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Environment

Environment defined as the sum total of water, air, and land and interrelationships that exist among them and also with the human beings, other living organisms and materials. Environment includes all the physical, chemical, biological and conditions that surround and affect organisms during lifetime.

Environmental Engineering

Environmental engineering is the integration of science and engineering principle to:

- improve the natural environment,
- provide healthy water, air, and land for human habitation and for other organisms,
- Clean up pollution sites.

Pollution

Pollution is the introduction of contaminants substance (gas, liquid, solid, or mix) or energy (heat, light, noise, or radiation) into environment that cause damage and undesirable change in the physical, chemical, biological characteristics of the air, water, or land which then affect the health, survival or activities of human and other living organisms.

Pollutants

A pollutant is any substance that causes pollution. Pollutants may be chemical, biological, thermal, radioactive or even mechanical (dust, sediment, grit, etc.). A pollutant has also been defined as any solid, liquid, or gaseous substance present in such concentration or energy as may be or tend to be injurious to the environment. These pollutants may be introduced into environment naturally or by human activity.

The various air, water, land pollutants:

- 1) Deposited matter: soot, smoke, tar, dust, grit, etc.
- 2) Gases: oxides of nitrogen (NO, NO₂), sulfur (SO₂), carbon mono oxide (CO), halogens (chlorine, bromine, iodine).
- 3) Acids droplets: sulphuric acid, nitric acid, etc.
- 4) Fluorides.
- 5) Metals: Mercury, lead, iron, zinc, nickel, tin, cadmium, chromium, etc.
- 6) Agrochemicals: Biocides (pesticides, herbicides, fungicides, etc.), fertilizers.
- 7) Complex organic substance: benzene, ether, acetic acid, etc.
- 8) Solid wastes.
- 9) Reactive waste.
- 10) Noise.
- 11) Odor.

Kinds of pollutants

Pollutants can be classified into two basic types:

- 1) Non-degradable pollutants: Those that either not degrade into simple or degrade only very slowly in nature and harmless substances. Some of these pollutants accumulate in the living organisms. Such as plastics, polyethylene, bags, insecticides, pesticides, mercury, lead, arsenic, heavy metals, synthetic fiber, glass objects, iron products and silver foil are non-biodegradable pollutants.
- 2) Biodegradable pollutants: Those pollutants can be harmless substances in nature and can be broken down into simpler in due course of time by the action of micro-organisms like certain bacteria. They may great problems when they accumulate. Domestic waste (garbage), urine, faecal matter, sewage, agriculture residues, paper, wood, cloth, cattle, animal bones, leather, wool, vegetable stuff or plants are biodegradable pollutants

Forms of pollution

The major forms of pollution are:

- 1) Air pollution.
- 2) Water pollution.
- 3) Soil pollution.
- 4) Marin pollution.
- 5) Noise pollution.
- 6) Radioactive contaminants.

1) Air pollution.

Air pollution is the release of chemicals and particulates into the atmosphere. Common gaseous pollutants included carbon monoxide, sulfur dioxide, chlorofluorocarbons (CFCs) and nitrogen oxide produced by industry and motor vehicles. Photochemical ozone and smog crated by nitrogen oxide and hydrocarbons react to sunlight.

2) Water pollution

Water pollution cause by:

- Discharge of wastewater from commercial and industrial waste (intentionally or through spills) into surface water.
- Discharges of untreated domestic sewage and chemical contaminants such as chlorine from treated sewage.
- Release of waste and contaminants into surface runoff flowing to surface waters (including urban runoff and agricultural runoff, which may contain chemical fertilizers and pesticides).
- Waste disposal and leaching into groundwater, eutrophication, and littering.

3) Soil pollution.

Soil pollution occurs when chemicals are released by spill or underground leakage. The most soil pollutants are hydrocarbons, heavy metals, herbicides, pesticides and chlorinated hydrocarbons.

4) Marin pollution

Marin pollution occurs when polluted material entering the sea or ocean. These pollutants include most nutrients, sediments, pesticides, heavy metals, pathogens, and thermal pollution. The pollutants come from land-based sources, such as sewage, forestry, farming activities, industrial discharges, mining and landfill sites oil. 50% of oil pollution of the marine environment comes from land as runoff from cars, heavy machinery, industry and other land-based sources. Shipping of crude oil, oil spills resulting from accidents.

5) Noise pollution

Noise pollution is the disturbing or excessive noise that may harm the activity or balance of human or animal life. two type of noise:

- **The outdoor noise:** the source of most outdoor noise worldwide is mainly cause by machines and transportation systems, motor vehicles, aircraft, and trains. The outdoor summarized by the environmental noise.
- **The indoor noise:** this can cause by machines, building activities, and music performances, especially in some workplaces.

6) Radioactive pollution

Radioactive pollution is the release the radioactive waste into the environment. This radioactive material emitted radiation. This radiation causing abnormal growth and possibly cancer, and this radiation remain in the atmosphere for years, slowly diminishing over time. The sources of radioactive pollution are the major sources of the radioactive wastes that are generated and are responsible for radioactive pollution are as follows:

- (i) Uranium mining
- (ii) Production of nuclear fuel
- (iii) Nuclear power reactors
- (iv) Use of radioactive isotope in industries for various applications
- (v) Nuclear tests
- (vi) Disposal of nuclear waste.

Pollution allowable limits in the environment

The pollution allowable limits mean the specification of maximum allowable concentration of pollutants permissible in the environment. Such specification, usually known as “Environmental quality standards’ (EQS), or “ambient environmental standards’ (AES).

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National Ambient Air Quality Standards (NAAQS)

Pollutant [final rule cite]		Primary/ Secondary	Averaging Time	Level	Form
Carbon Monoxide [76 FR 54294, Aug 31, 2011]		primary	8-hour	9 ppm	Not to be exceeded more than once per year
			1-hour	35 ppm	
Lead [73 FR 66964, Nov 12, 2008]		primary and secondary	Rolling 3 month average	0.15 $\mu\text{g}/\text{m}^3$ ⁽¹⁾	Not to be exceeded
Nitrogen Dioxide [75 FR 6474, Feb 9, 2010] [61 FR 52852, Oct 8, 1996]		primary	1-hour	100 ppb	98th percentile of 1- hour daily maximum concentrations, averaged over 3 years
		primary and secondary	Annual	53 ppb ⁽²⁾	Annual Mean
Ozone [73 FR 16436, Mar 27, 2008]		primary and secondary	8-hour	0.075 ppm ⁽³⁾	Annual fourth-highest daily maximum 8-hr concentration, averaged over 3 years
Particle Pollution Dec 14, 2012	PM _{2.5}	primary	Annual	12 $\mu\text{g}/\text{m}^3$	annual mean, averaged over 3 years
		secondary	Annual	15 $\mu\text{g}/\text{m}^3$	annual mean, averaged over 3 years
		primary and secondary	24-hour	35 $\mu\text{g}/\text{m}^3$	98th percentile, averaged over 3 years
	PM ₁₀	primary and secondary	24-hour	150 $\mu\text{g}/\text{m}^3$	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide [75 FR 35520, Jun 22, 2010] [38 FR 25678, Sept 14, 1973]		primary	1-hour	75 ppb ⁽⁴⁾	99th percentile of 1- hour daily maximum concentrations, averaged over 3 years
		secondary	3-hour	0.5 ppm	Not to be exceeded more than once per year

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Water quality standards for List I substances

Parameter	Unit	Water quality standard		Standstill Provision ^a
		Estuary ^b	Marine	
Mercury	µg Hg/l	0.5 DAA	0.3 DAA	yes ^c
Cadmium	µg Cd/l	5 DAA	2.5 DAA	yes
Hexachlorocyclohexane ^d	µg HCH/l	0.02 TAA	0.02 TAA	yes
Carbon tetrachloride	µg CCl ₄ /l	12 TAA	12 TAA	no
Dichlorodiphenyltrichloroethane				
(all 4 isomers, total DDT)	µg DDT/l	0.025 TAA	0.025 TAA	yes
(para, para-DDT)	µg ppDDT/l	0.01 TAA	0.01 TAA	yes
Pentachlorophenol	µg PCP/l	2 TAA	2 TAA	yes
Total >drins=	µg/l	0.03 TAA	0.03 TAA	yes
Aldrin ^e	µg/l	0.01 TAA	0.01 TAA	yes
Dieldrin ^e	µg/l	0.01 TAA	0.01 TAA	yes
Endrin	µg/l	0.005 TAA	0.005 TAA	yes
Isodrin ^e	µg/l	0.005TAA	0.005 TAA	yes
Hexachlorobenzene ^f	µg HCB/l	0.03 TAA	0.03 TAA	yes
Hexachlorobutadiene ^f	µg HCBd/l	0.1 TAA	0.1 TAA	yes
Chloroform ^f	µg CHCl ₃ /l	12 TAA	12 TAA	no
1,2-Dichloroethane ^g (ethylenedichloride)	µg EDC/l	10 TAA	10 TAA	no
Perchloroethylene ^g (tetrachloroethylene)	µg PER/l	10 TAA	10 TAA	no
Trichlorobenzene ^g (all isomers)	µg TCB/l	0.4 TAA	0.4 TAA	yes
Trichloroethylene ^g	µg TRI/l	10 TAA	10 TAA	no

Water and Wastewater Treatment

Water is the most abundant chemical component in the biosphere. It is important to all life on the earth including human life.

Source of water

The main sources of water are:

1. **Ground water:** is the water that has percolated (مترشح) downward from the ground surface through the soil pores. Water is normally withdrawn from these reservoirs by well.
2. **Surface water:** All water on the surface of the Earth including lakes, ponds, rivers, streams and rainfall water. It is important source of public water supplies because of high withdrawn rates. Surface water supplies are not reliable (موثوق) as groundwater sources because the surface water is restricted by various sources of pollution, such as industrial and municipal wastes. Direct use of rainfall water is limited but it is important water source in a few areas.
3. **Sea water:** it is a valuable in unlimited quantities. This can be converted into fresh water by a number of processes. Conversion cost is 2 to 5 times higher than these of treating fresh water. Desalination is term used for removal of dissolved salts from water.
4. **Reclaimed wastewater:** is the water that has been treated sufficiently for direct reuse in industry and agriculture and for limited municipal application.

Utilization of water

The most important utilization are:

1. **Irrigation:** the amount of water required for irrigation purpose various with climate of region and the type of crops that are raised.
2. **Domestic water supply:** the requirements vary from season to season and from rural to urban areas.
3. **Power generation:** cooling is principle water use in thermal power generation and more than 99% of water used are required for condenser cooling.
4. **Industrial water use:** industry is much dependent on adequate water supply. The enormous demand of industry for water is obvious such as H_2SO_4 production, oil refinery, milk products, etc.

Types of water pollutants and their effects

The main pollutants in water are:

1. Oxygen demanding wastes:

Biological waste like food waste, dead plant, and animal tissue that consumed oxygen dissolved in water during its degradation by bacteria, thus oxygen required for survival of fish, other marine animals, and marine plants.

a- Dissolved oxygen, DO:

Dissolved oxygen is the amount of oxygen dissolved in water to sustain the plant and animal life in any aquatic system.

b- Biochemical oxygen demand, BOD:

BOD is the measurement of the amount of oxygen utilized by microorganisms during oxidation of organic material. It is the most widely known measurement for assessing the water pollution by a given organic waste.

2. pathogens:

Pathogens are a disease causing agents. Water is a potential carrier of pathogenic microorganisms. These pathogens are carried into the water bodies by sewage and waste from farms and various industries.

3. Refractory organic compounds:

These include pesticides, herbicides, phenols, synthetic organic chemical and detergents. These compounds in contrast to the organic waste are not biodegradable and may persist for a long periods.

4. Nutrients:

Nutrients are the chemical material required to growth of aquatic life, Such as nitrogen and phosphorus. Nitrogen and phosphorus enter the water bodies directly from the manufacture and use of fertilizers and from the processing of biological material such as food and textiles. When large concentrations of nutrient are present in water, an excess growth of algae known as algae bloom appears. This produces an unsightly green slime layer over the surface of water body lead to eutrophication.

5. Inorganic chemical:

These include inorganic salts, mineral acids, and heavy metal compounds. Most of these are toxic and are capable of killing living organisms in the water bodies.

6. sediments:

These include soil, sand, and mineral particles or pulverized coal ash. Their effects increasing turbidity and consequently of reducing the amount of sunlight available to water plants.

7. Radioactive substances:

Radioactive substances include radioactive material and radioactive waste. The refining of uranium is the most important source of radioactive waste producing radium, bismuth, etc. Radioactive substances can enter human with food and water and accumulated in blood, liver, muscular tissues (انس الجوع ضايه) causing to serious of health problem to human kinds.

8. Thermal pollution

Power plant and industry use large quantities of water for cooling purpose. This could results in increase in the temperature of the water bodies and causing decrease in the percentage of dissolved oxygen in the aquatic media and then decreases in the saturation percentage.

9. Oils:

Oils are important commodity and virtual for every human activity now. Oil wastes enter rivers and other water bodies from several sources like industrial effluents, oil refineries, storage tank, automobile waste oil, and petrochemical plants. Oil insoluble in water so it floats and spread rapidly into a thin layer. The lighter low molecular-weight elements, which are most toxic to organism, evaporate at slow rate effects on life in the water.

Oxygen demanding waste

Dissolved oxygen (DO)

Dissolved is essential for sustaining the plant and animal life in any aquatic system. There are four processes which actually affected the DO content:

- Reaeration
- Photosynthesis (تركيب ضوئي)
- Respiration (تنفس)
- Oxidation

Reaeration

Is the process by which oxygen transfer takes place form atmosphere to water.

The solubility of oxygen in fresh water at saturation point decreases with an increase in temperature, see Fig.1.

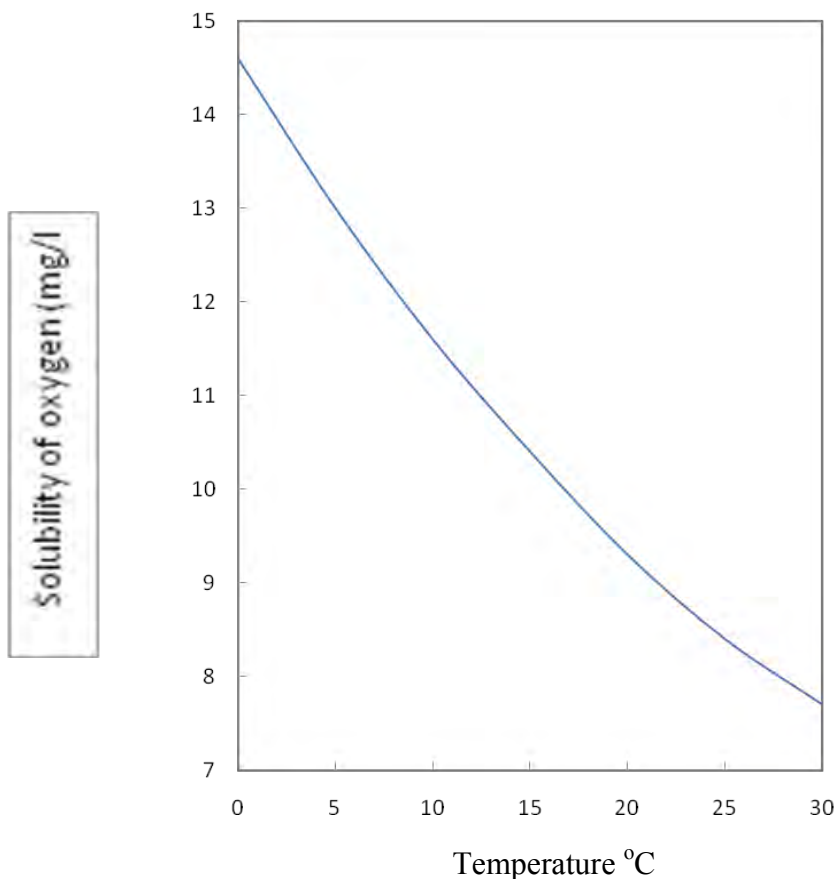


Fig.1 Saturation concentration of dissolved oxygen in fresh water

The rate of oxygen transfer (or rate of reaeration) depend on:

- 1- The rate of absorption through the air-water interface.
- 2- The rate of dispersion within the body of water near the surface.

The driving force for oxygen transfer is the difference between the saturation concentration C_S of dissolved oxygen and the actual concentration C_L present in water. Since the solubility of oxygen in water is very low, the main resistance to mass transfer is on the liquid side of the interface so that the absorption is liquid-film controlled. The rate of oxygen transfer across unit area of surface in unit time, N , so that

$$N = k_L (C_S - C_L) \quad (1)$$

where

N = Oxygen transfer rate, $\text{kg/m}^2 \cdot \text{s}$

C_S = Saturation concentration of dissolved oxygen in water, mg/l

C_L = Actual concentration of dissolved oxygen in water, mg/l

k_L = Liquid phase mass transfer coefficient, m/s or m/day

If the oxygen is transferred into a volume of water, V , having a total interfacial area, A , in contact with the gas phase, then the rate of oxygen transfer per unit volume of water is given by

$$\frac{dC_L}{dt} = \frac{NA}{V} = K_L \frac{A}{V} (C_S - C_L) = r(C_S - C_L) \quad (2)$$

where

$\frac{dC_L}{dt}$ = is the oxygen transfer rate

$K_L \frac{A}{V}$ = reaeration or reoxygenation rate constant, $1/\text{day}$

$(C_S - C_L)$ = is the deference between the saturation concentration of DO and the actual concentration of DO presented in water. This deference is often referred as the oxygen deficit, D :

$$D = (C_S - C_L) \quad (3)$$

Photosynthesis

Photosynthesis requires solar energy radiation. During the process, the green plants such as algae (الطحالب) utilize carbon dioxide and the inorganic nutrient in the water to synthesis organic materials and liberate oxygen.

Since the process occurs only during the present of sun-light, the DO level in the water increases during the day.

Respiration

At night the algae and the micro-organisms compete with each other for both dissolved oxygen and organic compounds. This bacterial respiration is responsible for the production of carbon dioxide and subsequent depletion of dissolved oxygen.

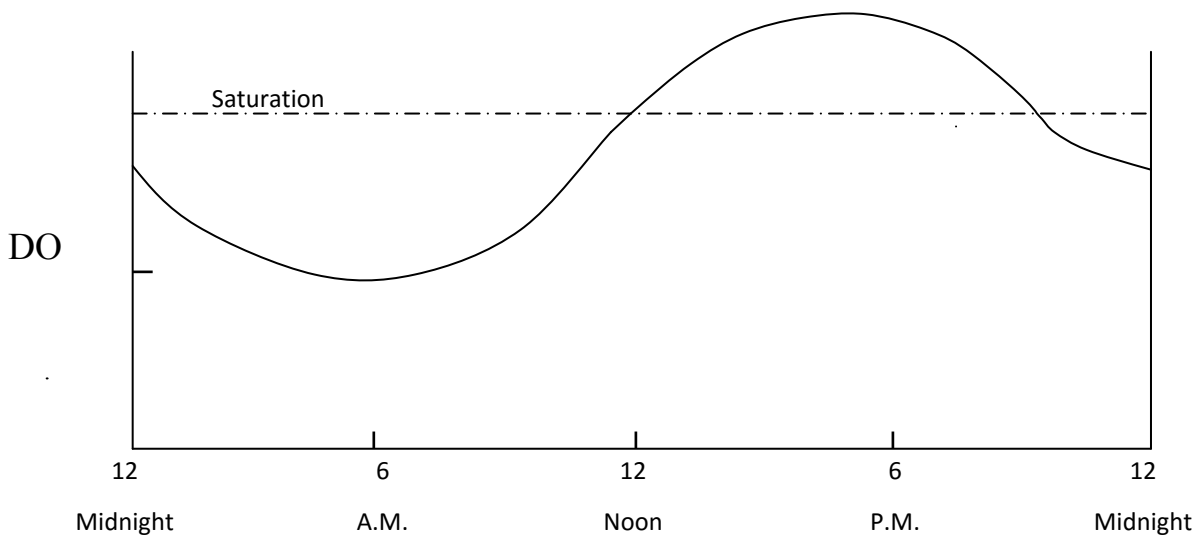


Fig.2 Diurnal variation of dissolved oxygen

Combination of the three effects of respiration, photosynthesis and reaeration results in a diurnal variation in dissolved oxygen concentration from the values that far exceed saturation during the day to much lower values or depletion at night.

Oxidation

In this process the oxygen is depleted by micro-organism during the oxidation of organic material

Pollution results when the oxygen demand exceeds the available oxygen

Biochemical Oxygen Demand, BOD

BOD is the measure of the oxygen utilized by micro-organism during the oxidation of organic material. BOD is the measurement for the water pollution.

If a given amount of organic matter is introduced, the rate of oxidation of organic matter (the rate of decline of BOD) can be approximated as a first-order chemical reaction whose may be expressed as:

$$\frac{dL}{dt} = -k_1 L \quad (4)$$

where

L = the BOD remaining in time t, mg/l

Integration of Eq,3 at time t = 0 and L = L_u :

$$\int_L^{L_u} \frac{dL}{L} = k_1 \int_t^0 dt$$

To get

$$\frac{L}{L_u} = \exp(-k_1 t) = 10^{-k_1' t} \quad (5)$$

$$k_1' = \frac{k_1}{2.303}$$

where

L_u = the ultimate BOD, mg/l

k₁ = the deoxygenation constant, 1/day.

The ultimate BOD means the original concentration of the organic material before any biological action has occurred.

The amount of BOD remaining at any time t, equals

$$L = L_u \left(10^{-k_1' t} \right) \quad (6)$$

If Y represent the amount of BOD utilized at any time t, then

$$L_u = L + Y \quad (7)$$

or

$$Y = L_u - L = L_u \left(1 - 10^{-k_1' t} \right) \quad (8)$$

A standard way to measure the BOD is to determine the amount of oxygen required by bacteria during the first five days of decomposition at 20°C :

$$Y_5 = L_u - L_5 = L_u \left(1 - 10^{-5k_1'}\right) \quad (9)$$

Y_5 = the 5-day BOD at 20°C

The relationship among L , L_u and Y is shown in Figs 3 and 4. Fig.3 shows the BOD remaining versus time.

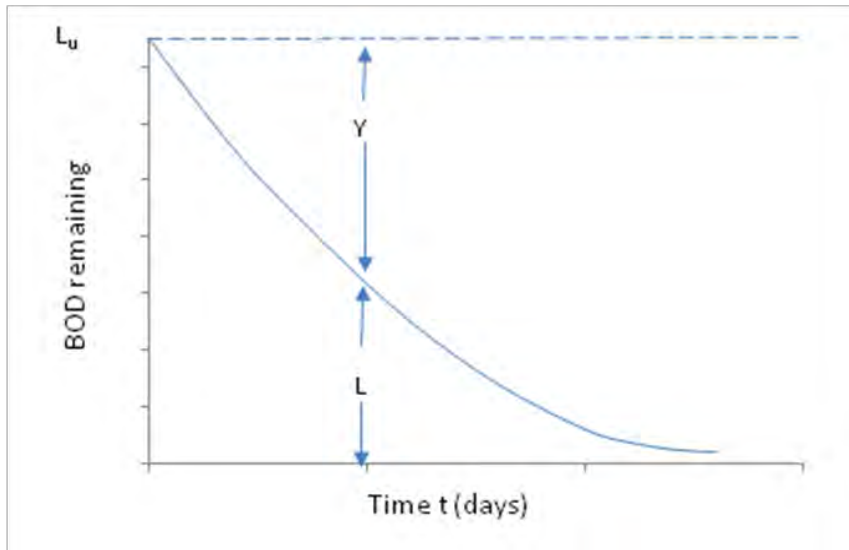


Fig.3 BOD remaining versus time

Fig.4 shows the BOD utilized versus time:

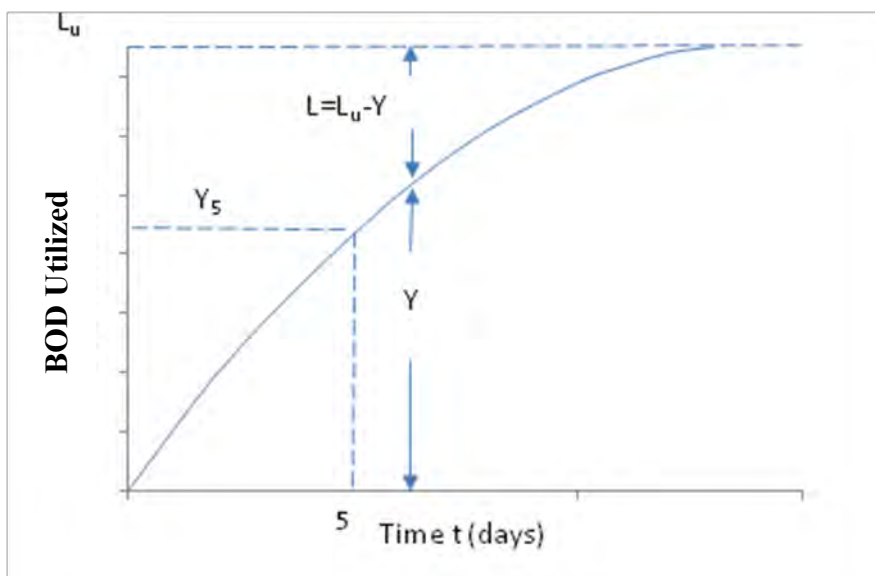


Fig.4 BOD utilized versus time

Several methods are available for determining k_1' and L_u which include:

- (1) The least square methods. (2) The method of moments. (3) The daily difference method. (4) The rapid rate method. (5) The Thomas method.

The Thomas method is probably the simplest to use. This method is based on the similarity of two functions:

$$\frac{(1 - 10^{-k_1' t})}{2.3 k_1' t [1 + (2.3/6) k_1' t]^3} \quad (10)$$

Using this method the following equation can be written as:

$$\left(\frac{t}{Y}\right)^{1/3} = (2.3 k_1' L_u)^{-1/3} + \left[\frac{(k_1')^{2/3}}{3.43 (L_u)^{1/3}} \right] t \quad (11)$$

A plot of $(t/Y)^{1/3}$ versus time t will give a straight line whose slope, b and intercept a can be used to calculate k_1' and L_u

$$k_1' = 2.61 \frac{b}{a} \quad (12)$$

$$L_u = \frac{1}{2.3 k_1' a^3} \quad (13)$$

Table.1 show some typical values of k_1' and L_u .

Note

Drinking water has BOD less than 1 mg/l

Water consider fairly pure with a BOD of 3 mg/l

But when BOD reaches 5 mg/l, the water is of doubtful purity

Table.1. Some typical values of k_1' and L_u

Type of wastewater	k_1' (day ⁻¹)	L_u (mg/l)
Weak wastewater	0.152	150
Strong wastewater	0.165	200
Primary sewage effluent	0.152	75-150
Secondary sewage effluent	0.052-0.100	15-75

Example 1

The following BOD results are observed for a sample of raw sewage at 20°C:

T (days)	0	1	2	3	4	5
Y (BOD, mg/l)	0	65	109	138	158	172

Calculate the reaction-rate constant k_1' and the ultimate BOD, L_u

Solution

1. Construct the following table for plotting,

$(t/Y)^{1/3}$	0.249	0.264	0.279	0.294	0.307
t	1	2	3	4	5

2. Plot the value $(t/Y)^{1/3}$ versus t (see the Fig.5 below)
3. From the plot: the slop b = 0.012, and the intercept a = 0.235
4. Computes k_1' and, L_u

$$k_1' = 2.61 \frac{b}{a} = k_1' = 2.61 \frac{0.012}{0.235} = 0.133 \text{ day}^{-1}$$

$$L_u = \frac{1}{2.3k_1'a^3} = L_u = \frac{1}{2.3(0.133)(0.235)^3} = 252 \text{ mg/l}$$

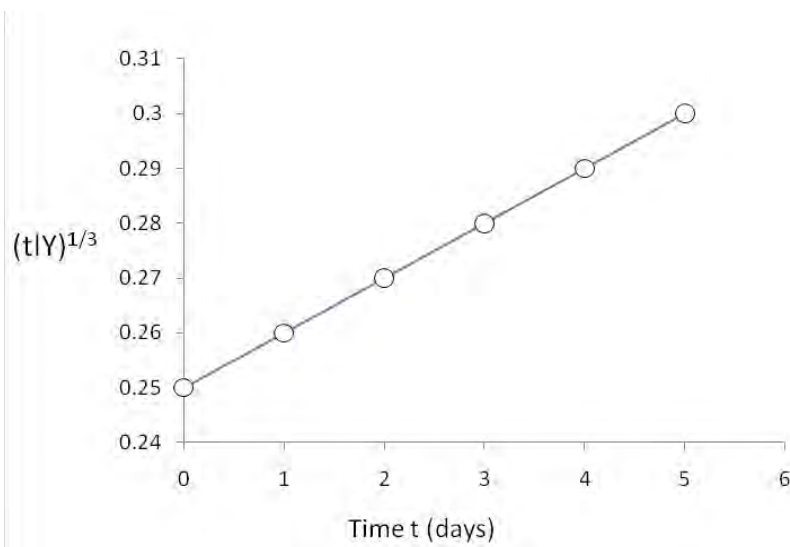


Fig.5 Example 1 $(t/Y)^{1/3}$ versus t

The reaction rate constant k_1' depends on the temperature (T) and may be described by Van't Hoff Arrhenius equation:

$$\frac{d(\ln k_1')}{dT} = \frac{E}{R_u T^2} \quad (14)$$

where

E = activation energy, cal/mol

R_u = universal gas constant

T reaction temperature, K

Integration between the limits of T_o and T we get:

$$\ln \frac{k_{1,T}'}{k_{1,T_o}'} = \frac{E(T - T_o)}{R_u T T_o} \quad (15)$$

For most cases of the wastewater treatment processes the term $E/R_u T T_o$ is nearly constant, then Eq.15 becomes:

$$\ln \frac{k_{1,T}'}{k_{1,T_o}'} = \text{const.}(T - T_o) \quad (16)$$

Therefore

$$\frac{k_{1,T}'}{k_{1,T_o}'} = \exp[\text{const.}(T - T_o)] \quad (17)$$

Let $\exp(\text{const}) = \theta$ = temperature coefficient, then Eq.17 becomes:

$$k_{1,T}' = k_{1,T_o}' \theta^{(T - T_o)} \quad (18)$$

If the value of k_{1,T_o}' is determined at 20°C, then the reaction rate constant k_{1,T_1}' becomes

$$k_{1,T}' = k_{1,20}' \theta^{(T - 20)} \quad (19)$$

Note

Although θ was assumed to be constant. It varies slightly with temperature and the following values are recommended:

$\theta = 1.135$ for Temp. range 4-20 °C

$\theta = 1.135$ for Temp. range 20-30 °C

Example 2

Show that the ratio of the $2\frac{1}{4}$ -day, 35oC BOD to the 5-day 20oC BOD is approximately unity.

Solution

Putting $\Theta = 1.056$ in Eq.18, we get

$$k'_{1,35} = k'_{1,20} (1.056)^{(35-20)} = 2.264k'_{1,20}$$

Now
$$Y_5 = L_u \left(1 - 10^{-5k'_{1,20}} \right)$$

and
$$Y_{2\frac{1}{4}} = L_u \left(1 - 10^{-5(2.25)k'_{1,35}} \right)$$

or
$$Y_{2\frac{1}{4}} = L_u \left(1 - 10^{-5(2.25)(2.264)k'_{1,20}} \right)$$

$$Y_{2\frac{1}{4}} = L_u \left(1 - 10^{-5.09k'_{1,20}} \right) = Y_5$$

Oxygen sag curves

The discharge of waste into a body of water results in the depletion of dissolved oxygen level (deoxygenation) as the wastes oxidized by bacteria. Opposite to this drop in dissolved oxygen (depletion) is reaeration which replace oxygen through the surface of water, at a rate which is proportional to the rate of depletion of oxygen below the saturation value.

The simulations action of oxygenation and reaeration produces a typical pattern in the dissolved oxygen concentration of aquatic system. This pattern is known as the dissolved-oxygen sag and the typical curve is shown in the figure below

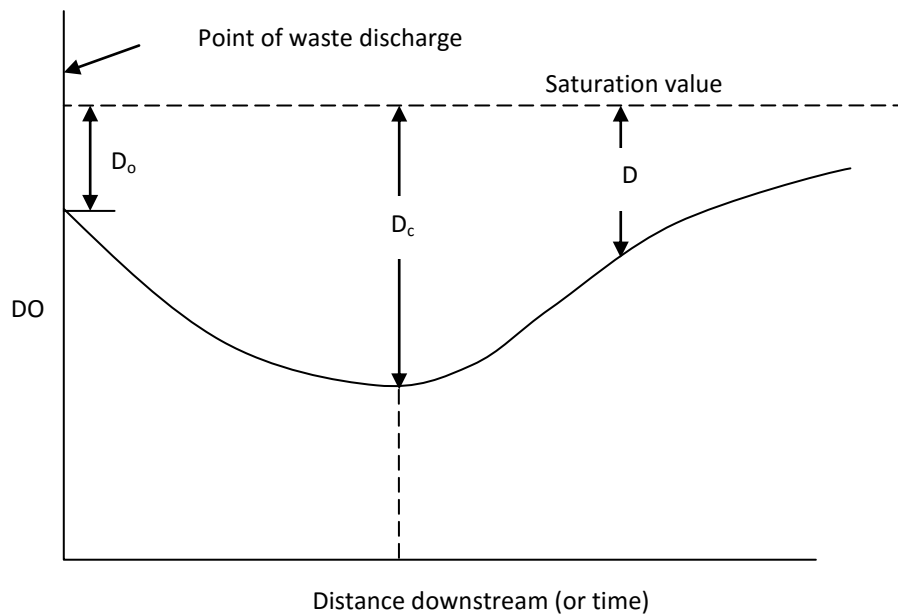


Fig.6 Oxygen sag curve

The following conclusion can be seen from oxygen sag curve:

1. Initially the sag curve drops as the waste deplete the oxygen faster than it can be replaced.
2. At the point where the dissolved oxygen (DO) is a minimum, the rate of reaeration becomes equal to the rate of deoxygenation. This point is the critical point.
3. Beyond the critical point, the rate of reaeration exceeds the rate of deoxygenation and dissolved oxygen level (DO) begin to increase and eventually return to normal.

The simultaneous action of deoxygenation and reaeration can be described by the equation:

$$\frac{dD}{dt} = k_1 L - k_2 D \quad (20)$$

where

D = dissolved oxygen deficit, mg/l or kg/m³

L = concentration of organic material (the BOD remaining in time t), mg/l or kg/m³

k_1 = deoxygenation constant, day⁻¹

k_2 = reaeration constant, day⁻¹

L can be expressed in terms of ultimate BOD, L_u as (see Eq.4):

$$L = L_u e^{-k_1 t} \quad (21)$$

Substituting Eq.19 in Eq.18 and integrating we get:

$$D = \frac{k_1 L_u}{k_2 - k_1} (e^{-k_1 t} - e^{-k_2 t}) + D_o e^{-k_2 t} \quad (22)$$

where D is the dissolved oxygen deficit in time t, (mg/l) and D_o = initial oxygen deficit at the point of waste discharge (mg/l).

since $e^{-kt} = 10^{-k' t}$

where $k' = \frac{k}{2.303}$

then $D = \frac{k'_1 L_u}{k'_2 - k'_1} (10^{k'_1 t} - 10^{k'_2 t}) + D_o 10^{k'_2 t} \quad (23)$

Both k'_1 and k'_2 are temperature dependent. The temperature effects on k'_1 as in Eq.17. The temperature effect on k'_2 can be evaluated as follows:

$$k'_{2,T} = k'_{2,20} (1.047)^{T-20} \quad (24)$$

where

$k'_{2,T}$ = reaeration constant at temperature T °C

$k'_{2,20}$ = reaeration constant at temperature 20 °C

The critical dissolved oxygen deficit D_c , where the rate of oxygen utilized for waste material decomposition equals to the rate of atmosphere reaeration, and this can be evaluated by simply setting $dD/dt = 0$ in Eq.18 and $D = D_o$, as:

$$k_1 L - k_2 D_c = 0$$

and

$$L = L_u e^{-k_1 t}$$

then

$$(33a) \quad k_2 D_c = k_1 L = k_1 L_u \exp(-k_1 t_c)$$

$$D_c = \frac{k_1}{k_2} L_u \exp(-k_1 t_c) \quad (25)$$

the critical time (t_c) can be obtained by differentiating Eq.20 with respect to t_c can be obtained by differentiating Eq.20 with respect to t and setting dD/dt to get:

$$t_c = \frac{1}{k_2 - k_1} \ln \left[\frac{k_2}{k_1} \left(1 - D_o \frac{k_2 - k_1}{k_1 L_u} \right) \right] \quad (26)$$

k_1' can be evaluated from the BOD test in the laboratory

k_2' must be determined from field information . O'Conner and Dobbins gave the following empirical equation for determining k_2' at 20 °C

$$k_2 = 3.9 \frac{V^{0.5}}{H^{1.5}} \quad (27)$$

where

V = velocity of flow, m/s

H = depth of flow, m

... required to reach the critical point is significant because at this point conditions in the stream will be at their worst. The DO level will be minimum and reaches zero, then anaerobic conditions may prevail leading to the death of aerobic aquatic inhabitants. This is illustrated in Fig. 7.8 for three different levels of BOD discharge from a point source.

Example 3

The town of Venkatapur discharges 17,360 m³/d of sewage into a nearby stream. The stream has a minimum flow of 0.4 m³/s, depth of 2.5 m and a velocity of 5 kmph. Other information pertaining to the stream and the sewage are as follows:

	Temp (°C)	DO (mg/l)	BOD ₅ (mg/l)
Stream	20	8.5	10
Sewage	25	1.0	200

The deoxygenation constant (k_1) evaluated at 20°C = 0.35 d⁻¹. Determine the critical oxygen deficit, D_c , and its location, x_c .

Solution

The flow of sewage into the stream,

$$Q_{se} = \frac{17360 \text{ m}^3/\text{d}}{(86400 \text{ s/d})} = 0.20 \text{ m}^3/\text{s}$$

The temperature of the stream after mixing,

$$T_m = \frac{Q_{se} T_{se} + Q_{st} T_{st}}{Q_{se} + Q_{st}}$$

Substituting the values,

$$T_m = \frac{0.2(25) + 0.4(20)}{0.2 + 0.4} = 21.7^\circ\text{C}$$

Similarly, the DO of the stream after mixing,

$$DO_m = \frac{Q_{se} DO_{se} + Q_{st} DO_{st}}{Q_{se} + Q_{st}}$$

Substituting the values,

$$DO_m = \frac{0.2(1.0) + 0.4(8.5)}{0.2 + 0.4} = 6.0 \text{ mg/l}$$

The BOD₅ = Y_5 , after mixing is similarly given by

$$Y_{5,m} = \frac{Q_{se} Y_{5,se} + Q_{st} Y_{5,st}}{Q_{se} + Q_{st}}$$

280 Environmental Pollution Control Engineering

Substituting the values,

$$Y_{5,m} = \frac{0.2(200) + 0.4(10)}{0.2 + 0.4} = 73.3 \text{ mg/l}$$

The ultimate BOD after mixing is then calculated:

$$L_{u,m} = \frac{Y_{5,m}}{1 - e^{-5k_1}}$$

In the above equation k_1 , is evaluated at 21.7°C , the temperature of the stream after mixing the sewage.

We have, from data $k_{1,20} = 0.35 \text{ d}^{-1}$

Now $k_{1,21.7} = k_{1,20} \theta^{(21.7-20)}$

Taking $\theta = 1.056$

$$k_{1,21.7} = 0.35(1.056)^{(21.7-20)} = 0.384 \text{ d}^{-1}$$

Therefore,

$$L_{u,m} = \frac{73.3}{1 - e^{-5(0.384)}} = 86.2 \text{ mg/l}$$

The saturation concentration of dissolved oxygen at $21.7^\circ\text{C} = 9.0 \text{ mg/l}$ (from Fig. 7.1)
Therefore, the initial oxygen deficit,

$$D_0 = 9.0 - 6.0 = 3.0 \text{ mg/l}$$

The reaeration constant, k_2 , at 20°C can be calculated using Eq. (7.31):

The velocity of the stream = 5.0 kmph

or $V = 1.39 \text{ m/s}$. The depth of the stream, $H = 2.5 \text{ m}$. Substituting these values in Eq. (7.31):

$$k_{2,20} = \frac{3.9(1.39)^{0.5}}{(2.5)^{1.5}} = 1.16 \text{ d}^{-1}$$

The reaeration constant, k_2 , at 21.7°C can be obtained from Eq. (7.28):

$$k_{2,21.7} = 1.16(1.047)^{(21.7-20)} = 1.25 \text{ d}^{-1}$$

The critical time using Eq. (7.30):

$$t_c = \frac{1}{(1.25 - 0.384)} \ln \left[\frac{1.25}{0.384} \left(1 - 3.0 \frac{(1.25 - 0.384)}{0.384(86.2)} \right) \right]$$

$$t_c = 1.264 \text{ d}$$

The critical distance, $x_c = t_c V = (1.264) (5) (24) = 152 \text{ km}$

7.3.2 Disease Causing Agents

Water is a potential carrier of pathogenic micro-organisms. These pathogens are carried

Wastewater

Wastewater can be defined as any water that contains impurities or pollutants in the form of solid, liquid or gases or their combinations in such a concentration that is harmful if disposed into the environment.

Classification of wastewater

Wastewater can be classified by their origin as: domestic wastewater and industrial wastewater.

1. *Domestic wastewater*: that is collected and discharged from residential and commercial establishments.
2. *Industrial wastewater*: is formed at industrial plants where water is used for various processes and also for washing and rinsing of equipment.

Wastewater treatment

The objective of wastewater treatment is to reduce the concentration of pollutants in water to the level so that the treated water will meet the acceptable quality standards and will not adversely affect the environment.

The wastewater treatment processes are usually grouped as:

1. Primary treatment: this process removes identifiable suspended solids and floating matter. Primary treatment system is always physical process.
2. Secondary treatment: this is designed to remove the organic matter that is soluble or in the colloidal form. These processes are commonly biological in nature.
3. Tertiary treatment or advanced treatment: this treatment may involve physical, chemical or biological processes or their various combinations depending on the impurities to be removed. The advanced waste treatment processes are expensive, and are used only when water produced is required to be of high quality.

1. Primary treatment

Primary treatment is mainly a removal of solids through the following steps:

a. Pretreatment:

Wastewater is pretreated to remove large floating and suspended solids. It consists of:

1. Screening: Screens of various sizes and shapes are used depending on the nature of solids to be removed. Fixed bar screens are the most common types of screen used in domestic wastewater facilities.
2. Grit removal: After screening the wastewater enters the grit chamber for removal of inorganic grit consisting of sand and gravels without removing the organic material.

b. Sedimentation:

In this step, the settleable solids are removed by gravitational settling. Settling tank is used to settle as much of the solids matter as possible. The settling tank which follows pretreatment is known as a primary clarifier. The solids settle at the bottom of the tank as a raw sludge. This sludge is removed as underflow either by vacuum or by raking it to a discharge point at the bottom of the tank, while the clarified liquid escapes as overflow. Sedimentation tank may be rectangular or circular tank.

c. Flocculent settling:

The process of flocculent settling takes place when the velocity of the particles increases due to coalescence with other particles.

d. Flotation:

Flotation may be used in place of sedimentation for treating industrial wastewater containing finely divided suspended solids and oily matter.

2. Secondary biological treatment:

The water leaving the primary treatment has lost the solid matter but still contains the organic matter. This organic matter still represents a high demand for oxygen, BOD. This demand for oxygen must be removed. The objective of secondary treatment is thus to remove BOD. The following systems used for secondary biological treatment:

a. Activated sludge system:

Wastewater after primary treatment enters an aeration tank where the organic is brought into intimate contact with the sludge from the secondary clarifier. This sludge is heavily laden with microorganisms which are in active state of growth. Air is introduced into the tank, either in the form of bubbles through diffuser or by surface aerators. The microorganisms utilize the oxygen in the air and convert the organic matter into stabilized compounds such as NO_3 , SO_4 , CO_2 , and synthesis new bacteria cells. The effluent from the aeration tank containing

the flocculent microbial mass known as the sludge, is separated in settling tank which called a secondary or final clarifier. In the settling tank the separated sludge exists without contact with organic and becomes activated. A portion of the activated sludge is recycled to the aeration tank as seed and the rest is wasted, as shown in Fig.7. The activated sludge system consists of:

- 1- Aeration tank.
- 2- Solid-liquid separator.
- 3- Recycle activated sludge.

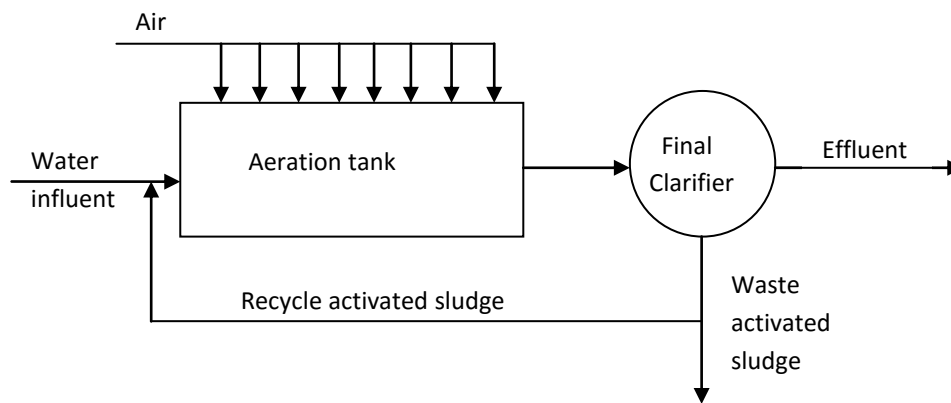


Fig.7. Block diagram of the activated sludge system

b. Trickling-filter(biological-film system):

Wastewater is brought into contact with a mixed microbial population in the form of a slim film attach to the surface of a solid support medium (rocks). Trickling filters are most popular for treating domestic sewage because of its ease of operation.

c. Sludge treatment and disposal:

Handling and disposal of sludge from secondary biological wastewater treatment plants is an important problem. The common unit operation of sludge treatment and disposal are concentration or thickening, digestion, conditioning, dewatering, oxidation, and safe disposal.

3. Tertiary treatment(Advanced treatment):

The effluent from a typical secondary treatment still contains a significant amount of various types of pollutants such as suspended solids, BOD, nutrient, dissolved solids, and toxic substances. A variety of methods are used to satisfy any of several specific goals which are:

- 1- Removal of suspended solids.
- 2- Removal of BOD.
- 3- Removal of nutrient.
- 4- Removal of dissolved solids
- 5- Chemical oxidation.

3.1. Removal of suspended solids (SS)

Several methods are used to remove of suspended solids, but the most commonly methods used are:

- 1-Microscreening
- 2- coagulation.

3.2. Removal of BOD

There are four main types

- 1- Aerobic ponds.
- 2- Facultative ponds.
- 3- Aerated ponds
- 4- Anaerobic ponds.

3.3. Removal of nutrient

Include removal of nitrogen and phosphorous as described below:

3.3.1. Nitrogen removal:

All forms of nitrogen in wastewater effluent are harmful. Two popular methods of nitrogen removal are:

1- *Ammonia stripping*: after second treatment all the nitrogen exit as ammonia. This can be removed by stripping.

2- *Nitrification- denitrification*:

Nitrification is the process in which bacteria convert ammonia nitrogen to nitrate ions, NO_3^- .

De-nitrification is the process of reduction of the nitrate ions, produced from nitrification process, by anaerobic bacteria.

3.3.2. Phosphorous removal:

The main processes used for the removal of phosphorous from wastewater are:

- 1- *Chemical precipitation,*
- 2- *Biological phosphorous removal.*

3.3.3. Removal of dissolved solids

The dissolved solids are both organic and inorganic types. Number methods have been used for the removal:

- 1- Adsorption by activated carbon.
- 2- Solvent extraction.
- 3- Ion exchange.
- 4- Reverse osmosis.
- 5- Electrodialysis.

3.3.4. Chemical oxidation

Chemical oxidation are widely used for disinfection, removing organic materials that are resistant to biological or other treatment processes and conversion of cyanides to innocuous products. This process can be done by:

- 1- Chlorine.
- 2- Ozone.

Example:

In order to facilitate the above three steps of wastewater treatment, primary, secondary, and advanced, a typical wastewater (Table.1) will be assumed. It will be further assumed that the effluent from this wastewater treatment must following effluent standard:

$$\begin{aligned} \text{BOD} &\leq 15 \text{ mg/l} \\ \text{SS} &\leq 15 \text{ mg/l} \\ \text{P} &\leq 1 \text{ mg/l} \end{aligned}$$

Table.1. Characteristic of a typical domestic wastewater

Parameter	Typical Value for domestic sewage, Mg/l
Biochemical oxygen demand,	250
Suspended solids, SS	220
Phosphorous	8

After the primary, secondary, and tertiary treatment the approximate water quality obtained and presented in Table.2.

Chemical Process Eng. Branch / Forth Year
Environmental Engineering & Industrial Safety

Parameter	Raw wastewater	Following primary treatment	Following secondary treatment	Following tertiary treatment
BOD	250	175	15	10
SS	220	60	15	10
P	8	7	6	0.5

It can be said that:

Primary treatment is mainly to remove of solids, although some BOD is removed.

Secondary treatment is to remove part of BOD and the remaining suspended solids, SS.

Tertiary treatment is more efficient in the removal of BOD and SS.

Atmosphere of Earth and Global Problem

Atmosphere of earth

The atmosphere comprises of a mixture of gases (e.g., N₂, O₂, CO₂, Ar etc) surrounding the planet earth. It extends up to about 500 km above the surface of the earth. The atmosphere acts as a gaseous blanket protecting the earth by absorption the dangerous ultraviolet solar radiation (UV), warming the surface of the earth through the heat retention (greenhouse effect). The greenhouse effect' which keeps the earth warms enough to sustain the life on the earth.

Composition of Earth's atmosphere

The composition of gases in the atmosphere is:

- The major gases of the atmosphere are nitrogen (N₂), Oxygen (O₂) and Water vapor (H₂O).
- The minor gases in the atmosphere are: Argon (Ar) and carbon dioxide (CO₂).
- The trace gases in the atmosphere are: Methane, Nitrous oxide, Hydrogen, ozone. Nitrogen dioxide, Carbon monoxide, Ammonia, Neon, Helium, etc.

Layers of Earth's atmosphere:

The atmosphere can be broadly divided into four major regions with widely varying temperature even within each region. These regions are: Troposphere, Stratosphere, Mesosphere, and thermosphere. See Table.1.

Table 1. Characteristics of the major regions of the atmosphere

Name of region	Height above the earth's surface, km	Temperature ranges, °C	Major Chemical species present
Troposphere	0-11	15 to -56	O ₂ , N ₂ , CO ₂ , H ₂ O
Stratosphere	11-50	-56 to -2	O ₃
Mesosphere	50-85	-2 to -92	O ⁺ ₂ , NO ⁺
Thermosphere	85-500	-92 to 1200	O ⁺ ₂ , O ⁺ , NO ⁺

1. Troposphere: This layer is closest to the Earth's surface, and extends up to an altitude of 11 km (Table.1). It is also the layer where majority of our weather occurs. This layer is primary composed of 78% nitrogen and 20.9% oxygen (make up air) and other gases including greenhouse gases. All atmospheric water vapor or moisture is found in this layer.

2. Stratosphere: This layer lies directly above the troposphere. It extends about 11-50 km above the Earth's surface. It contains the ozone layer. About 90% of the ozone in the Earth's atmosphere is found in this region. The ozone layer absorbs the ultraviolet radiation from the Sun. very little weather occurs in the stratosphere.

3. Mesosphere: This area is directly above the stratosphere, it extends about 50-85 km above the Earth's surface.

Thermosphere: This layer extends from 85-500 km above the Earth's surface.

Global air pollution problems

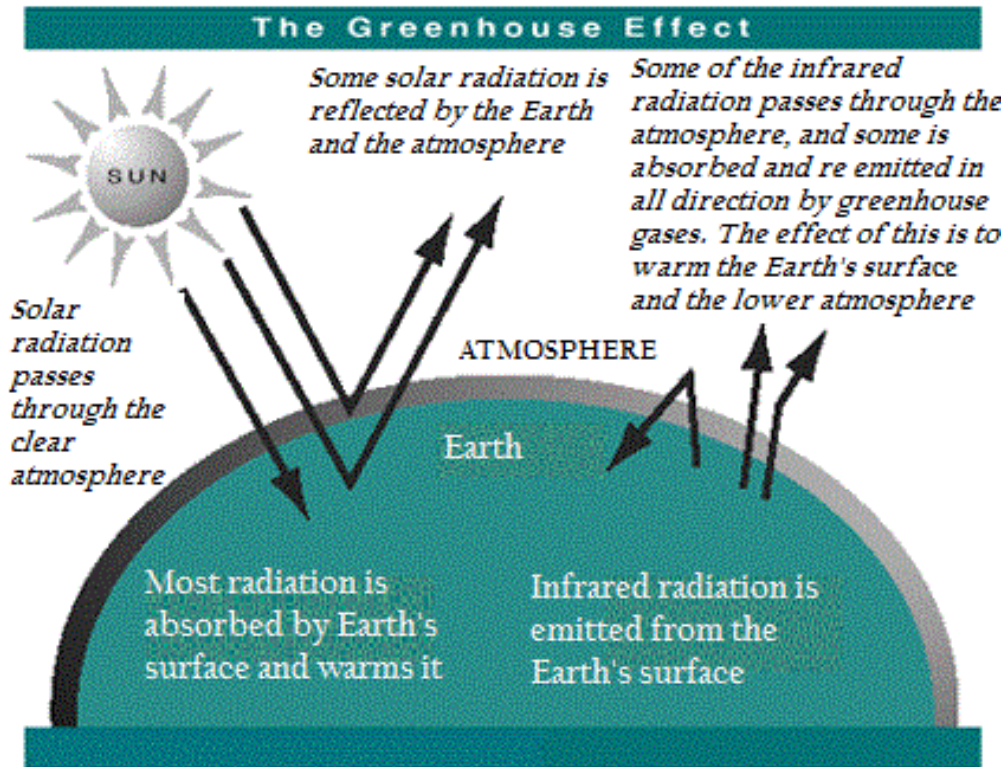
The main global pollution problems are:

1. greenhouse effect and global warming,
2. ozone depletion,
3. acid rain.

1) Greenhouse Effect and global warming

Greenhouse Effect:

The solar energy coming from the sun passes through the atmosphere gases to reach the Earth's surface. Roughly one-third of this radiation absorbed is reflected directly back to the space. The remaining two-thirds are absorbed by the earth's surface and warm it. A long wave infrared (IR) radiation (heat) emitted from the Earth's surface. Some of IR radiation passes through the atmosphere into the space and some of it is absorbed by certain gases in the atmosphere, called greenhouse gases and re-emitted in all direction. The effect of this is to warm the Earth's surface and the lower atmosphere. This phenomenon is called the greenhouse effect. These gases essentially act as blanket, making the earth's surface warmer than otherwise it would be. Fig.8 explain this phenomenon.



Fig,8 The greenhouse effect

Table 2 Major greenhouse gases are

Greenhouse Gas	Chemical symbol	Sources
Water vapor	H ₂ O	Naturally occurring. Rising global temperatures may act to increase water vapor in the atmosphere.
Carbon Dioxide	CO ₂	Naturally occurring. Also it occurs as a result of human activities such as burning of coal, oil, and natural gases.
Methane	CH ₄	It produces by both the natural and human process. It is produced when plants decay and where there is very little air. It is also called swamp gas because it is abundant around the water and swamps.
Nitrous Oxide	N ₂ O	Generated by burning fossil fuels, in the manufacture of nitrogen fertilizer and by use of this fertilizers in agricultural.

Ozone	O ₃	Naturally occurring. Ultraviolet radiation and oxygen interacted to form ozone in atmosphere. Ozone layer helps to protect the earth from ultra-violet radiation
Chlorofluorocarbons, CFCs	Various compounds	Increasing the use of CFCs tend to destroy ozone in the upper atmosphere causing depletion the ozone layer.

Among the greenhouse gases, water vapor and carbon dioxide are the most important greenhouse gases.

The greenhouse gases acting like the greenhouse allow the solar radiation in the range 300 to 2500 nm (e.g. near UV, visible and near IR region), while filtering the dangerous UV radiations (e.g. < 300 nm)

Important of greenhouse effect:

The important of greenhouse effect is:

1. To maintain the average temperature of world. The average temperature should remain constant and governs all life process.
2. To maintain the sea level.
3. The polar ice caps remain intact.

Global warming

Global warming is increase in global average temperature near the Earth's surface as a result of increasing in concentration of greenhouse gases in the atmosphere from human activities. If more greenhouse gases are added to the atmosphere from human activities, these gases will absorb more of infrared radiation reflected by the Earth's surface then the surface and the lower atmosphere will warm further. This extra warming is called the global warming.

Since the beginning of industrialization, 200 years ago, concentration of these gases has increases. It is estimated that the Earth's average temperature has raised 0.6 °C since 1880 because of emission of greenhouse gases from human activities.

Carbon dioxide and global warming

Global warming is caused by the emission of greenhouse gases. 72% of the totally emitted greenhouse gases is carbon dioxide (CO₂), 18% methane and 9% nitrous oxide (NO_x). Carbon dioxide emissions therefore are the most important cause of global

warming. CO₂ is created by burning of fuels like e.g. oil, natural gas, diesel, petrol, and ethanol. The emissions of CO₂ have been dramatically increased within the last 50 years and are still increasing by almost 3% each year, see Fig.9 below:



Fig,9 CO₂ emissions world-wide by year and CO₂ concentration in the atmosphere by year

The carbon dioxide is released to the atmosphere where it remains for 100 to 200 years. This leads to an increasing concentration of carbon dioxide in our atmosphere (see above on the right hand side), which in turn causes the average temperature on Earth to raise (see Fig.10 below).

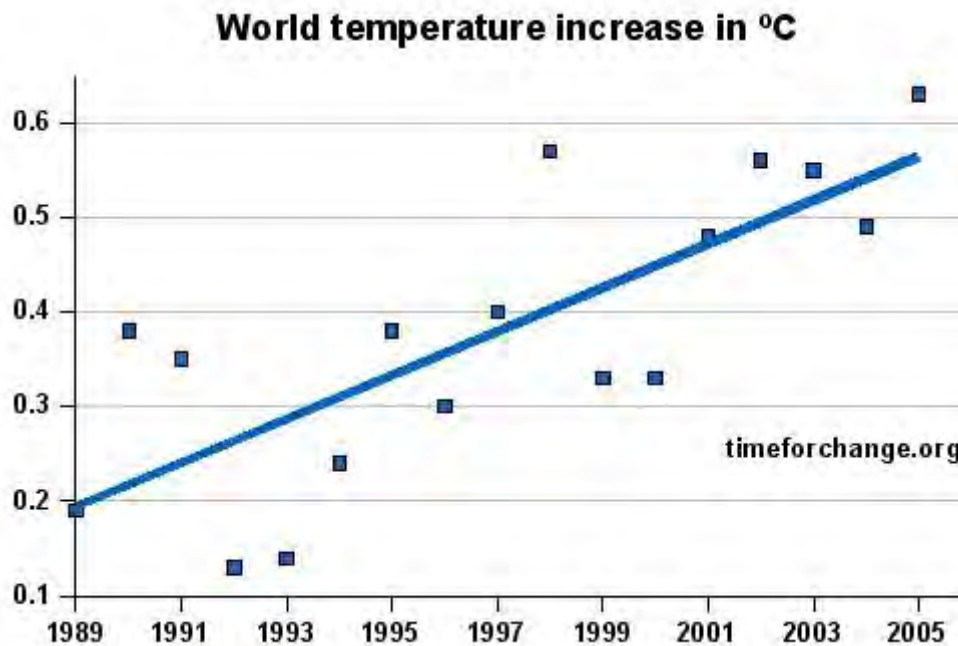


Fig.10 Increase of global average temperature for the last 20 years (source: wri.org)

Effects of global warming

The following effects will result from the global warming (rising temperature):

- 1- Thermal expansion of the water and melting of polar ice caps would cause sea level to rise.
- 2- Could lead to changes in regional wind systems which would influence global rainfall distribution and lead to redistribution and frequency of flood, drought, and forest fires.
- 3- growth in insect population: Climate change would create favorable conditions for growth in insect population, which this has a bad effect on agriculture and human health.
- 4- Disrupts the Water supply and droughts would be more common.

International action to reduce global warming

Kyoto protocol : Held in December 1997, at the city of Kyoto. The Kyoto is a legally binding agreement under which 37 developing countries committed themselves to reduce their annual greenhouse gases emission to an average of 5% less than 1990 levels by 2012 because they are responsible for 36% of the world CO₂ emission. Now more than 500 cities around the world have taken up programs to reduce their greenhouse emission.

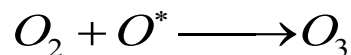
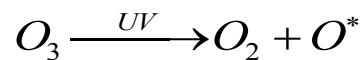
Controlling global warming

- 1- Reduce deforestation and develop way to sustainable agriculture.
- 2- Use of technologies to absorb CO₂ from emission.
- 3- Increased absorption of CO₂ by planting more trees.
- 4- Sequester CO₂ in deep Ocean.
- 5- Increased dependence on renewable energy source.

2) The Ozone Layer and Ozone Layer Depletion

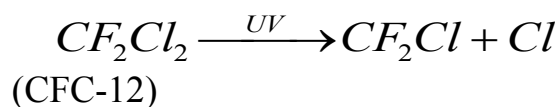
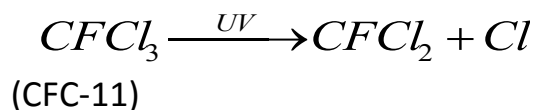
The Ozone Layer

The ozone layer in the stratosphere serves as a shield, protecting the earth's surface from the sun's ultraviolet radiation (UV). Ozone layer absorbs 97-99% of the UV radiation. As the ozone absorbs UV-radiation, it is broken into oxygen molecule and oxygen radical. The oxygen and the oxygen radical then recombine to form new ozone molecule, available to absorb more UV-radiation.

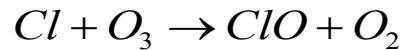


Ozone layer depletion

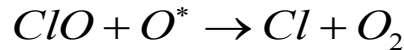
The ozone layer depletion occurs as results of releasing of chemicals such as chlorofluorocarbons (CFCs). CFCs when first used in air conditioning and refrigeration systems valued for their non-toxic and stable properties. CFCs introduced in the lower troposphere pass through the ozone without any change and reach the stratosphere. Here, they impact by the UV-radiation and release destructive chlorine atoms:



The chlorine atom quickly reacts with the ozone molecule breaking it into oxygen:



The ClO produced reacts with oxygen radical forming more chlorine atom that can react with more ozone



The above reaction also removes the oxygen radical thus preventing it from recombined with the oxygen to form an ozone molecule. The overall effect is a decrease in the amount of ozone that leads to ozone removal from stratosphere.

Source of ozone layer depletion

The facts the ozone layer depletion was discovered in the mid of 1980. The main source of ozone layer depletion is

- 1- Chlorofluorocarbon, CFCs: CFCs are cause damage to ozone layer. When CFCs reach the upper atmosphere they are degraded by UV radiation to produce chlorine atom. This atom breaks up ozone molecules to form oxygen and ozone then disappear and depleted.
- 2- Nitrous oxide: It produces from the microbial action on the nitrogenous fertilizers, which cause depletion of the ozone layer.
- 3- Nuclear test: Nuclear explosions release high quantity of various gases and other materials which damage the ozone layer.

International action to protect the ozone layer

Montreal protocol: is an international agreement signed in Montreal city of Canada in 1987. It goal was to cut emission of CFCs into atmospheres by about 35% between 1989 and 2000.

3) Acid rain

Acid rain is mainly caused by the release of sulfur dioxide (SO₂) and oxide of nitrogen (NO_x) during fossil fuel combustion and the use sulfur coal and oil. When these gases are discharged into atmosphere they react with water, oxygen, and other gases in the atmosphere to form sulfuric acid, ammonium, and nitric acid. These acids then disperse

over large areas because of wind patterns and fall back to the ground with rainwater as acid rain.

Unpolluted rain is naturally acidic with a pH of about 5.6 due to CO₂ in the atmosphere, which reacts with rainwater forming carbonic acid (H₂CO₃):



Carbonic acid is a weak acid and the acidity in rainwater can quickly be neutralized on contact with materials. But the present of sulfuric acid or nitric acid in the atmosphere could lower the pH of rain droplets to value below 5.6 and such rain is considered acidic and it called "acid rain".

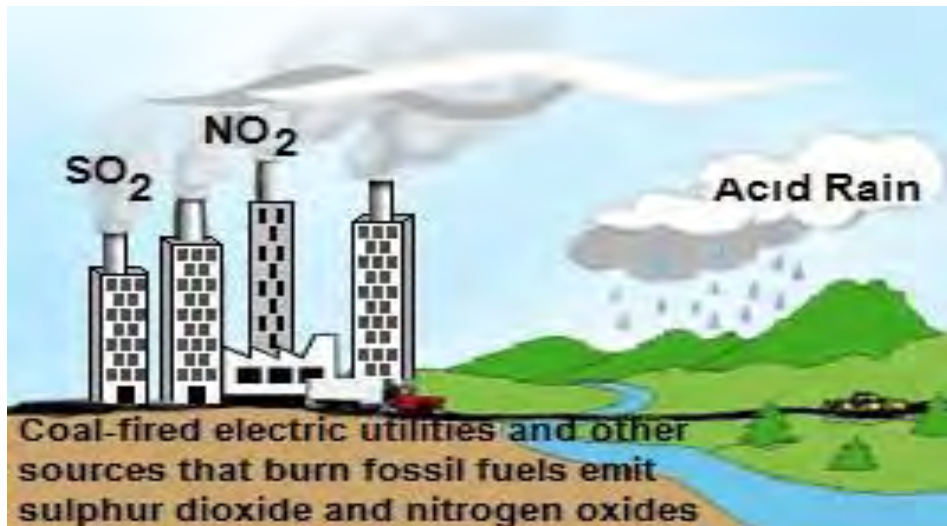


Fig.11 Acid Rain

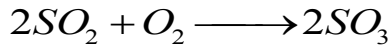
Effects of acid rain

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

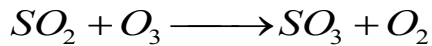
- 1- Effects on water bodies: acid rain causes acidulation of lake and streams and contributes to damage of tree at high elevation and much sensitive forest.
- 2- Effect on material: acid rain accelerates the decay of building, bridge, and other structures may by corrosion.
- 3- Effect of human health: acid rain caused acidification of air, water and food that damage the human health. It can also release heavy metals from the pipes of the distribution systems into the potable water supply.

Chemical processes of acid formation in atmosphere

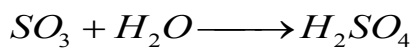
A large part of SO₂ in the atmosphere is oxidized to sulfur trioxide SO₃:



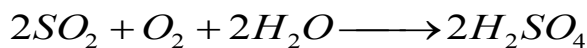
Also SO₂ reacted with atmospheric ozone to give sulfur trioxide SO₃:



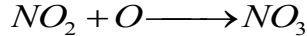
Sulfur trioxide SO₃ is then quickly combined with moisture (water) in the atmosphere to form sulfuric acid mist:



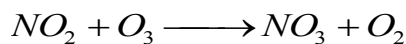
The overall reaction is:



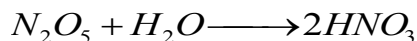
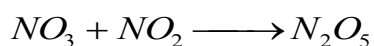
Nitrogen dioxide reacts with atomic oxygen to give nitrogen trioxide:



Also NO₂ reacted with atmospheric ozone to give nitrogen trioxide NO₃:



NO₃ reacted with NO₂ forming N₂O₅, which react with moisture (water) forms nitric acid:



Control strategies for acid rain

- 1- The use of low sulfur 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 desulfurization systems in large power plants can reduce emission of SO₂.

Air pollution

Air pollution may be defined as any atmospheric condition in which certain substances are present in such concentration that can produce undesirable effects on man and his environment. These substance include gases, particulate, radioactive materials, and many others. Most of these materials are naturally present in the atmosphere in low concentrations and are usually considered to be harmless.

Classification of air pollutants

The air pollutants may be classified in different ways as follows:

1) According to origin:

A. **Primary pollutants** are those that are emitted directly from the sources into the atmosphere. A general list of primary air pollutants are:

- 1- Particulate matter such as ash, smoke, dust, fumes, mist, fog, spray, and aerosol.
- 2- Inorganic gases such as sulfur dioxide, hydrogen sulfide, nitric acid, ammonia, carbon monoxide, carbon dioxide, and hydrogen fluoride.
- 3- Olefin and aromatic hydrocarbons.
- 4- Radioactive compound.

Carbon dioxide is generally not considered an air pollutant but, because of its global concentration, its influence on global climate is great concern.

B. **Secondary pollutants** are those that are formed from chemical and photochemical interactions among primary pollutants and normal atmospheric constituents in the atmosphere. Pollutants such as sulfur trioxide, nitrogen dioxide, PAN (peroxyacetyl nitrate), ozone, aldehydes, ketenes and various sulfate and nitrate salts.

2) According to chemical composition:

A. Organic pollutants, e.g. hydrocarbons, aldehydes, ketones, amine, and alcohols.

B. Inorganic pollutants

1. Carbon compounds (e.g. CO and carbonates)
2. Nitrogen compounds (e.g. NO_x and NH₃)
3. Sulfur compounds (e.g. H₂S, SO₂, SO₃, and H₂SO₄)
4. Halogen compounds (e.g. HF, HCl and metallic fluorides)
5. Oxidizing agents (e.g. O₃)

C. Particulates (e.g. fly ash, silica, asbestos and dusts from transport mining, metallurgical and other industrial activities)

3) According to state of matter:

A. Gaseous pollutants which get mixed with air and do not normally settle e.g. CO, NO_x, and SO₂.

B. Particulates pollutants which comprised of finally divided solids or liquids and often exist in in colloidal state as ash, smoke, dust, fumes, mist, fog, spray, and aerosol.

Sources of air pollution

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

(a) **Industrial waste:** There are numbers of industries which are sources of air pollution. Petroleum refinery are the major source of gaseous pollutants, Cement factories emit plenty of dust, stone crushers , food and fertilizers industries which emit gaseous pollutants, and chemical manufacturing industries which emit acid vapors in air.

(b) **Thermal power stations:** The chief pollutants are fly ash,SO₂, and other gases and hydrocarbons.

(c) **Automobiles:** the source of emission of vehicles exhaust. This exhaust produced many air pollutants such as CO, NO_x lead oxides

Air Pollutants and their effects

The most common pollutants emitted from these different sources are as follows:

(1) **Carbon compounds:** These are mainly CO₂ and CO, the former (CO₂) released by combustion of fossil fuels (coal, oil, etc.) and the latter (CO) by automobile exhausts.

(2) **Sulfur compounds:** These include SO₂, H₂S, and H₂SO₄, mostly released by burning of fossil fuel (coal, etc.) in the thermal power plants and industrial units such as manufacturing of sulfuric acid, fertilizers and refineries.

- (3) **Nitrogen oxides:** These include chiefly NO, NO₃, HNO₃. Mostly released by automobiles, power plants and chemicals as well as other industries.
- (4) **Ozone (O₃):** It's level may rise in atmosphere due to human activities.
- (5) **Fluorocarbons:** These come from industries, insecticides spray, etc.
- (6) **Hydrocarbons:** these are chiefly benzene, etc., which are mostly discharged by automobile and industries.
- (7) **Metals:** These include chiefly lead, nickel, arsenic, tin, vanadium, titanium, cadmium, etc., present in air as solid particles or liquid droplets or gases. They are produced metallurgical processes, automobile, etc.
- (8) **Particulate matter:** These are fly ash, dust, grit and other suspended particulates Matter (SPM) released from power plants and industries (stone crushers, etc.). These also bacterial cells, fungal spores, and pollens in air as biological particulates pollutants.

Particulate matter

Particulate refers to all atmospheric substances that are not gases. They can be suspended droplets or solid particles or mixture of the two. Particulates can be composed of inert or extremely reactive materials ranging in size from 100 μm down to 0.1 μm and less. The inert materials do not make any changes in the environment as a result of combustion or any other process, whereas the reactive materials could be further oxidized or may react chemically with the environment.

Air borne particulate

Air born particles can be classified as:

Dust: It contains particles of the size ranging from 1 to 200 μm. These are formed by natural disintegration of rock and soil or by the mechanical process of grinding and spraying. They have large settling velocities and are removed from the air by gravity and other process.

Smoke: It contains fine particles of the size ranging from 0.01 to 1 μm, which are they liquid or solid, and are formed by combustion or by other processes.

Fume: These are solid particles of the size ranging from 0.1 to 1 μm , and are normally released from chemical or metallurgical processes.

Mist: It is made up of liquid droplets generally smaller than 10 μm , which are formed by condensation in the atmosphere or released from industrial operations.

Fog: It is the mist in which the liquid is water.

Aerosol: These included all air-born suspensions either solid or liquid. These are generally smaller than 1 μm .

Air pollution control equipment

The various air pollution control equipments are used to control the air pollution from stationary sources. These equipments are conveniently divided into two types, one type are those which applicable for controlling particulate, and the other that used for controlling gaseous pollutants as shown in Fig.9.

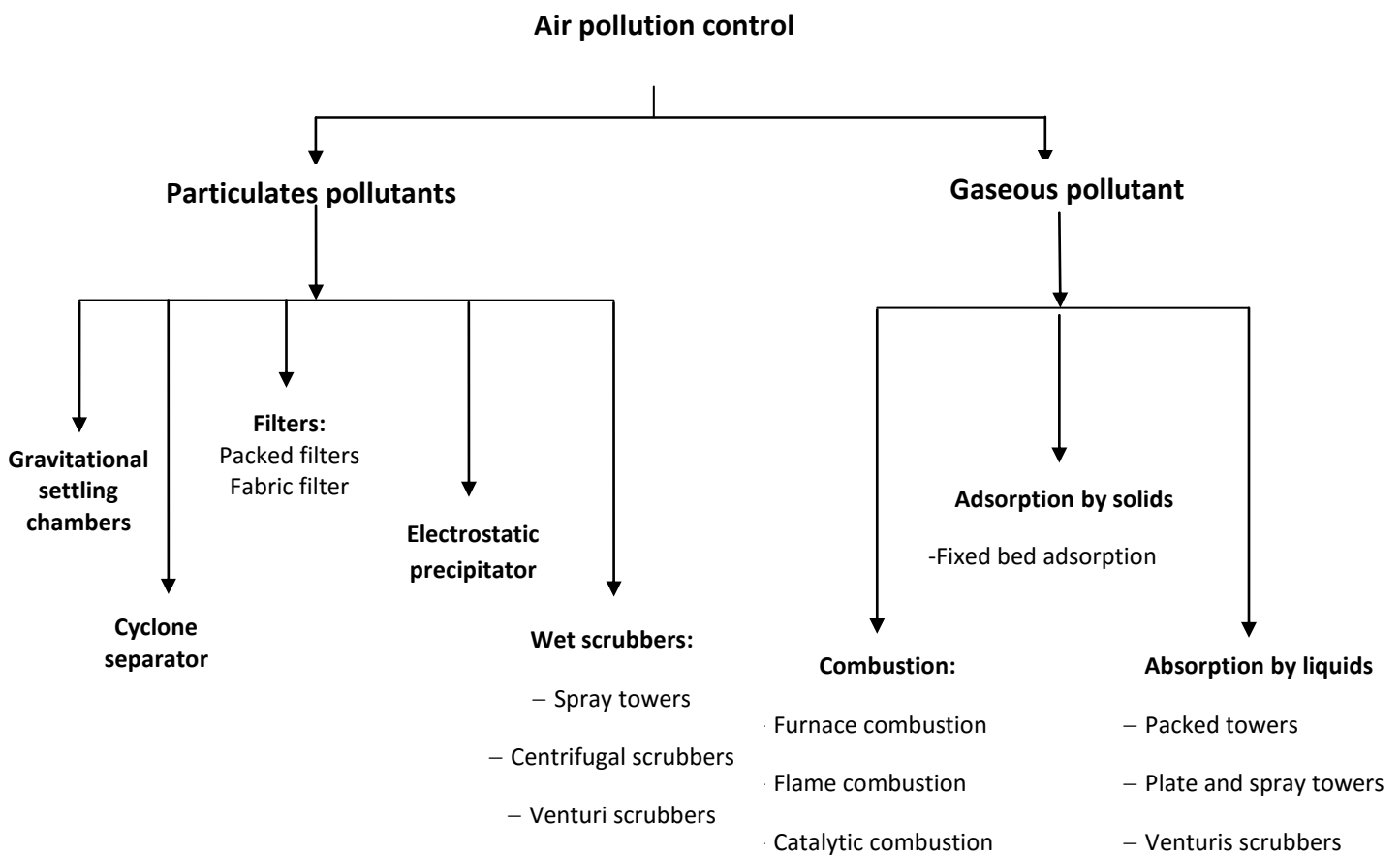


Fig.12. The most commonly equipments deal with air pollution control from stationary sources

Control of Particulate Pollutants

Particulate control equipment

Particulate matter emitted in gaseous streams consists of discrete and minute suspended particles. Particle sizes range from $100\ \mu\text{m}$ to $0.1\ \mu\text{m}$ and even less. The choice of collection devices depends upon a number of factors:

- 1- The physical and chemical properties of the particulates.
- 2- The range of volumetric flow rate of the gas stream.
- 3- The particulate size and its concentration in gas stream.
- 4- The temperature and humidity of the flow stream.
- 5- The toxicity and inflammability
- 6- The collection efficiency that required for outlet stream.

1- Gravitational settling chambers

Gravitational force may be employed to remove particulate in settling chambers when the settling velocity is greater than about $25\ \text{ft/min}$ ($13\ \text{cm/s}$). The basic characteristic of settling chambers:

- 1) They are generally used to remove of coarse particles larger than $50\ \mu\text{m}$ from gas streams, but their efficient are quite small for particles smaller than $50\ \mu\text{m}$.
- 2) Since most of particles in the gas stream are much smaller sizes than $50\ \mu\text{m}$, these devices are used as a primarily prior to passing the gas stream through high efficiency devices.
- 3) They offer low pressure drop and required simple maintenance.

The simplest form of gravity settling chamber is shown in Fig.13.

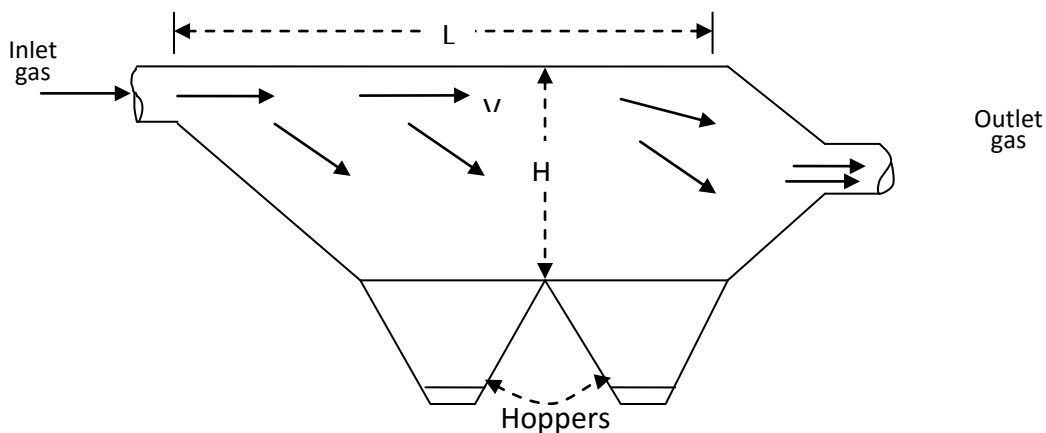


Fig.13. A gravitational settling chamber

The efficiency of equipment depends on the residence time of the gas in the settling chamber which is related to the velocity of the gas flow and the chamber volume.

2- Cyclone separators

Cyclone separators utilize a centrifugal force generated by spinning gas stream to separate the particulates from the carrier gas. The centrifugal force on particles in a spinning gas stream is much greater than gravity; therefore, cyclones are effective in the removal of much smaller particles than gravitational settling chambers, and required much less space to handle the same gas volumes.

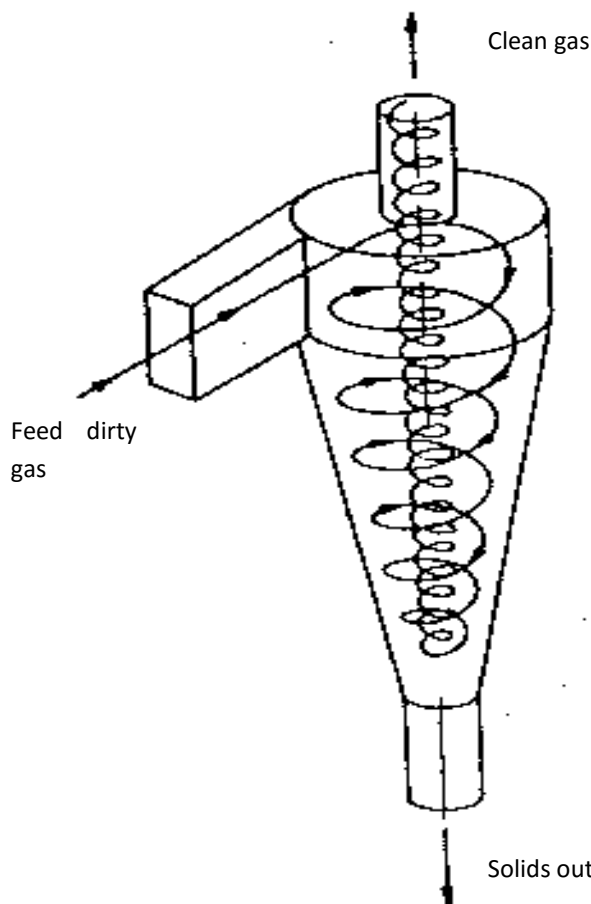


Fig.14. A cyclone separator

The most commonly used design is the reverse flow cyclone, see Fig.14. The dirty gas flows tangentially into the cyclone at the top, and spiral down near the outer radius and then back upward in the center core, in a second smaller diameter spiral, and exit at the top through a central vertical pipe. The particle moves radials to the walls, slide down the walls, and are collected at the bottom.

Type of cyclones

Three types of cyclones:

1- Conventional cyclones

It is applied to remove of particles of 25 μm or larger with an efficiency greater than 90%.

2- High efficiency cyclones

The inlet gas velocity is higher, thereby importing a higher centrifugal force. These types are effective with particle sizes down 5 μm .

3- High volume cyclones

Particle size are generally larger than 50 μm are collected with great efficiency. They can handle larger flow.

Fig.15 shows typical curves for several types of equipment with their fraction collection efficiency as a function of particle size

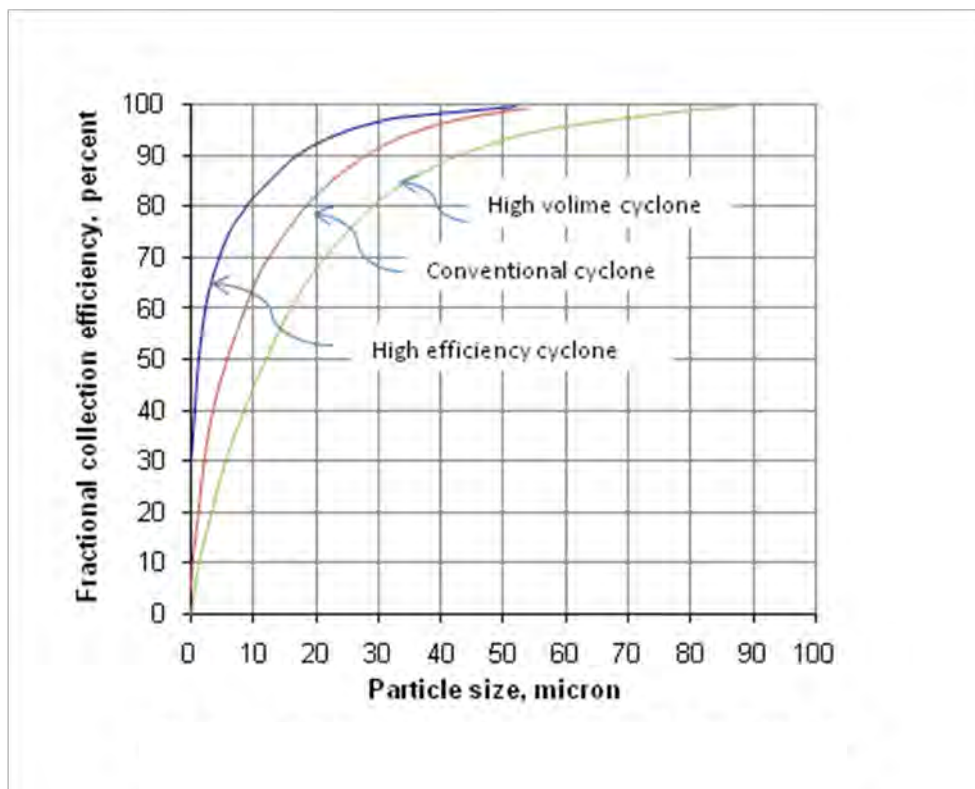


Fig.15. the fractional collection efficiency as a function of particle size for several types of cyclones.

3- Fabric filter (or bag filter)

Filtration is one of the oldest and most widely used methods of separating particulate from a carrier gas. A filter generally is a porous structure which tends to retain the particulate as the carrier gas passes through the void of filter, and allowing clean gas to pass out.

The fabric filter consists of several tubular bags or an envelope, called a baghouse, hanged in such a manner that the collected particle fall into a hopper. The dirty gas enters the bag at the bottom and passes through the fabric filter, while the particulate is deposited on the inside of the bag and the gas passes out from their side to be finely released out of the filter system as a clean gas. Fig.13 shows a typical baghouse.

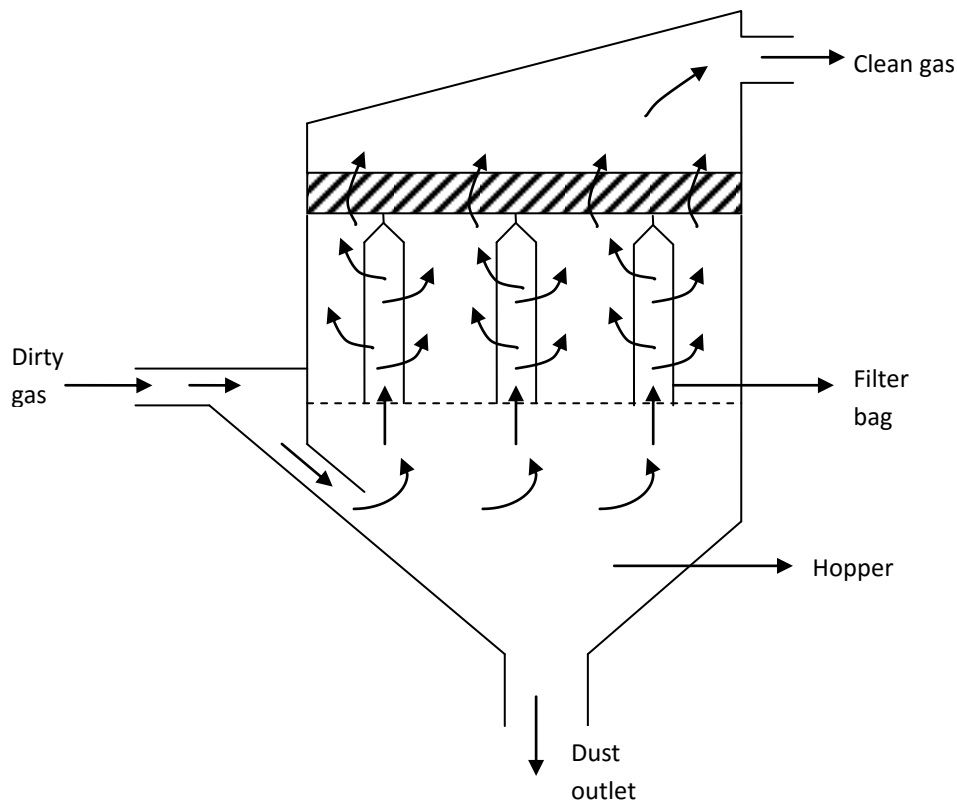


Fig.16. Typical bag house

The advantages of fabric filter

- 1- High collection efficiency over broad range of particle size.
- 2- Retention of finest particles.
- 3- Relatively low pressure drops.
- 4- Collection of particulates in dry form.

The main disadvantages of fabric filter

- 1- Their large size.
- 2- High construction costs.
- 3- Hydroscopic material cannot be handling.

4- Electrostatic precipitators, ESP

Electrostatic precipitator is a physical process by which particles suspended in gas stream are discharged electrically and, under the influence of the electrical field, separated from the gas stream. A typical wire and pipe precipitator is shown in Fig.17.

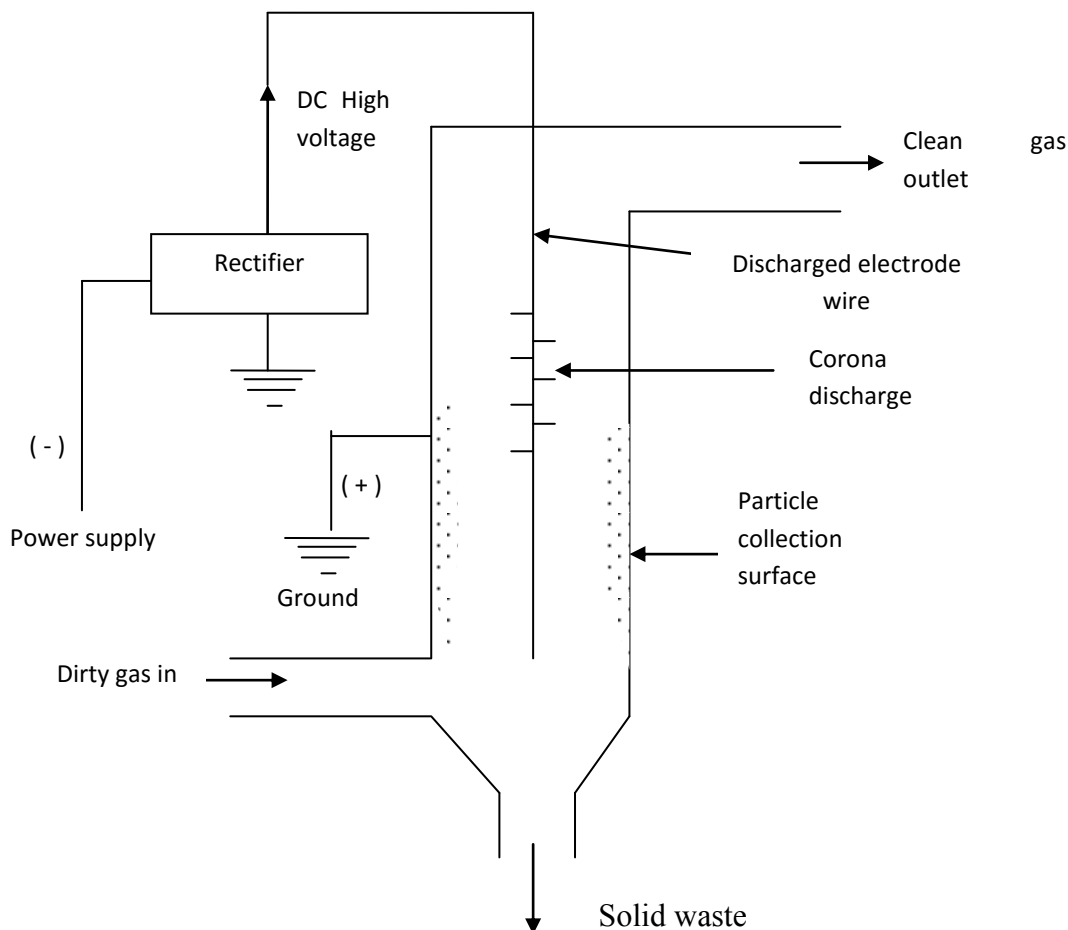


Fig.17. Electrostatic precipitators

The ESP system consists of a positively charged (grounded) collecting surface and a high-voltage discharge electrode wire (negative electrode) suspended axially in the tube. At a very DC a corona discharge occurs close to the negative electrode, setting up an electric field between the wire electrodes and the collecting surface electrode.

Electrons are released at the wire electrode in a corona discharge. As the particle-laden gas enters near the bottom and flows upward, these electrons attach themselves to particles to charge them. The charge particles are derived by the electric field toward the grounded surface of tube; on the surface the particles lose their charge and collection occur.

Advantages of electrostatic precipitators

- 1- Pressure drop and hence power requirement is small compare to that of other devices.
- 2- High collection efficiencies very small particles can be collected wet and dry.
- 3- Can handle both gas and mists for high volume flows.
- 4- Low energy consumption.
- 5- Ability to operate with relatively high temperature gases.

Disadvantages of electrostatic precipitators

- 1- Relatively high initial cost and large space requirement.
- 2- It is necessary to safeguard operating person from high voltage.
- 3- Collection efficiency can deteriorate (بتدور) gradually.

5- Wet scrubbers

Wet scrubber is one of the particulate control equipment in which water is used to capture particulate dust. The resulting the solids are removed from the gas stream by water as slurry. The principle mechanism involved impact (impingement) of the dust particles and water droplet in order to achieve good contact time.

The advantages of wet scrubbers

- 1- Simultaneously removal of gases and particulate.
- 2- Can effectively remove fine particulate, both liquid and solid, ranging from 0.1-20 μm from gas stream.
- 3- Equipment occupies only a moderate amount of space compared to dry collectors such as bag house.

The disadvantages of wet scrubbers

- 1- Relatively high energy costs.
- 2- Problem of wet sludge disposal.

- 3- Corrosion problems
- 4- The wet sludge causes water pollution and there is need to treatment method to remove particles from the water.
- 5- Very small particles (sub-micron sizes) may not captured.

The major types of wet scrubbers are:

- 1- Spray scrubbers
- 2- centrifugal scrubbers
- 3- Venture scrubbers

1-Spray scrubbers

The simplest type of wet scrubbers is a spray tower (Fig.18) in which the polluted gas flows upward and water droplet is sprayed downward by means of spray nozzles located across the flow passage. The particle from the polluted gas is colliding with water droplet and the water droplet contaminated with this particle. If the gas flow rate is relatively slow, the contaminated water droplets will settle by gravity to the bottom of the tower as slurry. A mist eliminator is usually placed at the top of the tower to remove both exes clean water droplet and dirty droplets which are very small that cannot be settled and thus carried upward by the gas flow.

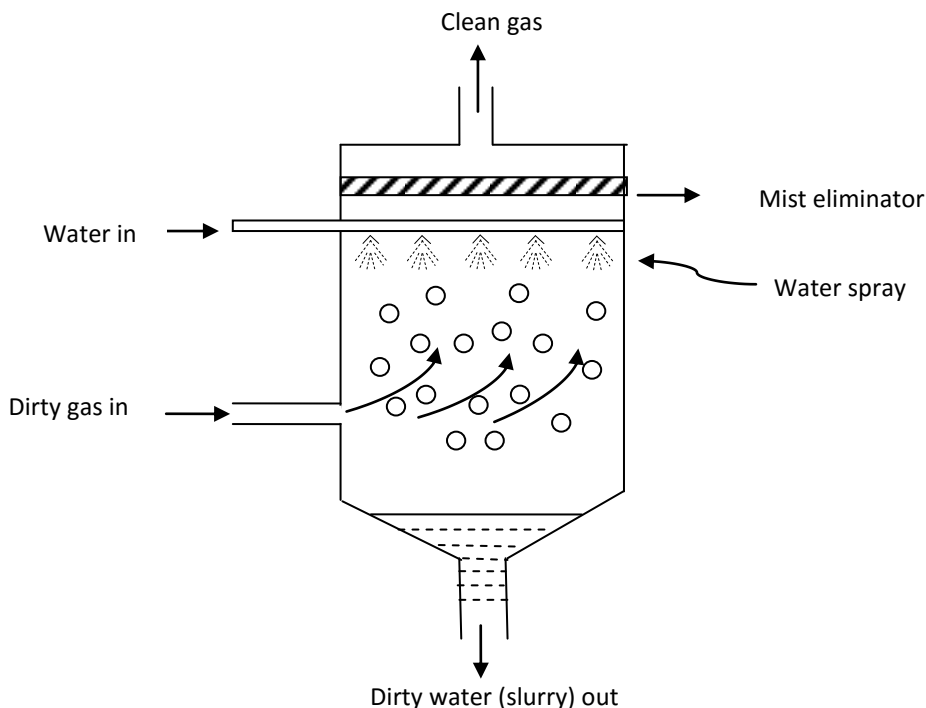


Fig.18. Sketch of a spray tower scrubber

High pressure spray produce small droplet with more surface area per mass of water used. The effectiveness spray towers ranges from 95% for 5 μm particles 99% for 25 μm particles. Spray tower is a counter current flow and may be circular or rectangular spray tower as shown in Fig.18.

2-Centrifugal scrubbers

Fig.19. shows centrifugal scrubber. The polluted gas introduced tangentially into the lower portion of the vertical cylinder. Water drops are injected from multiple nozzles, which throw the water radially outward across the flow gas stream. These droplets are caught in the spinning gas stream and are thrown upward towards the wall by centrifugal force. During their motion the, the droplets collide with particles and capture them. The scrubbing liquid along with the particles flows down the wall to the bottom of the scrubber and exits as slurry. The cleaned gas exists through a demister and is processed for the removal of any entrained water droplets.

The collection efficiency for the particles smaller than those recovered in spray towers can be increased through the use of centrifugal scrubbers. Commercial scrubbers have operating efficiency of 97% or better for particles larger than 1 μm .

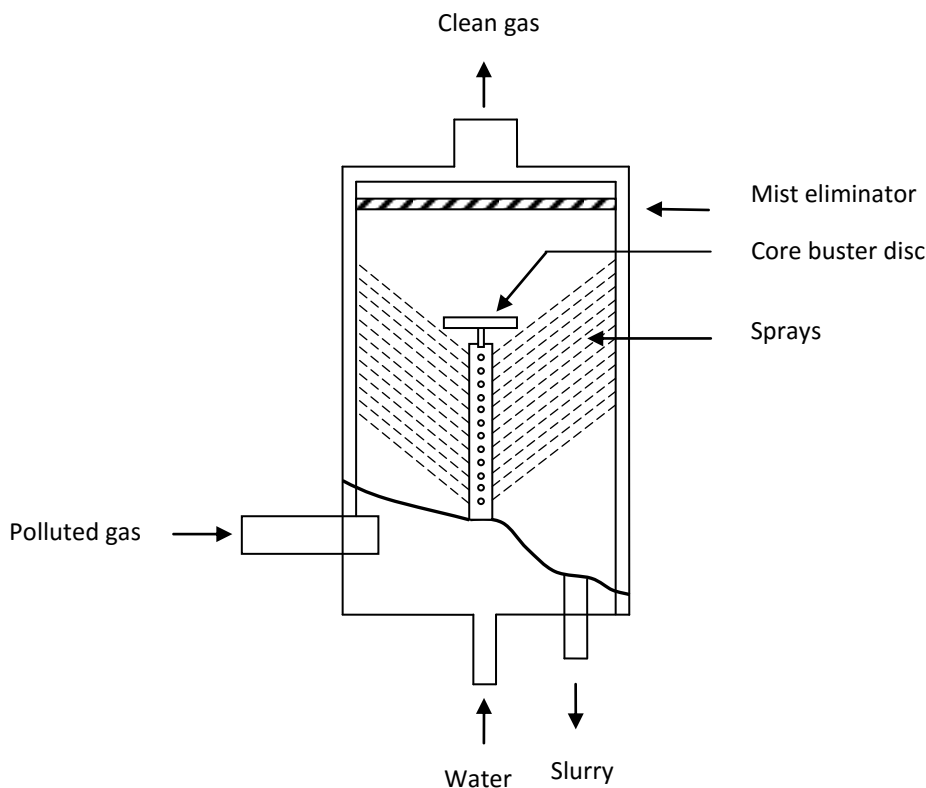


Fig.19. Centrifugal Scrubber, tangential entry

3-Venturi scrubbers

A venturi is a rectangular or circular flow channel which converges to a narrow throat section and diverges back to its original cross section area. The narrow throat causes acceleration of the velocity of the gas to a high level in the venturi section.

Fig.20. shows a vertical downward venturi with throat injection. A bank of nozzles on either side of throat injects water into high velocity gas stream. The high velocity gas assist in atomizing the liquid injected into the gas. The drops collide with dust particles in the gas to form dust-water agglomerates. The gas-liquid mixture is then directed to a separation device such as cyclone separator where the droplets carrying the particulates are separated from the gas stream. Venturi scrubbers offer high performance collection of fine particles usually smaller than 2 to 3 μm . They are suitable when the particulate matter is sticky, flammable or highly corrosive.

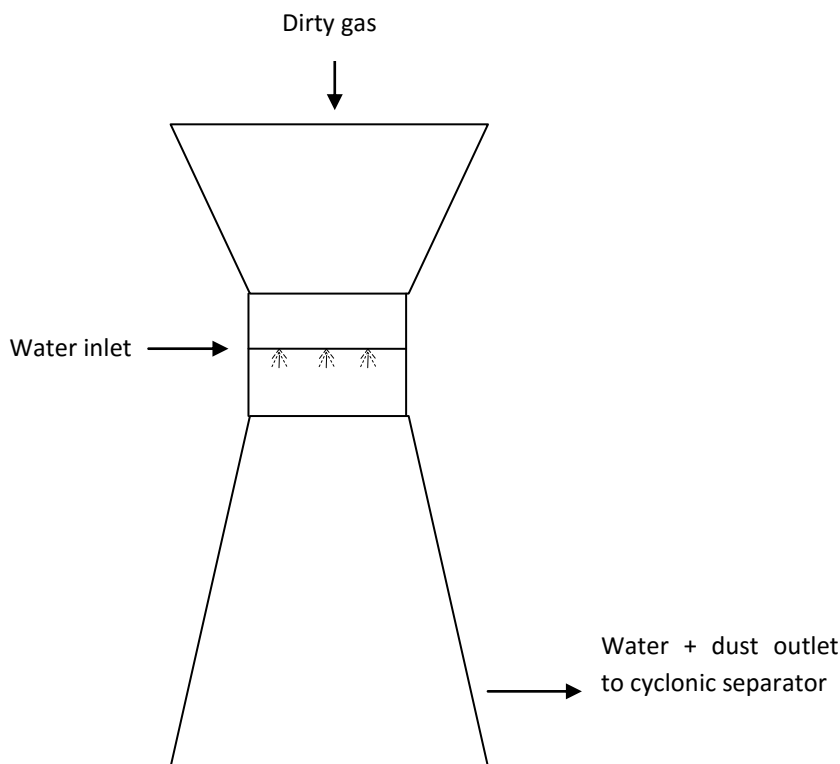


Fig.20. Vertical downward venturi scrubber with throat injection

Air pollution equipment design

Collection efficiency

The collection efficiency measures the system performance. This expressed as a percentage

$$\eta_T = 100 \times \frac{\text{weight.of .material.collected}}{\text{Total.amount.enterin.collector}}$$

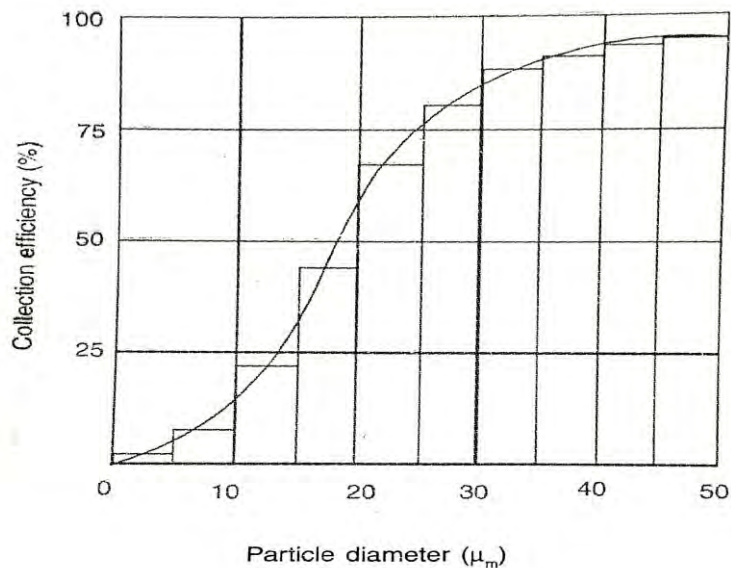


Fig.29. Fractional efficiency curve

where m_i – amount in range “I” entering the collector.

The collection efficiency in each size range can be computed by the equation,

$$\eta_i = \frac{\text{fraction.in.range."i".collected}}{m_i} \times 100$$

The overall collection efficiency η_T can be calculated over n number of size Fractions as:

$$\eta_T = \frac{\sum_{i=1}^n m_i \eta_i}{M} \quad (1)$$

where M = total amount entering the collector.

Example 1

The following table shows the size distribution of dust sample and the fraction efficiency of removal in a gas cleaning equipment. Calculate the overall collection efficiency.

Dust size	Weight per 100 g of dust (g)	Fractional efficiency η_i (%)
< 5	2	1
5-10	2	7
10-15	4	16
15-20	7	44
20-25	10	67
25-30	8	81
30-35	7	88
35-40	10	92
40-50	15	93
50-60	20	95
60-70	10	98
>70	5	100

Answer

Using Eq.1 we can calculate the overall collection efficiency η_T as

$$\eta_T = \frac{\sum_{i=1}^n m_i \eta_i}{M} = \sum_{i=1}^n w_i \eta_i \quad (1)$$

where $w_i = \frac{m_i}{M}$, the weight fraction in each size. Then the following we get

Dust size	Weight per 100 g of dust (g)	Weight fraction w_i	Fractional efficiency η_i (%)	$w_i \times \eta_i$
< 5	2	0.02	1	(0.02 x 1)
5-10	2	0.02	7	(0.02x7)
10-15	4	0.04	16	(0.04x16)
15-20	7	0.07	44	(0.07x44)
20-25	10	0.1	67	(0.1x67)
25-30	8	0.08	81	(0.08x81)
30-35	7	0.07	88	(0.07x88)
35-40	10	0.1	92	(0.1x92)
40-50	15	0.15	93	(0.15x93)
50-60	20	0.2	95	(0.2x95)
60-70	10	0.1	98	(0.1x98)
>70	5	0.05	100	(0.05x100)
				$\eta_T = 80.17$

Air pollution equipment design

1. Settling chamber design (gravity settling)

1.1. Terminal settling velocity

A gravity settler is simply a long chamber through which the contaminated gas passes slowly, allowing time for particles to settle by gravity to the bottom. The important parameter is the terminal or settling velocity of the particle, V_t the terminal velocity is defined as the constant downward speed that a particle attains in a direction parallel to the Earth's gravity field.

If the particle is settling in a fluid at its terminal velocity, three forces acting on it: drag, buoyancy, gravity force, as shown in Fig.21. The terminal settling velocity of the particles is found from forces balance as:

$$F_g = F_D + F_B \quad (2)$$

where

$$F_g = \text{gravity force (secondary Newton law)} = m_p g \quad (3)$$

$$F_D = \text{drag force} = F_D = \frac{\rho_g V_t^2 A C_D}{2} \quad (4)$$

$$F_B = \text{buoyancy force} = F_B = m_p \left(\frac{\rho_g}{\rho_p} \right) g \quad (5)$$

$$m_p = \text{mass of particle} = \rho_p V_p$$

$$g = \text{gravitational acceleration, m}^2/\text{s}$$

$$\rho_g = \text{gas density, kg/m}^3$$

$$\rho_p = \text{particle density, kg/m}^3$$

$$C_D = \text{drag coefficient}$$

$$V_t = \text{terminal velocity, m/s}$$

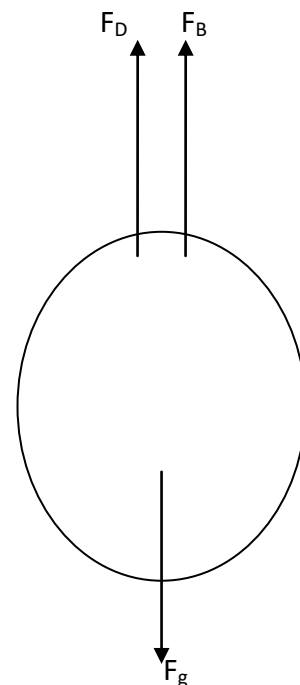


Fig.21 the forces acting on a particle in a fluid

A = frontal cross sectional area, m²

V_p = volume of particle, m³

Substituting Eqs. 3,4 and 5 in the overall balance Eq. 2 we get

$$m_p g = \frac{\rho_g V_t^2 A C_D}{2} + \left(\frac{\rho_g}{\rho_p} \right) g \quad (6)$$

The general solution to Eq.6, in term of V_t, is

$$V_t = \sqrt{\frac{2m_p g (\rho_p - \rho_g)}{\rho_p \rho_g A C_D}} \quad (7)$$

for spherical particle

$$V_p = \frac{\pi}{6} d_p^3, \quad A = \frac{\pi}{4} d_p^2, \quad m = \rho_p V_p$$

where d_p = particle diameter, m. substituting the value of V_p and A in the above equation of V_t, we get

$$V_t = \sqrt{\frac{4g d_p (\rho_p - \rho_g)}{3C_D \rho_g}} \quad (8)$$

Eq.8 is the general equation for the terminal settling velocity

where C_D is the drag coefficient which is related to the particles Reynolds number,

Where
$$\text{Re}_p = \frac{\rho_g V_t d_p}{\mu_g} \quad (9)$$

The general drag coefficient for spherical particles may be represented by three relationships.

❖ **In Stocks law region**, laminar flow around the particle

$$C_D = \frac{24}{Re_p} \quad \text{for } Re_p < 0.1 \quad (10)$$

- ❖ **In transition region, ($0.1 < Re < 1000$)** this region between the Stokes law region and turbulent region

$$C_D = \frac{18.5}{Re_p^{0.6}} \quad \text{for } 0.1 \leq Re_p \leq 1000 \quad (11)$$

- ❖ **In the turbulent region, ($Re_p < 1000$),** the drag force becomes almost constant with the value of 0.45,

$$C_D = 0.45 \quad \text{for } Re > 1000 \quad (12)$$

The drag coefficient can be calculating within the required range of Reynolds number and then substituted in the Eq(8) to determine the terminal velocity as:

1. Substituting Eqs.9 and 10 into Eq.8, we can calculate the terminal settling velocity in the Stokes region:

$$V_t = \frac{gd_p^2(\rho_p - \rho_g)}{18\mu_g} \quad (13)$$

2. Substituting Eqs.9 and 11 into Eq.8 we can calculate the terminal settling velocity In the transition region.

$$V_t = 0.153 \frac{g^{0.71} d_p^{1.14} (\rho_p - \rho_g)^{0.71}}{\rho_g^{0.29} \mu^{0.43}} \quad (14)$$

3. Substituting Eqs.9 and 12 into Eq.8 , we can calculate the terminal settling velocity in the turbulent region:

$$V_t = 1.73 \left[\frac{gd_p(\rho_p - \rho_g)}{\rho_g} \right]^{1/2} \quad (15)$$

It is difficult to estimate Reynolds number and then to estimate which C_D correlation used to calculate terminal velocity, V_t , because V_t is presented in Reynolds number and C_D equations. Therefore the following equation is used to provide a convenient correlation using K, as

$$K = d_p \left[\frac{g(\rho_p - \rho_g)\rho_g}{\mu_g^2} \right]^{1/3} \quad (16)$$

If the size of particles is known, K value can be calculated from Eq.8:

- If $K < 3.3$ then Stokes region applied to estimate V_t , Eq.13.
 If $3.3 \leq K \leq 43.6$ then transition region applied to estimate V_t , Eq.14.
 If $K \text{ value} > 43.6$ then turbulent region applied to estimate V_t , Eq.15

Example 2

Three different fly ash particles settled through air, their sizes are 0.4, 40, 400 μm . calculate the terminal settling velocity for each particle assume the particle are spherical. Data required given below:

$T_{\text{air}} = 114.5 \text{ }^\circ\text{C}$, $P_{\text{air}} = 1 \text{ atm}$, $\mu_{\text{air}} = 0.021 \text{ cp}$, sp.gr. of fly ash = 2.31

Note: Use K-value as a guide for the region.

Answer

$$K = d_p \left[\frac{g(\rho_p - \rho_g)\rho_g}{\mu_g^2} \right]^{1/3} \quad (16)$$

the gas is air. The density of gas

$$\rho_g = \frac{P.MW_t}{RT}$$

Gas constant $R = 0.082 \frac{atm.m^3}{kgmol.K}$, $T_{air} = 114.5 + 273 = 387.5K$, then the air density

$$\rho_g = \frac{(1)(29)}{(0.082)(387.5)} = 0.9126 kg / m^3$$

The viscosity of air

$$\mu_g = 0.021cp = 0.021 \times 10^{-3} kg / m.s$$

The density of fly ash = ρ_p

$$\rho_p = sp.gr \times \rho_{H_2O} = 2.31 \times 1000 = 2310 kg / m^3$$

$$K = d_p \left[\frac{9.81(2310 - 0.9126)(0.9126)}{(0.21 \times 10^{-3})^2} \right]^{1/3}$$

$$K = 36056.5d_p \tag{a}$$

For $d_p = 0.4 \mu m = 0.4 \times 10^{-6} m$

$$K = 36056.5(0.4 \times 10^{-3}) = 0.014$$

$K < 3.3$ then use stocks region for calculating the settling velocity Eq.13

$$V_t = \frac{9.81(0.4 \times 10^{-6})(2310 - 0.9126)}{18(0.21 \times 10^{-3})} = 9.58 \times 10^{-6} m / s$$

For the other particle diameter (40 and 400 μm) are illustrated in the following table

Particle Size μm	K	Region	V_t m/s
0.4	0.014	Stocks	9.58×10^{-6}
40	1.442	Stocks	0.0958
400	14.423	Transition	26.72

1.2. Retention time, τ

Additional parameter in design of settling chamber hydrodynamic is retention time, τ , where

$$\tau = \frac{V}{Q} = \frac{L * W * H}{W * H * u} = \frac{L}{u} \quad (17)$$

where

V = the volume of the settling chamber, m^3

Q = the volumetric flow of gas stream, m^3/s

u = linear gas velocity, m/s

L, W, H = chamber length, width, and height respectively, m

1.3. Chamber efficiency, η

$$\eta = \frac{V_t L}{Hu} \quad \text{or} \quad \eta = \frac{V_t W L}{Q} \quad (18)$$

For most air pollution applications, Stock's law Eq.13 is appropriate substituting in Eq.10 as

$$\eta = \frac{d_p^2 g (\rho_p - \rho_g) L}{18 \mu_g H u} \quad (19)$$

With 100% efficiency ($\eta = 1$), Eq.19 becomes

$$d_{p,\min} = \sqrt{\frac{18 \mu_g H u}{g (\rho_p - \rho_g) L}} \quad (20)$$

or

$$d_{p,\min} = \sqrt{\frac{18 \mu_g Q}{g (\rho_p - \rho_g) W L}} \quad (21)$$

Eq.20 & 21 is to determine the minimum particle size $d_{p,\min}$ can removed with 100% efficiency (completely removed).

Example 3

A hydraulic acid mist in air at 25 °C is to be collected in a gravity settling chamber. Calculate the smallest mist droplet that will be collected by the chamber, applying stock's law. The operating data and dimension of settler are given below:

Wide (W) = 30 ft, Height (H) = 20 ft, Length (L) = 50 ft, $Q_{\text{gas}} = 50 \text{ ft}^3/\text{s}$, $\rho_g = 0.076 \text{ lb/ft}^3$, $\mu_g = 1.24 \times 10^{-5} \text{ lb/ft.s}$, sp.gr of acid mist = 1.6

Answer

$$d_{p,\min} = \sqrt{\frac{18\mu_g H u}{g(\rho_p - \rho_g)L}} \quad (20)$$

$$\rho_p = \text{sp.gr} \times \rho_{H_2O} = 1.6 \times 62.4 = 99.84 \text{ lb / ft}^3$$

$$u = \frac{Q}{A} = \frac{Q}{HW} = \frac{50}{(20)(30)} = 0.083 \text{ ft / s}$$

$$\begin{aligned} d_{p,\min} &= \sqrt{\frac{18(1.24 \times 10^{-5})(20)(0.083)}{32.2(99 - 0.076)(50)}} \\ &= 4.81 \times 10^{-5} \text{ ft} \left(\frac{0.3048 \text{ m}}{1 \text{ ft}} \right) \left(\frac{10^6 \mu\text{m}}{1 \text{ m}} \right) \\ &= 14.7 \mu\text{m} \end{aligned}$$

Design of settling chamber

To design a settling chamber the following equations seems to be useful as a guide:

$$WL = \frac{18\mu_g Q}{g\rho_p d_p^2} \quad (22)$$

$$A_c = WH = \frac{Q}{u} \quad (23)$$

where

A_c = cross sectional area of the settling tank

Q = volumetric flow rate of the gas stream

W = width of settling chamber

H = height of settling chamber

L = Length of settling chamber

u = linear gas velocity, as a design rule of thumb must be below 10 ft/s (30 m/s).

The minimum height of the chamber (H) should be 1 m for cleaning.

Note Eq. 22 estimated from Eq.19 assuming $\eta = 1$ for design purpose

Example 4

Design a gravity settler to remove all the iron particles from a dust laden stream. The particles diameter $d_p = 35 \mu\text{m}$. Use the following data:

Gas is air at ambient condition with characteristics:

$Q_g = 70 \text{ ft}^3/\text{s}$, $u = 10 \text{ ft/s}$, $\rho_g = 0.0775 \text{ lb/ft}^3$, $\mu_g = 1.23 \times 10^{-5} \text{ lb/ft.s}$, $\rho_p = 475.7 \text{ lb/ft}^3$

Note: use K-value to estimate type of region.

Answer

$$K = d_p \left[\frac{g(\rho_p - \rho_g)\rho_g}{\mu_g^2} \right]^{1/3}$$

The gas density can be neglected compare to the particle density

$$d_p = 35 \mu\text{m} \left(\frac{1\text{m}}{10^6 \mu\text{m}} \right) \left(\frac{1\text{ft}}{0.3048\text{m}} \right) = 11.48 \times 10^{-5} \text{ ft}$$

$$K = 11.4 \times 10^{-5} \left[\frac{9.81(475.7)(0.0775)}{(1.23 \times 10^{-3})^2} \right]^{1/3} = 2.28$$

2.28 < 3.3 then stock's law region applied. From Eq.20 using $d_p = d_{p\text{min}} = 35 \mu\text{m}$

$$WL = \frac{18 \mu_g Q}{g \rho_p d_p^2} = \frac{18(1.23 \times 10^{-5})(130)}{9.81(475.7)(11.48 \times 10^{-5})^2}$$

$$WL = \text{Collection Area} = 142.5 \text{ ft}^2$$

$$Q = u \times \text{Frontal Area} = u * H * W$$

$$HW = \frac{Q}{u} = \frac{130}{10} = 13 \text{ ft}^2$$

The minimum vertical height required for cleaning purpose ($H = 1 \text{ m} = 3.3 \text{ ft}$)

$$\therefore HW = 13 \text{ ft}^2 \Rightarrow W = \frac{13}{H} = \frac{13}{3.3} = 3.94 \text{ ft}$$

$$\therefore WL = 142.5 \text{ ft}^2 \Rightarrow L = \frac{142.5}{3.94} = 36.2 \text{ ft}$$

$$\begin{aligned} \therefore \text{Total volume of settler} &= WHL \\ &= (3.94)(3.3)(36.2) \\ &= 470.7 \text{ ft}^3 \end{aligned}$$

Design multi-tray Settling chamber

A more elaborate settling chamber is the Howard type whose simplified diagram is shown in Fig.22

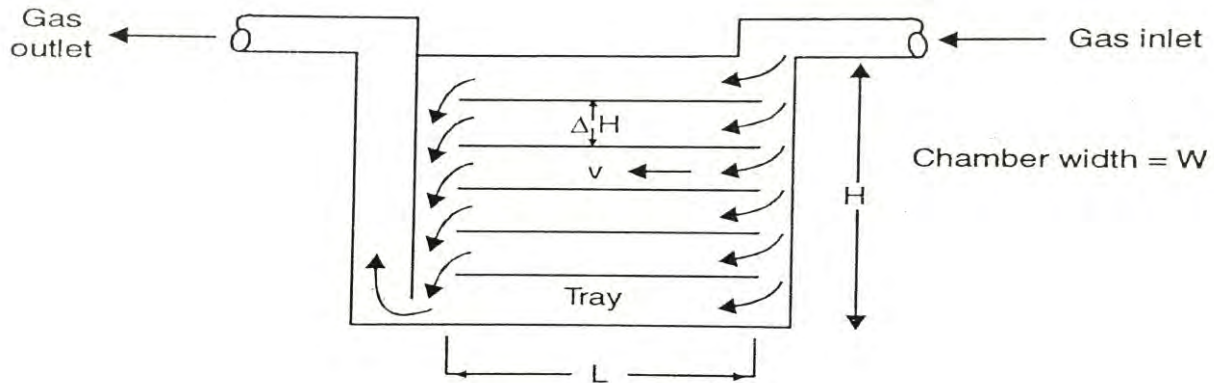


Fig.22. Howard settling chamber

For settling chamber having the dimensions $L \times W \times H$ and n number of trays including the bottom surface (Fig.22), the hydraulic diameter for flow passage between the trays is given by

$$D_h = \frac{2W\Delta H}{W + \Delta H} \quad (24)$$

and the Reynolds number,

$$\text{Re} = \frac{vD_h\rho_g}{\mu_g} \quad (25)$$

$$v = \frac{Q}{nW\Delta H}$$

where Q = volumetric flow rate of the gas stream

Substituting for v and D_h in the Eq.25, we get

$$\text{Re} = \frac{2Q\rho_g}{n\mu_g(W + \Delta H)} \quad (26)$$

The spacing between the trays is, ΔH is given by

$$\Delta H = \frac{H}{n}$$

Provided there is no dust layer initially present on the tray surface. Substituting for ΔH in Eq.26 we have

$$\text{Re} = \frac{2Q\rho_g}{\mu_g(nW + H)} \quad (27)$$

The efficiency of collection

$$\eta = \frac{V_t n W L}{Q} \quad (28)$$

and the minimum particle size that can removed 100% efficiency can be found from the equation,

$$d_{p,\min} = \sqrt{\frac{18\mu_g Q}{n W L g(\rho_p - \rho_g)}} \quad (29)$$

Note: previous equations assuming the laminar flow

Example 5

A multi-tray settling chamber having 8 trays. Including the bottom surface, handles 6 m³/s of air at 20 °C. The trays are spaced 0.25 m apart and the chamber is to be 1 m wide and 4 m long.

1. What is the minimum particle size of density 2000 kg/m³ that can be collected with 100% efficiency?
2. What will be the efficiency of the settling chamber if 50 μm particles are to be removed?

Assume Laminar flow condition within the chamber.

μ_g at 20 °C = 1.81x10⁻⁵ kg/m.s, ρ_p = 2000 kg/m³.

Answer

From Eq.29

$$d_{p,\min} = \sqrt{\frac{18\mu_g Q}{n W L g(\rho_p - \rho_g)}}$$

Since the $\rho_p \gg \rho_g$, ρ_g may be neglected in the above equation.

$$d_{p,\min} = \sqrt{\frac{18(1.81 \times 10^{-5})6}{8(1)(4)(9.81)(2000)}} = 5.6 \times 10^{-5} m = 56 \mu m$$

From Eq.28 and using Stock's law for V_t

$$\eta = \frac{V_t n W L}{Q} = \frac{g d_p^2 (\rho_p - \rho_g) n W L}{18 \mu_g Q}$$

$\eta_{100} = 1$, then the efficiency to remove 50 μm is:

$$\frac{\eta}{\eta_{100}} = \left(\frac{d_p}{d_{p.\min}} \right)^2$$

$$\frac{\eta}{1} = \left(\frac{50}{56} \right)^2 = 80\%$$

Turbulent Flow model (well-mixed settling)

This model is often referred as the well-mixed settling model.

Assume that the gas flow is totally mixed in y-direction and not in x-direction

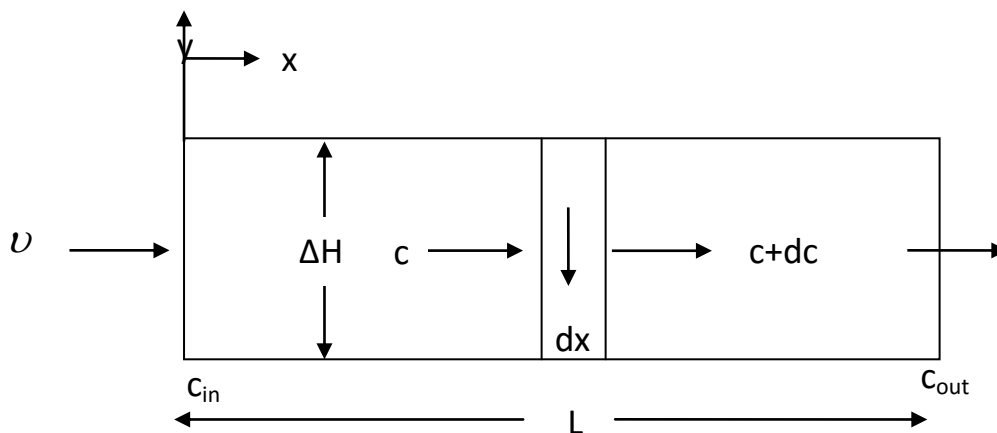


Fig.23. Gravity settling in a horizontal duct: turbulent flow

$$\left\{ \begin{array}{l} \text{Mass concentration of} \\ \text{particles entering the} \\ \text{elemental volum (} Adx \text{)} \end{array} \right. = \left\{ \begin{array}{l} \text{Mass concentration of} \\ \text{particles leaving the} \\ \text{elemental volum (} Adx \text{)} \end{array} \right. + \left\{ \begin{array}{l} \text{Mass concentration of} \\ \text{particles leaving the} \\ \text{elemental volum (} Adx \text{)} \end{array} \right. \quad 67$$

$$cAv = (c + dc)Av + cv_t W dx \quad (30)$$

where c = mass concentration of the particles, and $A = W\Delta H$

$$\int_{c_{in}}^{c_{out}} \frac{dc}{c} = \frac{v_t W}{Av} \int_0^L dx$$

$$\ln \frac{c_{out}}{c_{in}} = \frac{v_t WL}{Av} \quad (31)$$

The efficiency $\eta = 1 - \frac{c_{out}}{c_{in}}$ (32)

Substituting Eq.31 into Eq.32 we get the efficiency in term of volumetric flow rate,

The efficiency $\eta = 1 - \exp\left[-\frac{nWLv_t}{Q}\right]$ (32)

Noting that the term in the bracket is the negative of the efficiency term for the laminar flow (Eq.28), we can write as:

$$\eta_{turb} = 1 - \exp(-\eta_{lami}) \quad (32)$$

Example 6

In example 5, is the laminar flow assumption justified? If not, what is the collection efficiency for 56 and 50 μm particles?

answer

The Reynolds number calculated using Eq.27 as:

$$\text{Re} = \frac{2Q\rho_g}{\mu_g(nW + H)} \quad (27)$$

The kinematic viscosity of air at 20 °C, is $1.51 \times 10^{-5} \text{ m}^2/\text{s}$.

where The kinematic viscosity = $\frac{\mu_g}{\rho_g} = 1.51 \times 10^{-5} \text{ m}^2 / \text{s}$, and $H = 2 \text{ m}$, then:

$$\begin{aligned} \text{Re} &= \frac{2Q\rho_g}{\mu_g(nW + H)} \\ &= \frac{2Q}{\left(\frac{\mu_g}{\rho_g}\right)(nW + H)} \\ &= \frac{2(6)}{1.51 \times 10^{-5}(8 \times 1 + 2)} = 79470 \end{aligned}$$

The flow is turbulent and the laminar flow assumption in example 5 was not justified. Hence, using Eq.32 we get:

$$\eta = 1 - \exp\left[-\frac{nWLv_t}{Q}\right] \quad (32)$$

The terminal velocity using stock's law Eq.13:

$$V_t = \frac{gd_p^2(\rho_p - \rho_g)}{18\mu_g} \quad (13)$$

The dynamic viscosity of air $\mu_g = 1.81 \times 10^{-5}$ kg/m.s

$$\eta = 1 - \exp\left[-\frac{(8 \times 1 \times 4)v_t}{6}\right]$$

The terminal velocity:

$$V_t = \frac{9.8 \times 2000 \times d_p^2}{18(1.81 \times 10^{-5})}$$

$d_p, \mu\text{m}$	$V_t, \text{m/s}$	η
50	0.15	0.55 or 55%
56	0.188	0.63 or 66%

2. Centrifugal separators (Cyclone separators) design

2.1. Cyclone design

Two standard designs for gas-solid cyclones; (a) high-efficiency cyclone, Fig.24 (a) and (b) high gas flow rate cyclone, Fig.24 (b). The performance curves for the high efficiency cyclone and high gas rate cyclone are shown in Fig.24 (a) and (b) These curves can be transformed to other cyclone sizes and operating conditions by use the following scaling equation for a given separating efficiency:

$$d_2 = d_1 \left[\left(\frac{D_{C2}}{D_{C1}} \right)^3 \times \frac{Q_1}{Q_2} \times \frac{\Delta\rho_1}{\Delta\rho_2} \times \frac{\mu_2}{\mu_1} \right] \quad (14)$$

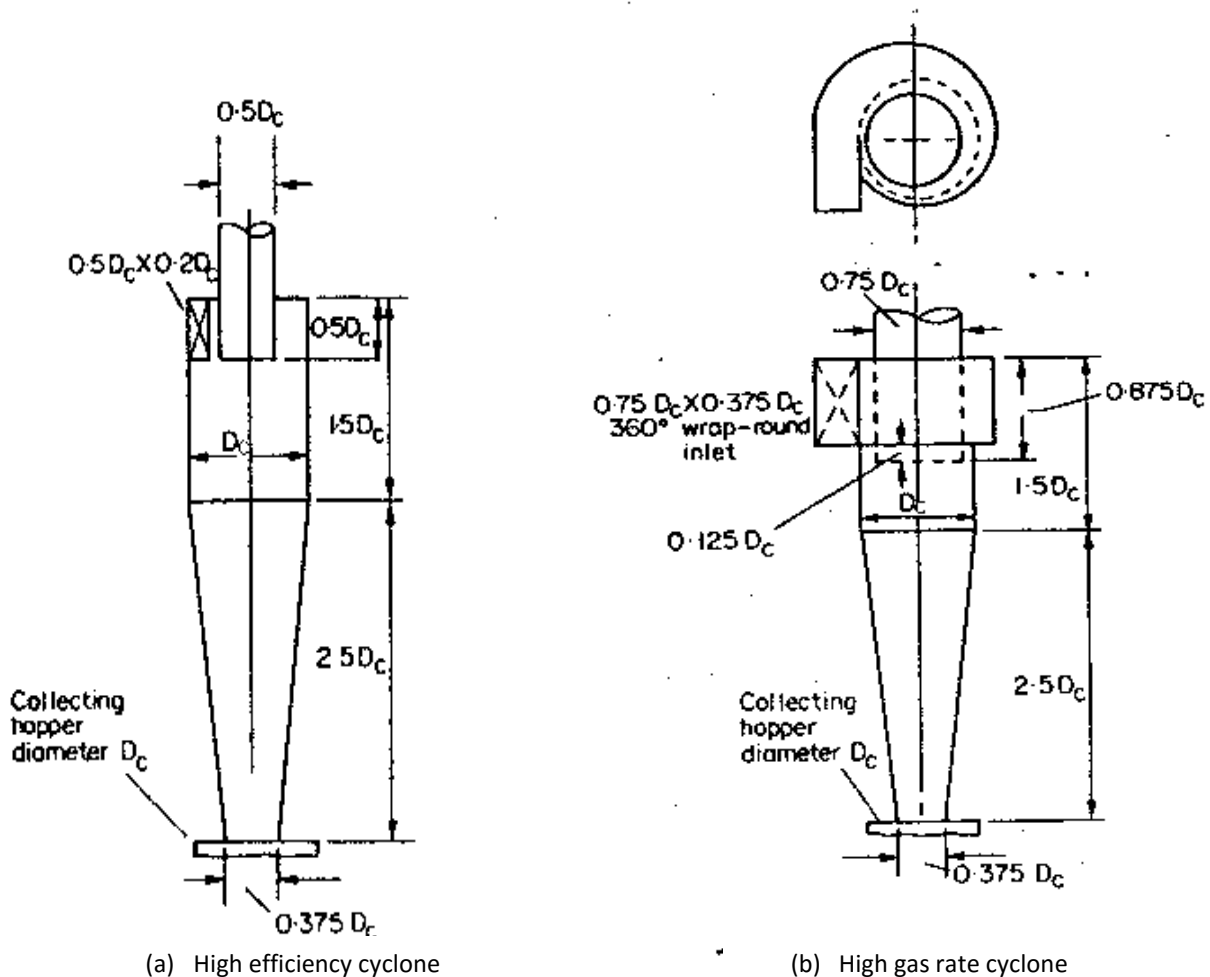
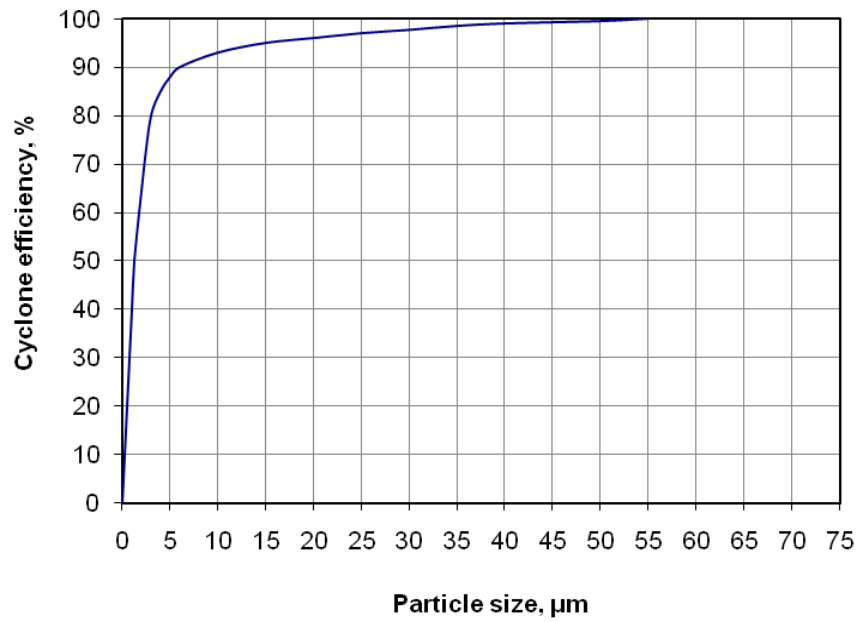
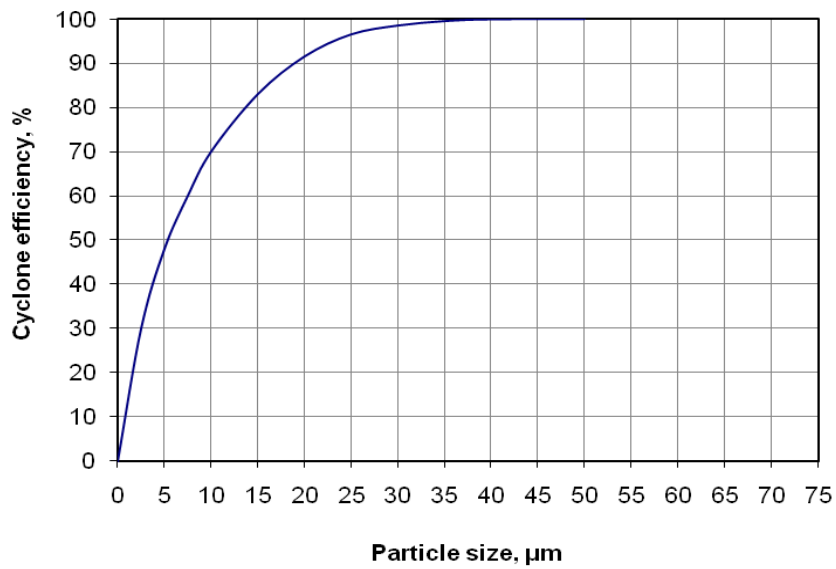


Fig.24. Standard cyclone dimension



(a) High efficiency Cyclone



(b) High gas rate cyclone

Fig.25. Performance curves, standard conditions

where

d_1 = mean diameter of particle separated at standard condition, at chosen separation efficiency, Fig.25.

d_2 = mean diameter of particle separated in proposed design, at the same separation efficiency.

D_{C1} = diameter of standard cyclone = 8 inches (203 mm).

D_{C2} = diameter proposed cyclone, mm

Q_1 = standard flow rate, m^3/h .

for high efficiency design = 223 m^3/h .

for high throughput design = 669 m^3/h .

Q_2 = proposed flow rate, m^3/h .

$\Delta\rho_1$ = solid-fluid density difference in standard condition = 2000 kg/m^3 .

$\Delta\rho_2$ = solid-fluid density difference, proposed design.

μ_1 = fluid viscosity (air at 1 atm, 20 °C = 0.018 mNs/m^2).

μ_2 = fluid viscosity, proposed design.

Hint

Cyclones should be designed to give an inlet velocity of between 9 and 27 m/s (30-90 ft/s). The optimum velocity has been found to be 15 m/s (50 ft/s).

2.2. Cyclone pressure drop

the pressure drop in cyclone will be due to the entry and exit losses, and friction and kinetic energy losses in the cyclone. The empirical equation can be used to estimate the pressure drop:

$$\Delta p = \frac{\rho_g}{203} \left\{ u_1^2 \left[1 + 2\phi^2 \left(\frac{2r_t}{r_e} - 1 \right) + 2u_2^2 \right] \right\} \quad (14)$$

where

Δp = cyclone pressure drop, millibars.

ρ_g = gas density, kg/m³.

u_1 = inlet duct velocity, m/s.

u_2 = exit duct velocity, m/s.

r_t = radius of circle to which the center line of the inlet is tangential, m

r_e = radius of exit pipe, m

ϕ = fraction from Fig.13.

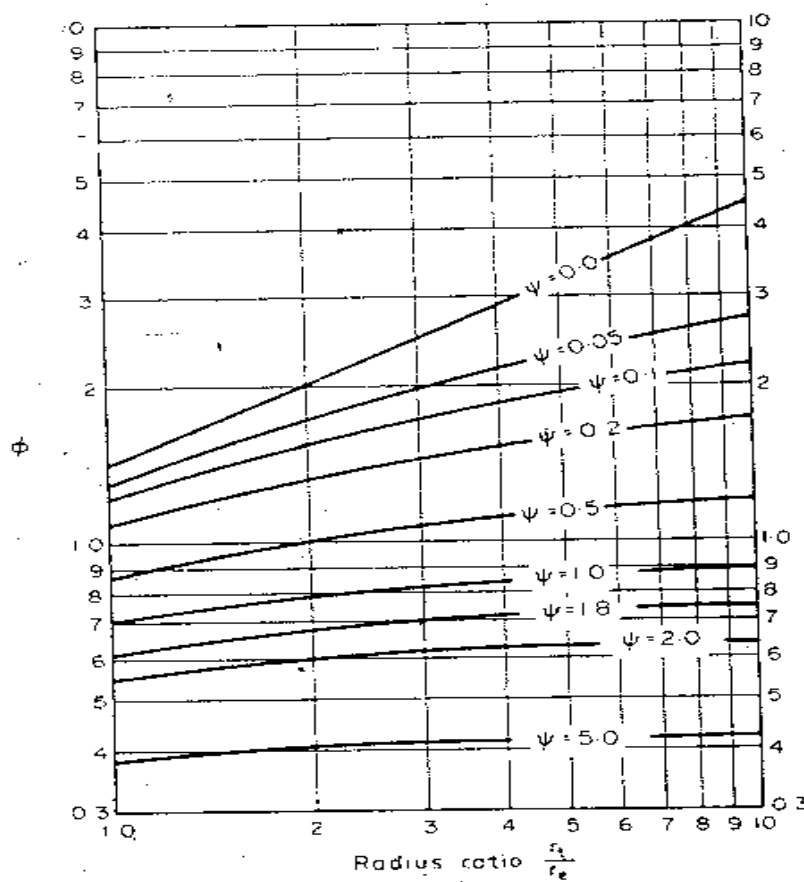


Fig.26. Cyclone pressure drop factor

Ψ = parameter in Fig.26..

$$\psi = f_c \frac{A_s}{A_1}$$

where

f_C = fraction factor, taken as 0.005 for gas.

A_S = surface area of cyclone expose to the spinning fluid, m².

For design purpose this can be taken as equal to the surface area of a cylinder with the same diameter as the cyclone.

A_1 = area of inlet duct, m².

2.3. Cyclone efficiency

The efficiency of cyclone can be estimated by using the concept of a cut diameter, cut diameter can be defined as the particle diameter at which 50% of particle are removed by cyclone:

$$d_{p_{50}} = \left[\frac{9\mu_g b}{2\pi N V_g (\rho_p - \rho_g)} \right]^{1/2} \quad (15)$$

where

μ_g = gas viscosity, kg/m.s.

b = cyclone inlet width, m.

N = effective number of outer turn in the cyclone (normally about 4).

V_g = inlet gas velocity, m/s.

ρ_p = particle density, kg/m³.

P_p = gas density, kg/m³.

The cut diameter can be used to establish the collection efficiency for any other diameter particle, d_p , as shown in Fig.27.

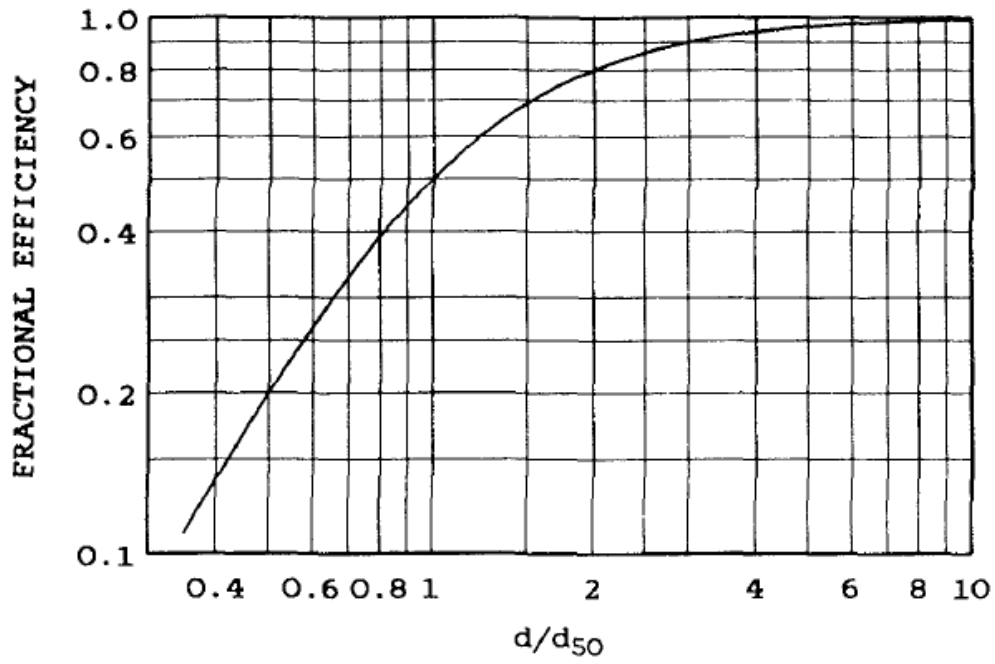


Fig.27. Cyclone efficiency versus particle-size ratio

Solid Waste Management

Solid waste

Solid waste, often called the third pollution, after air and water pollution. Solid waste is that material which arises from various human activities and which is normally discharged as useless or unwanted. It consists:

- Highly heterogeneous mass of discharged materials from the urban community (المخلفات الحضرية).
- The more homogeneous accumulation of agricultural, industrial and mining waste.

Classification of solid wastes

Solid wastes may be classified based party on content and party on moisture and heating value. A typical classification is as follows:

1. **Garbage (المخلفات المتعفنة):** Refers to the putrescible solid waste constituents (المخلفات المتعفنة) produced during the preparation or storage of meat, fruit, vegetables etc. These wastes have a moisture content of about 70% and heating value of about 6×10^6 J/kg.
2. **Rubbish (المخلفات غير المتعفنة):** Refers to non-putrescible solids waste constituents, either combustible or non-combustible. Combustible wastes would include paper, wood scrap, rubber, leather etc. Non-combustible wastes are metals, glass, ceramics etc. These wastes contain a moisture content of about 25% and heating value of the waste is around 15×10^6 J/kg.
3. **Pathological wastes (المخلفات المرضية):** Dead animals, human waste, etc. The moisture content is 85% and there are 5% non-combustible solids. The heating value is around 2.5×10^6 J/kg.
4. **Industrial wastes (المخلفات الصناعية):** Chemicals, paints, sand, metal ore processing, fly ash, sewage treatment sludge etc.
5. **Agricultural wastes (المخلفات الزراعية):** Farm animal manure (السماد), crop residues etc.

Solid waste disposal methods

An appropriate selection of disposal method of solid waste:

1. Can save and avoid future problems.
2. The method should also provide opportunities for recycling of materials if possible
3. Should not pollute the air, the ground water, the surface water or the land.

Several disposal methods are being used in the various parts of the world and the most prominent of these are:

1. Open dumping نظايات العرض لحو
2. Sanitary landfill دفن القوي انتلص حي
3. Incineration لا حرق
4. Composting التسويد

1. Open dumping

- Open dumping is practiced in many cities because it is cheap and requires no planning.
- The open dumps cause public health problems by encouraging the breeding of flies, rats, mosquitoes and other pests.
- They also become source of objectionable odors and cause air pollution when the wastes are burned in order to reduce their volume and conserve space.

2. Sanitary landfill دفن القوي انتلص حي

Sanitary landfilling is an engineering operation, designed and operated according to acceptable standards. It may be defined as a method of disposing refuse on land without creating nuisances or hazards to public health or safety.

In sanitary landfill operation, refuse is spread and compacted in thin layers within a small area. This layered structure is usually referred to as a cell. The cell is then covered with a layer of soil which is spread uniformly and then compacted. To provide an adequate seal the cover should normally be at least 20 cm thick. When a number of cells reach the final desired elevation, a final cover of about one meter of earth is placed and it is again compacted. The final cover is necessary to prevent rodents (القوقوارض) from burrowing (الاختباء) into refuse.

3. Incineration

Incineration involves burning of solid wastes at high temperature, leftover ashes, glass, metals and unburned combustible amount to perhaps 25% of the original waste. Incineration leads to air pollution unless the plant is designed, equipped and operated to comply with air pollution standards. Typical air pollution from incineration is fly ash, SO₂, hydrogen chloride, and organic acid. Incineration is an economic method for solid waste disposal because useful material and energy can be recovered from the process. Heat can be recovered by putting a waste heat boiler or some other recovery device on an existing waste incinerator. The solid waste has about one-third the heating value of coal with very low sulfur content.

The advantages of incineration include wide range ability for handling varying loads and small space requirement for ultimate disposal. However, the method requires fairly high level of maintenance and the operating costs are higher than those for operating of a sanitary landfill.

4. Composting التسويد

Composting of refuse is an aerobic method of decomposing solid waste. Many types of microorganisms already present in the waste stabilize the organic matter in the waste to produce a soil conditioner.

Initially, the process starts with the mesophilic bacteria بكتريا which oxidize the organic matter in the refuse to carbon dioxide and liberate heat. The temperature rise to about 45 °C and at this point the thermophilic bacteria take over and continue to decomposition. During this phase, the temperature further rise to about 60 °C . The refuse is periodically turned over to allow sufficient oxygen to penetrate to all parts of the material to support aerobic life. After about three week, the compost is stabilized. The end point of operation can be measured by noting a drop in temperature. The compost should have an earthy smell and a dark brown color.

Industrial Safety

An industrial safety system is a countermeasure crucial in any hazardous plants such as oil and gas plants and nuclear plants. They are used to protect human, plant, and environment in case the process goes beyond the control margins.

Type of industrial safety system

- Process Safety System or Process Shutdown System, (PSS).
- Safety Shutdown System (SSS): This includes Emergency Shutdown-(ESD)
- Emergency Depressurization-(EDP) Systems.

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