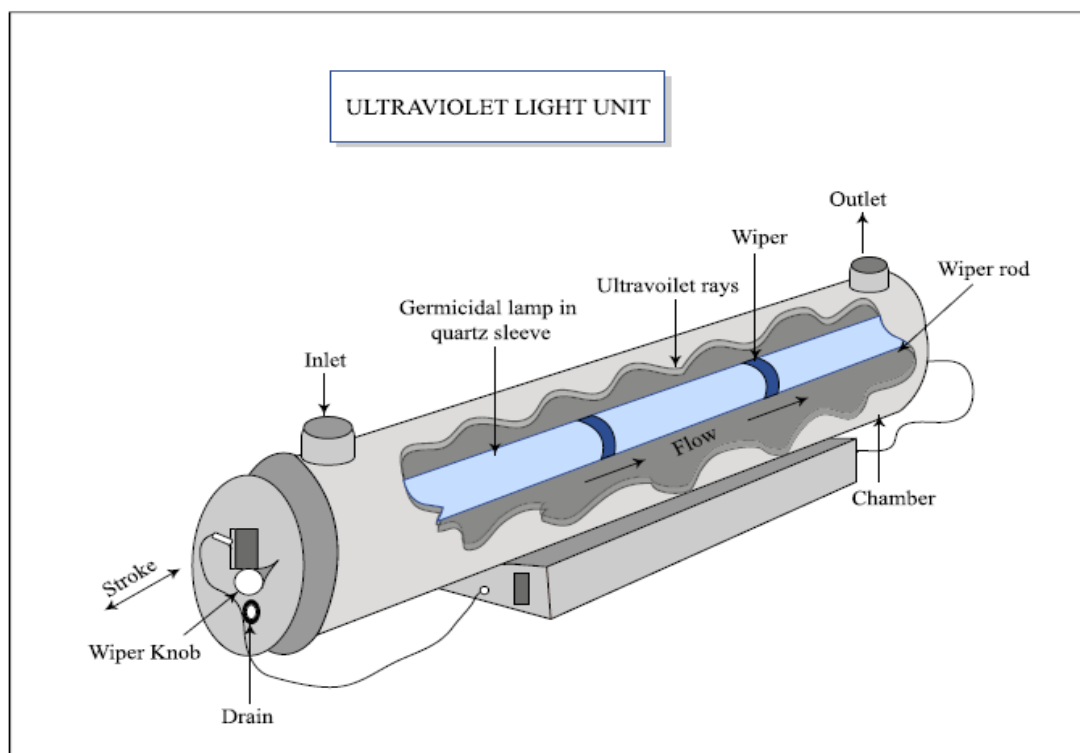
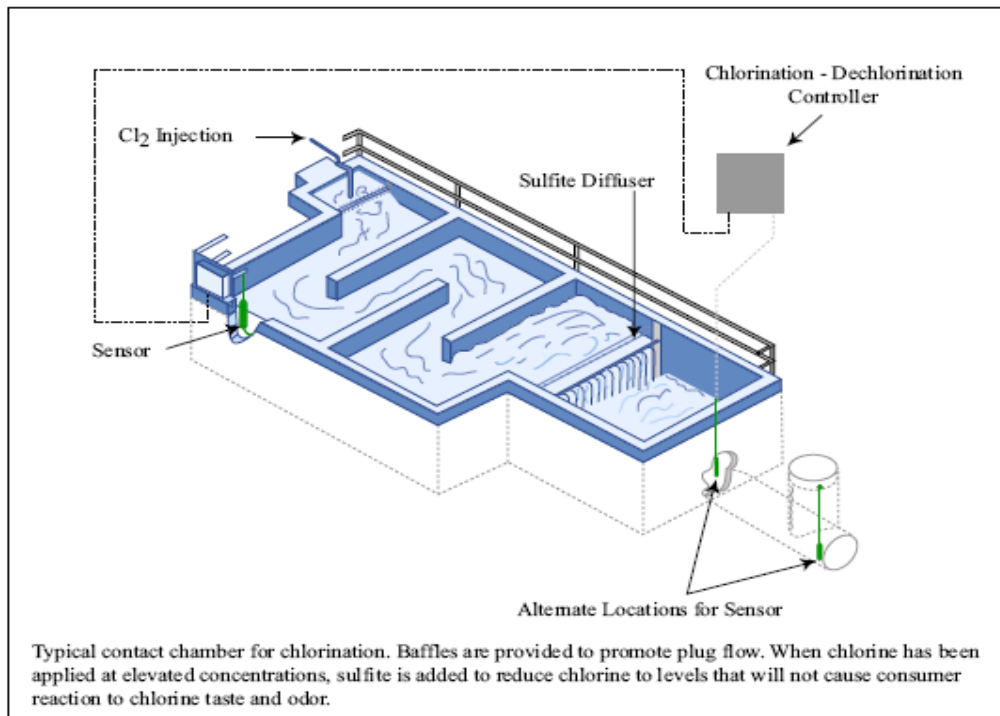
### ***FILTRATION:***

The conventional filtration process is probably the most important single unit operation of all the water treatment processes. It is an operation process to separate suspended matter from water by flowing it through porous filter medium or media. The filter media may be silica sand, anthracite coal, diatomaceous earth, garnet, ilmenite, or finely woven fabric.



### ***DISINFECTION:***

Disinfection is a process to destroy disease-causing organisms, or pathogens. Disinfection of water can be done by boiling the water, ultraviolet radiation, and chemical inactivation of the pathogen. In the water treatment processes, pathogens and other organisms can be partly physically eliminated through coagulation, flocculation, sedimentation, and filtration, in addition to the natural die-off. After filtration, to ensure pathogen-free water, the chemical addition of chlorine (so called chlorination), rightly or wrongly, is most widely used for disinfection of drinking water. For the public health standpoint, chlorination of drinking water provides more benefits than its shortcoming due disinfection by-products (DBPs). The use of ozone and ultraviolet for disinfection of water and wastewater is increasing in the world.



## **(WASTEWATER):**

### ***WHAT IS WASTEWATER?***

Wastewater,” also known as “sewage,” originates from household wastes, human and animal wastes, industrial wastewaters, storm runoff, and groundwater infiltration. Wastewater, basically, is the flow of used water from a community. It is 99.94 percent water by weight. The remaining 0.06 percent is material dissolved or suspended in the water. It is largely the water supply of a community after it has been fouled by various uses.

### ***CHARACTERISTICS OF WASTEWATER:***

**Physical Properties of Wastewater:** When fresh, wastewater is gray in color and has a musty and not unpleasant odor. The color gradually changes with time from gray to black. Foul and unpleasant odors may then develop as a result of septic sewage. The most important physical characteristics of wastewater are its temperature and its solids concentration. Temperature and solids content in wastewater are very important factors for wastewater treatment processes. Temperature affects chemical reaction and biological activities. Solids, such as total suspended solids (TSS), volatile suspended solids (VSS), and settleable solids, affect the operation and sizing of treatment units.

### ***Chemical Constituents of Wastewater:***

The dissolved and suspended solids in wastewater contain organic and inorganic material. Organic matter may include carbohydrates, fats, oils, grease, surfactants, proteins, pesticides and other agricultural chemicals, volatile organic compounds, and other toxic chemicals (household and industrial). Inorganic may include heavy metals, nutrients (nitrogen and phosphorus), pH, alkalinity, chlorides, sulfur, and other inorganic pollutants. Gases such as carbon dioxide, nitrogen, oxygen, hydrogen sulfide, and methane may be present in a wastewater.

**Biological Characteristics of Wastewater:**

The principal groups of microorganisms found in wastewater are bacteria, fungi, protozoa, microscopic plants and animals, and viruses. Most microorganisms (bacteria, protozoa) are responsible and are beneficial for biological treatment processes of wastewater. However, some pathogenic bacteria, fungi, protozoa, and viruses found in wastewater are of public concern.

**SEWER SYSTEMS:**

Sewers are underground conduits to convey wastewater and stormwater to a treatment plant or to carry stormwater to the point of disposal. Sewers can be classified into three categories: sanitary, storm, and combined. Community sewer systems, according to their discharging types, can be divided into separated and combined sewer systems.

**QUANTITY OF WASTEWATER:**

The quantity of wastewater produced varies in different communities and countries, depending on a number of factors such as water uses, climate, lifestyle, and economics. A typical wastewater flow rate from a residential home in the world might average 70 gal (265 L) per capita per day (gal/(c . d)). Approximately 60 to 85 percent of the per capita consumption of water becomes wastewater.

**Design Flow Rates:**

The average daily flow (volume per unit time), maximum daily flow, peak hourly flow, minimum hourly and daily flows, and design peak flow are generally used as the basis of design for sewers, lift stations, sewage (wastewater) treatment plants, treatment units, and other wastewater handling facilities. Definitions and purposes of flow are given as follows.

The design average flow is the average of the daily volumes to be received for a continuous 12-month period of the design year. The average flow may be used to estimate pumping and chemical costs, sludge generation, and organic-loading rates.

- The maximum daily flow is the largest volume of flow to be received during a continuous 24-hour period. It is employed in the calculation of retention time for equalization basin and chlorine contact time.
- The peak hourly flow is the largest volume received during a one hour period, based on annual data. It is used for the design of collection and interceptor sewers, wet wells, wastewater pumping stations, wastewater flow measurements, grit chambers, settling basins, chlorine contact tanks, and pipings. The design peak flow is the instantaneous maximum flow rate to be received. The peak hourly flow is commonly assumed as three times the average daily flow.
  - The minimum hourly flow is the smallest hourly flow rate occurring over a 24-hour period, based on annual data. It is important to the sizing of wastewater flow meters, chemical-feed systems, and pumping systems.
  - The minimum daily flow is the smallest volume of flow received during a 24-hour period. The minimum daily flow is important in the sizing of conduits where solids might be deposited at low flow rates.

**EXAMPLE: Estimate the average and maximum hourly flow for a** community of 10,000 persons. **SEWER**

Step 1. Estimate wastewater daily flow rate

Assume average water consumption = 200 L/(c · d)

Assume 80% of water consumption goes to the sewer

$$\begin{aligned}\text{Average wastewater flow} &= 200 \text{ L/(c · d)} \times 0.80 \times 10,000 \text{ persons} \times 0.001 \text{ m}^3/\text{L} \\ &= 1600 \text{ m}^3/\text{d}\end{aligned}$$

Step 2. Compute average hourly flow rate

$$\begin{aligned}\text{Average hourly flow rate} &= 1600 \text{ m}^3/\text{d} \times 1 \text{ d}/24 \text{ h} \\ &= 66.67 \text{ m}^3/\text{h}\end{aligned}$$

Step 3. Estimate the maximum hourly flow rate

Assume the maximum hourly flow rate is three times the average hourly flow rate, thus

$$\begin{aligned}\text{Maximum hourly flow rate} &= 66.67 \text{ m}^3/\text{h} \times 3 \\ &= 200 \text{ m}^3/\text{h}\end{aligned}$$

### **SEWER CONSTRUCTION:**

Conduit material for sewer construction consists of two types: rigid pipe and flexible pipe. Specified rigid materials include asbestos—cement, cast iron, concrete, and vitrified clay.

Flexible materials include ductile iron, fabricated steel, corrugated aluminum, thermoset plastic (reinforced plastic mortar and reinforced thermosetting resin), and thermoplastic.

### **Sample of questions:**

Q1 : explain the major pollutants for water and its allowable levels.

Q2 :explain the most indicator in water treatment

Q3 : explain the types of methods of water treatment .

Cont...

1. Describe the various water resources.
2. Sketch and describe simon's rain gauge.
3. Describe the surface sources of water supply with illustrations.
4. Describe the various constructions required for making a suitable source of surface water supply.
5. What do you mean by storage capacity of reservoirs ?
6. Describe the subsurface or underground sources of water supply.
7. Define porosity and permeability.
8. Tabulate the porosity and permeability of some common soils.
9. Explain the methods of assessment of the ground water yield.
10. Describe the various methods of drilling of tube-wells.
11. Describe the various methods of development of tube-wells.
12. What do you mean by yield of a tube-well?
13. Develop the expression for finding yield of tube-well in unconfined aquifer.
14. Develop the expression for finding yield of tube-well in confined aquifer.
15. Discuss the various water supply schemes with suitable examples.
16. Describe the term quality of water.



17. Tabulate the physical and chemical standards of water and their permissible limits.
18. What are the bacteriological & virological standards of potable water ?
19. Tabulate the various toxicological materials found in water and their limits.
20. Describe the physical characteristics of water.
21. Describe the chemical characteristics of water.
22. What do you mean by treatment of water? Briefly explain the various methods of treatment.
23. What is the importance of disinfection? Describe the various methods of disinfection.
24. What are the waterborne diseases?
25. What are the suitability criteria of good disinfectant?
26. What is residual chlorine? How do you measure it on site?
27. Describe the various water softening processes.
28. What is the requirement of pressure of water to be supplied to the residences?
29. What is aeration of water? Why and how is it done?
30. What is the purpose of water softening? Explain various methods of water softening.

Cont...

1. What do you understand by wastewater management?
2. Describe the statutory water and sanitation boards.
3. Describe the method of design of sewer line alongwith the hydraulics of sewers.
4. What do you mean by treatment of wastewater?
5. Define biochemical oxygen demand and chemical oxygen demands.
6. What are the various unit operations and processes in water treatment?
7. What are the various unit operations and processes in wastewater treatment?
8. Describe the various methods of treatment of wastewater.
9. Tabulate the functions and efficiencies of various treatment units.
10. Explain the anaerobic digestion and the biogas.
11. Describe the disposal of treated wastewater.
12. Write a short note on Eutrophication.
13. Describe the disposal of wastewater in water bodies.

14. Describe the disposal of wastewater on land.
15. What are the various methods of onsite sanitation.
16. Describe the septic tanks and soakpits.
17. Explain the inhouse treatment of wastewater and saving of water.

### **Solid wastes:**

Anything that is not of further use in a process is known as waste for that process. That can be useful for other process and can be termed as raw material for that process. So actually waste is a misplaced resource. When this waste is in a comparatively solid form it is known as the solid waste. Whatever may be the form of waste, it deteriorates the environment if it is disposed in an offensive manner. The waste water and its treatment and disposal have already been discussed Solid waste is defined as discarded solid fraction produced from domestic, commercial, trade, industrial, agricultural, institutional, mining activities and public services. The waste is a term that means useless, unwanted or discarded material. According to the American Public Works Association the solid waste is classified in twelve categories as, garbage, rubbish, ashes, Street sweepings, dead animals, abandoned vehicles, construction/demolition waste, industrial refuse, special waste such as hospital waste, bulky waste, animal and agricultural waste, and sewage treatment residue (semi solid fraction known as sludge).

### **CLASSIFICATION OF SOLID WASTE**

The solid waste can be classified as per the Manual on Municipal Solid Waste Management, Government of India publication as follows:

- (i) Domestic/Residential waste: This type of waste is originated from single or multifamily household units. These wastes are generated from the household activities such as cooking (ashes) cleaning (dust) repairs (residues), hobbies (unuseables), redecoration, empty containers, used packets, old clothes, books, papers, broken glass, plastic items, broken and useless furniture.
- (ii) Municipal waste: Municipal waste includes waste resulting from municipal activities and services such as street sweepings, dead animals, market waste and abandoned vehicles. Generally, this term 'Municipal Waste' is used in a wider sense to incorporate domestic wastes, institutional wastes and commercial wastes.

(iii) Commercial waste: This category includes solid wastes that originate in offices, wholesale and retail markets, restaurants, hotels, warehouses (godowns) and other commercial establishments.

(iv) Institutional waste: These are those wastes generated from institutions such as schools, colleges, universities, hospitals and research institutes. Some of these wastes (like hospitals) may be hazardous (more bad, offensive, strong, disease producing) waste.

(v) Garbage: Garbage is the term applied to animal and vegetable wastes generated from the handling, storage, sale, preparation, cooking and serving of food. Such wastes contain putrescible (easily and quickly biodegraded with bad smell) organic matter. This attracts rats, flies, mosquito and other vermin, which is why it requires immediate attention.

(vi) Rubbish: It is a general term applied to solid wastes originating in households, commercial establishments and institutions excluding garbage and ashes.

(vii) Ashes: These are the residues from the burning of wood, coal, charcoal, coke and other combustible matter for cooking and heating in houses institutions and small industries. When produced in large quantities in thermal power plants (fly ash) they are known as industrial wastes. Ashes consists of fine powdery residue, cinders and clinkers often mixed with small pieces of metal and glass.

(viii) Bulky waste: Bulky wastes are large household wastes that cannot be accommodated in the normal storage containers of the household and thus they require special collection. Actually in India there is hardly any waste collected in this category as it is sold to the kabaries.

(ix) Street sweepings: The waste collected from streets, walkways, parks etc. is known as street sweepings. In developing countries like our country manual street sweeping is done and it makes the largest portion of the municipal solid waste as we are in a habit of throwing everything on the streets. It includes mainly dust, dirt, plastic bags (thin), dry leaves, useless papers, cardboard, rags, tyres, vegetable matter etc. In our country most of the usable portion of the waste like rags, paper, thick plastic bags, plastic utensils, any form of metal is collected by the rag pickers. The organic matter including the paper and even plastic sheets is consumed by cows and other stray animals. Only in big cities or the developed countries they form the part of waste. That is why the calorific value of Indian solid waste is far less in comparison to the other countries.

(x) Dead animals: This term includes the dead animals that die naturally or by accidents on roads. It does not include the animal parts from slaughter houses which are regarded as industrial waste. There are two types of dead animals, large and small. The smaller ones like dogs cats rabbits, rats etc., are either consumed by the other animals or can be easily lifted and disposed. The large ones like cows, horses, camels etc. require special and immediate attention as traffic is affected and they emit foul smell.

(xi) Construction and demolition waste: These are the wastes generated by the residue of the construction, refurbishment, repair and demolition of houses, commercial buildings and other structures. Generally, the demolition waste is used by the contractors in filling low lying areas and the plinth filling of new houses and nothing is left on the sites. Even then some small quantity of sand, stone or concrete may be left.

(xii) Industrial wastes: The discarded solid material of manufacturing processes and industrial operations comes in this category. There is a vast range of substances that are unique for each industry so they are considered separately from municipal wastes.

(xiii) Hazardous waste: Hazardous waste is defined as wastes of industrial, institutional or consumer origin that, because of their physical, chemical or biological characteristics are potentially dangerous to human beings and the environment. In some cases the active agents may be liquid or gaseous, they are classified as solid waste because they are confined in solid containers.

Typical examples are solvents, paints, and pesticides whose spent (empty) containers are frequently mixed with municipal wastes and become part of the urban waste stream. Certain hazardous waste can explode in the incinerators (controlled large kilns) and cause fires at land fill sites. Others such as pathological (disease producing) wastes from hospitals and radioactive waste, require special handling at all times. Proper management practice should ensure that hazardous wastes are collected, stored, transported and disposed off separately, preferably after treatment to make them harmless.

(xiv) Sewage waste: The solid by-products of sewage treatment are classified as sewage wastes. They are mostly organic and produced from the treatment of organic sludge from both the raw and treated sewage. The inorganic fraction of raw sewage such as grit is separated at the preliminary stage of treatment, but because it entrains

putrescible organic matter that may contain disease producing bacteria (pathogens), must be buried or disposed of quickly.

**Table 4.1 Classification of Solid Waste in Tabular Form**

<b>Type of solid waste</b>	<b>Description</b>	<b>Sources</b>
Food Waste (garbage)	Waste from preparation, cooking and serving of food market refuse, waste from handling, storage and sale of meat and vegetables	Households, institutions and commercial centers such as hotels, stores, restaurants, markets etc.
Rubbish	Combustible (primarily organic) paper, cardboards, cartons, wood boxes, plastics, rags, clothes, beddings, lather rubber grass, leaves yard trimmings. Non combustible (primarily inorganic) metals, tin cans, metal foils, dirt, stones bricks, ceramics, crockery, glass bottles, other mineral refuse	As above
Ashes and residues	Residues from fires used for cooking and for heating buildings, cinders, clinkers, thermal power plants.	As above
Bulky waste	Large auto parts, tyres stoves, refrigerators, other large appliances, furniture, large crates, branches of trees etc.	As above
Street waste	Street sweepings, dirt, leaves, catch basin dirt animal droppings content of litter receptacles dead animals	Streets, sidewalks, alleys, vacant plots
Dead animals	Small animals: cats, dogs, poultry etc. Large animals: horses, cows etc.	Same as above
Construction and demolition waste	Plumber, roofing and sheathing scrap, rubble broken concrete plaster, conduit pipes, insulating wires etc.	Construction and demolition sites, remodeling, repairing sites
Industrial waste & sludges	Solid wastes resulting from industry processes and manufacturing operations, such as food processing wastes, boiler house cinders, wood plastic and metal scraps and shavings etc., sludge of sewage treatment plants and septic tanks, coarse screenings grit etc.	Factories, power plants, treatment plants etc.
Hazardous waste	Hazardous wastes: pathological waste, explosives, radioactive material toxic waste etc.	Households, hospitals, institutions, stores, industry etc.
Horticulture wastes	Tree trimmings, leaves, waste from parks and gardens etc.	Parks gardens roadside trees etc.

## Simple Diagram of a Solid Waste Stream:

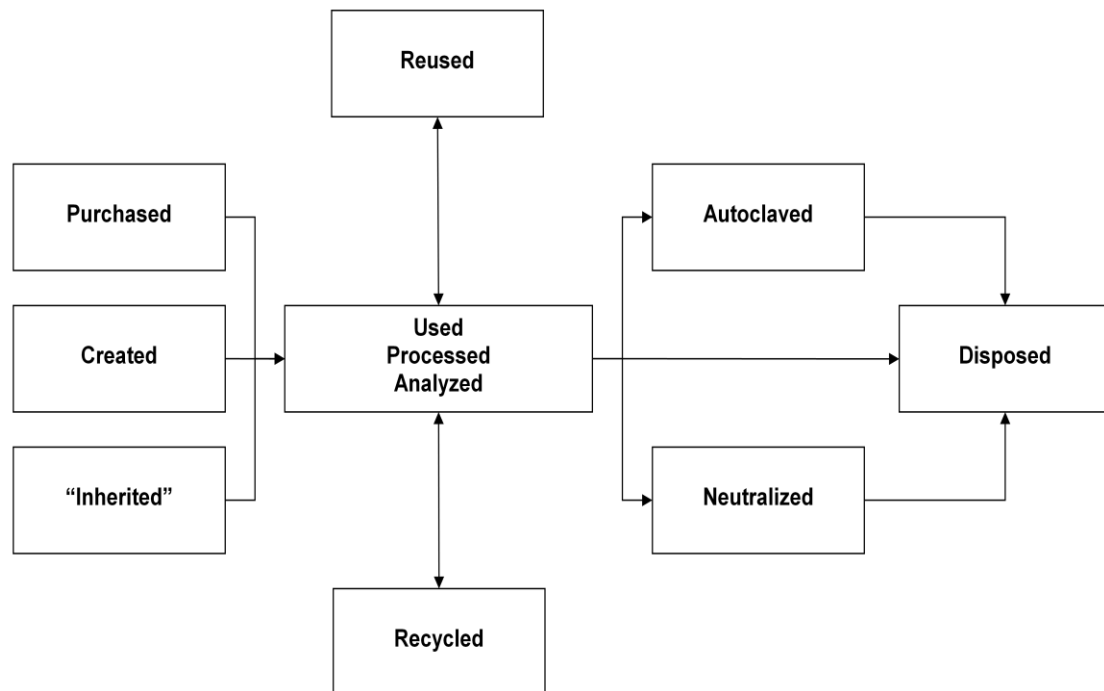
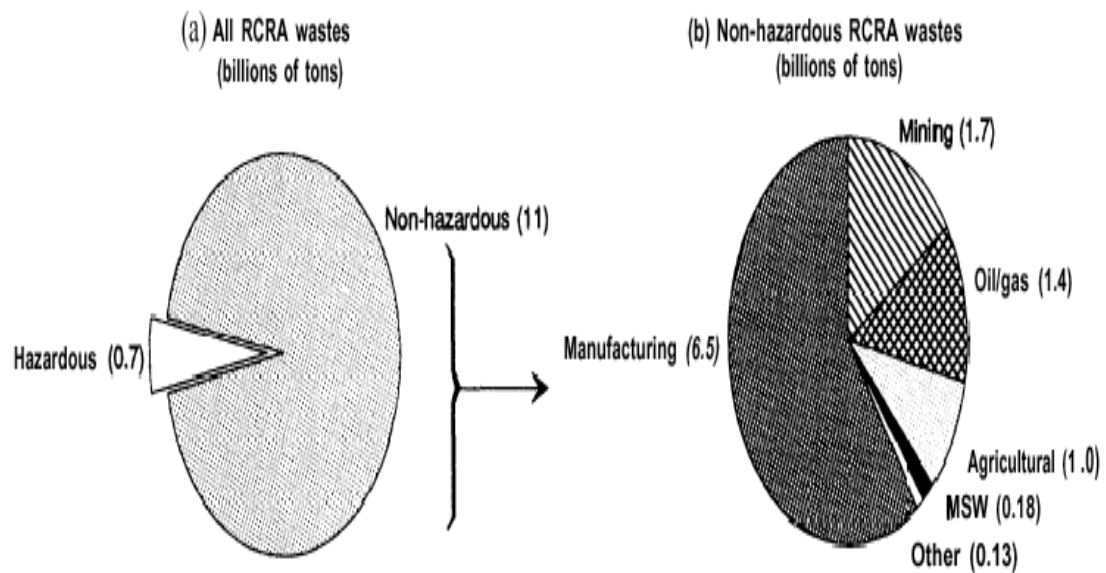


Figure 1-2—"Solid" Wastes as Defined Under the Resource Conservation and Recovery Act (RCRA)



## PHYSICAL CHARACTERISTICS

(i) Density: The knowledge of density is important for the design of all elements of the solid waste management systems like storage, transport and disposal. For example for a known volume of the solid waste its density gives us the idea about the requirement of the truck in tonnage. Every truck or similar vehicle has a permitted load capacity say 12 ton or so which it can carry according to law. In developed countries as their waste is light so compaction reduces the cartage charges substantially. The density varies significantly from source to the disposal site because of handling, change in moisture content, densification due to vibration of movement, disturbance by animals and birds (scavengers) etc. The following table gives some data from MSWM for density of municipal solid waste in some Indian cities. It is evident from the above table that density is more in Jaipur waste as because of desert conditions there is more sand and other inorganic heavy matter. These figures are only indicative and are to be verified before the actual design of a system. Actually it is very important that the solution to any SWM problem should be site specific and time specific. The same city may show different composition after some years.

(ii) Moisture content: Moisture content of the solid waste is expressed as the weight of moisture per unit weight of wet material. Moisture content varies generally from 20 to 45% depending upon the climatic conditions and level of city (income group) etc. The increase of moisture content increases the weight and thus the cost of transportation and thus the storage section should take care of it.

(iii) Calorific value: Calorific value is the amount of heat generated from combustion of a unit weight of a substance, expressed as kilo calorie per kilogram. The calorific value is determined in the laboratory by Bomb Calorimeter. Table 4.3 shows typical values of the residue and calorific value for the different components of the municipal solid waste. If the energy is to be recovered or the waste is to be disposed, by incineration (controlled burning) the following points should be considered:

- Organic matter gives energy only in dry condition.
- The moisture content as free water reduces the dry organic matter per kilogram and hence requires a significant amount of energy for evaporation.
- The ash content of the waste reduces the proportion of dry organic material per kilogram of waste. It also retains some heat. So for economic recovery of energy the waste should contain minimum amount of moisture, ash and other inorganic matter.

These are the significance of determination of physical characteristics.

## **CHEMICAL CHARACTERISTICS**

The chemical characteristics of solid waste are determined for assessing the treatment process. Mainly three chemical characteristics are determined, chemical, bio-chemical and toxicological.

- Chemical quantities of solid waste in Indian urban centers are pH, nitrogen, phosphorus, and potassium (N-P-K), total carbon, carbon/nitrogen ratio, calorific value.
- Bio-chemical characteristics include carbohydrate, proteins, natural fiber, and biodegradable factor.
- Toxic characteristics include heavy metals, pesticides, insecticides etc.

Consideration of lipids (fats, oils and grease) should also be done as they are of a very high calorific value (about 38000 Kcal/kg). These days synthetic organic materials like plastic have become a significant component of solid waste accounting for 5-7%. Non-biodegradable and thus poses a great problem. It chokes the drains and if burnt it produces poisonous gases. The thin plastic sheets and bags are not recycled as the cost of making it dirt & oil free makes the process uneconomical.

All the above considerations of characteristics are required to design, conceive and assess the most appropriate ways of transportation, the requirements of treatment, extraction of energy and the safe, sanitary way of disposal for the protection of environment.

## **WASTE MANAGEMENT APPROACH**

The solid waste management has a twofold approach. First is the minimization of waste at the source and other is the control on environmental pollution during its storage, conveyance and disposal. Prevention is always better than cure. If the production of waste can be reduced at the source level it shall reduce the cost of conveyance treatment, disposal and shall save the environment. The waste minimization techniques are grouped in four major categories for hazardous as well as non-hazardous waste, as follows:

### **1 Inventory Management and Improved Operation**

- Inventorisation (making stock registers) and tracing of all raw materials.
- Purchasing of lesser toxic and more non-toxic production material.



- Implementation of employee's training and management feedback.
- Improving material receiving, storage and handling practices.

#### Modification of equipment

- Installation of equipment that produce minimum waste.
- Modification of equipment to enhance recovery or recycling options.
- Redesigning of equipment or production lines to produce less waste.
- Improving operating efficiency of equipment.
- Observing strict preventive maintenance programme.

#### Modifications in Production Process

- Selection of non-hazardous raw material.
- Segregation of waste for recovery.
- Identification and elimination of leakages.
- Optimization of reactions and raw material use.

#### Recycling and reuse

- Installation of closed-loop systems
- Recycling off site for another use
- Exchange of wastes

By adopting the above waste minimization techniques the waste is minimized at the source so that its handling and transportation charges are reduced and lesser efforts are to be done in disposal.

## **2 Utilization of Waste**

After minimizing the waste at source one can think about the utilization of waste of one operation in the other operations as shown in the table below.

**Table 4.7 Utilization of Waste**

<b>S. No.</b>	<b>Waste</b>	<b>Areas of application</b>
1	Flyash (fine coal ash generated by combustion of coal in power plants etc. One portion is the bottom ash another is the one collected in the separators from the flue gases.)	<ul style="list-style-type: none"> <li>i As raw material in manufacturing of cement</li> <li>ii As binding material with cement</li> <li>iii As filler in mines</li> <li>iv As plasticizer</li> <li>v As an aggregate in cellular concrete bricks and blocks</li> <li>vi For stabilization of soil</li> </ul>
2	Blast furnace slag	<ul style="list-style-type: none"> <li>i Manufacturing slag cement, super sulphated cement</li> <li>ii Making expansive cement, coloured cement and high early-strength cement</li> <li>iii In refractory and ceramic industry</li> <li>iv As a structural fill</li> <li>v As aggregate in concrete</li> </ul>
3	Ferro-alloy and other metallurgical slag	<ul style="list-style-type: none"> <li>i As structural fill</li> <li>ii In making pozzolana metallurgical cement</li> </ul>
4	Byeproduct gypsum	<ul style="list-style-type: none"> <li>i Gypsum plaster</li> <li>ii As retarder in cement setting</li> <li>iii As mineraliser</li> </ul>
5	Lime sludge (phos-phochalk, paper and sugar sludges)	<ul style="list-style-type: none"> <li>i As a sweetener for lime in cement manufacture</li> <li>ii Manufacturing of lime pozzolana brick/ binders</li> <li>iii For recycling in parent industry</li> <li>iv Manufacturing of building lime</li> </ul>
6	Chromium sludge	<ul style="list-style-type: none"> <li>i As a raw material component in cement sludge</li> </ul>

Contd....

		ii Manufacturing of coloured cement as a chromium bearing material
7	Red Mud	i As a binder ii Making construction blocks iii As a cellular concrete additive iv Coloured composition for concrete v In making floors and other tiles vi Red mud polymer door
8	Pulp and Paper	Lignin

After having all this information let us examine the present status of solid waste management and what should have been done.

## **SOLID WASTE MANAGEMENT: AN OVERVIEW**

The solid waste management has the following components:

- (i) Identification of waste and its minimization at the source
- (ii) Collection, segregation and storage at the site of collection
- (iii) Transportation
- (iv) Treatment
- (v) Energy recovery
- (vi) Disposal

### **1 Identification of Waste and its Minimization at the Source**

By the above described classification methods one can identify the waste easily. Identification helps in further processes of transportation, treatment and disposal, for example the hazardous waste is to be tackled in a different manner than the ordinary MSW. The minimization of the waste production is the best strategy. For this, first of all the process should be such that there is a least production of waste. For example if in a footwear making industry if the cut on the rubber sheet is made in such a way that alternate piece of the pair are placed one by the side of other; there shall be least production of waste sheet. Then the next step is to reuse the remaining waste sheet in the same process. But now there is a limit beyond which this cannot be used to maintain the required quality. This further remaining portion of the sheet comes as real waste to this process of footwear making. Now if a toy making machine is installed in the same factory which can use this remaining rubber sheet as the raw

material. Then there shall be no waste production in the first factory and only the second unit shall produce some waste. Thus, the waste has been minimized at the source. This reduces the cost of transportation etc. everything. The second example is the production of flyash as the waste in the thermal power plants. A huge quantity of flyash is produced where coal is burnt for making electricity. This flyash requires a large valuable land for disposal. As this flyash can be used for making of flyash bricks, making of cement and can be used with cement as binder etc; if sold or supplied free of cost from the site itself ; shall reduce the burden of disposal. The third example is the utilization of waste food products in a hostel or a hotel for making biogas. By the anaerobic digestion of this organic matter (waste food) the biogas can be produced easily. This gas can be used there itself for cooking or heating purposes. This shall reduce the biodegradable waste at the source itself. The fourth example is the utilization of kitchen waste in a household in making the compost and utilizing it in the kitchen garden itself. If more advanced techniques like Vermi-composting are adopted this can be done in a more beneficial way.

The above mentioned methods can be adopted on a large scale also, but for that the waste is firstly collected, transported and then utilized. This incurs a large cost. So it is always preferable that if the waste production is minimized or the waste is reused, recycled at the source itself. Thus, the waste minimization is achieved through careful planning, changing attitude, sometimes special investments (as the toy factory in the above example), and most important is a real commitment. The self-motivated willing reduction of waste is generally not possible, so strict enforcement of the law should be there. The waste reduction and reuse, recycling should be given incentives from the government in the form of tax reduction and soft loans.

## **2 Collection, Segregation and Storage at the Site of Collection**

The main problem of solid waste management is the collection of solid waste. The household waste consists of all types of general waste. At present there is no scientific, clean, hygienic, efficient practice of waste collection including the metro cities. There is no practically imposed penalty on throwing of waste on the streets. Even defecating on open plots, sides of roads, railway lines; spitting on roads is a very common practice and nobody bothers about it. The ugly unhygienic scenes, and the bad smell (due to anaerobic digestion of organic matter) worsen the situation. Actually we are in a bad habit of either throwing the waste in front of the neighbor's

door, or on a vacant land or directly on the road. Even if the municipality provides a waste collection bin, nobody bothers to put the waste carefully in it. So the collection of waste is a big problem. In most of the developing countries the waste is handled manually. First of all the sweepers sweep the roads, streets etc. with their age old brooms (with poor designs). Then they will make heaps of the collected waste. The other person then lifts this collected waste to some ill maintained wheel barrows and transport it to the collection depots and make a heap there. Then the rag-pickers shall start their work and pick only most useful items to them as the thick plastic bags or metal if any. The stray animals like dogs, cows, pigs shall find their food from this heap and scatter it on the collectyion site. Then it shall be manually picked up at some irregular interval, transported in open tractor trolleys and then disposed off on some open land.

The industrial waste is also handled in the same way. The collection and storage of waste is the most neglected operation in any industry. The wastewater having harmful colours, dyes, metals, heavy metals, organic matter (having high BOD) is discharged in the open drains to pollute the land and the river water. Similarly, the solid waste is thrown in open areas wherever the nearest site is available (may it be unguarded private land or government land).

The best way would have been the segregation of waste at the generation point. Segregation means collecting it in different bins, or plastic bags. The domestic waste can be broadly separated as reusable (paper, plastic, metal etc.), and non reusable. The non reusable may have organic matter like kitchen waste or inorganic matter like dust, dirt etc. The organic matter is liable to decomposition (putrescible) and thus requires immediate attention. Fortunately in India the usable matter is rarely discarded as solid waste except which cannot be sold to kabaries. So even if only two containers or bags are used for separating organic and inorganic waste the problem is solved. This separated waste should be regularly collected by the worker directly from the houses at some well-defined time. Then it should be transported in (covered vehicles)to some waste collection depots for utilization/transportation to different sites. The organic waste can be used for the production of biogas or for the extraction of energy, incineration (controlled burning or making organic compost, and vermi-composting. The storage in the intermediate collection sites should again be covered and out of the reach of the stray animals. Here it is proposed to make payment to the person collecting waste on the basis of the weight/volume of the waste collected by him/her

and not on the daily basis. Here lies the actual problem. Because of the structure of the local municipal corporations and many other pressures this is generally not feasible. This is possible only if this work is given on contract basis and the work is done in a scientific professional way with the people's participation (segregation and proper handing over of the waste).

### **3 Transportation of Solid Waste**

As stated earlier the waste is transported from the storage depots to the disposal sites in tractor trollies or ill designed open trucks. Though it has been instructed by the Hon'ble court that the transportation must be done in closed containers only. The industrial waste must be transported separately and must be disposed in a safe way after suitable treatment. Any type of the hazardous waste should be labeled and coded so that in case of an accident the emergency services know how to handle a spillage. Actually the work of transportation of solid waste must be done through the technically competent and well reputed contractors under the strict supervision of the experienced and honest municipal authorities and watchful citizens.

### **4 Treatment of Solid Waste**

The waste has to be treated before disposal for the protection of environment. In the treatment the biodegradable waste can be processed by composting, vermi-composting, anaerobic digestion or any other appropriate biological processing for stabilization of waste. Actually every organic matter has a tendency to be converted into inorganic matter as the later is a stabilized form. If this conversion takes place in absence of oxygen (anaerobic digestion) which is a general case in solid waste processing, foul gases are evolved. During the anaerobic decomposition dirty, offensive dark coloured fluid is also generated that is known as the leachate.

Generally the solid waste contains both municipal and industrial waste. Small scale industries also generate huge quantity of solid waste and they are generally not in a position to treat their waste individually. It is therefore advisable that in a group of small scale industries the different wastes are characterized, identified, quantified and stored for treatment through a combination of recycling, recovery and reuse of resources such as, raw material, bio gas, steam and manure. The combined effluent treatment plants are to be operated by the local bodies where the cost of construction operation and maintenance is to be shared by the industry in proportion to the quality

and quantity of their waste. However the assessment of the quality and quantity of waste is very difficult and requires appropriate testing facilities. In any case the solid waste should be reduced in quantity at the source, segregated, then carefully transported and the economically treated before the final disposal.

## **5 Energy Recovery and Disposal**

The most common methods of energy recovery and disposal for non-hazardous solid waste are incineration, composting and landfill. The final disposal of waste should be done in such a way that it remains a waste in actual sense, i.e. nothing can be recovered out of it and it could not be used anywhere. So before putting it on land for landfilling if it has a substantial portion of biodegradable fraction then compost (organic manure) should be made out of it. This shall reduce the final volume of the waste to be disposed on land and shall give us money in terms of the manure. The organic manure is environment friendly and also provides us micronutrients that increase the fertility of the soil. If this work is done more effectively by some special worms this is known as vermi-composting.

### **5.1 Incineration**

Incineration means burning of solid waste in controlled conditions. The most usual practice of disposal of solid waste is burning in open fields. This slow burning at low temperature produces many hazardous gases. Generally the waste is collected in the streets or roads and the heap of this waste is left there itself for drying or collection of more waste on it. Then this waste is either transported to some distant site or burnt there itself. This waste contains inorganic matter also and because of this burning in heaps there is no control of supply of oxygen or rather there is no oxygen supply except that present in the voids. This incomplete combustion at a low temperature produces hazardous gases and these gases pollute the environment very close to us. Particularly the gases produced by the burning of plastic, rubber and other such materials produce very much harmful gases. Incinerator means any enclosed device using controlled flame combustion. Incineration uses heat to convert complex toxic organic compounds into mostly carbon dioxide and water. At temperatures ranging from 400 to 1600°C complex organic molecules break down into basic atoms. The incineration is a good method of disposal and recovery of energy (in the form of heat produced by burning) only if it works properly. The combustion temperatures of

conventional incinerators are about 760° C in the furnace and more than 870° C in the secondary combustion chamber. These high temperature are required to avoid odour from incomplete combustion but are not sufficient to burn or even melt the glass. Some modern incinerators use supplementary fuel to produce high temperatures upto 1650° C to convert even metal and glass to ashes. These incinerators reduce waste volume significantly i.e. upto 97%.

There are so many factors like thermal feed rate, waste feed rate, organic chlorine feed rate, minimum combustion gas temperature, gas residence time, adjustment of primary and secondary combustion units, removal of HCl, Suspended Particulate Matter (SPM) and other air pollutants produced; that are to be controlled. Actually, the incineration is best way of disposing hazardous waste, like hospital and other wastes. The incineration is definitely better than open burning but as stated earlier if it is not properly working, with all controls, then it can prove to be more dangerous, as it gasifies the pollutants and sends them to the atmosphere.

In general incinerators comprise of a storage pit, fuel tanks, a furnace, a heat recovery boiler, effluent gas purification unit, an induced draft fan and a stack (chimney). Though incineration is extensively used as a useful method of waste disposal, it is associated with some polluting discharges which are of environmental concern. These can effectively be controlled by installing suitable pollution control measures and by construction of furnace suitably and by controlling the combustion process. For the removal of SPM from the effluent gas a scrubbing water treatment unit or even Electro Static Precipitators are used in good installations.

## **5.2 Landfill**

The most common and easy way of disposal of solid waste is dumping it on land. The inorganic waste like construction and demolition waste can be easily used for filling of low lying areas or plinth filling of buildings or the earthwork of roads. When the combined waste (inorganic and organic) is disposed on the land then the decomposition of the organic matter takes place in due course of time. This decomposition produces gases (like methane) and dark coloured dirty offensive water known as leachate. If the ground on which the waste is disposed is pervious then this leachate percolates and mixes with the ground water and badly pollutes it. If the waste is hazardous means that contains harmful chemicals and heavy metals, or pathogens then the situation becomes more aggravated. The mixing of these pollutant through leachate makes the water polluted and contaminated. Secondly in open landfills the



rain water increases the volume of leachate and mixes it with the ground or surface water source more easily. So the landfill should be so designed that it contains an impermeable barrier to stop the mixing of leachate with the water. It should have a diversion for the rain water and proper arrangement of the collection treatment and disposal of leachate. Such type of landfill is known as the sanitary landfill and is the most desirable ones. They may appear costly, but for long lifetime of such works and comparing the end results the cost/ton of waste disposed might be less than any other method of disposal.

### **5.3 Composting**

The organic matter (consisting of carbon, hydrogen, nitrogen, oxygen, and sulfur) has a tendency of being converted into inorganic matter as the later is a stable form. The food, excreta and other organic waste gets decomposed (changed into inorganic form) and produce gases like biogas (mainly methane) and solids of decomposition like sulfates, nitrates, phosphates etc. These solid (nutrient) are extracted by the roots of plants and trees in dissolved form and they again produce the organic matter in the form of their products. Those products come in the food chain and again the organic waste is produced. This way the different natural cycles keep on proceeding. Composting is an organized method of producing compost manure (decomposed organic matter) through this natural phenomenon. Compost is more useful as it contains the nutrients like N, P, K as well as the micronutrients. Micronutrients like iron are very much useful for good health and immunity. As the organic matter can be decomposed in two ways i.e. in the presence of oxygen or in the absence of oxygen, composting can be done aerobically or anaerobically. During aerobic composting aerobic micro-organisms oxidize the organic compounds to carbon dioxide, nitrite and nitrates. The reaction is exothermic and the temperature rises. The nitrates, sulfates etc. are used by the plants and carbon is synthesized in the photosynthesis by the plants. In the anaerobic process the anaerobic bacteria, while metabolizing the nutrients, break down the organic compounds through a process of reduction. The gases evolved are mainly CH<sub>4</sub> and CO<sub>2</sub> (bio-gas). If collected properly as in a biogas plant the gas can be used for heating or even for driving engines. The composting can be done to the collected organic waste at some site or at the individual house hold.

### 5.3.1 Vermi-composting

In the case of households or colonies vermi-composting which involves the stabilization of organic solid waste through special earthworm by conversion of the organic matter to worm casting is also done. Vermicomposting involves the culture of earthworms(vermiculture) for the stabilization of different variety of organic solid waste. Earthworms feed on any organic waste and consume two to five times of their body weight, excrete the mucus coated undigested matter as wormcasts. Wormcasts consists of organic matter that has undergone physical and chemical breakdown through the muscular activity that grinds the material to a particle size of 1 to 3 micron. The nutrient present in the wormcast are easily soluble in water and are thus readily available for the plant growth. Vermi-composting is a rich source of macro and micronutrients, vitamins, enzymes, antibiotics and hormones. As per the MSWM the vermi-composting involves the stabilization of organic solid waste through earthworm consumption which converts the material into worm castings. Vermi-composting is the result of combined activity of micro-organisms and earthworms. Microbiological decomposition of biodegradable organic matter occurs through extracellular enzymatic activities (primary decomposition) whereas decomposition in earthworm occurs in alimentary tract by micro-organisms inhabiting the gut (secondary decomposition). Microbes such as fungi, actinomycetes, protozoa etc. are reported to inhabit the gut of earthworms. Ingested feed substrates are subjected to grinding in the anterior part of the worms gut (gizzard) resulting in particle size reduction. Vermitechnology, a tripartite system which involves biomass, microbes and earthworm as influenced by the abiotic factors like temperature, moisture and aeration etc. Microbial ecology changes according to change of abiotic factors in the biomass but decomposition never ceases. Conditions unfavorable to aerobic decomposition result in the death of earthworms and subsequently on vermi-composting occurs. Hence, preprocessing of the waste as well as providing favourable environmental condition is necessary for vermi-composting. The vermi-compost (manure) is relatively more stabilized and harmonises with soil system without any ill effects. Unfavourable conditions such as particle size of biomass and extent of its decomposition, very high temperature increase, anaerobic condition, toxicity of decomposition products, etc. matter much for the activity and progress of worms. This technology has been used for agriculture waste and is used on organic municipal solid waste also. The worms are special earthworms known as *Pheretima* sp, *Eisenia* sp,

and *Perionyx excavatus* sp. These worms survive in the temperature range of 20-40°C and moisture range of 20-80%. The worms do not survive in pure organic substrate containing more than 40% fermentable organic substances. So fresh waste is mixed with partially or fully stabilized waste before it is subjected to vermi-composting. The worms are also adversely affected by high concentrations of such heavy metals as cadmium, chromium, lead and zinc. Due to these problems the vermi-composting is successful more on the household level (vegetables etc, organic waste) than the municipality level.

## **ENERGY RECOVERY FROM MUNICIPAL SOLID WASTE**

The municipal solid waste contains organic (vegetables, food etc.) as well as inorganic matter (dust, dirt etc.). It is desirable that the energy present in its organic portion can be recovered through suitable processing and treatment technologies. Along with the gain of energy the following benefits are also there:

- (i) The total quantity of waste gets reduced by nearly 60 to 90% depending upon the characteristics of waste and the adopted process.
- (ii) As the quantity reduces the demand for land required for landfill as disposal also reduces.
- (iii) The cost of transportation also reduces as the quantity reduces.
- (iv) The overall environmental pollution reduces.

Therefore, the energy recovery is as useful as the reuse and recycle of waste at the source. Following are the basic techniques of energy recovery as per the MSWM:

- (i) Thermo-chemical conversion: This process entails thermal decomposition of organic matter to produce either heat energy or fuel oil or gas; and
- (ii) Bio chemical conversion: This process is based on enzymatic decomposition of organic matter by microbiological action to produce methane gas or alcohol. The thermo-chemical conversion processes are useful for wastes containing high percentage of organic non-biodegradable matter and low moisture content. The main technological option in this category includes Incineration (already explained) and Pyrolysis/ Gasification.

The biochemical conversion processes, are preferred for wastes having high percentage of organic bio-degradable (putrescible) matter and high moisture content.

The main technological option under this category is Anaerobic Digestion also known as Biomethanation.

## **1 Parameters Affecting Energy Recovery**

The main parameters that determine the potential of recovery of energy from waste are physical and chemical characteristics of waste and the recovery of energy also depends upon the process employed. The main physical parameters are:

- Size of constituent
- Density
- Moisture content

Smaller size of the constituents aids in faster decomposition of the waste due to more specific area. Waste of high density shows a high proportion of biodegradable organic matter whereas the low density indicates the higher presence of paper plastic etc. High moisture content causes biodegradable waste fraction to decompose more rapidly than in dry conditions. The high moisture content makes the waste rather unsuitable for thermo-chemical conversion (like incineration, pyrolysis, gasification) for energy recovery as a major amount of heat is wasted in evaporating the moisture.

The important chemical parameters for determining the energy recovery potential and the suitability of waste treatment through bio-chemical or thermo-chemical conversion are as follows:

- Volatile solids
- Fixed carbon content
- Calorific value
- Carbon and nitrogen ratio
- Toxicity
- Inerts

For different processes of energy recovery the desirable range for different parameters is shown in the table given below. Generally for achieving satisfactory extraction of

energy sorting, segregation and addition of required parameters is necessary.

**Table 4.8 Desirable Range of important Waste Parameters for Technical Viability of Energy Recovery ( source manual on MSWM)**

<b>Waste treatment method</b>	<b>Basic principle</b>	<b>Important waste parameters</b>	<b>Desirable range (suitably processed waste)</b>
Thermo-chemical Conversion	Decomposition of organic matter by action of heat	Moisture content Organic/Volatile matter	< 45% > 40%
Incineration pyrolysis gasification		Fixed carbon Total Inerts Net-calorific value	< 15% < 35% > 1200 kcal/kg
Bio-chemical conversion	Decomposition of organic matter by microbial action	Moisture content Organic-Volatile matter	> 50% > 40%
Anaerobic digestion/ bio-methanation		C/N ratio	25–30

Like this energy can be recovered from the solid waste which reduces the volume also and makes the waste suitable for final disposal. Now the final disposal may be as landfill, but it has also to be done in such a way to protect the environment from its bad effects (like leachates etc.). That is known as sanitary landfill.

## **SANITARY LANDFILL**

The term ‘Landfill’ means a unit operation for final disposal of municipal solid waste on land that is designed and constructed with the objective of minimum impact on the environment. The term sanitary landfill is used for a landfill with the provision of liner (protective layer) and leachate collection system to prevent ground water contamination. Landfilling is done for the mixed waste that is not hazardous but not found suitable for waste processing, and recycling. Land fill is not suggested for bio waste as energy can be recovered out of it and its decomposition in the landfill shall produce leachates. Actually landfilling should be used as the final disposal method and should be adopted for the waste from which the recycling is not possible and economic extraction of energy is also not possible. Sometimes it is useful for hazardous waste disposal, but then it has to be done very carefully. The following are the essential components of a MSW landfill as per the manual on MSWM:

- (i) A liner system at the base and sides of the landfill which prevents migration of leachate or gas to the surroundings soil.

- (ii) A leachate collection and control facility which collects and extracts within and from the base of the landfill and then treats the leachate.
- (iii) A gas collection and control facility which collects and extracts gas from within and from the top of the landfill and then treats it or uses it for energy recovery.
- (iv) A final cover system at the top of the landfill which enhances surface drainage, prevents infiltrating water and supports surface vegetation.
- (v) A surface water drainage system which collects and removes all surface runoff from the landfill site.
- (vi) An environmental monitoring system which periodically collects and analyses air, surface water, soil-gas and ground water samples around the landfill site.
- (vii) A closure and post closure plan which lists the steps that must be taken to close and secure a landfill site once the filling operation has been completed and the activities for long term monitoring, operation and maintenance of the completed landfill.

## **HAZARDOUS WASTE MANAGEMENT**

It is difficult to define the hazardous waste exactly as it is a very general and wide term. However, it may be defined as any waste in solid, liquid or gaseous form which because of its quantity and concentration or its physical, chemical, radiological, or infectious characteristics, may cause ill effect on the human health or the environment if not properly stored, transported and disposed. The designation of a material to be hazardous is done through the standard tests for the following criteria:

- Radioactivity: If the level of radioactivity exceeds the permissible concentration limits the waste is termed as hazardous.
- Bio-concentration: This criteria is used for chemicals such as chlorinated hydrocarbon pesticides.
- Flammability: The ease with which certain substance catches fire and sustains combustion.
- Reactivity: Chemicals like sodium are extremely reactive with water.
- Toxicity: The capacity of causing damage to the human health and the environment, like the poisonous effect is the measure of toxicity.
- Genetic and carcinogenic potential: The potential of causing cancer etc.

By the above criteria the hazardous waste can be identified but the actual impact is based upon the quantity. It can be suggested that the most suitable method of dealing

with hazardous waste is converting it into non-hazardous form, but that is not possible always, and may not be economical and technically possible also. The most commonly used method of disposing of hazardous waste is the hazardous waste landfill. The specially designed landfills are used to provide complete protection for the surface and subsurface waters from the hazardous waste. As they have to carefully deal with, such type of landfills are equipped with clay liners, monitoring wells and ground water barriers. The strategy is strict segregation from the environment and complete care in storage and transportation.

The waste generated from medical activities can also be hazardous, toxic and even lethal because of their high potential of disease transmission. The hazardous and toxic part of waste from hospitals comprising infectious, bio-medical and radioactive materials as well as sharps (needles, knives etc.) creates a great risk if not handled properly. Actually a major part of biomedical waste is non-hazardous, but if proper segregation is not there it makes the whole waste as hazardous. Apart from a part of hazardous waste the biomedical waste should be studied separately.

## **BIO-MEDICAL WASTE**

As per the manual on MSWM the bio-medical waste means any solid and/or liquid waste including its container and any intermediate product, which is generated during the diagnosis, treatment or immunization of human beings or animals or in research pertaining there to or in the production or testing thereof. The physico-chemical and biological nature of these components, their toxicity and potential hazard are different, necessitating different methods/options for their treatment/disposal in schedule I of the bio-medical waste (management and handling) the waste originating from different kinds of such establishment, has been categorized in different categories as below:

Components of bio-medical waste

- Human anatomical waste (tissues, organs, body parts etc.)
- Animal waste (as above from veterinary hospitals etc.)
- Microbiology and biotechnology waste, such as laboratory cultures, microorganisms, human and animal cell cultures, toxins etc.
- Waste sharps, such as hypodermic needles, syringes, scalpels, broken glass etc.
- Discarded medicines and cyto-toxic drugs.



- Soiled waste such as dressings, bandages, plaster casts, material contaminated with blood etc.
- Solid waste (disposable items like tubes, catheters etc. excluding sharps).
- Liquid waste generated from any of the infected areas.
- Incineration ash.
- Chemical waste.

If the above mentioned bio-medical wastes are not handled properly they shall create many hazards. As per the manual on MSWM the following are the main environmental concerns with respect to improper disposal of bio-medical waste management:

- Spread of infection and disease through vectors (fly, mosquito, insects etc.) which affect the in-house as well as surrounding population.
- Spread of infection through unauthorized recycling of disposable items such as hypodermic needles, tubes, blades, bottles etc.
- Reaction due to use of discarded medicines.
- Toxic emissions from defective/inefficient incineration.
- Indiscriminate disposal of incinerator ash/residues.

For safe handling of the biomedical waste it is recommended that proper labeling and colour coding is done. It is desirable to use colour coding means use of specific coloured container with liner/sealed container (for sharps) for particular wastes. The untreated waste should not be stored for a period of more than 48 hours. For this purpose a simple notice in English, Hindi and local language describing clearly about the storage of a particular category of waste in a particularly labeled and coloured container is a must. The container should be sturdy enough, without any puncture and leakage. The container should be covered and preferably operated by foot. In case of plastic bags they should be fitted securely in a container. The sharps must be stored in a puncture proof container and before putting them in the containers they must be mutilated by a needle cutter. The containers should be wheeled and placed in a permanent position tightly. They should be carried for further transportation preferably from the separate corridors and should not cross the regular path of patients and visitors. Different methods of treatment and disposal are useful for the different category of the bio-medical waste. Depending upon the quantity of waste generated small installations may adopt local (in house) disinfections, mutilation/shredding and



autoclaving and off-site incineration at a common facility followed by a sanitary and secured landfill.

**Questions:**

1. Define the term waste. What do you mean by solid waste?
2. Describe 'solid waste management'.
3. What is the problem of solid waste? How much solid waste is produced in our country?
4. How do you classify the solid waste and what is the importance of classification?
5. What is hazardous waste and its problem?
6. Explain the terms garbage and rubbish.
7. Describe the composition of solid waste.
8. Tabulate and explain the physical characteristics of solid waste.
9. Tabulate and explain the chemical characteristics of solid waste.
10. What are the expected quantities of solid waste?
11. Tabulate the quantities of solid wastes in Indian urban centres.
12. Describe the physical characteristics of solid waste like density, moisture content etc.
13. Describe the chemical characteristics of solid waste.
14. Describe the waste management approach with inventory management etc.
15. How can the solid waste be utilized?
16. Write down the detailed overview on solid waste management.
17. Explain the different ways and means of collection of solid waste.
18. Explain the different ways and means of transportation of solid waste.
19. Explain the different ways and means of treatment of solid waste.
20. Describe the term energy recovery from solid waste.
21. What is incineration? Describe the process of incineration.
22. What is landfill? Describe the problem of leachate.
23. Describe the term composting, its methods and advantages.
24. What is vermi-composting? Explain the process and its advantages.
25. Write in details the method of energy recovery from solid waste. What are the parameters that affect the energy recovery?

26. What is the desirable range of waste parameters for technical viability of energy recovery?
27. What is sanitary landfilling
28. Explain in details the hazardous waste management.
29. What is biomedical waste and what are the special measures to be taken in its management?
30. Write a short note on biomedical waste management.