Arba Minch Water Technology Institute
Faculty of Water Supply and Environmental Engineering

Wastewater & Solid waste management

- **Course Code:** *WSEE-3172*
- **Prerequisite:** *Water supply & treatment, Hydraulics II*
- **Target group:** *G_3-HWRE*

Academic year: *2019/20*

Semester: *II*

Instructor: *Zenebe A.*

Contents included in this course

- **Part I: - Sewer system**
- **Part II:- Wastewater treatment**
- **Part III:- Solid waste management**

Part I:- Sewer system

The main objective:

➢ How to plan, design and construct wastewater conveyance systems

The Specific Objectives

- To identify Systems of sanitation and its application in varying geophysical conditions
- To know types of wastewater and its sources of generation
- To differentiate Methods of collection, design and construction
- To know Sewer maintenance; appurtenances and it respective importance

Outline for Part I

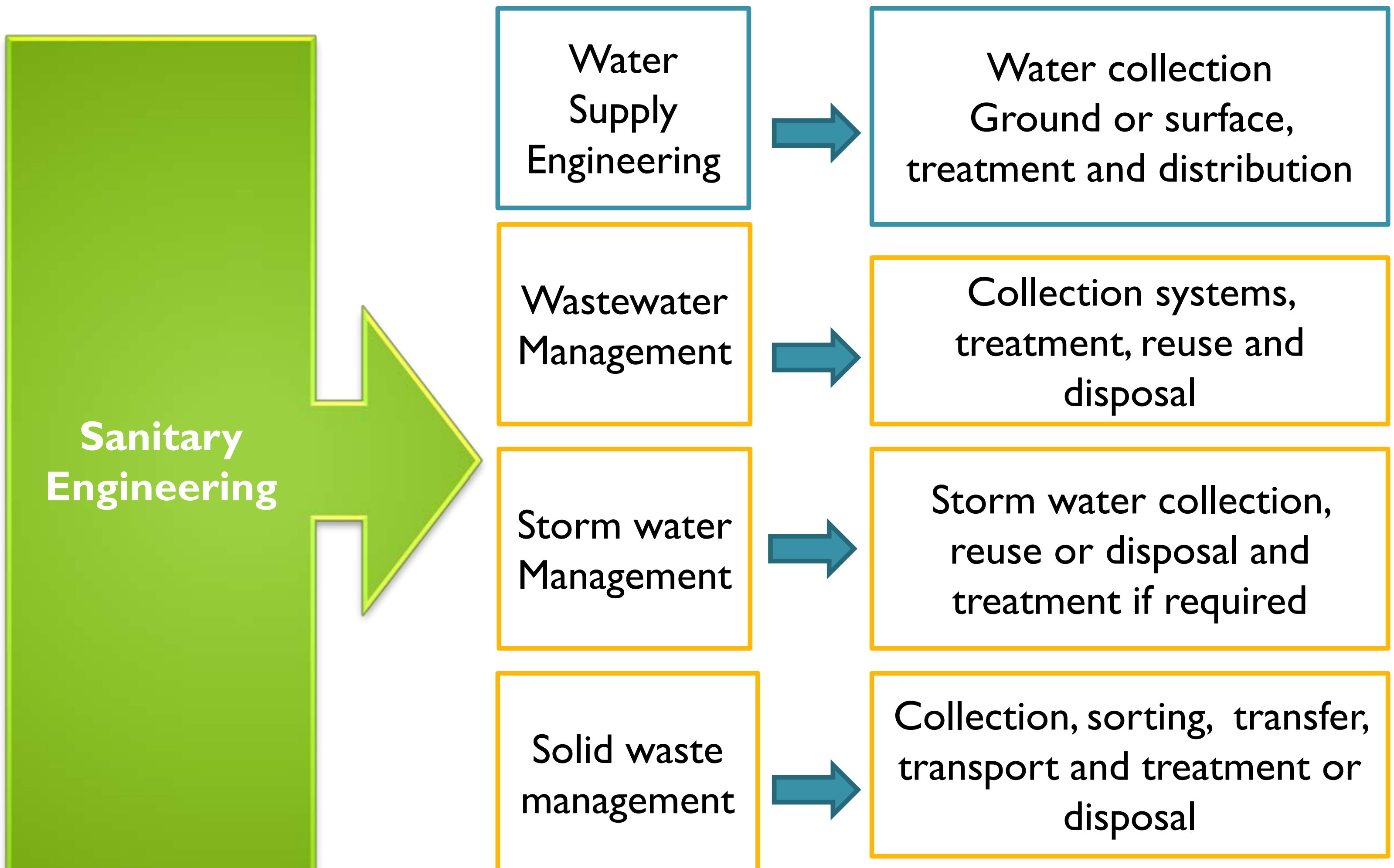
1) **INTRODUCTION TO SANITATION & SANITARY ENGINEERING**
2) **DESIGN SEWAGE QUANTITY ESTIMATION**
3) **HYDRAULIC DESIGN OF SEWERS**
4) **SEWERS CONSTRUCTION, MAINTENANCE AND REQUIRED APPURTENANCES**

Part I:- Lecture 1

INTRODUCTION TO SANITATION & SANITARY ENGINEERING

Chapter I
INTRODUCTION TO SANITATION & SANITARY ENGINEERING

- **Sanitary engineering** is the application of engineering methods to improve sanitation of human communities, primarily by providing the removal and disposal of human waste.
- **Sanitary** engineering is a design and construction specialty that confronts issues related to public health.
- Professionals in the field build new sanitation systems and repair existing structures to improve health and safety.
- Like engineers in other specialties, sanitary engineering professionals draw blueprints, make computer models, and develop models before initiating a new construction project.
- They run computer simulations and small-scale physical experiments to test the effectiveness of a system.
- The sanitary engineer job became essential with the rapid increase of cities and other rural population concentrations.


Sanitary Engineering
Water Supply Engineering
Water collection Ground or surface, treatment and distribution
Wastewater Management
Collection systems, treatment, reuse and disposal
Storm water Management
Storm water collection, reuse or disposal and treatment if required
Solid waste management
Collection, sorting, transfer, transport and treatment or disposal

Important terms in wastewater collection system

- **Sewage:** It is a broad term that indicates the liquid waste originating from the uses of water. It includes domestic wastewater (discharge from toilets, urinals, kitchen, bathrooms etc), wastewater generated from commercial establishments, institutions, industrial establishments and also the ground water and storm water that may enter into the sewers.
- **Storm water:** It indicates the rain water of the locality.
- **Sanitary sewage:** . It is the wastewater generated from the lavatory basins, urinals and water closets of residential buildings, office building, theatre and other institutions. This is very fouling in nature.
- **Infiltration:** It is the water which inters the sewers from ground water through Leaks from loose joints or cracks
- **Inflow:** It is the water which inters the sewers from the manholes during rainfall events.

Important terms in wastewater collection system

- **Sewer:** Sewers are under ground pipes or conduits which carry sewage to points of disposal.
- **Sewerage:** **It** refers to devices, equipments and appurtenances for the collection, transportation and pumping of sewage. Basically it is the science of collecting and carrying sewage by water carriage system through sewers.
- **Sullage**: This refers to the wastewater generated from bathrooms, kitchens, washing place and wash basins, etc. Composition of this waste does not involve higher concentration of organic matter and it is less polluted water as compared to sewage.
- **Night Soil**: It is a term used to indicate the human and animal excreta.

System of Sanitation

- Depending upon the type of *waste,* two systems may be employed for its collection, conveyance and disposal :
  - **(a) Conservancy system**
  - **(b) Water carriage system**

A. Conservancy System

- This is an old system in which various types of wastes, such as night soil, garbage etc. are collected separately in vessels or deposited in pools or pits and then removed periodically at least once in 24 hours.
- The system is also known as the dry *system*.

Advantages of conservancy system

1. Initial cost is low, because storm water can pass through open drains.
2. The quantity of sewage reaching at the treatment plant is low.
3. The sewer section is small and no deposit of silting because storm water goes in open drains.

Disadvantages of conservancy system

1. Hygiene and sanitary aspect: The conservancy system is highly unhygienic and cause insanitary conditions since the excreta starts decomposing within few hours of its production.

2. Transportation aspect

- Transportation of night soil takes place in open carts through streets and other crowded localities. This is highly undesirable.

3. Labour aspect

- The working of the system depends entirely on the mercy of labour (sweepers). If they go on strike even for one day for any reason whatsoever, the previes/ lavatories can not be used because of foul smell.
- The whole locality will smell very badly.

4. Building design aspect

- The lavatories or previes are to be located outside the house and slightly away from the main building.
- The compact design is therefore not possible.

5. Conditions of drains

- Insanitation may be there due to carriage of sullage through open drains laid in the streets.

6. Human Aspect

- In the present day world, when man has progressed much, it is highly humiliating to ask human beings to transport night soil in pails on their heads.

7. Risk of Epidemic

- Due to improper or careless disposal of night soil, there are more chances of outbreak of epidemic.

8. Pollution problems

- The liquid wastes from lavatories etc., during their washing, may soak in the ground, thus contaminating the soil.
- If the ground water is at a shallow depth, it may also be polluted due to percolation of waste water.

9. Cost consideration

- Though the system is quite cheap in the beginning, its maintenance and establishment costs (i.e. recurring expenditure) are very high

10. Disposal land requirement

- The system requires considerable land for the disposal of sewage.

B. Water Carriage system

- The sewage so formed in water carriage system consists of 99.9 % of water and 0.1 % of solid matters.
- In this system, the collection, conveyance and disposal of various type of wastes are carried out with the help of water.
- Thus, water is used as medium to convey the waste from its point of production to the point of its treatment or final disposal.
- Sufficient quantity of water is required to be mixed with the wastes so that dilution ratio is so great that the mixture may flow just like water.

Advantage of water carriage system

1. *Hygienic and sanitary aspect* : The system is very hygienic since the night soil and other waste water is conveyed through closed conduits which are not directly exposed to the atmosphere. There is no bad smell because of continuous flow.

2. Epidemic Aspect

- There are no chances of outbreak of epidemic because flies and other insects do not have direct access to the sewage.

3. Pollution Aspect

- The liquid wastes etc. are directly conveyed through the sewers, and therefore there are no changes of the waste water being soaked in the ground thus contaminating the soil.
- No possibility of groundwater contamination

4. Compactness in design

- Since the latrines are flushed after every use, excreta does not remain and there are no foul smells. The latrines can therefore be attached to the living and bed rooms. This permits a compact design.

5. Labour Aspect

- The labour required for the operation and maintenance is extremely small.
- Labour may be required for pumping operations and blockage cleaning

6. Treatment Aspect

- The system permits the use of modern methods of treatment of the sewerage collected through the sewers.
- The treated waste water and sewage can be safely disposed off without any risk.

7. Land disposal requirement

- Because of treatment facilities, the land required for the disposal of the treated wastewater is very much smaller than· that required for the conservancy system.

Disadvantages:

1. High initial cost.
2. High Operating & Maintenance costs.
3. During rainy season large volume of sewage is to be treated compared to remaining period of year.

Comparison of both systems

- This has been left to you as a home work

Objective Questions

1. Conservancy system is also known as ________________ .
2. If the rainfall is there for a shorter duration, and does not take place throughout the year, it is more economical to adopt __________________
3. __________________ is preferred when, space available for laying the sewers is restricted.

Theory Questions

Q1. Differentiate between

a) Conservancy system and Water carriage system

b) Combined sewer and separate sewers

Q2. Explain factors affecting selection of

Conservancy system Water carriage system

Q3. Write short notes on

i. Combined sewer

ii. Separate sewer

Q4. Mention 5 advantages of water carriage system.

Q5. Explain the combined system of sewerage. Also mention the factors governing choice of combined system.

Q6. Compare conservancy system with water carriage system.

Q7. Describe any two methods of collection of various types of wastes in the conservancy system.

Questions

- What are systems of sanitation?
- What mean by Water carriage system?
- https://www.slideshare.net/reddyas/sewerage-system-56376402

Any
question????????
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Part I:- Lecture 2

Sewage system
and
Sewage Quantity Estimation

The Session topic objectives

I. To identify types of sewage systems
II. To differentiate the factors which govern the selection of sewage systems
III. To estimate sanitary sewage and storm water quantity

Sewage System

- The water carriage system can be divided into the following types:

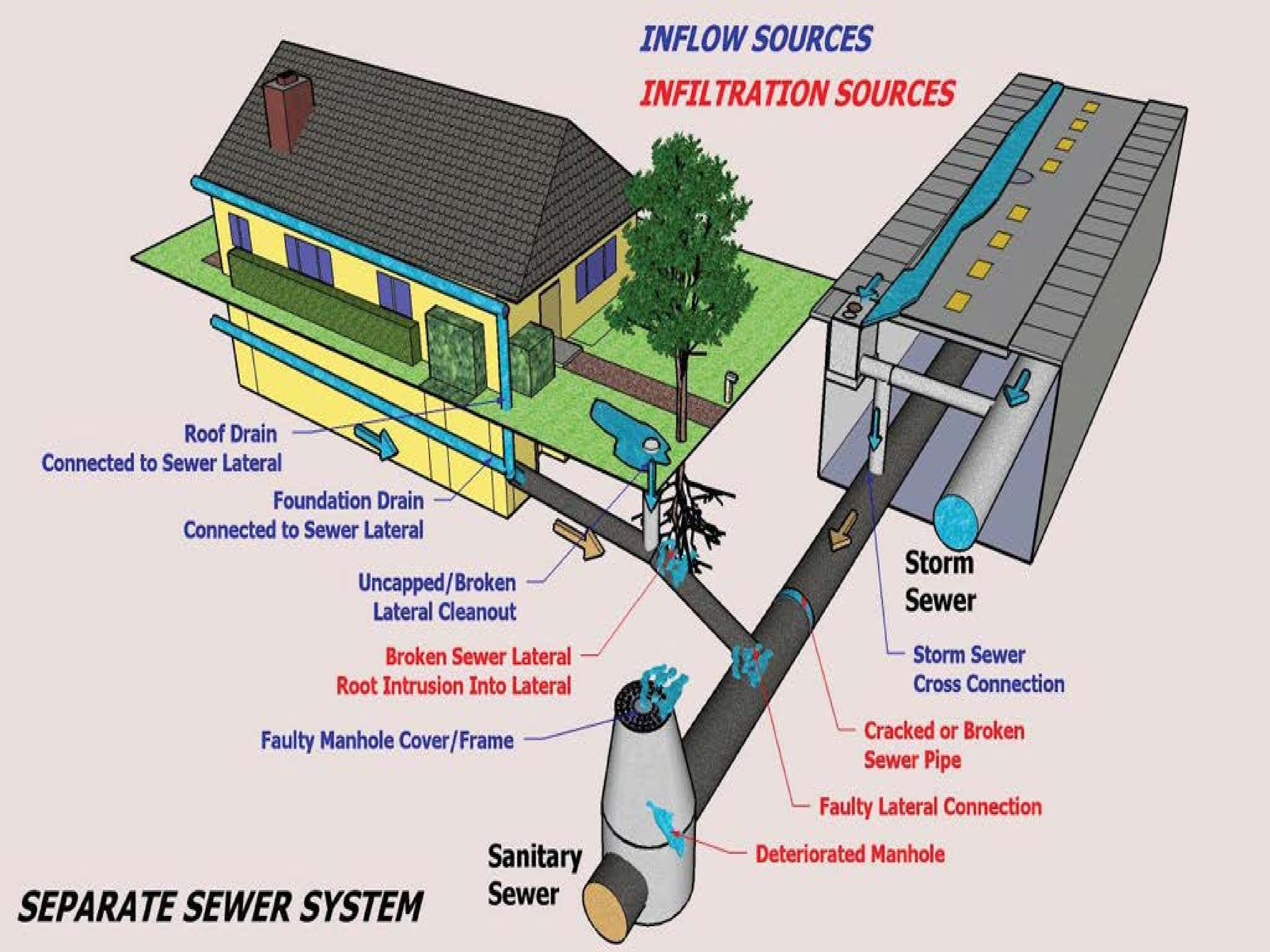
A. Separate system

B. Combined system

C. Partially Combined system

A. Separate system

- The separate system provides two separate systems of sewers.
- The one intended for the conveyance of foul sewage only; and
- The other for the rain water, including the surface washing from certain streets, overflow from public baths and foundations etc.



INFLOW SOURCES
INFILTRATION SOURCES
Roof Drain
Connected to Sewer Lateral
Foundation Drain
Connected to Sewer Lateral
Uncapped/Broken
Lateral Cleanout
Broken Sewer Lateral
Root Intrusion Into Lateral
Faulty Manhole Cover/Frame
Storm
Sewer
Storm Sewer
Cross Connection
Cracked or Broken
Sewer Pipe
Faulty Lateral Connection
Deteriorated Manhole
Sanitary
Sewer
SEPARATE SEWER SYSTEM

Factors affecting selection of separate system

1. Financial aspects
2. Flat topography
3. Rainfall pattern
4. Outlet conditions
5. Pumping aspect
6. Subsoil conditions
7. Development pattern

Advantages of separate sewer system

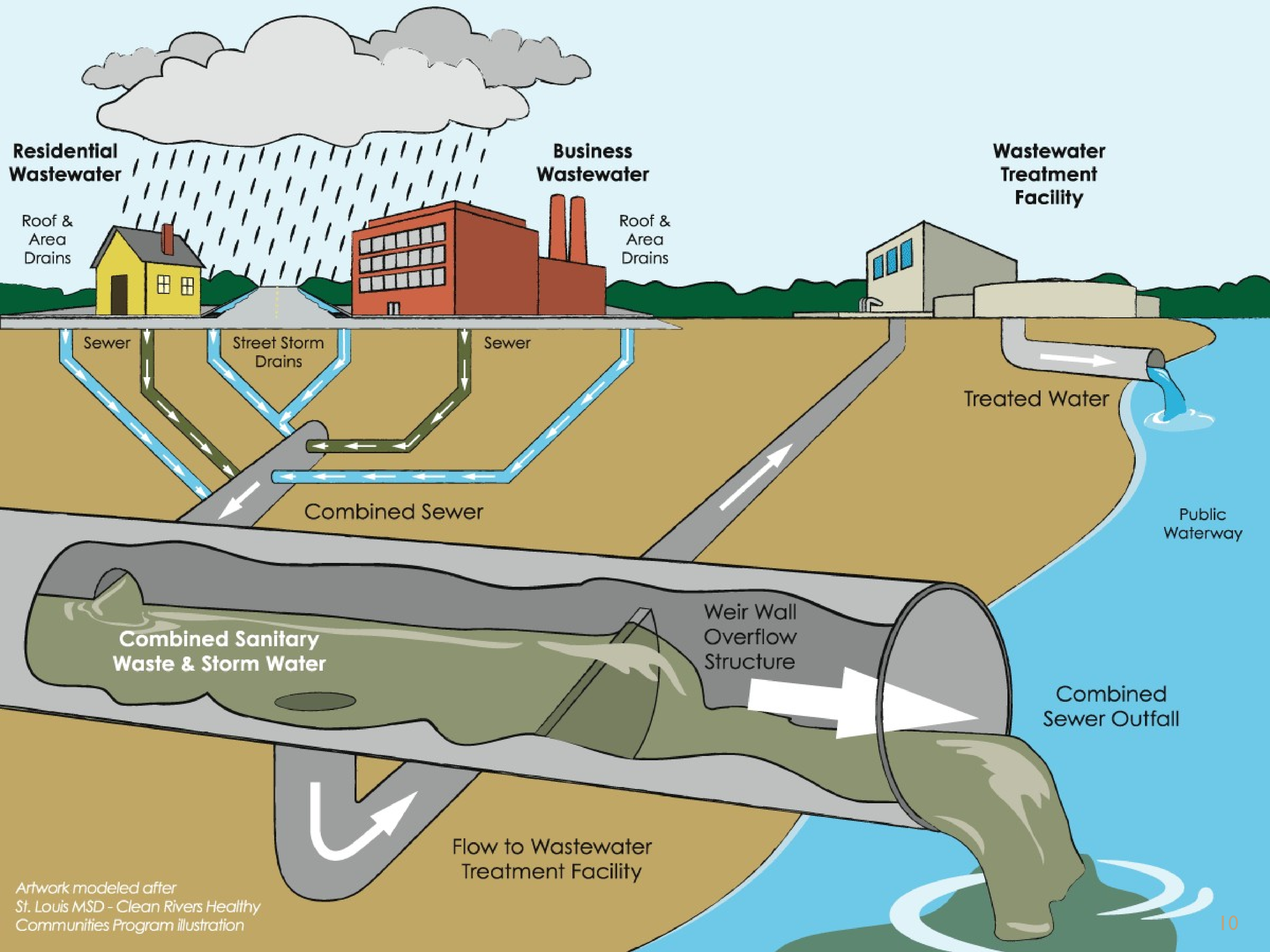
- The size of sewers are small
- Sewage load on treatment units is small
- River or stream waters are not polluted
- Storm water can be discharged into streams or rivers without any treatment
- Economical for sewage pumping since the quantity is small

Disadvantages of separate sewer system

1. Since the sewers are of small size, it is difficult to clean
2. They are easily get clogged .
3. Two sets of sewers may ultimately prove to be costly.
4. Storm water sewers are only used during rainy season

B. Combined system

- The combined system provides only one sewer to **carry both the foul sewage as well as the rain water.**
- The sewage and rain water are carried to the sewage treatment plant, before its final disposal.


Residential Wastewater
Roof & Area Drains
Business Wastewater
Roof & Area Drains
Wastewater Treatment Facility
Sewer
Street Storm Drains
Sewer
Treated Water
Combined Sewer
Public Waterway
Weir Wall Overflow Structure
Combined Sanitary Waste & Storm Water
Combined Sewer Outfall
Flow to Wastewater Treatment Facility
Artwork modeled after St. Louis MSD - Clean Rivers Healthy Communities Program illustration

Factors affecting selection of combined system

1. Space restriction
2. Integrated development
3. Even rainfall pattern
4. *Conversion of existing storm water drains*
5. *Pumping requirements*

Advantages of combined sewer system

1) Large sewer size don't clog easily and are easy to clean
2) Laying one set of sewer is economical
3) The strength of sewage is reduced by dilution
4) Maintenance cost is reasonable

Disadvantages of combined sewer system

1) Large sewers are difficult for handling and transport
2) Due to storm water load the treatment plant is high
3) During heavy rains sewers may overflow causing nuisance
4) Pumping is uneconomical
5) Storm water is unnecessarily polluted

C. Partially combined system

- In this system, only one set of underground sewers is laid.
- These sewers admit the foul sewage as well as the early washings by rains. As soon as the quantity of storm water exceeds a certain limit, the storm water overflows, and is thus collected and conveyed in open drains to the natural streams.

Advantages of partially combined

1. **The sewers are of reasonable size.** Their cleaning is therefore not very difficult.
2. It combines the advantage of both the separate as well as the combined systems.
3. The storm water permitted in the sewers eliminates its chances of chocking. The sewers are completely cleaned during rainy season.
4. The problem of disposing off storm water from homes is simplified.

Disadvantages of partially combined

1. During the dry weather, when there is no rain water, the velocity of flow will be low. Thus self cleansing velocity may not be achieved.
2. The storm water increases the load on treatment units.
3. The storm water also increases the cost of pumping.

Sanitary Sewage estimation

- Before designing the sewer, it is necessary to know the discharge i.e., quantity of sewage, which will flow in because;-
  - far lower estimation than reality will soon lead to inadequate sewer size after commissioning and the sewers may not remain adequate for the entire design period.
  - Similarly, very high discharge estimated will lead to larger sewer size affecting economy of the sewerage scheme, and
  - the lower discharge may not meet the criteria of the self cleansing velocity and hence leading to deposition in the sewers.
- Since sewers are designed to serve for some more future years, engineering skills have to be used to accurately estimate the sewage discharge.

Sanitary Sewage estimation

- Dry weather flow is the flow that occurs in sewers in separate sewerage system or the flow that occurs during dry seasons in combined system.
- This flow indicates the flow of sanitary sewage which depends up on;-
  1) the rate of water supply,
  2) type of area served,
  3) economic conditions of the people,
  4) weather conditions and
  5) infiltration of groundwater in the sewers, if sewers are laid below groundwater table.

Sanitary Sewage estimation

Two Parameters:

1. The contributing population, and
2. Per capita (per person) flowrate of sewage

Both of these quantities depend on the design period

❖ **Design period:** The length of the time up to which the capacity of a sewer will be adequate.

❖ Normally design period for a sewerage system is considered as **30 years**

❖ But, mechanical rotating equipment such as pumps are designed for **15 years**

Sanitary Sewage estimation

❖Prospective population of the project area (may be a city, town or a metropolitan area) can be projected by one of the methods below.

Methods:

- Demographic population projection
- Arithmetical increase method
- Incremental Increase method
- Geometrical Increase method
- Growth rate
- Graphical method
- Logistic method

As you have learnt previously in water supply & treatment classes

Where is the forecast found for design purposes?

❖Normally for a city, population growth forecasts are found from the master-plan prepared by town planning or other relevant authorities.

What to do when masterplan or planners' documents are unavailable?

Floor-Space Index Based Calculation

1. FSI is the ratio of the total floor area of buildings on a certain location to the size of the land of that location.
2. From the city-plan find out the % of the total area available for residential development
3. Actual total floor area = Area for residential development X Floor Space Index (FSI)
4. Find out floor area required for one person or assume it depending on the available data from the city. Normally it is 9 sqm/person.
5. Find out the density of population per hectare
6. Multiply the density with the total area of the city to find out the total population

This total population can be used for estimating the quantity of total sewage flow.

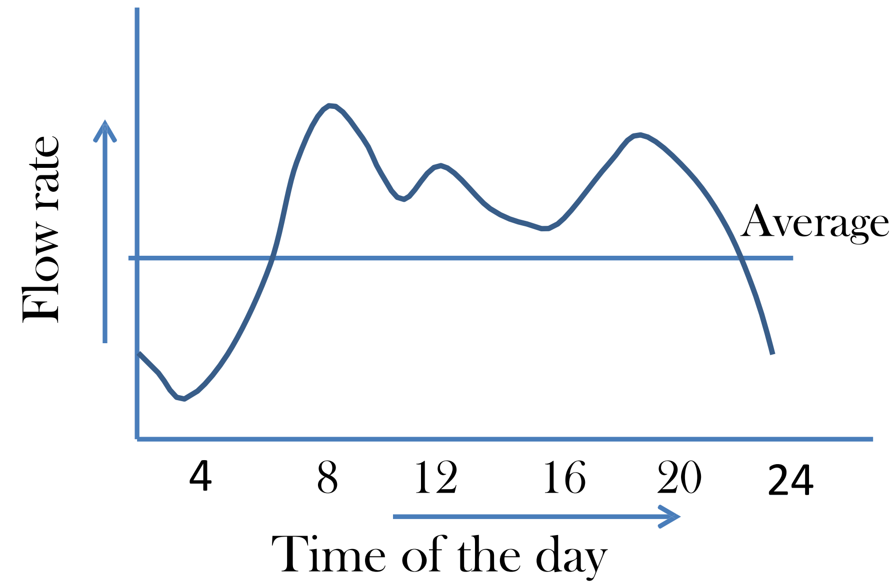
Sanitary Sewage estimation

- Theoretically speaking, the quantity of should be equal to the quantity of water supplied to the contributing area, from the water-works.
- But in actual practice, this is not the precise quantity, certain additions and subtractions do take place from it, as explained below:
  i. Additions due to unaccounted private water Supplies
  ii. Additions due to infiltration and inflow.
  iii. Subtractions due to water losses.
  iv. Subtraction due to water not entering the sewerage 'system
- The net quantity of sewage = the accounted quantity of water supplied + factors **(i)** and **(ii)** - factors (iii) and (iv), described above.
- Generally, 75 to 80% of accounted water supplied is considered as quantity of sewage produced. .

Variations in Flow and Peak Factor

❖Water consumption varies from hour to hour. Along with daily variations, there are also seasonal variations.

❖For design purpose, sewers are always designed to carry maximum or peak flow rates, rather than designing it for average flowrate.



$$\text{Peak Factor (PF)} = \frac{\text{Maximum wastewater flow rate}}{\text{Average wastewater flow rate}}$$

Population	Peak factor
< 20,000	3.0
20,000 – 50,000	2.5
50,000 – 750,000	2.25
> 750,000	2.0

Sanitary Sewage estimation

- Generally the peak and minimum flow of sewage is the relation of population in thousands.
- The peak flow is the product of peak factor with average flow and the minimum flow is the product of minimum factor with average flow; based on this

$$\frac{Qpeak}{Qave} = \frac{5.5}{\left(\frac{P}{1000}\right)0.18} \quad \text{and} \quad \frac{Qmin}{Qave} = 0.2\left(\frac{P}{1000}\right)0.16$$

Where: - P = population in thousands

Q peak= peak sewage flow

Qmin & Qave = minimum & average sewage flow respectively.

Estimation of Storm Water

❖ The quantity of storm water (runoff) reaching to the sewers or drains is very large as compared with sanitary sewage.

Runoff quantity depends on:

- ✓ Rainfall Characteristics (Intensity, Duration and space- time distributions)
- ✓ Characteristics of the watershed surface (nature,permeability, slope, and landscaping)
- ✓ Time of concentration (time required for flow to reach the sewer)

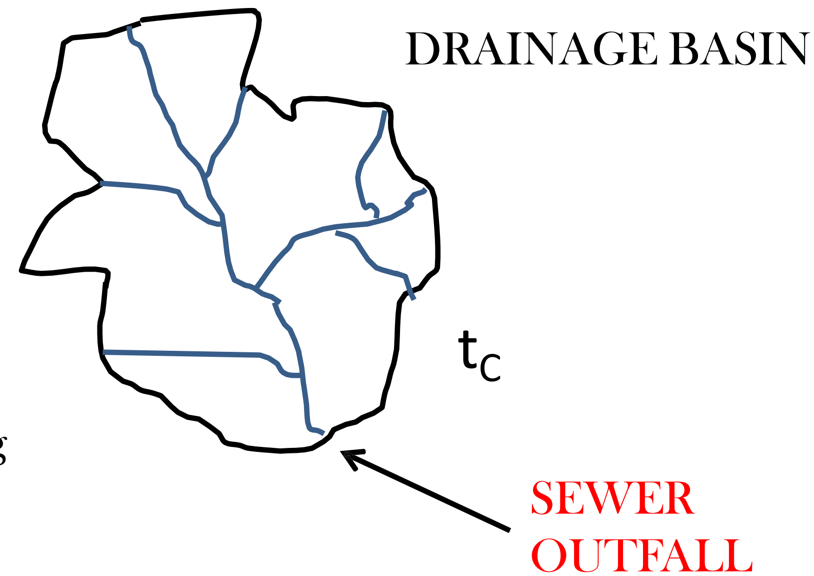
❖ Storm sewers are designed for a rainfall with particular frequency or return period. The design rainfall is fixed after economic considerations involving the Intensity-duration and frequency (IDF) curves in an area.

❖ The design should be adequate to carry from a basin or watershed the maximum runoff caused by the design rainfall.

Time of Concentration (t_c)

❖The period of time after which the entire basin area starts contributing to the run-off.

❖Varies from 3 to 30 minutes



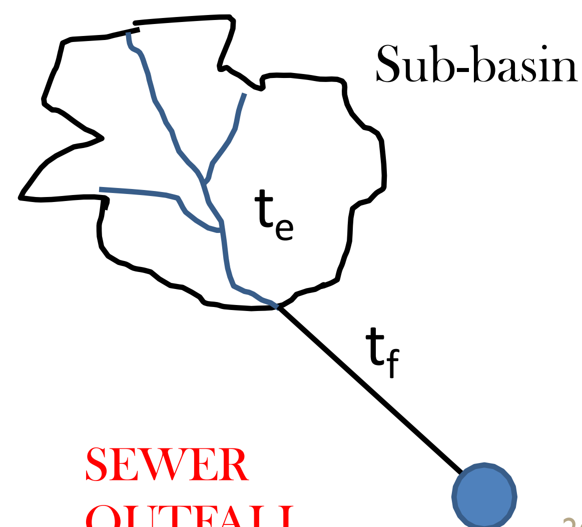
❖Maximum run-off is obtained from a rain having a duration equal to the time of concentration.

❖The duration of such a rainfall is called critical rainfall duration and the intensity of such rainfall is known as critical rainfall intensity.

$$t_c = t_e + t_f$$

t_e= time of entry

t_f= time of flow



❖**Time of entry :** is the longest time required for a water droplet in an urban sub-basin to travel to a street inlet.

Kirpich's model:

$$t_e = \frac{0.0195 L^{0.77} F}{s^{0.385}}$$

L= maximum distance travelled by the water on the surface

S= average slope of the route travelled by water

F = Ground surface friction factor

Surface type	**F**
Rural watershed (flat ground)	1.0
Grass surface	2.0
Concrete or Asphalt surface	0.4
Concrete channel	0.2

❖**Time of flow :** is the time required for water to travel to a sewage outfall from the street inlet in the urban sub-basin. **It is always computed considering that the pipe is running full.**

$$v = \frac{1}{n} R^{2/3} s^{1/2}$$

$$t_f = \frac{L}{v}$$

Estimation of Storm Water

❖Storm water quantity can be estimated by rational method as below:

Q =C.I.A/360

Where,

Q = Quantity of storm water, m^3/sec

C = Coefficient of runoff

I = intensity of rainfall, mm/hour,and

A = Drainage area in hectares

Or

Q = 0.278 C.I.A

Where, Q is m^3/sec; I is mm/hour, and *A is* area in square kilometer

Estimation of Storm Water Contd.

- ***Runoff Coefficient:*** can be defined as a fraction, which is multiplied with the quantity of total rainfall to determine the quantity of rain water, which will reach the sewers.
- The runoff coefficient depends upon the porosity of soil cover, wetness and ground cover.
- The overall runoff coefficient for the catchment area can be worked out as follows:

C = [A1.C1 + A2.C2 + ….+ An.Cn] / [A1 + A2 + …+ An]

Where, A1, A2, …. Are types of area with C1, C2, …. as their coefficient of runoff, respectively.

Questions

1) Why we need to estimate the quantity of sewage as appropriately as possible?
2) What mean by dry weather flow?
3) List factors that could limit Design Period?
4) How do you estimate future Sewage generation?
5) Why do you think sewage generation peak is in a kind of lag mood to that of water consumption?

Any question plz????

Part I:- Lecture 3

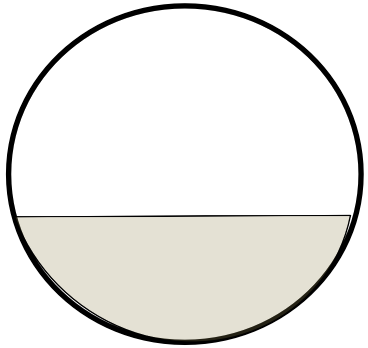
Hydraulic Design of Sewer

Session topic objectives

- *At the end of this session students were able;-*

1) *To have an understanding how design & construction of sewerage differs from water supply*
2) *To Identify empirical formula which the best suits flow in sewer lines*
3) *To know how to design non scouring and silting velocity of flow*
4) *To Characterize hydraulic elements of circular sewer section*

Difference between Sewers and Treated Water Conduits



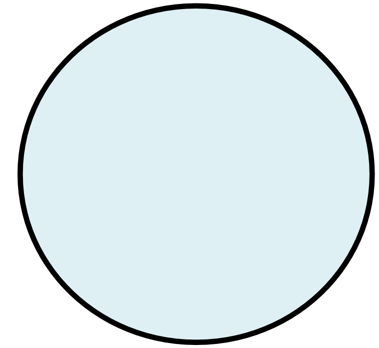
SEWER

1. They are never designed to run full; there is always an empty space provided at the top.

Reasons: a) Biodegradation causes generation of gases like methane, hydrogen sulfide, ammonia etc. which can get dissolved if running under pressure.

b) At same slopes, the velocity and carrying capacity is more when it runs partially full.

2. It is unpressurised. It maintains a gravity flow; It is laid in gradients or slopes.



WATER CONDUITS

1. They are always designed to run full.

2. It is pressurized. Normally, we do **not** worry about the slope of the water mains or lines when we lay them.

Designing Sewer Systems

❖Sewers are designed taking consideration of 30 years.

❖Population in the initial years of the design period are low compared to the design population at the end of design period

❖Peak flow rate in the initial years is low compared to the designed peak flow rate (ultimate peak flow)

❖Sizing should be such that it will attain the self-cleansing velocity at the average design flow rate or at least at the maximum flow rate at the beginning of the design period.

Requirements of Design and Planning of Sewerage system

- The sewers should be laid at least 2 to 3 m deep to carry sewage from basement.
- The sewage should flow under gravity with 0.5 to 0.8 full at designed discharge, i.e. at the maximum estimated discharge.
- The sewage is conveyed to the point usually located at low lying area, where the treatment plant is located.
- Treatment plant should be designed taking into consideration the quality of raw sewage expected and to meet the discharge standards.

HYDRAULIC DESIGN OF SEWERS

- Design of sewers are done assuming steady state conditions. Steady state means that the discharge or flow rate at a point remains time invariant.
- Carry the peak flow rate for which the sewer is designed
- This is directly connected with the maximum achievable velocity in the sewers. We do not want the sewage pipe materials to get worn out.
- The wastewater manual recommends a maximum velocity of 3 m/s.
- Transport suspended solids in such a manner that the siltation in a sewer is kept to a minimum
- This condition gives us an idea about the minimum velocity that has to be maintained inside a sewer during a low flow period.

Provision of Freeboard in Sewers

Sanitary Sewers

- Sewers with diameter less than 0.4 m are designed to run half full at maximum discharge, and
- sewers with diameter greater than 0.4 m are designed 2/3 to ¾ full at maximum discharge.
- The extra space provided in the sewers provides factor of safety to counteract against the following factors:

1. Safeguard against lower estimation of the quantity of wastewater to be collected at the end of design period due to private water supply by industries and public. Thus, to ensure that sewers will never flow full eliminating pressure flow inside the sewer.

Provision of Freeboard in Sewers

2. Large scale infiltration of storm water through wrong or illegal connection, through underground cracks or open joints in the sewers.
3. unexpected increase in population or water consumption and the consequent increase in sewage production.

- Storm water drains are provided with nominal freeboard, above their designed full supply line because the overflow from storm water drains is not much harmful.
- Minimum of 0.3 m free board is generally provided in storm water drains.

Hydraulic Formulae for Determining Flow Velocities

- Sewers of any shape are hydraulically designed as open channels, except in the case of inverted siphons and discharge lines of pumping stations. Following formulae can be used for design of sewers.

1. Manning's Formula

- This is most commonly used for design of sewers. The velocity of flow through sewers can be determined using Manning's formula as below:

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

Where,

V = velocity of flow in the sewer, m/sec

R = Hydraulic mean depth of flow, m, R = A/P

A = Cross section area of flow, m^2 &

P = Wetted perimeter, m

Hydraulic Formulae cont'd…

n = Manning's coefficient depends upon the type of the channel surface i.e., material and lies between 0.011 to 0.015 for brick sewer

it could be 0.017 to 0.03 for stone facing sewers.

S = Hydraulic gradient, equal to invert slope for uniform flows.

2. Chezy's Formula

$$V = c\sqrt{Rs}$$

V = velocity of flow in the channel in, m/sec

R = hydraulic mean radius of channel, i.e. hydraulic mean depth of channel

S = hydraulic gradient, equal to the ground slope for uniform flows, i.e. the head drop between the two points divided by the length

C = a constant, called Chezy's constant , **can be calculated by using Bazin's formula.**

- ✓ Constant (C) is very complex. Depends on size, shape and smoother roughness of the channel, the mean depth etc.

Bazin's formula

$$C = \frac{157.6}{[1.81 + (K/R^{1/2})]}$$

Where,

K= Bazin's constant

R= hydraulic radius

Sr. No.	Inside nature of the sewer	K values
1.	Very smooth	0.109
2.	Smooth: bricks & concrete	0.290
3.	Smooth: rubble masonry	0.833
4.	Good, earthen material	1.540
5.	Rough: bricks & concrete	0.500
6.	Rough earthen material	3.170

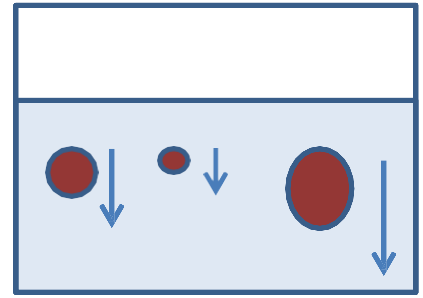
Maximum Velocity in sewers

- The smooth interior surface of a sewer pipe gets **scoured** due to continuous abrasion caused by the suspended solids present in sewage.
- It is therefore, necessary to limit the maximum velocity in the sewer pipe.
- This limiting will mainly depend upon the material of the sewer.
- Moreover, care should be taken to see that at the time of maximum flow, the velocity generated does not exceed the scouring value.

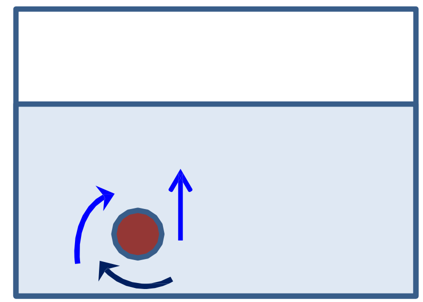
Minimum Velocity in a Sewer

The velocity should be such that:

A) It will not allow the particles to settle inside the sewer



B) Even if there is a deposition, it will promote scouring of the particles so that it can self - cleanse itself



❖The generation of Self-cleansing velocity should occur within the sewer for at least once in a day.

Self Cleansing Velocity

$$V_S = \frac{1}{n} R^{\frac{1}{6}} \sqrt{k(S_S - 1)D_p}$$

n = roughness coefficient

R = Hydraulic Mean Radius = $\frac{A}{P}$

A= Area of the channel

P= Wetted perimeter of the channel

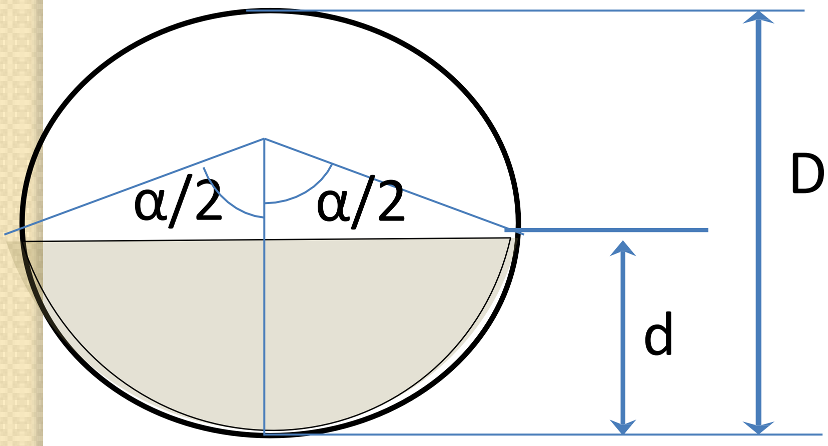
S_s = Specific gravity of the particle

k = Dimensionless constant, 0.04 for granular particles, **0.8** for organic matters

D_P = Diameter of the particle for which the sewer will be designed, this is the maximum particle size the sewer can safely carry

❖ Sewers are always designed to attain the self cleansing velocities

Characteristics of hydraulic elements of circular sewer section running full or partial



✓Capital Letters denote the situation when the **sewers run full**

❖**Depth at partial flow**

$$d = [\frac{D}{2} - \frac{D}{2}\cos\frac{\alpha}{2}]$$

❖**Depth proportionate**

$$\frac{d}{D} = \frac{1}{2}[1 - \cos\frac{\alpha}{2}]$$

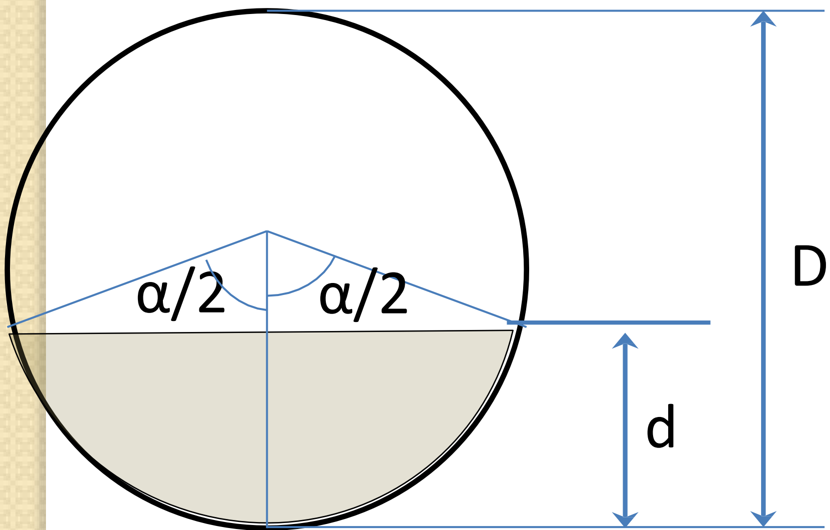
❖**Area proportionate**

$$A = \frac{\pi}{4} D^2$$

$$\frac{a}{A} = [\frac{\alpha}{360} - \frac{\sin\alpha}{2\pi}]$$

❖**Area at partial flow**

$$a = \frac{\pi}{4} D^2 [\frac{\alpha}{360} - \frac{\sin\alpha}{2\pi}]$$



❖**Perimeter at full flow**

$$P = \pi D$$

❖**Perimeter at partial flow**

$$p = \pi D * \frac{\alpha}{360}$$

❖**Perimeter proportionate**

$$\frac{p}{P} = \frac{\pi D * \frac{\alpha}{360}}{\pi D} = \frac{\alpha}{360}$$

❖**Hydraulic radius at full flow**

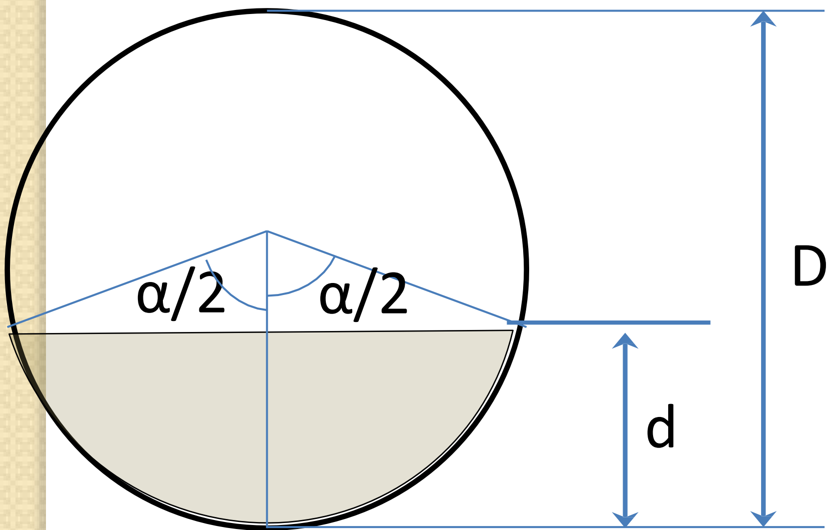
$$R = \frac{A}{P} = \frac{\frac{\pi D^2}{4}}{\pi D} = \frac{D}{4}$$

❖**Hydraulic radius at partial flow**

$$r = \frac{a}{p} = \frac{D}{4}[1 - \frac{360 \sin \alpha}{2\pi\alpha}]$$

❖**Mean hydraulic radius proportionate**

$$\frac{r}{R} = [1 - \frac{360 \sin \alpha}{2\pi\alpha}]$$



❖**Velocity at full flow**

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

❖**Velocity at partial flow**

$$v = \frac{1}{n} r^{2/3} s^{1/2}$$

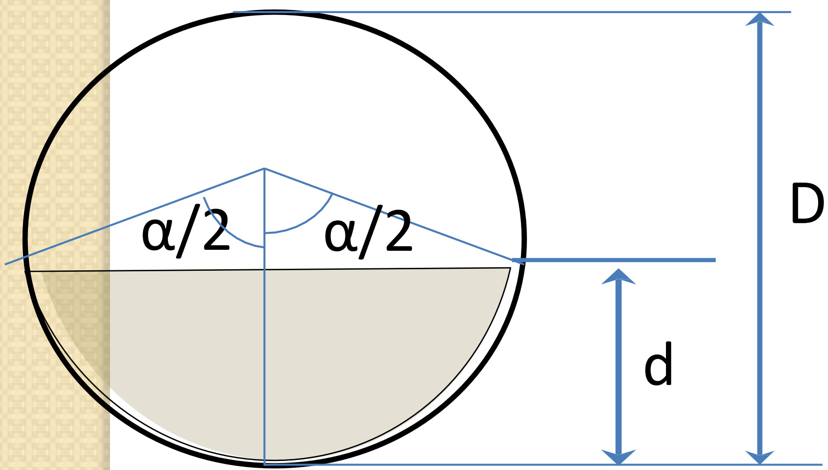
❖**Velocity proportionate**

$$\frac{v}{V} = \frac{r^{2/3}}{R^{2/3}} = \left(\frac{r}{R}\right)^{2/3} = \left[1 - \frac{360 \sin\alpha}{2\pi\alpha}\right]^{2/3}$$

❖**Discharge proportionate**

$$\frac{q}{Q} = \frac{a.v}{A.V} = \frac{a}{A} * \frac{v}{V} = \left[\frac{\alpha}{360} - \frac{\sin\alpha}{2\pi}\right]\left[1 - \frac{360 \sin\alpha}{2\pi\alpha}\right]^{2/3}$$

❖Summary



$$\frac{d}{D}=\frac{1}{2}[1-\cos\frac{\alpha}{2}]$$,Depth proportionate

$$\frac{r}{R}=[1-\frac{360\sin\alpha}{2\pi\alpha}]$$,H.radius proportionate

$$\frac{v}{V}=\left[1-\frac{360\sin\alpha}{2\pi\alpha}\right]^{2/3}$$,Velocity proportionate

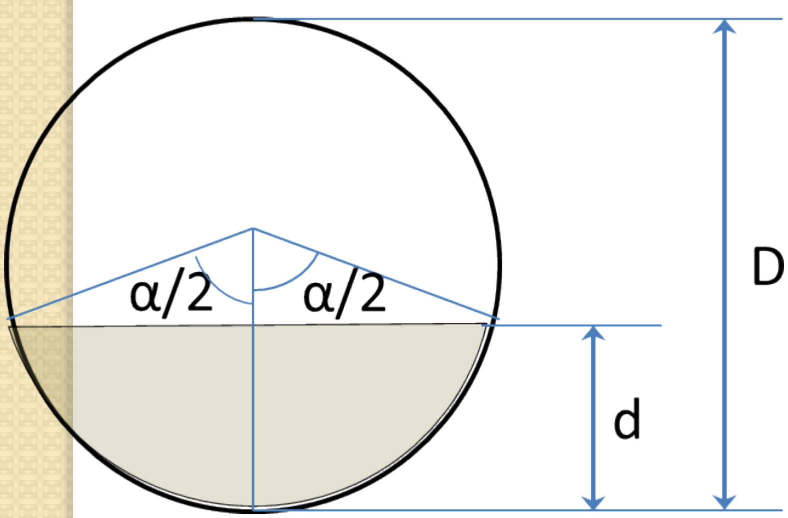
$$\frac{q}{Q}=\left[\frac{\alpha}{360}-\frac{\sin\alpha}{2\pi}\right]\left[1-\frac{360\sin\alpha}{2\pi\alpha}\right]^{2/3}$$

Discharge proportionate,

❖In all the above expressions, α is the only variable, all other parameters are constant.

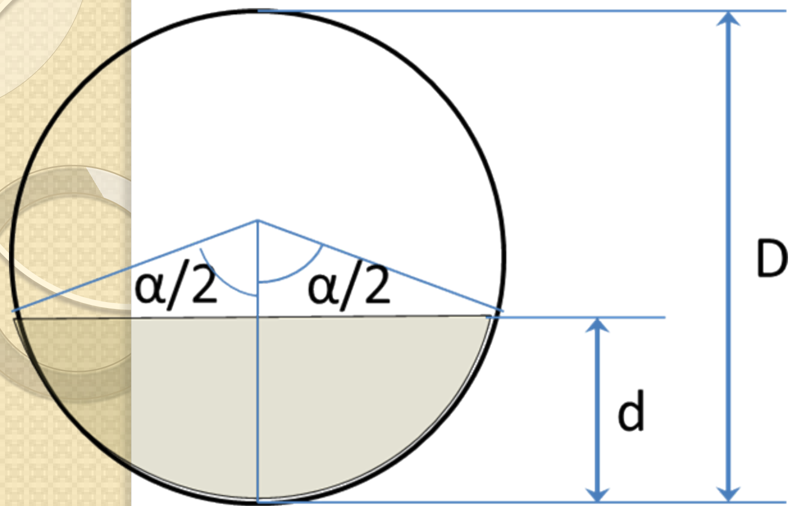
❖Thus at different values of α, the above proportional elements can be easily calculated

d/D	a/A	v/V	q/Q
1.00	1.00	1.00	1.00
0.9	0.949	1.124	1.066
0.8	0.858	1.140	0.988
0.7	0.748	1.120	0.838
0.5	0.5	1.000	0.500
0.4	0.373	0.902	0.337



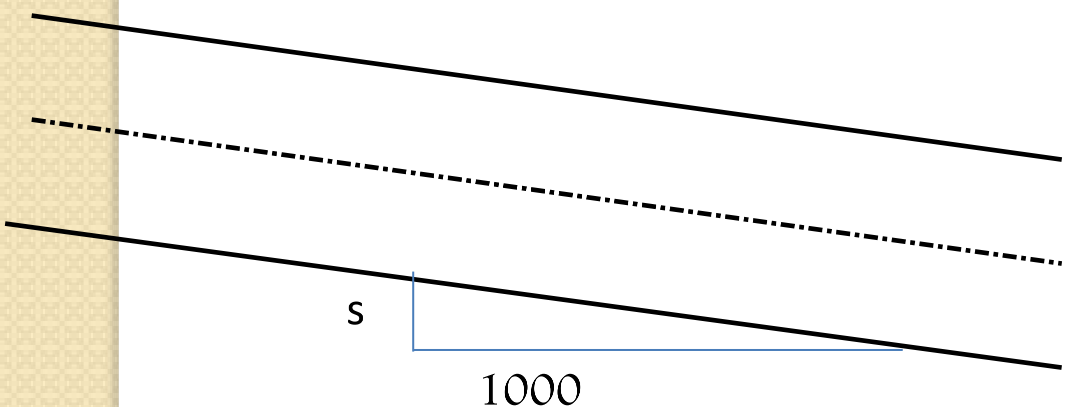
✓Capital Letters denote the situation when the sewers run full

❖Maximum velocity is achieved when the sewers are designed to run at 80% of the full depth.



$$v = \frac{1}{n} r^{2/3} s^{1/2}$$

$$r = \frac{a}{p} = \frac{D}{4}\left[1 - \frac{360 \sin\alpha}{2\pi\alpha}\right]$$



Velocity at partially full flow → v

Velocity at full flow → V

$$\frac{v}{V} = \left[1 - \frac{360 \sin\alpha}{2\pi\alpha}\right]^{2/3}$$

For Partially-full flow *v* is not influenced by the diameter of the pipe, rather is much influenced by the slope of the channel

FROM THE SEWAGE TREATMENT MANUAL

RECOMMENDED SLOPES FOR MINIMUM VELOCITY

Present peak flow in lps	Slope per 1,000
2	6.0
3	4.0
5	3.1
10	2.0
15	1.3
20	1.2
30	1.0

- ❖After finding the minimum slope required, the pipe size is decided on the basis of ultimate design peak flow rate and the permissible depth of flow. Adoption of the above slopes would ensure minimum flow velocity of 0.6 m/s
- ❖Minimum size for a public sewer is 150 mm diameter
- ❖Minimum size for a public sewer in hilly terrain is 100 mm diameter

Questions

1) What differs sewers from water supply lines?
2) What is the use of knowing self-cleansing velocity and non-scouring velocity?
3) Which discharges could be used in the design of sewers and why?

Any question plz????

Part I:- Lecture 4

Sewer construction, appurtenance used and maintenance

Objectives of the session

- Identify constraints of sewerage line construction and engineering considerations
- Evaluate the most important factors considered to select sewer material
- Understand the role of sewer appurtenant structures on ventilation, efficient operation and maintenance of sewerage system

Sewer Materials

- The following factors are to be carefully considered while making selection for the materials of sewer.

  i. Resistance to corrosion
  ii. Resistance to abrasion
  iii. Strength and durability
  iv. Light weight
  v. Imperviousness
  vi. The economy and cost
  vii. Hydraulically efficient (Smooth)

Forces Acting on Sewer Pipes

- The structural design of the sewer pipes should be such as to enable them to withstand the various forces likely to come on them.
- The following forces generally come into play in the sewer pipes:
  1. Internal pressure of sewage
  2. Pressure due to external loads
  3. Flexural stresses

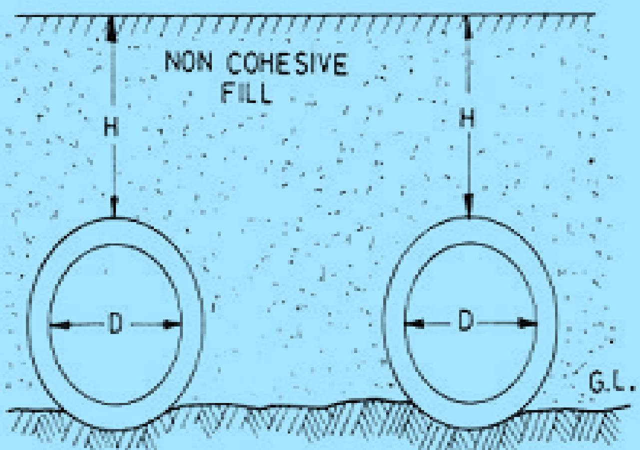
Cont…

1. For pipes resting on or projecting above undisturbed ground in cohesion less soils and covered with fills, such as in a high way culvert
   - the external load likely to come per unit length of pipe (W) is given by:

$$W = C_p . \gamma . D^2$$

Where

- Cp - a coefficient whose value depends upon the type of pipe and character of foundation backfill. Typical values of Cp are given in table below
- γ - Sp.Wt. of fill material
- D - the external diameter of the pipe

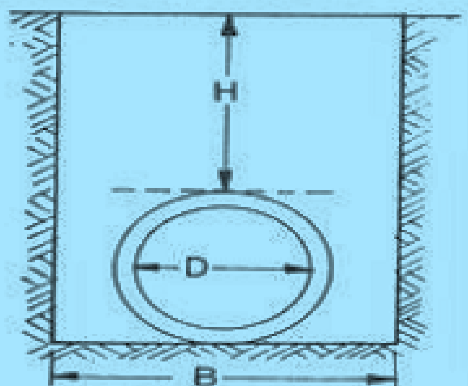


Conditions	$\frac{\text{Cover depth}}{\text{External pipe dia}} = \frac{H}{D}$	Value of C_p	
		For rigid pipes	For flexible pipes
(1)	(2)	(3)	(4)
	1.0	1.2	1.1
	2.0	2.8	2.6
	3.0	4.7	4.0
	4.0	6.7	5.4
	6.0	11.0	8.2
	8.0	16.0	11.0

2. For flexible pipes (such as steel pipes) buried in narrow trenches and with thoroughly compacted side fills, such as shown in Fig. below,
   - the external load per unit length of the pipe is given by:

$$W = C.\gamma.B.D$$

- Where
  - C = a coefficient, characterizing the fill material and the ratio H/B. Typical values are given in table below.

Conditions	*Fill Material*	*Dry Sand and Gravel*	*Satu-rated top soil*	*Clay*	*Satu-rated clay*
	Specific wt. in kg/m³	1600	1600	1920	2080
	values of $\frac{H}{B}$	*C*	*C*	*C*	*C*
 Narrow trench such that $B \leq 1.5.D.$	1.0	0.84	0.86	0.88	0.90
	2.0	1.45	1.50	1.55	1.62
	3.0	1.90	2.00	2.10	2.26
	4.0	2.22	2.33	2.49	2.65
	5.0	2.45	2.60	2.80	3.03
	6.0	2.60	2.78	3.04	3.33
	7.0	2.75	2.95	3.23	3.57
	8.0	2.80	3.03	3.37	3.76
	9.0	2.88	3.11	3.48	3.92
	10.0	2.92	3.17	3.56	4.04
	12.0	2.97	3.24	3.68	4.22
	14.0	3.00	3.28	3.75	4.34

3. For rigid pipes (such as concrete, cast iron, vitrified clay, etc.) buried in narrow trenches and thoroughly compacted with cohesion less fills, the external load per unit length of the pipe is given by:

$$W = C.\gamma.B$$

4. The amount of superimposed loads (such as traffic load, etc.) which is transmitted to the pipe can be evaluated by using Boussinesq's equation. Assuming the fill surface to be horizontal, the equation is:

$$P_t = \frac{3H^3 P}{2\pi Z^5}$$

- Where
  - Pt - unit pressure developed at any point in the fill at a depth H below the surface due to traffic load
  - P - Load superimposed
  - H - Distance of the top of pipe below the surface of the fill
  - Z - the slant height of the considered point from the load P.

$$Z = \sqrt{\left(\frac{Space\ between\ the\ wheels}{2}\right)^2 + H^2}$$

- The following are the various materials, which are used for sewers.

i. Asbestos cement sewers
ii. Cast-Iron sewers
iii. Cement concrete sewers
iv. Stoneware sewers
v. Brick sewers
vi. Corrugated iron sewers
vii. Plastic sewers
viii. Steel sewers

Asbestos Cement Pipes

- These sewers are made from a mixture of asbestos fibers, cement and silica.
- They are available up to sizes of 900mm and 3 to 4m in length.

Advantages:

i. Easy to cut and join.
ii. Durable and good resistance to corrosion.
iii. The inside surface is smooth.
iv. Light in weight and hence easy to handle.

Disadvantages:

1. Brittle and cannot stand impact forces during handling operations.
2. The structural strength is poor and hence cannot be laid to resist heavy external loads.
3. They are susceptible to corrosion by sulphuric acid from H_2S gas generated in sanitary waste water or by some industrial chemicals.

Cement Concrete Sewers

- The cement concrete sewers may be plain or reinforced.
- The plain cement concrete sewers are used up to the diameter of 600mm and beyond **600mm** reinforcement is provided.

Advantages:

1. These are strong and impervious.
2. Larger diameter can be made.
3. Inner surface of sewer is smooth.
4. For attack of chemical and erosive actions the inner surface should be lined with vitrified clay.

Disadvantages:

1. They easily get corroded and pitted by the action of sulphuric acid produced from H_2S gas.
2. They are also susceptible to erosion by sewage containing too much silt and grit
3. Heavy weight, transportation and handling is difficult.
4. Joints should be carefully filled.

Stoneware Sewers

- The stoneware sewers are also known as the vitrified clay sewers or salt-glazed sewers
- They are prepared from various clays and shapes in required proportion, allowed to dry and then burnt in a kiln.
- A small quantity of salt is added to kiln get glass like glaze on the surface of pipes.

- **Advantages:**
  1. These pipes are strong enough to take backfilling and traffic
  2. The interior surface of sewers are smooth and impervious
  3. The overall performance is very good
  4. These sewers are cheap and easily available
  5. These sewers are durable and better resistance to corrosion & erosion
  6. These sewers are capable of withstand hydraulic pressure up to 0.15N/mm^2 and bear a load of soil of about 4.5m depth

Disadvantages:

1. These are brittle in nature and may damage in handling or transport.
2. These are not strong enough to allow sewage under pressure. Because they are weak in tension.
3. These are difficult to handle or transport because of heavy weight.

Laying of Sewers

- The construction of sewer consists of the following works:
  a. Marking center lines of sewers
  b. Excavation of trenches
  c. Checking the gradient
  d. Preparation of bedding
  e. Laying of sewers
  f. Jointing
  g. Back filling

Marking Center Line of Sewer

- The center line of a sewers are marked on the streets and roads from the plans starting from the lowest point or outfall of the main proceeding upwards.
- For checking the levels of sewer pipes and their alignment temporary benchmarks are established at 200 - 400m intervals.
- The reduced level (R.L) of these benchmarks should be calculated
- On the center line position of sewer appurtenances are also marked

Excavation Trenches

- After marking the layout of the sewer lines on the ground, the first step is the removal of pavement
- After removing pavements, the excavation of trenches is done manually or by machinery.
- The width of excavation at any level will depend upon the width of the trench at the bottom, and the additions due to side slopes and due to timbering etc.
- The trench is excavated between two manholes, and the sewer is laid between them.
- The width of sewer line is 15cm more than external diameter of sewer for easiness in lowering and adjusting the sewer pipe.

Preparation of Bedding

- When a sewer has to be laid in a soil underground strata the trench shall be excavated **deeper than** what is ordinarily required trench bottom or rock.
- In the case of very bad soil the trench bottom shall be filled in with cement concrete of appropriate grade.
- In areas subject to subsidence the pipe sewer shall be laid on a timber platform or concrete cradle supported on piles.
- In the case of cast-in-site sewers and R.C.C section with reinforcement, bearing capacity is encountered and soil stabilization shall be done either by rubber, concrete or wooden crib.

Jointing and laying of Sewers

- The Cast Iron pipes
  - shall be examined for line and level and the space left in the socket shall be filled in by pouring molten pig lead of best-quality
- For concrete pipes,
  - the collars shall be placed symmetrically over the end of two pipes and the annual space between the inside of the collar and the outside of the pipe shall be filled with cement slurry.
- For stoneware:
  - All the joints shall be caulked with tarred gasket in one length for each joint and sufficiently long to entirely surround the spigot end of the pipe.

Back-filling of Trenches

- The trenches are back filled with excavated soil after removal of pebbles and stone-pieces by ramming the soil in layers using with water.
- When the height reaches to 60cm above the crown of the pipe, back filling is stopped for at least one weak for weathering.
- After a week, again backfilling is started in layers and the trench is filled 15cm above the ground level.
- During the course of time the back filled soil gets compacted and the filled soil comes to the ground level.
- Back filling will be after 7 days for precast pipes and 14 days after in the case of cast-in-site sewers.

PEORIA, ILL. 78" sewer, Div. F
Manhole in the distance. Note
unsheeted trench and cradle.


2008 2 28

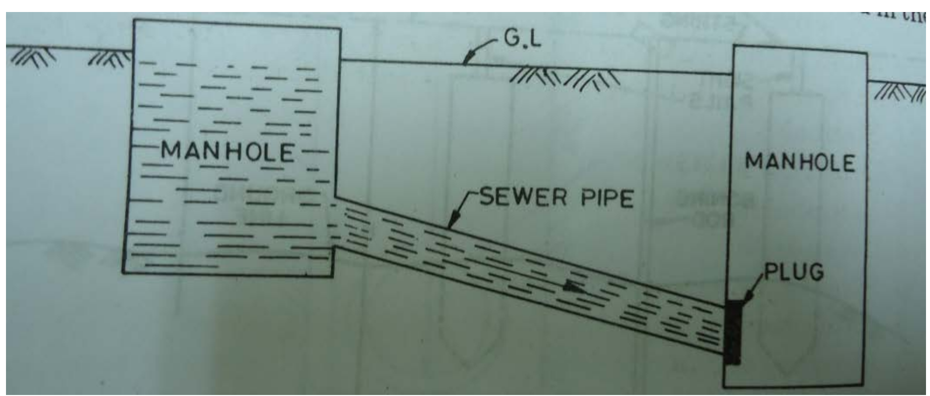
Testing of sewer

- The testing of sewers is necessary as any leakage, improper joints, straightness or obstruction of sewers may occur during laying of sewers.
- These defects may be removed or repaired after detection.
- So there are various tests by which these defects may be detected. These tests are :-
  - Water Test.
  - Smoke Test.
  - Test For Obstruction

Testing of sewer

Water Test: for leakage

- Each section of the sewer is tested for water tightness preferably between the manholes.
- Testing of sewers done by plugging the lower end of the sewer and fill water in the manhole in the upper end.
- The depth of the water in the manhole is maintained to the testing head of about 1.5m.
- The sewer line is watched by moving along the trench.



Smoke Test

- The purpose of smoke testing is to find potential points of inflow and infiltration in the sanitary sewer system that could lead to high flows during a storm.

- Smoke testing forces smoke-filled air through a sanitary sewer line.

- The smoke under pressure will fill the main line plus any connections and then follow the path of any leak to the ground surface, quickly revealing the source of the problem.
- Only enough force to overcome atmospheric pressure is required.

Test For Obstruction

- For straightness or obstruction of pipe, this test can be used. There are many methods for obstruction or straightness :

1.To check the obstruction of sewer pipe, a ball of suitable diameter is rolled down from upstream side. The diameter of ball should be less then the diameter sewer. If there is no obstruction, the ball can be taken out at downstream side.

2. The straightness can also be checked by placing a lamp at one end and a mirror at the other end.

If the full circle of light is visible at other end, then the sewer is straight and there is no obstruction.

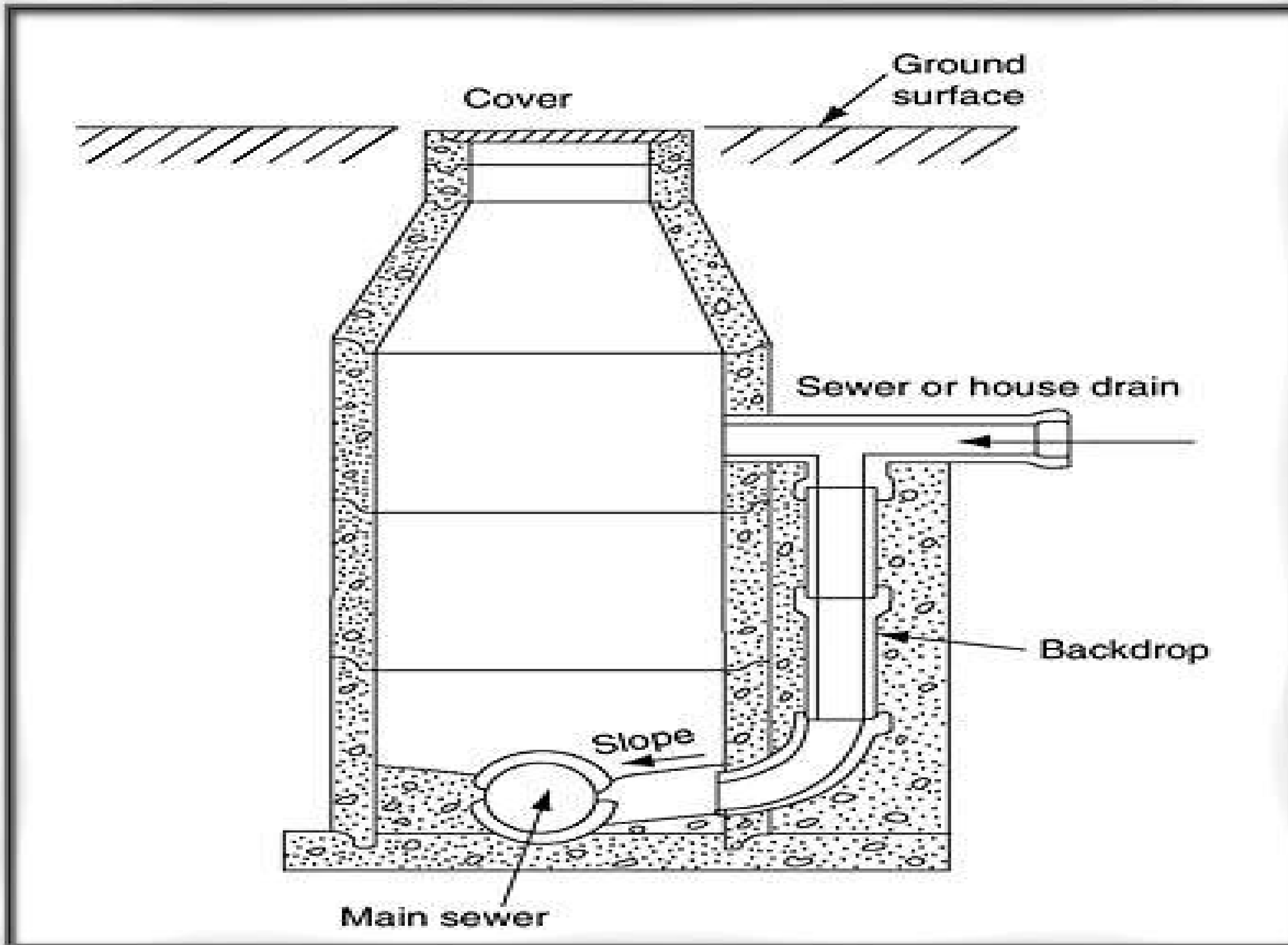
If there is any obstruction within the sewer line, it can also be traced out.

Sewer Appurtenances

- Sewer appurtenances are the various accessories on the sewerage system and are necessary for the efficient operation of the system.

- They include man holes, lamp holes, street inlets, catch basins, inverted siphons, and so on.

- **Man-holes**: Man holes are the openings of either circular or rectangular in shape constructed on the alignment of a sewer line to enable a person to enter the sewer for inspection, cleaning and flushing.
- They serve as ventilators for sewers, by the provisions of perforated man-hole covers.
- Also they facilitate the laying of sewer lines in convenient length.
- Man-holes are provided at all junctions of two or more sewers, whenever diameter of sewer changes, whenever direction of sewer line changes and when sewers of different elevations join together.


Ground
surface
Cover
Sewer or house drain
Backdrop
Slope
Main sewer

HELLHOLE

H/L: How many more lives will cost $1.25? Please call 010-62357575 to report manhole cover theft so we can put an end to this.

Challenge: In 2006, 47 people were reported dead and over 10,000 injured across China as a result of stolen manhole covers. Every day, an average of 12 covers go missing from the city streets of Shanghai. 24,000 were reported stolen in Beijing alone in 2004. And for what? A single stolen manhole cover can be sold for no more than 10rmb, or $1.25. Yet that one missing cover creates an unmarked "death trap" for the many people walking or riding on city streets every day.

Solution: 10 manholes around Beijing were marked with handicapped icons and roadblock cones were set up to attract attention. Written in bold Chinese characters was a statistic on the number of people injured every year as a result of missing manhole covers and a hotline number to call for reporting the crime.

Result: According to the Beijing Municipal Administration Commission, the day after the launch they received more than 190 calls from concerned citizens in the morning alone. The reported missing manhole covers were replaced or recovered within 48 hours.

Beijing Municipal Administration Commission

Special Man-holes

- Junction chambers: Man-hole constructed at the intersection of two large sewers.

- Drop man-hole: When the difference in elevation of the invert levels of the incoming and outgoing sewers of the man-hole is more than 60 cm, the interception is made by dropping the incoming sewer vertically outside and then it is jointed to the man-hole chamber.

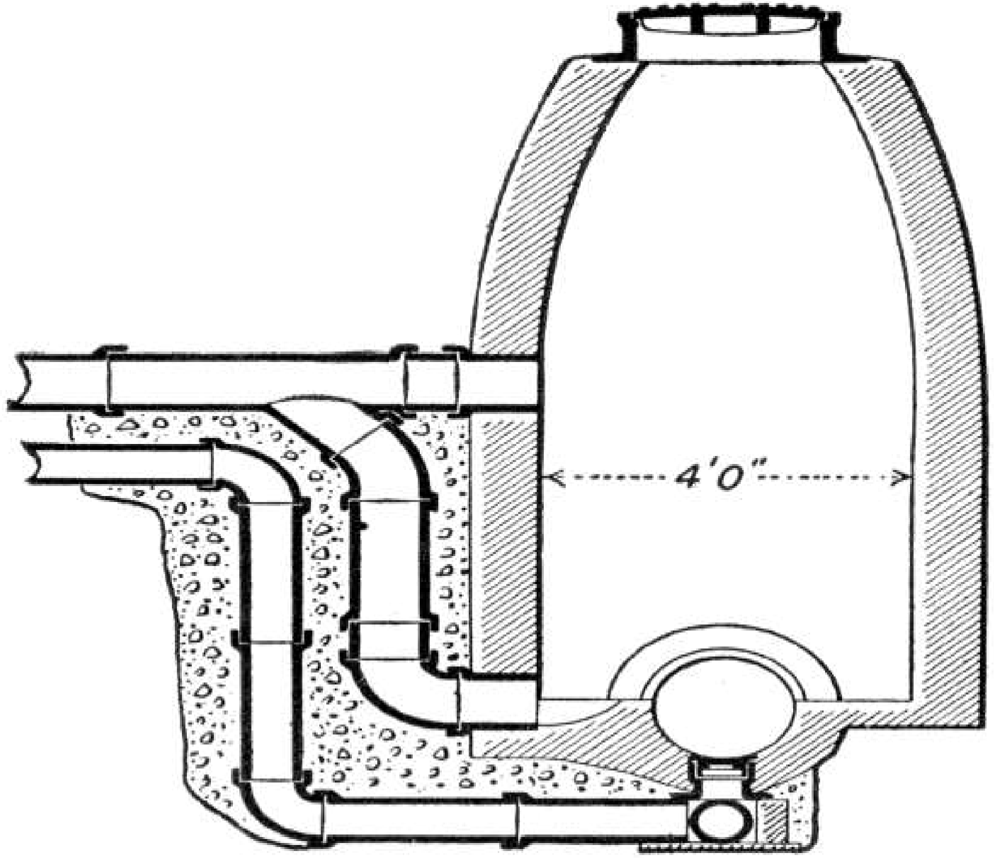


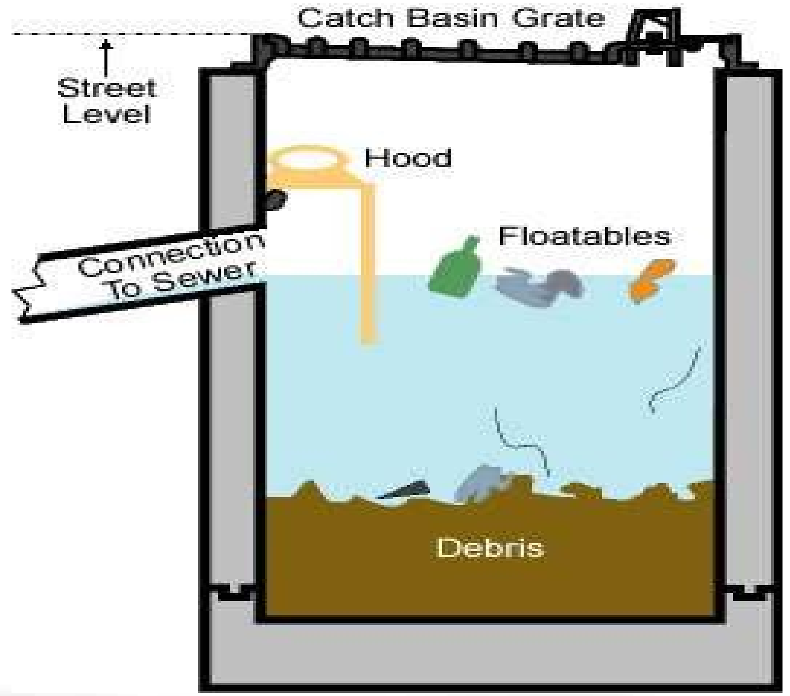
FIG. 219.—Double drop manhole, Medford, Mass.

- **Flushing man-holes**: They are located at the head of a sewer to flush out the deposits in the sewer with water.

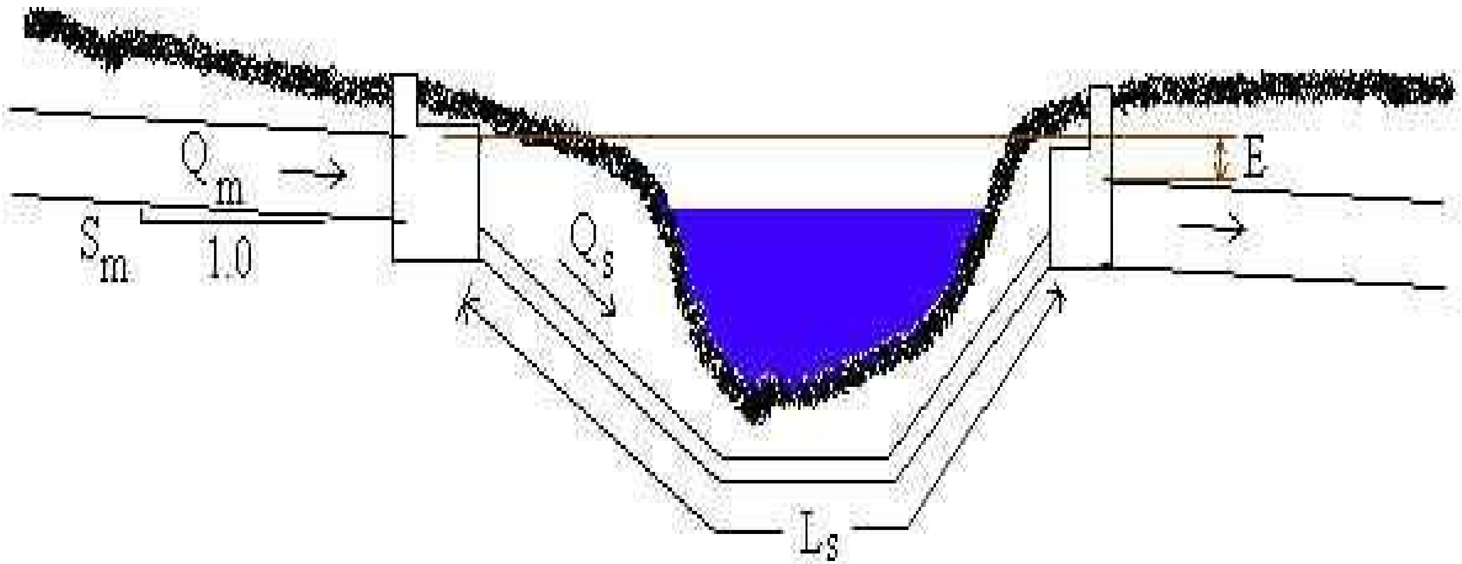
- **Lamp-holes**: Lamp holes are the openings constructed on the straight sewer lines between two man-holes which are far apart and permit the insertion of a lamp into the sewer to find out obstructions if any inside the sewers from the next man-hole.

- **Street inlets:** Street inlets are the openings through which storm water is admitted and conveyed to the storm sewer or combined sewer. The inlets are located by the sides of pavement with maximum spacing of 30 m.

❖ **Catch Basins**: Catch basins are small settling chambers of diameter 60 - 90 cm and 60 - 75 cm deep, which are constructed below the street inlets. They interrupt the velocity of storm water entering through the inlets and allow grit, sand, debris and so on to settle in the basin, instead of allowing them to enter into the sewers.



- **Inverted siphons**: These are depressed portions of sewers, which flow full under pressure more than the atmospheric pressure due to flow line being below the hydraulic grade line.
- They are constructed when a sewer crosses a stream or deep cut or road or railway line.
- To clean the siphon pipe sluice valve is opened, thus increasing the head causing flow.
- Due to increased velocity deposits of siphon pipe are washed into the sump, from where they are removed.



Q_m
S_m
1.0
Q_s
E
L_s

Maintenance, Cleaning and Ventilation of Sewers

- **Maintenance of Sewers**
  - Sewer maintenance generally involves their cleaning to keep them free from any clogging and to carry out the repairs to the damaged portions if any, so as to prolong their life and to ensure efficient functioning.
  - The proper maintenance of sewers is therefore absolutely necessary in order to make a sewerage system function efficiently.
  - The sewer maintenance generally includes:
    a) Their frequent inspection and supervision,
    b) Measuring the rate of flow,
    c) Cleaning and flushing,
    d) Repairing the leaking joints or any other damaged portions.

Cleaning of Sewers

- Sewers should be periodically cleaned so as to avoid their complete clogging.
- For cleaning small sewers which cannot be entered into by manual labour, flushing operations are essential.
- Large sized sewers which can be entered into by men are generally cleaned by manual labour.
- Precautions to be taken while entering sewers various poisonous and explosive gases which are generally found in sewers are: hydrogen sulphide (H_2S), carbon dioxide (CO_2), and (CH_4) along with petrol vapors.

Ventilation of Sewers

- The sewers must be properly ventilated for the following reasons:

i. The decomposition of sewage inside the sewers may result in the production of various sewer gases, such as, CO_2, CO, CH_4, H_2S, NH_3, N_2, etc.
   - These gases, if not removed, may cause serious problems, and prove hazardous to the workers entering the sewers.
   - Methane gas being highly explosive, if not removed, may even blow off the manhole covers.

ii. To ensure a continuous flow of sewage inside the sewer.
   - This is achieved by ventilation by keeping the surface of sewage in contact with free air and thus preventing the formation of air-locks in the sewage.

- **Methods of Ventilation**
   i. Use of ventilating columns (placed at intervals of 150 to 300m along the sewer lines)
   ii. Use of ventilating manhole covers (provided with perforations)
   iii. Proper Design of Sewers (designed partially full)
   iv. House vent and Soil pipes (ventilating house drains and public sewers)

Questions

1) What are the requirements to select sewer materials?
2) How could we test leakage in the construction of sewers?
3) What are the activities in the maintenance of sewers?

Any question plz????

Example: -1 Finding out population density based on Floor Space Index method

1. A well-planned city has following areas earmarked for its development in the planning stage: Roads- 20%; Gardens- 15%; Schools – 5%; markets and Commerical places – 2%; Hospital and medical facilities – 2% and rest is residential area. The Floor Space Index (FSI) for the city is fixed at 2. If the floor area is 9 sqm/ person, find out the projected population density of the city in numbers/ hecatare.

Solution:

Residential Area (%) = 100 – (20+15+5+2+2) = **56**

Actual Floor Area = Area of the land X FSI

Population that can reside in the area = Actual Floor area / Area required by a person

= 0.56*2/9 persons/m^2

Population density (numbers / hectare) = (0.56*2*1000)/9

= **1244**

Example:-2

1. Determine designed discharge for a combined system serving population of 50000 with rate of water supply of 135 LPCD. The catchment area is 100 hectares and the average coefficient of runoff is 0.60. The time of concentration for the design rainfall is 30 min and the relation between intensity of rainfall and duration is : I = 1000/(t + 20).

Solution

❖Estimation of sewage quantity

✓Considering 80% of the water supplied will result in wastewater generation,

the quantity of **sanitary** sewage = 50000 x 135 x 0.80/1000 = 5400 m3/day = **0.0625m^3/sec**

✓Considering peak factor of 2.5, the design Q for sanitary sewage = 0.0625 x 2.5 = **0.156 m^3/sec**

❖Estimation of storm water discharge Intensity of rainfall, I = 1000/(t + 20)

Therefore, I = 1000/(30 + 20) = 20 mm/h

Hence, **storm** water runoff, Q = C.I.A/360

= 0.6 x 20 x 100/(360) = **3.33 m^3/sec**

Therefore, design discharge for combined sewer = 3.33 + 0.156 = **3.49 m^3/sec**

2. The catchment area is 300 hectares. The surface cover in the catchment can be classified as given below:

Type of cover	**Coefficient of runoff**	**Percentage**
Roofs	0.90	15
Pavements and yards	0.80	15
Lawns and gardens	0.15	25
Roads	0.40	20
Open ground	0.10	15
Single family dwelling	0.50	10

Calculate the runoff coefficient and quantity of storm water runoff, if intensity of rainfall is 30 mm/h for rain with duration equal to time of concentration. If population density in the area is 350 persons per hectare and rate of water supply is 200 LPCD, calculate design discharge for separate systems and combined system.

Solution for #2

❖ ***Estimation of sanitary sewage quantity***

Considering 80% of the water supplied will result in wastewater generation,

the quantity of sanitary sewage = 350 x 300 x 200 x 0.80/1000

= 16800 m^3/day

= **0.194 m^3/sec**

Considering peak factor of 2.5,the design discharge for

sanitary sewage = 0.194 x 2.5 = **0.486 m^3/sec**

❖ ***Estimation of storm water discharge***

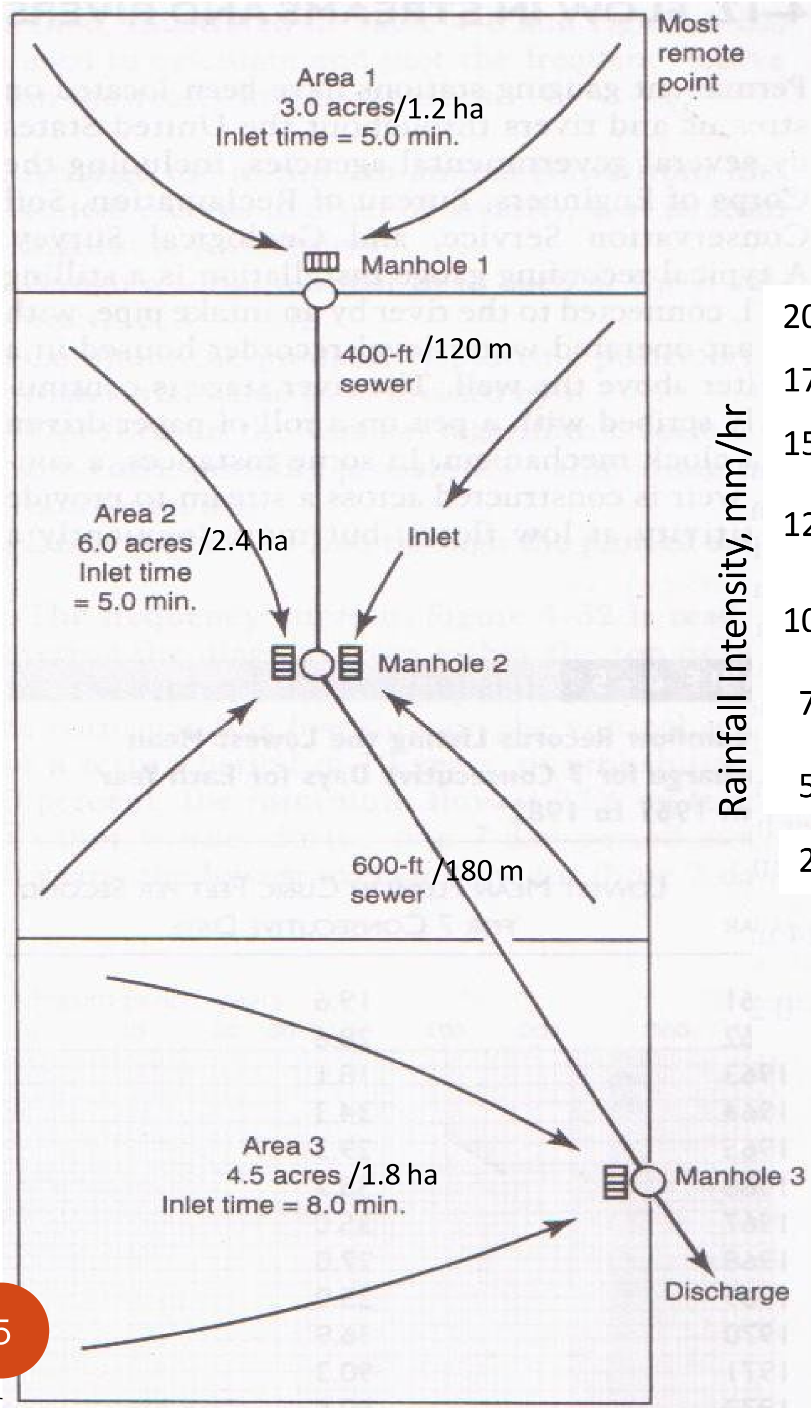
Intensity of rainfall, I = 33 mm/h

C= 0.9 x 0.15 + 0.8 x 0.15 + 0.15 x 0.25 + 0.4 x 0.2 + 0.1 x 0.15 + 0.5 x 0.1 = **0.4375**

Hence, storm water runoff, Q = C.I.A/360

= 0.4375 x 33 x 300/(360) = **12.03 m^3/sec**

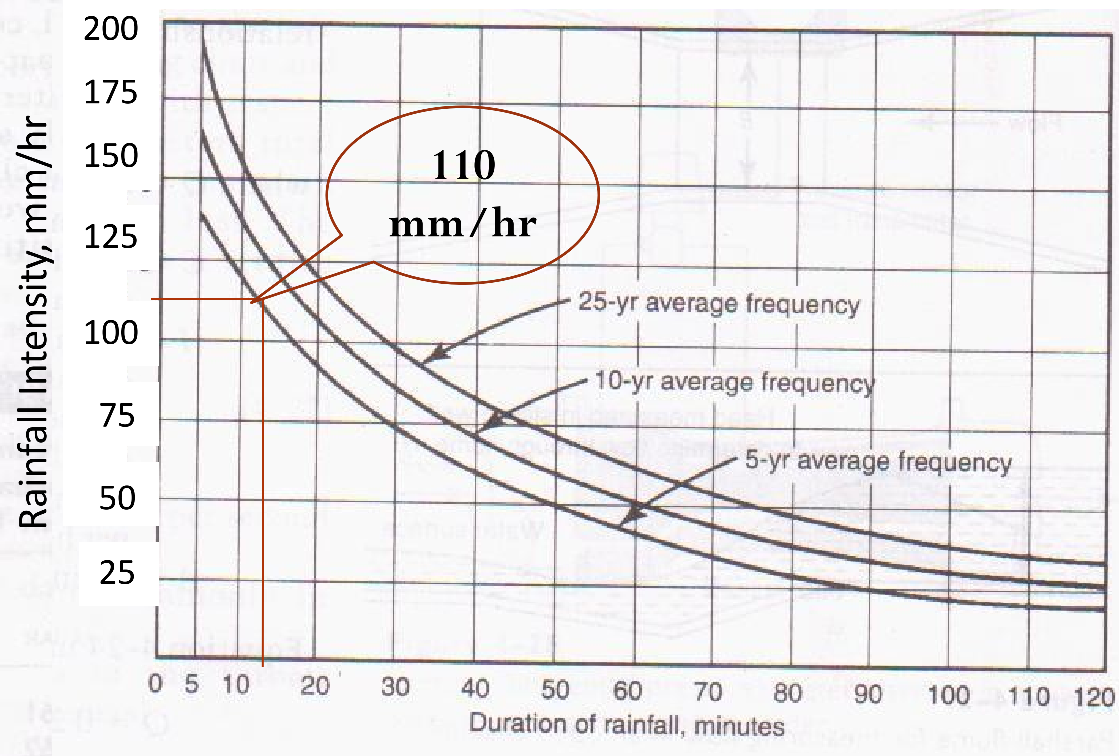
Therefore, design discharge for combined sewer = 12.03 + 0.486 = **12.516 m^3/sec**



3. Find out the maximum design runoff at the discharge point

Assume: C = 0.3 (Entire area), 5-year frequency, vel. In sewers = 0.6 m/s

110 mm/hr



Solution:~

❖Flow time in sewer from MH 1 → MH 2

= (120 m)/ (0.6 m/s) (60 s/ min) = **3.3 min**

❖Flow time in sewer from MH 2 → MH 3

= (180 m)/(0.6 m/s) (60 s/ min) = **5.0 min**

Time of concentration from remote points of 3 separate areas to MH 3: Area 1: 5.0 + 3.3 + 5.0 = **13.3 min**

Area 2: 5.0 + 3.3 = **8.3 min**

Area 3: 8.0 min (inlet time only)

❖Max. time conc. = Duration of rainfall = **13.3 min**

I = 110 mm/hr. for 5 year frequency

Sum of CA values = 0.3 (1.2 + 2.4 + 1.8) = **1.62**

Q = 10 x 110 x 1.62 = **1782 m^3/hr.**

Example:~ 3

1. A trunk sewer is to be sized for a 25 km^2 (2,500 ha) city. It will be 60% residential, 30% commercial, and 10% industrial. The residential area will have 40% large lots, 55% small lots, single - family and 5% multistory apartments. The average domestic wastewater flow rate is 800 L/d/capita ($9.26x10^{-6}$ m^3/sec/person), the average commercial flow rate is 25,000 L/D/ha ($2.89x10^{-4}m^3$/sec/ha), and the average industrial flow rate is 40,000 L/d/ha ($4.63x10^{-4}m^3$/sec/ha). I & I is 1,000 L/d/ha for the entire area. Estimate the peak and minimum flows to be handled by the trunk sewer. The saturation densities for the residential areas are given in the table:

Type of area	Density (persons/ha)
Large lots	5–7
Small lots, single-family	75
Small lots, two-family	125
Multistory apartments	2,500

Source: American Concrete Pipe Association (1981).

Solution:

Step 1:~ The residential area will be 60% of 2,500 ha = **1,500 ha**. The flow rates for each residential area will be:

Type	Area (ha)	Density (person/ha)	Population	Flow (m^3/s)
Large lots	0.40*1500 = 600	6	600*6 = 3,600	$9.26*10^{-6}*3600$ **= 0.03**
Small lots, single family	0.55*1500 = 825	75	825*75 = 61, 875	$9.26*10^{-6}*61,875$ **= 0.57**
Multistory apartments	0.05*1500 = 75	2,500	75*2,500 = 187,500	$9.26*10^{-6}*187,500$ **= 1.74**
Total			**252975**	**2.34**

Step 2:~ The commercial area will be 30% of 2,500 ha, 0.3*2,500 = 750 ha, with a flow rate of $2.89x10^{-4}$ m^3/sec/ha, the average flow for commercial areas will therefore be

$$= 2.89x10^{-4}\ m^3/sec/ha * 750\ ha$$

$$= \mathbf{0.22 m^3/sec.}$$

Step 3:~ The industrial area covers 10% of 2,500 ha then, 0.1*2,500 = **250** ha, with a flow rate of $4.63 \times 10^{-4} m^3/sec/ha$, the average flow for industrial areas will therefore be

$$= 4.63 \times 10^{-4} m^3/sec/ha * 250\ ha$$

$$= \mathbf{0.12\ m^3/sec.}$$

Step 4:~ The Inflow & Infiltration (I & I) for the entire area is:

(1,000 L/ha)*(2500 ha) = 2.5×10^6 L/day = **0.03 m^3/sec**

- The total city flow, excluding I&I, will therefore be:

$$2.34 + 0.22 + 0.12 = \mathbf{2.68\ m^3/sec.}$$

- The total city population will be 252,975 (or **252.975** thousands of people).

Step 5:~ The peak and minimum flow rates can therefore be estimated:

$Q_{peak}/Q_{av} = 5.5/\ P^{0.18} = \mathbf{2.0}$, and $Q_{min}/Q_{av} = 0.2*P^{0.16} = \mathbf{0.48}$ then,

- The peak flow is therefore estimated to be, = 2.0 (2.68 m^3/sec) + 0.03 m^3/sec

  = **5.39 m^3/sec**
- The minimum flow is estimated to be, = 0.48 (2.68 m^3/sec) + 0.03 m^3/sec

  = **1.32 m^3/sec**

Example :4

1. Calculate the velocity of flow and corresponding discharge in a sewer of circular section having diameter equal to 1 m, laid at a slope of 1 in 500. Sewer runs at a depth of 0.6 depth. Use Manning's n = 0.012

Solution:-

When sewer runs full

$Q = A\,V = ((3.14)\,(1^2)/4)\ x(1/0.012)\ x(1/4)^{2/3}\ x\ (1/500)^{1/2}$

$= \mathbf{1.162\ m^3/s}$

$V = ((1/0.012))\ x(1/4)^{2/3}\ x\ (1/500)^{1/2} = \mathbf{1.479\ m/s}$

When sewer runs partially full (d/D = 0.6)

From table when **d/D** = 0.6; **q/Q** = 0.671, **v/V** = 1.072

So, q = 0.671 (1.162) = **0.78 m^3/s**, and

v = 1.072 (1.479) = **1.586 m/s**

2. A town has a population of 100,000 persons with a per capita water supply of 200 L/d. Design a sewer running 0.7 times full at maximum discharge. Take Manning's n= 0.013 at all depths of flows. The sewer is to be laid at a slope of 1 in 500. Take a peak factor of 3.

Solution:-

Average sewage flow =(100000)*(200)*(0.8)/(24x3600x100)

= **0.185 m^3/s.**

Peak flow = (3)*(0.185) = **0.555 m3/s,** This is **q at 0.7** depth;

Now from table for **d/D = 0.7**, q/Q is 0.85 and v/V is 1.12

So, Q = 0.555/0.85 = **0.6536 m^3/s**

When sewer runs full

Then Q = A V = 0.6536 = (3.14) (D^2)/4 (1/0.013) $(D/4)^{2/3}$ $(1/500)^{1/2}$

0.6536 = 1.052 $D^{8/3}$

Solving for D

D = **0.836 m**

Contd.

V = Q/A = 0.6536/ (3.14x 0.836x0.836/4) = **1.19 m/s**

So, v at 0.7 depth shall be

1.12(V) = 1.12(1.19) = 1.33 m/s ok (1.0~1.6)

qmin = 1/3 of average flow = 0.185/3 = **0.0617 m3/s**

qmin/Q = 0.0617/0.6536 = **0.0944**

For qmin/Q = 0.0944; d/D = 0.21 and vmin/V = 0.625

So, vmin = 0.625 (1.19) = **0.744m/s** which is more than 0.6 m/s …. ok

Part II:- Wastewater Treatment

Course Objectives

At the end of this specific part students will be able :

- To describe basic methods for industrial and municipal wastewater treatment and the process involved
- To formulate the design of wastewater treatment facilities.

Outlines for Part II

1. **Introduction**
   - General about wastewater treatment
   - Objectives of wastewater treatment
   - Wastewater treatment standards
2. **Characteristics of wastewater**
   - Physical, chemical and bacteriological characteristics of waste water
   - Measurement of concentration of contaminants in wastewater
   - Mathematical model for the BOD curve

Outlines for Part II

3. **Wastewater treatment methods**
   - Preliminary wastewater treatment
   - Primary wastewater treatment
4. **Biological wastewater treatment**
   - Microorganisms and their role in wastewater treatment
   - Types of biological process for wastewater treatment
5. **Tertiary wastewater treatment**
6. **Wastewater effluent disposal techniques**
   - Land disposal and treatment
   - Disposal by dilution and oxygen sag curve

Part II

Lecture 1

Introduction to wastewater treatment

General About WWT

What is Wastewater?

✓Wastewater is used water!
✓Water that has been used and contains domestic, industrial, institutional and commercial waste products is called ***wastewater.***

What is wastewater treatment?

- Removing contaminants or pollutants from wastewater.

Fig. 1.1. Improperly disposed ww.

General About WWT

Some contaminants in WW.

a) **Suspended solids:** lead to the development of sludge deposits and anaerobic conditions

b) **Pathogens:** cause diseases

c) **Nutrients:** essential for growth (N, P, K,…)

d) **Refractory organics**: oppose conventional methods of wastewater treatment.

e) **Heavy metals** :may have to be removed if the wastewater is to be reused

f) **Dissolved inorganic solids** (calcium, sodium, and sulfate): may have to be removed if the wastewater is to be reused

g) **Organic matters**

❖Therefore, Wastewater should be collected and treated before its ultimate disposal in order to :

- Reduce spread of **communicable diseases**
- Prevent surface and ground water **pollution**.

General About WWT

- The wastewater can be broadly divided into two categories:

1. **Biodegradable wastewater**:
   - The wastes in general have a predominance of biodegradable organic matter
   - The stabilization of organic matter is accomplished biologically using a variety of microorganisms.
   - Based on bacterial relationship to oxygen the micro-organisms can be:
     a) obligate aerobes: utilise oxygen
     b) obligate anaerobes: without oxygen
     c) facultative anaerobes: utilise oxygène if présent and not if not present
     d) denitrifiers

2. Non-biodegradable wastewater

- The wastewater are rich in non-biodegradable matter consisting of solids and liquids in suspended or dissolved form, including various inorganic and organic, many of which may be highly toxic.

General About WWT

- Methods of treatment in which the application of physical forces dominates are called **unit operation**
- Methods of treatment in which chemical or biological activity involved are known as **unit process**.
- WWT applies any of this operations, processes or combination of both.
- WWT is the combination of physical, chemical and biological processes.

Objectives of WWT

1. Removal of pollutants, the **protection and preservation of our natural resources**
2. **Protection of human health** by the destruction of pathogenic organisms prior to treated effluent being discharged to receiving water bodies and land.

Wastewater Treatment Standards

- Environmental standards are developed to ensure that the **impacts of treated wastewater discharges into receiving waters are acceptable.**

Effluents from different establishments should be:

1. Free from materials and heat which are **harmful to human, animal, aquatic life.**
2. Free from anything that will **settle in receiving waters forming putrescence**
3. Free from floating debris, oil, scum and other materials;
4. Free from materials and heat that **produce color, turbidity, taste or odor**
5. Free from **nutrients** in concentrations that create nuisance growths of aquatic weeds or algae in the receiving waters.

Part II

Lecture 2

CHARACTERISTICS OF WASTEWATER

Physical, Chemical and Bacteriological Characteristic of Wastewater

Physical Characteristics

- Turbidity , color, odor, temperature, solids

Chemical Characteristics

- pH, Chloride Contents, Nitrogen compounds, Phosphorus, Dissolved Oxygen (DO), Bio-Chemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD)

Biological Characteristics

Physical Characteristic of Wastewater

What is the turbidity, color, odor, temperature of sewage?

- Turbid, grey/soapy/black after putrefaction, musty (not offensive)/bad smell after H_2S released, **warmer**

Solids

- Sewage only contains about 0.05 to 0.1 percent solids
- Solids present in sewage may be in any of the 4 forms:
  - suspended solids: solids which remain floating in sewage.
  - dissolved solids: remain dissolved in sewage just as salt in water
  - colloidal solids: are finely divided solids remaining either in solution or in suspension.
  - settleable solids: solid matter which settles out.

Physical Characteristic of Wastewater

- The proportion of these different types of solids is generally found as:
- **Inorganic matter** consists of minerals and salts, like: sand, gravel, debris, dissolved salts, chlorides, sulphates, etc.
- **Organic matter** consists of:
  I. **Carbohydrates** such as cellulose, cotton, fiber, starch, sugar, etc.
  II. **Fats and oils** received from kitchens, laundries, garages, shops, etc.
  III. **Nitrogenous compounds** like proteins and their decomposed products, including wastes from animals, urea, fatty acids, hydrocarbons, etc.

Chemical Characteristic of Wastewater

pH

- is a method of expressing the acid condition of the WW.
- For proper treatment, wastewater pH should normally be in the range of 6.5 to 9.0.
- the fresh sewage is generally alkaline in nature (pH > 7); but as time passes, its pH tends to fall due to production of acids by bacterial action in anaerobic or nitrification processes.

Chloride Contents

- derived from the kitchen wastes, human feces, and urinary discharges, etc.
- when the chloride content of a given sewage is found to be high, it indicates the presence of industrial wastes or infiltration of sea water

Chemical Characteristic of Wastewater

Nitrogen compounds

- The presence of nitrogen in sewage indicates the presence of organic matter, and may occur in:
  a) Free ammonia, called ammonia nitrogen;
  b) Organic nitrogen;
  c) Nitrites; and
  d) Nitrates

Phosphorus

- is essential to biological activity and must be present in at least minimum quantities or secondary treatment processes will not perform.
- Excessive amounts can cause stream damage and excessive algal growth.

Chemical Characteristic of Wastewater

Dissolved Oxygen (DO)

- DO is very important for aquatic life like fish,…
- the treated sewage should ensure at least **4ppm of DO in it before discharging it to river stream**;
- otherwise, fish are likely to be killed, creating nuisance near the vicinity of disposal.
- very fresh sewage contains some DO, which is soon depleted by aerobic decomposition.

Chemical Oxygen Demand (COD)

- measures the total quantity of oxygen required for oxidation of organics into carbon dioxide and water.

Chemical Characteristic of Wastewater

Bio-Chemical Oxygen Demand (BOD)

- used as a measure of the quantity of oxygen required for oxidation of biodegradable organic matter by aerobic biochemical action.
- The rate of oxygen consumption is affected by a number of variables:
  - temperature, pH, the presence microorganisms, and the type of organic and inorganic material.
- **The greater the BOD, the more rapidly oxygen is depleted in the water body.**
- The consequences of high BOD are the same as those for low DO:
  - aquatic organisms become stressed, suffocate, and die.

Bacteriological Characteristic of Wastewater

Biological Characteristics

- ✓ are due to the presence of bacteria and other living microorganisms, such as algae, fungi, protozoa, etc.
- ✓ Most of the huge number of bacteria present in sewage is harmless non-pathogenic bacteria.
- ✓ They are useful and helpful in bringing oxidation and decomposition of sewage.

Measurement of Concentration of Contaminants in Wastewater

- The most important standard methods for analysis of organic contaminants/oxygen demand are:
  1. Theoretical Oxygen Demand (**ThOD**)
  2. Chemical Oxygen Demand (**COD**)
  3. Biochemical Oxygen Demand (**BOD**)

Measurement of Concentration of Contaminants in Wastewater

1. **Theoretical Oxygen Demand (ThOD)**

- This is the theoretical amount of oxygen required to oxidize the organic fraction of the wastewater completely to carbon dioxide and water.
- E.G. calculate the amount of oxygen required to oxidize 300mg/l of glucose is:

$$\boldsymbol{C_6H_{12}O_6 + 6O_6 \rightarrow 6CO_6 + 6H_2O}$$

(C = 12, H = 1 and O = 16), $C_6H_{12}O_6$ is 180 and $6O_2$ is 192; then, ThOD of, $\frac{192}{180} * 300 = 321$ mg/l .

- Because WW is so complex in nature its ThOD cannot be calculated, but in practice it is approximated by the chemical oxygen demand.

Measurement of Concentration of Contaminants in Wastewater

2. **Chemical Oxygen Demand (COD)**

- is determined by performing a lab test with a strong oxidant like dichromate solution.
- In order to perform this test, a known quantity of WW is mixed with a known quantity of standard solution of potassium dichromate, and the mixture is heated.
- The organic matter is oxidized by $\mathbf{K_2Cr_2O_7}$ (in the presence of H_2SO_4) helps to digest/break down the complex molecules.
- **COD** used more of to measure **non-biodegradable matter.**

❖ **The advantage of COD** measurements is that they are obtained very quickly (within 3 hours)

❖ **The disadvantages**, they do not give any information on the proportion of the WW that can be oxidized by bacteria.

Measurement of Concentration of Contaminants in Wastewater

3. **Biochemical Oxygen Demand (BOD)**

- Oxygen demand of WW is exerted by three classes of materials:

1. **Carbonaceous organic materials** usable as a source of food by aerobic organisms
2. **Oxidizable nitrogen** derived from nitrite, ammonia, and organic nitrogen compounds which serve as food for specific bacteria (e.g., Nitrosomonas and Nitrobacter).
3. **Chemical reducing compounds**, e.g., ferrous ion (Fe^{2+}), sulfites (SO_3^{2-}), and sulfide (S^{2-}) which are oxidized by dissolved oxygen.

- For domestic sewage, nearly all oxygen demand is due to **carbonaceous organic materials.**

Measurement of Concentration of Contaminants in Wastewater

- The BOD test results are used for the following purpose:
  i. Determination of the quantity of oxygen required
  ii. Determination of size of WW treatment facilities
  iii. Measurement of efficiency of some treatment methods
  iv. Determination of strength of sewage
  v. Determination of quantity of clear water required for dilution during disposal.

BOD test: dilution test method procedures

1. Sample is diluted with specially prepared dilution water
2. The water is aerated to saturate it with oxygen before mixing it with sample
3. Initial DO of diluted sample is measured
4. Then, incubated for 5days at $20^{o}c$, after 5days DO measured again

Measurement of Concentration of Contaminants in Wastewater

- Then, oxygen consumed = $DO_{initial} - DO_{final}$

$$\boldsymbol{BOD_5} = (oxygen\ consumed) * dilution\ factor$$

Where, dilution factor (Df) = $\frac{volume\ of\ diluted\ sample}{volume\ of\ undiluted\ WW\ sample}$

e.g., if 1ml of sewage diluted to make 100ml of test sample, what is the dilution factor?

Mathematical Model for the BOD Curve

The rate of oxygen utilization, at a given incubation time decreases as concentration of organic matter remaining un-oxidized becomes gradually smaller.

The rate of de-oxygenation depends on temperature and amount and nature of organic matter

Thus, at a certain temperature, the rate of de-oxygenation is assumed to be directly proportional to the amount of organic matter at that time

i.e., $\frac{dL_t}{dt} = -kL_t$ ....(2.2)

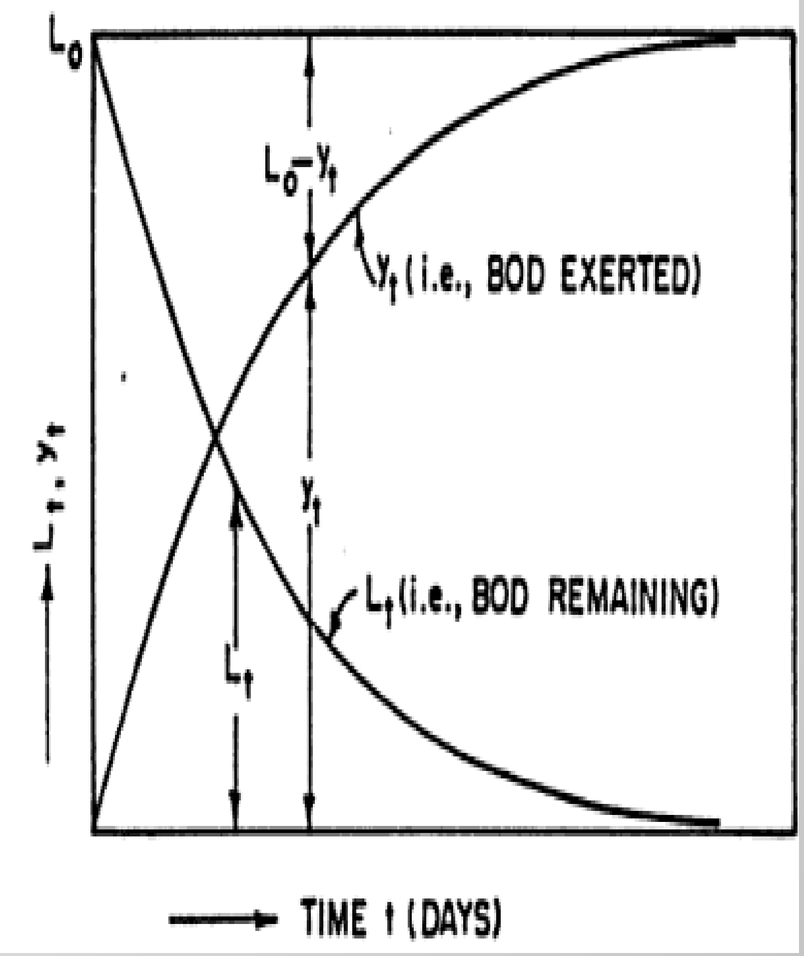


Fig. First stage BOD curve

Mathematical Model for the BOD Curve

- Where,
  - Lt = oxygen equivalent of carbonaceous oxidizable organic matter after t days from the start of oxidation (mg/l).
  - $\frac{dL_t}{dt}$ = rate of disappearance of organic matter by aerobic biological oxidation
  - t = time in days.
  - K = rate constant (in per day)
  - Minus sign indicates that with the passage of time (i.e., increase in t) the value of Lt decreases

Mathematical Model for the BOD Curve

- Integrating the above equation (2.2), we get

$$\int \frac{dL_t}{dt} = \int -kL_t$$

$$log_e L_t = -kt + C \quad \ldots\ldots\ldots(2.3)$$

Where, C is a constant of integration,

When t = zero (0), i.e. at start Lt = L. Substituting in the equation (2.3), we have

$$log_e L \quad = -k * 0 + C$$

$$C = log_e\ L$$

$$log_e L_t = -kt + log_e L$$

$$log_e L_t - log_e L \quad = -kt$$

Mathematical Model for the BOD Curve

- $$log\frac{L_t}{L} = 2.3log_{10}\frac{L_t}{L} = -kt$$

$$log_{10}\frac{L_t}{L} = \frac{-kt}{2.3}$$

$$log_{10}\frac{L_t}{L} = -0.434kt \text{ ....(2.4)}$$

Using 0.434k = k_D is the De-oxygenation constant or the BOD rate constant,

$$log_{10}\frac{L_t}{L} = -k_D t$$

$$\frac{L_t}{L} = 10^{-k_D t} \text{ ....(2.5)}$$

$$L_t = L10^{-k_D t} \text{ ....(2.6)}$$

Mathematical Model for the BOD Curve

- Now, L is the initial organic matter (expressed as oxygen equivalent)
- Lt is the organic matter left after t days; which means that during t days,

the quantity of organic matter oxidized = L - Lt.....(2.6)

Let say the quantity of organic matter oxidized is Y_t

$$Y_t = L - L_t$$

$$Y_t = L\,(1 - \frac{L_t}{L})$$

$$\frac{L_t}{L} = 1 - \frac{Y_t}{L}$$

But, also $\frac{L_t}{L} = 10^{-k_D t}$, from equation (2.5)

Mathematical Model for the BOD Curve

- Therefore, $1 - \frac{Y_t}{L} = 10^{-k_D t}$

$\boldsymbol{Y_t = L(1 - 10^{-k_D t})}$.......**(2.7)**

$\boldsymbol{Y_t}$ is the oxygen absorbed in t days, i.e. BOD of t days.

e.g. $\boldsymbol{BOD_5 = Y_5 = L(1 - 10^{-5k_D})}$

The ultimate first stage BOD (Yu) would be obtained from the equation (2.7), substituting t =∞days in it.

$$Y_u = L(1 - 10^{-k_D \infty})$$

$\boldsymbol{Y_u = BOD_u = L}$ ......**(2.8)**

Hence, the ultimate first state $\boldsymbol{BOD_u}$ (Yu) of a given sewage is equal to the initial oxygen equivalent of the organic matter present in this sewage (L)

Mathematical Model for the BOD Curve

K_D value

The value of KD determines the speed of the BOD reaction, without influencing the ultimate BOD

The coefficient of de-oxygenation is different at different temperatures, but finally, Yu is constant.

$$K_{DT} = K_{D(20)} * 1.047^{T-20}$$

KD(20°) = De-oxygenation constant at 20°c. varies b/n (0.05 to 0.2) per day depending upon the nature of the organic matter.

KD(T) = De-oxygenation constant at température T°c.

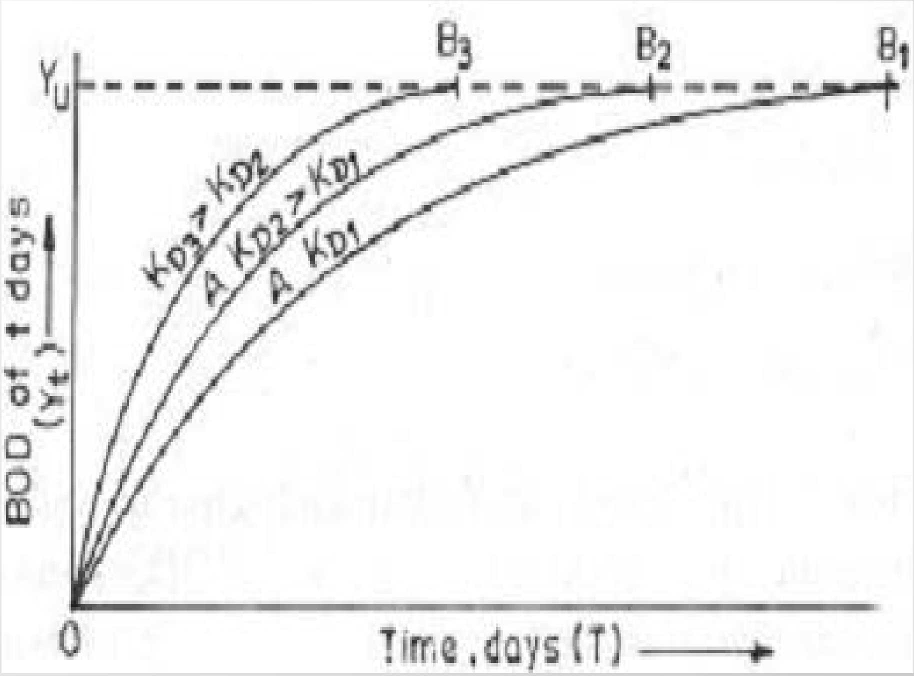


Fig. of BOD exertion as a function of K_D

Mathematical Model for the BOD Curve

Table: Typical values of K_D at 20°c for various types of waters and WW

Water type	K_D value per day
Tap waters	< 0.05
Surface waters	0.05 - 0.1
Municipal wastewaters	0.1 - 0.15
Treated sewage effluents	0.05 - 0.1

Table: Sewage type depending on BOD value

Nature of sewage	5 day BOD at 20°C (ppm or mg/l)
1. Strong sewage	450 to 550
2. Average sewage	350
3. Weak sewage	250
4. Standard filter sewage effluent	20
5. Very good filter sawage effluent	5 to 10

Mathematical Model for the BOD Curve

Problems

1. In order to conduct a 5-day BOD test the sample of WW was diluted with specially prepared dilution water, with a dilution factor of 150. the contents of DO in the beginning and end of test were 11ppm and 7ppm respectively. Compute the 5-day BOD. What is the nature of the WW?

Solution:

$$\mathbf{BOD_5} = (\text{oxygen consumed}) * \text{dilution factor}$$

$$\mathbf{BOD_5} = (11 - 7) * 150$$

$$\mathbf{BOD_5} = 600\text{ppm}$$

This indicates the WW is strong, need proper treatment before disposal.

Mathematical Model for the BOD Curve

2. Determine the ultimate BOD for a sewage have 5-day BOD at 20°c as 160ppm. Assume the de-oxygenation constant as 0.2per day.

Solution:

- we have, $BOD_u = Yu = L$
- From, $BOD_5 = Y_5 = L(1 - 10^{-5k_D})$
- $160 = L(1 - 10^{-5*0.2})$
- L = 177.78ppm

Mathematical Model for the BOD Curve

3. The BOD_5 of a wastewater is 150mg/l at 20°c. The k value is known to be 0.23 per day. What would BOD8 be, if the test was run at 15°c?

Solution: $BOD_8 = Y_8 = L(1 - 10^{-8k_D})$

But, $BOD_5 = Y_5 = L(1 - 10^{-5k_D})$ at 20°c

$$150mg/l = L(1 - 10^{-5*0.23})$$

L = 161mg/l

And $\mathbf{K_{D15}} = \mathbf{K_{D(20)}} * \mathbf{1.047^{15-20}}$

$\mathbf{K_{D15}} = \mathbf{0.23 * 1.047^{15-20}}$ **= 0.18**

So, $BOD_8 = Y_8 = 161(1 - 10^{-8*0.18})$ = 156mg/l

Part II

Lecture 3

PRELIMINARY AND PRIMARY WASTEWATER TREATMENT METHODS

3.1 Preliminary Treatment

- Preliminary treatment consists in separating the floating materials (like dead animals, tree branches, papers, pieces of rags, wood, etc.), and also the heavy settle able inorganic solids.
- It also helps in removing the oils and greases, etc. from the sewage.
- This treatment reduces the BOD of the wastewater, by about 15 to 30%.
- The processes used are:
  - ✓ Screening for removing **floating** papers, rags, clothes, etc
  - ✓ Grit chambers or Detritus tanks for removing **grit** and **sand**
  - ✓ Skimming tanks for removing **oils** and **greases**

3.1.1 Screening

- Screening is the **very first operation** carried out at a sewage treatment plant.
- It consists of passing the sewage through different types of screens, so as to trap and remove the floating materials.
- The main idea of providing screens is to protect the pumps and other equipments from the possible damages due to the floating matter of the sewage.
- Screens should preferably be placed before the grit chambers.
- They may sometimes be accommodated in the body of the grit chambers themselves.

Types of Screens, their Designs and Cleaning

- Depending upon the size of the openings, screens may be classified as coarse screens, medium screens, and fine screens.

A) Coarse screens:

- ✓ They are also known as Racks, and the spacing between the bars (i.e. opening size) is about 50 mm or more.
- ✓ These screens do help in removing large floating objects from sewage.
- ✓ They will collect about 6 liters of solids per million liter of sewage.
- ✓ The material separated by coarse screens, usually consists of rags, wood, paper, etc., which will not putrefy, and may be disposed of by incineration, burial, or dumping.

Preliminary Treatment

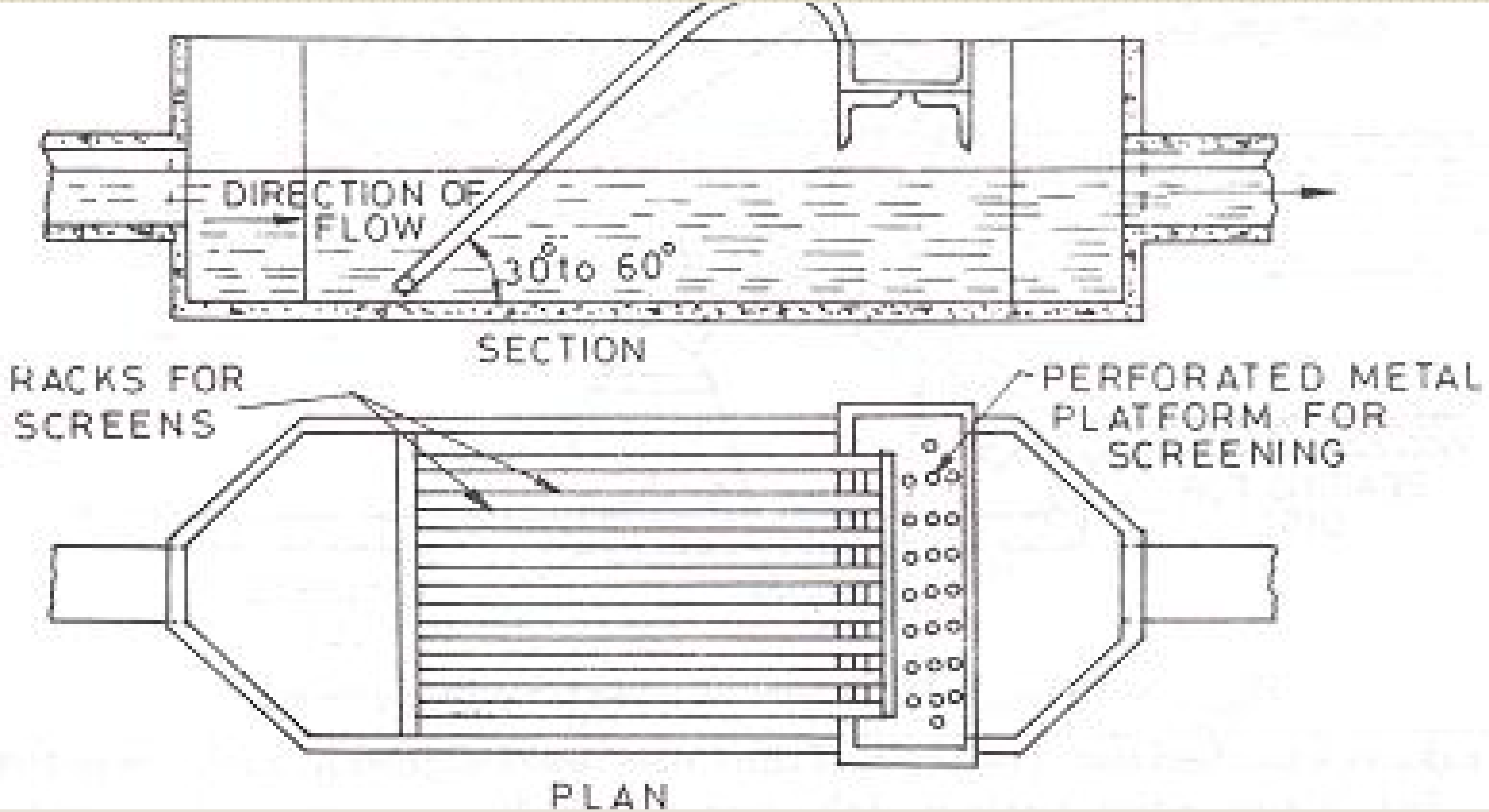
Preliminary Treatment

Preliminary Treatment

B) Medium screens:

- ✓ The spacing between bars is about 6 to 40 mm.
- ✓ These screens will ordinarily collect 30 to 90 liters of material per million liter of sewage.
- ✓ The screenings usually contain some quantity of organic material.
- ✓ which may putrefy and become offensive and must therefore, be disposed of by incineration, or burial (not by dumping).
- ✓ Coarse and medium screens are made of steel bars, fixed parallel to one another at desired spacing on a rectangular steel frame, and are called ***bar screens.***
- ✓ These screens are generally kept inclined at about 30 to 60° to the direction of flow, so as to **increase the opening area** and **to reduce the flow velocity**; and thus making the **screening more effective.**

Preliminary Treatment



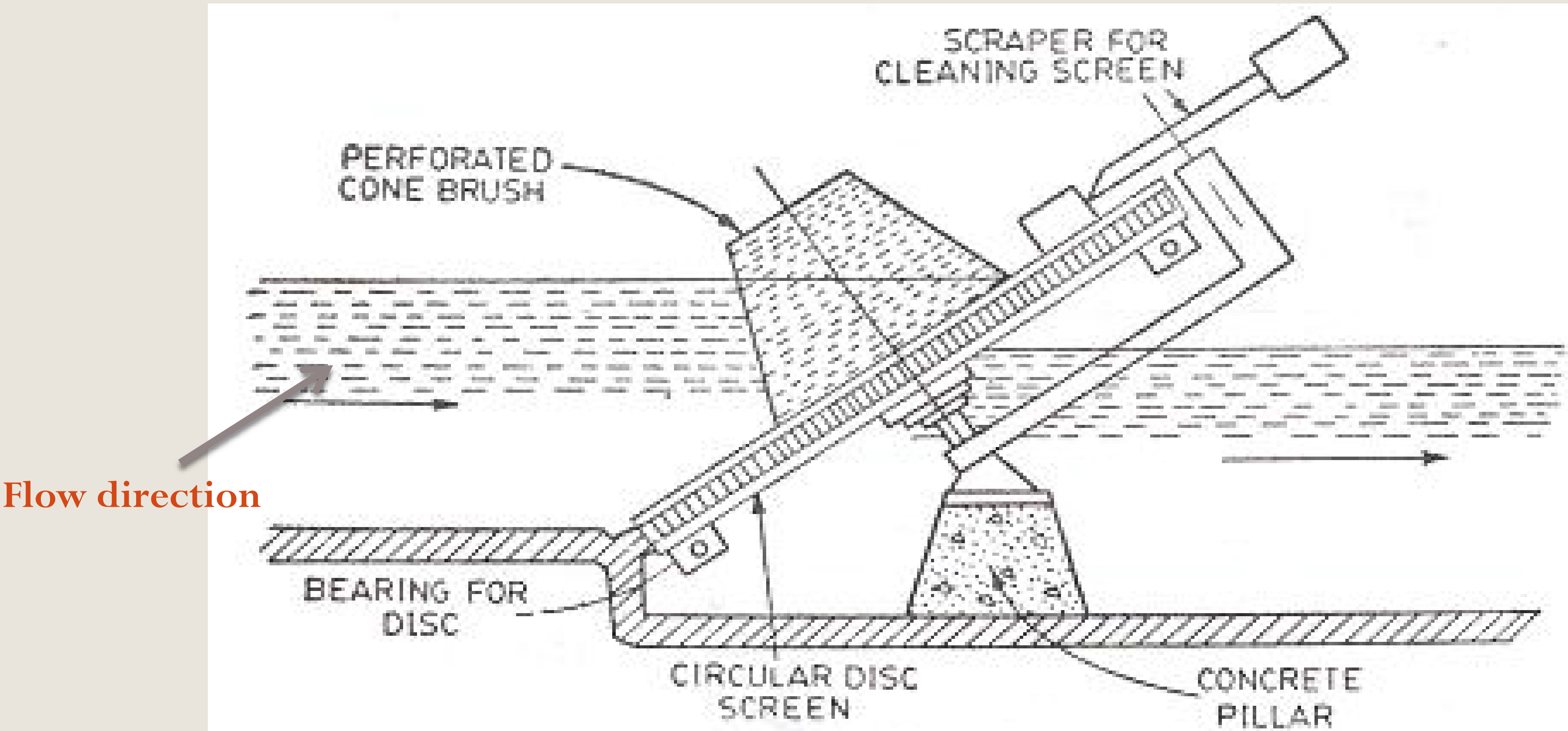
❖ **While designing the screens, clear openings should have sufficient total area, so that the velocity through them is not more than 0.8 to 1m/sec.**

C) Fine Screens:

- Have perforations of 1.5 mm to 3 mm in size.
- They remove as much as 20% of the suspended solids from sewage.
- These screens however, get clogged very often and need frequent cleaning.
- They are, therefore, used only for treating the industrial wastewaters.
- These screens will considerably reduce the load on further treatment units.
- Brass or Bronze plates or wire meshes are generally used for constructing fine screens.
- The metal used should be resistant to rust and corrosion.

Preliminary Treatment

➢ The fine screens may be disc or drum type, and are operated continuously by electric motors.



3.1.2 Grit Removal Basins

- The grit chamber remove the inorganic particles (specific gravity about 2.65 and nominal diameter of 0.15 to 0.20mm or larger) such as sand, gravel, grit,..etc
- Other non putresible materials that may clog channels or damage pumps due to abrasion, and to prevent their accumulation in sludge digesters.
- Grit chambers are, nothing but like sedimentation tanks, designed to separate the intended heavier inorganic materials by the process of sedimentation due to gravitational forces.
- And to pass forward the lighter organic materials. They causing septicity of sewage and requiring unnecessary labor and expenses for disposal of removal.

Preliminary Treatment

Divide wall

Grit chamber

Screening

Preliminary Treatment

- The grit quantity may vary between 0.004 - 0.037m3/1000m3 of sewage for separate sewage system;
- While this may range between 0.004 - 0.180 m3/1000 m3 for combined sewage system.
- Generally, grit chambers are designed to remove all particles with a nominal diameter of 0.02mm having settling velocity of about 2.3cm/s (at 10°c).
- Although some grit removal devices are designed to remove 0.15mm sand particles having settling velocity of about 1.3cm/s (at 10°c).
- They are designed to have constant velocity horizontal flow at varying discharges.
- The constant velocity is achieved by providing a velocity control section; such as a proportional flow weir at the effluent end of a rectangular chamber.

Preliminary Treatment

I. Constant Velocity Horizontal Flow Grit Chambers

- Such a grit channel is an enlarged channel to:
  - increase the cross-section then,
  - reduce the flow velocity of sewage then,
  - to settle down the heavy inorganic materials do by gravity, and
  - the lighter organic materials remain in suspension, and, then
  - go out along with the effluent of the grit basin.

Preliminary Treatment

- the **flow velocity** should neither be too low as to cause the settling of **lighter organic matter**, nor should it be so high as not to cause the settlement of the **entire silt and grit** present in sewage.
- The flow velocity should also be enough to scour out the settled organic matter, and reintroduce it into the flow stream.
- Such a critical scouring velocity is, given by the modified Shield's formula, which states that horizontal velocity.
- Critical scour velocity

$$V_H = 3 \text{ to } 4.5\sqrt{gd(G-1)}$$

NB:

- In practice, a flow velocity of about **0.25 to 0.3m/sec** is adopted for the design of grit basins..

3.1.3 Tanks for Removing Oils and Grease

1. Skimming Tanks

- Skimming tanks are sometimes employed for removing oils and grease from the sewage, and placed before the sedimentation-tanks.
- They are used where sewage contains too much of grease or oils which include fats, waxes, soaps, fatty acids, etc.
- These materials may enter into the sewage from the kitchens of restaurants and, houses, from motor garages, oil refineries, soap and candle factories, etc.
- They are, thus, normally present in large amounts in the industrial wastewaters.
- It interfere with the activated sludge treatment process, and prevent biological growth on the trickling filters.
- A detention period of about 3 to 5 minutes is usually sufficient.

Preliminary Treatment

- The amount of compressed air required is about 300 to 6000m3 per million liters of sewage.
- The surface area required for the tank can be found out by using the formula:

$$A = 0.00622 * \frac{q}{V_r}$$

Where, q = rate of flow of sewage in m^3/day

V_r = minimum rising velocity of greasy material to be removed in m/minute

= 0.25m/minute in most cases

- The efficiency of a skimming tank can be increased considerably (three to four times) by passing chlorine gas (2mg/liter of sewage) along with the compressed air.

Preliminary Treatment

2. Vacuators

- Grease can also be removed from the sewage by vacuum floatation method, by subjecting the aerated sewage to a vacuum pressure of about 0 - 25cm of mercury for 10 to 15 minutes in a vacuator.
- This causes the air bubbles to expand and move upward through the sewage to the surface.
- The rising bubbles lift the grease and the lighter waste solids to the surface, where they are removed through skimming troughs.
- Heavier solids settle to the tank bottom, where they are collected and carried away for sludge treatment and disposal.

3. Disposal of Skimming's

- The oil and greasy material removed as skimmings from the skimming tanks or vacuators can be disposed of either by burning or burial.
- It is generally too polluted to be of any economic use.

2. Design a suitable grit chamber cum Detritus tank for a sewage treatment plant getting a dry weather flow from a separate sewerage system @4001/s. Assume the flow velocity through the tank as 0.2m/sec and detention period of 2 minutes. The maximum flow may be assumed to be 3 times of dry weather flow.

Solution

Detritus tanks are nothing but rectangular grit chambers, designed to flow with a smaller flow velocity (of about 0.09m/sec) and longer detention periods (3 to 4 minutes)

The length of the tank

= Velocity ∗ Detention time = 0.2 ∗ (2 ∗ 60) = 24m

The discharge passing through each tank

= 400l/s = 0.4m3/sec

Preliminary Treatment

- Therefore, Cross-sectional area required

$$A = \frac{discharge}{velocity} = \frac{0.4}{0.2} = 2m$$

Assuming the water depth in the tank to be 1.2m,

$$\text{The width of the tank} = \frac{cross\text{–}sectional\ area}{depth}$$

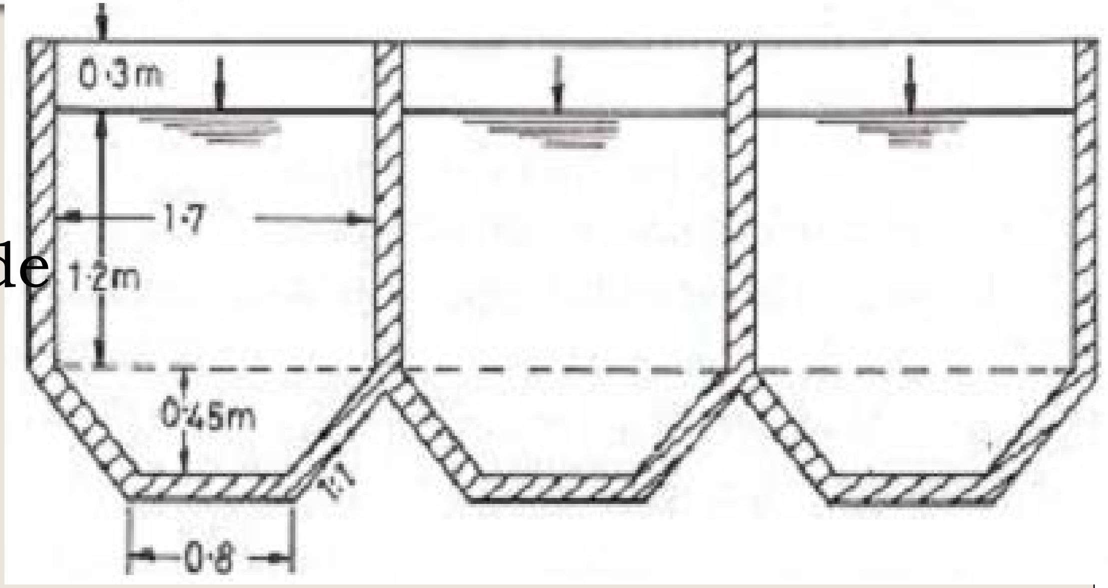
$$= \frac{2}{1.2} = 1.7m$$

Hence, use a Detritus tank with 24m*1.7m*1.2m size.

At the top, a free-board of 0.3m may be provided; and at the bottom, a dead space depth of 0.45m for collection of detritus may be provided.

Thus, the overall depth of the tank = 1.2 + 0.3 + 0.45 = 1.95m.

Preliminary Treatment



The tank will be 1.7m wide up to 1.5m depth, and then the sides will slope down to form an elongated trough of 24m length and 0.8m width at the bottom with rounded corners, as shown in figure

3.2 Primary Wastewater Treatment

- Primary treatment consists in removing large suspended organic solids.
- This is usually accomplished by sedimentation in settling basins.
- The liquid effluent from primary treatment, often contains a large amount of suspended organic material, and **has a high BOD** (about **60%** of original).
- Sometimes, the preliminary as well as primary treatments are classified together, under primary treatment.
- The organic solids which are separated out in the sedimentation tanks (in primary treatment) are often stabilized by anaerobic decomposition in a digestion tank or are incinerated.
- The residue is used for landfills or soil conditioners.

3.2.1 Sedimentation

1. Necessity of Sedimentation in Treatment of Wastewaters

- As discussed in the previous slides, the screens and the grit chambers do remove most of the floating materials (like paper, rags, cloth, wood, tree branches, etc.) and the heavy inorganic settle able solids from the sewage.
- However, a part of the suspended organic solids which are **too heavy to be removed as floating matters, and too light to be removed by grit chambers.**
- The sedimentation tanks are thus designed to remove a part of the organic matter from the sewage effluent coming out from the grit chambers.
- In a complete sewage treatment, the sedimentation is, in fact, carried out twice; once before the biological treatment (i.e. **primary sedimentation**) and once after the biological treatment (i.e. **secondary sedimentation**).
- When chemical coagulants are also used for flocculating the organic matter during the process of sedimentation, the process is called chemical precipitation.

Primary Wastewater Treatment

2. Types of Settling

- Depending on the particles concentration and the interaction between particles, four types of settling can occur;

1. Discrete
2. Flocculent
3. Hidered
4. Compression

1. Discrete particle settling

- ✓ The particles settle without interaction and occur under low solids concentration.
- ✓ A typical occurrence of this type of settling is the removal of sand particles.

Primary Wastewater Treatment

2. Flocculent settling

- This is defined as a condition where particles initially settle independently, but flocculate in the depth of the clarification unit.
- The velocity of settling particles is usually increasing as the particles aggregates.

3. Hindered/zone settling

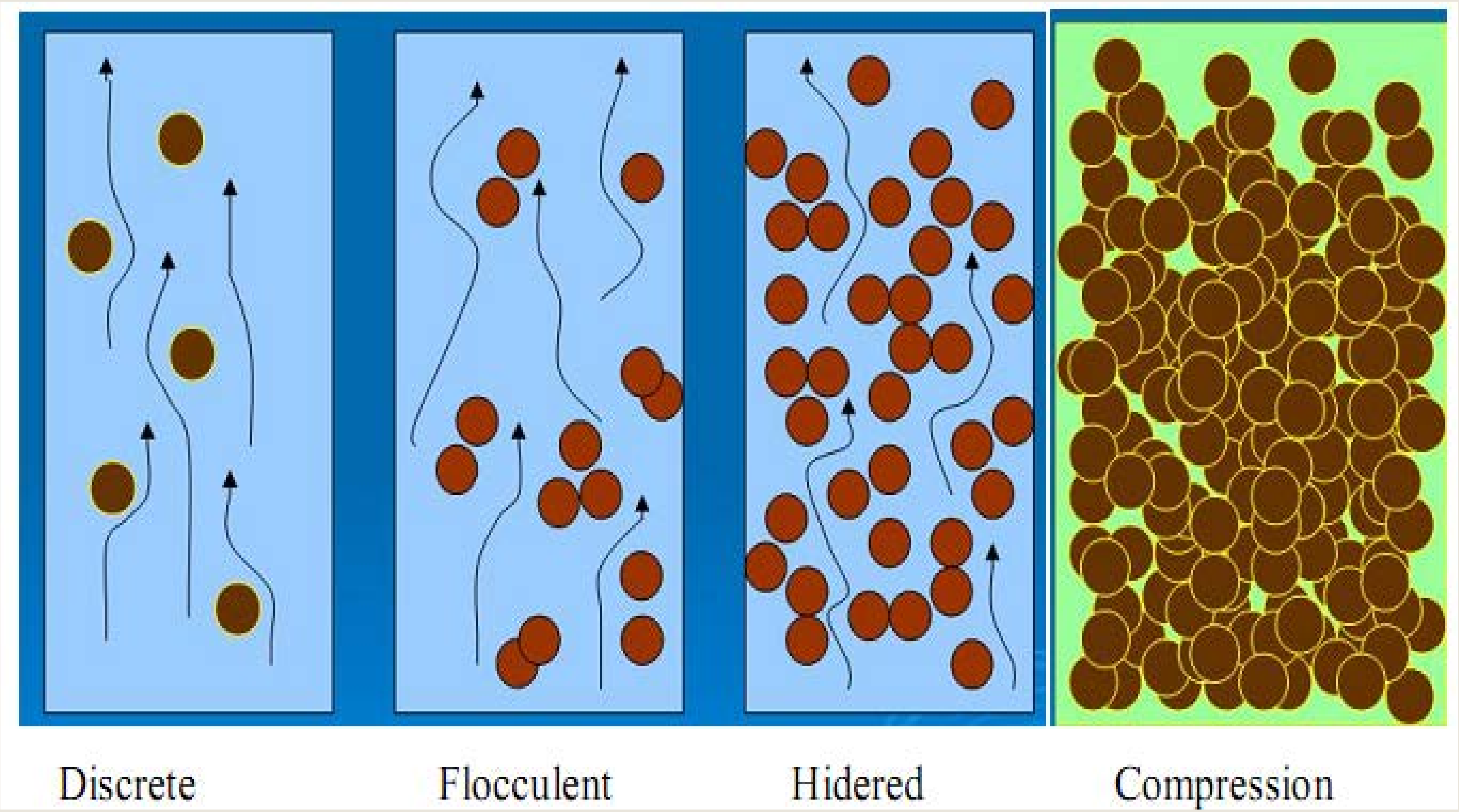
- Inter-particle forces are sufficient to hinder the settling of neighboring particles.
- The particles tend to remain in fixed positions with respect to each others.
- This type of settling is typical in the settler for the activated sludge process (secondary clarifier).

Primary Wastewater Treatment

4. Compression settling

- This occurs when the particle concentration is so high that particles at one level are mechanically influenced by particles on lower levels.
- The settling velocity then drastically reduces.

Primary Wastewater Treatment



- **Settling of Discrete Particles (Type I Settling)**
  - when discrete particles is placed in quiescent fluid, it will accelerate until the friction resistance (drag force, FD) is equal to the impelling force (driving force) acting on the particles.
  - At this stage, the particles attain a uniform or terminal velocity and settles down with this constant velocity called settling velocity, V_s.
  - The settling velocity of this particle is expressed by Stoke's law,

$$V_s = \frac{g}{18}(G-1)\frac{d^2}{v}$$

Primary Wastewater Treatment

Table. Design criteria for primary sedimentation tank

parameter	value	
	range	typical
Detention time, hr	1.5-2.5	2
Overflow rate, $m^3/m^2/d$		
Average flow	32-48	
Peak flow	80-120	100
Weir loading, m3/m/d	125-500	250
Dimensions, m		
Rectangular		
Depth	3-5	3.6
Length	15-90	25-40
Width*	3-24	6-10
Sludge scrapper speed, m/min	0.6-1.4	1
Circular		
Depth	3-5	4.5
Diameter	3.6-60	12-45
Bottom slope, mm/m	60-160	80
Sludge scrapper speed, m/min	0.02-0.05	0.03

*must divide into bays of not greater than 6m wide

Source: Howard S. Peavy

2. A municipal wastewater treatment plant processes an average flow of 5000m3/d, with peak flow as high as 12,500m3/d. design a primary clarifier to remove approximately 60 percent of the suspended solids at average flow.

Solution:

Assume overflow rate of 35m3/m2.d

$$A_s = \frac{Q}{q_o} = \frac{5000m3/d}{35m3/m2.d} = 143m2$$

Assume tank shape as circular,

$$A_s = \frac{\pi d^2}{4}$$

Primary Wastewater Treatment

- $$143 = \frac{\pi d^2}{4}$$

d=13.5m

Assume depth 3m

$$volume = 143 * 3m = 429m3$$

And detention time

$$t_d = \frac{volume}{discharge} = \frac{429m3}{5000m3/d} = 0.09d = 2.06hr$$

Exercise: redesign using peak flow and compare the result.

1. A city must treat about 15,000m3/d of water. Flocculating particles are produced by coagulation and column analysis indicates that an overflow rate of 20m/d will produce satisfactory removal at a depth of 3.5m. Determine the size of the required settling tank. And check detention time, check horizontal velocity.

Take length to width ratio as 3/1.

Solution:

I. Compute surface area (provide two tanks at 7500m3/d each)

$$Q = q_o A_s$$

$$7500m3/d = 20m/d * A_s$$

$$A_s = 374m2$$

II. length-to-width ratio of 3/1, calculate surface dimensions.

w*3W = 375m2

Width= 11m

Length=34

Primary Wastewater Treatment

III. Check retention time.

$$t = \frac{volume}{flow\ rate} = \frac{11m * 34 * 3.5}{\frac{7500m}{d} * \frac{1d}{24hr}}$$

$$t = 4.19hr$$

IV. check horizontal velocity

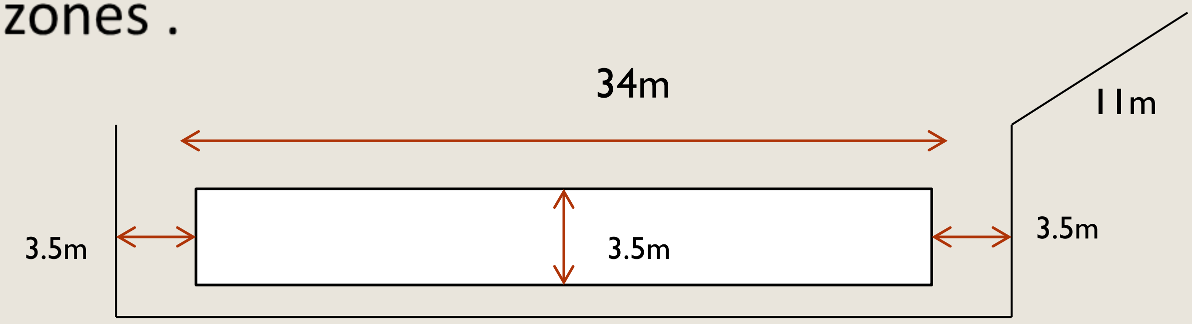
$$v_h = \frac{Q}{A_x} = \frac{\frac{7500m^3}{d} * \frac{1d}{24hr}}{11m * 3.5m} = 8.1m/hr$$

Primary Wastewater Treatment

V. check weir overflow rate. If simple weir is placed across end of the tank, overflow length will be 11m and overflow rate will be

$$\frac{7500m3}{d} * \frac{1d}{24hr} * \frac{1}{11m} = 28.4\frac{m^3}{hr.m}$$

VI. Add inlet and outlet zones equal to depth of tank and sludge zones .



Depth settling zone plus 0.5 freeboard plus 0.5 sludge zone.

Problems

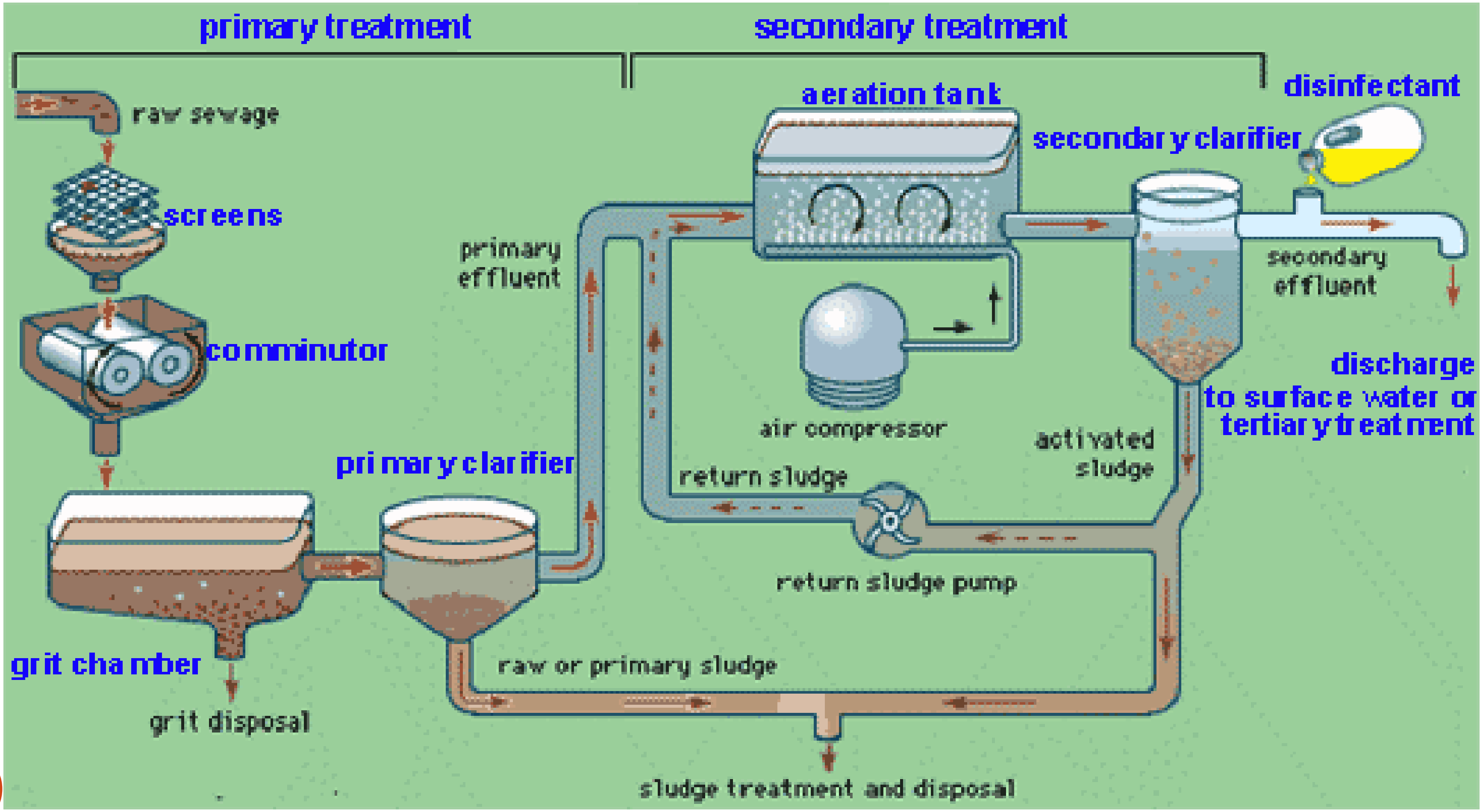
1. Design a suitable rectangular sedimentation tank (provided with mechanical cleaning equipment) for treating the sewage from a city provided with an assured public water supply system, with a maximum daily demand of 12 million liters per day. Assume suitable values of detention period and velocity of flow in the tank. Make any other assumptions, wherever needed.

Take detention period 2.5 hrs.

Part II

Lecture 4

SECONDARY & TERTIARY WASTEWATER TREATMENT



The Role of Microorganisms in Wastewater Treatment

- Micro-organisms are important in the treatment of WW.
- They are (bacteria, fungi, protozoa, and crustaceans) play an essential role in the conversion of organic waste to more stable or less polluting substances.

How?

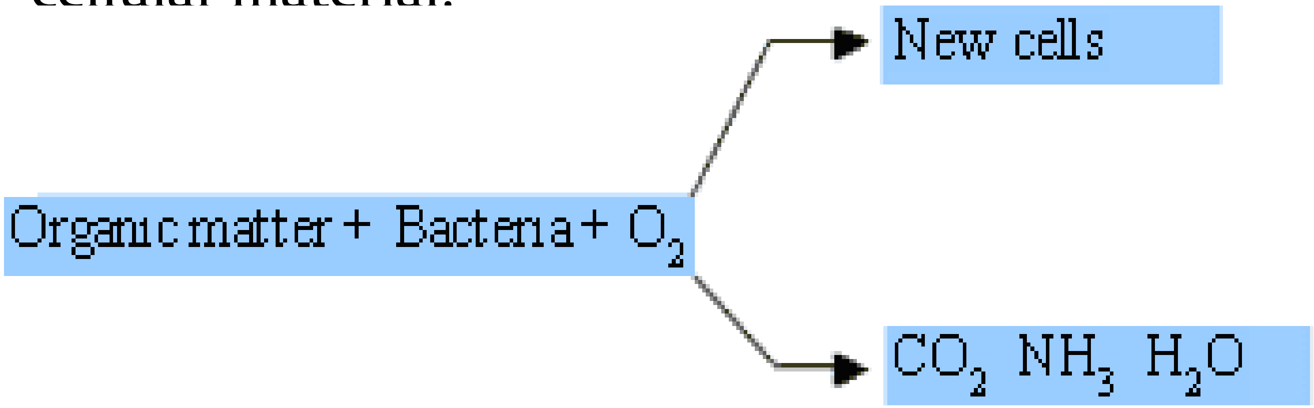
- Waste from humans is a useful food substrate for the micro-organisms.
- And they require cellular building blocks, such as (carbon) C, (hydrogen) H, (oxygen) O, (nitrogen) N, (phosphorus) P, and minerals for growth.
- These can be obtained through consuming organic substances containing these elements, or from inorganic materials, such as carbon dioxide, water, nitrate and phosphate.

The Role of Microorganisms in Wastewater Treatment

- Micro-organisms also require energy.
- They obtain this through respiration. In this process organic carbon is oxidized to release its energy.
- Oxygen or other hydrogen acceptors is needed for the respiration process.
- Algae and photosynthetic bacteria utilize energy from sunlight, while certain types of bacteria can utilize energy from chemical reactions not involving respiration.
- These building blocks and energy are used to synthesize more cells for growth and also for reproduction.
- Finally new cells die-off and settle down/removed by other means.

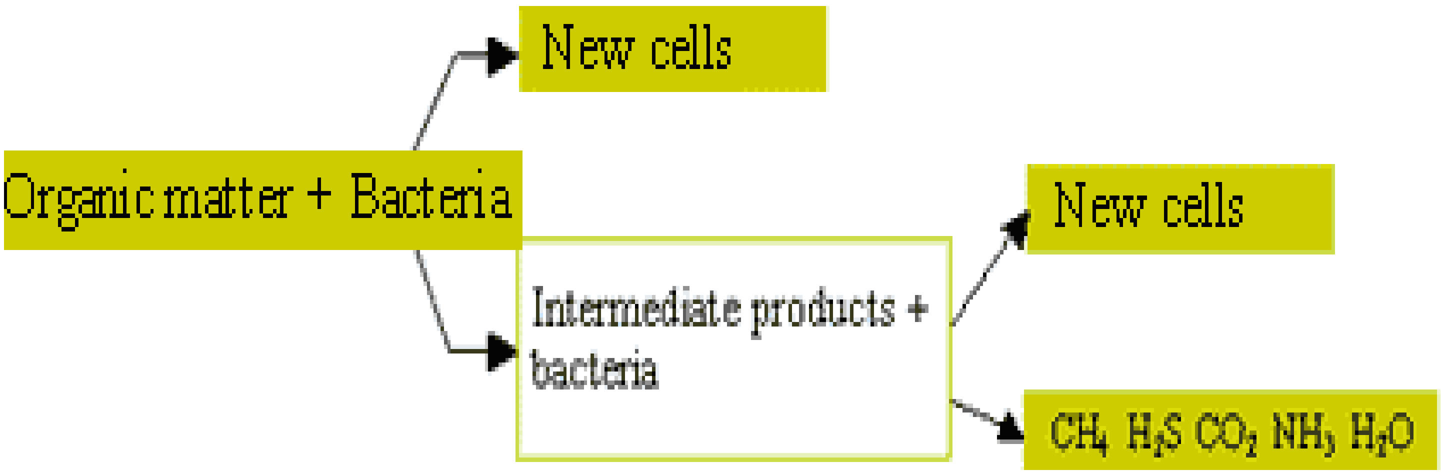
The Role of Microorganisms in Wastewater Treatment

- Three types of processes to represent the conversion of organic wastes by micro-organisms.
  1. **Aerobic oxidation** : utilize oxygen to oxidize organic substances to obtain energy for maintenance, mobility and the synthesis of cellular material.



  2. **Anaerobic oxidation**: utilize nitrates, sulphates and other hydrogen acceptors to obtain energy for the synthesis of cellular material from organic substances.

The Role of Microorganisms in Wastewater Treatment



- **Methane (CH_4)** is a source of heat but, if released to the atmosphere without being combusted, it contributes to the greenhouse gas effect.
- **Hydrogen sulphide (H_2S)** contributes to WW odor which is rotten egg smell.

3. **Photosynthetic.**

$$aCO_2 + rH_2O + tNH_3 \xrightarrow{\text{Sunlight}} C_wH_xO_yN_z + bO_2$$

Microbial Growth Kinetics

- Growth of a microbial population is defined as an increase in numbers or an increase in microbial mass.
- Growth rate is the increase in microbial cell numbers or mass per unit time.
- Microbial populations can grow as:
  1. Batch cultures (closed systems) or
  2. Continuous cultures (open systems)

Microbial Growth Kinetics

1. **Batch Cultures**

- When a suitable medium is inoculated with cells, the growth of the microbial population shows four distinct phases.

The lag phase is a period of cell adjustment to the new environment

At **log/exponential phase** the number of cells increases exponentially

At **stationary phase** microorganisms cannot grow indefinitely, mainly because of lack of nutrients and electron acceptors, and the production and the accumulation of toxic metabolites.

During **death phase**, the death (decay) rate of the microbial population is higher than the growth

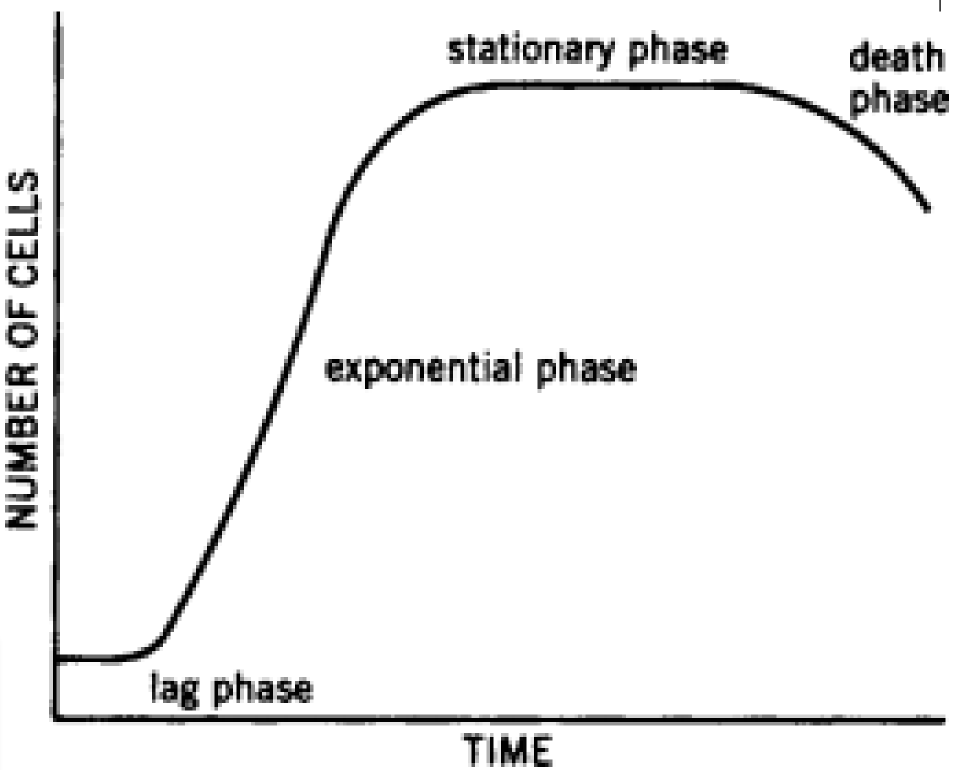
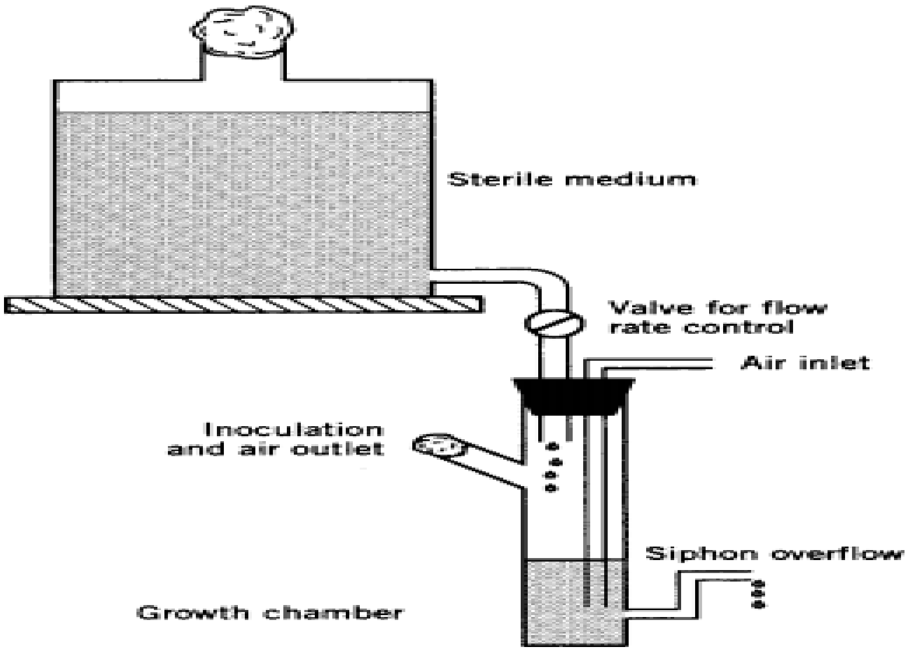


Figure of Microbial growth curve

2. Continuous Culture of Microorganisms

- the exponential growth phase over a long period of time can be achieved by growing continuously the cells in a completely mixed reactor in which a constant volume is maintained.
- The most commonly used device is the chemostat



Microbial Growth Kinetics

Physical and Chemical Factors Affecting Microbial Growth are :-

1. Substrate Concentration
2. Temperature
3. pH
4. Oxygen Level

Biological Wastewater Treatment

- To introduce WW contact with bacteria (cells) which feed organic matter in WW.
- The purpose of biological treatment is **BOD** reduction.

Principle:

→ Simple bacteria (cells) eat the organic material.

→ Through their metabolism, the organic material is transformed into cellular mass,

→ This cellular mass can be precipitated at the bottom of a settling tank or retained as slime on solid surfaces or vegetation in the system.

→ Then, the WW exiting the system is much clearer than it entered.

→ Cells need oxygen to breath, so adequate supply of oxygen should be for the operational biological WWT.

Biological Wastewater Treatment

The common methods of biological wastewater treatment are:

a) Aerobic processes such as **trickling filters,** rotating biological contactors, **activated sludge process, oxidation ponds and lagoons,** oxidation ditches, **constructed wetland**
b) Anaerobic processes such as anaerobic digestion, and
c) Anoxic processes such as denitrification.

1. TRICKLING FILTERS

- consist of tanks of coarser filtering media(see figure-next page).

I. Principles of operation

- over tanks of coarser filtering media the WW is allowed to sprinkle or trickle down, by means of spray nozzles or rotary distributors.
- The percolating sewage is collected at the bottom of the tank through a well designed under-drainage system.
- sufficient quantity of oxygen is supplied by providing suitable ventilation facilities in the body of the filter
- The purification is done mainly by the aerobic bacteria, which form a bacterial film around the particles of the filtering media.
- The effluent must be taken to the secondary sedimentation tank for settling out the organic matter oxidized while passing down the filter.

Biological Wastewater Treatment

Figure of Photographic view of trickling filter with its rotary distributors

Biological Wastewater Treatment

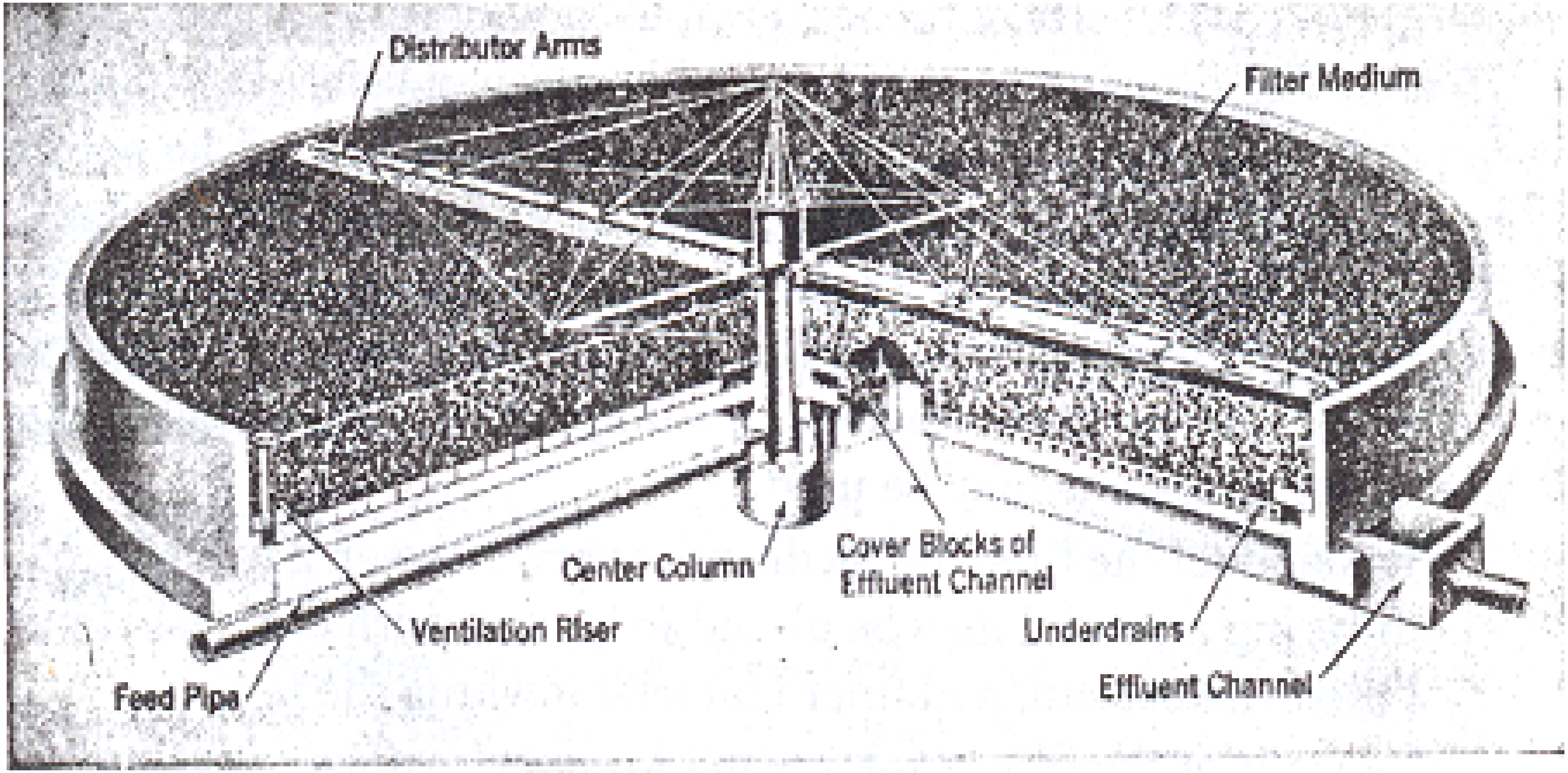


Fig. 9.18. (*b*) Photographic view of a conventional Circular Trickling filter with Rotary distributors.

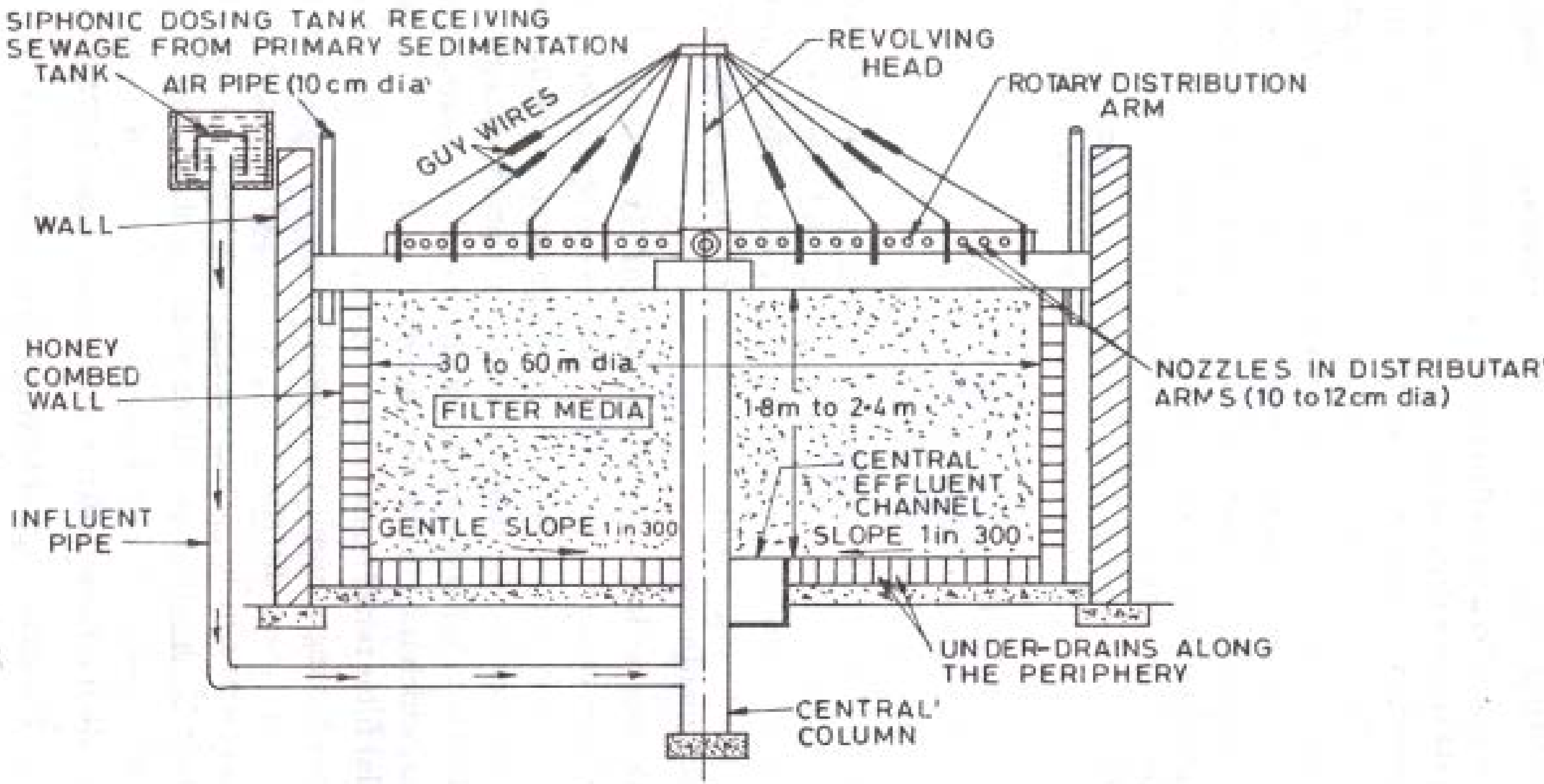


Fig. 9.18. (*a*) Typical section of a conventional Circular Trickling filter with Rotary distributors (vertical scale shown enlarged).

Figure of Typical section of a conventional circular trickling filter

II. Sewage distributors over filters: they are two

- Rotary distributors and spray nozzles.

Difference between the rotary distributors and that of spray nozzles

- ✓ With a rotary distributor, **the application of sewage to the filter is practically continuous**;
- ✓ whereas with spray nozzles, **the filter is dosed for 3 to 5 minutes, and then rested** for 5 to 10 minutes before the next application.

III. Filtering medias (stone used)

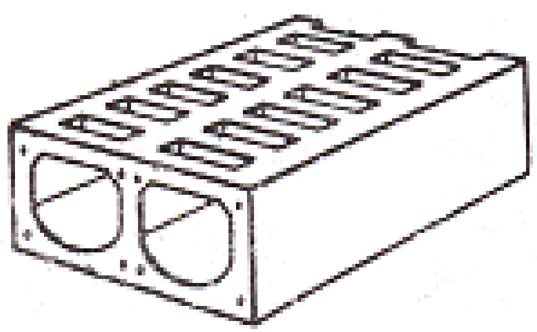
- consists of coarser materials like cubically broken stones or slag
- free from dust and small pieces.
- The size of the material used may vary between 25 to 75mm.
- should be washed before it is placed in position.
- should not be easily affected by acidic WW, and should be sufficiently hard.
- Its resistance to freezing and thawing is another important property,

Biological Wastewater Treatment

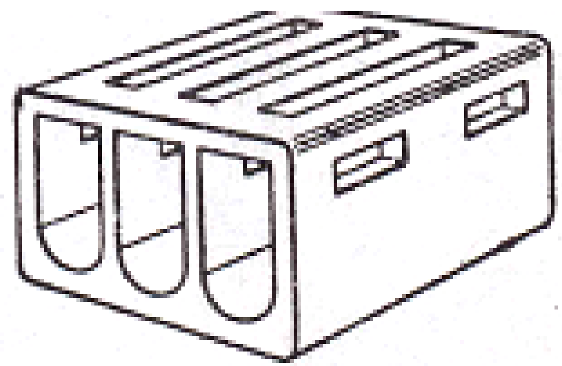
- The depth of the filtering media may vary between 2 to 3 meters.
- The filtering material may be placed in layers; with coarsest stone used near the bottom, and. finer material towards the top.

IV. Under drains

- Ensures satisfactory drainage
- Also ensure satisfactory ventilation and aeration of the filter bed
- Vitrified clay blocks are generally used as under-drains.



(a) Under-drain block for standard trickling filters.



(b) Under-drain block for high rate trickling filters with heavy hydraulic loading

Types of Trickling Filters

1. Conventional trickling filters or low rate trickling filters

2. High rate filters or High rate trickling filters

Design of Trickling Filters

It involves the design of :

- ✓the diameter of the circular filter tank and its depth,
- ✓also design of the rotary distributors and under-drainage system.

- The design of the filter size is based upon the values of the filter-loadings adopted for the design.
- This loading on a filter can be expressed in two ways:

(i) **Hydraulic-loading rate**: the quantity of sewage applied per unit surface area of the filter per day

a) For conventional filters may vary between **22** and **44** (normally 28) M.L/ha/day.

b) For the high rate trickling filters it is about 110 to 330 (normally 220) M.L/ha/day

(i) **organic loading rate**:

- the mass of BOD per unit volume of the filtering media per day.
- for conventional filters it vary between 900 to 2200 kg of BOD_5 per ha-m.
- about 6000 - 18000 kg of BOD_5 per ha-m in high rate trickling filters.

With an assumed value of organic loading (900 to 2200kg/ha-m)and hydraulic loading (22 and 44 Ml/ha/day).

$$total\ volume\ of\ filter = \frac{total\ BOD5}{organic\ loading}$$

$$surface\ area\ of\ the\ filter = \frac{total\ volume\ of\ filter}{hydraulic\ loading}$$

- Knowing the volume and area of the cylindrical filter, we can easily find out its diameter and depth.

Biological Wastewater Treatment

- The filter diameter and depth is designed for average value of sewage flow.
- The rotary distributors, under-drainage system, and other connected pipe lines etc. are, however, designed for peak flow and of course checked for the average flow.
- Moreover, since the rotary distributors are available indigenously only up to 60m in length,
- It is desirable to keep the diameter of the filter tank up to a maximum of 60m.
- If the required filter diameter is more than 60m, then it is better to use more units of lesser diameter.

Efficiency of High Rate Filters

- The efficiency of high rate filters depend upon the volume of the re-circulated flow (in comparison
- to the volume of raw sewage) and also upon the organic loading.
- The ratio (R/I) of the volume of sewage re-circulated (R) to the volume of raw sewage (I) is called recirculation ratio, and is an important feature in obtaining the efficiency of the filter plant (or to work out the required degree of treatment for obtaining certain efficiency), The recirculation ratio is connected to another term called ***recirculation factor*** (F) by the relation:

Efficiency cont…

$$F = \frac{1 + \frac{R}{I}}{\left(1 + 0.1 * \frac{R}{I}\right)^2}$$

The recirculation factor (F) also represents the number of effective passages through the filt

Thus, when there is no recirculation and $\frac{R}{I}$ is zero, F is unity.

The efficiency of the single stage high rate trickling filter can then be worked out by using tl equation,

$$\eta(\%) = \frac{100}{1 + 0.0044\sqrt{\frac{Y}{V * F}}} \qquad 4.22$$

Where, Y - the total organic loading in kg/day applied to the filter, i.e. the total BOD in kg. Tl

term $\frac{Y}{V * F}$ is also called unit organic loading on filter, i.e., u

V - Filter volume in hectare meters

F - Recirculation factor

Efficiency cont...

- In a two stage filter, the efficiency achieved in the first stage will be obtained by the previous equation; and in the second stage, it is obtained as:
- Final efficiency in the two stage filter

$$\eta' = \frac{100}{1 + \frac{0.0044}{1-\eta} * \sqrt{\frac{Y'}{V' * F'}}}$$

Where, Y' - Total BOD in effluent from first stage in kg/day

V' - Volume of second stage filter in ha-m

F' - Recirculation factor for the second stage filter

η'- Final efficiency obtained after two stage filtration

These equations are very important, as they form the basis of designing high rate filters.

Example 1:

- Design high rate two stage trickling filter to treat the sewage by assuming 35% of BOD is removed at primary sedimentation. Also determine the effluent BOD and filter efficiency with following data:-

Wastewater temperature	20°C
Plant flow Q	2 Mgal/d (7570 m^3)
BOD_5 in raw waste	300 mg/L
Volume of filter (each)	16,000 ft^3 (453 m^3)
Depth of filter	7 ft (2.13 m)
Recirculation for filter 1	$= 1.5\ Q$
Recirculation for filter 2	$= 0.8\ Q$

Solution:-

Step 1. Estimate BOD loading at the first stage

Influent BOD $C_1 = 300\text{ mg/L}\,(1 - 0.35) = 195\text{ mg/L}$

$$W = QC_1 = 2\text{ Mgal/d} \times 195\text{ mg/L} \times 8.34\text{ lb/(Mgal}\cdot\text{mg/L)}$$
$$= 3252\text{ lb/d}$$

Step 2. Calculate BOD removal efficiency of filter 1

$$F = \frac{1 + r_1}{(1 + 0.1r_1)^2} = \frac{1 + 1.5}{(1 + 0.1 \times 1.5)^2}$$
$$= 1.89$$

$$E_1 = \frac{100}{1 + 0.0561\sqrt{W/VF}}$$
$$= \frac{100}{1 + 0.0561\sqrt{3252/(16 \times 1.89)}}$$
$$= 63.2\,(\%)$$

Step 3. Calculate effluent BOD concentration of filter 1

$$C_{1e} = 195\text{ mg/L}\,(1 - 0.632)$$
$$= 71.8\text{ mg/L}$$

Cont…

Step 4. Calculate BOD removal efficiency of filter 2

$$F' = \frac{1 + 0.8}{(1 + 0.1 \times 0.8)^2} = 1.54$$

$$\text{Mass of influent BOD} = 2 \times 71.8 \times 8.34$$

$$= 1198 \text{ (lb/d)}$$

$$E_2 = \frac{100\%}{1 + 0.0561\sqrt{1198/(16 \times 1.54)}}$$

$$= 71.9\%$$

Step 5. Calculate effluent BOD concentration of filter 2

$$C_{2e} = 71.8 \text{ mg/L} \times (1 - 0.719)$$

$$= 20.1 \text{ mg/L}$$

Step 6. Calculate the overall efficiency

(a) Using Equation

$$E = 100 - 100[(1 - 0.35)(1 - 0.632)(1 - 0.719)]$$

$$= 93.3\%$$

(b)

$$E = (300 \text{ mg/L} - 20.1 \text{ mg/L})/(300 \text{ mg/L})$$

$$= 0.933$$

$$= 93.3\%$$

Example 2

- Calculate the BOD loading, hydraulic loading, BOD removal efficiency, and effluent BOD concentration of a single-stage trickling filter based on the following data:

❖ Design assumptions:
  - Influent flow =1530 m^3/d
  - Recirculation ratio = 0.5
  - Primary effluent BOD = 130 mg/L
  - Diameter of filter = 18 m
  - Depth of media = 2.1 m
  - Water temperature =18°C

Solution)

(1) BOD loading rate ($kg/m^3/d$)

- BOD load = BOD Conc. x Influent flow
  = 130 mg/L x 1530 m^3/d =**198.9 kg/d**
- Volume of filter = surface area of filter x depth
  = π (18 m x 18m)/4 X 2.1 m = **533 m^3**
- BOD loading rate = BOD load / volume of filter
  =**0.37 $kg/m^3/d$**

Cont…

(2) Hydraulic loading rate ($m^3/m^2/d$)

- Total flow to the media = influent + recirculation flow
  = 1530 m^3/d + (1530 m^3/d x 0.5)
- Surface area of filter = π (18 m x 18m)/4 = **254 m^2**
- Hydraulic loading rate = Total flow to the media / area of filter
  = **9.04 $m^3/m^2/d$**

(3) Effluent BOD (mg/L)

- BOD removal efficiency for first-stage filter at 20°C, %

$$E_1 = \frac{100}{1 + 0.4432\sqrt{\frac{w_1}{VF}}}$$

$$F = \frac{1+R}{(1+R/10)^2} = \frac{1+0.5}{(1+0.5/10)^2} = 1.36$$

Cont…

$$E_1 = \frac{100}{1 + 0.4432\sqrt{\frac{w_1}{VF}}} = \frac{100}{1 + 0.4432\sqrt{\frac{0.37}{1.36}}} = 81.2\%$$

$$E_{18} = \quad E_{20}(1.035)^{18-20} = 81.2(1.035)^{-2} = 75.7\%$$

$$Effluent\ \ BOD\,(mg/L) = 130\,mg/L \times \frac{(100 - 75.7)}{100}$$

2. **ACTIVATED SLUDGE PROCESS**

- provides an excellent method of treating sewage.
- BOD removal is up to 80 - 95%, and bacteria removal is up to 90 - 95%.

Principle of operation:

- ✓ The WW effluent from primary sedimentation tank mixed with 20 to 30% of volume of activated sludge (from ASP unit).
  - ➢ This activate sludge contains a large concentration of highly active aerobic microorganisms.
- ✓ The sewage are intimately mixed together with a large quantity of air for about 4 to 8 hours.
- ✓ The moving organisms will oxidize the organic matter and the suspended and colloidal matter tends to coagulate and form a precipitate which settles down readily in the secondary settling tank.

Biological Wastewater Treatment

- ✓ The settled sludge (containing microorganisms) called activated sludge is then recycled to the head of the aeration tank to be mixed again with the sewage being treated.

- The mixture of WW and activated sludge is called mixed liquor.
- The biological mass (biomass) in the mixed liquor is called mixed liquor suspended solids (MLSS) or mixed liquor volatile suspended solids (MLVSS).
- The MLSS consists mostly of microorganisms, non-biodegradable suspended organic matter, and other inert suspended matter.

Units of an Activated Sludge Plant

1. Aeration Tanks
2. secondary clarifier

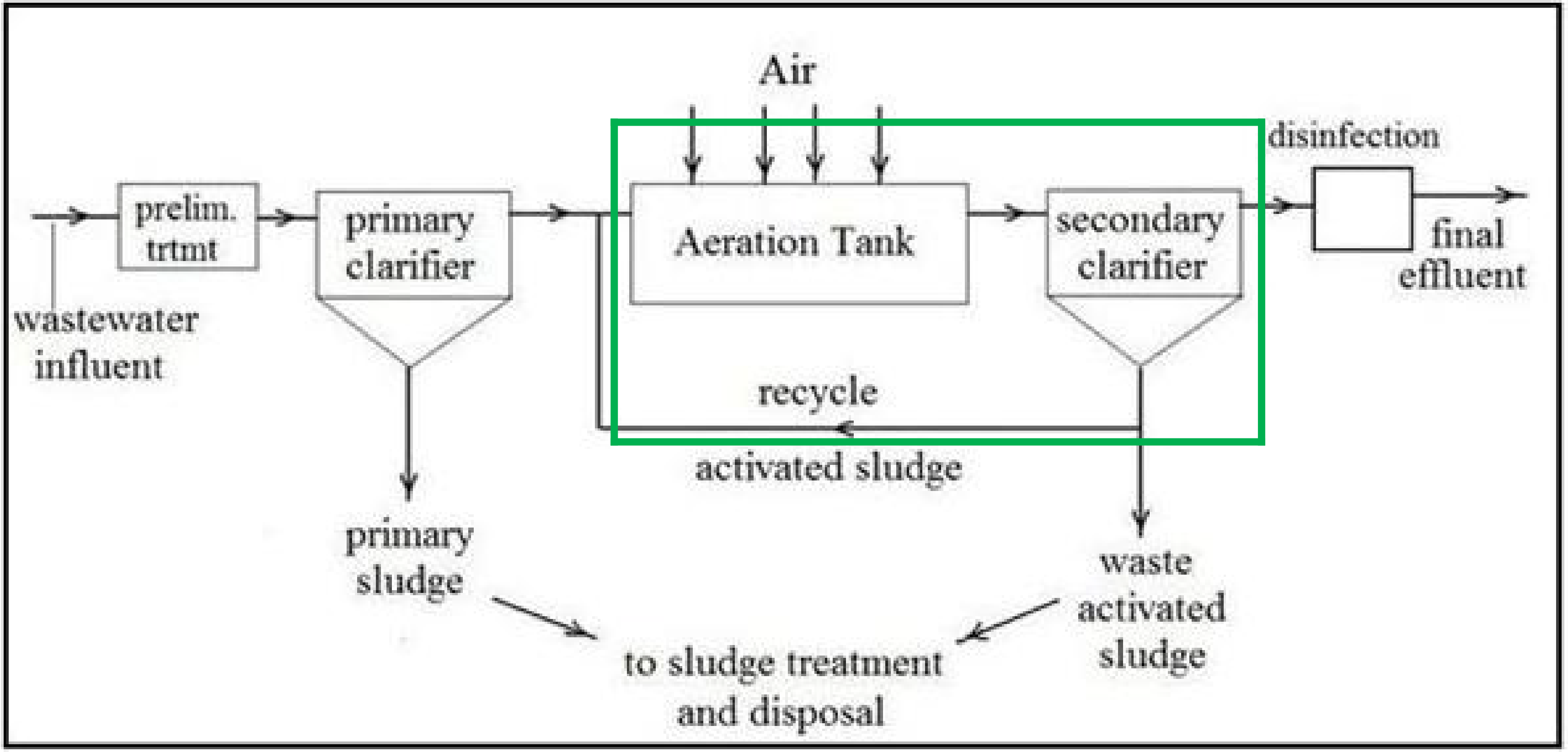


Figure of a conventional AS plant giving high degree of treatment

Biological Wastewater Treatment

1. **Aeration tanks**

- Is tank in which mixed liquor get mixed with air.
- are normally rectangular tanks 3 to 4.5m deep and about 4 to 6m wide.
- The length may range between 20 to 200m and the detention period between 4 to 8 hours for municipal sewages.
- Air is continuously introduced into these tanks using one of the following method:

  I. **Air diffusion**: compressed air under a pressure of 35-70kN/m2 is introduced into the aeration chamber by diffuser.

  II. **Mechanical aeration**: atmospheric air is brought in contact with the sewage in this method.

2. **Secondary Sedimentation Tank**

- From the aeration tank, the WW flows to the final sedimentation tank.
- The detention period for such a sedimentation tank may be kept between 1.5-2 hours, as the same is usually found to give optimum results.
- The length to depth ratio may be kept at about 7 for rectangular ones.
- The depth may be kept in the range of 3.5 to 4.5m.

Design considerations in an activated sludge plant

1. Aeration Tank Loadings
2. Sludge Volume Index (SVI)

1. Aeration Tank Loadings

The important terms which define the loading rates of an activated sludge plant, include:

i. Aeration Period (i.e. Hydraulic Retention Time - HRT)
ii. BOD loading per unit volume of aeration tank (i.e. volumetric loading)
iii. Food to Micro-organism Ratio (F/M Ratio)
iv. Sludge age

i. The Aeration Period or HRT

- For continuous flow aeration tank,

$$\text{Detention period (t)} = \frac{\text{Volume of the tank}}{\text{Rate of sewage flow in the tank}} = \frac{V(m^3)}{Q(m^3/hr)}$$

ii. Volumetric BOD Loading

$$= \frac{\text{Mass of BOD5 applied per day to the aeration tank through influent sewage in gm}}{\text{Volume of the aeration tank in m}^3}$$

$$= \frac{\mathrm{Q} * \mathrm{Y_o}\ (\mathrm{gm})}{\mathrm{V}\ (\mathrm{m}^3)}$$

Where, Q = Sewage flow into the aeration tank in m3

Y_o= BOD5 in mg/l (or gm/m3) of the influent sewage

V = Aeration tank volume in m3

(iii) Food (F) to Micro-organisms (M) Ratio

- The BOD load applied to the system in kg or gm is represented as food (F), and the total microbial suspended solid in the mixed liquor of the aeration tank is represented by M.

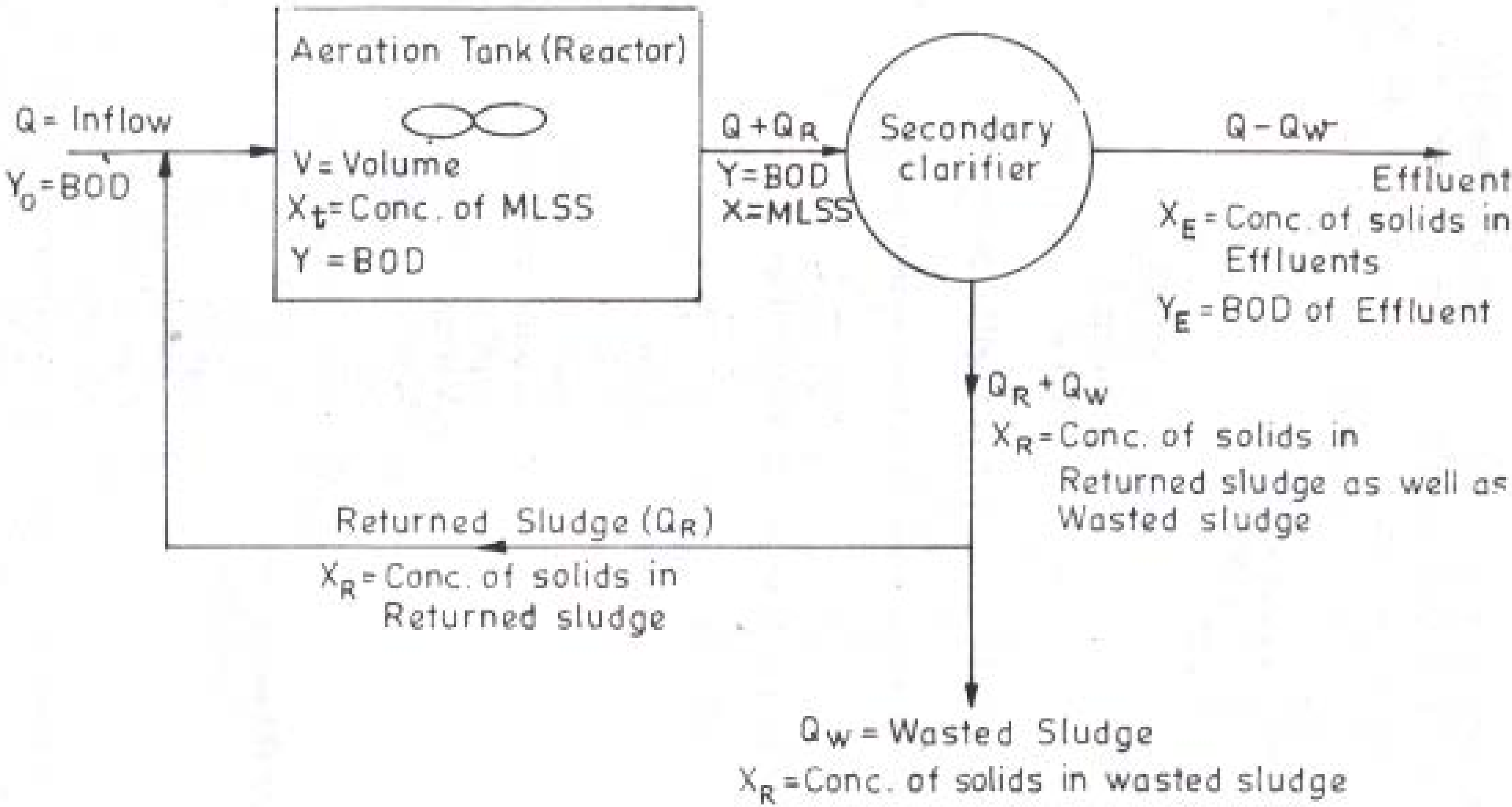
$$\text{F/M ratio} = \frac{\text{Daily BOD5 load applied to the aerator system in gm}}{\text{Total microbial mass in the system in gm}}$$

Daily BOD load applied to the aerator system

F = Q*BOD_5gm/day

F = Q*$Y_o$gm/day ……………..(4.1)

Biological Wastewater Treatment



Flow chart of conventional activated sludge plant

The total microbial mass in the aeration system (M): Mixed Liquor Suspended Solids (MLSS) times the volume of the aeration tank (V).

$$M = MLSS * V$$

$$= X_t * V \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(4.2)$$

Where, X_t is MLSS in mg/l

Dividing (4.1) by (4.2), we get

$$\frac{F}{M}\text{ratio} = \frac{F}{M} = \frac{Q}{V} * \frac{Y_o}{X_t}$$

iv. Sludge Age

- average time for which particles of suspended solids remain under aeration.

$$\text{Sludge age } (\theta_c) = \frac{\text{Mass of suspended solids (MLSS) in the system (M)}}{\text{Mass of solids leaving the system per day}}$$

Mass of solids in the reactor $(\text{M}) = \text{V} * (\text{MLSS})$

$$= \text{V} * X_t$$

Mass of solids leaving the system per day is equal to Mass of solids removed with the wasted sludge per day plus Mass of solids removed with the effluent per day

Mass of solids removed with the wasted sludge per day

$= Q_w * X_R$ ………4.3

Mass of solids removed with the effluent per day

$$= (Q - Q_w) * X_E \text{……….4.4}$$

Therefore, Total solid removed from the system per day is the summation equation 4.3 and 4.4.

$$= Q_w * X_R + (Q - Q_w) * X_E$$

Thus:

$$\text{Sludge age} = \theta_c = \frac{V * X_t}{Q_w * X_R + (Q - Q_w) * X_E}$$

When the value of X_E (suspended solids concentration in the effluent of activated sludge plant) is very small, then the term $((Q - Q_w) * X_E$ in the above equation can be ignored, leading to:

$$\theta_c = \frac{V * X_t}{Q_w * X_R}$$

- another rational loading parameter is the specific substrate utilization rate (q) per day, and is defined as:

$$q = Q * \left(\frac{Y_o - Y_E}{V * X_t}\right)$$

- Under steady state operation, the mass of wasted activated sludge is further given by:

$$Q_w * X_R = y * Q(Y_o - Y_E) - K_e * X_t * V \ldots\ldots 4.5$$

Where, y = maximum yield coefficient

$$y = \frac{\text{microbial mass synthesized}}{\text{mass of substrate utilized}}$$

K_e= Endogenous respiration rate constant (per day)

- The values of y and K_e are found to be constant for municipal waste waters, their typical values being:

y = 1.0 with respect to TSS (i.e. MLSS)

= 0.6 with respect to VSS (i.e. MLVSS)

K_e = 0.06 (per day)

From equations (4.5), dividing all terms for$X_t * V$ we can also work out as:

$$= \frac{1}{\theta_c} = yq - K_e$$

2. Sludge Volume Index (SVI)

- is used to indicate the physical state of the sludge produced in a biological aeration system.
- It represents the degree of concentration of the sludge in the system,
- Done in lab.

$$SVI = \frac{Vo\ (ml/l)}{Xo\ (mg/l)} = \frac{V_o}{X_o}\ ml/mg$$

Where, Vo:settled sludge volumein ml in liter of mixed liquor.

Xo:concentration of settled suspended solids in a liter of mixed liquor inmg.

- The usual adopted range of SVI is between 50 - 150 ml/gm and such a value indicates good settling sludge.

Sludge Recycle and Rate of Return Sludge

- The relationship b/n sludge recirculation ratio $\frac{Q_R}{Q}$ with X_t (MLSS in tank) and X_R (MLSS in returned or wasted sludge) is given as:

$\frac{Q_R}{Q} = \frac{X_t}{X_R - X_t}$, Where, QR = Sludge recirculation rate in m3/d

Xt= MLSS in the aeration tank in mg/l

XR = MLSS in the returned or wasted sludge in mg/l

The settleabilityof sludge is determined by sludge volume index (SVI), which is determined in the laboratory.

- If it is assumed that the sedimentation of suspended solids in the laboratory is similar to that in the sedimentation tank, then:

$$X_R = \frac{10^6}{SVI}$$

where, SVI value in mg/l

Then,

$$\frac{Q_R}{Q} = \frac{X_t}{\frac{10^6}{SVI} - X_t}$$

- The return sludge has always to be pumped and the pump capacity should be designed for a minimum return sludge ratio of 0.50 to 0.75 for large plants and 1.0 to 1.5 for smaller plants irrespective of the theoretical requirement.

Size and Volume of the Aeration Tank

- Using equation (a)

$$\theta_c = \frac{V * X_t}{Q_w * X_R} \ldots\ldots\ldots\ldots\ldots a$$

Using equation (b)

$$Q_w * X_R = y * Q(Y_o - Y_E) - K_e * X_t * V \ldots\ldots\ldots b$$

- Using combination of Equations (a) and (b:

$$V * X_t = \frac{y * Q(Y_o - Y_E)\theta_c}{1 + K_e\theta_c}$$

- Alternatively, the tank volume can be determined for an assumed value of F/M ratio and tank MLSS (Xt).

$$\frac{F}{M} = \frac{Q}{V} * \frac{Y_o}{X_t}$$

Oxygen Requirement of the Aeration Tanks

- The total oxygen requirement may be computed by using the equation

$$O_2 = \left(\frac{Q(Y_o - Y_E)}{f} - 1.42 Q_w * X_R\right) \text{gm/day}$$

Where,

$$f = \frac{BOD_5}{BOD_u} = \frac{\text{5 day BOD}}{\text{Ultimate BOD}} \cong 0.68$$

1.42 = oxygen demand of biomass in gm/gm

- The above formula represents the oxygen demand for carbonaceous BOD removal and does not account for nitrification.

Table 4-4 Characteristics and design parameters of different activated sludge systems

Process type	Flow regime	MLSS mg/l	$\frac{MLVSS}{MLSS}$	$\frac{F}{M}$	HRT hrs	Volumetric Loading kg BOD_5 per m^3	SRT (days) θ_c	$\frac{Q_R}{Q}$ Return Sludge ratio	BOD removal percent	kg O_2 reqd. per kg BOD_5 removed	Air requirement in m^3 per kg of BOD_5 removed
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Conventional	Plug	1500 to 3000	0.8	0.4 to 0.3	4 to 6	0.3 to 0.7	5 to8	0.25 to 0.5	85 to 92	0.8 to 1.0	40 to 100
Taperd aeration	Plug	1500 to 3000	0.8	0.4 to 0.3	4 to 6	0.3 to 0.8	5 to 8	0.25 to 0.5	85 to 92	0.7 to 1.0	50 to 75
Step aeration	Plug	2000 to 3000	0.8	0.4 to 0.3	3 to 6	0.7 to 1.0	5 to 8	0.25 to 0.75	85 to 92	0.7 to 1.0	50 to 75^{+}
Contact stabilization	Plug	1000 to 3000* 3000 to 6000**	0.8	0.5 to 0.3	0.5 to 1.5* 3 to 6**	1.0 to 1.2	5 to 8	0.25 to 1.0	85 to 92	0.7 to 1.0	50 to 75
Complete mix	Complete mix	3000 to 4000	0.8	0.5 to 0.3	4 to 5	0.8 to 2.0	5 to 8	0.25 to 0.8	85 to 92	0.8 to 1.0	50 to 75
Modified ae[illegible]	Plug	300 to 800	0.8	3.0 to 1.5	1.5 to 3	1.2 to 2.4	0.2 to 0.5	0.05 to 0.15	60 to 75	0.4 to 0.6	25 to 50
Ex[illegible] aeration	Complete mix	3000 to 5000	0.5 to 0.6	0.18 to 0.1	12 to 24	0.2 to 0.4	10 to 25	0.5 to 1.0	95 to 98	1.0 to 1.2	100 to 135

Example

1. Design a conventional activated sludge plant to treat domestic sewage with diffused air aeration system, given the following data:

   Population = 35000

   Average sewage flow = 180 l/c/d

   BOD of sewage = 220mg/l

   BOD removed in primary treatment = 30%

   Overall BOD reduction desired = 85%

Solution:

Requirements: dimension of aeration tank, dimension of secondary clarifier,

Daily sewage flow

$$= Q = 180 * 35000 \text{ l/day} = 6300 \text{m}^3/\text{day}$$

BOD of sewage coming to aeration

$$= Y_o = 70\% * 220mg/l = 154mg/l$$

BOD removed in activated plant

$$= 0.85 * 154 = 130.9mg/l$$

Check for Efficiency in Activated plant $= \frac{130.9}{154} = 0.85$ =85%

From Table 4 4, for efficiency of 85 - 92%, we use F/M ratio as 0.4 to 0.3 and MLSS between 1500 and 3000.

So let us adopt F/M = 0.30, and MLSS (Xt) as = 3000 mg/l

Using $\frac{F}{M} = \frac{Q*Y_o}{V*X_t}$, calculate the volume of aeration tank.

- $$0.30 = \frac{6300m^3/d * 154\text{mg/l}}{\text{V} * 3000\text{mg/l}}$$

V = volume of aeration tank

$$= \frac{6300 * 154}{3000 * 0.30} = 1078\text{m}^3$$

Check for Aeration period or HRT (t)

$$\text{Using, t} = \frac{\text{V}}{\text{Q}} = \frac{1078m^3}{6300m^3/d} * 24\ \text{h/d}$$

$$= 4.11\ \text{h (within the limits of 4 to 6 h)} \ldots \ldots\ \text{ok}$$

Check for sludge age(θ_c)

From equation

$$V * X_t = \frac{y * Q(Y_o - Y_E)\theta_c}{1 + K_e\theta_c}$$

Where, V = 1078m3

Xt = 3000mg/l

y = yield coefficient = 1.0 with respect to MLSS

Q = 6300m3/d

Ke = Endogenous respiration constant = 0.06d-1

Yo = BOD of influent in aeration tank = 154mg/l

YE = BOD of effluent = (154-130.9)mg/l = 23.1mg/l

Substituting the values, we get

- $$1078m^3 * 3000\text{mg/l} = \frac{1 * 6300m^3/d(154 - 23.1)\,mg/l * \theta_c}{1 + 0.06d^{-1} * \theta_c}$$

$\theta_c = 5.13 days$ … … . .ok! as it lies between 5 and 8 days

Check for volumetric loading

Volumetric loading = $\frac{Q * Y_o}{V}$ gm of BOD/m³ of tank volume

$$= \frac{6300m^3/d * 154\,mg/l}{1078m^3} = 900\ \text{mg}/l = 0.9\ \text{kg/m}^3$$

(not within the permissible range of 0.3 - 0.7kg/m³)

So increase the volume of aeration tank!!!

0.45 when we increase the volume we must reduce Xt amount, this value is in limit

(i) Check for Return sludge ratio (for SVI ranging between 50 - - 150ml/gm

Let us take 100ml/gm.

Using equation

$$\frac{QR}{Q} = \frac{X_t}{\frac{10^6}{SVI} - X_t}, \quad X_t \text{ is MLSS}$$

Where, SVI = 100ml/gm

X_t = 3000mg/l

$$\frac{QR}{Q} = \frac{3000}{\frac{10^6}{100} - 3000} = 0.43 = 43\%$$

(i.e. within the prescribed range of 25 to 50%) ...ok!

Tank Dimensions

Adopt aeration tank of depth (D) 3m and width (B) 4.0m. The total length of the aeration channel required

$$= \frac{\text{Total volume required}}{\text{B} * \text{D}} = \frac{1078m^3}{4.0\text{m} * 3\text{m}} = 90\text{m}$$

- ✓ Provide a continuous channel, with 3 aeration chambers, each of 30m length.
- ✓ Total width of the unit, including 2 baffles each of 0.25m thickness = 3 * 4.0m + 2 * 0.25 = 12.5m.
- ✓ Total depth provided including free-board of 0.5m will be 3 + 0.5 = 3.5m.

Overall dimensions of the Aeration tank will be 30m * 12.5m * 3.5m.

Rate of Air Supply Required

Assuming the air requirement of the aeration tank to be 100m^3 of air per kg of BOD removed,

Air required i.e. blower capacity

$$= 100 * \frac{130.9\text{mg/l} * 6300m^3/d}{1000} = 53\text{m}^3/\text{min}$$

Design of Secondary sedimentation Tank

Adopting a surface loading rate of $20m^3/day/m^2$ at average flow of $6300m^3/day$,

(i) Surface area required

$$= \frac{6300m^3/d}{20m^3/d/m^2} = 315\mathrm{m}^2$$

Adopting a solids loading of $125kg/day/m^2$ for MLSS of 3000mg/l (3kg/m3),

(i) the surface area required

$$= \frac{6300m^3/d * 3\mathrm{kg}/m^3}{125\mathrm{kg/day/m}^2} = 151.2\mathrm{m}^2$$

The higher surface area of $315m^2$ is adopted.

Adopting a circular tank,

$$\text{diameter of tank} = \sqrt{\frac{315 * 4}{\pi}} = 20\text{m}$$

Weir loading for a circular weir placed along the periphery of the tank having length 20πm will be:

$$= \frac{6300}{20\pi}\,\text{m}^3/\text{day}/\text{m} = 100.3 < 150;\ \text{ok!}$$

Note: If weir loading exceeds the permissible value; we may provide a trough instead of a single weir at the periphery.

Hence, provide 20 m diameter secondary settling tank.

Design of Sludge Drying Beds

In order to design sludge drying beds, the quantity of excess wasted sludge will be calculated by using the equation below:

$$\theta_c = \frac{V * X_t}{Q_w * X_R}$$

$$5.13\ \mathrm{d} = \frac{1078m3 * 3\mathrm{kg/m^3}}{Q_w * X_R}$$

$$Q_w * X_R = \frac{1078m3 * 3\mathrm{kg/m^3}}{5.13\mathrm{d}} = 630\mathrm{kg/d}$$

If density of sludge is known, it is possible to calculate the required volume of sludge. For e.g. 10 kg/m^3 SS concentrating in secondary sludge, sludge volume

$$= \frac{630\mathrm{kg/d}}{10\mathrm{kg/m^3}} = 63\mathrm{m^3/d}$$

Note: This secondary sludge volume of 63m^3/d shall be taken to sludge drying beds, along with the primary sludge.

Part II:- Lecture 5

3. **Waste Stabilization Pond**

- Is large shallow basins enclosed by earthen embankments in which wastewater is biologically treated by natural processes involving pond algae and bacteria.(see fig on next slide)

Types of Ponds are:-

- ✓ Anaerobic Ponds
- ✓ Facultative and
- ✓ Maturation/aerobic pond

- WSP comprise a single series of these anaerobic, facultative and maturation ponds or several of such series in parallel.
- A long hydraulic retention time is necessary because of the slow rate at which the organic waste is oxidized.
- Typical hydraulic retention times range from 10 -100 days depending on the temperature of a particular region.

Biological Wastewater Treatment

Figure of Waste Stabilization Pond

I. Anaerobic Ponds

- Anaerobic ponds are unmixed basins designed to enhance the settling and biodegradation of particulate organic solids by anaerobic digestion.
- Pond depth is usually between 3 to 5 meters and
- HRT for municipal sewage is b/n 1 - 3 days and for industrial WW may increase to 20 days.
- In cold climates, anaerobic ponds mainly act as settling ponds, whereas higher sewage temperatures enhance the anaerobic degradation process.
- At higher temperatures BOD is therefore more effectively removed.
- Typical TSS removal percentages range between 50 and 70%.
- BOD removal rate is increase with temperature and range b/n 30 and 75%.

Treatment Mechanisms

- BOD removal is the combined effect of sedimentation and biological degradation.
- Biological degradation is due to the anaerobic degradation of complex organic material.
- Anaerobic ponds require some preliminary treatment of municipal WW.
  - ✓ Usually coarse screening and grit chamber is applied

II. Facultative Ponds

- Are the second treatment step in a pond system.
- In facultative ponds the anaerobic pond effluent is further treated, aimed at further BOD, nutrient and pathogen removal.
- Facultative ponds are usually 1.5 - 2.5m deep.
- The HRT of this ponds is varies b/n 5 and 30 days.

Processes In facultative ponds

- The top layer of facultative ponds is aerobic due to oxygen production by algae and the bottom layer is anaerobic due to the absence of algae activity.
- The three main mechanisms for BOD removal are; aerobic digestion, sedimentation and anaerobic digestion.
- Sedimentation results only in temporary storage of BOD in the sludge layer.
- This BOD (in sludge) is removed while the pond is de-sludged.
- Part of the sludge BOD is however anaerobically transformed into methane gas.

III. Maturation Ponds

- Maturation ponds are shallow ponds (1 - 1.5m deep).
- An active algal biomass is maintained throughout the entire depth of the system
  - so that during daytime large amounts of oxygen are produced.
- BOD removal is much slower than in facultative ponds, since the most easily degradable substances consumed already.
- The major application for maturation ponds is to polish or upgrade facultative pond effluents and achieve substantial microbial reductions to allow safe use of the effluents in agriculture or aquaculture

Removal of Pathogenic Microorganisms in maturation pond

- Pathogen removal occurs in anaerobic, facultative and maturation ponds, but only maturation ponds are designed on the basis of required removal rates for pathogens.
- Four groups of pathogenic micro-organism can be distinguished in WW: bacteria, viruses, protozoa and helminthes.
- Both helminth eggs and protozoan cysts are removed by sedimentation.
- Removal of bacteria (fecal coliform) and virus is due to a combination of several processes:
    - ✓ Adsorption to particles and subsequent sedimentation
    - ✓ Grazing by other micro-organisms (protozoa)
    - ✓ Natural decay

Biological Wastewater Treatment

In series

In parallel

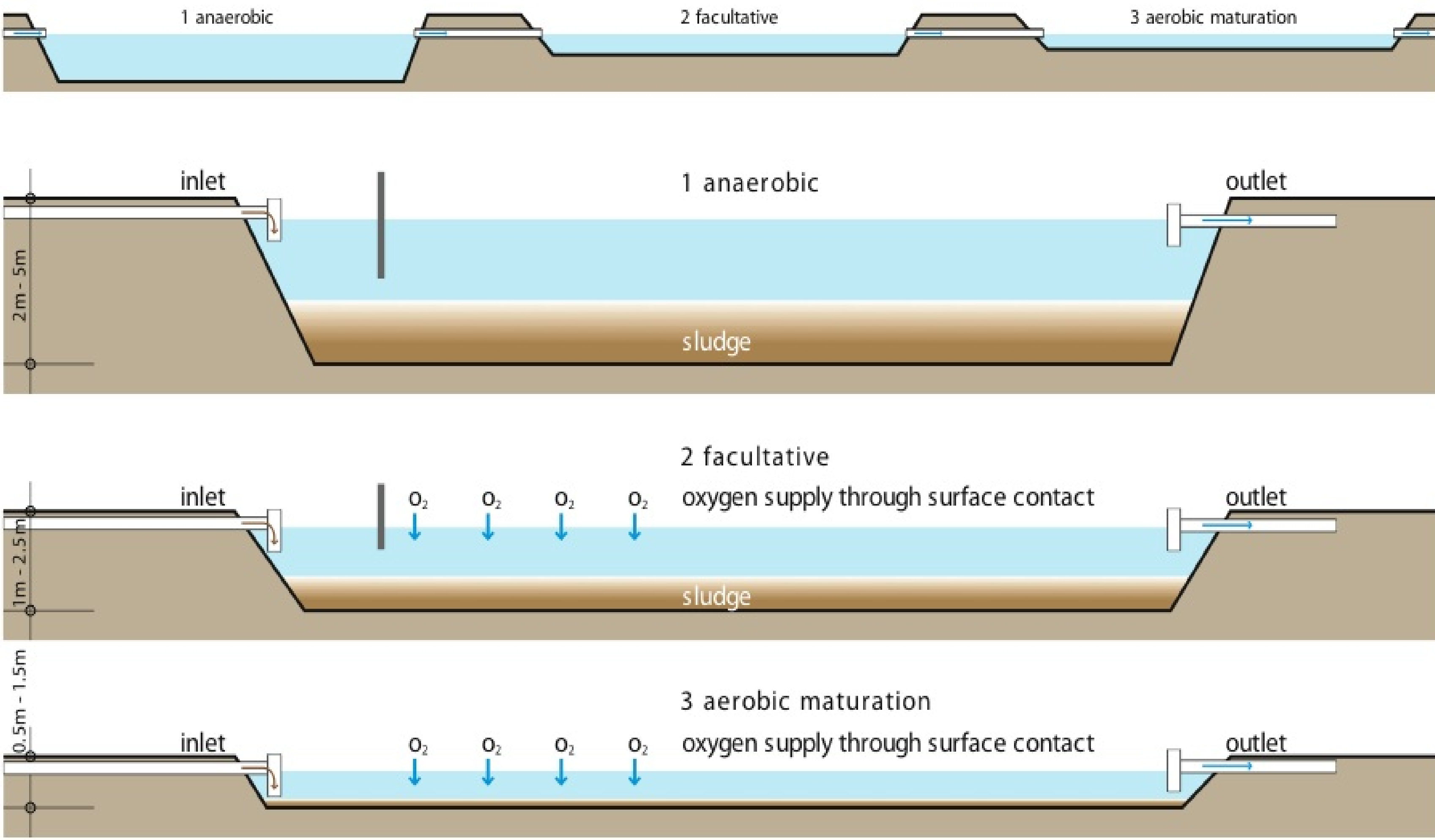


Figure of Typical scheme of a waste stabilization system

Physical Design of WSP

i. **Pond Location:** Ponds should be located at least 200m downward from the community they serve and away from any Likely area of future expansion.

ii. **Preliminary Treatment: a**dequate screening and grit removal facilities must be installed.

iii. **Pond Geometry:** pond geometry includes not only the shape of the pond but also the relative positions of its inlet and outlet.

iv. **Pond Configurations:** Configurations can includes either series or parallel operations

- ✓ the advantages of series operation is improved treatment because of reduced short circuiting and
- ✓ the advantages of parallel configuration is that the loading can be distributed more uniformly over a large area
- ✓ combinations of parallel & series operation can be accomplished

Process Design of WSP

i. Effluent Quality Requirements

- The general WHO guideline standards for the discharge of treated wastewaters into inland surface waters :

Parameter	Effluent limit
BOD	30 mg/l
Suspended solids	100 mg/l
Total N	100 mg N/l
Total ammonia	50 mg N/l
Free ammonia	5 mg N/l
Sulphide	2mg/l
pH	5.5 – 9.0

ii. Design Parameters

- The four most important parameters for WSP design are temperature, net evaporation, flow and BOD.
- Faecal coliform and helminth egg numbers are also important if the final effluent is to be used in agriculture or aquaculture.
- The usual design temperature is the mean air temperature in the coolest month.
- Net evaporation has to be taken into account in the design of facultative and maturation ponds,
- But in anaerobic scum will prevent it, because it covers the surface.
- The mean daily flow must be estimated since the size of the ponds, and hence their cost, is directly proportional to the flow.

Biological Wastewater Treatment

- The BOD may be measured using 24-hour flow-weighted composite samples.
- If WW does not yet exist, it should be estimated from the following equation:

$$BOD\ g/l = \frac{B(g/d)}{Q(l/d)}$$

Where

B = BOD contribution, g/c/d

Q = wastewater flow, l/c/d

- Values of B vary between 30 and 70g/c/d, with rich communities producing more BOD than poor communities.

A suitable design value for Ethiopia is 45g/c/d

(source: AA Water Sewerage Authority report 2003)

Design of Anaerobic Ponds

Designed without risk of odour & nuisance on the basis of volumetric BOD loading (λv, g/m^3/d), which is given by:

$$\lambda v = \frac{total\ BOD}{volume\ of\ pond} = \frac{y_o Q}{V}$$

Where y_o = influent BOD, mg/l

Q = flow, m^3/d

V = anaerobic pond volume, m^3

- Once a value of λv has been selected, the anaerobic pond volume is then calculated from above equation.
- The mean hydraulic retention time in the pond (θ, d) is determined from: $\theta = \frac{V}{Q}$

Table of Volumetric loading ($g/m^3/d$) Vs temperature

Temperature (^0C)	Volumetric loading (g/m^3d)	BOD removal (%)
< 10	100	40
10 - 20	20T - 100	2T + 20
20 - 25	10T + 100	2T + 20
> 25	350	70

Source: Mara and Pearson, 1986 and Mara et al., 1997

- Retention times in anaerobic ponds < 1 day should not be used.
- If the value of θ < 1 day, a value of 1 day should be used and the corresponding value of V recalculated.

Design Facultative Ponds

designed on the basis of surface BOD loading(λS, kg/ha/d), which is given by:

$$\lambda S = \frac{y_o Q}{A_s}$$

Where A_s = facultative pond surface area, m^2

- The permissible design value of λS is given with temperature relation by Mara (1987) as global design equation:

$$\lambda S = 350(1.107 - 0.002T)^{25-T}$$

- Once a suitable value of λS has been selected, the pond area is calculated from above equation and its retention time (θ_s, in d) from:

$$\theta_f = \frac{A_s D}{Q_m}$$

Where: D = pond depth, m, Qm = mean flow, m^3/day

Design of Maturation Ponds

- Designed for Faecal Coliform, Helminth Egg, and Nutrient Removal

Faecal Coliform Removal: using method of Marais (1974)

- This assumes that faecal coliform removal can be modeled by first order kinetics in a completely mixed reactor.
- The resulting equation for a single pond is thus:

$$N_e = N_i(1 + K_T * HRT)$$

Where Ne = number of FC per 100 ml of effluent

Ni = number of FC per 100 ml of influent

K_T = first order rate constant for FC removal, per day

HRT = retention time, d

❖ Reading assignment

- ✓ Is a final treatment stage.
- ✓ The purpose of tertiary treatment is to raise the effluent quality before it is discharged to the receiving environment (sea, river, lake, ground, etc.).
- ✓ More than one tertiary treatment process may be used at any treatment plant.
- ✓ It is also called effluent polishing.

Tertiary Treatment Processes

Filtration

- Sand filtration removes much of the residual suspended matter.
- Filtration over activated carbon, also called carbon adsorption, removes residual toxins

Lagooning

- provides settlement and further biological improvement through storage in large man-made ponds or lagoons.
- These lagoons are highly aerobic

Nitrogen removal

Ammonia —oxidation→ nitrate (nitrification),

Nitrate —reduction→ nitrogen gas (de-nitrification)

Then, N_2 gas is released to the atmosphere and thus removed from the water.

- Sand filters, lagooning and reed beds can all be used to reduce nitrogen,

Tertiary Treatment Processes

Phosphorus removal

- Phosphorus can be removed biologically
- Phosphorus removal can also be achieved by chemical precipitation, usually with salts of iron (e.g. ferric chloride), aluminum (e.g. alum), or lime.
- This may lead to excessive sludge production as hydroxides precipitates and the added chemicals can be expensive.

Disinfection

- Is a process of killing/deactivating the microorganisms in water.
- Common methods of disinfection include ozone, chlorine, ultraviolet light, or sodium hypochlorite.
- Chlorination remains the most common form of WW disinfection due to its low cost and long-term history of effectiveness.

Odour Control

- Odours emitted by sewage treatment are typically an indication of an anaerobic or "septic" condition.
- odours is treated with carbon reactors, a contact media with bio-slimes, small doses of chlorine, or circulating fluids to biologically capture and metabolize the obnoxious gases.
- Other methods of odour control exist, including addition of iron salts, hydrogen peroxide, calcium nitrate, etc. to manage hydrogen sulfide levels.

Part II:
Lecture 6
SEWAGE EFFLUENT DISPOSAL TECHNIQUES

There are two general methods of disposing of the sewage effluents:

1. Dilution i.e. disposal in water; and
2. Effluent Irrigation or Broad Irrigation or Sewage Farming, i.e. disposal on land

Disposal by Dilution and Oxygen Sag Curve

- The effluent from the sewage treatment plant is discharged into a river stream, or a large body of water, such as a lake or sea.
- The discharged sewage, in due course of time, is purified by what is known as self purification process of natural waters.

❖ Disposal by Dilution method is favourable:

(i) When sewage is comparatively fresh (4 to 5hr old), and free from floating and settleable solids,

(ii) When the diluting water has high dissolved oxygen content.

(iii) Where diluting waters are not used for the purpose of navigation or water supply,

(iv) Where the flow currents of the diluting waters are favorable, causing no deposition, nuisance or destruction of aquatic life.

Disposal by Dilution and Oxygen Sag Curve

Dilution in Rivers and Self Purification of Natural Streams

- the receiving water gets polluted due to waste products, present in sewage effluents.
- because the natural forces of purification, such as dilution & dispersion, sedimentation, oxidation-reduction in sun-light, etc., go on acting upon the pollution elements, and bring back the water into its original condition.
  - This automatic purification of polluted water, in due course, is called the self-purification phenomenon.

i. **Dilution and Dispersion**

When sewage of concentration Cs flows at a rate Qs in to a river stream with concentration CR flowing at a rate QR, the concentration C of the resulting mixture is given by:

Disposal by Dilution and Oxygen Sag Curve

- $$C_sQ_s + C_RQ_R = C(Q_s + Q_R)$$
  $$C = \frac{C_sQ_s + C_RQ_R}{Q_s + Q_R}$$

This equation is applicable separately to concentrations of different impurities, such as, oxygen content, BOD, suspended sediments, and other characteristic contents of sewage.

(ii) Sedimentation

The settleable solids, if present in sewage effluents, will settle down into the bed of the river, near the outfall of sewage, thus, helping in the self purification process.

(iii) Sun-light

The sun light has a bleaching and stabilizing effect of bacteria. It also helps certain micro-organisms to derive energy from it, and convert themselves into food for other forms of life, thus absorbing carbon dioxide and releasing oxygen by a process known as photo synthesis.

Disposal by Dilution and Oxygen Sag Curve

The Oxygen Deficit of a Polluted River-Stream.

- The oxygen deficit D at any time in a polluted river-stream is the difference b/n the actual DO content of water at that time and the saturation DO content.

$$\text{Oxygen deficit (D)} = \text{Saturation DO} - \text{Actual DO}$$

- In order to maintain clean conditions in a river-stream, the D must be nil, and this can be found out by knowing the rates of de-oxygenation and re-oxygenation.

Rate de-oxygenation

- Is due to the amount of organic matter remaining to be oxidized at the given time (i.e. Lt).

Disposal by Dilution and Oxygen Sag Curve

Rate Re-oxygenation

- Due to atmosphere supplies of oxygen to the water

Oxygen Deficit Curve

- In a running polluted stream exposed to the atmosphere, the de-oxygenation as well as the re-oxygenation go hand in hand.
- If de-oxygenation is more rapid than the re-oxygenation, an oxygen deficit will result.
- The amount of resultant oxygen deficit can be obtained by algebraically adding the de-oxygenation and re-oxygenation curves
- The resultant curve so obtained is called the oxygen sag curve or the oxygen deficit curve.

Disposal by Dilution and Oxygen Sag Curve

- It can also be seen that when the de-oxygenation rate exceeds the re-oxygenation rate, the oxygen sag curve shows increasing deficit of oxygen;
- but when both the rates become equal, the critical point is reached, and then finally when the rate of de-oxygenation falls below that of re-oxygenation, the oxygen deficit goes on decreasing till becoming zero.
- The entire analysis of super-imposing the rates of de-oxygenation and re-oxygenation have been carried out mathematically, and the obtained results expressed in the form of famous Streeter-Phelps equation; i.e.,

$$D_t = \frac{K_D * L}{K_R - K_D} * \left[(10)^{-K_D * . t} - (10)^{-K_R * t} \right] + \left[D_0 * (10)^{-K_R * t} \right] \ldots 5.2$$

Disposal by Dilution and Oxygen Sag Curve

Where, D_t = the DO deficit in mg/l after t days.

L = Ultimate first stage BOD of the mix at the point of waste discharge

D_o = Initial oxygen deficit of the mix at the mixing point in mg/l.

K_D= De-oxygenation coefficient (BOD rate constant) for the WW, determined in the laboratory. K_D varies with temperature as:

$$K_{D(T)} = K_{D(20)} * (1.047)^{T-20°}$$

K_R = Re-oxygenation coefficient for the stream, varies with temperature as per the equation:

$$K_{R(T)} = K_{R(20)} * (1.016)^{T-20°}$$

t = x/u, x=distance at which D_t occur, u=velocity of river

- ✓ The oxygen deficit curve can be plotted easily with the help of Eq. (5.2), by using different values of t in days:

Disposal by Dilution and Oxygen Sag Curve

Critical Deficit, Dc

$$D_c = \frac{k_d}{k_r} L_0 e^{-k_d t_c}$$

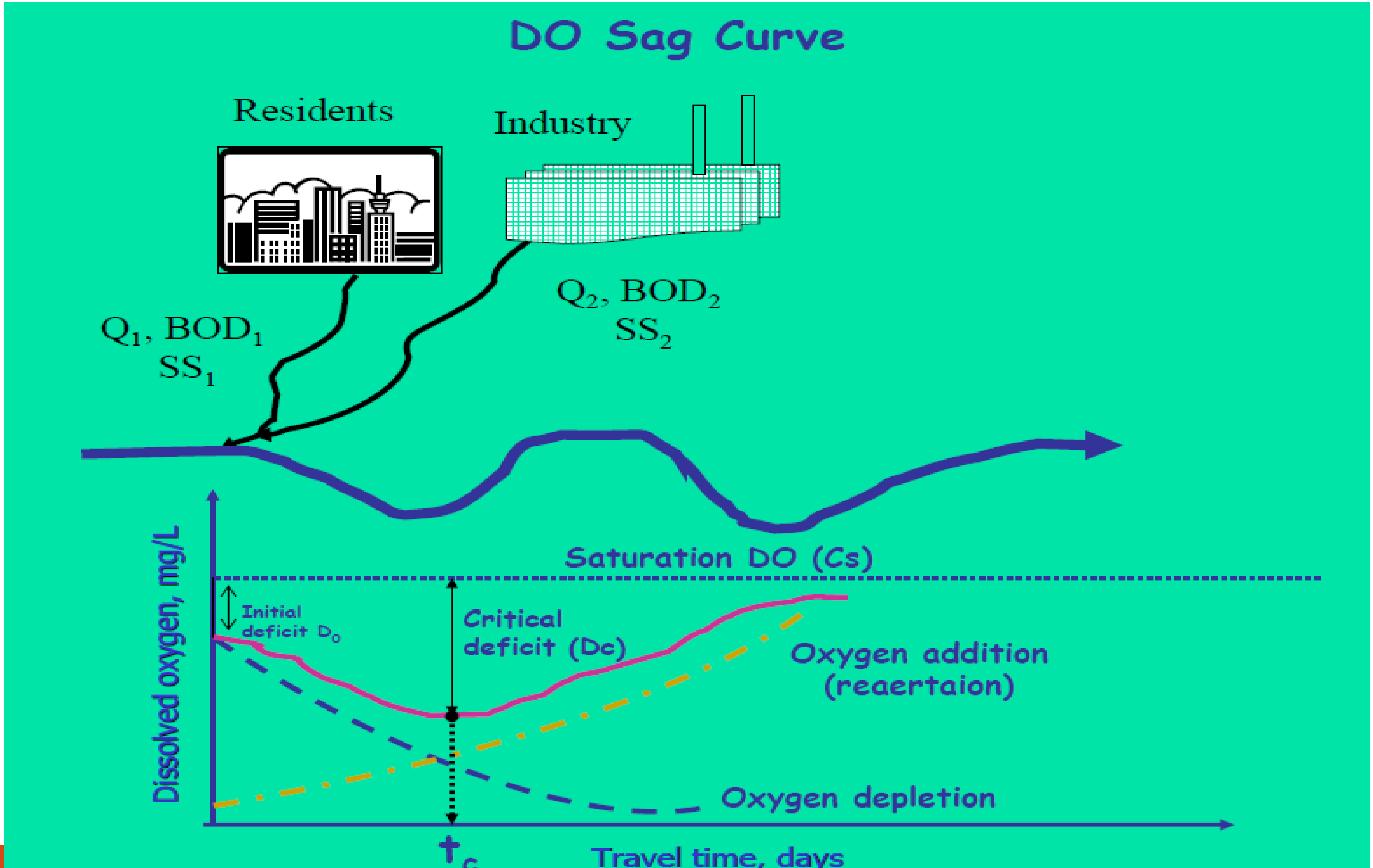
Equation 5.3

Critical Time, tc

$$t_c = \frac{1}{k_r - k_d} \ln\left[\frac{k_r}{k_d}\left(1 - D_0 \frac{k_r - k_d}{k_d L_o}\right)\right]$$

Equation 5.4

Disposal by Dilution and Oxygen Sag Curve



Disposal of Sewage Effluents on Land for Irrigation

- In this method, the sewage effluent is generally disposed of by applying it on land.
- This method can then be used for irrigating crops.
- help in increasing crop yields (by 33% or so) (fig below).
- When raw or partly treated sewage is applied on to the land, a part of it evaporates, and the remaining portion percolates through the ground soil.
- While percolating through the soil, the suspended particles present in the sewage are caught in the soil voids.
- If proper aeration of these voids is maintained, the organic sewage solids caught in these voids get oxidized by aerobic process.

- Application of too strong or too heavy load of sewage will also similarly result in the quick formation of anaerobic conditions.
  - soil to get clogged
- Hence, the sewage load should be reduced by diluting it or by pre-treating it.

Table of Recommended Doses for Sewage Farming

Types of soil	**Doses of sewage in cubic meters per hectare per day**	
	Raw sewage	**Settled sewage**
Sandy	120 – 150	220 – 280
Sandy loam	90 – 100	170 – 220
loam	60 – 80	110 – 170
Clayey loam	40 – 50	60 – 110
clayey	30 – 45	30 - 60

EXAMPLE 1

- A wastewater of 5.0 m3/sec is discharged into a river of flow 50 m3/sec. The ultimate BOD of wastewater is 200 mg/l and DO is 1.5 mg/l. The river water has a BOD of 3 mg/l and DO of 7 mg/. The re-aeration coefficient of the river water is 0.2/day and BOD decay coefficient is 0.4/day. The river has a cross-sectional area of 200 m2and the saturated DO concentration of the river water is 8 mg/l.
- (a) At a downstream point of **10 km** calculate the DO of the mixture.
- (b) At which point the DO is a minimum(Tc).

CONT…

Given

Flow rate of river water = 50 m^3/sec

Wastewater flow rate = 5 m^3/sec

BOD of river water = 3 mg/ℓ

BOD of wastewater = 200 mg/ℓ

$$\text{BOD of the mixture} = \frac{(50)(3)+(5)(200)}{50+5} = 20.91 \text{ mg}/\ell$$

DO of the river water = 7 mg/ℓ

DO of the wastewater = 1.5 mg/ℓ

$$\text{DO of the mixture} = \frac{(50)(7)+(5)(1.5)}{50+5} = 6.5 \text{ mg}/\ell$$

Initial oxygen deficit = Saturated DO – Initial DO of the mixture

CONT…

$D_o = 8.0 - 6.5 = 1.5$ mg/ℓ

$$\text{Velocity of flow} = \frac{\text{Rate of flow}}{\text{Area of cross-section}} = \frac{50+5}{200} = 0.275 \text{ m/s}$$

Length of flow = 10 km = 10000 m

$$\text{Time} = \frac{\text{Distance}}{\text{Velocity}} = \frac{10000}{0.275} = 36363.63\ s = 0.42\ d$$

Deoxygenation constant (k) = 0.4 /day

Reaeration constant (k_2) = 0.2 /day

Oxygen Sag curve in a polluted stream is given by Streeter and Phelp's equation:

$$D_t = \frac{kL_o}{k_2 - k}[10^{-kt} - 10^{-k_2 t}] + D_o 10^{-k_2 t}$$

$$D_t = \frac{(0.4)(20.91)}{(0.2-0.4)}\left[10^{-(0.4)(0.42)} - 10^{-(0.2)(0.42)}\right] + (1.5)(10^{-(0.2)(0.42)})$$

$$D_t = \frac{8.364}{-0.2}[0.6792 - 0.8241] + (1.5)(0.8241)$$

$D_t = 7.289$ mg/ℓ

$$t_C = \frac{1}{k_2 - k} \text{In}\left[\frac{k_2}{k}\left(1 - \frac{D_o(k_2 - k)}{k\,L_o}\right)\right]$$

$$t_C = \frac{1}{0.2-0.4} \text{In}\left[\frac{0.2}{0.4}\left(1 - \frac{(1.5)(0.2-0.4)}{(0.4)(20.91)}\right)\right]$$

$$t_C = (-5)\ \text{In}\left[0.5\left(1 - \frac{(-0.3)}{8.364}\right)\right]$$

$t_C = (-5)$ In[0.5)(1.0358)]

$t_C = (-5)\ (-0.65797) = 3.289$ days

Distance = Velocity × t_c = (0.275 × 3.289 × 60 × 60 × 24)/(1000) = 78.15 km

Thanks for your Active participation!!!!

Solid Waste Management

Contents

General Overview

- Solid wastes are the wastes arising from human activities which are solid and discarded as useless or unwanted.
- The term **municipal solid waste**, refers to solid wastes from houses, streets and public places, shops, offices, and hospitals.

- A society receives energy and raw material as inputs from the environment and gives solid waste as output to the environment. Fig. below.
- In the long-term perspective, such an input-output imbalance degrades the environment.

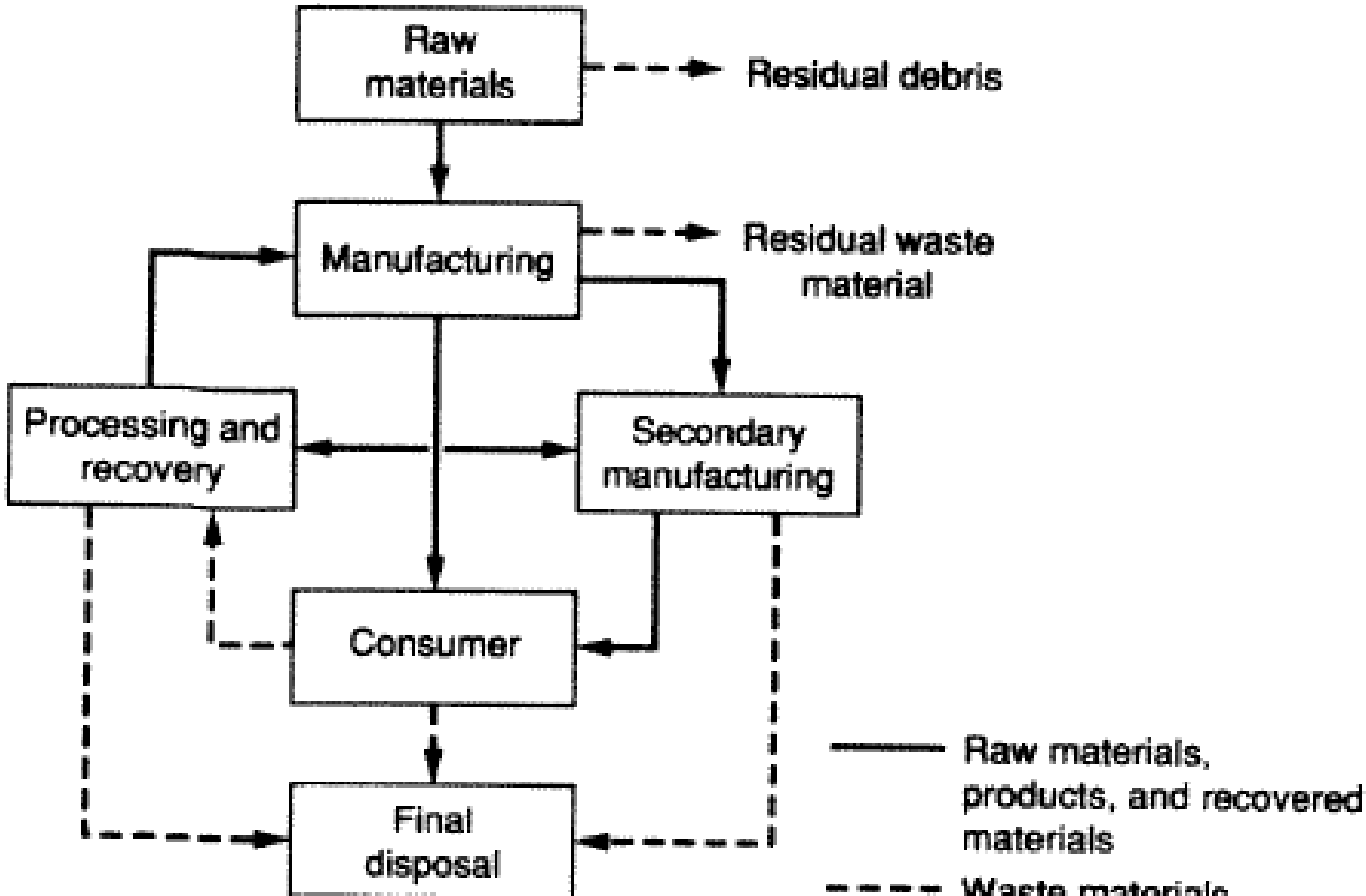


Fig. 1 Materials flow and the generation of solid waste in a technological society

What will happen if the generated solid waste is not properly managed?

I. Environmental Impact of Solid Waste Disposal on Land

- When solid waste is disposed off on land in open dumps or in improperly designed landfills, it causes the following impact on the environment.

a. **ground water contamination**
   - by the leachate generated from the waste dump

b. **surface water contamination**
   - by the run-off from the waste dump

c. **bad odour, pests, rodents** and wind-blown litter in and around the waste dump

d. **generation of inflammable gas** (e.g. methane) within the waste dump

e. **bird menace** above the waste dump which affects flight of aircraft

f. **release of green house gas**

g. fires within the waste dump

What should be done?

Solid Waste Management

- Solid waste management may be defined as:

  a) the discipline associated with the control of generation, storage, collection, transfer and transport, processing and disposal of solid waste.

  b) It is one among the basic essential services provided by municipal authorities in the country to keep urban centers clean.

Why SWM is needed?

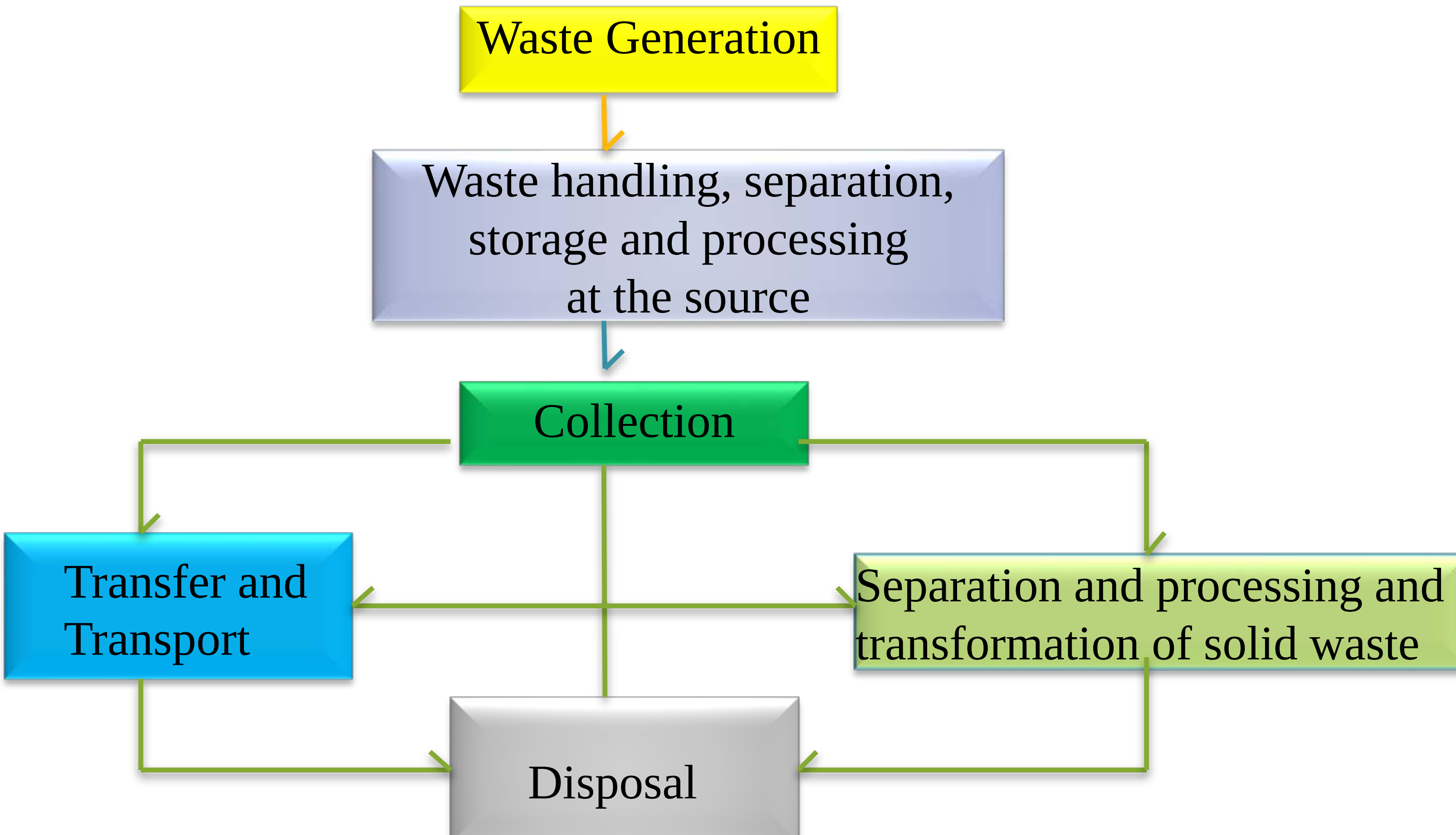
Objective of Solid Waste Management

1) To protect the health of the population
2) To promote environmental quality and sustainability,
3) To support economic productivity and employment generation
4) To reduce the quantity of solid waste disposed off on land by recovery of materials and energy from solid waste

- **The scope of SWM encompasses**
  - planning and management systems, waste generation processes, and organizations, procedures and facilities for waste handling

ii. Functional elements of SWM

- Means activities associated with the management of solid wastes from the point of generation to the final disposal point.



Cont…

1. **Waste generation**
   - activities in which materials are identified as no longer useful and are either thrown away or gathered together for disposal
2. **Waste handling, separation, storage and processing at source**
   - activities related to management of waste until they are put in storage containers for collection

◦ **Handling**

- Movement of loaded containers
  to point of collection

Cont…

- **Separation**
  - this is grouping the waste into various categories depending on the nature of SW e.g.
    - Organics
    - Paper
    - Bottles
    - Cans etc
  - Important step in recovering materials for recycling and reuse, and storage at source

Cont…

- **Storage**
  - On site storage important for the following reasons:
    - Public health concerns
    - Aesthetic considerations


- **Processing at source**
  - involves activities such as compacting and yard composting

Cont…

3. Collection

- includes gathering of solid wastes and recyclable materials, transport of these to the location where collection vehicle is emptied
  - location could be
    - processing facility
    - transfer station
    - landfill site


Primary Collection

Cont…

4. **Separation, Processing and Transformation**

- Occurs primarily in locations away from the source of waste generation.
- Sorting of commingled (mixed) wastes usually occurs at a materials recovery facility, transfer stations, combustion facilities, and disposal sites.
- **Sorting often includes**
  - the separation of bulky items,
  - separation of waste components by size using screens,
  - manual separation of waste components,
  - separation of ferrous and non-ferrous metals

Cont…

- Waste processing is undertaken:
  - to recover conversion products and energy
    - transform organic fraction by
      - biological process – aerobic composting
      - chemical process – combustion/incineration
- Transformation processes are used
  - to reduce the volume, weight, size of waste requiring disposal without resource recovery.
    - size reduction by shredding
    - volume reduction by compaction and combustion

Cont…

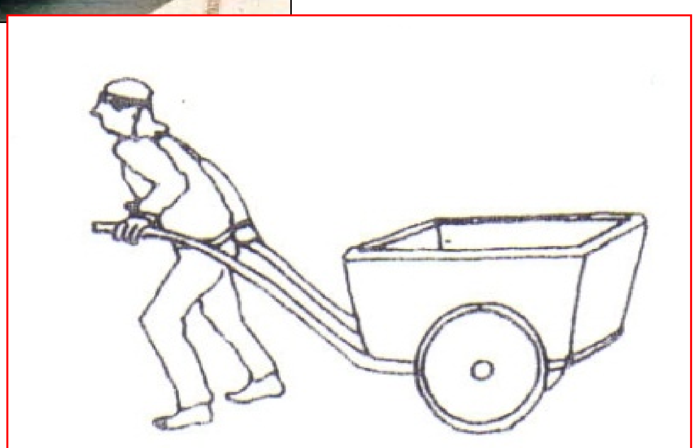
5. **Transfer and Transport**

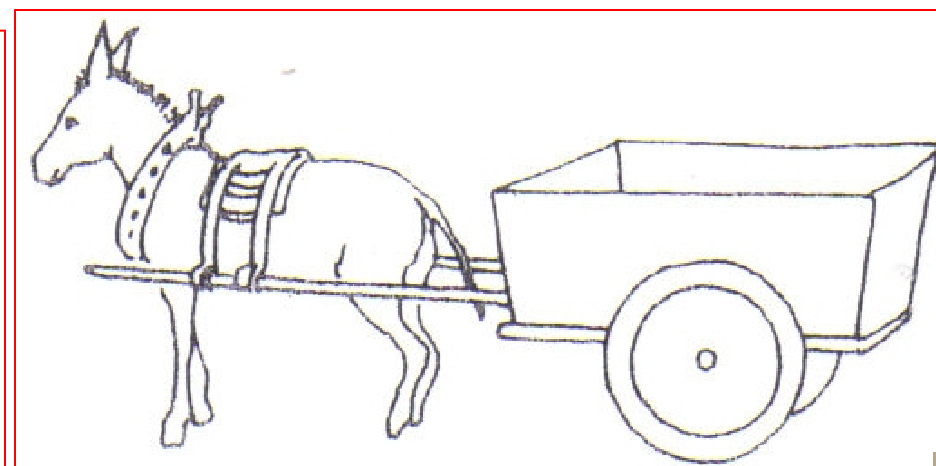
- The functional element of transfer and transport involves two steps:

  i. the transfer of wastes from the smaller collection vehicle to the larger transport equipment and

  ii. the subsequent transport of the wastes, usually over long distances, to a processing or disposal site. (i.e when disposal sites are far from point of collection)

Transfer station





Cont…

6. Disposal

- Land filling or Dumping
- Incineration/combustion
  - Combustion is the controlled burning of waste in a designated facility to reduce its volume and, in some cases, to generate electricity.
  - These activities are used to manage waste that cannot be prevented or recycled.

iii. Integrated Solid Waste Management

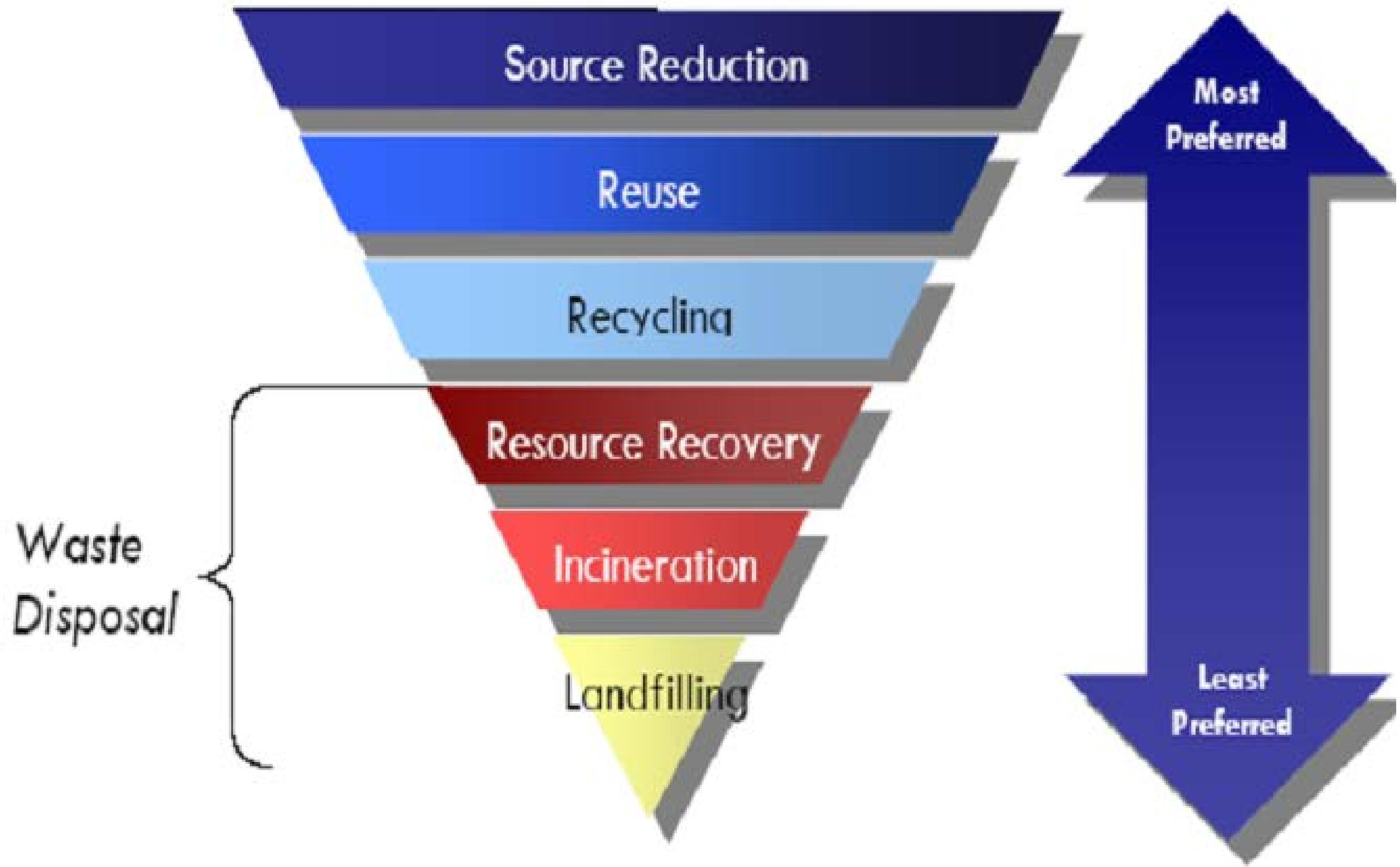
- ISWM is the selection and application of suitable techniques, technologies and management programs covering all types of solid wastes from all sources to achieve the twin objectives of:
  - waste reduction (produce 'more with less')
  - effective management of waste still produced after waste reduction

- ISWM
  - refers to the strategic approach to sustainable management of solid wastes covering all sources and all aspects covering generation, segregation, transfer, sorting, treatment, recovery and disposal in an integrated manner, with an emphasis on maximizing resource use efficiency

Cont…

- An effective ISWM System considers how to prevent, recycle, and manage solid waste in ways that most effectively protect human health and the environment
- ISWM activities and hierarchy are:
  1. Waste prevention/ Source reduction
  2. Recycling
  3. Waste transformation(composting/ combustion)
  4. Landfilling

ISWM hierarchy



ISWM: Waste Prevention

- **Prevent** waste from being generated through the following Strategies:
  - less packaging
  - packaging with minimum toxic content
  - design products to last longer
  - reuse products and materials, repair broken items
  - The modern concept of waste minimization is based on the **three 'R's** are:
  - Reduce, Reuse and Recycle.

ISWM: Recycling

- Involves collecting, reprocessing and/or recovering certain waste materials (e.g. glass, paper, metals, plastics) to make new materials or products.
    - Environmental and economic benefits
        - jobs and income
        - supply raw material to industry
        - reduce demand on resources and amount of waste requiring disposal by landfilling

ISWM: Waste transformation

- Involves physical, chemical, or biological alteration of waste, techniques are applied to:
  - Improve efficiency of SWM systems and operations
  - recover conversion products (e.g. compost) and energy (heat and combustible biogas)
  - results in reduced use of landfill capacity

ISWM: Landfilling

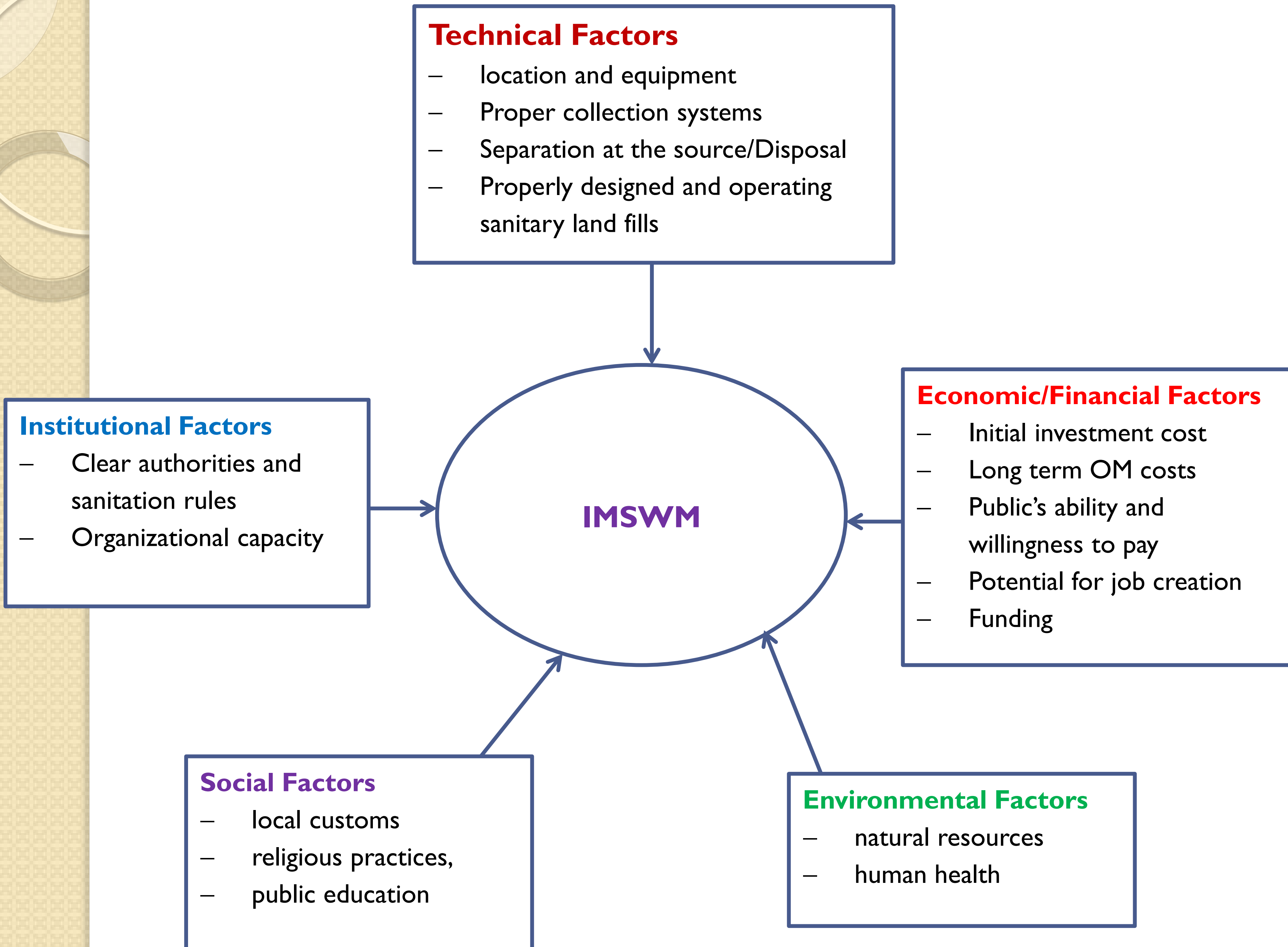
- Activities used to manage waste that cannot be prevented or recycled
  - Waste is placed in properly designed, constructed and managed land fills
    - Methane recovery (biogas)
- Represents the least desirable means of dealing with society's wastes

iv. Need for ISWM

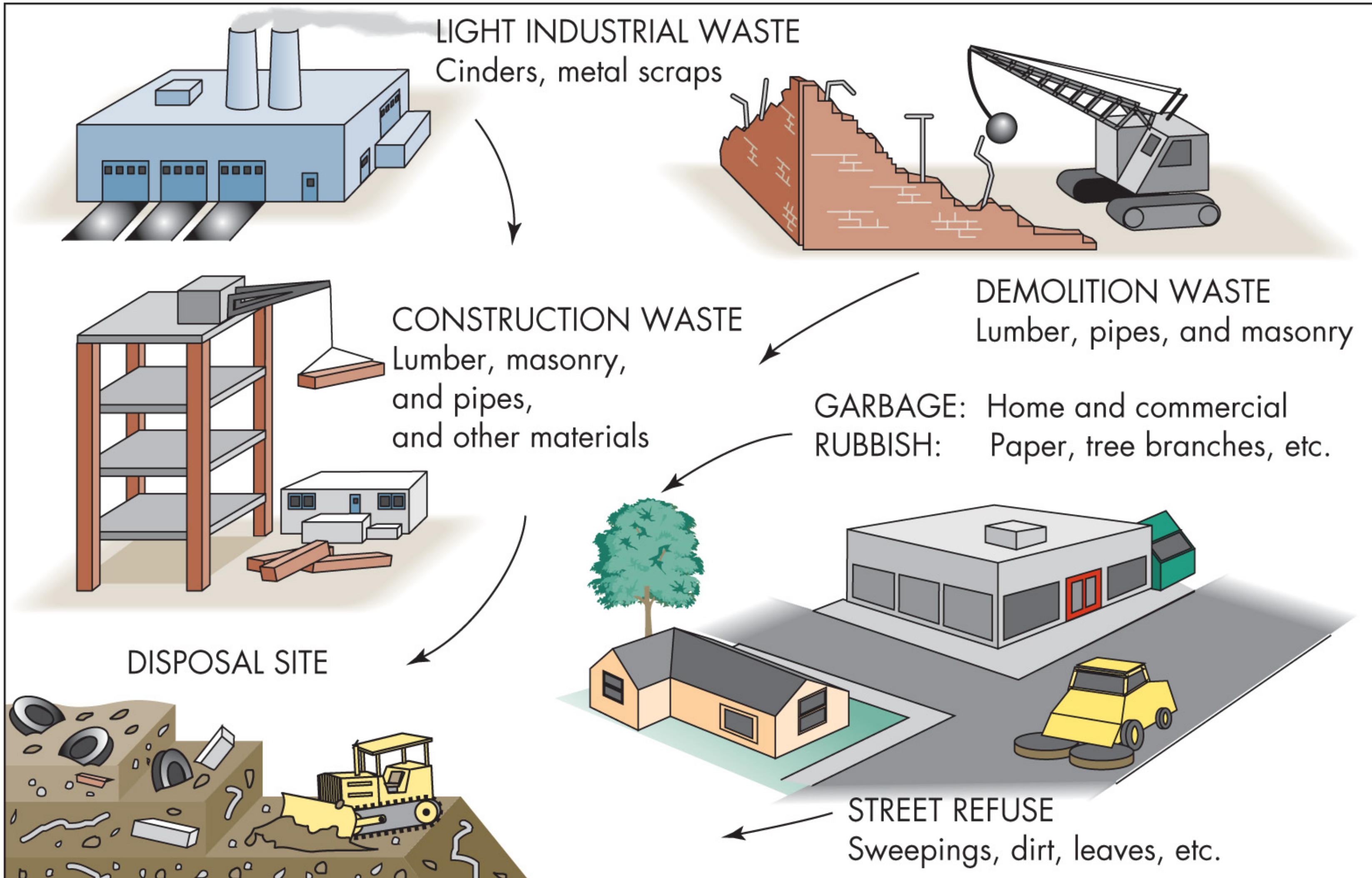
- Cities are facing an increasing growth in population,
  - increasing quantities of waste being generated
- Due to changing lifestyles and consumption patterns,
  - the quantity of waste generated has increased with quality and composition of waste becoming more varied and changing
- Industrialization and economic growth has produced more amounts of waste, including hazardous and toxic wastes
- Local Governments are now looking at waste as a business opportunity:
  a. to extract valuable resources contained within it that can still be used and
  b. to safely process and dispose wastes with a minimum impact on the environment

v. Planning for ISWM

- Planning is the first step in designing or improving a waste management system.
- Waste management planners should take into consideration the following factors;
  - Institutional,
  - Social,
  - Financial /Economic,
  - Technical, and
  - Environmental factors.


Technical Factors
– location and equipment
– Proper collection systems
– Separation at the source/Disposal
– Properly designed and operating sanitary land fills
Institutional Factors
– Clear authorities and sanitation rules
– Organizational capacity
IMSWM
Economic/Financial Factors
– Initial investment cost
– Long term OM costs
– Public's ability and willingness to pay
– Potential for job creation
– Funding
Social Factors
– local customs
– religious practices,
– public education
Environmental Factors
– natural resources
– human health

Source, Composition and Properties of Solid Waste



1. Sources of municipal solid wastes

- Solid waste can be categorized based on the source:
  - Residential
  - Commercial
  - Institutional
  - Construction and demolition
  - Municipal services
  - Treatment plant sites
  - Industrial
  - Agricultural
- Municipal solid waste (MSW) is normally assumed to include all community wastes with the exception of industrial and agricultural wastes.
- Residential and commercial
  - Organic and inorganic solid wastes from residential and commercial areas
    - Food waste, paper of all types, card board, plastics of all types, textiles, rubber, leather, wood and yard wastes, glass, ceramics, tin cans, aluminum, ferrous metals, and dirt

3. Composition of solid wastes

- *Composition* is the term used to describe the individual components that make up a solid waste stream and their relative distribution, usually based on percent by weight.
- Information and data on the physical composition of solid wastes are important in the
  - selection and operation of equipment and facilities
  - assessing feasibility of resource and energy recovery
  - analysis and design of landfill disposal facilities

II. Physical, chemical, and biological properties of municipal solid waste

- These properties must be known to develop and design integrated solid waste management of MSW.

1. **Physical properties:**
   a. Specific weight
   b. Moisture content
   c. Particle size and size distribution
   d. Field capacity
   e. Permeability of compacted waste
2. **Chemical properties of MSW**
   i. Proximate analysis
   ii. Fusing point of ash
   iii. Ultimate analysis (elemental analysis) (major elements)
   iv. Energy content
3. **Biological properties of MSW**

- The production of odours and the generation of flies are related to the putrescible nature of the organic materials.

Hazardous Waste (HW)

- Wastes or combinations of wastes that pose potential hazard to humans or other living organisms since such wastes:
  - are non-degradable or persist in nature
  - Can be biologically magnified
  - Can be lethal
  - May otherwise cause or tend to cause detrimental cumulative effect
- Any substance or mixture of substances having properties capable of producing adverse effects on health and safety of a human beings and environment.

Properties of Hazardous Waste

- Properties of waste materials that have been used to assess whether a waste is hazardous are related to questions of **safety** and **health**.

- Safety related properties
  - Corrosivity
  - Explosivity
  - flammability
  - Ignitability
  - Reactivity

- Health related properties
  - Carcinogenicity
  - Infectivity
  - Irritant
  - Mutagenicity
  - Toxicity
  - Radioactivity
  - Teratogenicity

Sources and Types of Hazardous Waste

- Typical HW from residential sources
  - Household cleaners
  - Personal products
  - Automotive products
  - Paint products
  - Garden products
- They are toxic and can be hazardous to health and the environment.
- The most effective way to eliminate the small quantities of hazardous wastes now found in municipal solid waste is ***to separate them at the point of generation.***

Mismanagement of HW causes;

- Ground water pollution
- Pollution of streams, rivers, lakes, and other surface waters
- Killing aquatic life
- Destroy wildlife
- Cause respiratory illness, skin diseases, elevated levels of toxic materials on the blood and tissue of human and domestic livestock.
- Resulted in fires, explosives, the generation of toxic gases that have killed or seriously injured workers and firefighters.

Engineering Principles of solid waste management

- The quantities of solid waste generated and collected are of critical importance:
  - **- In selecting specific equipment**
  - **- In designing of:**
    - ✓ **waste collection routes**
    - ✓ **materials recovery facilities (MRF's) and**
    - ✓ **disposal facilities**
- The design of special vehicles for the curbside collection of source-separated wastes depends on the quantities of the individual waste components to be collected.
- The sizing of MRFs depends on the amounts of waste to be collected as well as the variations in the quantities delivered hourly, daily, weekly and monthly.
- The sizing of landfills depends on the amount of residual waste that must be disposed of after all the recyclable materials have been removed.

Measures and Methods Used to Assess Quantities

- The principal reason for measuring the quantities of solid waste generated, separated for recycling and collected for further processing or disposal can be used to develop and implement effective SWM.
- Methods commonly used to assess solid waste quantities are:
  a. Load-count analysis
  b. Weight- volume analysis
  c. Material-balance analysis

Factors that affect generation rates

- Factors that influence the quantity of municipal wastes generated include:
  1. Source reduction (rate of generation)
  2. Extent of recycling (rate of collection)
  3. Geographic location
  4. Season of the year
  5. Collection frequency (affects amount of waste)
  6. Use of kitchen food waste grinders
  7. Public attitudes
  8. Legislation

Collection System Types

❖ The collection systems have been classified according to their mode of operation into two categories

- Hauled Container System (HCS)
  - Container is moved to disposal site
  - Used for construction & demolition waste
  - High generation rates (open markets)
  - One drive and frequent trips
  - low volume utilization unless loading aids are provided

- Stationary Container System (SCS)
  - Container remains at site (residential and commercial)
  - May be manually or mechanically loaded
  - Container size and utilization are important

Recovery of Materials in MSW

- Materials separated from MSW can be used directly as:
  - raw material for remanufacturing and reprocessing
  - feedstock for production of biological and chemical conversion products
  - fuel source for the production of energy
  - land reclamation
- In assessing the opportunities for recycling
  - the available options for separation and processing of waste materials
  - the economics of material recovery and
  - material specifications

Development and Implementation of MRFs

- **Engineering considerations:**

  i. Definition of the function of the MRF
  ii. Selection of the material to be separated
  iii. Identification of the material specification
  iv. Development of separation process flow diagrams
  v. Determination of process loading rate
  vi. Layout and design of the physical facilities
  vii. Selection of equipment & facilities used
  viii. Environmental studies
  ix. Aesthetic considerations
  x. Adaptability of the facility to potential changes

Need for transfer operations

- **Factors that make the use of transfer operations attractive and a necessity : When;**

1) Direct hauling is not economically feasible.
2) Processing centers cannot be reached directly by highway.
3) Illegal dumping due to excessive haul distances
4) Use of small-capacity collection vehicles
5) Existence of low-density residential service areas
6) HCS with small containers for collection of wastes from commercial sources

Types of Transfer Stations

- Depending on the method used to load the transport vehicles, transfer stations may be classified into three general types:
  - Direct-load
  - Storage-load
  - Combined direct-load and discharge-load

Direct-load transfer stations

Transfer Station Design

- Important factors in the design of transfer stations:

i. Type of transfer operation
   - An adequate area is necessary in case of waste recovery

ii. Storage and throughput capacity requirements
   - Collection vehicles do not have to wait too long to unload

iii. Equipment and accessory requirements
   - Depends on the capacity of the station

iv. Sanitation requirements

Location of Transfer Stations

- Transfer stations should be located:
  - As near as possible to the solid waste production areas to be served
  - Within easy access of major arterial highway routes as well as near secondary or supplemental means of transportation
  - Where there will be a minimum of public and environmental objection to the transfer operations
  - Where construction and operation will be most economical

- Additionally, if the transfer station site is to be used for processing operations involving materials recovery and/or energy production, the requirements for those operations must also be assessed.

Biological and Chemical Conversion Technologies

Biological conversion of MSW

- The two common biological processes used to transform organic materials into gaseous, liquid and solid conversion products are:
  - Aerobic Composting
  - Anaerobic Digestion (AD)
- Anaerobic processes offer the benefit of energy recovery in the form of methane gas and thus net energy producers.
- Aerobic processes are net energy users b/c oxygen must be supplied for waste conversion but can significantly reduce the volume of organic portion of MSW

Comparison of composting and AD

Table: Comparison of aerobic composting and AD for processing the of MSW

Characteristic	Aerobic composting	Anaerobic digestion
Energy use	Net energy consumer	Net energy producer
End products	Humus, CO_2, H_2O	Sludge, CO_2, CH_4
Volume reduction	Up to 50%	Up to 50%
Processing time	20 to 30 days	20 to 40 days
Primary goal	Volume reduction	Energy production
Secondary goal	Compost production	Volume reduction, waste stabilization

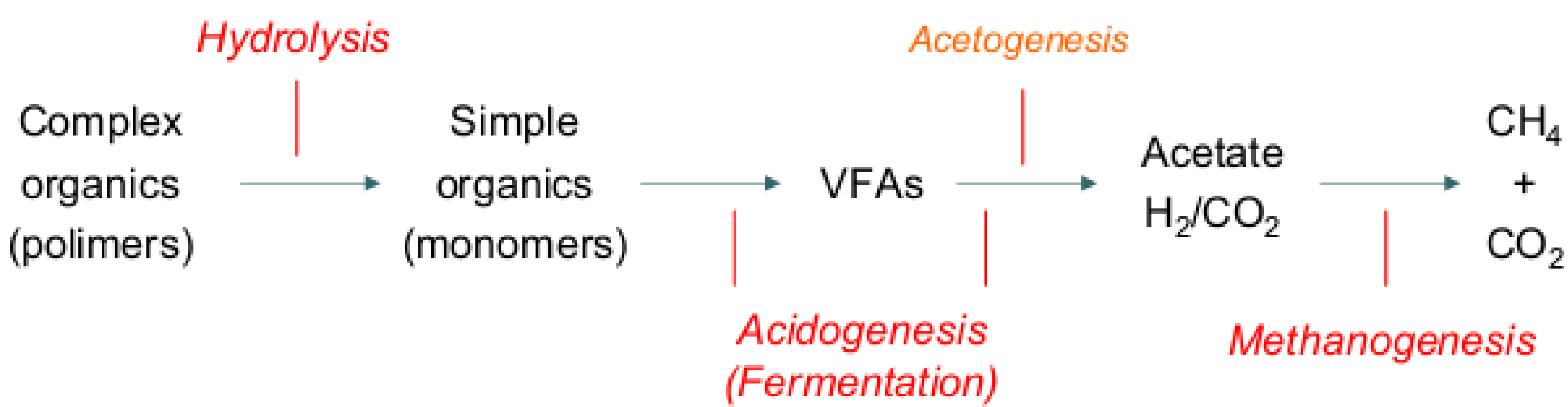
Process description

Composting operations consist of three basic steps:

1. Pre-processing of the MSW
   - Receiving
   - Removal of recoverable materials
   - Size reduction
   - Adjustment of waste properties (C/N ratio, addition of moisture and nutrients and etc.)
2. Decomposition of the of MSW
3. Preparation and marketing of the final compost product

Anaerobic Digestion (AD)

- Anaerobic digestion of organic material is basically a 3-stage process: large organic polymers are first hydrolyzed and then fermented into short-chain volatile fatty acids
- These acids are then converted into CH_4 and CO_2.



Chemical processes for the recovery of conversion products from SW

Process	Conversion product	Pre-processing
Acid hydrolysis	Glucose, other sugars	Separation of organic fraction, particle size reduction
Alkaline hydrolysis	Glucose, other sugars	
Various chemical conversion processes	Synthetic oil, gas, cellulose acetate	

- Acid hydrolysis at 180 - 230°c and under slight pressure is used to recover glucose from cellulose containing waste (e.g., newsprint).

$$(C_6H_{10}O_5)_n + H_2O \rightarrow nC_6H_{12}O_6$$

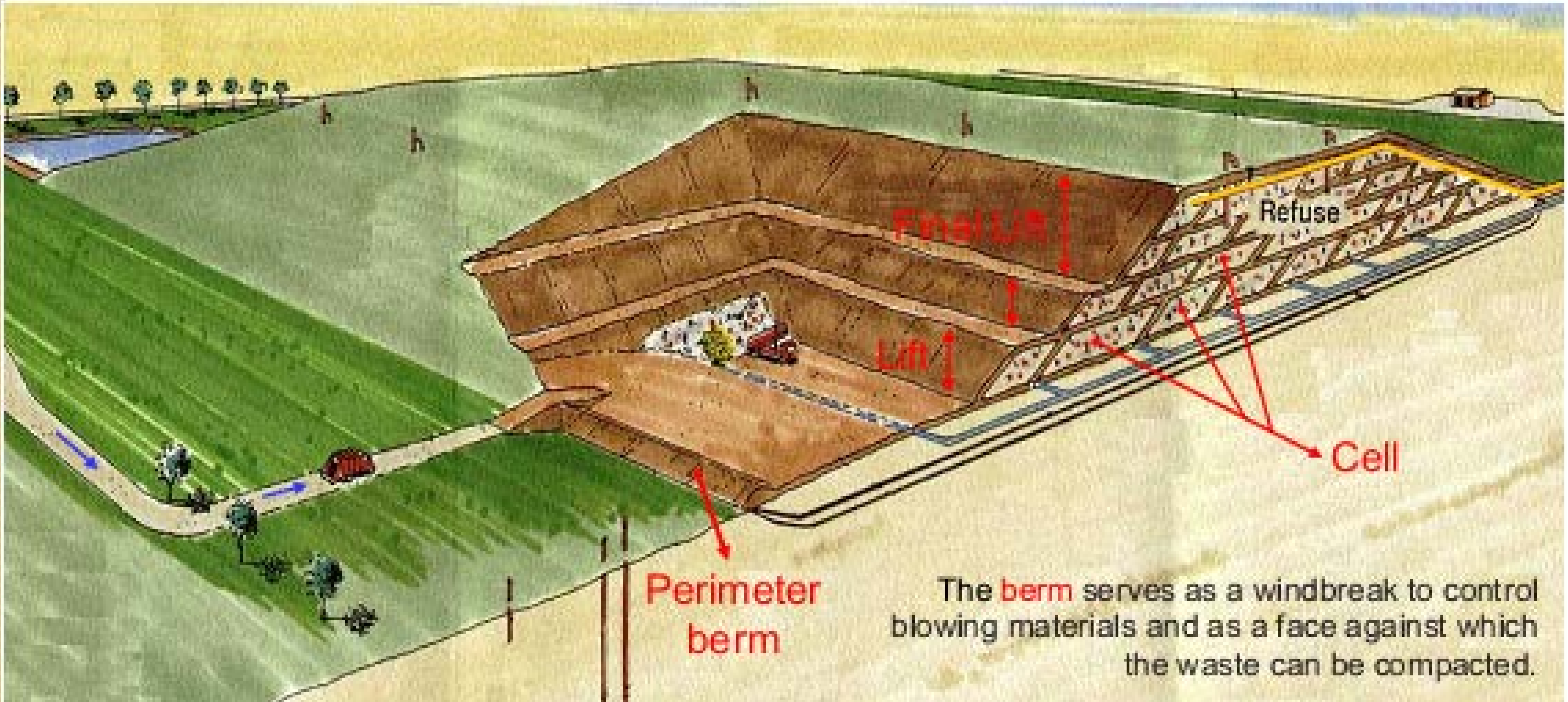
cellulose glucoce

Disposal of Solid Wastes and Residual Material

Landfilling Process

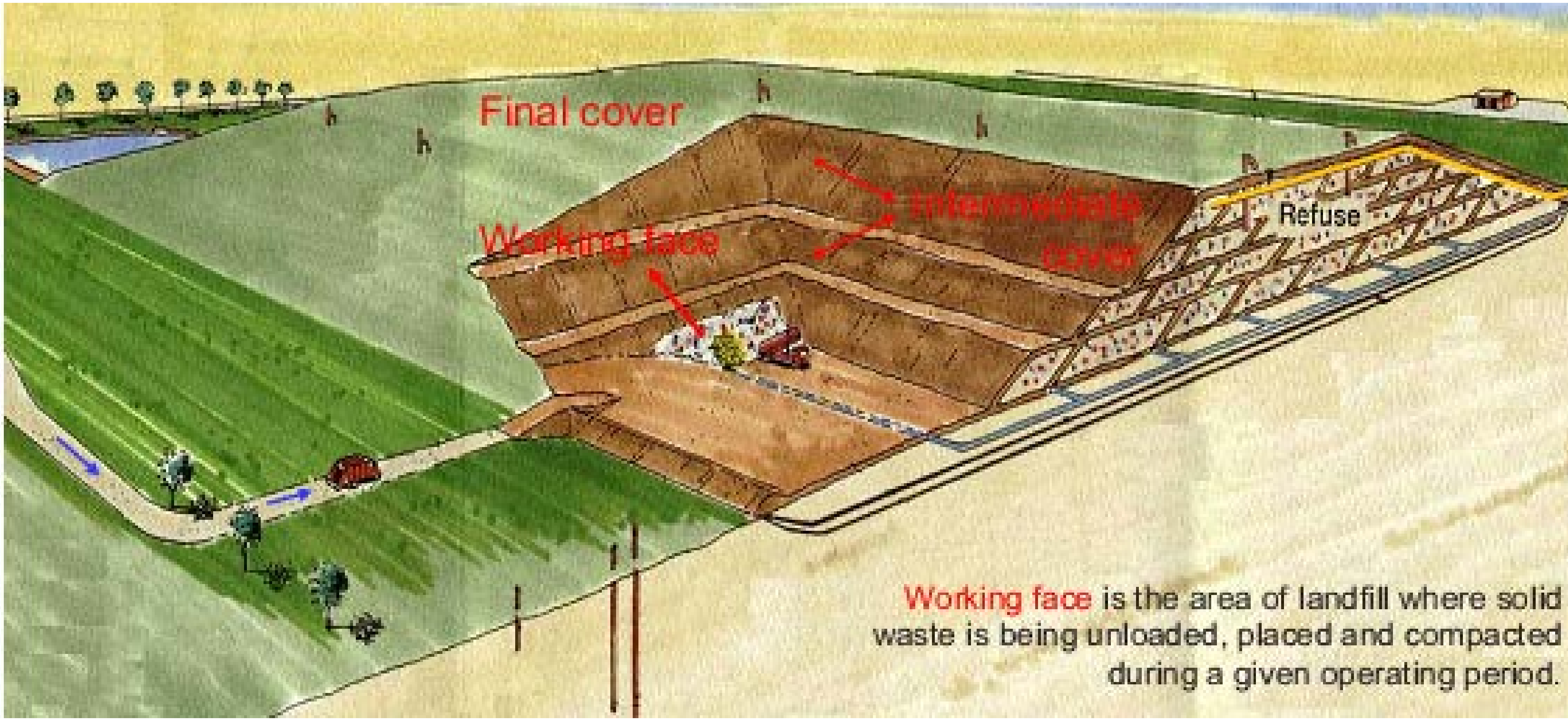
- Landfills are physical facilities used for the disposal of residual solid wastes in the surface soils of earth.
- Sanitary landfill is an engineered facility for the disposal of MSW, designed and operated to minimize public health and environmental impacts.
- Landfilling is the process by which residual solid waste is placed in a landfill.
- It includes:
  - Monitoring of the incoming waste stream
  - Placement and compaction of waste, and
  - Installation of landfill environmental monitoring and control facilities

Landfilling terms



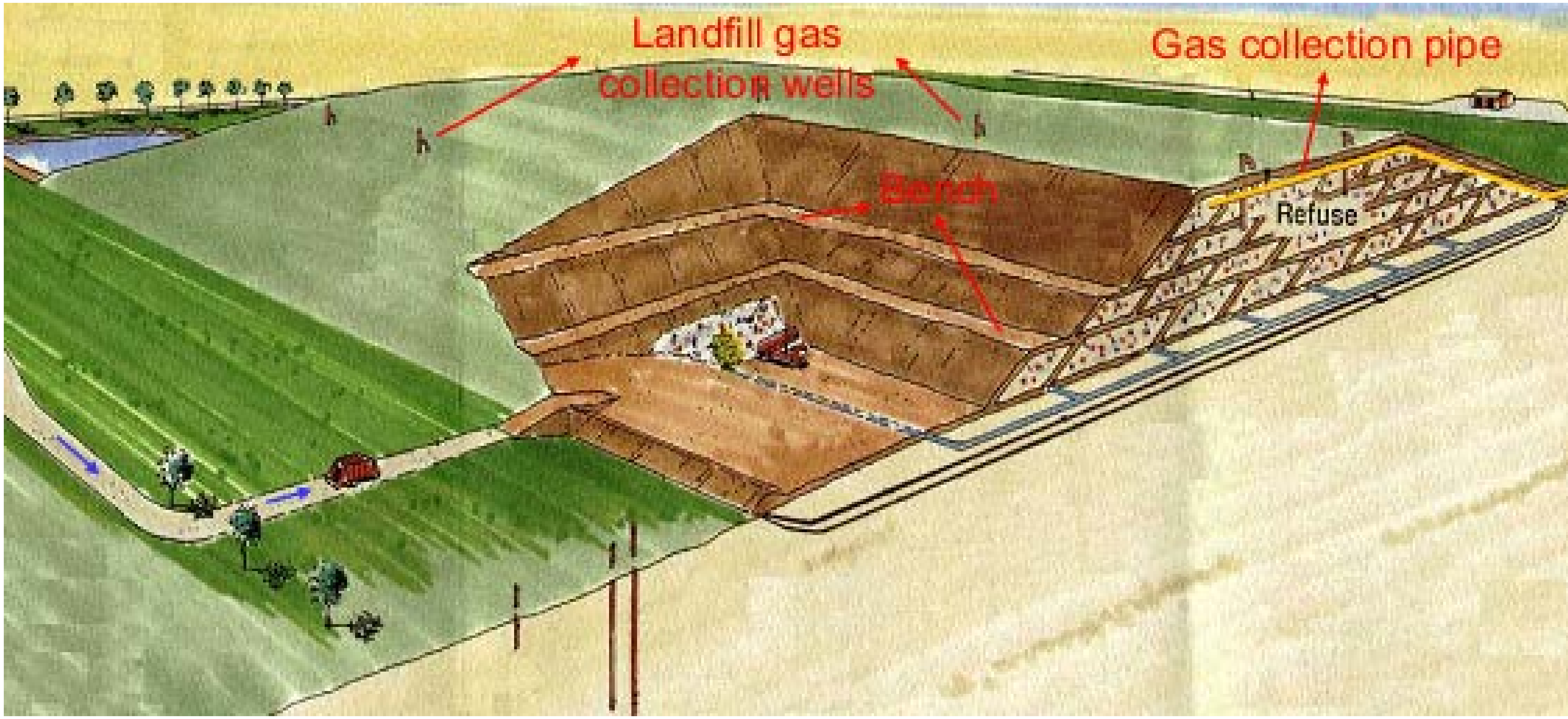
- Cell is the volume of material placed in a landfill during one operating period, usually one day.
- Lift is a complete layer of cells over the active area of landfill.

Landfilling terms



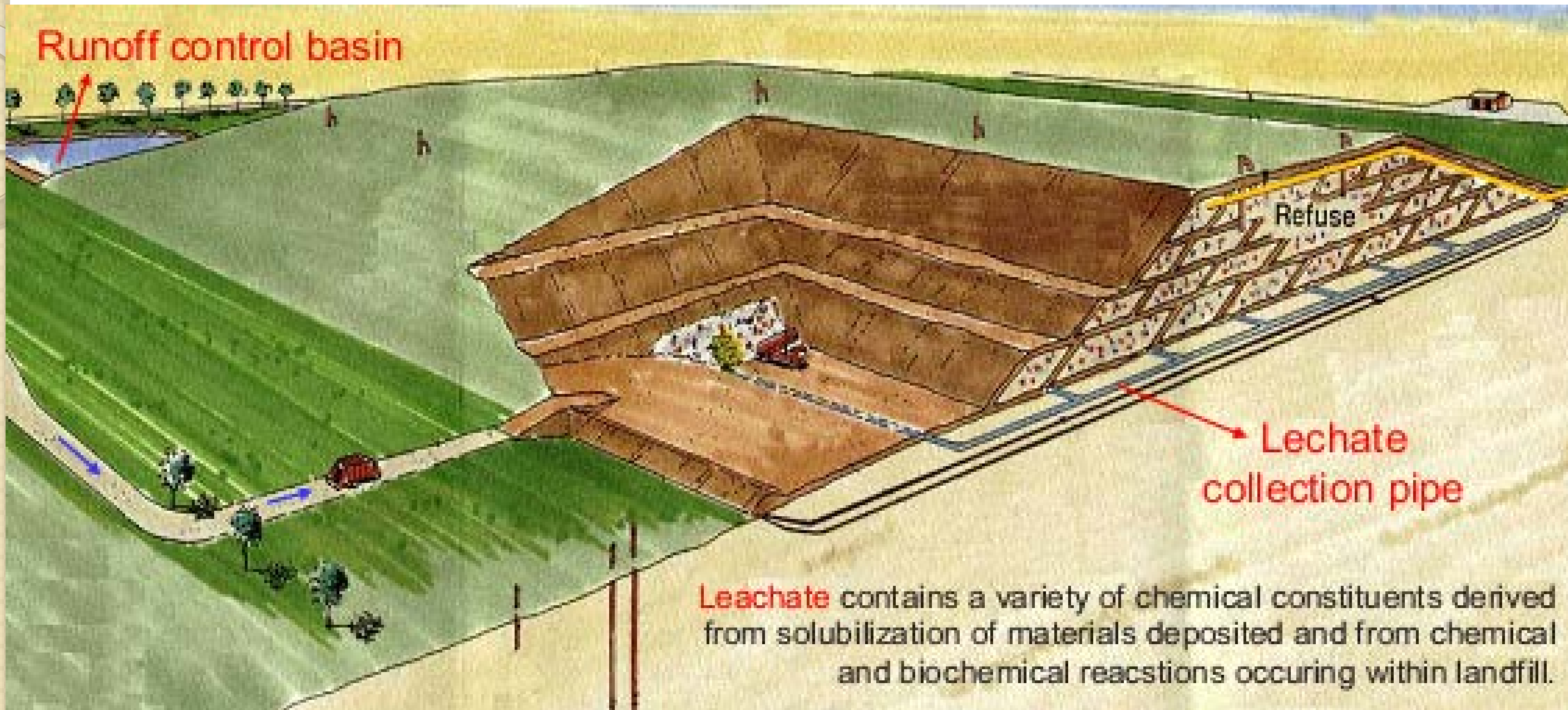
- Daily cover is the soil or alternative materials such as compost that are applied to the working faces of the landfill at the end of each operating period. usually consists of 15 to 30 cm of native soil
- Intermediate covers are placed at the end of each phase (series of lifts); these are thicker than daily covers, typically 45 cm
- Final cover is applied to the entire landfill surface after all landfilling operations are complete.

Landfilling terms



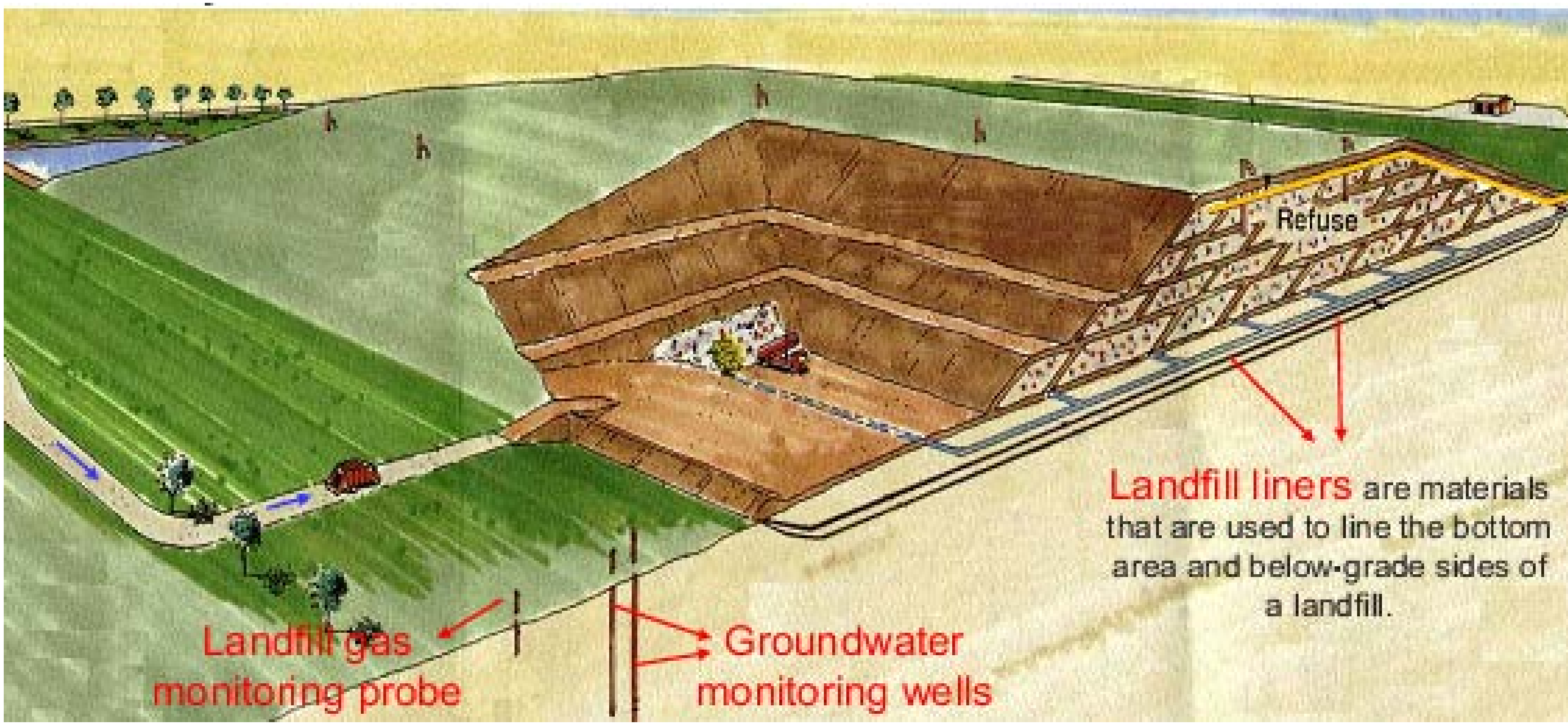
- Bench (or terrace) is used to maintain the slope stability of the landfill, for placement of surface water drainage channels and for the location of landfill gas recovery piping.
- Landfill gas is mixture of gases found within landfill. It mainly consists of CH_4 & CO_2

Landfilling terms



- Liquid that collects at the bottom of a landfill is known as leachate.
- It is a result of percolation of precipitation and uncontrolled runoff.
- It can also include water initially contained in the waste as well as infiltrating groundwater.

Landfilling terms



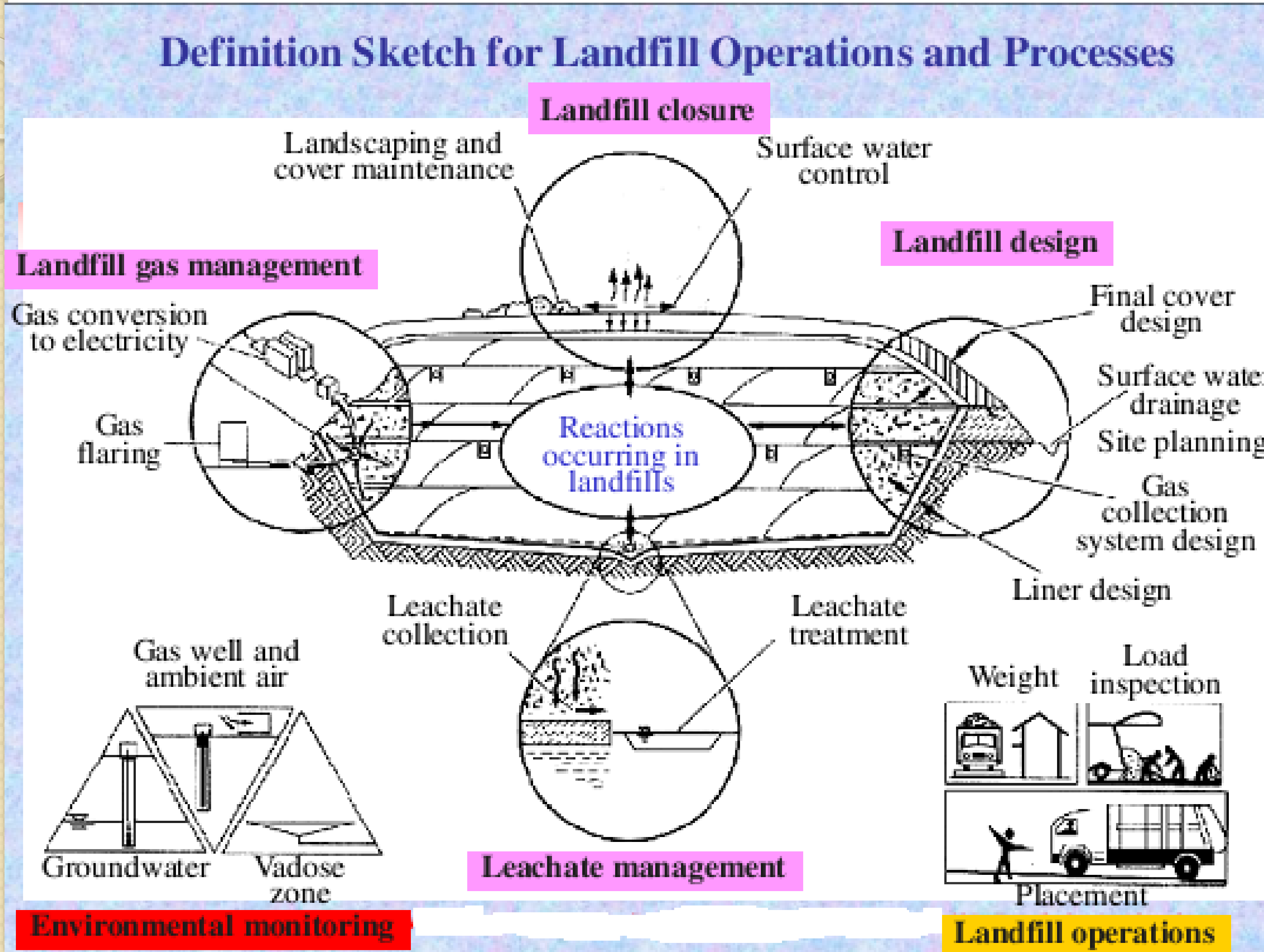
- Environmental monitoring involves the activities associated with collection and analysis of water and air samples, that are used to monitor the movement of landfill gases and leachate at the landfill site.

Landfill planning, design and operation

The principal elements that must be considered:

- Landfill layout and design
- Landfill operations and management
- Reactions occurring in landfill
- Management of landfill gases
- Management of leachate
- Environmental monitoring
- Landfill closure and post-closure care

Landfill operations and processes

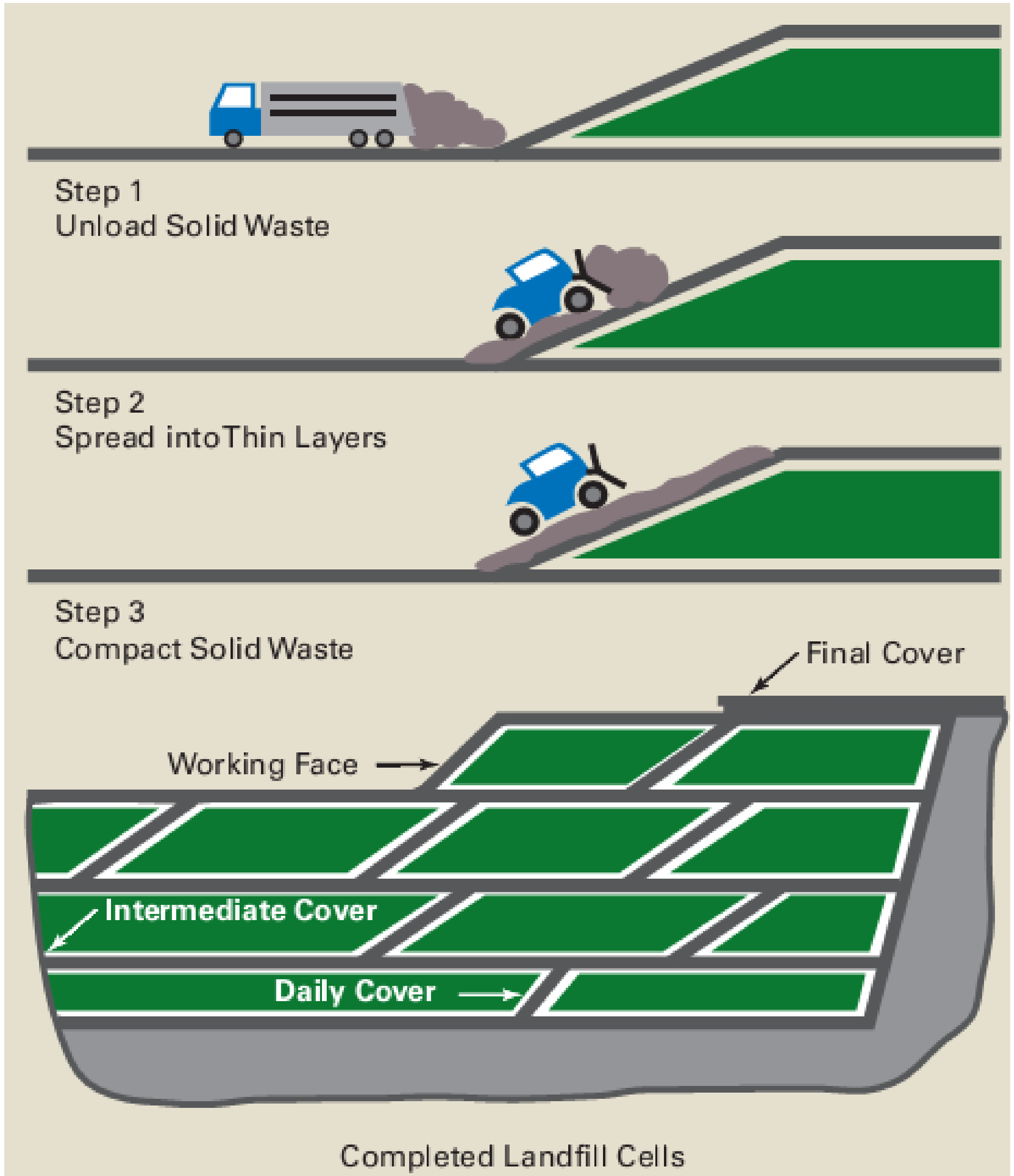


Preparation of site for landfilling

- Existing site drainage is modified to route any runoff away from the intended landfill area
- Access roads and weighing facilities are constructed and fences are installed
- Landfill bottom and subsurface sides are excavated and prepared. Excavations are carried out over time, rather than preparing the entire landfill bottom at once
- The bottom is shaped to provide drainage of leachate and a low-permeability (clay, geo-membrane) liner is installed.
- Leachate collection and extraction facilities are placed within or top of the liner.

Preparation of site for landfilling

Solid Waste Placement and Compaction



Placement of wastes

Reactions occurring in landfills

I. Biological reactions

- Organic material in MSW leads to the evolution of landfill gases and leachate.

II. Physical reactions

- Lateral diffusion of gases in landfill and emission of landfill gases to the surrounding environment
- Movement of leachate within landfill & into underlying soils
- Settlement caused by consolidation and decomposition of landfilled material

Reactions occurring in landfills

III. Chemical reactions

- Dissolution and suspension of landfill material and biological conversion products in leachate
- Evaporation and vaporization of chemical compounds into landfill gas
- Sorption of volatile and semi-volatile organic compounds into landfilled material
- Dehalogenetaion and decomposition of organic compounds
- Oxidation-reduction reactions affecting metals and solubility of metal salts

Concerns with landfilling

- The goal for the design and operation of a modern landfill is to eliminate or minimize:

1. uncontrolled release of landfill gases might cause odor and other potential dangerous conditions
2. impact of uncontrolled discharge of landfill gases on greenhouse effect in the atmosphere
3. uncontrolled release of leachate might migrate down to underlying groundwater or to surface water
4. breeding and harboring of disease vectors in improperly managed landfills
5. health and environmental impacts associated with the release of the trace gases arising from hazardous materials placed in the landfills in the past

Landfilling Methods

1. Excavated cell/trench Method
   - It is ideally suited to areas where an adequate depth of cover material is available at the site and where water table is not near the surface.
2. Area Method
   - It is used when the terrain is unsuitable for excavation.
   - High-groundwater conditions necessitate the use of this type.
3. Canyon/depression Method
   - Dry borrow pits and quarries are used.
   - Control of surface drainage often is critical factor in the development of depression sites.

Landfill Siting Considerations

- Haul distance
- Location restrictions
- Available land area
- Site access
- Soil conditions and topography
- Climatologic conditions
- Surface water hydrology
- Geologic and hydro-geologic conditions
- Local environmental conditions
- Ultimate use of completed landfills

Pond/Lake	> 200m
River	> 100m
Flood plain	> 100 year flood
Highway	> 200m
Habitated area	> 500m
Public parks	> 300m
Airports	Aviation Authorities
Ground Water Table	> 2m

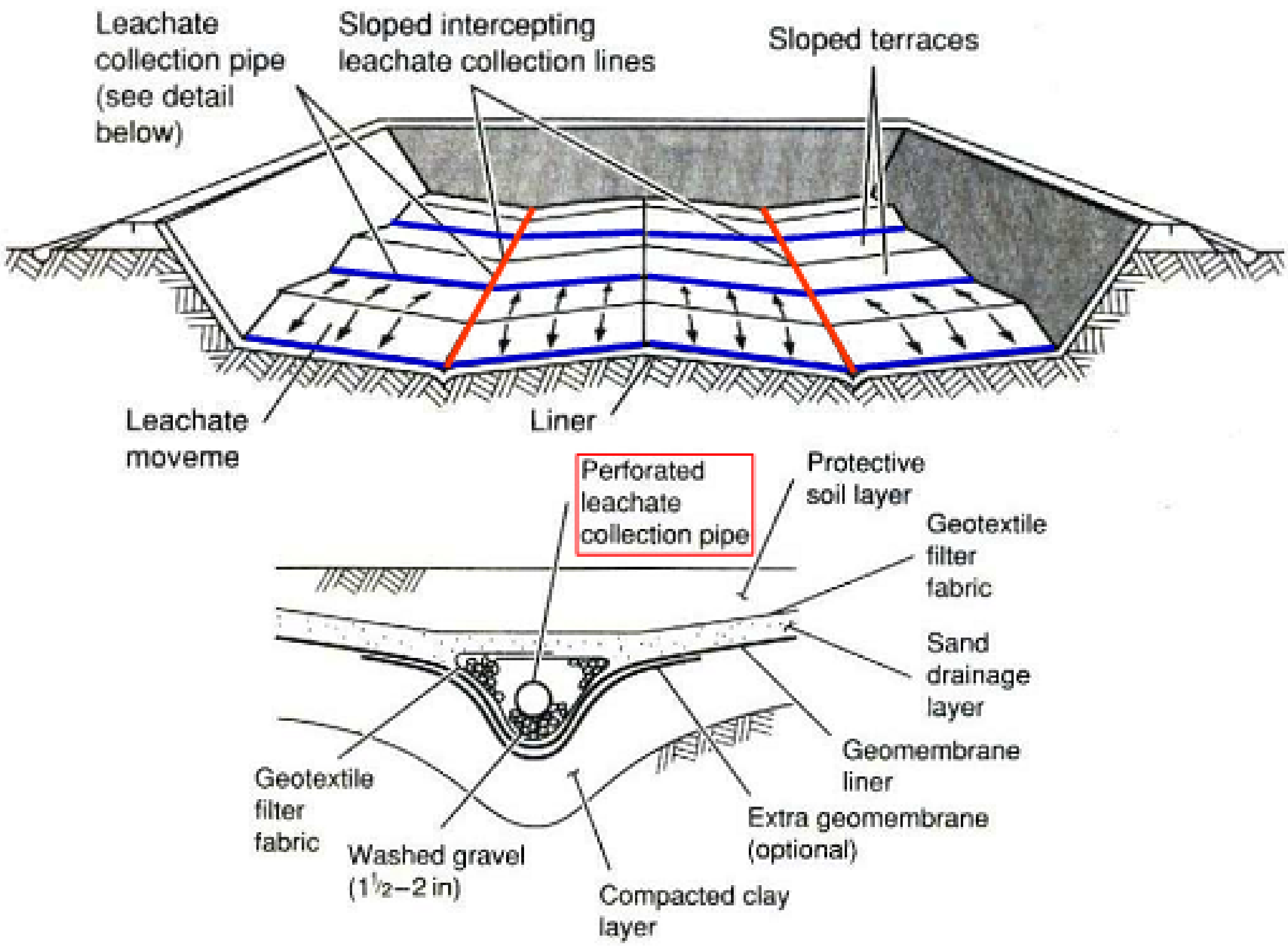
Control of Landfill Gases

- The movement of landfill gases is controlled:
  - i. to reduce atmospheric emissions
  - ii. to minimize the release of odorous emissions
  - iii. to minimize subsurface gas migrations and
  - iv. to allow the recovery of energy from methane
- In passive control systems, the pressure of the gas that is generated within landfill serves as the driving force for the movement of the gas.
- In active control systems, energy in the form of an induced vacuum is used to control the flow of gas.

Management of Landfill Gas

- Flaring (thermal destruction)
  - CH_4 and VOCs in landfill gas are combusted in the presence of oxygen contained in air to CO_2, SO_2, NO_x and other related gases.
- Energy recovery
  - Landfill gas is usually converted to electricity using internal combustion engines, gas or steam turbines.
- Gas purification and recovery
  - Separation of CO_2 from CH_4 can be accomplished by physical/chemical adsorption and membrane separation.

Leachate collection systems



Leachate collection system with graded terraces

Leachate management options

- Leachate recycling
  - An effective method for the treatment of leachate is to collect and re-circulate the leachate through the landfill.
- Leachate evaporation
  - One of the simplest leachate management systems involves the use of lined leachate evaporation ponds.
- Leachate treatment
  - Where leachate recycling and evaporation is not used and the direct disposal of leachate to a WWTP is not possible, some form of pretreatment or complete treatment will be required.
- Discharge to municipal wastewater collection system

Surface Water Management

- Surface water control systems:
  - Surface water drainage facilities
  - Storm water storage basins
  - Intermediate cover layers
  - Final cover layers

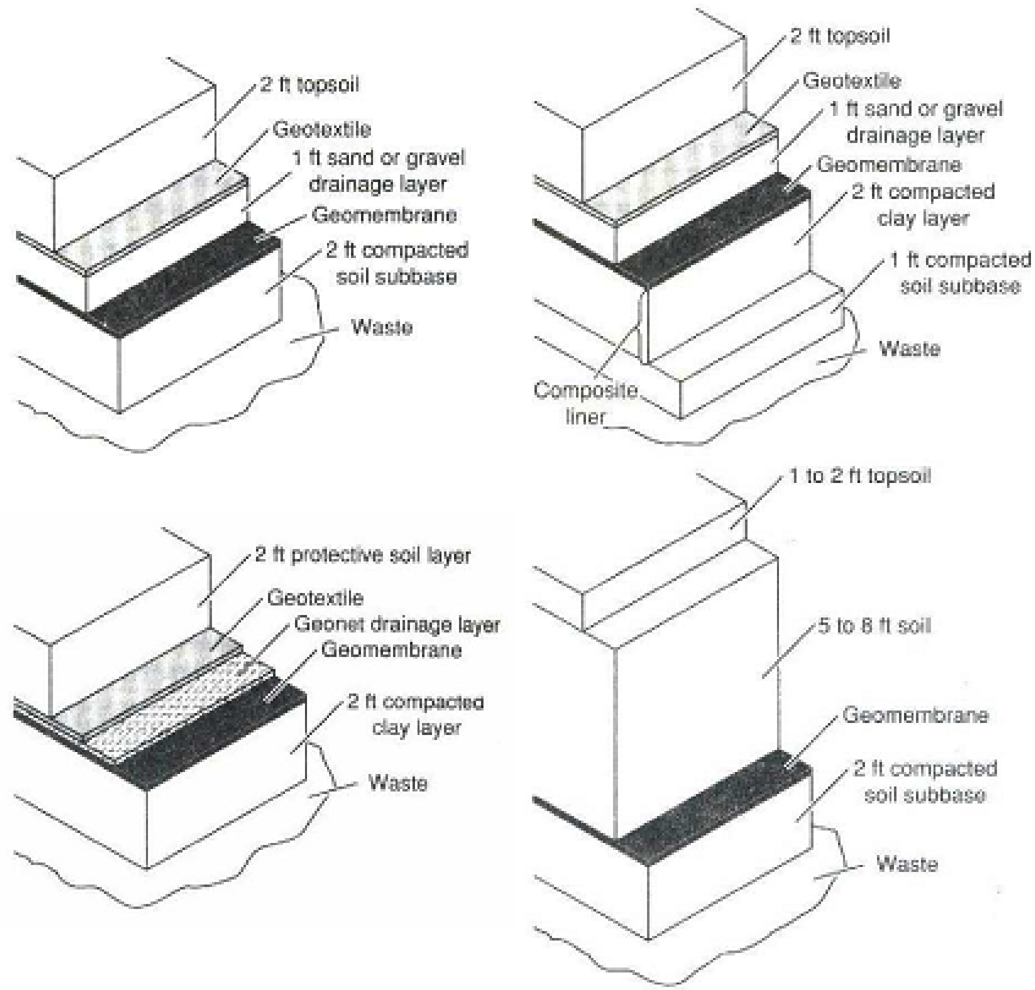
Intermediate cover layers;

- They are used to cover the wastes placed each day:
  - ✓ to eliminate harboring disease,
  - ✓ to enhance aesthetic appearance of landfill site and
  - ✓ to limit the amount of surface infiltration

Final cover layers

Surface layer	Cover soil, available locally or imported
Protective layer	
Drainage layer	Sand, gravel or geonet and geotextile separator
Barrier layer	Geomembaren
Subbase	Compacted and graded native soil

Typical components that constitute a landfill cover



Typical landfill final cover configurations

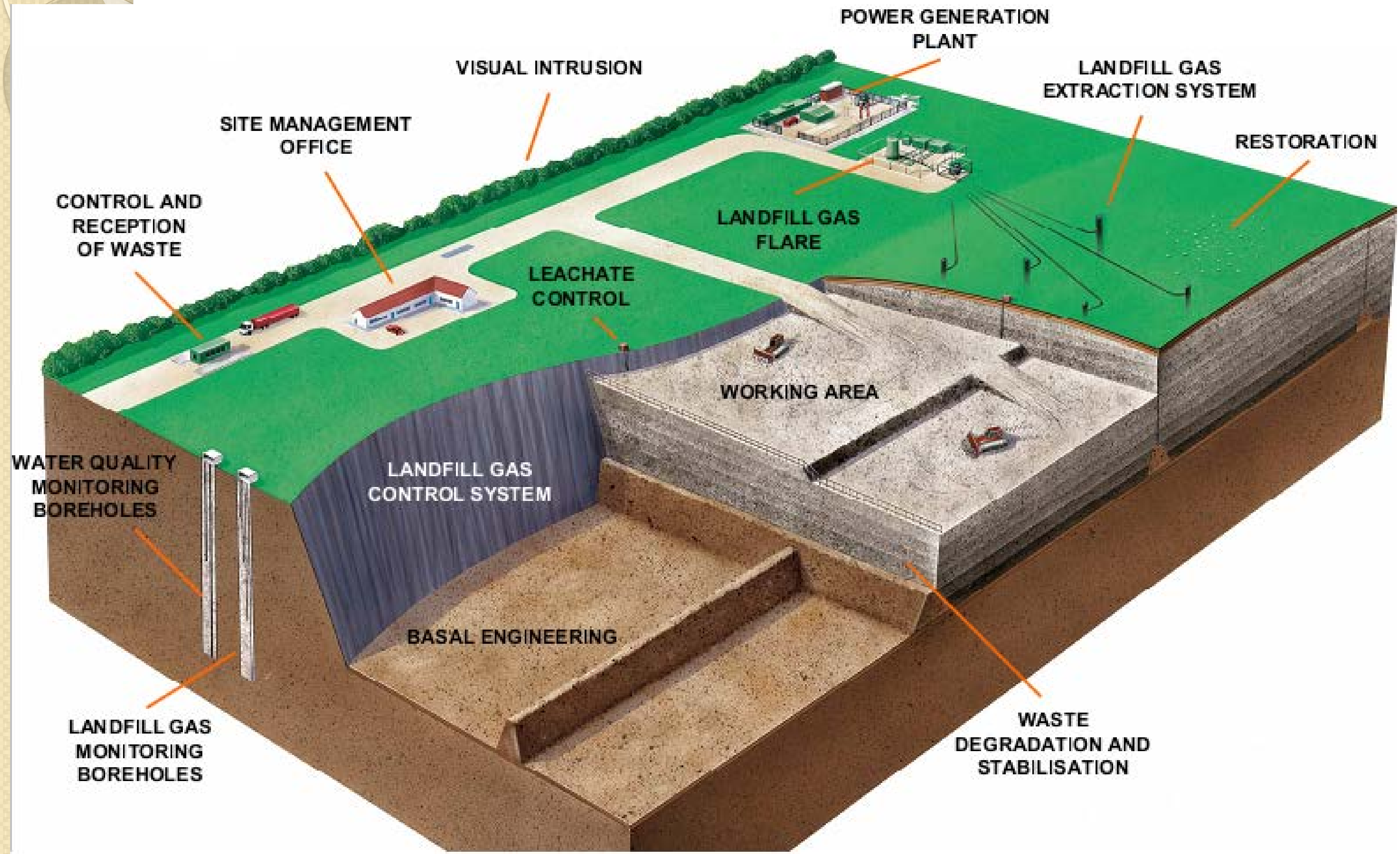
Layout & Preliminary Design of Landfills

- Important topics that must be considered in a landfill design:
  - Layout of landfill site
  - Types of wastes that must be handled
  - The need for a convenience transfer station
  - Estimation of landfill capacity
  - Evaluation of the geology and hydrology of the site
  - Selection of landfill gas and leachate control facilities
  - Layout of surface drainage facilities
  - Aesthetic design considerations
  - Monitoring facilities
  - Determination of equipment requirements
  - Development of an operations plan

Layout of Landfill Sites

- In planning the layout of a landfill site, the location of the following must be determined:
  - Access roads, office space and plantings
  - Equipment shelters and (if used) scales
  - Storage and/or disposal sites for special wastes
  - Areas to be used for waste processing
  - Areas for stockpiling cover material
  - Drainage facilities
  - Location of landfill gas management facilities
  - Location of leachate treatment facilities
  - Location of monitoring wells

Layout of Landfill Sites



Design of Landfills

- Important factors to consider in the design of landfills:
  - Access (roads to landfill site, temporary roads to unloading area)
  - Land area (large enough for 10 - 25 years)
  - Landfilling method (excavated cell/trench, area, canyon)
  - Completed landfill characteristics (slope of final cover: 3 -6%)
  - Surface drainage (to divert surface water runoff)
  - Intermediate cover material (waste to cover ratio: 5 – 10: 1)
  - Final cover (multilayer design)
  - Landfill liner (multilayer design, leachate collection system)
  - Cell design and construction

Waste Volume and Landfill Capacity

- The total landfill area should be approximately 15% more than the area required for landfilling to accommodate all infrastructure and support facilities.
- There is no standard method for classifying landfills by their capacity.
- However, the following nomenclature is often observed in literature:
  - Small size landfill : less than 5 hectare area
  - Medium size landfill : 5 to 20 hectare area
  - Large size landfill : greater than 20 hectare area.

Landfill Closure and Post closure Care

- They are the terms used to describe what is to happen to a completed landfill in the future.
- Development of Long-Term Closure Plan
  - Cover and landscape design
  - Control of landfill gases
  - Collection and treatment of leachate
  - Environmental monitoring systems
- Post closure Care
  - Routine inspections
  - Infrastructure maintenance
  - Environmental monitoring systems

Thank you for your attention

Don’t miss

To take a minute every day at your home to collect your own waste orderly!!