SANITARY ENGINEERING

Introduction

Dr. Mahesh Bhattarai. Rabin Maharjan

OUTLINES

- Introductions
- Quantity of waste water
- Characteristics and examination of sewage
- Design and construction of sewers
- Sewer appurtenances
- Sewage disposal
- Sewage treatment
- Sludge treatment and disposal
- Disposal of sewage form isolated buildings
- Solid waste disposal

INTRODUCTIONS

- Sanitary Engineering is a branch of public health engineering which deals with collection, conveyance, treatment and safe disposal of solid and liquid waste
- For pollution control
- For control of pathogens
- for extraction of water and other required fertilizers
- For conserve environment and nature, etc.

HISTORICAL BACKGROUND

- 3750 BC Nippur India
- 26th century BC, Tell Asmar in Iraq
- From 1550 an 1700 practiced in Germany and England resp.
- Heavily practiced after out break of Cholera in 1848, 1849, 1852, 1853 & 1854 claiming lives of 25000
- J.W. Adams first design sewer system in Brooklyn and E.S. Chesbrough in Chicago
- In Nepal, during Rana period constructions were made which still runs today

IMPORTANCE

- Causes pollution in land, water and air
- When starts decomposition gives offensive smells
- Source of pathogens and vectors
- Degrade environment and cause loss of biodiversity, fertility, life, etc.
- Hence needed proper and effective study and make in use for collection, conveyance, treatment and safe disposal of waste

COMMON TERMS

A. Refuse: all rejected or left as worthless liquid, semi solid or solid waste. It consist of :
   - Garbage: containing large amount of organic and rotten (putrefying) matters like paper fruits, vegetables, grass, leaves, etc. from market and other public places
   - Rubbish: dry and combustible form office, residence factories etc. like paper, furniture, building materials etc.
   - Sullage: waste water form bathroom, kitchen, wash basins, and other washing places and usually doesn't smell because of low organic matters
   - Subsoil water: portion of ground water entering in sewer lines form faulty joints and cracks
   - Storm water: rain water
   - Night soil: human and animal excreta

COMMON TERMS

A. Refuse

- Sewage(wastewater) : all kinds of liquid waste and may contain pathogens. organic matters, metals, harmful chemicals etc.
  - Storm water: rain water
  - Sanitary sewage: wastewater from residential and industrial areas
    - Domestic sewage: form lavatory basins, urinals, water closets, etc. of residential buildings, theaters, and other institution and assembly buildings
    - Industrial sewage: from industrial and commercial establishments containing high organic matters and other harmful chemicals

COMMON TERMS

B. Sewers : generally underground and partially flowing conduit responsible for conveying the sewage form place of discharge to disposal

- Separate sewer: carrying only domestic and industrial sewage only
- Storm sewer: carrying rainwater only
- Combined sewer: carrying fully or partially of both rain water, domestic and industrial sewage
- Main or trunk sewer: serves as a main or an outlet of large are. Submain, or branches feeds sewage to mains
- Branch or sub mains: collect sewers form laterals and delivers to main
- Laterals: first stage of conveyance which collects sewage form source of sewage like houses, industries etc. and conveys it to branch
- House sewer: carries form house to streets or laterals
- Outfall sewer: carries form source to final point of discharge or disposal

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COMMON TERMS

C. Invert and crown: lowest and topmost part of internal cross section

D. Sewerage: includes structure, devices, equipment, used for removal of sewage. It is science of collecting and carrying of sewage through sewers by water carrying system

MANAGEMENT METHODS

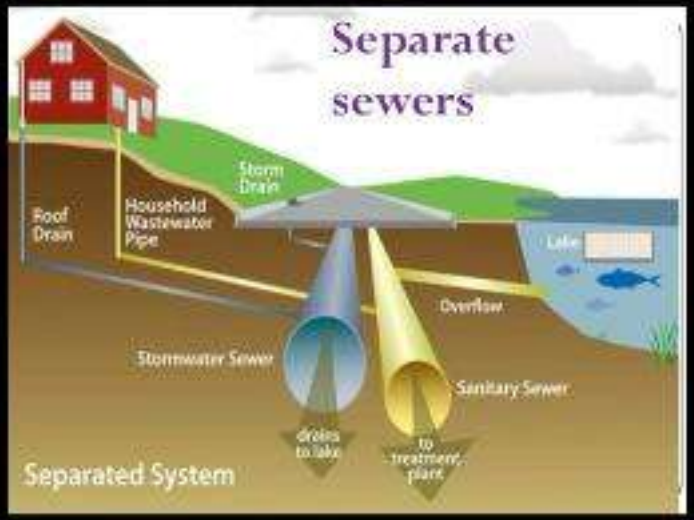
- Collection work
- Conveyance
- Treatment
- Disposal

OBJECTIVE OF SEWAGE DISPOSAL

- Dispose human waste in a safe place before start of decomposition
- Take waste water immediately to avoid breading mosquito, flies, bacteria etc.
- Discharge sewage to water bodies or land after treating so that no pollution occurs
- Utilize fertilizing value of sewage
- To treat sewage onsite and decentralized
- To treat and dispose safely and scientifically so that the public health is not effected

SANITATION SYSTEM

- Waste collection and disposal is of 2 types
- Conservancy system and water carriage system



CONSERVANCY SYSTEM

- Old system in use still in underdeveloped places
- Dry refuse are collected in containers and transported and disposed off in trucks, carts, etc.
- Combustibles are burned and non combustible are disposed in landfills
- Human excreta are collected and removed by human agency and buried in trenches and after 2 -3 years used as manure
- Sullage and storm water is carried separately and disposed off via open or closed drains

CONSERVANCY SYSTEM

- Merits
  - Simple and Cheap in construction and initial investments
  - Quantity reaching to treatment plant is low
  - No silting and clog problem in open drains
- Demerits
  - Unhygienic and chance of contamination is high
  - Drains are difficult in crowded areas
  - More land is required for human excreta
  - No compact design of buildings as latrines are to be kept away
  - Sub soil contamination
  - Aesthetic of the city
  - Decomposition creates the bad smell

WATER CARRIAGE SYSTEM

- Water is cheapest substance to collect and carry sewage
- 99.9 % water 0.1% solid matters
- Conveyed through the water carrying sewers in city
- Sewers are hydraulically designed to avoid silting and scouring

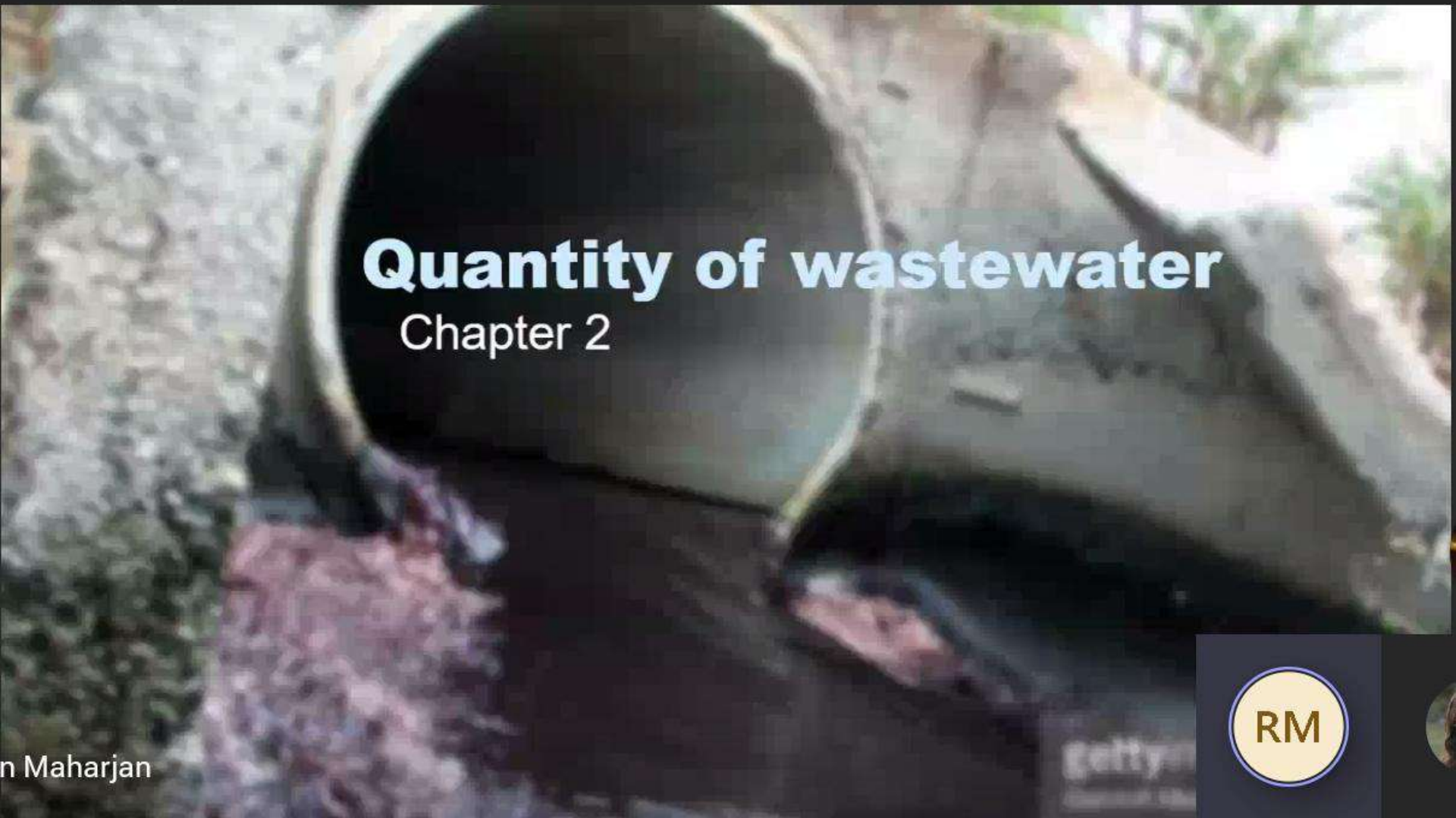
WATER CARRIAGE SYSTEM

- Merits
  - Hygienic as no human agency is in direct contact
  - No nuisance in city as it has closed drains
  - Drains occupy no space as they are generally underground
  - Self cleansing due to efficient hydraulic design of sewers
  - Compact designs can be made as latrines are safe
  - Usual water supply is enough to operate
  - Sewage after treatment can be use for irrigation
  - Manual works are less required

- Demerits
  - High initial and maintenance cost
  - Large quantity of sewage to be treated

TYPE OF SEWERAGE (WATER CARRIAGE) SYSTEM

- Combined system
- Separate system
- Partially separate system


Quantity of wastewater
Chapter 2
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Introduction

- Is calculated or estimated from the characteristics of its source
- Classified waste water as 2 types

  - **Sanitary sewage or dry weather flow (DWF)**

  Waste water for residence, industries, ground water infiltration etc.

  - **Storm sewage or wet weather flow (WWF)**

  Waste water collected due to runoff and its quantity is huge compared to DWF

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Sources of sanitary sewage

- Public water supply: domestic and industrial use provided by municipal effort (KUKL)
- Private water supply: provided by local authorities in schools, halls,(Tankers, jars etc.)
- Private source: wells. Lakes, canals etc.
- Infiltration of ground water: sub soil water form joints and leaks
- Unauthorized connections: entrance of rain waters, and other unknown connections

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Factors affecting sanitary sewage

- Population: higher the population, higher is the sanitary sewage & vice versa
- Rate of water supply: higher the water supply higher is the sewage
- Type of area: Residential, industrial or commercial and their type
- Additions: infiltrations to sewers, unauthorized connections and other sources
- Subtractions: evaporations, infiltrations to ground, consumptions etc.

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Determination of quantity of sewage

- DWF = total quantity of water supply + additions – subtractions

- Cannot be exactly calculated but taken as 70-90% (80%) of total supply
- Sewer design is taken so that it can carry more than the average annual flow of sewage (called Peak Flow)
- Peak flow is calculated for peak factor (P_f = 2-4 [a multiplier])

- So, DWF = Population X 70-90% of water supply rate

Design quantity of sewage (Q_{sa}) = Peak factor (P_f) x DW

Factors affecting storm water

- Characteristics, slope, shape and area of the catchment
- Imperviousness of soil in catchment
- Obstruction in flow of water like trees, vegetation, fields, gardens etc.
- Initial wetness of the catchment
- Intensity and duration of rainfall
- Atmospheric pressure, humidity, temperature wind etc.
- No. of depressions, trenches, water pockets, ditches etc.
- Time required for the flow to reach the sewer

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Determination of wet weather flow

WWF = total rainfall – losses due to evaporation, absorption, transpiration, percolations, fill of depressions.

Two methods of determinations

1) Rational method
2) Empirical formulae method (Not in syllabus)

Rational method

$$Q_{st} = C\,I\,A/360 \qquad (m^3/s)$$

Where, Q_{st} = quantity of storm sewage in m^3/s

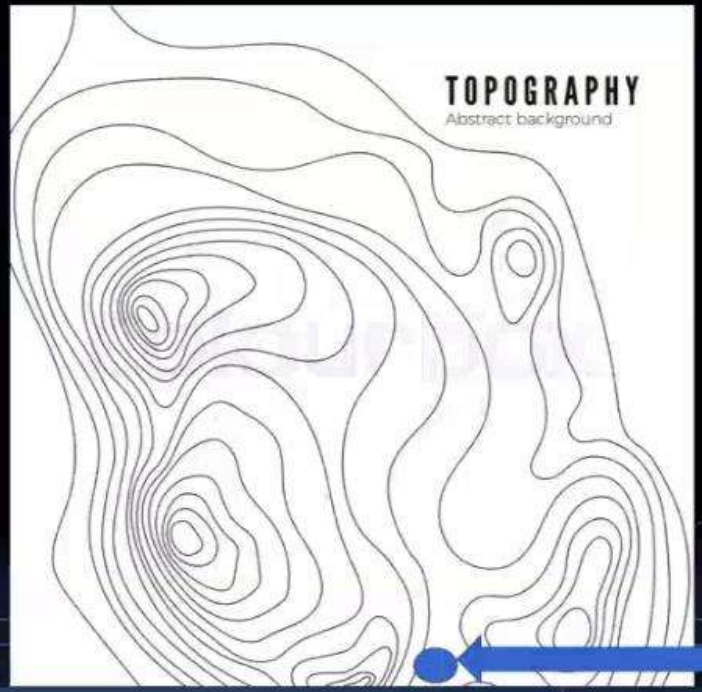
C = coefficient of runoff (weight average if many C)

I = intensity of rainfall in mm/hr

A = Area of the catchment in hector (1ha = 10^4 m^2)

Rational method

- Catchment area (A): area contributing to rain water to point of sewer



Rational method

- Coefficient of runoff (C): it is ratio of runoff to rainfall

as **runoff ≠ rainfall** (due to various factors)

If more than 1 "C"s then, use weighted formula for calculation of single C represent the whole catchment

$$C = \frac{c_1 a_1 + c_2 a_2 + c_3 a_3 + \cdots}{a_1 + a_2 + a_3 + \cdots}$$

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Rational method

description of area	runoff coefficient (C)***			
	5-year	10-year	50-year	100-year
Paved Surfaces/Buildings	0.94	0.95	0.98	0.98
Gravel Surfaces, Compacted	0.45	0.50	0.55	0.60
Gravel Surfaces, Loose Graded or Not Compacted	0.35	0.40	0.45	0.50
Industrial Light, 60% Impervious	0.64	0.69	0.79	0.83
Industrial Heavy, 75% Impervious	0.76	0.79	0.86	0.89
Commercial/Business Areas, 85% Impervious	0.81	0.85	0.91	0.92
Residential Row houses/town houses, 65% Impervious	0.66	0.67	0.74	0.76
Residential 1/4 Acre lots, 40% Impervious*	0.48	0.49	0.58	0.62
Residential 1/2 Acre lots, 25% Impervious*	0.36	0.39	0.49	0.54
Residential 1 Acre lots, 20% Impervious*	0.32	0.34	0.46	0.51
Lawn, 0 to 2% slope (flat) **	0.22	0.22	0.30	[illegible]
Lawn, 2 to 7% slope (average) **	0.24	0.25	0.35	[illegible]
Lawn, 7% or greater (steep) **	0.26	0.30	0.38	[illegible]
Parks/Golf Courses/Cemeteries, 8% Impervious	0.21	0.21	0.28	[illegible]

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Rational method

- Intensity of rainfall (I): used in mm/h in formula

British Ministry of Health formula for Intensity of Rainfall:

$$i = \frac{760}{t+10}$$ for storm duration 5 to 20 mins

$$i = \frac{1020}{t+20}$$ for storm duration 20-100 mins

Where, i = intensity of rainfall and

t = duration of rainfall in mins or time of concentration

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Rational method

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Rational method

- Time of concentration

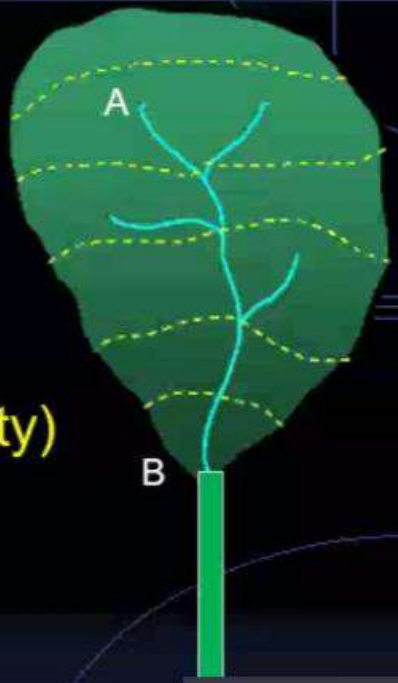
$$T_o = T_e + T_l$$

where,

T_0 =Time of concentration

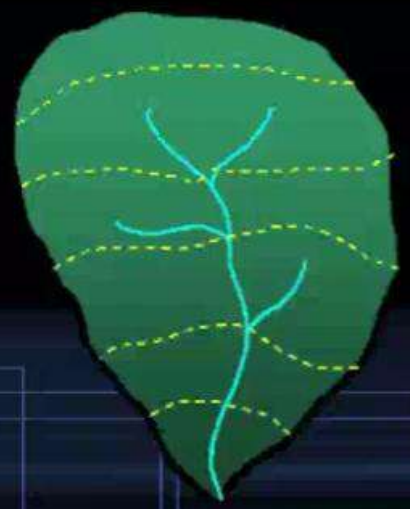
T_e =Time of entry (from A-B) (3-20mins)

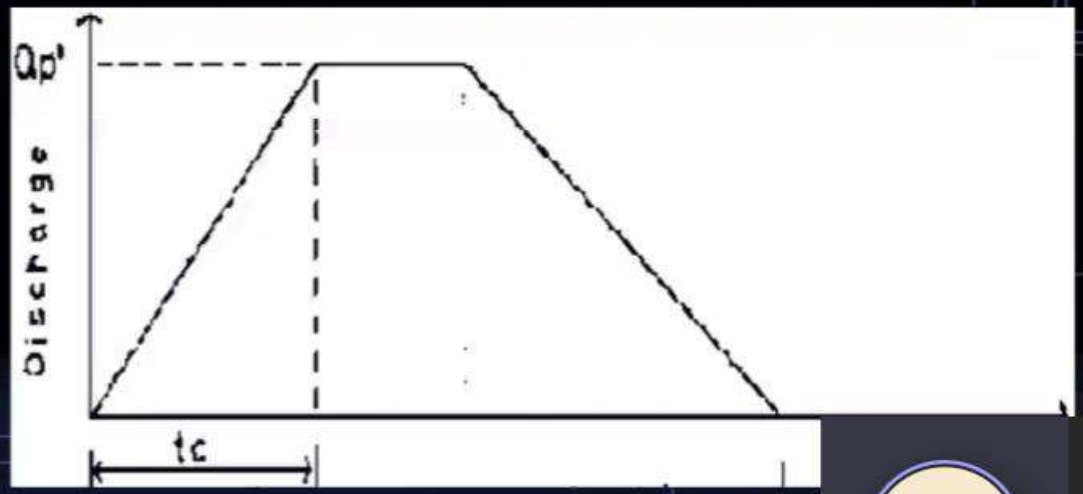
T_l =Time of travel (form B-P) (length/velocity)



Rational method

- Time of concentration: longest time taken to travel water form the farthest point of the catchment to any point of concentration considered for maximum flood. T_c is taken in design as max discharge occurs in T_c time





Example numerical

The catchment area of the city is 200 hectares. Assuming the surface on which rainfall is classified as follows.

S. No.	Type of surface	% Area	Runoff Coefficient or runoff ratio (C)
1	Roof	20	0.9
2	Pavement and yards	15	0.8
3	Lawns and gardens	30	0.15
4	Roads	20	0.4
5	Vacant plots	15	0.1

Calculate the impervious factor, if the maximum intensity of rainfall is 40 mm/hr. Also calculate the quantity of storm water, which will reach the sewer lines.

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Example numerical

Given.

Total area (A) = 200 ha, Intensity of rainfall (i) = 40 mm/hr.

Quantity of Storm water (Q_{st}) =?

Here,

For roof;

Area (a_1) = 20% of A = 0.2A.

Runoff coefficient (c_1) = 0.9

For pavement and yards;

Area (a_2) = 15% of A = 0.15A.

Runoff coefficient (c_2) = 0.8

For lawns and gardens;

Area (a_3) = 30% of A = 0.3A.

Runoff coefficient (c_3) = 0.15

For roads;

Area (a_4) = 20% of A = 0.2A.

Runoff coefficient (c_4) = 0.4

For vacant plots;

Area (a_5) = 15% of A = 0.15A.

Runoff coefficient (c_5) = 0.1

We have,

Overall runoff coefficient or runoff ratio,

$$C = \frac{c_1a_1 + c_2a_2 + c_3a_3 + c_4a_4 + c_5a_5}{a_1 + a_2 + a_3 + a_4 + a_5}$$

=

Again,

Quantity of storm water or WWF (Q_{st}) $= \frac{C\,i\,A}{360} =$

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Example numerical

In the example above if the density of the population is 300 person/ha and the rate of the water supply is 250 lpcd, calculate the quantity of sewage for

a. Separate system b. Combined system c. Partially separate system

Assume peak factor = 2 and assume other suitable data if necessary.

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Example numerical

(a) For separate system:

Q_{sa} = m^3/s and from example 2.1. Q_{st} = m^3/s Ans.

(b) For combined system:

$Q = Q_{sa} + Q_{st}$ = = m^3/s Ans.

(c) For partly separate system:

For partially separate system, considering storm water only from roof pavement and yards, then referring example 2.1,

For roof: a_1 = 20% of A = 0.2 × 200 = 40 ha. c_1 = 0.9

For pavement and yard, a_2 = 15% of A = 0.15 × 200 = 30 ha. c_2 = 0.8

$$\text{Overall 'C'} = \frac{c_1 a_1 + c_2 a_2}{a_1 + a_2} =$$

$$\text{Now, } (Q_{stp}) = \frac{C\,I\,A}{360} =$$

Hence, for partially separate system, design discharge is,

For sewer, $Q_1 = Q_{sa} + Q_{stp}$ = m^3/s Ans

For storm drain, $Q_2 = Q_{st} - Q_{stp}$ = m^3/s Ans

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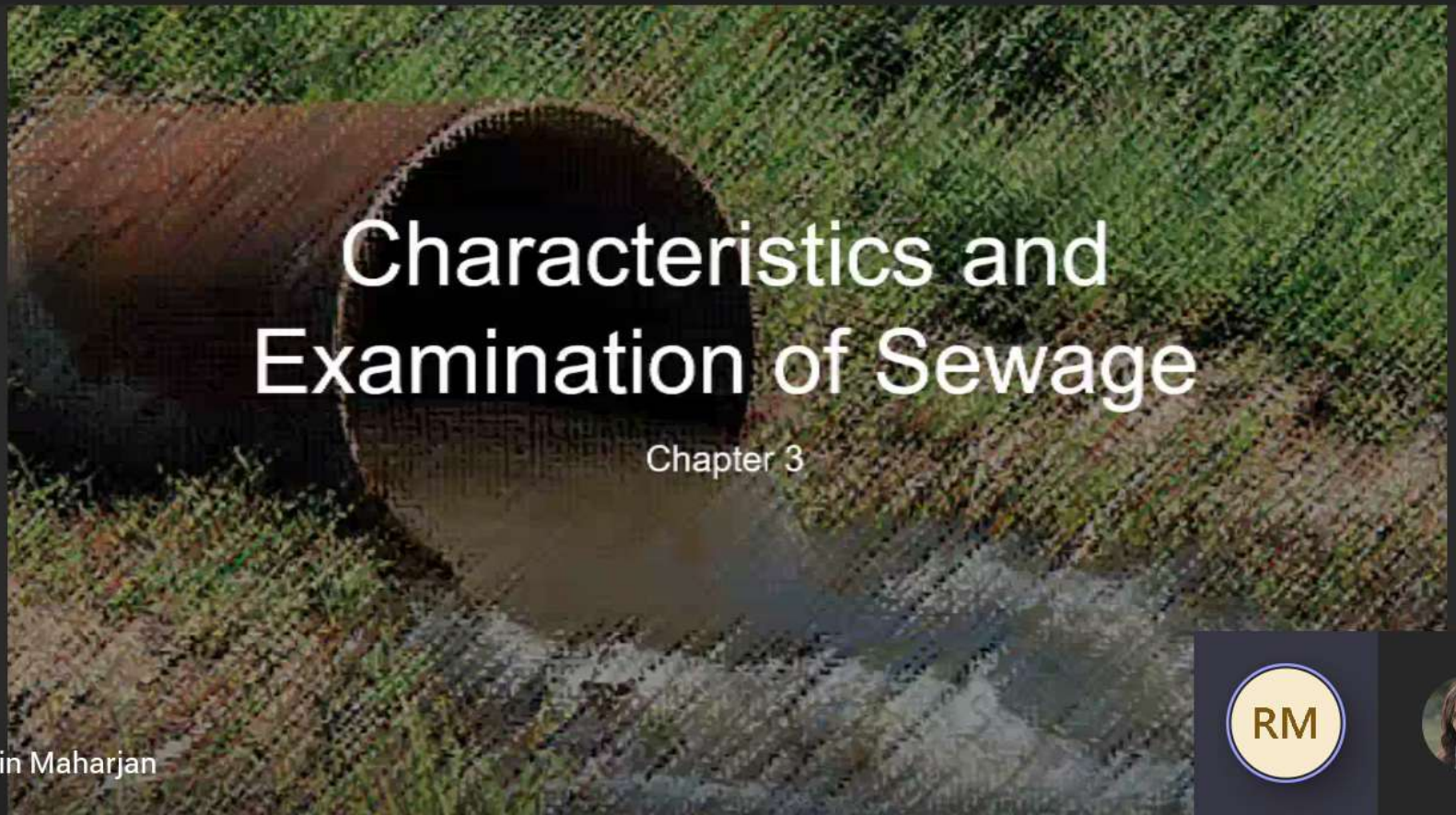
Characteristics and
Examination of Sewage
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Introductions

- Sewage contains organic and inorganic matters in suspended, colloidal and dissolved form along with the microorganisms

- Objective: (why we need to know sewage characteristics)
  - Process of origin
  - Type and scale of treatment plants
  - Scale of risk for biological and chemical contamination for measures
  - Fertilizing values and irrigation feasibility

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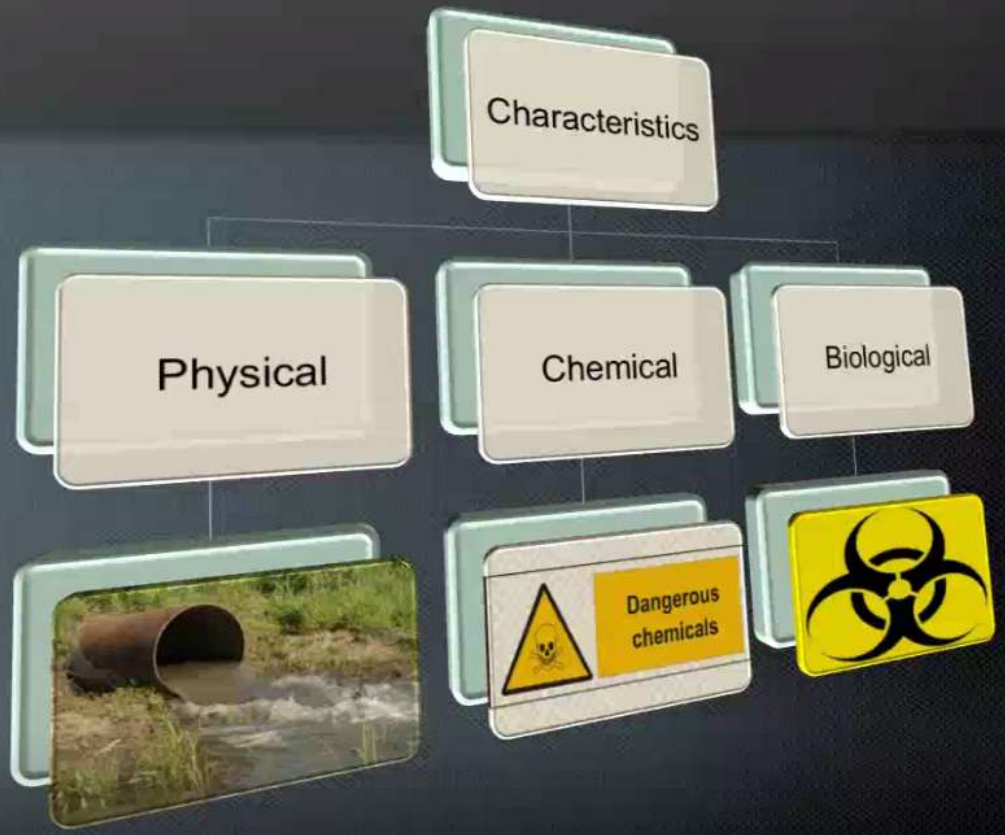

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Physical character

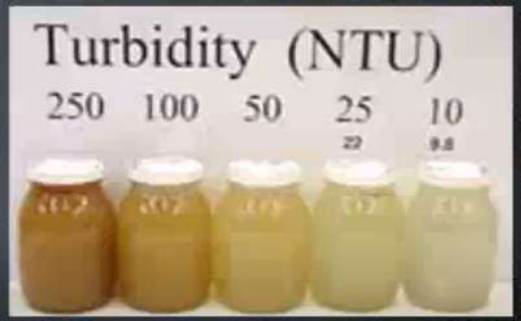
- Color:
  - caused by suspended or dissolved matters
  - Fresh is soap solution color (light grey brown)
  - after certain time it decomposes and get dark grey
  - After full decomposition it become black (septic sewage)
  - Industries' depends on nature and type of processes

- Odor
  - Fresh is soapy and oily in smell
  - Later after decomposition it have offensiv
  - Due to H_2S, CH_4, NH_3 etc.

Physical character

- Temperature:
  - Temperature is generally slightly higher than water due to various activities
  - Generally 3-27 ^{0}C in colder places and 30-35 ^{0}C in hotter places

- Turbidity:
  - Turbidity is higher than the water
  - Presence of high suspended matters and colloidal matters



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Physical character

- Solids:
  - 0.1% is solid in wastewater
  - 2 types → Suspended and Dissolved solids (separation by filtration)
  - Those retaining in filter paper → settleable and nonsettleable solids
  - Solids → evaporation at 105^{0}C for 24 hrs.
  - Volatile solids → escapes at 550±50^{0}C for 30min
  - Fixed solids→ remaining after volatilization

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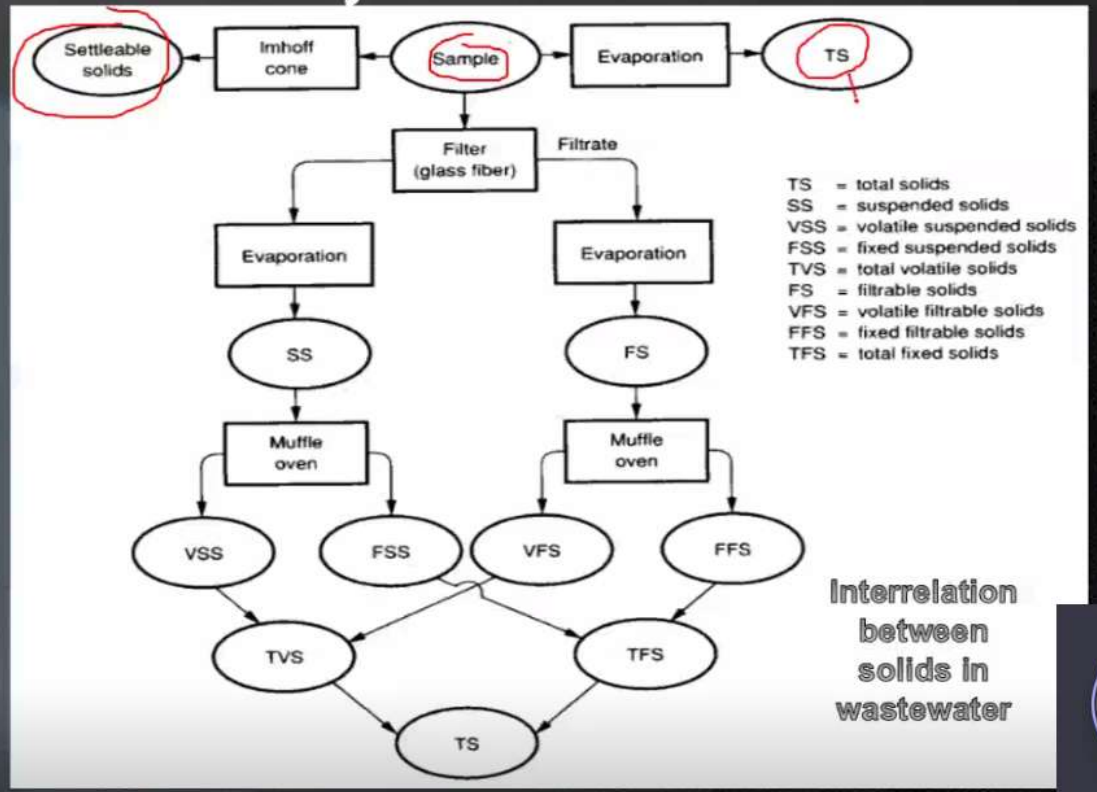
Physical character



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Chemical Character

- Contains simple salts, acids or bases to complex organic compounds for urine, faeces, inorganic chemicals etc.
- Effects in choice or treatments
- Nitrogen compounds, acids, bases, salts, industrial chemicals and cleaning agents, oils, chlorides, Sulphur, metals, toxic substances etc.
- pH, DO, BOD, COD,TOC, etc.

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Chemical Character

- pH:
  - pH = - log [H^+]
  - Normally it is slightly alkaline and has generally 7.3-7.5 pH
  - During decomposition it produces acids and drops pH
  - After oxidation it again becomes alkaline
  - Very low and very high pH indicates industrial or factories' waster

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Chemical Character

- DO (Dissolved Oxygen) :
  - The amount of oxygen dissolved in water that can be used by aquatic life for respiration
  - It indicates the sewage is fresh or not as decomposition takes DO.
- BOD (Biochemical Oxygen Demand):
  - It is oxygen required for the degradation of matters in wastewater by bio-chemical processes
- COD (chemical Oxygen Demand):
  - Amount of oxygen required for the chemical breakdown of waste matters
-

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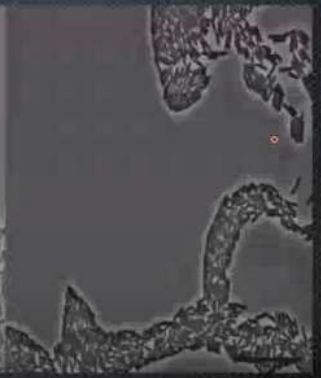
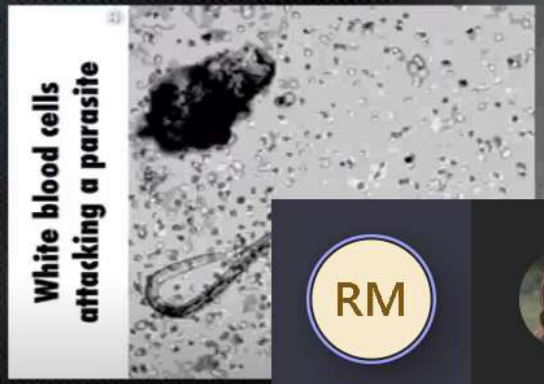
Biological Character

- Biological activity present in waster water
- Beneficial decomposing bacteria in large concentrations
- Pathogens like bacteria, virus, ascariases, helminthiasis, vectors etc.
- Pathogens form waste of sick people
- Indicator organisms are present due to containing of excretes





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Biological Character

- Micro organism can be broadly classified as
  - Aquatic plants: waterweeds, algae, etc
  - Aquatic animals: fish, snails, worms, etc
  - Aquatic fungi, bacteria, virus: microorganisms and pathogens
  - Bacteria needing free or dissolves oxygen to respire is called aerobic bacteria and those that can derive oxygen form other combined molecules are anaerobic bacteria and those that can behave as aerobic and anaerobic is facultative
  - Decomposition is possible due to these beneficial bacteria

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Sampling of sewage

- Collection of true representative sample of the sewage
- To determine its characteristics or quality
- Classified as
  - Grab Sample: taken at a point beneath the surface where thorough mixing is there. It represents the condition of sewage at that location at that time. Used for DO, pH, Chlorine, tempt., etc
  - Composite Sample: most of the time grab sample is not enough to represent its character, so no. of grab sample from different location and time are taken to and mixed to their weightage

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10:51 84%

Sampling of sewage

Recording is saved in the chat history. Learn more

- Preservatives and storage:
  - To preserve the character of the sewage and avoid changes that occurs in time of transport and before test
  - Chloroform, sulfuric acids, formaldehyde etc. are use as preservatives
  - Depends on type of test
  - Chloroforms are avoided for organic matters and grease tests
  - No preservatives are used for BOD and bacterial analysis
  - Storage is done in cold and below 0 ^{0}C for long storage
  - For bacterial analysis, storage is done near to 4^{0}C
  - Fresh sewage is to be analyses as soon as possible and to represents the most.

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Sampling of sewage

- Sample bottles must be clean and no contamination in it (phy,che,bio)
- Sample must contain
  - Source
  - Date
  - Time
  - preservatives used
  - Collector identity
  - Temperature
  - Atmospheric pressure

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COD Chemical Oxygen Demand

- Involves acid oxidation of waste matters by potassium dichromate
- Test of BOD needs 5 days but COD in hours
- For treatment plants as time required to test is low
- Suitable for organic matters present in industrial wasters having compounds that are toxic to biological life
- COD and BOD has no clear relation between them as it differs for matters in waste water

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10:59 83%
BIMLESH KUMAR JHA started recording

BOD Bio chemical Oxygen Demand

BIOCHEMICAL PROCESS

Organic matter + O_2 -> CO_2 + H_2O

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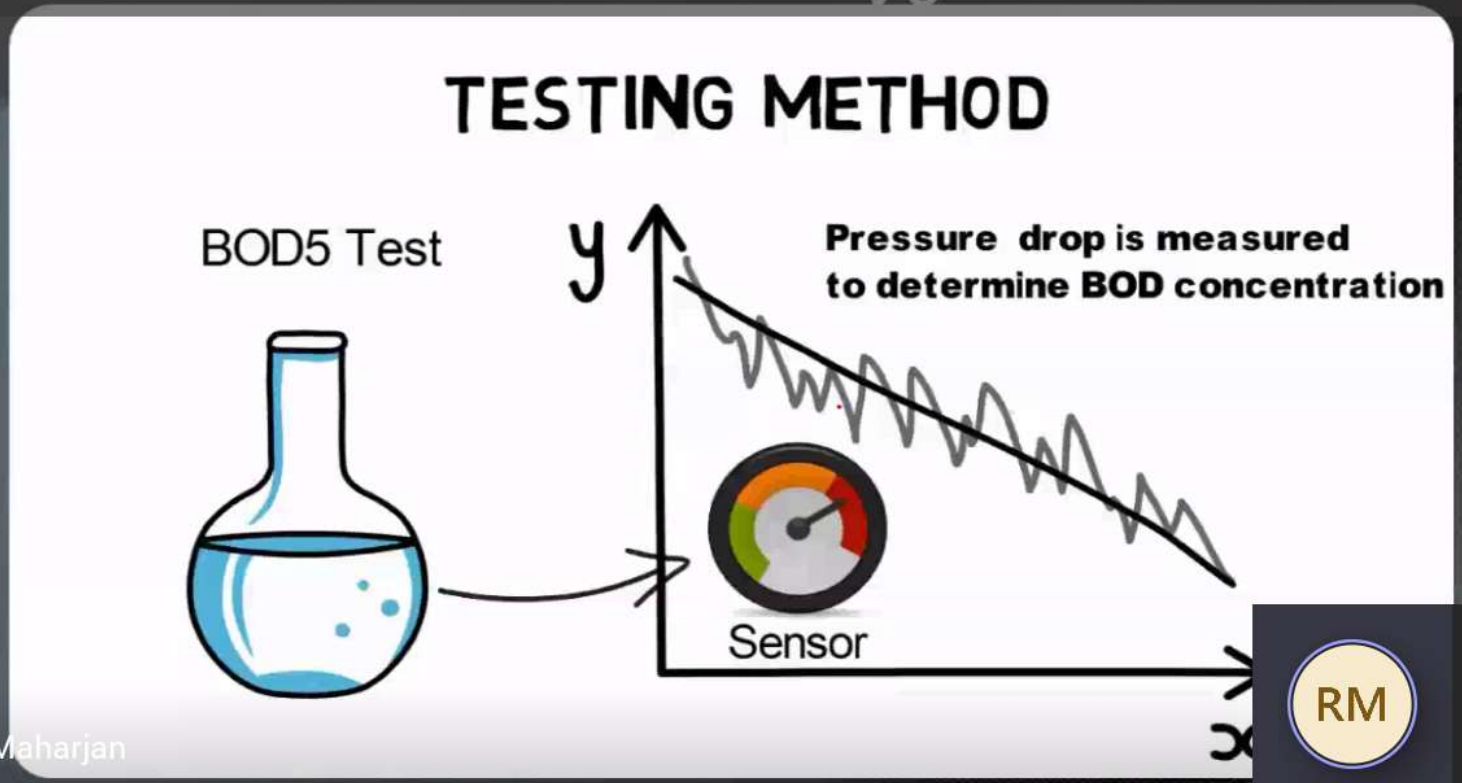
11:00 83%
BIMLESH KUMAR JHA started recording

BOD Bio chemical Oxygen Demand



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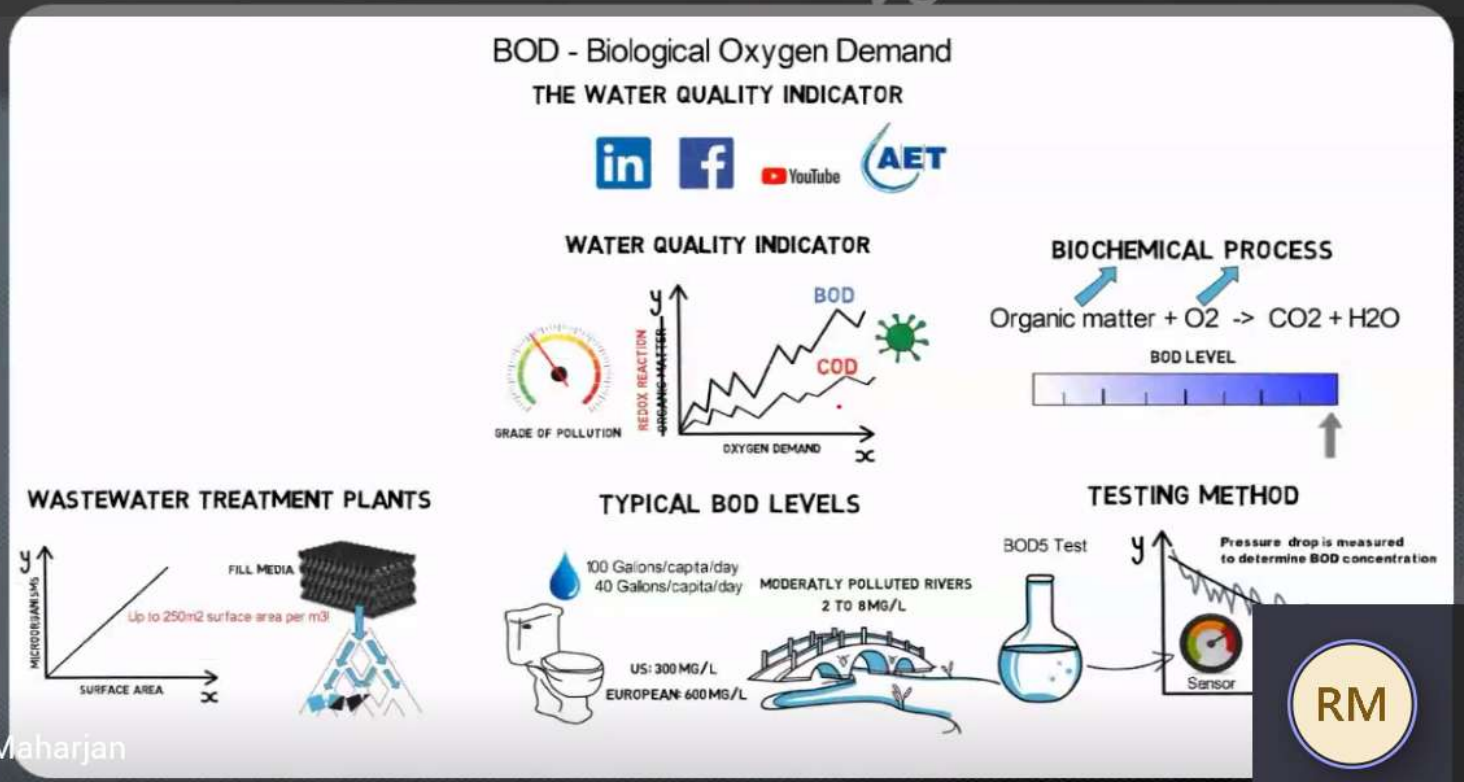
11:01 82%

BIMLESH KUMAR JHA started recording

BOD Bio chemical Oxygen Demand



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BOD Bio-chemical Oxygen Demand

- Oxygen required of bio chemical decomposition of organic matters in aerobic condition
- Indicates the aerobic biodegradable matters in sewage
- More BOD more oxygen needed
- If disposed without removal, water DO will get reduced significantly
- 2 stage of oxidation :
  - Carbonaceous Demand (7-10 days or more)
  - Nitrification Demand (very long period to stabilize)

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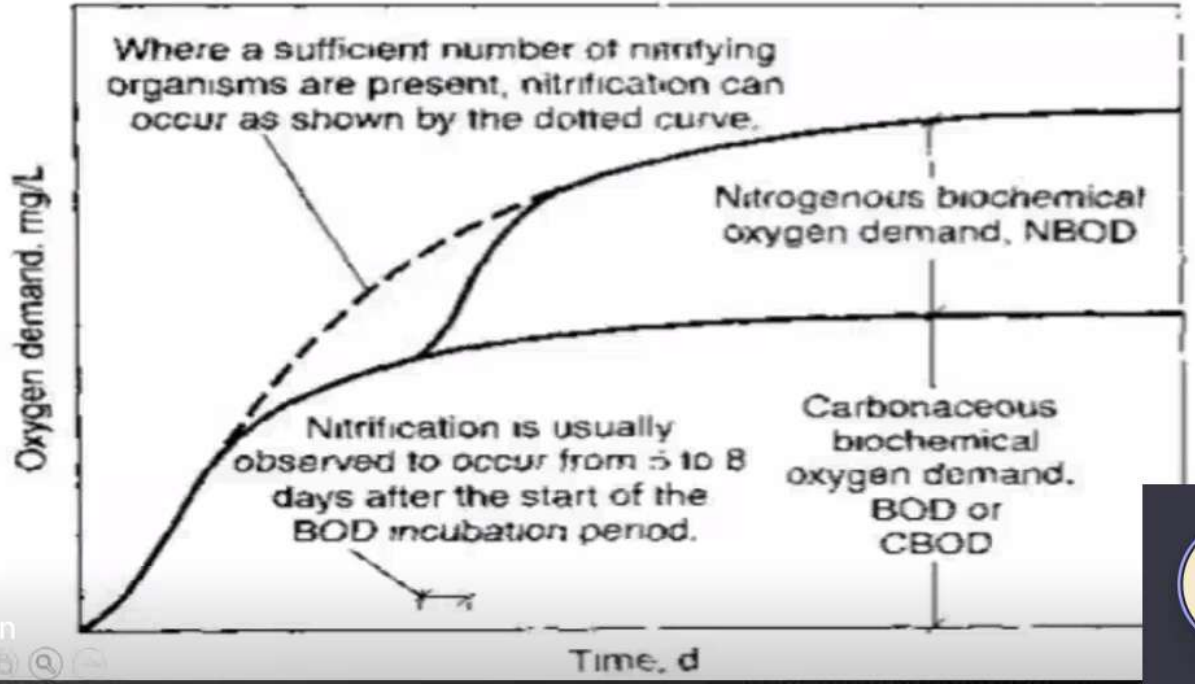
BOD Bio-chemical Oxygen Demand

Why BOD test is conducted for 5th day



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BOD Bio-chemical Oxygen Demand

- Complete BOD analysis is impractical so 5 days BOD at 20^0C is taken
- About 70-80% BOD is shown in 5 days
- Biodegradable matters are estimated so for other COD is used

- If t = time in days

  L_0 = initial BOD or Oxygen equivalent organic matters in water

  L_t = amount of remaining at time 't'

  Y_t = amount of BOD oxidized.

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Expressions of BOD

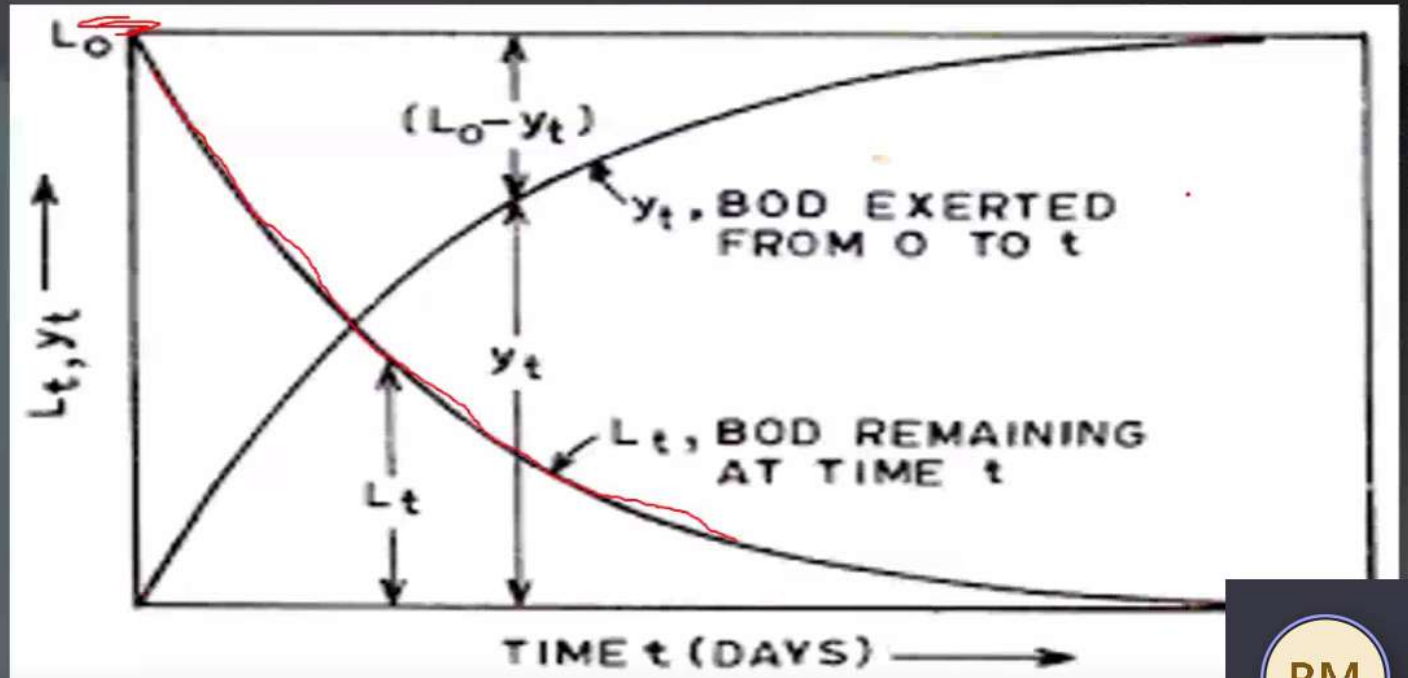

Fig. 8.8 First-stage BOD curve

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Expressions of BOD

- Mathematically,

$$\boxed{\frac{dL_t}{dt} \propto L_t \text{ or } \frac{dL_t}{dt} = -K_D\, L_t}$$ (negative indicates the decreasing rate)

K_D is the BOD rate constant or deoxygenation constant signifying the rate of oxidation of organic matter per day

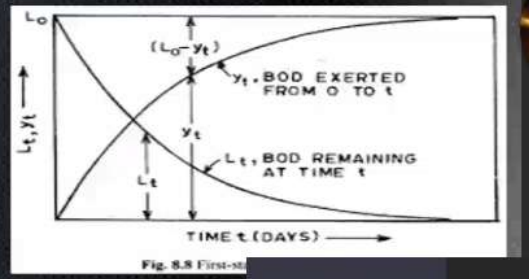

Fig. 8.8 First-st

$$\text{or, } \frac{dL_t}{L_t} = -K_D\, dt$$

On integration, $\int \frac{dL_t}{L_t} = \int -KD\, dt$

$$\text{or, } \log_e L_t = -K_D\, t + C$$

If $t = 0$ then, $L_t = L_0$ then gives $C = \log_e L_0$

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Expressions of BOD

Now using value of C,

$$\text{or, } \log_e L_t = -K_D t + \log_e L_0$$

$$\text{or, } \log_e \left(\frac{L_t}{L_0}\right) = -K_D t$$

If $\log_e x = 2.303 \log_{10} x$ then,

$$2.303 \, \text{Log}_{10} \left(\frac{L_t}{L_0}\right) = -K_D t$$

$$\text{Log}_{10} \left(\frac{L_t}{L_0}\right) = \frac{-K_D t}{2.303}$$

Putting $K = \frac{-K_D}{2.303}$ K is base 10 BOD rate constant

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Expressions of BOD

Now,

$$L_t = L_0\, 10^{-K t}$$

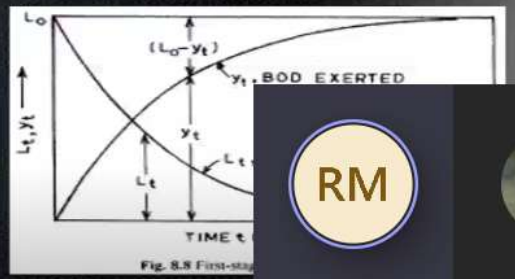
This is the equation of the amount of oxygen equivalent of remaining organic matter to be oxidized or BOD at time 't'

For total BOD exerted or oxidized is given by

$$Y_t = L_0 - L_t \quad = \quad L_0 - L_0\, 10^{-K t} \quad = L_0 \left(1 - 10^{-K t} \right)$$

BOD at time 't' is

$$BOD_t = Y_t = L_0 \left(1 - 10^{-K t} \right)$$



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Expressions of BOD

Now, for 5 days BOD

$$BOD_5 = L_0 \left(1 - 10^{-K t} \right)$$

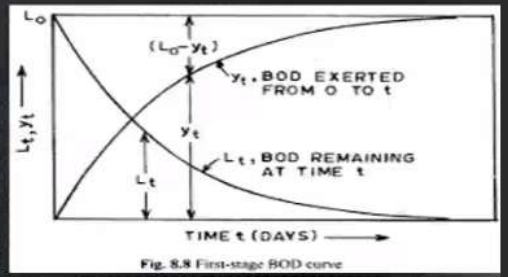

Fig. 8.8 First-stage BOD curve

For ultimate stage, $t = \infty$, $BOD_u = Y_u = L_0$

At 20^0C $K_{20}{}^0{}_C =$ 0.1/ day (base 10) and
0.23/day (base e)

$$K = K_{20}{}^0{}_C \, (1.047)^{T-20}$$

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Test on Sewage

- Physical test
- Chemical test
- Biological test

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Physical Test

- Temperature
- Color
- Odor
- Turbidity

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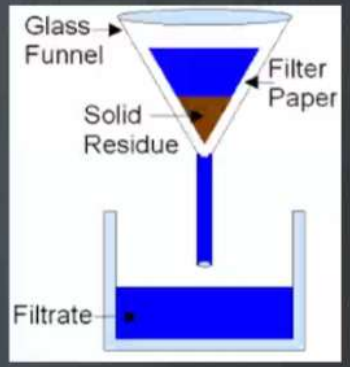
Chemical Test

- pH
- Solid test
  - Determination of TS, TSS, TDS, TVS, TDS, and SeS and NSS



- Dissolved Oxygen test – Winkler's method of titrati

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Chemical Test

- COD test
  - Potassium dichromate + Conc. Sulphuric acid + water sample
  - Boil for 2 hrs with silver sulphate
  - Titrate with ferrous ammonium sulphate for find remaining dichromate
  - Calculate COD with oxygen used from Dichromate

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Chemical Test

- BOD test
  - Direct method:
    - Enclosed vessel where sample and O_2 is kept and CO_2 absorption mechanism is there and O_2 consumed is directly measured (manometrically)
  - Dilution method
    - Sewage is diluted with saturated distill water and kept in air tight vessel or BOD bottle (2 SETs)
    - 1 set is measure for DO and other kept at 20^0C for 5 days
    - 2nd set is measured for DO in 5th day
    - Difference in DO is DO consumed
    - BOD_5 is DO consumed x dilution factor

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Biological Test

- Not so important (common knowledge)
- It is waste from domestic and other places so definitely contains bacteria, virus, worms etc.
- But absence of biological factors means waster water has harmful chemicals in it which needs proper treatment
- Tests are similar in water supply engineering

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Decomposition of Sewage

- Biological and chemical decompositions
- Organic matters in sewage are bio decomposition
- Food for bacteria –Nitrogenous and carbonaceous matters
- Output- CO_2, CH_4, NO_3, N_2, H_2S etc.
- Output depends on types of decompositions and biochemical reactions

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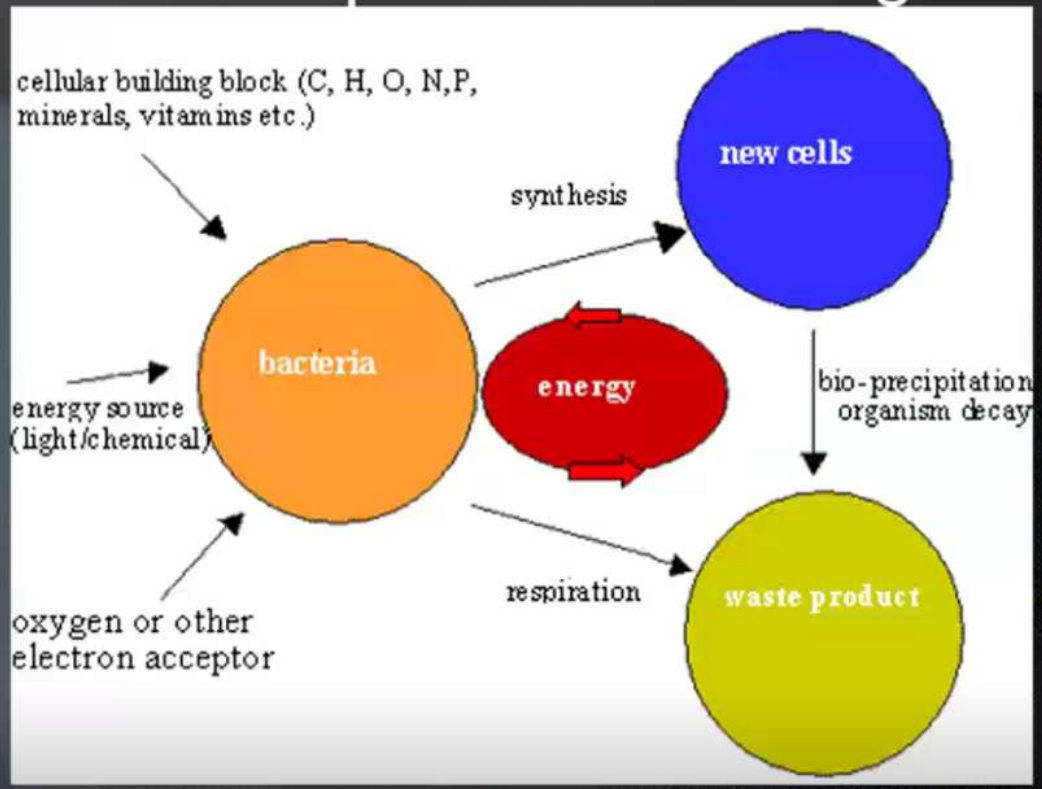
Decomposition of Sewage



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Decomposition of Sewage

Aerobic

- Needs O_2
- CO_2, NO_3, sulphates etc.
- Trickling filter, aeration tanks etc

Anaerobic

- Oxygen in other form
- CH_4, H_2, N_2, H_2S etc.
- Septic tank, sludg digestion tanks et

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Examples

- 4ml of raw sample is pipetted into 300 ml bod bottle and was filled completely filled with distilled water. DO initially was 9.5mg/l and after 5 days in incubation 20^0C it was 6.5mg/l. calculate the BOD_5 of sample.

- DO changed =
- DO consumed =
- Dilution Factor = Total volume / sample volume
- BOD_5 of sample =

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Examples

- Determine the 1 day BOD and ultimate first stage BOD for a waste water whose 5 day BOD at 20^0C is 200 mg/l. assume that K (base e) = 0.23/day

- K (base 10) = K (base e) /2.303 =

$$BOD_t = Y_t = L_0 \left(1 - 10^{-K\,t} \right)$$

- If time t= 5 days, BOD_5 = 200mg/l then, L_0 =
- BOD_1 =

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INTRODUCTION

- Sewer carry 0.1% solids and 99.9% water
- Must carry wastewater as designed through it safely
- Must have capacity in carrying high flow through it without spilling
- Must convey wastewater in safe velocity to not cause scour and breaks and leaks due to water force
- Must not get sediments deposited in sewer in low flow or low discharge
- Generally is designed as gravity flow for easy operation and open channel flow, so downward slope is to be maintained

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SHAPE OF SEWERS

- Requirements to be met for design:
  - In low flow, must have enough velocity to avoid silting
  - In high flow, must have enough freeboard (maintain open channel)
  - Ease in operation and maintenance
  - Structurally safe
  - Economic

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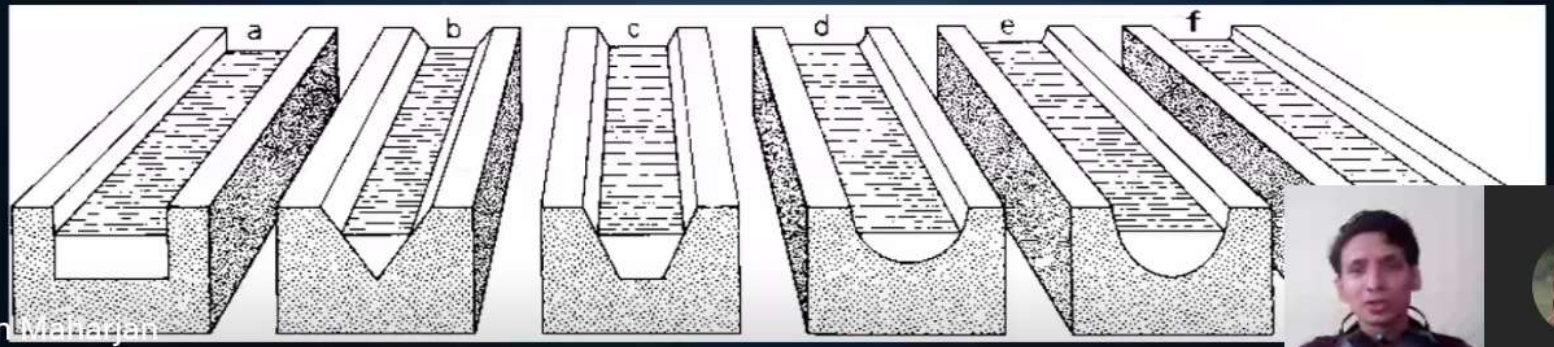
SHAPE OF SEWERS



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SHAPE OF SEWERS

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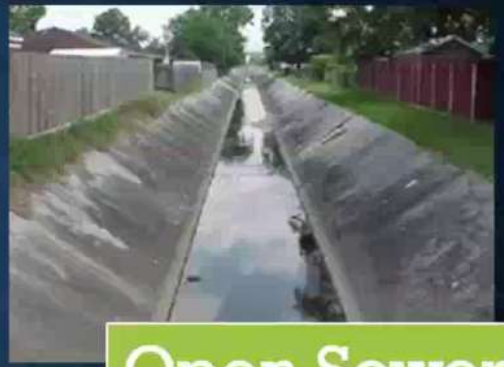
SHAPE OF SEWERS

- Shapes can be of various types from simple triangular or angular, rectangular, circular, parabolic, egg shape, elliptical, etc.
- Are of 2 types, Open sewer and Closed sewer
- Open sewer can be known as drains and generally carry storm waters
- Closed sewers have cover on top as on side of roads or a pipe sections as concrete pipes.



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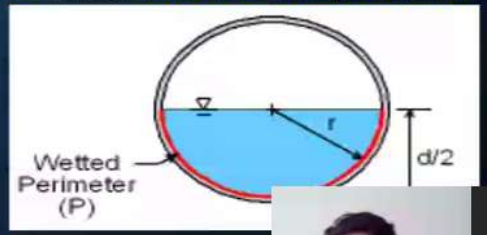
SHAPE OF SEWERS

- **Circular Sewer** : most commonly used
  - ❑ Merits
    - ➢ Hydraulically efficient shape, i.e. has least wetted perimeter to wetted area in other shapes and hence yields higher discharge
    - ➢ Cornerless so no depositions in corners
    - ➢ Easy to work with, can take external loads and utilize minimum materials to make
    - ➢ Stable and easy in laying
  - ❑ Demerits
    - ➢ In combined system, deposition is there in DWF, (hard maintain self-cleansing velocity)



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SHAPE OF SEWERS

- **Rectangular section**: is build by concreting base and sides of masonry brick with plaster and now a days sides and base are concreted insitu or pre casted. Its closed by cover or pre casted a rectangular pipe sections.
  - ❑ Merits
    - ➢Stability and ease in construction
  - ❑ Demerits
    - ➢Not good in hydraulically efficiency
    - ➢Silting in corner is there

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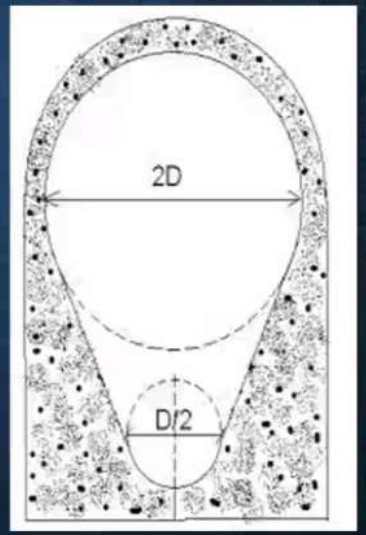
SHAPE OF SEWERS

- **Egg shaped Section**: has smaller radius at bottom and larger in top.
- Used for combined system or having drastic difference in low and high flow through it.
  - ❑ Merits
    - ➢Hydraulically efficient
    - ➢Used in combined system
    - ➢Maintain self-cleansing velocity
  - ❑ Demerits
    - ➢Difficult in construction
    - ➢Need proper handling and support i.e. not stable.



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SEWER MATERIALS

- **Good sewer materials**:
- Resistance to corrosion and abrasion due to impurities
- Durable and strong to hold external loads
- Structurally safe and hydraulically efficient
- Ease to work with or workability
- Water tight and no or very little leaks (leak in or leak out)
- Impervious to avoid water seepage though it
- Economic

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SEWER MATERIALS

- **Types of sewer materials**:
- Plain or reinforces concrete cement
- Asbestos cement
- Vitrified clay or stone ware
- Plastic
- Cast iron
- Brick
- Steel

Asbestos fifers in cement

Vitrified clay pipes

Brick Sewer

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SEWER MATERIALS

- **Vitrified clay:** manufactured from clay and shale vitrified in high temperature and has smooth surface. Generally used for house drains and laterals

❑ Merits

- ➢ Smooth and hard surface so less scour and abrasion
- ➢ Hydraulically efficient due to smoothness
- ➢ Resistance to sulphids and most acids
- ➢ Cheap and available

❑ Demerits

- ➢ Weak in tension and brittle
- ➢ Need proper handling

Vitrified clay pipes

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SEWER MATERIALS

- **Cast Iron**: manufactured form cast iron. Generally used for wet grounds, excess vibrations, external loads, expensive roads, etc.
  - ❑ Merits
    - ➢ Strength and handles vibration, internal and external pressure
    - ➢ Tensile, bending and compressive strength
    - ➢ Water tight and use for syphon and pumping
  - ❑ Demerits
    - ➢ Heavy and transport and handling is difficult
    - ➢ Expensive
    - ➢ Cause corrosion and rusting

Cast iron pipes

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SEWER MATERIALS

- **Plain or Reinforced Concrete**: manufactured precast or cast in-situ. Generally used pipe or may be open drains.
  - ❑ Merits
    - ➢ Resistance to corrosion and abrasion
    - ➢ Cheap and available
    - ➢ Good for external loads
    - ➢ Workability for in-situ casting
    - ➢ Low thermal expansions
  - ❑ Demerits
    - ➢ No pressure flow/low internal pressure
    - ➢ Low strength in tension and brittle
    - ➢ Good handling required and crown corrosion

Insitu casting drains

Concrete Cement pipes

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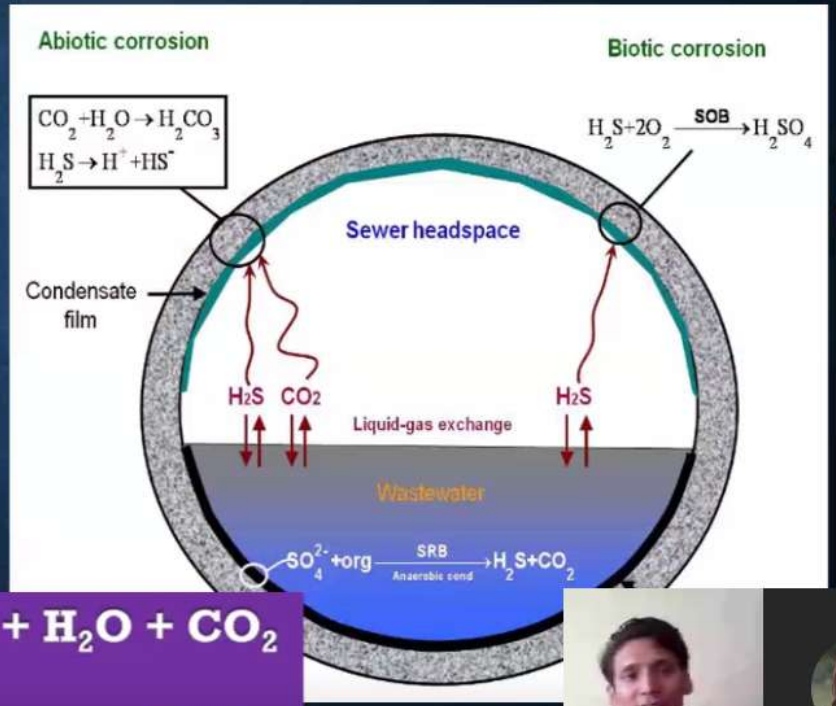
SEWER MATERIALS

- **Crown corrosion:**

H_2S gas in atmosphere makes contact with slime in the crown of the sewer , which contains more bacteria. Bacterial action converts,H_2S gas to sulphuric acid which causes corrosion in the crown of the pipe and this corrosion is also called crown corrosion



$$SO_4^{--} + \text{organic matter} \xrightarrow[bacteria]{} S^{--} + H_2O + CO_2$$

$$S^{--} + 2H^+ \rightarrow H_2S$$

$$H_2S + 2O_2 \xrightarrow[bacteria]{} H_2SO_4 \text{ (causing corrosion)}$$

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SEWER DESIGN CRITERIA

- Quantity of sewage (calculation of discharge)
  - Design period (25-30 yrs)
  - Water supply and usage calculation per capita
  - Population forecast as in water supply
  - Calculation of total flow (DWF & WWF)
- Select the sewer system and calculate quantity to be conveyed (separated, partially combined or combined)
- Select sewer shape and type (open or closed and shape of sewer and material type)
- Sewer size (15cm, 20cm, 25cm, 30cm,.....max of 3 m)
- Sewer gradient ranging from 1:100 to max of 1:20 to maintain gravity flow and minimum velocity required
- Depth of flow in sewer is 1/2 to 2/3 for full depth
- velocity of flow as to cause no silting and no scouring

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SELF CLEANSING / NON SELLELING / MINIMUM VELOCITY

- If sewer has velocity small enough to enhance the settling of the solids then the settled solids deposits at bottom and corrosion and clogging starts to occur
- Minimum velocity required to maintain the solids in wastewater in suspension or continuous flow
- May not be maintained all time but must be maintained once a day
- So velocity at peak flow must be greater than or equal self cleansing velocity
- Generally taken 0.6-0.9m/s for separate and taken 0.75m/s for combined system
- In flat areas 0.4 m/s in maintained and flushing tank is r
  periodically cleaning in sewer

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SELF CLEANSING / NON SELLELING / MINIMUM VELOCITY

- Mathematically given by Shield formula:

$$V_s = \sqrt{\frac{8K}{f}(G_s - 1)gd_s}$$

- Where,

❖ V_s = self cleansing velocity

❖ K = dimensionless constant depending on type of solids (0.04-0.3)

❖ f = Darcy's friction factor taken as 0.03

❖ G_s = sp.gr. of solid in sewer (1.2 organics – 2.65 inorganics)

❖ g = acc. due to gravity 9.81 m/s^2

❖ d_s = avg. diameter of solid particles in m

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SELF CLEANSING / NON SELLELING / MINIMUM VELOCITY

Diameter of sewer (mm)	*Minimum or self-cleansing velocity (m/s)*
150 to 250	1.00
300 to 600	0.75
Above 600	0.60

Type of material	*Velocity required to move (m/s)*
Angular stones	1
Round pebbles (12 mm to 25 mm diameter)	0.5 to 0.6
Fine gravel	0.3
Coarse sand	
Fine sand	
Fine clay and silt	

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NON SCOURING / LIMITING VELOCITY

- Maximum velocity that can be used avoiding scour and abrasion of the sewer materials
- Depends on the sewer material type
- Generally max of 3m/s is taken
- For hilly areas gradient gives higher velocity and to counter that drop manholes are used to check velocities and gradients

Sewer material	*Non-scouring or Limiting Velocity (m/s)*
Vitrified tiles and glazed bricks	4.5 to 5.5
Cast iron sewers	3.5 to 4.5
Stone ware sewers	3.0 to 4.0
Cement concrete sewers	2.5 to 3.0
Ordinary brick-lined sewers	1.5 to 2.5
Earthen channels	0.6 to 1.2

HYDRAULIC DESIGN FORMULAE

- Discharge $Q = AV$
- Velocities Chezy's formula $v = C\sqrt{RS}$ use Kutter's or Bazin's formula for C

$$C = \frac{2.3 + \frac{0.00155}{S} + \frac{1}{n}}{1 + \frac{n}{\sqrt{R}}\left(23 + \frac{0.00155}{S}\right)}$$

$$C = \frac{157.6}{1.81 + \frac{k}{\sqrt{m}}}$$

Hazen William's formula $v = 0.85\ C\ R^{0.63}\ S^{0.54}$

Crimps and Burge's formula $v = 83.47\ R^{2/3}\ S^{1/2}$

Manning's formula $v = 1/n\ .\ R^{2/3}\ S^{1/2}$

n = 0.011 – 0.06 and generally 0.014 for concrete pipes

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HYDRAULIC ELEMENTS IN CIRCULAR PIPES

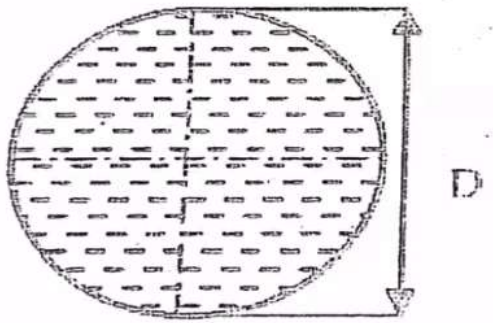

Figure 4.5 Circular sewer running full

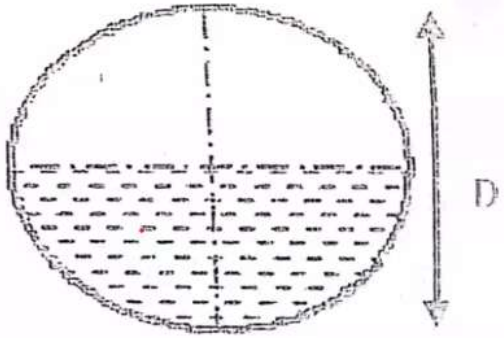

Figure 4.6 Circular sewer running half full

- Circular section running full $R = A/P = \pi D^2/4 / \pi D = D/$
- Circular section running half full $R = \pi D^2/4/2 / \pi D/2$

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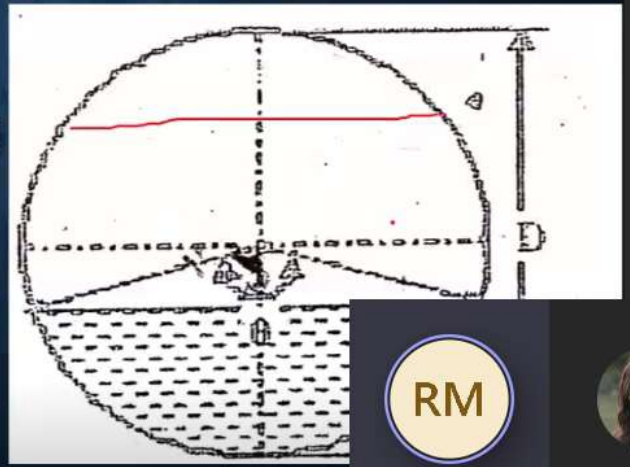
HYDRAULIC ELEMENTS IN CIRCULAR PIPES

- <u>Circular section in partially full</u>

if a, p, r and v be wetted area, wetted perimeter, hydraulic radius and velocity for partially filled

if A, P, R and V be wetted area, wetted perimeter, hydraulic radius and velocity for completely filled then

$$\text{Cos}\,(\theta/2) = \frac{\left(\frac{D}{2}\right)-d}{D/2} \quad \rightarrow \quad d = \frac{D}{2}\left(1-\cos\frac{\theta}{2}\right)$$



Proportional depth $\frac{d}{D} = \frac{1}{2}\left(1-\cos\frac{\theta}{2}\right)$

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HYDRAULIC ELEMENTS IN CIRCULAT PIPES

Proportional area $a = \frac{\pi D^2}{4} \times \frac{\theta}{360} - \frac{D}{2}\cos\frac{\theta}{2} \cdot \frac{D}{2}\sin\frac{\theta}{2} = \frac{\pi D^2}{4}\left[\frac{\theta}{360} - \frac{\sin\theta}{2\pi}\right]$

$$\frac{a}{A} = \left[\frac{\theta}{360} - \frac{\sin\theta}{2\pi}\right]$$

Proportional wetted perimeter $p = \frac{\theta \pi D}{360}$

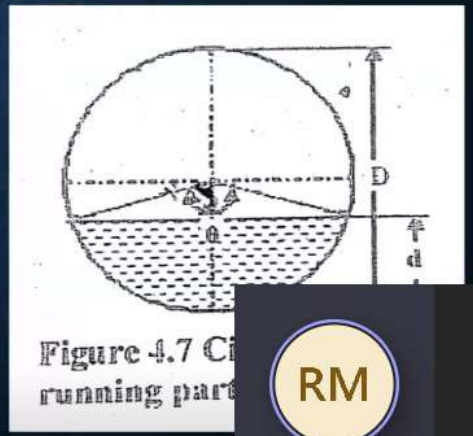
$$\frac{p}{P} = \frac{\theta}{360}$$

Proportional hydraulic mean radius

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

Proportional velocity $v/V = N/n\,(r/R)^{2/3}$

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



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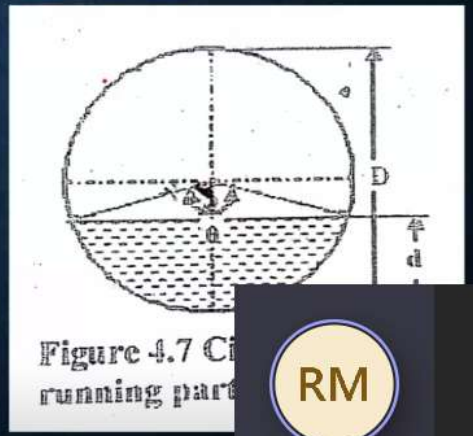
HYDRAULIC ELEMENTS IN CIRCULAT PIPES

if $\frac{N}{n} = 1$, $\quad \frac{v}{V} = \left[1 - \frac{360 \sin\theta}{2\pi\theta}\right]^{2/3}$

Proportional discharge, q = a.v

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

if $\frac{N}{n} = 1$ $\quad \frac{q}{Q} = \frac{\theta}{360}\left[1 - \frac{360 \sin\theta}{2\pi\theta}\right]^{2/3}$



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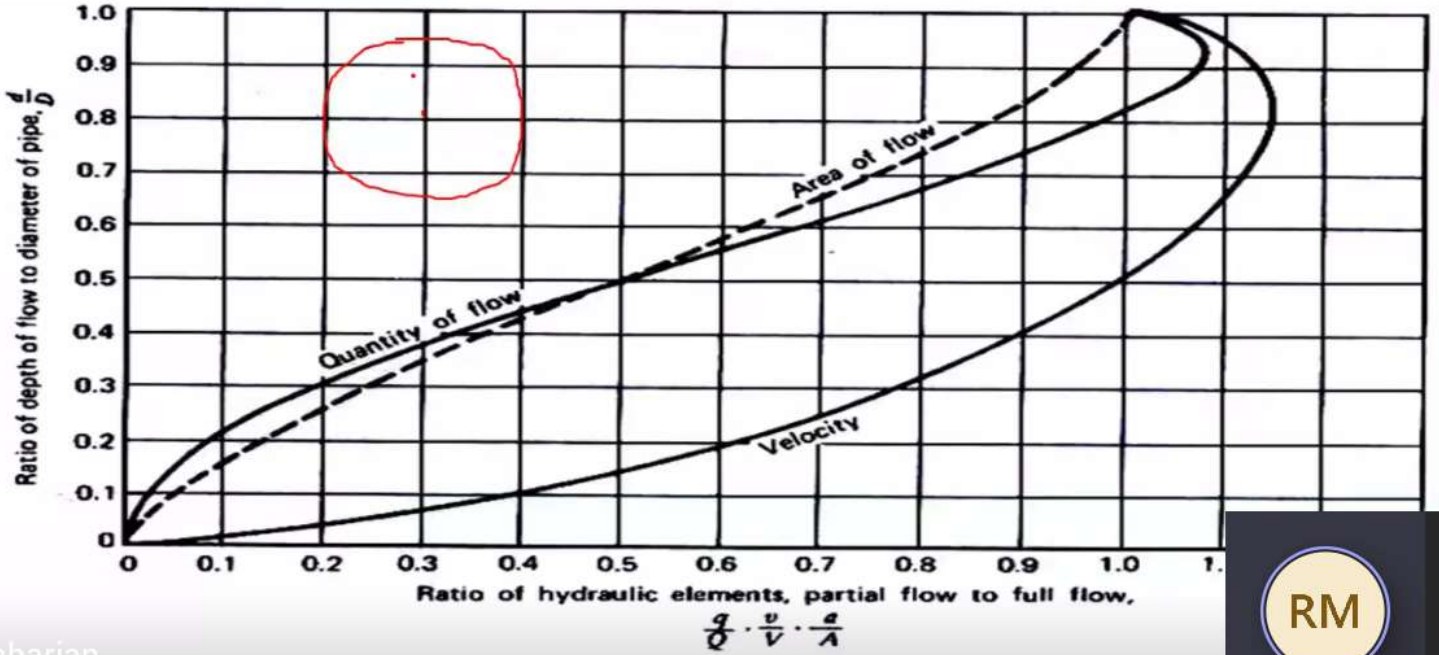
PARTIAL FLOW DIAGRAM

Variation of flow and velocity with depth in circular pipes



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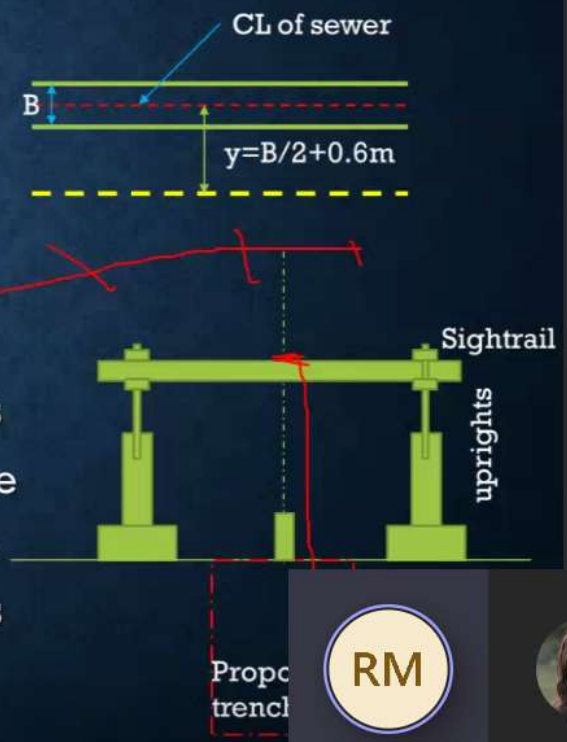
CONSTRUCTION OF SEWER

- Setting out of center line
  - Set form back ends as can be used down stream of sewer during construction
  - Generally manholes are transferred from L-section and topomap and sewers joins manholes
  - Marking Center line peg at 7.5/15m intervals
  - First method : offset line parallel to center line
  - Second method: uprights are driven in 2 side and chord is drawn along CL peg and work is done reference to chord (plan and depth)



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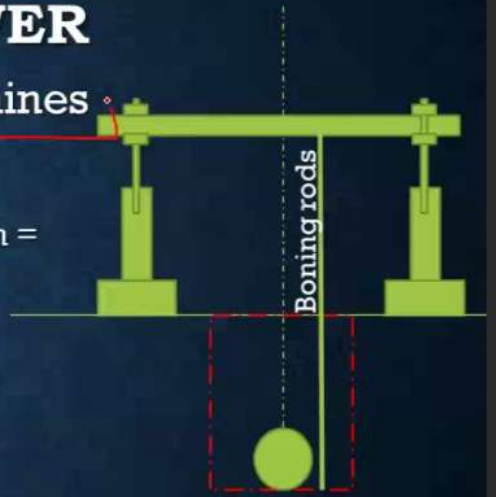
CONSTRUCTION OF SEWER

- Alignment and gradient: use peg and level machines
- Excavation, timbering and dewatering of trench
  - 0.9m height x0.6m width generally if depth increases form 1.5 m = timbering required
- Laying and Joining of pipe
- Testing of pipe:
  - Water test: (after 30mins. loss≤ 2L per cmØ *per Km length*)
  - Air test: (pressure equivalent of 100mm of water and not drop below 75mm of water)
- Back filling : layers of 15 cm is done at a time with watering filling 60cm above crown and left for weather after 1 week compaction and filling are done till 15 cm above ground surface.



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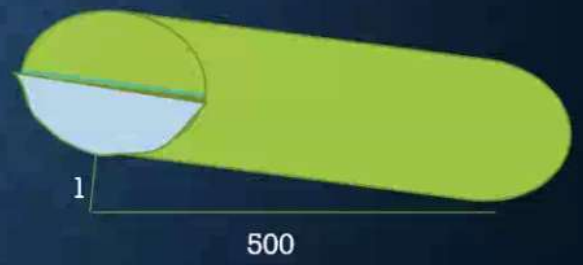
RM

EXAMPLES

- Calculate the velocity of the flow in the sewer running half full. The sewer laid at 1in 500 slopes having diameter of 150cm. Also determine the discharge flowing through the sewer assuming N=0.014 in manning's formula



- Wetted area (A) =
- Wetted perimeter (P) =
- Hydraulic mean radius (R) = A/P =
- $v = \frac{1}{N} R^{2/3} S^{1/2}$ =
- $Q = A \times v$ =

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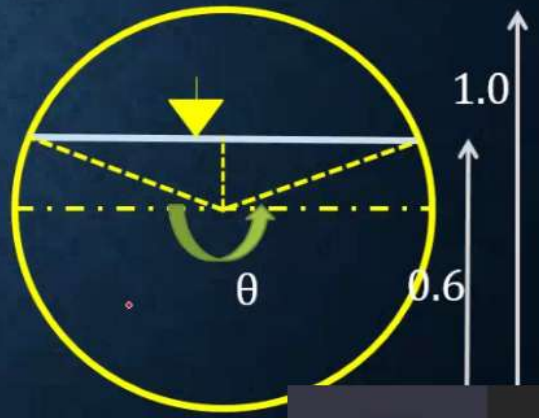
EXAMPLES

- Calculate the velocity and discharge of the flow in the sewer running 0.6m depth. The sewer laid at 1in 500 slopes having diameter of 100cm. Assuming N=0.014 in manning's formula
- Wetted area (A) =
- Wetted perimeter (P) =
- Hydraulic mean radius (R) = A/P =
- $$v = \frac{1}{N} R^{2/3} S^{1/2} =$$

  $$Q = A \times v =$$



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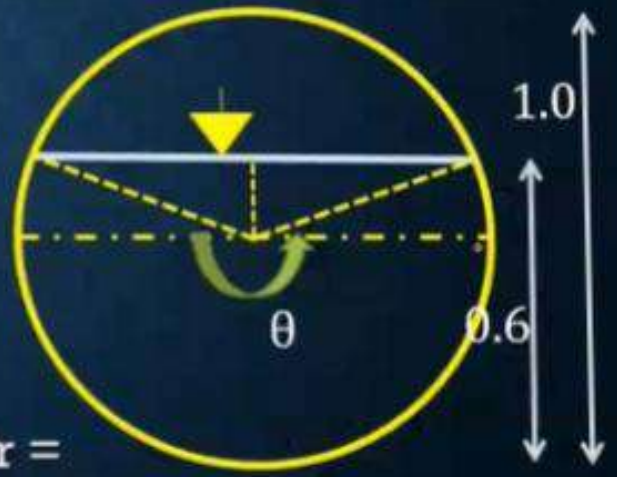
EXAMPLES

- Calculate the velocity and discharge of the flow in the sewer running 0.6m depth. The sewer laid at 1in 500 slopes having diameter of 100cm. Assuming N=0.014 in manning's formula

$$\frac{d}{D} = \frac{1}{2}\left(1 - \cos\frac{\theta}{2}\right) \rightarrow \theta =$$

$$\frac{a}{A} = \left[\frac{\theta}{360} - \frac{\sin\theta}{2\pi}\right] \rightarrow a =$$

$$\frac{p}{P} = \frac{\theta}{360} \rightarrow p =$$



$r = a/p =$

or, $\frac{r}{R} = \left[1 - \frac{360\sin\theta}{2\pi\theta}\right] \rightarrow r =$

- $v = \frac{1}{N} R^{2/3} S^{1/2} = ?$

$Q = A \times v = ?$

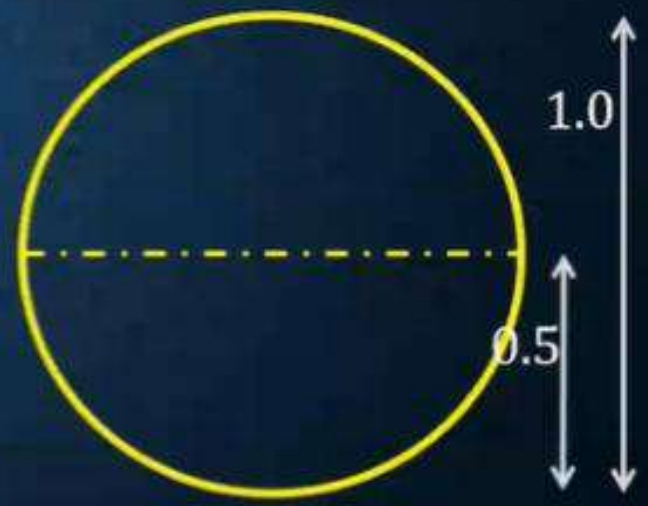
1.587m/s, 0.78m³/s

EXAMPLES

- Find the minimum velocity and gradient required to transport course sand through a sewer to 1.0m dia. the average size of sand particle is 1 mm and specific gravity is 2.65. assume K= 0.1, f = 0.03 , N = 0.013 and assume half flow in sewer

Shields formula

for critical velocity for self cleansing



$$V_s = \sqrt{\frac{8K}{f}(G_s - 1)gd_s} =$$ 0.657

A = P = R = 0.25m

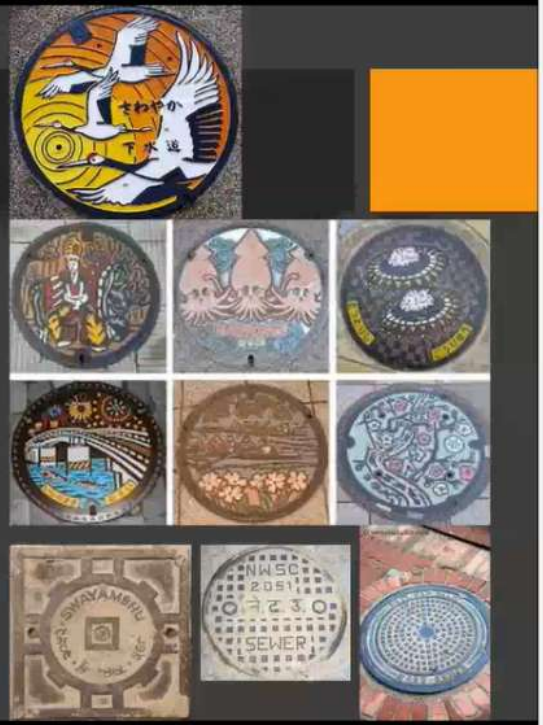
$$v = \frac{1}{N} R^{2/3} S^{1/2} \rightarrow$$:2160

Sewer Appurtenances

Chapter 5

Introductions

- Appurtenances are those structures, that are build in the sewers to help in efficient operation and maintainances
- They are build in regular intervals or places where they are demanded for its functions
- manholes, lamp holes, street inlets, catch basins, flush tanks, traps, syphons, etc.



Meeting chat

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AS AAVASH SUBEDI 10:34
.657 1:2156

BC BIKASH CHAUDHARY 10:34 1
0.657 1:2159

AVISHEK GUPTA 10:34
0.657,1:2150

AASHISH POKHREL 10:34
0.657, 1 in 2157

BB BAMDEV BHANDARI 10:34
.656m/s 1:2157

AP AYUSH PARAJULI 10:34
0.657, 1: 2159

AP ABHISHEK POUDEL 10:35
0.657 m/s , 1:2159

BS BUDDHA SUBEDI 10:35
0.657 1:2159

Meeting

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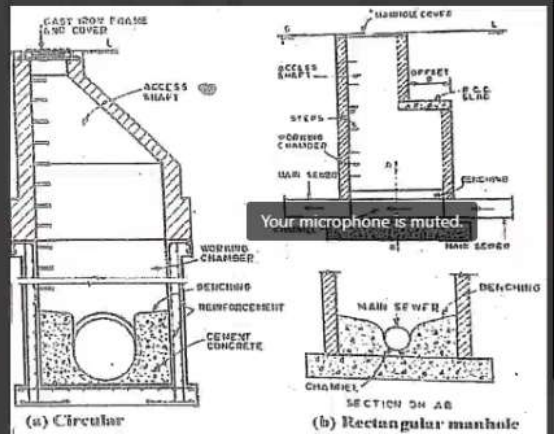
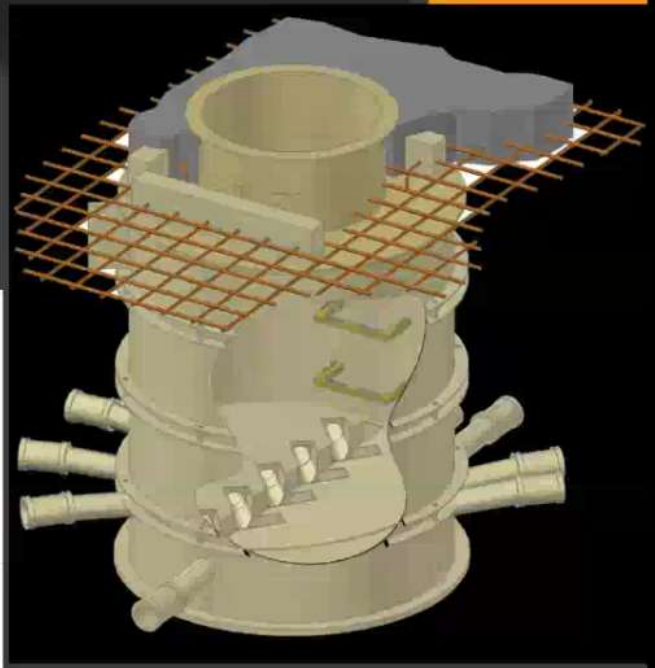
Manholes

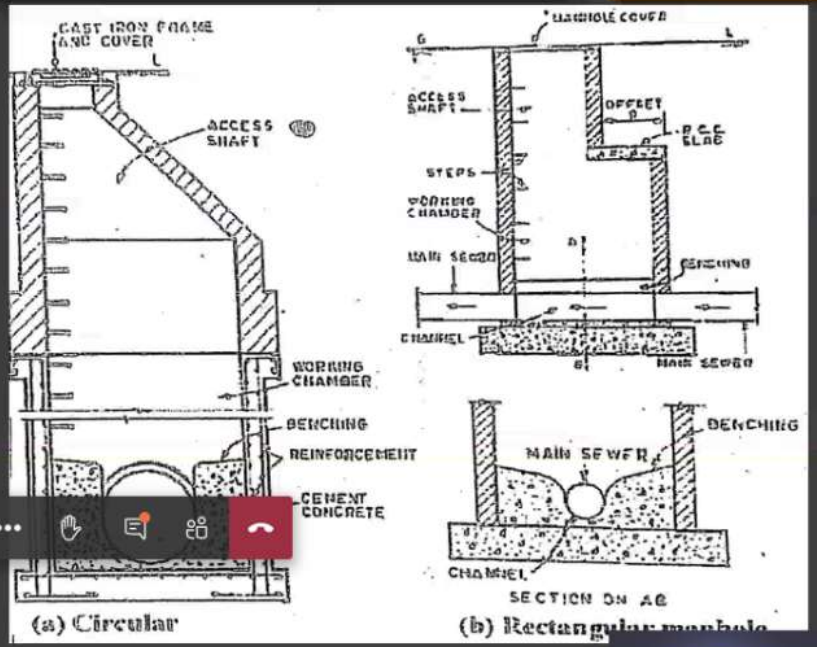
- Masonry or RCC structure of rectangular, square or circular shape along the sewer
- For inspection, testing, cleaning and removal of obstructions form sewer





Manholes

- Objectives of provision:
  - Manual access for inspection, cleansing, testing etc. in sewer
  - Joining sewer lines when change in direction or levels or both
  - Lay sewer in convenient length
  - Ventilation of sewer



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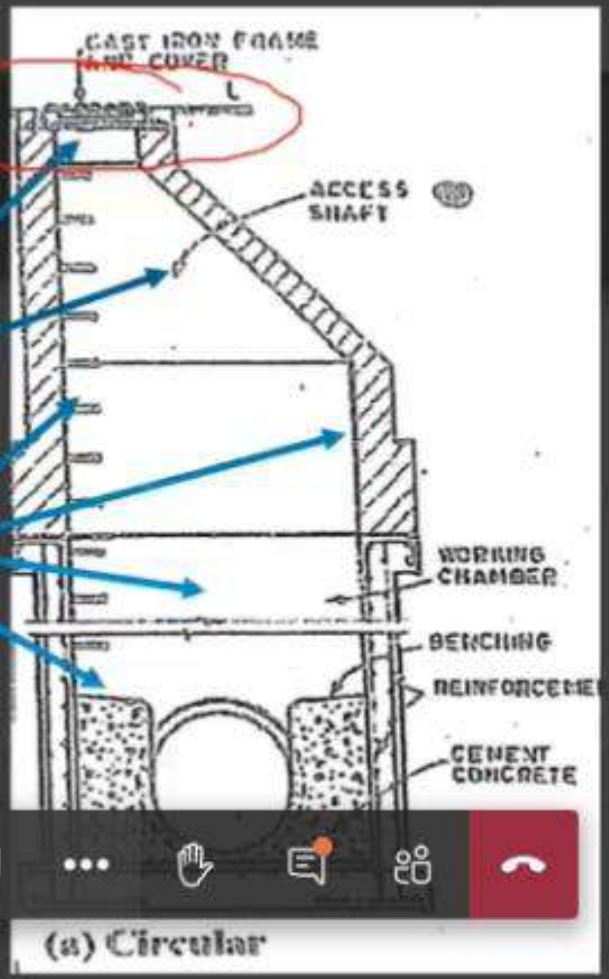
Manholes

- **Components of manholes:**
  - Top cover and Frame
  - Access shaft
  - Working chamber
  - Bottom / benching / invert
  - Side walls
  - Steps or ladders



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Manholes

- **Locations of provision of manholes:**
  - Generally directly over the sewer line at regular interval 45m to 300m
  - At every bends, junctions, change in level of sewer, change in gradient, change in direction, change in size, places of obstructions etc.
- **Spacing of manholes:**

Diameter (m)	≤ 0.3	0.3-0.6	0.6-0.9	0.9-1.2	1.2-1.5	≥ 1.5
Spacing (m)	45	75	90	120	250	300

50:41

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Manholes

- **Construction of manholes**:
  - Top cover and Frame: depth of frame is 20-25 cm and width is 10cm with clear cover of opening be least of 50 cm. top cover with frame weight about 90-270 kg
  - Access shafts: top portion provides access to working area for various purpose. Usually 0.6x0.7m rectangular or 0.6-0.75m dia. circular is provided
  - Working chamber: must be minimum of 0.9x1.2m for rectangular and 1.2m for circular
  - Bottom, invert or benching: made form concrete bed of 150-300mm thick with general 1:6 slope towards center at semicircular or U shaped

Manholes

- **Construction of manholes**:
  - Side walls: minimum thickness of 22.5 cm and depend on type of soil surrounding and the depth of manhole. Generally t = 10+4d is used as thumb rule, t = thickness and d = depth of manhole
  - Steps or ladders: to access the working area safely and easily. Made of CI or steel steps places 30cm apart vertically as ladder

57:38

Classification of Manholes

Shallow Manhole (Inspection Chamber)

- Depth 0.75-0.9m
- Start of the branch sewer with light CI cover

Normal / Medium Manhole

- Depth about 1.5m
- 1x1m square or 0.8x1.2 in rectangular

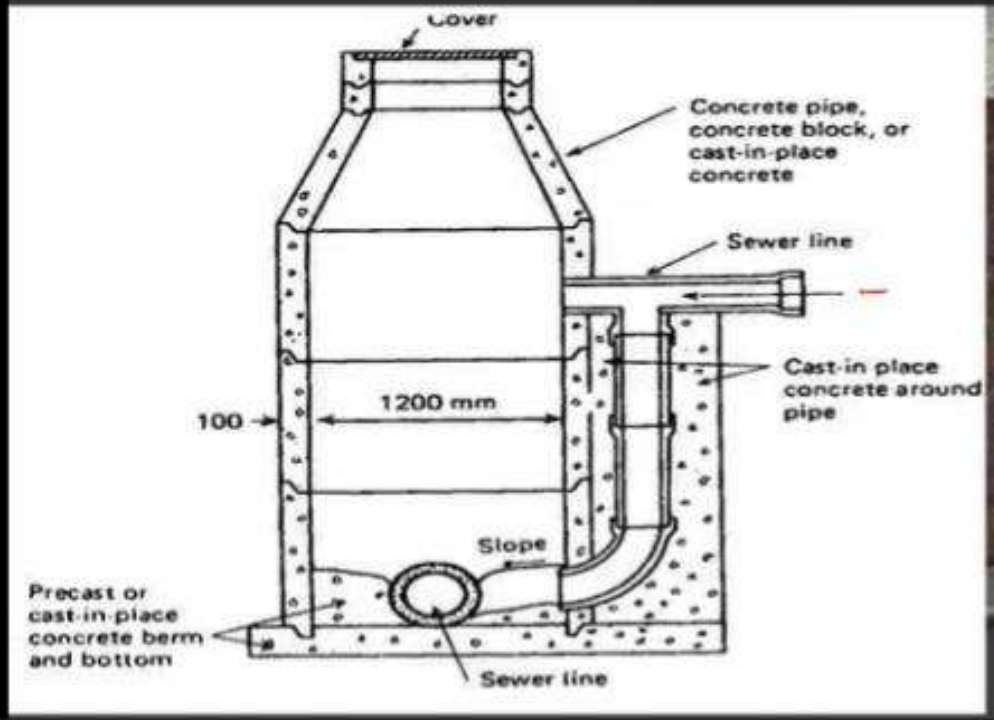
Deep Manhole

- Depth > 1.5m
- Larger at bottom and reduces at top opening

Drop Manholes

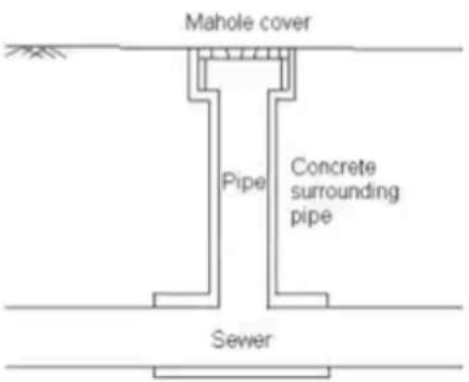
- Manhole connecting two or more of sewer lines at different levels
- Generally 0.5-0.6m above the main sewer line
- It helps to avoid splashing sewage into man working in hole and into side walls
- Facilitates the smooth fall of sewage
- Vertical drop type is common now-a-days

Drop Manholes

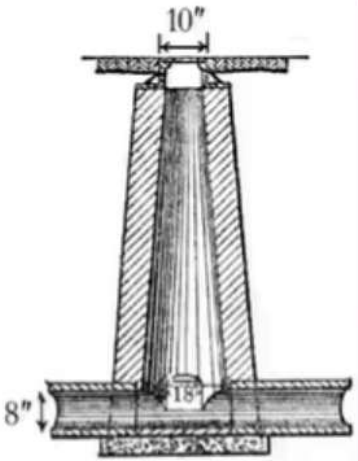


Lamp holes

- Main purpose is to allow laps to be lowered to the sewer so as to inspect it for obstructions
- Adjacent manholes are used to observe light from lamp holes
- Used where manhole placement is not possible/ narrow space, slight curve or change in gradient in between manholes
- Shaft of about 20-30cm dia of CI/RCC/brick with cover at top



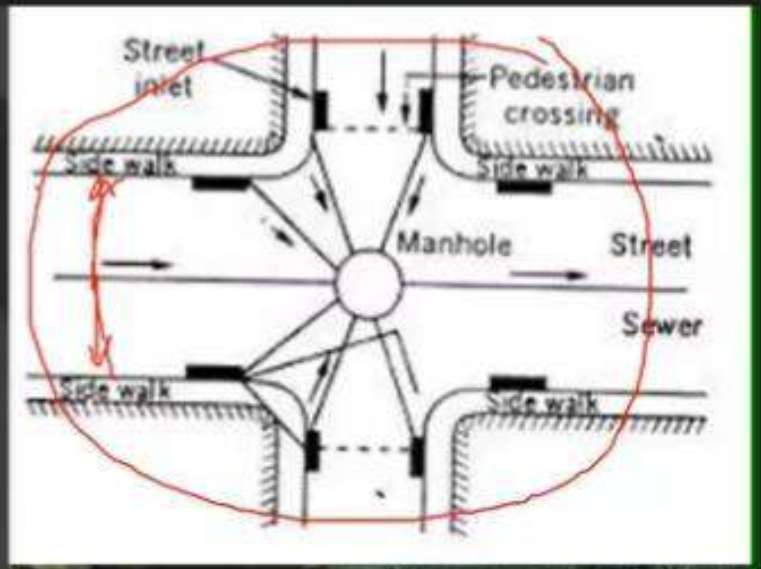
PIPE LAMPHOLE.



BRICK LAMPHOLE.

Street Inlets

- Device or inlet intercepting or collecting storm water or surface wash in streets
- Generally conveys through 25-30cm dia pipes
- Spacing of 100-130m and at every junctions to effectively and efficiently collect the waters



Street Inlets

Curb Inlets Vertical opening on curb with CI/steel bars

- Used for lesser quantity and less sediments are allowed to enter

Gutter Inlet Horizontal Opening with CI or Steel bars

- Large quantity of water

Combined (curb and Gutte

- Larger quantity of water

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bin Maharjan

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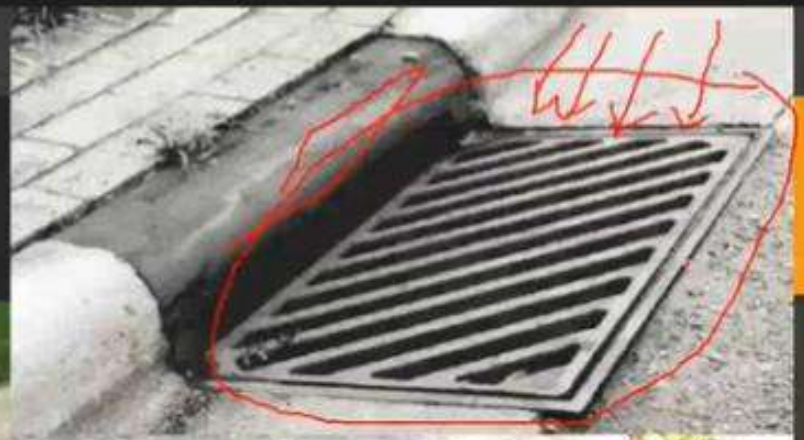
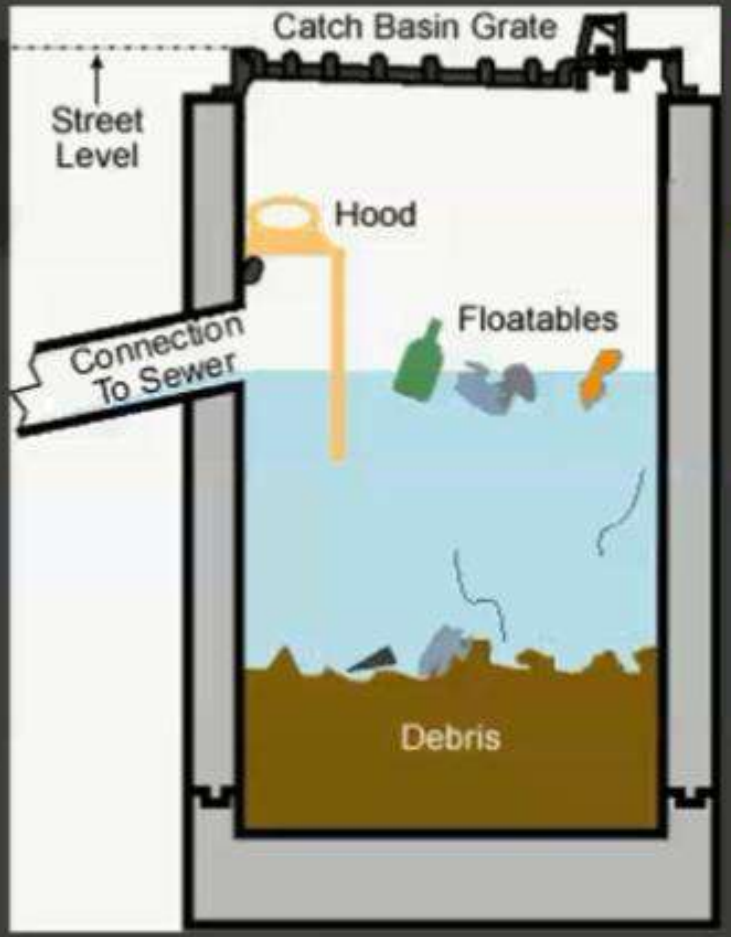
Search

Street Inlets



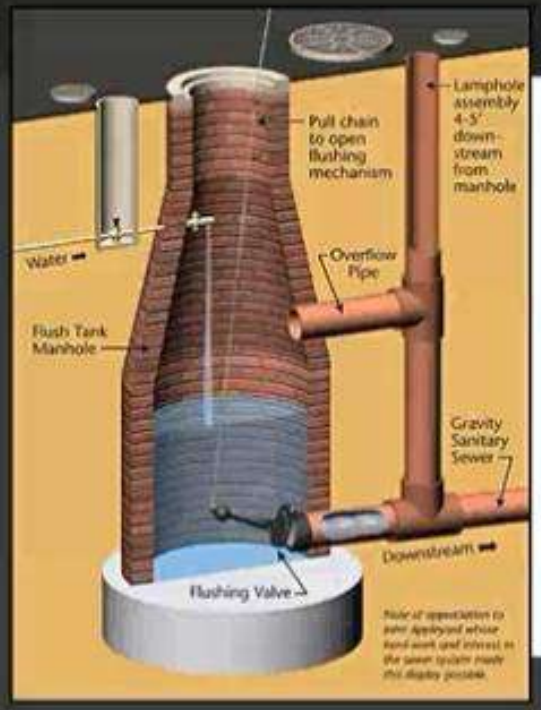
Catch basins or pits

- RCC / Masonry chamber below the street inlet to avoid flow of grit, sand and debris to the sewer
- Depth of 600-750mm and dimension of 600-900mm rectangular or square
- Sewer is about 60cm above the bottom of pit to avoid sediments
- Used in places of high debris and sediments



Flushing tanks

- Sewer get clogged due to debris and sediments as lack of self-cleaning in flat gradients
- Tanks use to flush the clogs of sewer is flushing tank
- Manual or automatic usually 2 -3 times a day



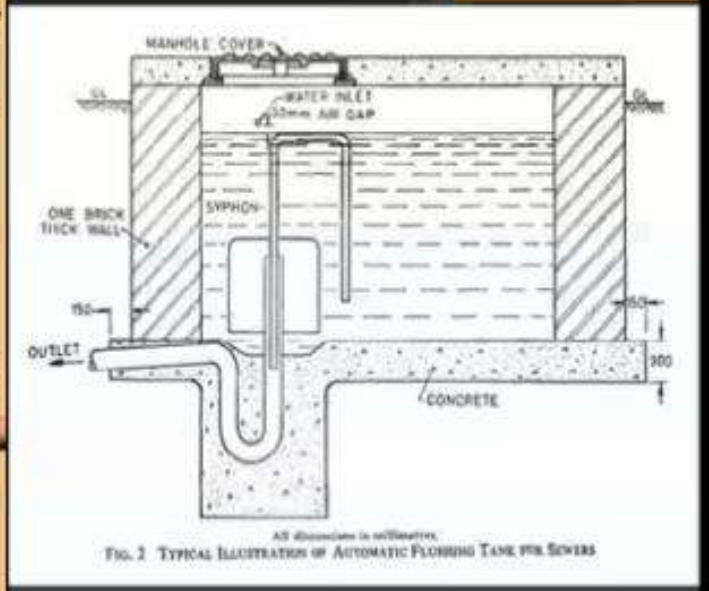
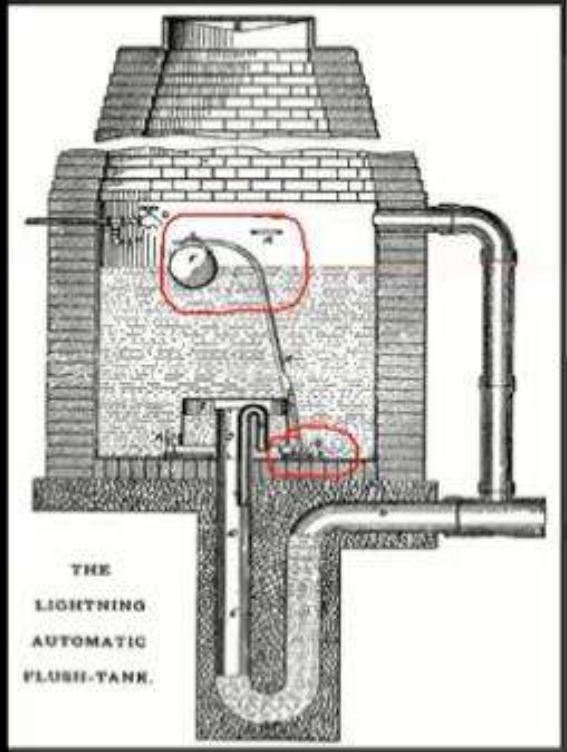


Fig. 2 Typical Illustration of Automatic Flushing Tank for Sewers

Flushing tanks



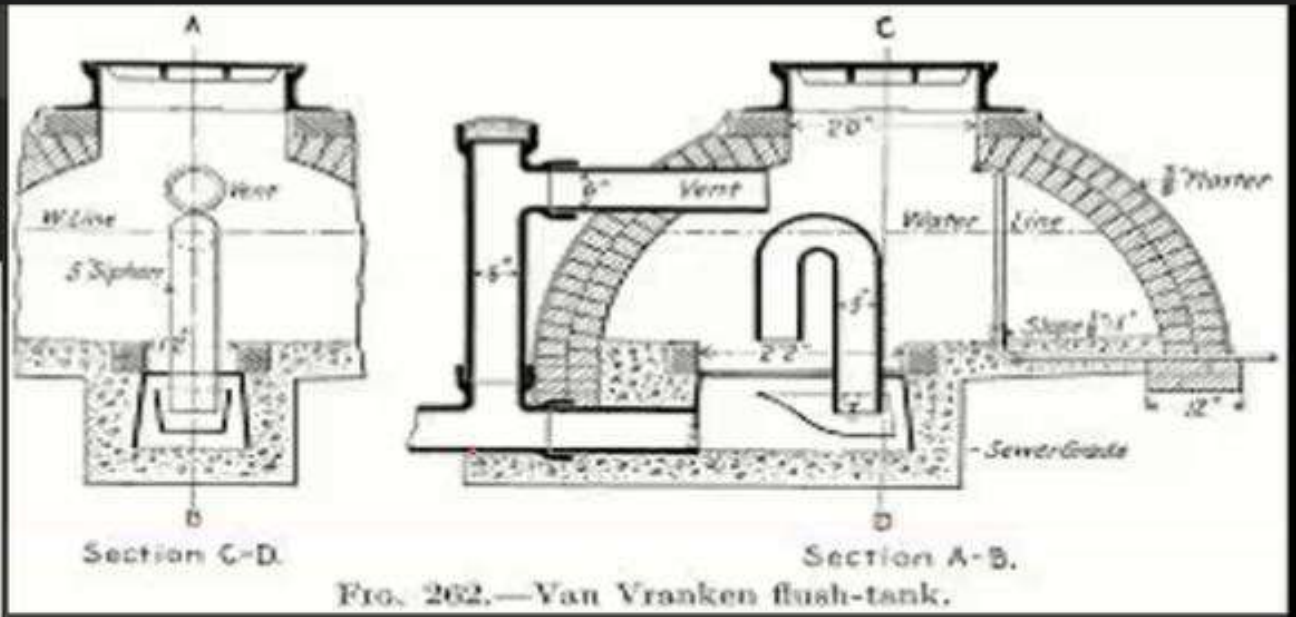


FIG. 262.—Van Vranken flush-tank.

- Automatic sewer contains concrete or masonry chamber with inlet, overflow and one outlet with U tube and bell to sewer
- Controlled by syphon action or by float valves

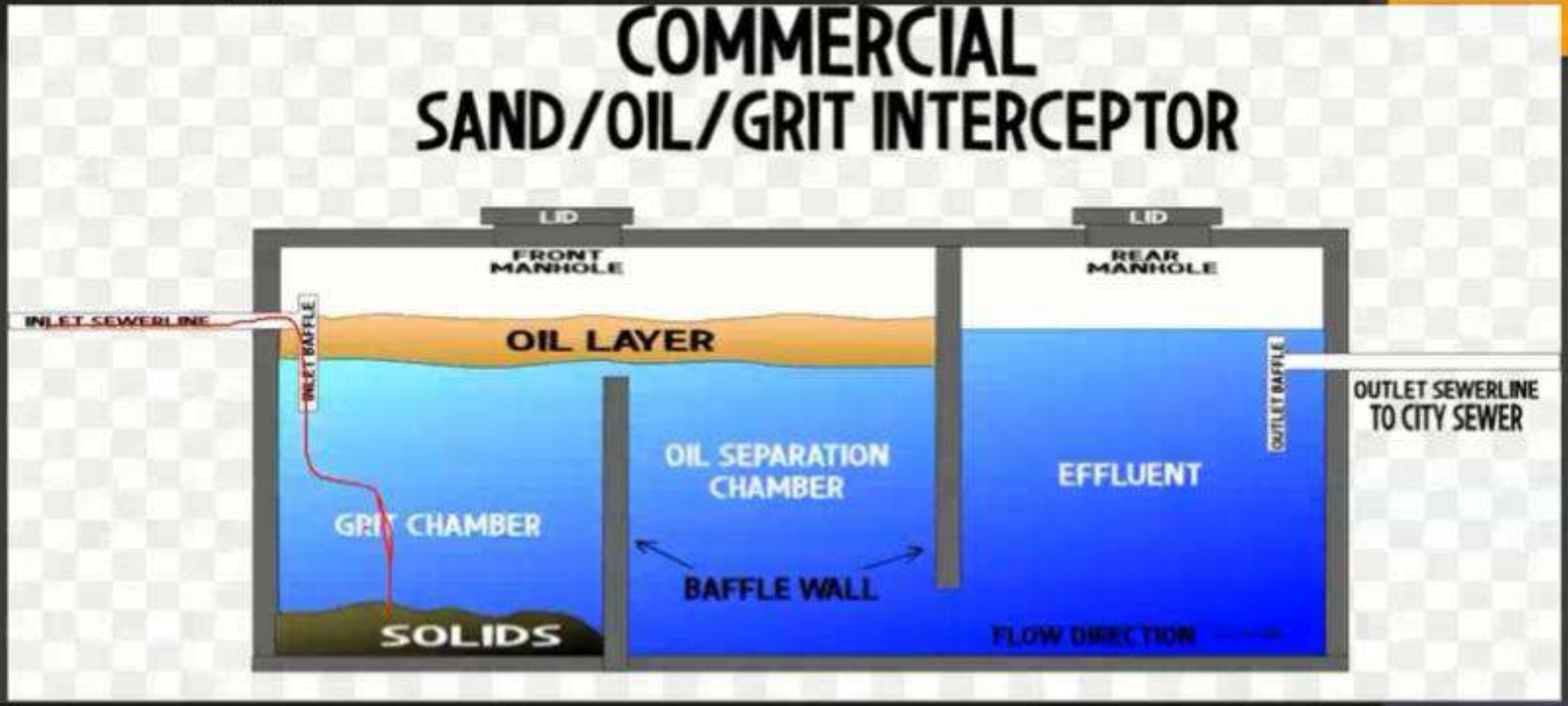
Flushing tanks

bin Maharjan

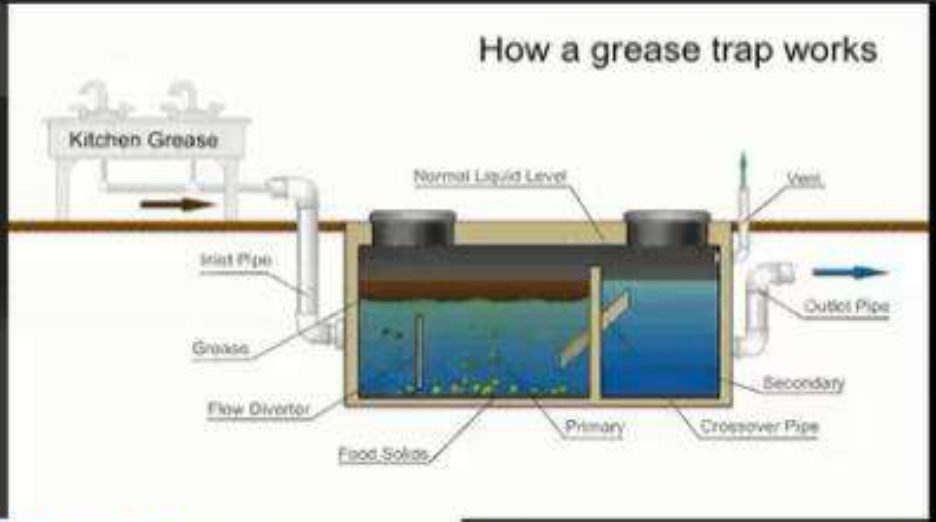
Sand, grease and Oil Trap

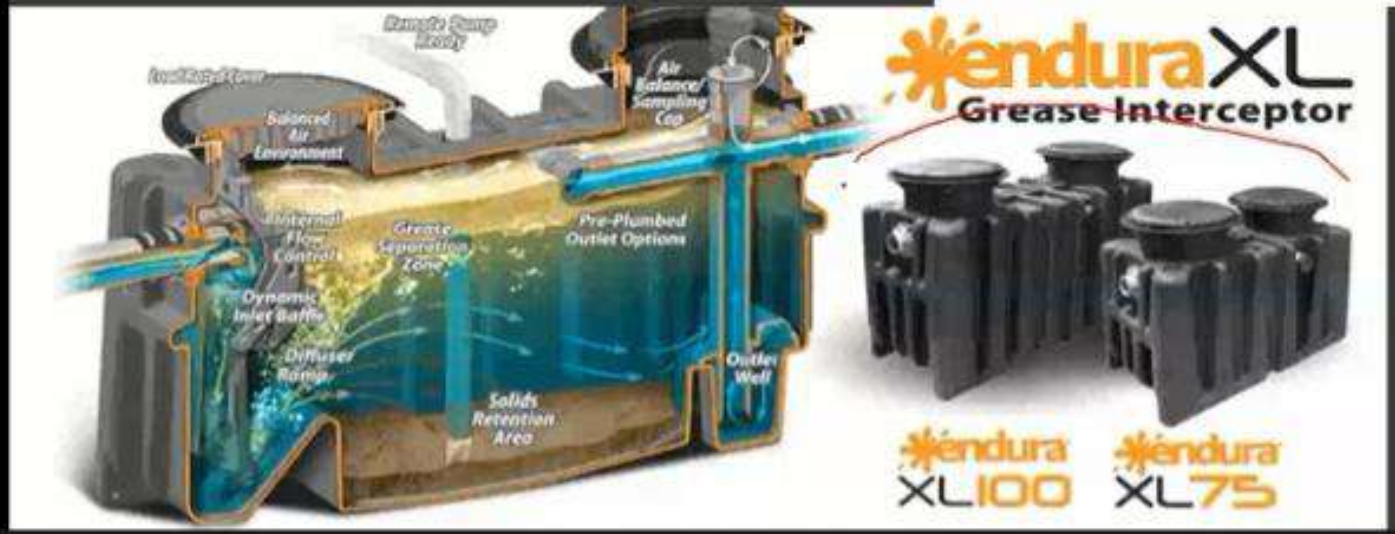
- Garages, kitchens, workshops, industries, etc.
- Grease, sand, oil, fat
- Sticks to interior of sewer and attaches more sediments and hardens to obstruct
- Treatment is difficult due to these
- So remove as much as possible near source
- RCC/masonry structure with baffles and gratings to separate floating and settling matters
- Regularly maintained and cleaned

Sand, grease and Oil Trap



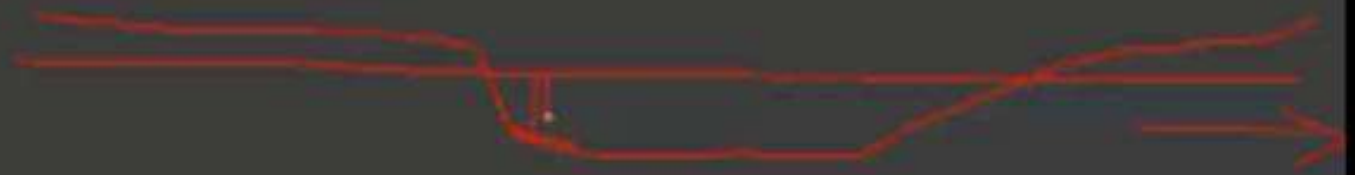
Sand, grease and Oil Trap





Inverted syphon / depressed sewer

- When there is obstruction or no supports, a depression is made in sewer longitudinal profiles where water flows under pressure
- Syphon action is there in depression so called inverted syphon
- More than one pipe are laid as inverted syphon for account of flow fluctuations (low flow 1 pipe and high flow more than one pipe)
- Can be manual operation of pipes or automatic by vertical arrangements



Inverted syphon / depressed sewer

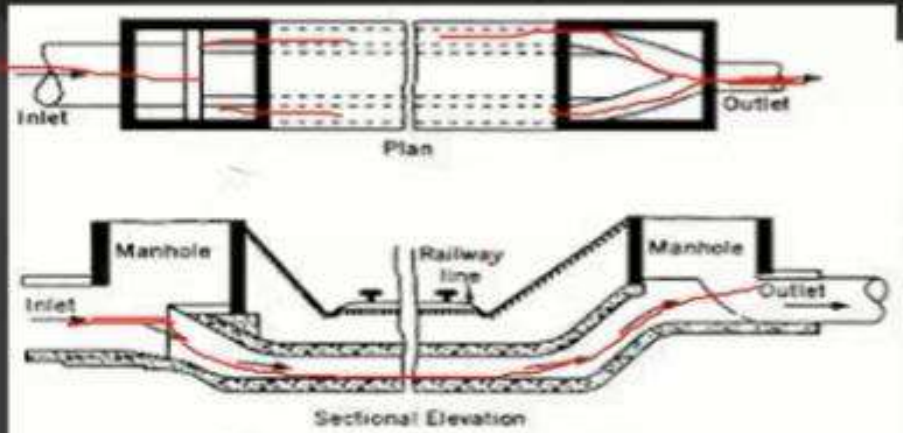
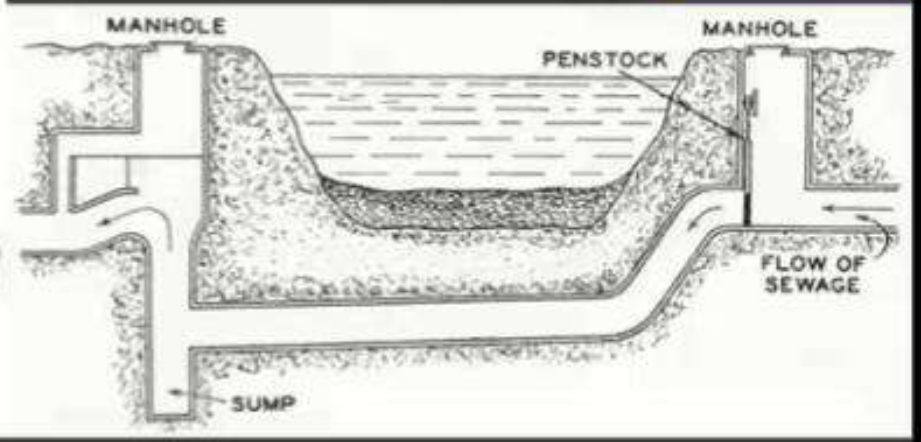


Fig. 7.11. Inverted Siphon.



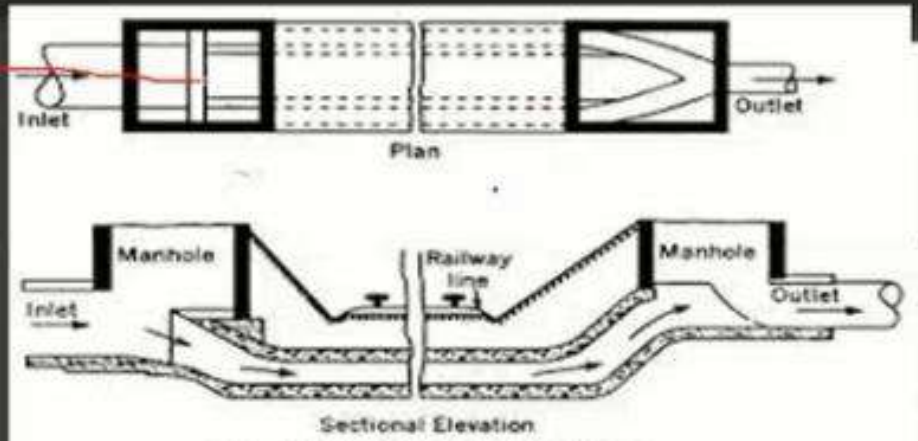
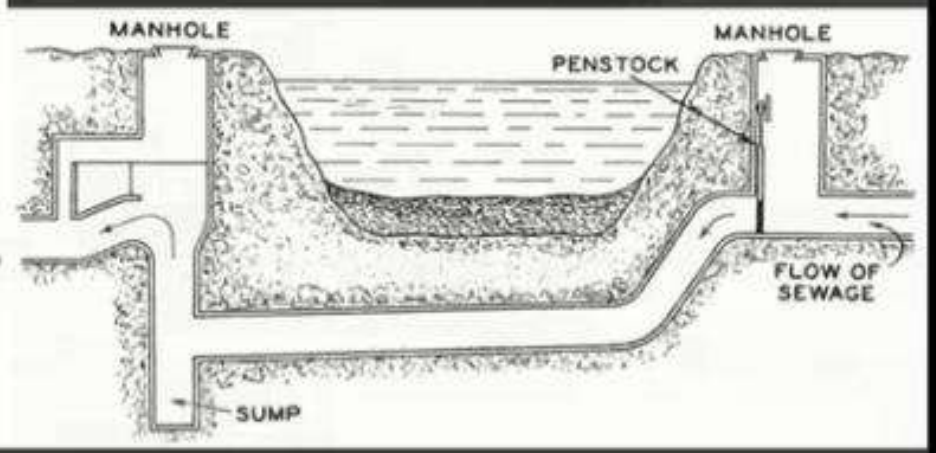


Fig. 7.11. Inverted Siphon.



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Sewer outlet

- Storm water or treated sewer is discharged in water bodies
- Needs protection to safely discharge without erosion in that place and also structurally protect the damage in outlet during floods etc.
- Usually discharged beyond the banks for proper dispersion and diffusions
- Masonry or RCC structures

Ventilation Shafts

- Sewer decomposes during convey
- Produces foul and harmful gases risk for human health and sewer life
- Methane is combustible
- Other gases cause corrosion and directly impact workers in sewer
- Ventilation is provided as ventilation shaft
- 80m-300m spaced generally
- Combined with manhole or can be separate of concrete base with RCC/CI pipes of 15-30cm dia
- Mesh and cowl is provided at top to avoid rainwater and insects
- Should be taller than tallest building in locality for venting off

Ventilation Shafts

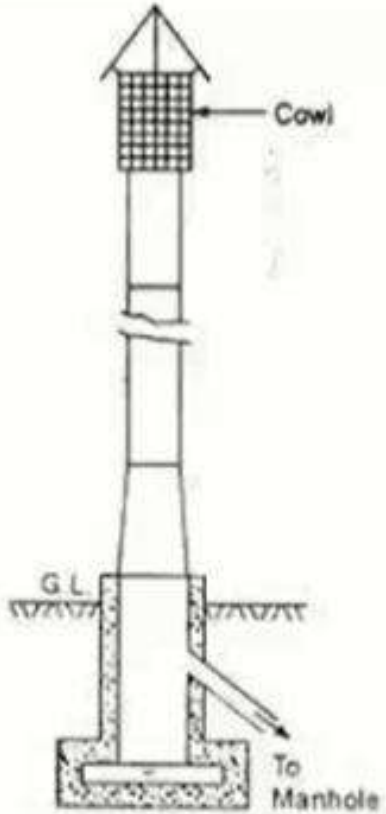
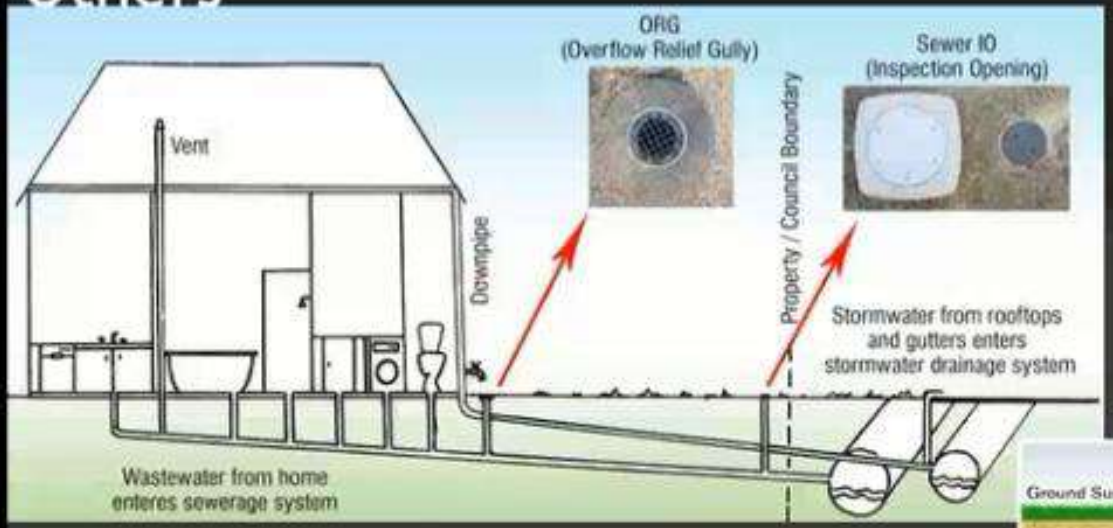
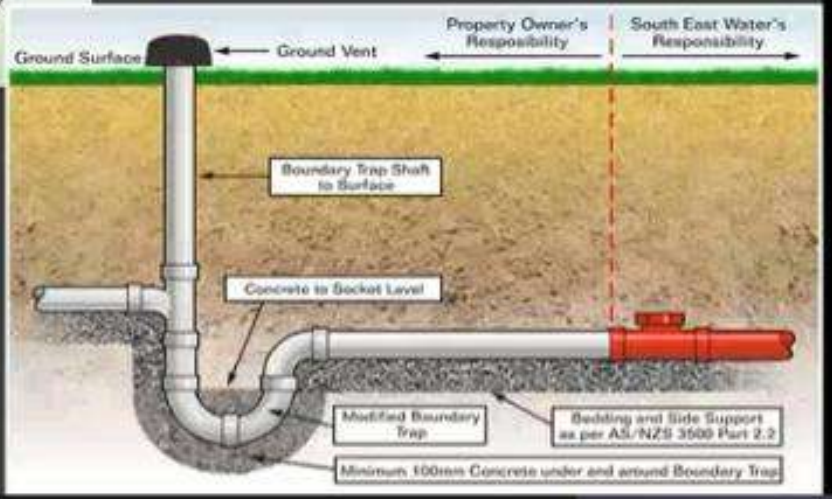


Fig. 7.15. Ventilating shaft.

Others


ORG
(Overflow Relief Gully)
Sewer IO
(Inspection Opening)
Vent
Downpipe
Property / Council Boundary
Stormwater from rooftops
and gutters enters
stormwater drainage system
Wastewater from home
enteres sewerage system


Ground Surface
Ground Vent
Property Owner's
Responsibility
South East Water's
Responsibility
Boundary Trap Shaft
to Surface
Concrete to Socket Level
Modified Boundary
Trap
Bedding and Side Support
as per AS/NZS 3500 Part 2.2
Minimum 100mm Concrete under and around Boundary Trap

Chapter 6: Wastewater Disposal

Necessity and objectives of wastewater disposal

A. Sources of wastewater and constituents:
   a. Industrial: constituents are dependent on the raw materials, process and final product
   b. Domestic/Commercial: toilets, washing and kitchen

B. Constituents in domestic wastewater
   a. Solids: suspended and dissolved
      i. Organic materials: suspended and dissolved
      ii. Inorganic materials; suspended and dissolved

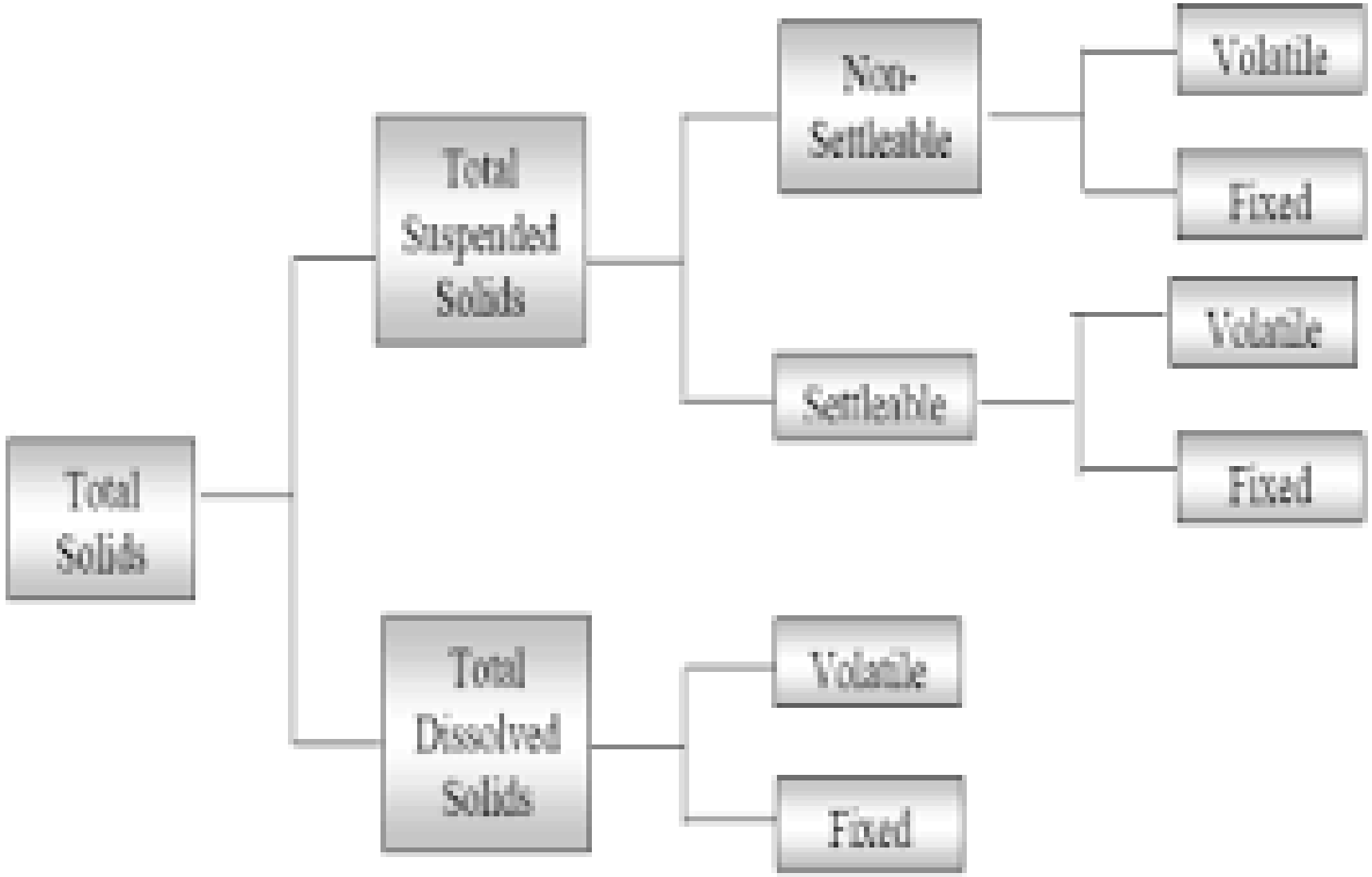
   b. Microorganisms (Pathogens are of concern)
   c. Gases

Chapter 6: Wastewater Disposal

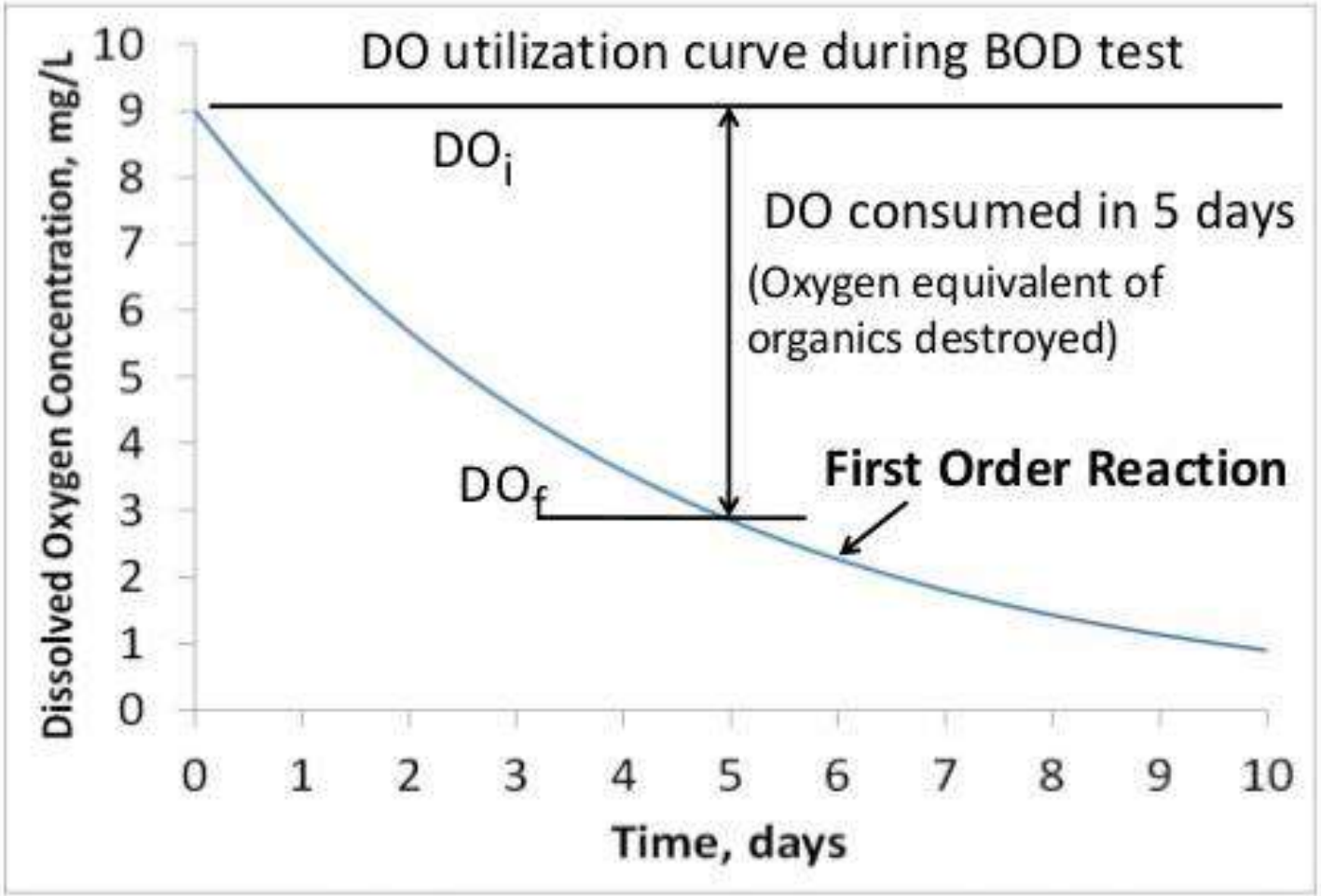
Necessity and objectives of wastewater disposal

A. Problems:
   a. Solids causes color, odor and turbidity
   b. Organic materials tends to putrefy and in process
      i. Demand oxygen
      ii. If, oxygen is absent produces bad smells as it undergoes anaerobic decomposition
   c. Pathogens causes and spreads diseases
   d. Gases (generally the product of decomposition, volatile gases from solvents and cleaners, causes odor problems)

Total Solid Analysis



BOD Reaction Kinetics

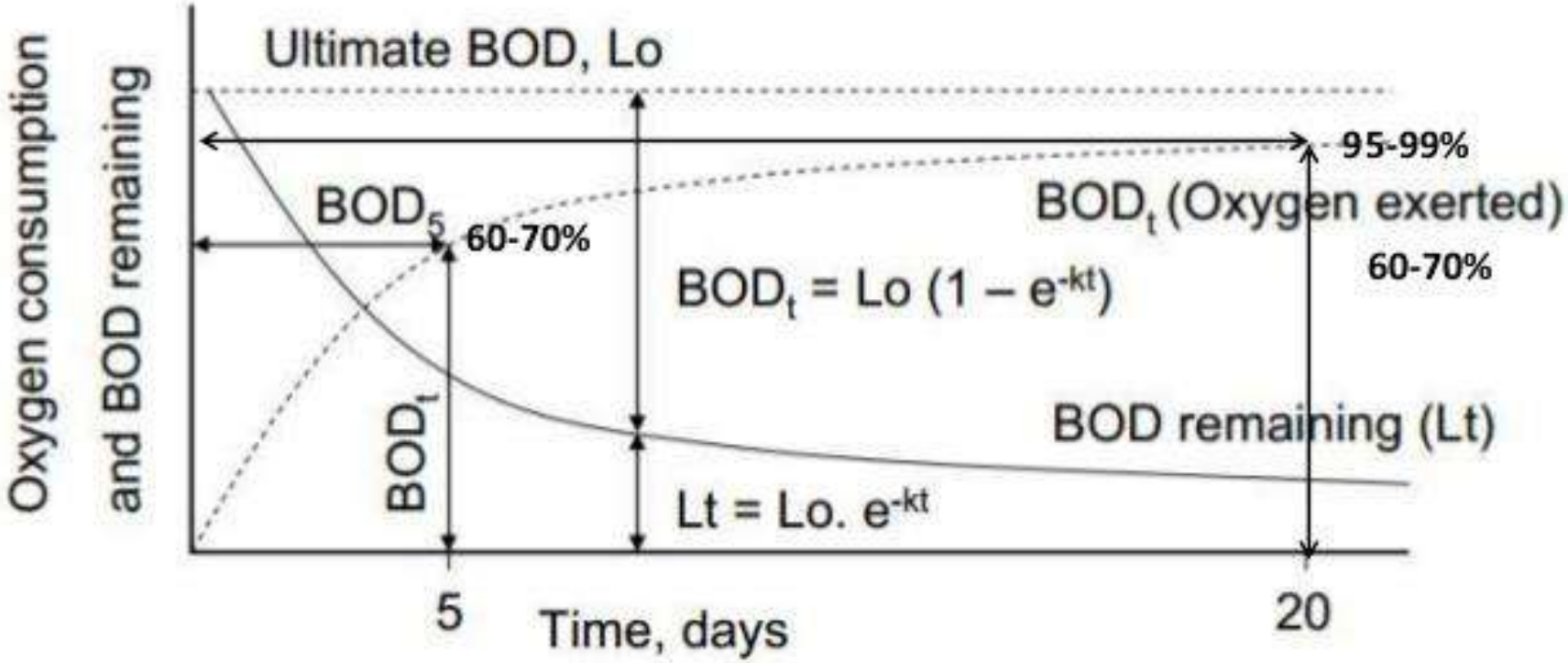


BOD_5= Oxygen equivalent of Organic destroyed in 5 days = DO consumed in 5 days

1. Organic matter disposed into the water body
2. Starts consuming dissolve oxygen (DO)
3. When we measure the 5 day DO consumption in controlled laboratory environment, we call it BOD_5
4. BOD is indirect measurement of organic matter

Biochemical Oxygen Demand

$$\text{Organic matter} + O_2 \xrightarrow{\textit{Microorganisms}} CO_2 + H_2O + \text{New Cells} + \text{Stable Products}$$



Variation in DO profile during BOD test with duration of incubation at 20°C

Chapter 6: Wastewater Disposal

Necessity and ***objectives*** of wastewater disposal

Make them Safe

a. Remove color, odor and turbidity by removing suspended and dissolved solids
b. Oxidize organic materials so that potential to decay or petrification is reduced
c. Oxidize and remove pathogens

Chapter 6: Wastewater Disposal

Wastewater ***disposal methods*** (often called as natural methods)

1. Dilution: Mix with a high volume-low concentration water body so that the ***concentration of mixture becomes acceptable***

$$C_m = \frac{Q_R C_R + QSC_S}{Q_R + QS}$$

Where, subscript R denotes River, S denotes sewage and m denotes the mixture

When $Q_R >>> Q_S$ and $C_R <<< C_s$

C_m will be very less and if acceptable can be disposed

(used to be acceptable but the acceptability is decreasing day by day and in many country prohibited by the Law)

Chapter 6: Wastewater Disposal

Where ***dilution*** is possible?

- Wastewater is quite fresh (discharged within 2-3 hours)
- Floating matter and settleable solids are already removed
- Water volume is large enough
- Diluting water has high DO content
- Thorough mixing with water body is possible
- When wastewater does not contain industrial wastewater and toxic substance
- Where receiving water is not source of drinking water

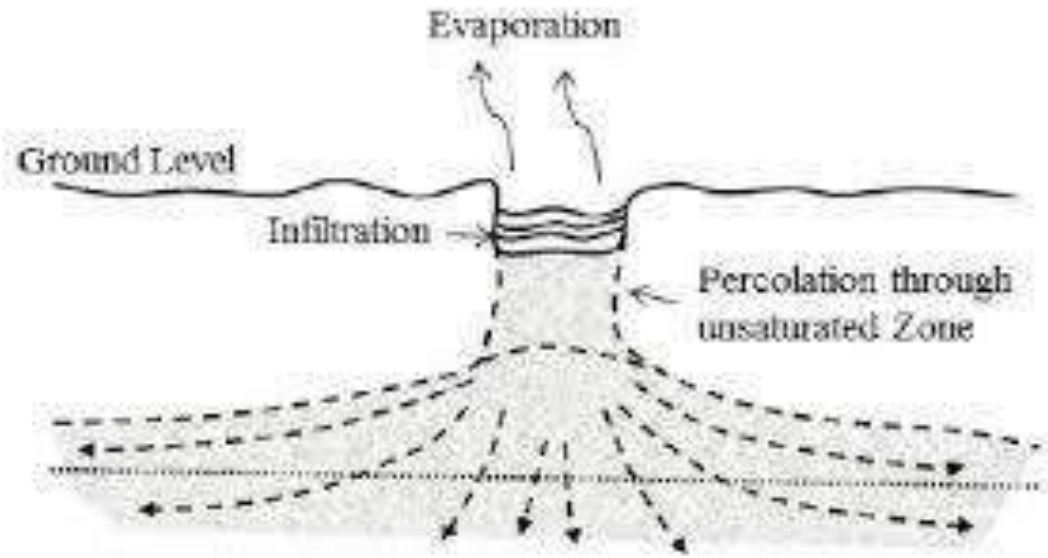
Chapter 6: Wastewater Disposal

Wastewater ***disposal methods*** (often called as natural methods)

1. Dilution:
2. ***Land Treatment:*** Apply on the land either on the surface or in the sub-surface

What will happen?

1. Evaporates, and
2. Infiltrates through the soil and mixes with groundwater



Chapter 6: Wastewater Disposal

Wastewater ***disposal methods*** (often called as natural methods)

Land Treatment: Apply on the land either on the surface or in the sub-surface

While moving through the soil,

1. particles > pore size are trapped (filtration)
2. soil contains consortium of microorganisms (mainly bacteria) that decomposes the Organic solids either suspended or dissolved
3. Pathogens will also be oxidized and filtered

Chapter 6: Wastewater Disposal

Okay, if they are that good then what is the problem?

We will come back later!!!!

Chapter 6: Wastewater Disposal

Land Treatment

1. Broad irrigation or sewage farming
2. Rapid infiltration
3. Overland runoff

In all application: Settled sewage i.e. primary treated sewage is preferred

Infiltration rate	***Application***
1. 6 – 25 mm/min	Rapid infiltration
2. 2 – 6 mm/min	Irrigation
3. <2 mm/min	Overland runoff

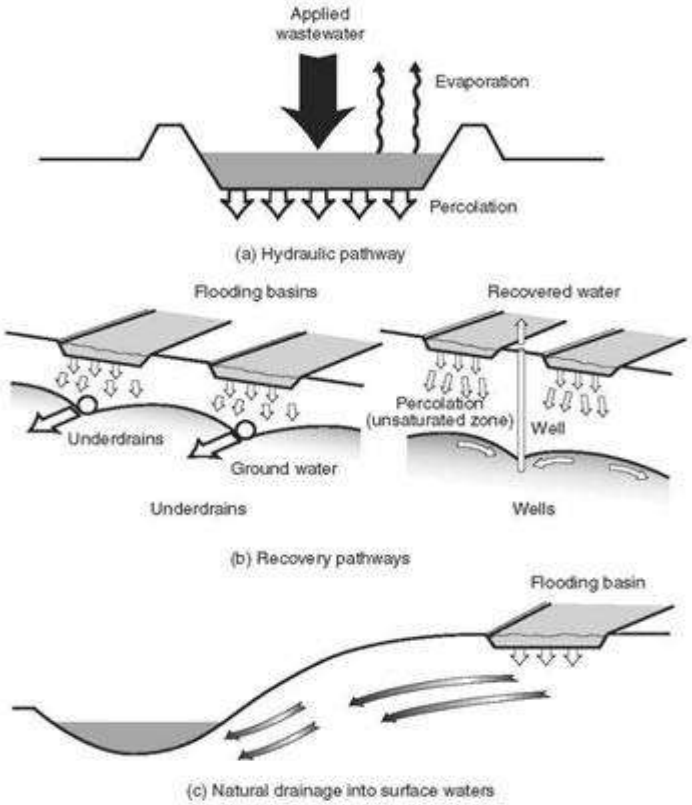


Figure 2. Hydraulic pathway for rapid infiltration (RI)[8]

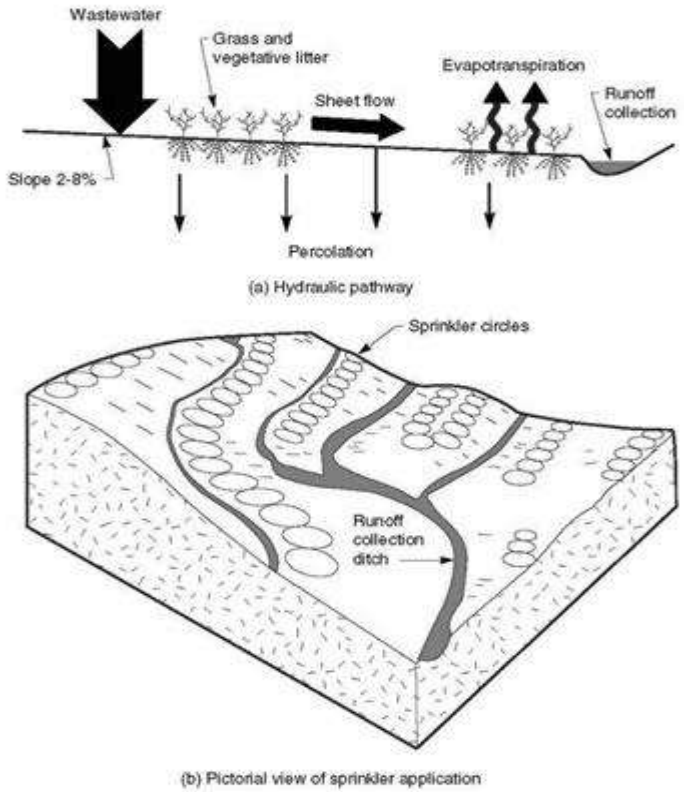


Figure 3. Hydraulic pathways for overland flow (OF)[8]

Application rate depends on hydraulic loading ($m^3/m^3/day$) and mass loading rate ($kg/m^2/day$)

Hydraulic loading rate = *f (Infiltration)*

Infiltration = *f (soil type, permeability)*

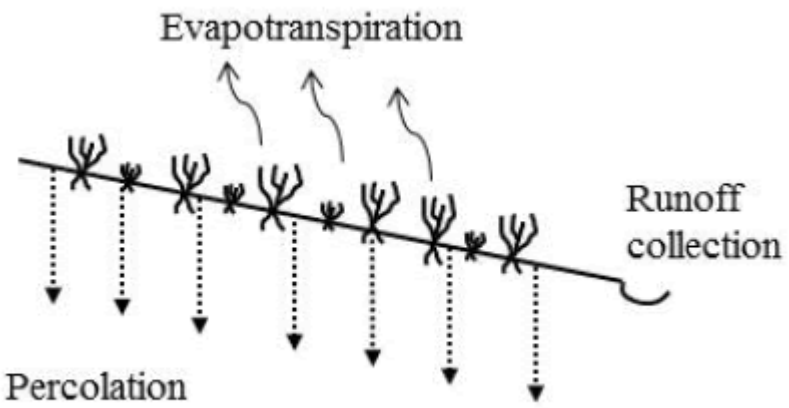
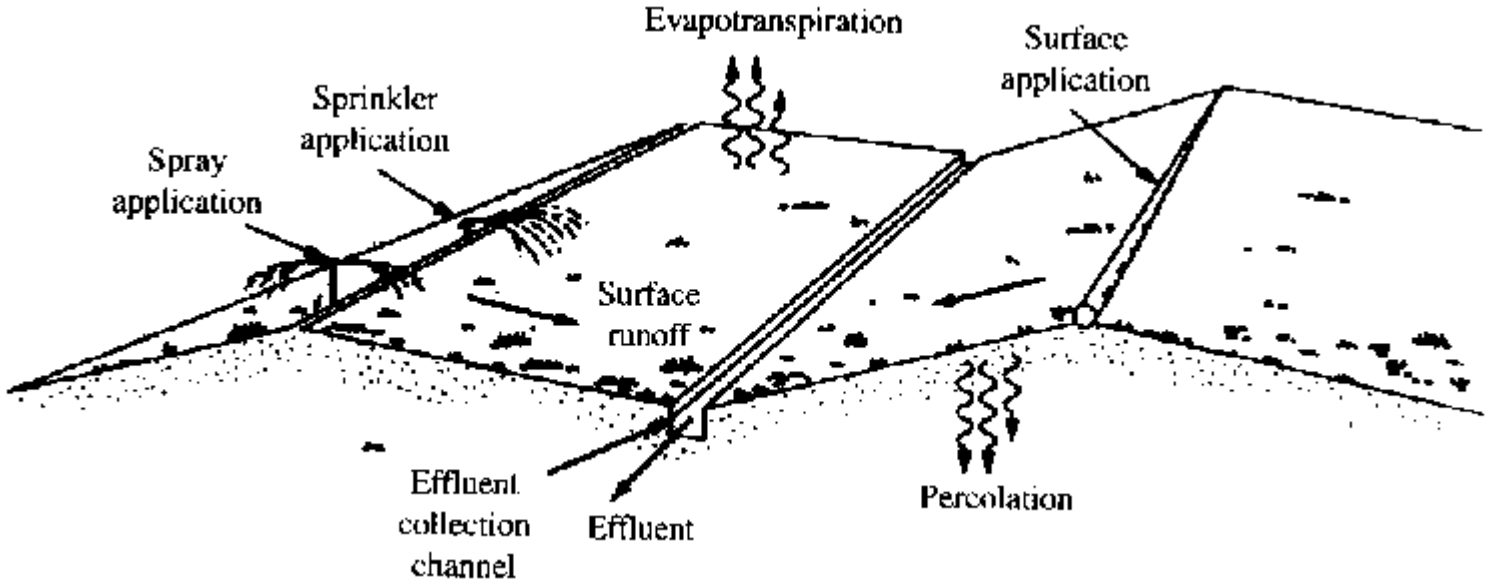


Figure 3: Overflow land treatment.



Types of irrigation

1. Sprinkler or Spray irrigation
2. Subsurface irrigation (supplied to root zone through open jointed pipes)
3. Surface irrigation
   i. Basin method
   ii. Flooding method
   iii. Furrow method

Indian Standards of Sewage Effluents for Sewage Farming

1. Total concentration of solids (inorganic) <= 2100 ppm
2. Percentage of Sodium with respect to total content of sodium, Calcium, Magnesium and Potassium <= 60%
3. Boron <=2 ppm
4. pH 5.5 – 9.0
5. BOD <=500 mg/l

Sewage Sickness

After continuous application:

soil gets clogged, aeration restricted, water logging- land is unsuitable to take further load- known as ***sewage sickness***

<u>To avoid sickness:</u>

1. Pretreatment of sewage
2. Provision of extra land
3. Under drainage of soil
4. Proper choice of land
5. Crop rotation
6. Shallow depth of application

Sodium Adsorption Ratio

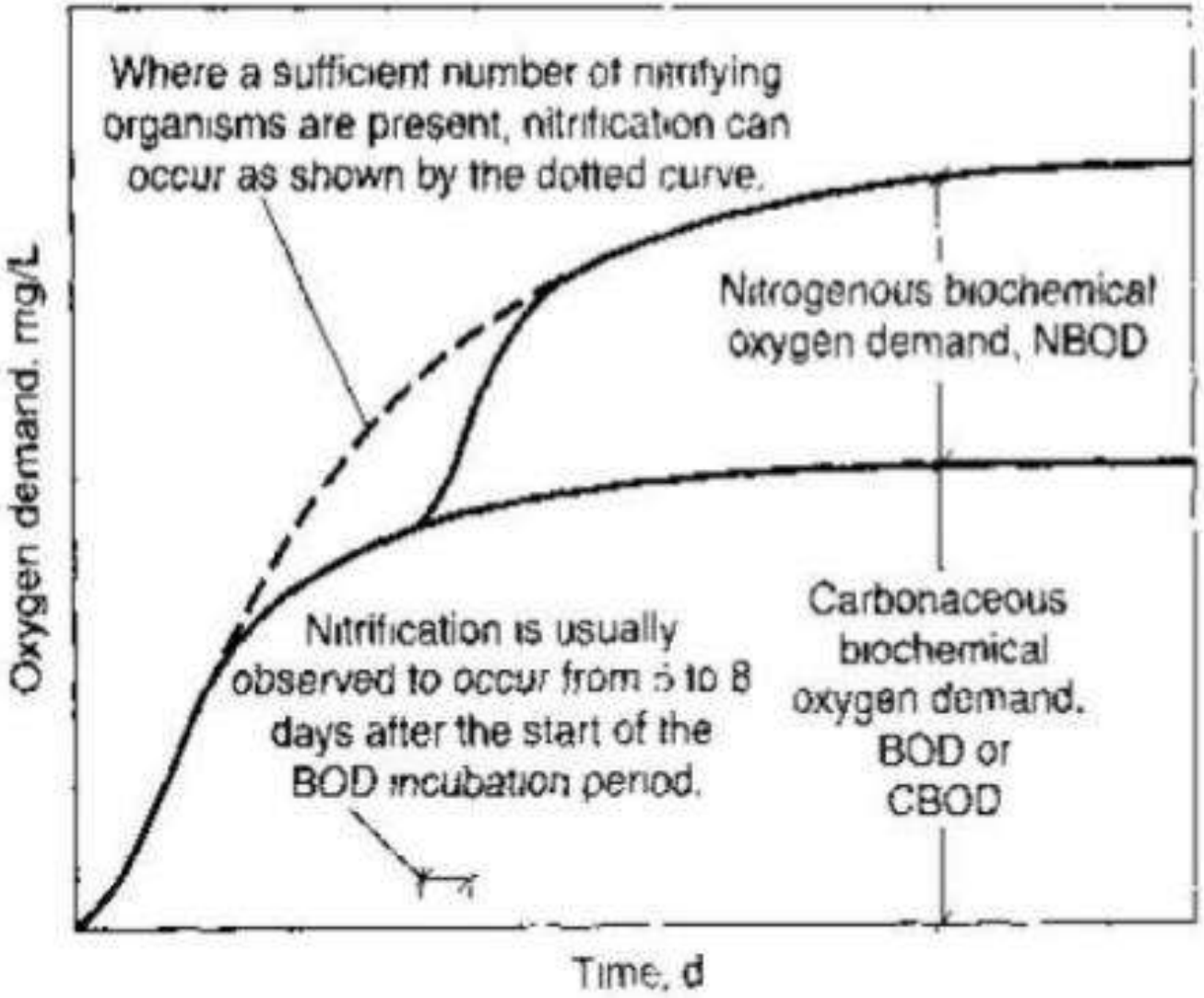
- "Sodium adsorption ratio" (SAR) is a measure of the amount of sodium (Na^+) relative to calcium (Ca^{2+}) and magnesium (Mg^{2+}) in the water extracted from a saturated soil paste.

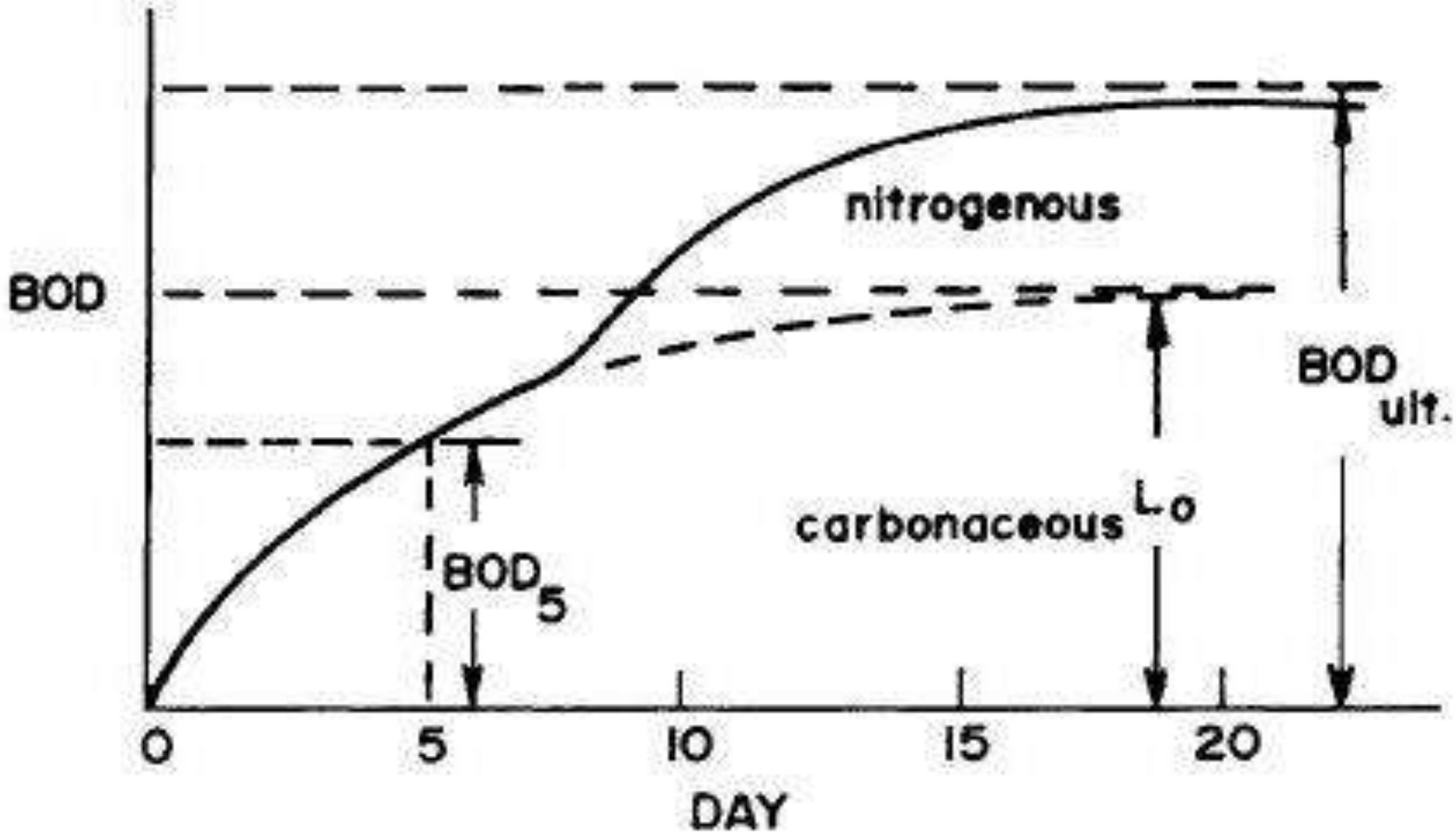
It is the ratio of the Na concentration divided by the square root of one-half of the Ca + Mg concentration. SAR is calculated from the equation:

$$SAR = Na^+ / [(Ca^{2+} + Mg^{2+})/2]^{0.5}$$

- Soils that have values for sodium adsorption ratio of 13 or more may have an increased dispersion of organic matter and clay particles, reduced saturated hydraulic conductivity and aeration, and a general degradation of soil structure.

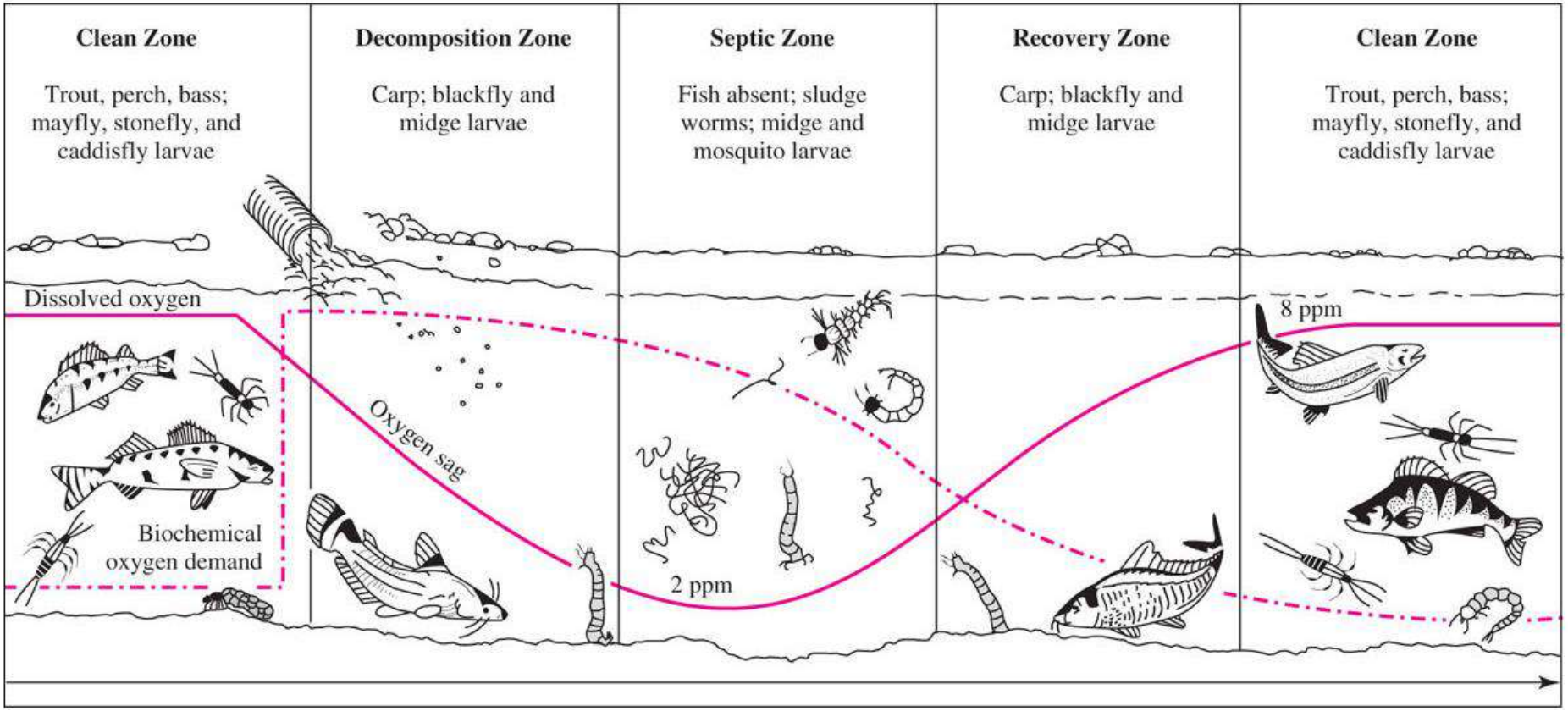
Why BOD test is conducted for 5th day




BOD
nitrogenous
BOD ult.
carbonaceous
L_o
BOD_5
0
5
10
15
20
DAY

Chapter 6:
Self purification of river/stream, DO Sag Curve – Streeter Phelps Model

Self purification of River/stream
DO Sag Curve

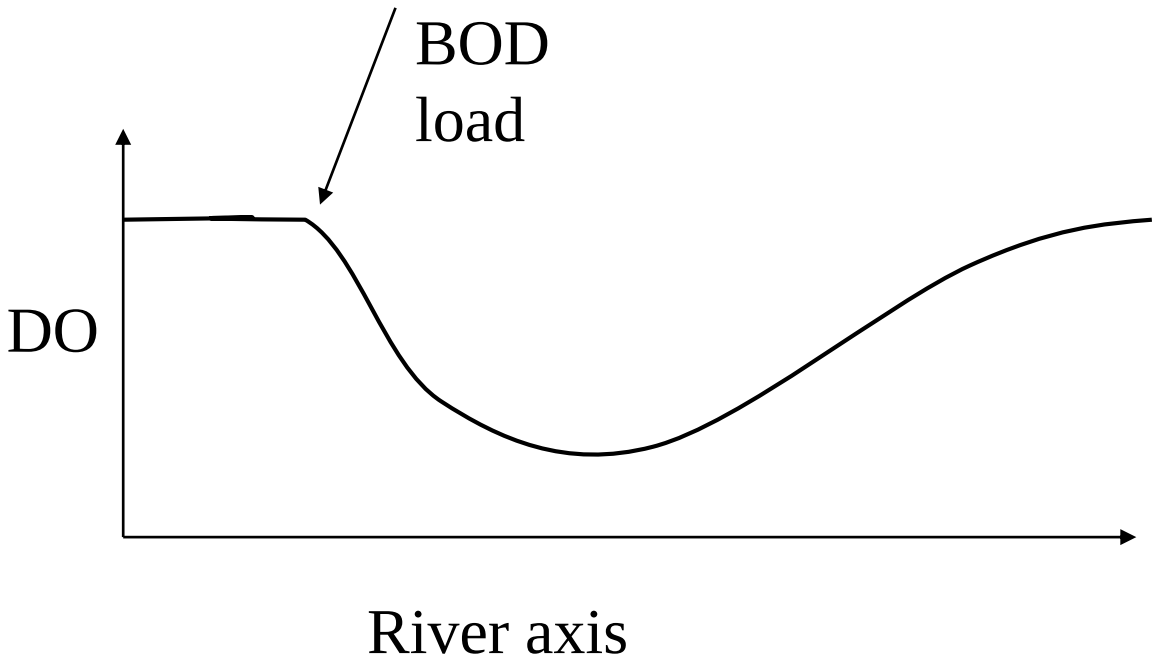


Self purification of River/stream

Factors affecting self purification

1. Dilution
2. Current
3. Sunlight
4. Sedimentation
5. Temperature
6. Oxidation-Reduction

Dissolve Oxygen Sag Curve



Major Proceses

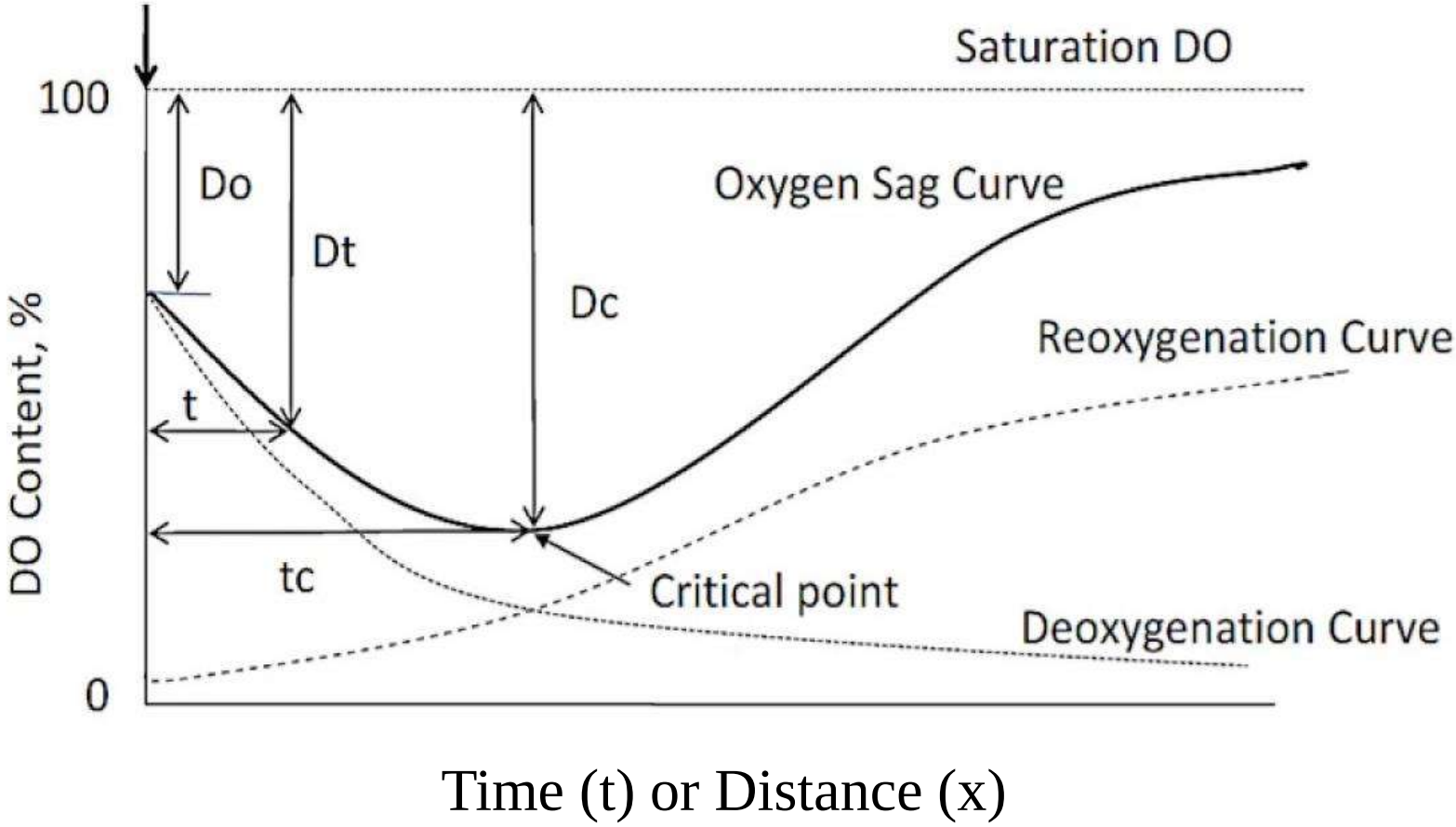
DO Source:

- Re-aereation of oxygen from the atmosphere
- Oxygen production/consumption by plants, algae

DO Sink:

- Oxidation of Organic matter (dissolved and particulate, measured as BOD)
- Sediment oxygen demand
- Oxygen consumption by respiration of algae and plants

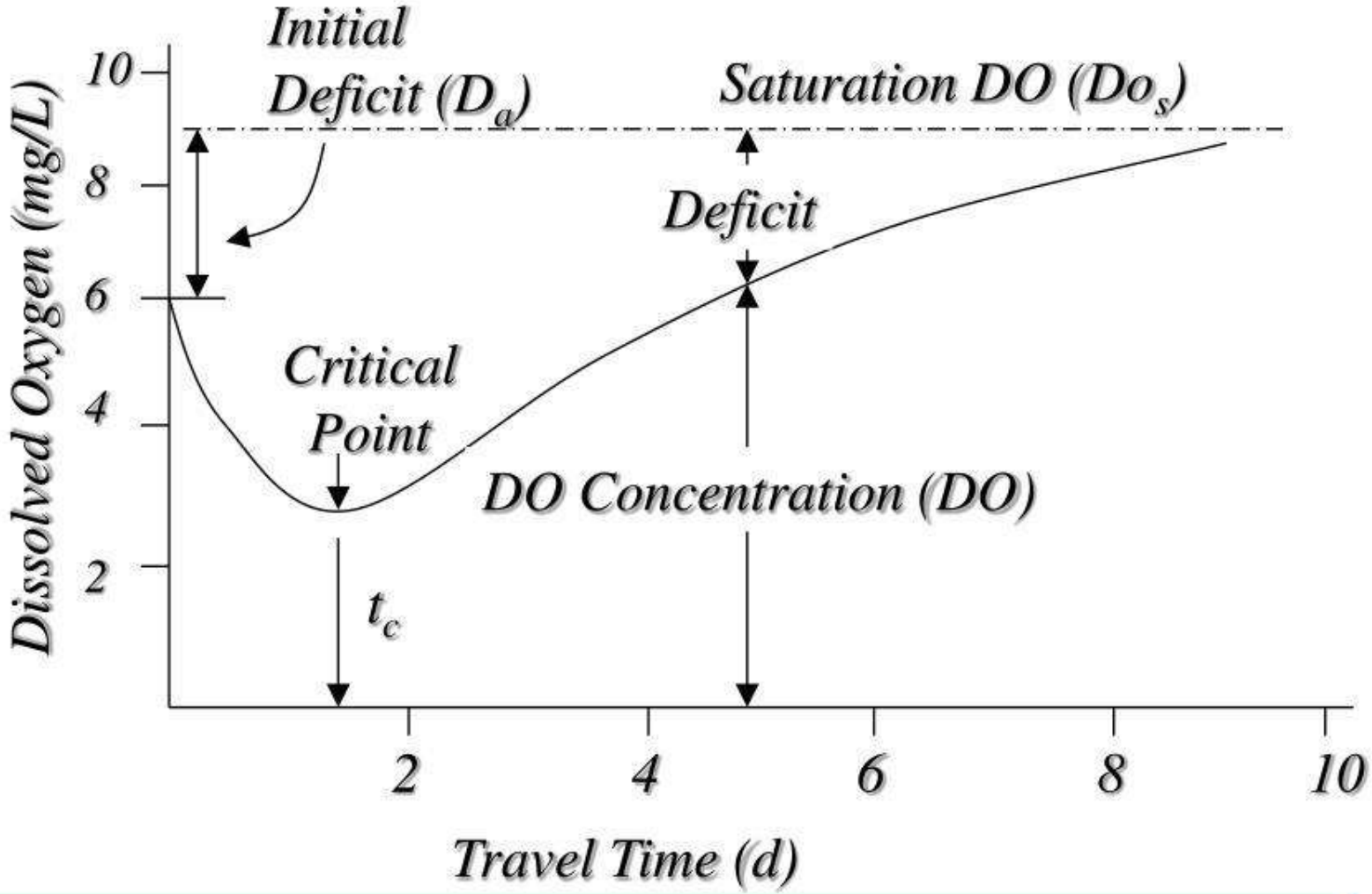
Dissolve Oxygen Sag Curve



Where, D_0 is initial DO deficit, D_t is deficit at any time t and D_c is the critical DO deficit

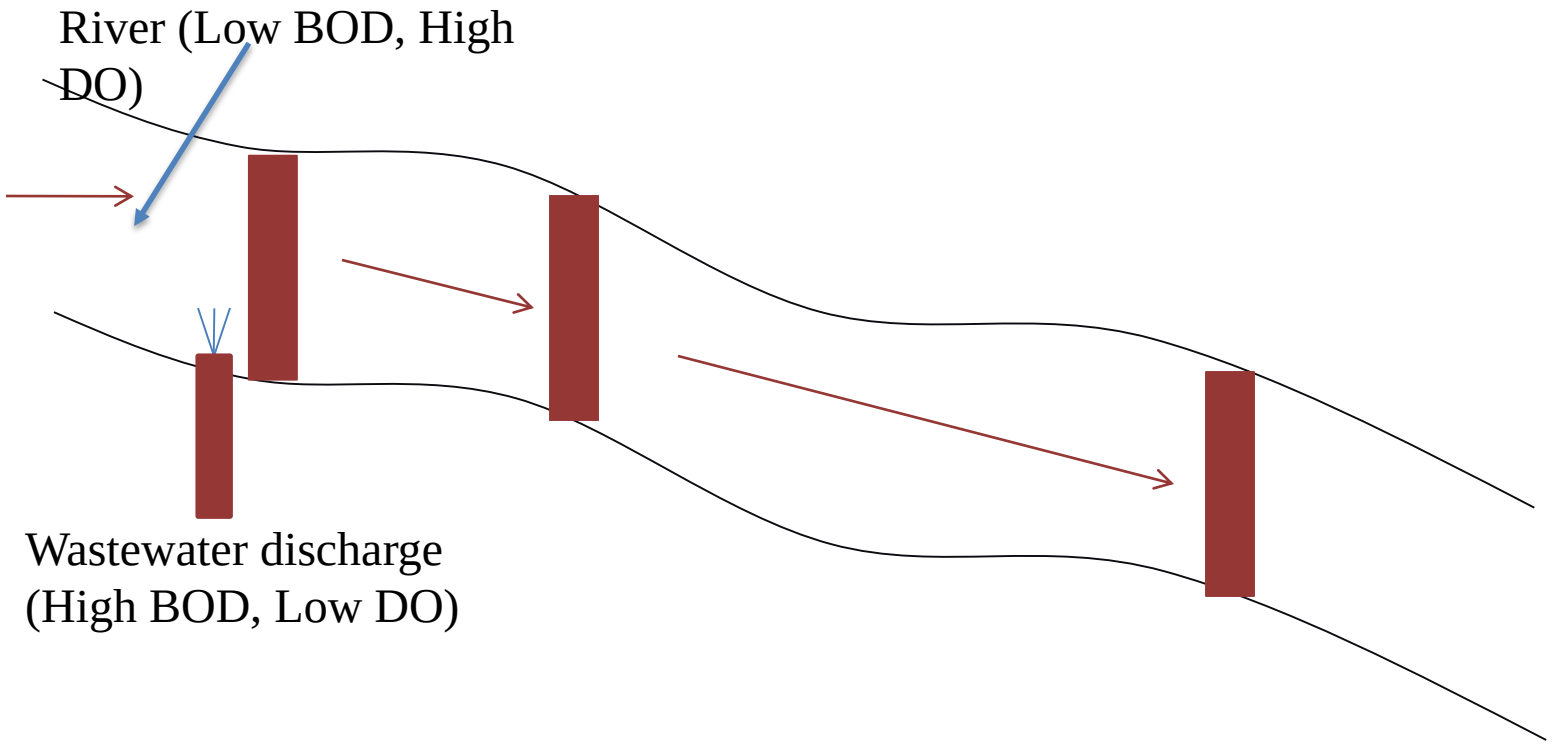
DO deficit = $DO_{saturation}$ - DO

Typical DO sag curve



Streeter-Phelps Model

Objective: derive a mathematical model to predict DO downstream: **DO(x,t)**



Assumptions:

1. completely and uniformly mixed in the cross flow and vertical direction
2. neglect pollutant dispersion

Oxidation of Organic Matter

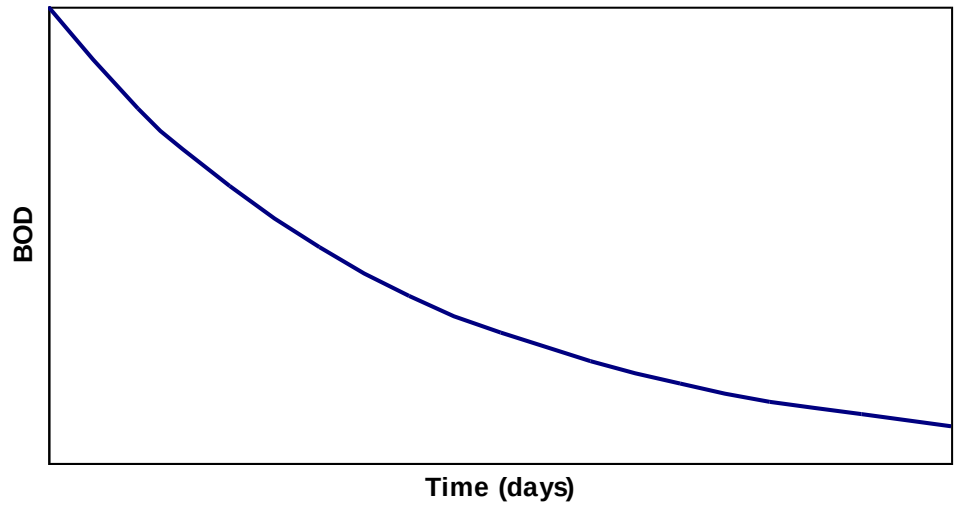
- Assume CBOD and NBOD ($NH_4^+ \rightarrow NO_3^-$) have same degradation rate.
- According to first order reaction:

$$\frac{dL}{dt} = -k_1 L$$

L = BOD (mg/l or g/m^3)
t = time (day)
k_1= BOD degradation rate constant (day^{-1})

Solution:

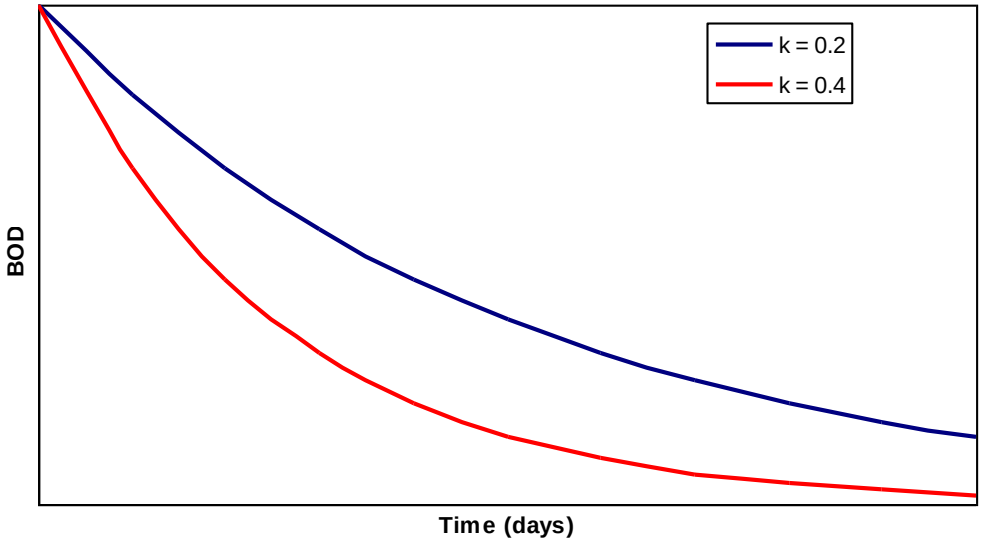
$$L = L_0 e^{-k_1 t}$$



Oxidation of Organic Matter

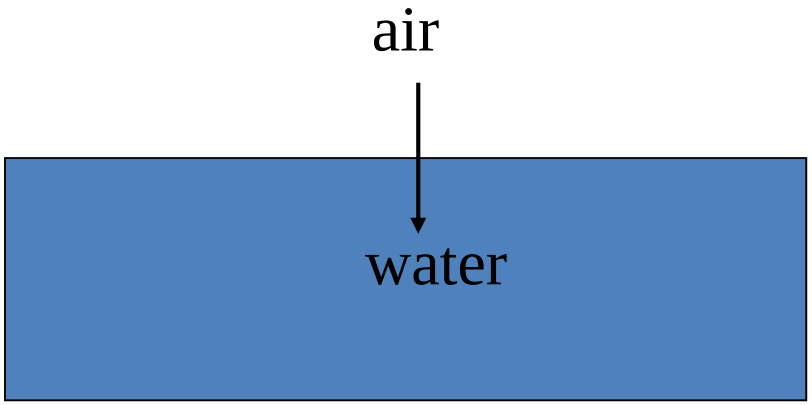
- Degradation rate constant k_1 for BOD :
- k_1 generally between 0.1 – 0.4 (day^{-1})
- Dependent on *e.g.* type of organic material, river characteristics: water velocity, depth of the river
- Increase of about 4% per ^oC
- $k_t = k_{20}\theta^{(T-20)}$
- θ =1.056 (T = 20-30°C)
- θ =1.047 (T = 4-20°C)
- θ =1.056 (T = 20-30°C)

k =2.303 K
k natural log
K log base 10



Re-aeration of Oxygen

- Driving force: Difference between O_2 concentration and saturation O_2 concentration, in the water:



k_2= re-aeration constant (day^{-1})
C = Oxygen concentration (mg/l)
C_{sat}= Saturation oxygen concentration (mg/l)

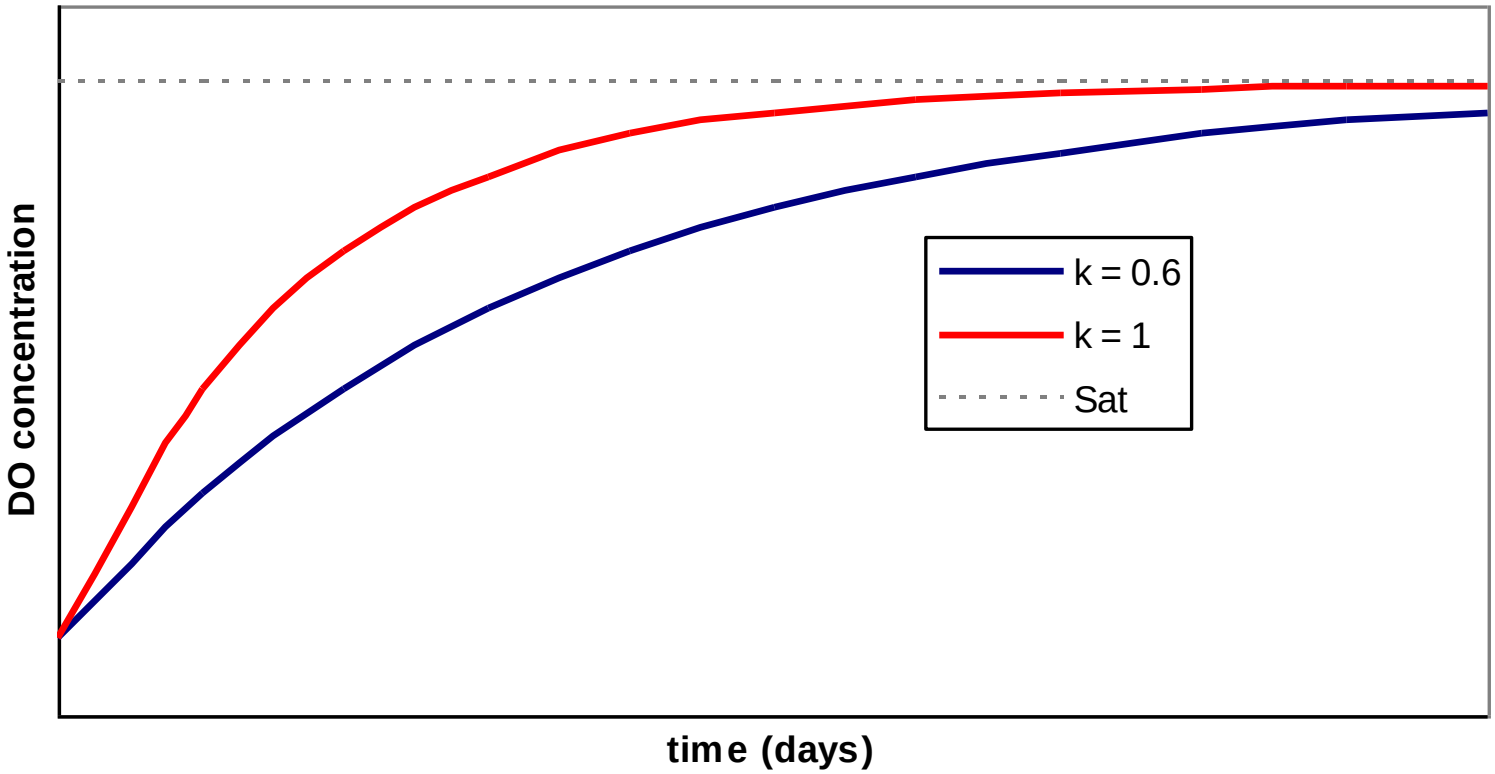
$$\frac{dc}{dt} = k_2\left(c_{sat} - c\right)$$

$k_t = k_{20}(1.024)^{T-20}$

Re-aeration

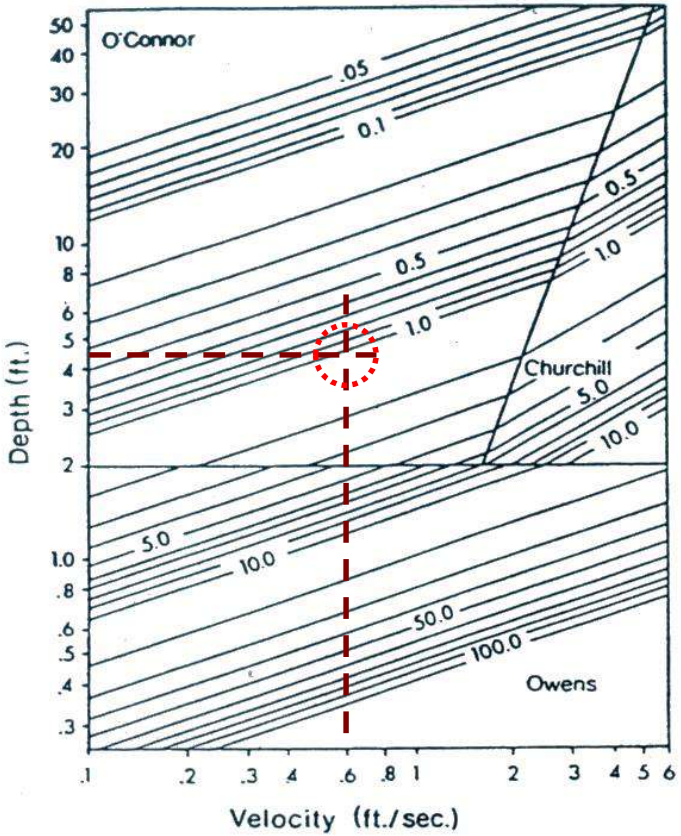
Solution at any time, **t**

Where, C_0= initial concentration, C= concentration at time t



Re-aeration in rivers

- Value k_2 dependent on:
- Velocity river : k_2 proportional to about $V^{0.5}$
- Water depth : k_2 proportional to about $1/H^{1.5}$
- Temperature: about 2% increase per ^0C



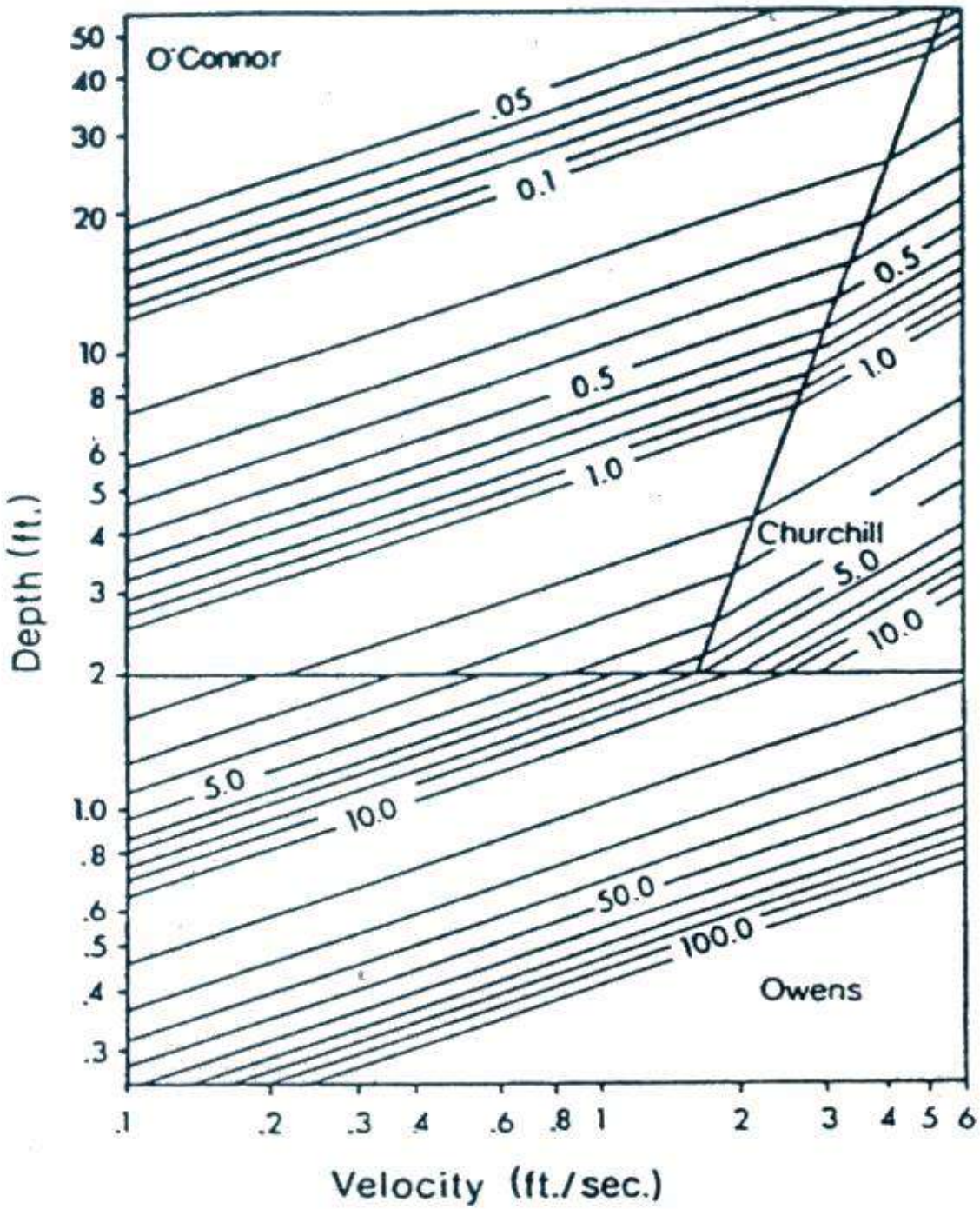
Empirical graph from different UK-USA researches

<u>Example</u>:

- Velocity = 0.6 ft/sec = 0.18 m/sec
- Depth = 4.5 ft = 1.4 m

k_2 = 1.0 day^{-1}

(Thomann and Müller (1987))


O'Connor
.05
0.1
0.5
1.0
0.5
1.0
Churchill
5.0
10.0
5.0
10.0
50.0
100.0
Owens
Depth (ft.)
50
40
30
20
10
8
6
5
4
3
2
1.0
.8
.6
.5
.4
.3
.1
.2
.3
.4
.6
.8
1
2
3
4
5
6
Velocity (ft./sec.)

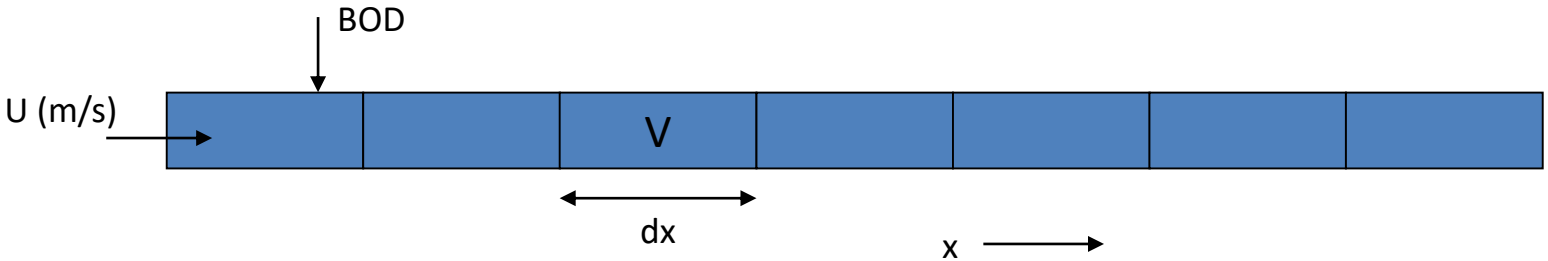
Sediment Oxygen demand

Bottom type and location	SOD ($g/m^2/day$)	
	Range	Average
Sphaerotilus (10 g dry wt/m^2)		7
Municipal sewage sludge – outfall vicinity	2-10	4
Municipal sewage sludge –"aged", downstream outfall	1-2	1.5
Estuarine mud	1-2	1.5
Sandy bottom	0.2-1.0	0.5
Mineral soils	0.05-0.1	0.07

(Thomann and Müller (1987))

- Especially important for organic-rich sediments
- Increase about 7% per ^{o}C
- SOD can be neglected for <u>deep</u> rivers

Streeter-Phelps DO model for a river



- Ignore SOD
- Ignore effect algae and water plants
- Ignore differences between CBOD and NBOD degradation

- Mass Balance for oxygen over a segment dx:

$$\frac{dD_t}{dt} = function\ of\ (deoxygenation\ and\ reoxygenation)$$

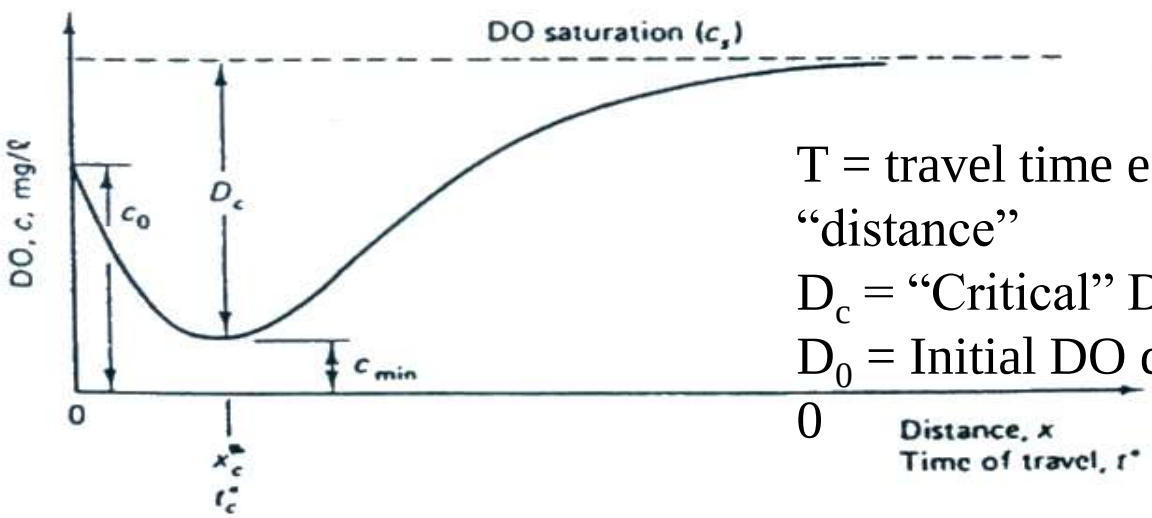
$$where, Dt = Cs - C, dissolve\ oxygen\ deficit\ at\ any\ time\ \boldsymbol{t}$$

Streeter-Phelps Model

$$\frac{dD_t}{dt} = \mathrm{k_1 L_t} - \mathrm{k_2 D_t}$$

$$where, Lt = L_0 e^{-k_1 t}$$

$$D_t = Cs - C = \frac{k_1 L_0}{k_2 - k_1}\left(e^{-k_1 t} - e^{-k_2 t}\right) + Doe^{-k_2 t}$$



T = travel time equivalent to "distance"

D_c = "Critical" DO deficit"

D_0 = Initial DO deficit, at time t = 0

Critical distance

- "Critical distance" x_c or critical travel time $t_c = x_c/U$, i.e. the distance/travel time where the <u>minimum</u> O_2 concentration in the river is reached or the highest (critical) DO deficit reached
- Time/Distance wrt DO_{min}
  - Minimal occurs when $dD_t/dt = 0$
  - Taking the sag equation with respect to ***t*** and setting it equal to zero, then solve for ***t***

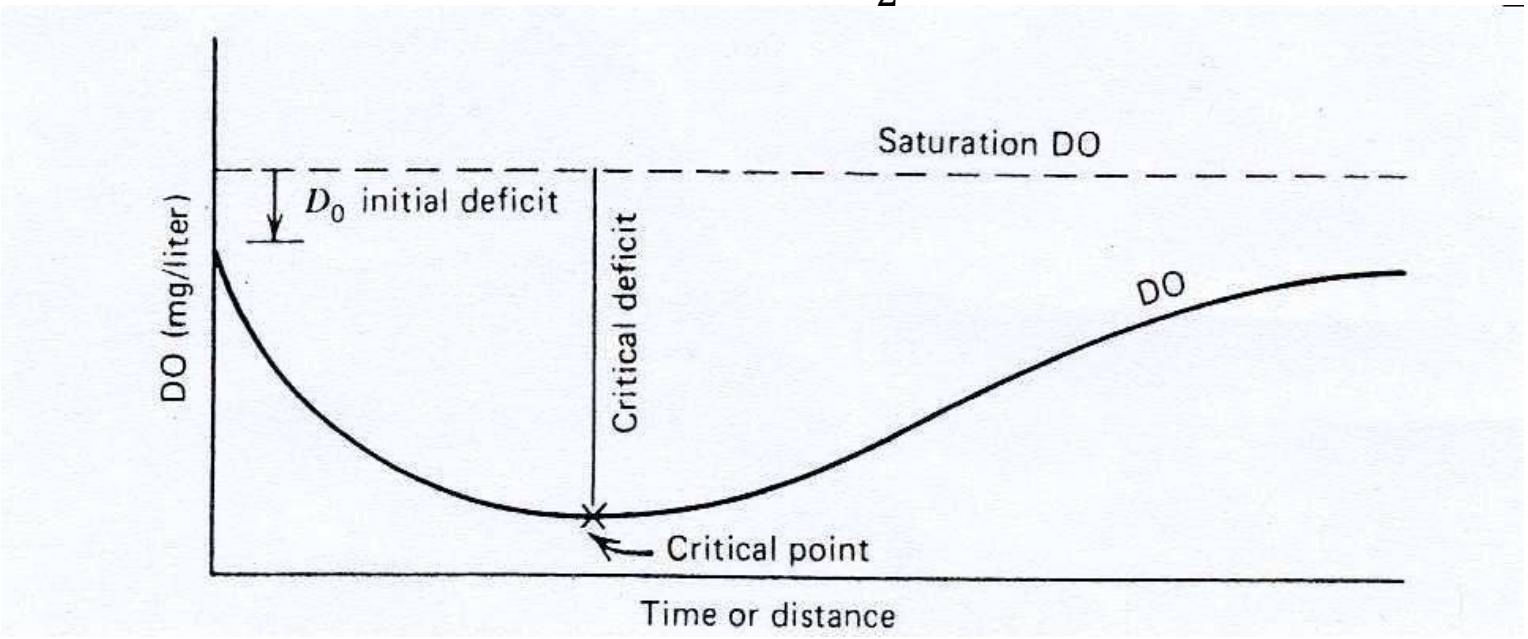
$$t_c = \frac{1}{k_2 - k_1} \ln \left[\frac{k_2}{k_1} \left(1 - \frac{D_0(k_2 - k_1)}{k_1 L_0} \right) \right]$$

Critical DO Deficit

$$\frac{dD_t}{dt} = \mathrm{k_1 L_t} - \mathrm{k_2 D_t}$$

$$\frac{dD_t}{dt} = 0$$

$$D_c = Cs - Cm_{in} = \frac{k_1}{k_2} L_0 e^{-k_1 t}$$



Problem #1

The initial BOD of a river just below a sewage outfall is 25 mg/L. The oxygen deficit just upstream from the outfall is 2 mg/L. The deoxygenation rate coefficient k_1 is 0.4/day, and the reaeration rate coefficient k_2 is 0.7/day. The river is flowing at a speed of 32 km/day. You have been asked to determine the impact of this single source on the river:

a) Find the critical distance downstream at which DO is a minimum
b) Find the minimum DO

Solution (a)

$$t^*{}_c = \frac{1}{k_2 - k_1} \ln\left[\frac{k_2}{k_1}\left(1 - \frac{D_0(k_2 - k_1)}{k_1 L_0}\right)\right]$$

$$t^*{}_c = \frac{1}{0.7 - 0.4} \ln\left(\frac{0.7}{0.4}\left(1 - \frac{2(0.7 - 0.4)}{0.4 * 25}\right)\right) = 1.65\ days$$

$$d_c = tc * u = 1.65\ days * 32\,\frac{km}{days} = 52.8\ km$$

Solution (b)

$$D_t = Cs - C = \frac{k_1 L_0}{k_2 - k_1}\left(e^{-k_1 t} - e^{-k_2 t}\right) + Doe^{-k_2 t}$$

$$D_t = \frac{0.4 * 25}{0.7 - 0.4}(e^{-0.4*1.65} - e^{-0.7*1.65}) + 2 * e^{-0.7*1.65}) = 7.36\ mg/l$$

OR

$$D_c = Cs - Cm_{in} = \frac{k_1}{k_2} L_0 e^{-k_1 t}$$

$$\mathrm{D_c} = \left(\frac{0.4}{0.7}\right) * 25 * e^{-0.4*1.65} = 7.38\ mg/l$$

Minimum DO = $DO_{saturation} - D_c$ = 10 - 7.36 = 2.64 mg/l

Assuming, $DO_{saturation}$ = 10 mg/l

Problem #2

Characteristics river/BOD load:

$k_1 = 0.3\ day^{-1}$

$k_2 = 0.9\ day^{-1}$

$L_0 = 30$ mg/L (BOD conc. in river after mixing

$C_s = 8.0$ mg/L (DO saturation concentration)

$t_c = 2.5$ days

Minimum DO will be: 3.3 mg O_2/L

Till what value should L_0 be reduced to reach DO standard = 5.0 mg/L?

(Answer: $L_0 < 19$ mg/L)

Chapter 7: Wastewater Treatment

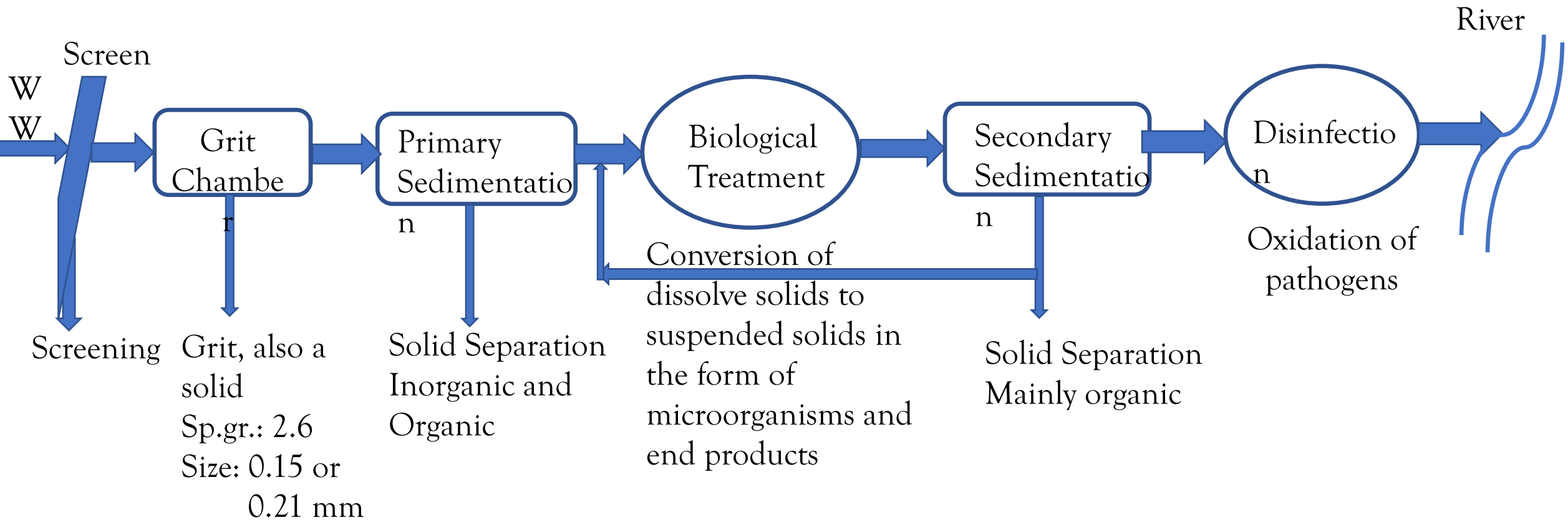
Overview

<u>Sanitary Sewage Constituents</u>

1. Floating debris/street litters
2. Solids
   i. Suspended (sands/grits, soils and clay particles, kitchen wastes, toilet wastes)
   ii. Dissolve solids (toilet wastes, kitchen wastes, washing detergents, cleaning solutions)
3. Organic Materials (toilet wastes, kitchen wastes)
4. Pathogens
5. Toxic organic and inorganic materials (e.g. heavy metals, solvents are in negligible quantity- present at traces)

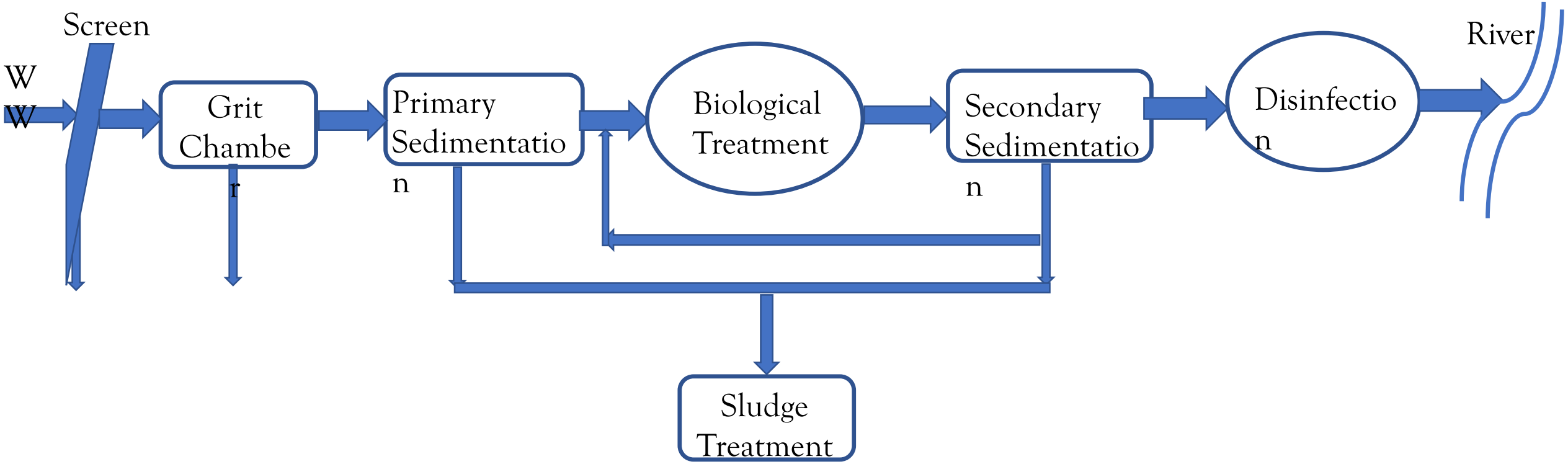
Chapter 7: Wastewater Treatment

Overview



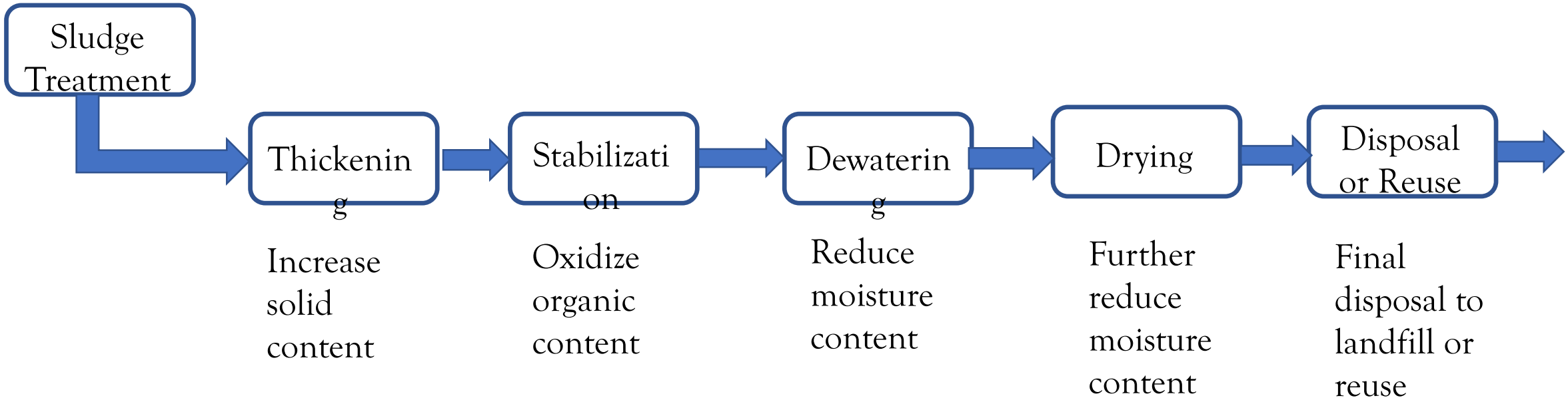
Chapter 7: Wastewater Treatment

Overview



Chapter 7: Wastewater Treatment

Overview



Screens

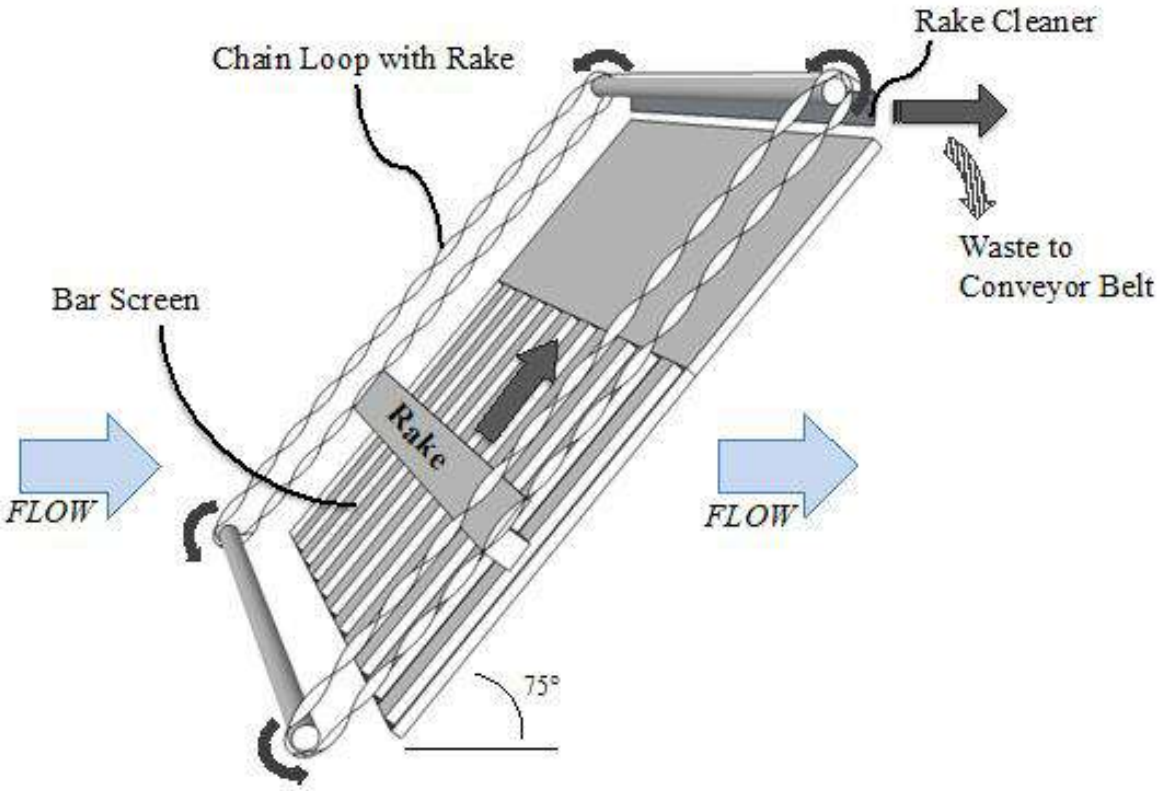
Screening

- for removing bigger suspended or floating matter, which would otherwise damage equipment or interfere with satisfactory operation of treatment units.

Types of Screens

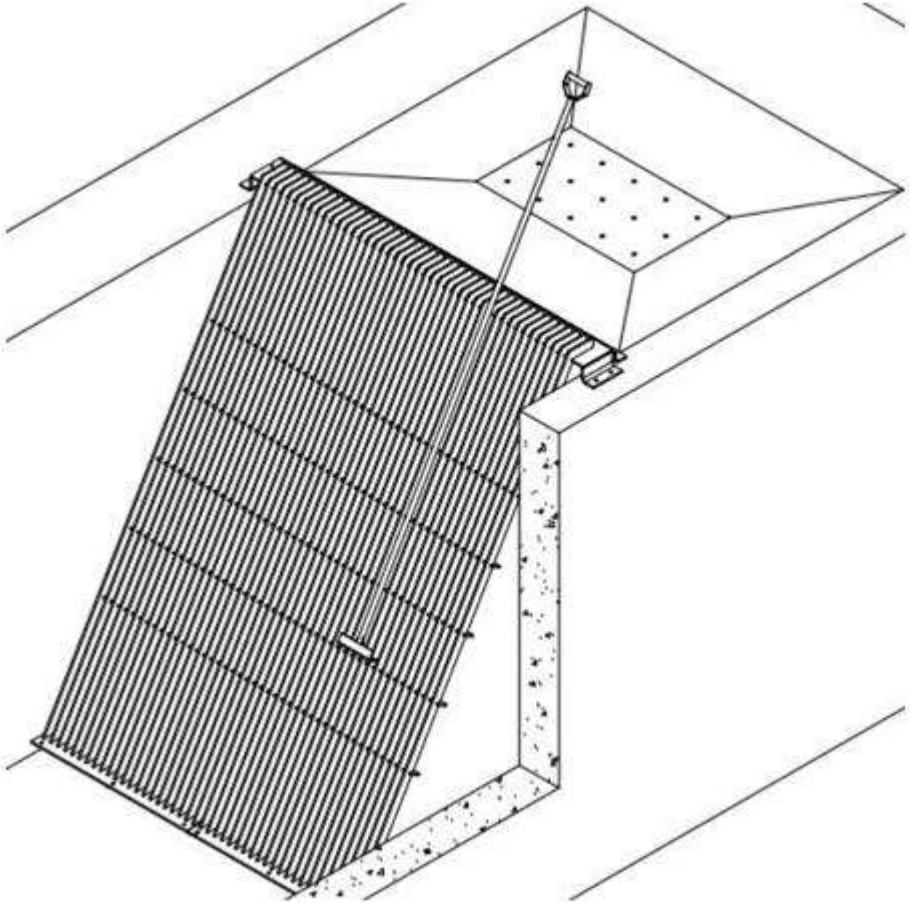
- **Coarse Screens:** Coarse screens also called **racks**, are usually **bar racks**, composed of vertical or inclined bars spaced at equal intervals across a channel through which sewage flows and have clear openings of 75 to 100 mm
- **Medium Screens:** Medium screens have clear openings of 20 to 50 mm. **Bar** are usually 10 mm thick on the upstream side and taper slightly to the downstream side. The bars used for screens are rectangular in cross section usually about 10 x 50 mm, placed with larger dimension parallel to the flow

Bar Racks



Hand cleaned racks are set usually at an angle of 45° to the horizontal to increase the effective cleaning surface and also facilitate the raking operations. Mechanical cleaned racks are generally erected almost vertically.

Bar Racks



Bar Racks/Screens

Bar racks are

- hand cleaned and mechanically cleaned.

These cleaning devices are rakes which periodically sweep the entire screen removing the solids for further processing or disposal.

- **Fine Screens:** Fine screens are mechanically cleaned devices using perforated plates, woven wire cloth or very closely spaced bars with clear openings of less than 20 mm. Fine screens are not normally suitable for sewage because of clogging possibilities.

Bar Racks: Design Information

Items	Hand Cleaned	Mechanically Cleaned
1. Bar Size: Width (mm) Depth (mm)	 5-15 27-75	 5-15 25-75
2. Clear spacing between bars (mm)	25-50	15-75
3. Slope from vertical (deg)	30-45	0-30
4. Approach velocity (m/s)	0.3-0.6	0.6-1
5. Allowable head loss (mm)	300	150

Velocity

The **velocity of flow ahead of and through the screen** varies and affects its operation.

- lower the velocity through the screen, the greater is the amount of screenings that would be removed from sewage.
- lower the velocity, the greater would be the amount of solids deposited in the channel, the design velocity should be such as to permit 100% removal of material of certain size without undue depositions.
- Velocities of ***0.6 to 1.2 m/s through the open area for the peak flows***
- velocity at low flows in the approach channel should ***not be less than 0.3 m/s*** to avoid deposition of solids

Head loss

Head loss varies with the quantity and nature of screenings allowed to accumulate between cleanings. The head loss created by a clean screen may be calculated by considering the flow and the effective areas of screen openings. The head loss through clean flat bar screens is calculated from the following formula:

$$h = 0.0729(V^2 - v^2)$$

where, h = head loss in m

V = velocity through the screen in m/s

v = velocity before the screen in m/s

Head loss

Another formula often used to determine the head loss through a bar rack is Kirschmer's equation:

$$h = b\left[\frac{W}{b}\right]^{4/3} h_v \mathrm{Sin}\theta$$

where h = head loss, m

b = bar shape factor (2.42 for sharp edge rectangular bar, 1.83 for rectangular bar with semicircle upstream, 1.79 for circular bar and 1.67 for rectangular bar with both u/s and d/s face as semicircular)

W = maximum width of bar u/s of flow, m

b = minimum clear spacing between bars, m

h_v = velocity head of flow approaching rack, m = $v^2/2g$

θ = angle of inclination of rack with horizontal

Screens: Head loss

The head loss through fine screen is given by

$$h = \frac{Qh}{2gCA}$$

where, h = head loss, m

Q = discharge, m^3/s

C = coefficient of discharge (typical value 0.6)

A = effective submerged open area, m^2

The quantity of screenings depends on the nature of the wastewater and the screen openings.

Grit Chambers

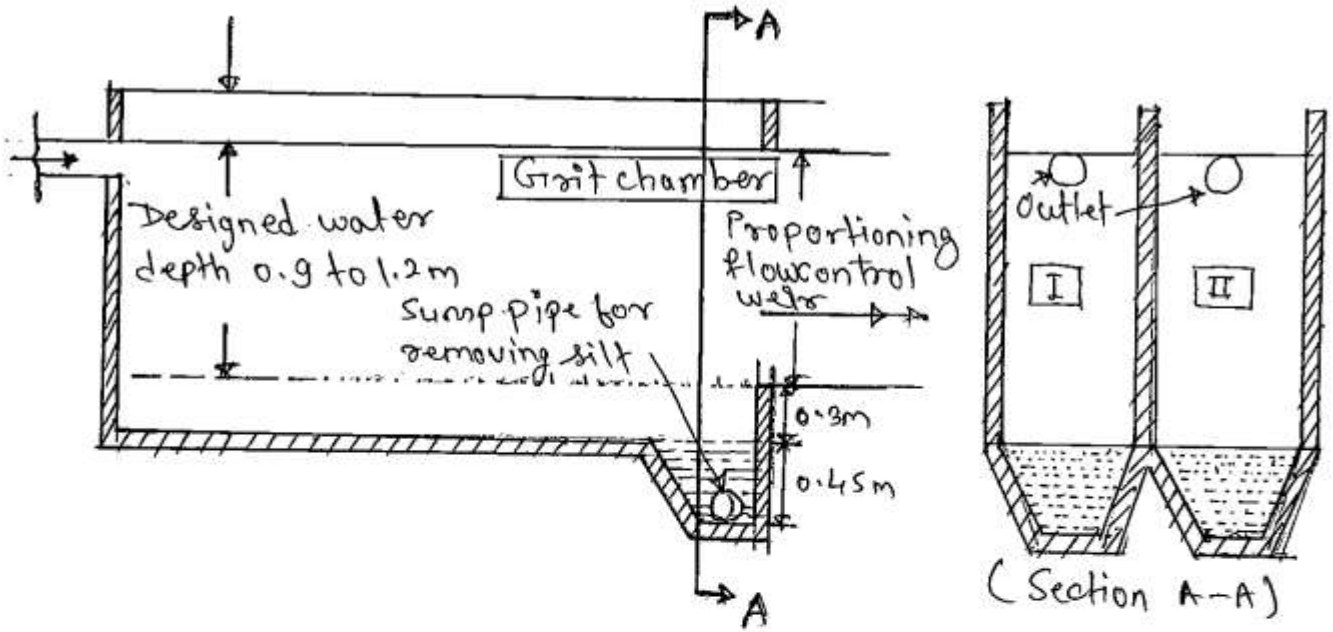
Grit chambers are basin to remove the inorganic particles to prevent

- damage to the pumps, and
- accumulation in sludge digestors

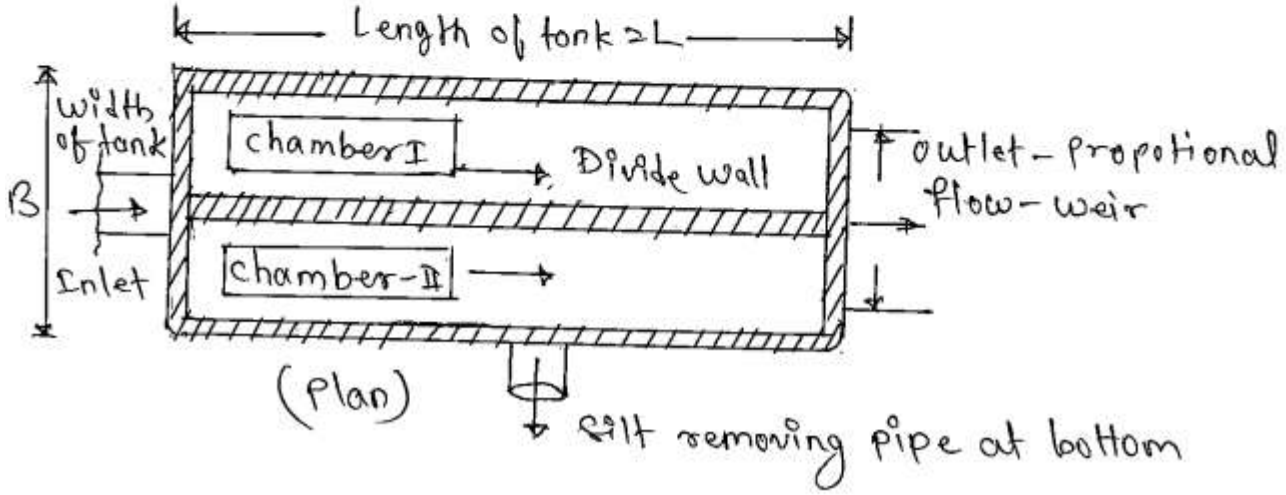
<u>Grit chambers are of two types</u>:

- mechanically cleaned and manually cleaned

In ***mechanically cleaned*** grit chamber, scraper blades collect the grit settled on the floor of the grit chamber. The grit so collected is elevated to the ground level by several mechanisms such as bucket elevators, jet pump and air lift.

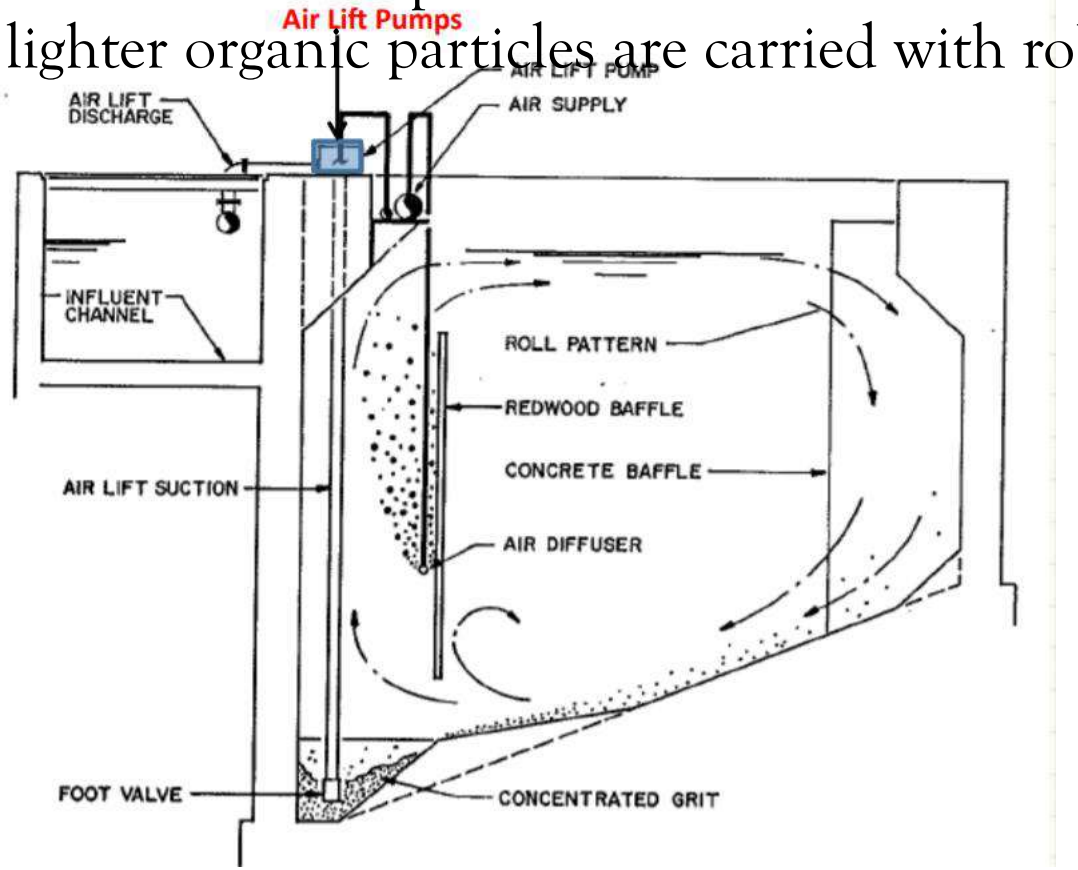

A
Grit chamber
Designed water depth 0.9 to 1.2m
Sump pipe for removing silt
Proportioning flowcontrol weir
0.3m
0.45m
A

Outlet
I
II
(Section A-A)


Length of tank = L
width of tank
B
Inlet
chamber I
Divide wall
chamber-II
outlet - propotional flow-weir
(Plan)
silt removing pipe at bottom

Aerated Grit Chambers

An aerated grit chamber consists of a standard spiral flow aeration tank provided with air diffusion tubes placed on one side of the tank. The grit particles tend to settle down to the bottom of the tank at rates dependent upon the particle size and the bottom velocity of roll of the spiral flow, which in turn depends on the rate of air diffusion through diffuser tubes and shape of aeration tank. The heavier particles settle down whereas the lighter organic particles are carried with roll of the spiral motion.



Design of Grit Chambers

Settling Velocity

- The settling velocity of discrete particles can be determined using appropriate equation depending upon Reynolds number.

Stoke's law: $v = \frac{g(Ss-1)d^2}{18\nu}$

where,

v = velocity,

Ss =specific gravity of solid,

d = particle diameter,

ν = kinematic viscosity (centistokes) = μ/ρ (μ is dynamic viscosity, centipoise)

Design of Grit Chambers

Settling Velocity

Stoke's law holds good for Reynolds number, R_e below 1.

$$R_e = \frac{vd}{\upsilon}$$

For grit particles of specific gravity 2.65 and liquid temperature at 10°C, $\upsilon = 1.01 \times 10^{-6}\ m^2/s$. This corresponds to particles of size less than 0.1 mm.

Design of Grit Chambers

- Transition law: The design of grit chamber is based on removal of grit particles with minimum size of 0.15 mm and therefore Stoke's law is not applicable to determine the settling velocity of grit particles for design purposes.

$$v = \sqrt{\frac{4(S_s - 1)d}{3C_D}}$$

where, C_D= drag coefficient

C_D can be approximated by

Design of Grit Chambers

C_D can be approximated by

$$C_D = \frac{24}{R_e} + \frac{3}{\sqrt{R_e}} + 0.34$$

Substituting the value of C_D in settling velocity equation

Principle of Working of Grit Chamber

Grit chambers are nothing but like sedimentation tanks, designed to separate

- heavier inorganic materials (specific gravity about 2.65) and
- to pass forward the lighter organic materials

Hence, *the flow velocity should neither be too low as to cause the settling of lighter organic matter, nor should it be too high to suspend grit*

The scouring velocity determines the optimum ***flow through velocity***.

This may be explained by the fact that the critical velocity of flow 'v_c' beyond which particles of a certain size and density once settled, may be again introduced into the stream of flow. It should always be less than the scouring velocity of grit particles.

Principle of Working of Grit Chamber

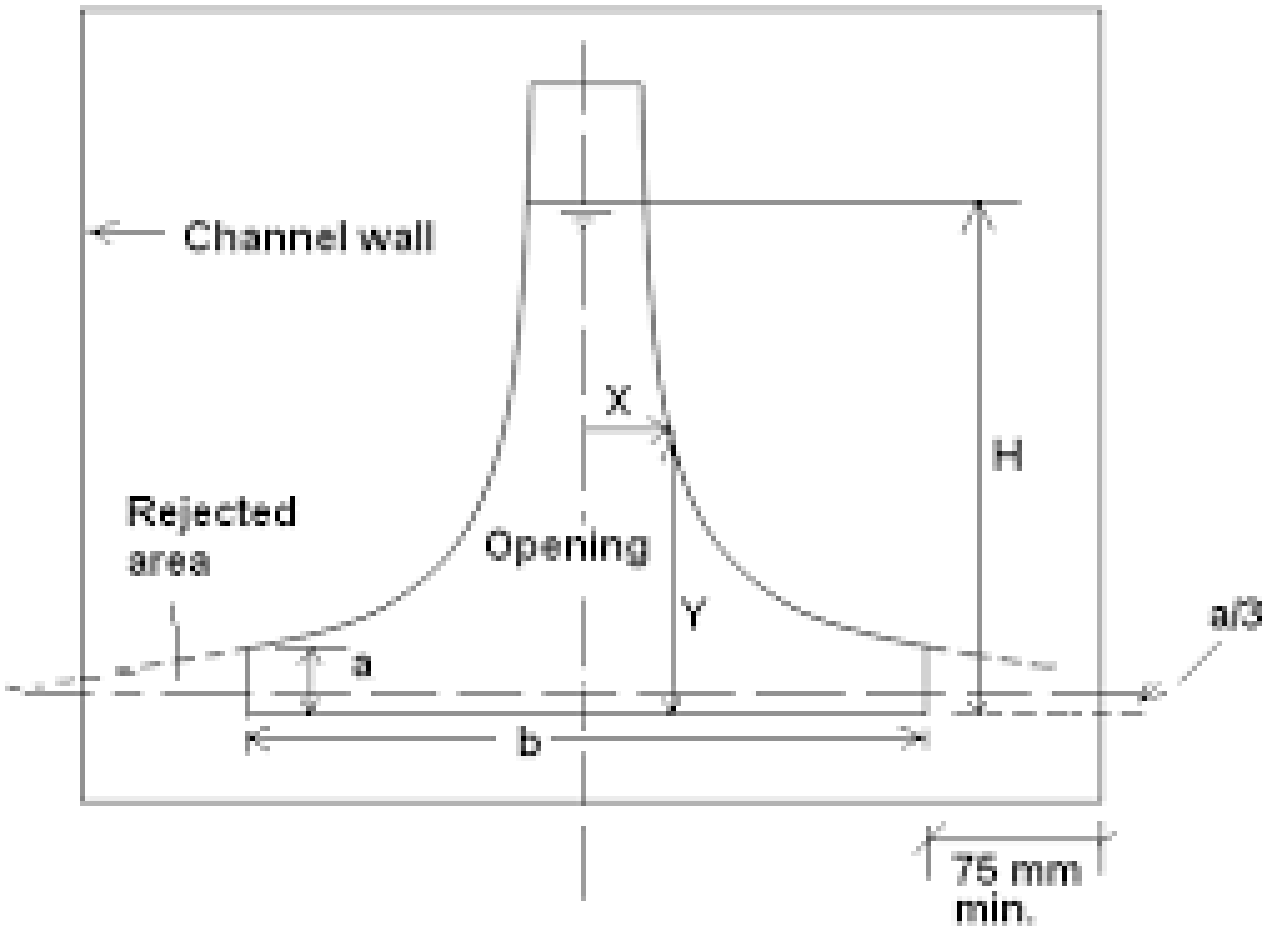
- The critical velocity of scour is given by Schield's formula:

$$V = 3\ to\ 4.5\{g(S-1)d\}^{1/2}$$

- A horizontal velocity of flow of 15 to 30 cm/sec is used at peak flows. This same velocity is to be maintained at all fluctuation of flow to ensure that only organic solids and not the grit is scoured from the bottom.
- Detention period for grit chambers vary between 60 to 90 seconds.

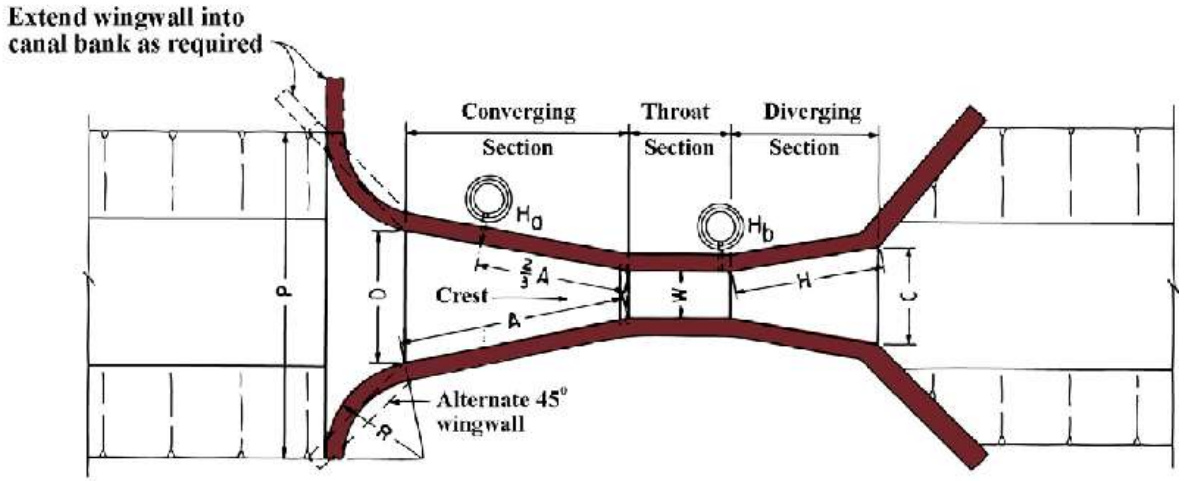
Types of Velocity Control Devices

- A rectangular shaped channel with proportional flow weir.

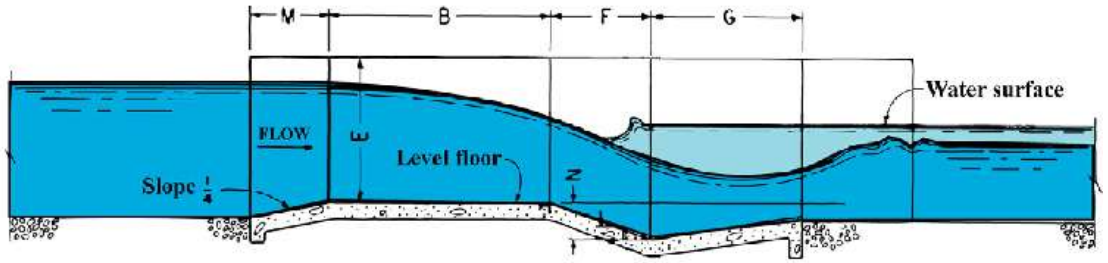


Types of Velocity Control Devices

- A parabolic shaped channel with a Parshall flume at the end which would also help easy flow



PLAN



PROFILE

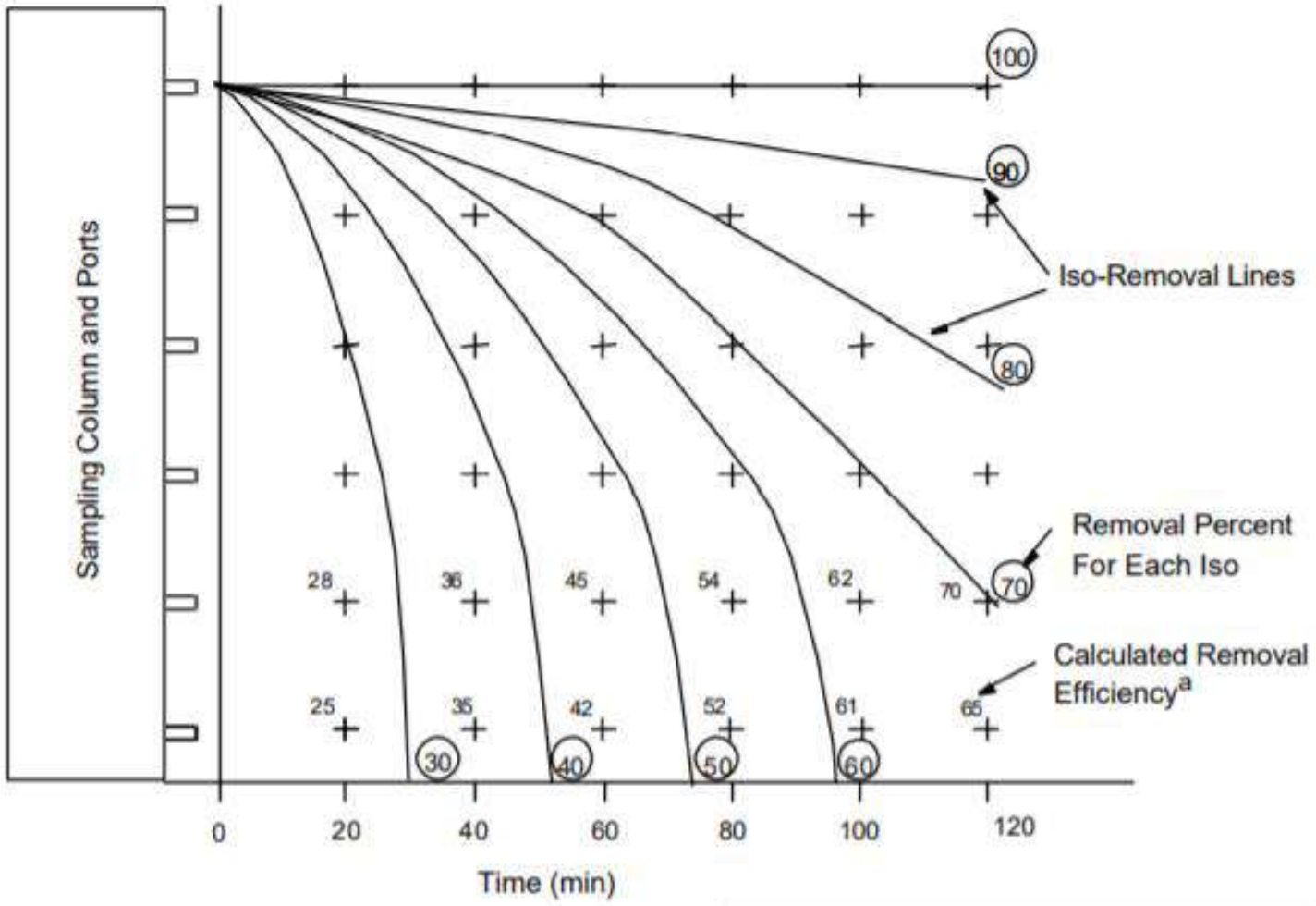
Primary Sedimentation

- Primary sedimentation in a municipal wastewater treatment plant is generally plain sedimentation without the use of chemicals. In treating certain industrial wastes chemically aided sedimentation may be involved.
- In either case, it constitutes flocculated particles in dilute suspensions. Therefore the settling type is ***flocculent settling.***
- Stokes equations cannot be used because the particles are constantly changing shape and size.
  - the particles do not remain discrete as in the case of grit,
  - but tend to agglomerate or coagulate during settling.

  Thus, their diameter keeps increasing and settlement proceeds at an over increasing velocity. Consequently, they trace a curved profile.
- The settling tank design in such cases depends on both ***surface loading*** and ***detention time***.

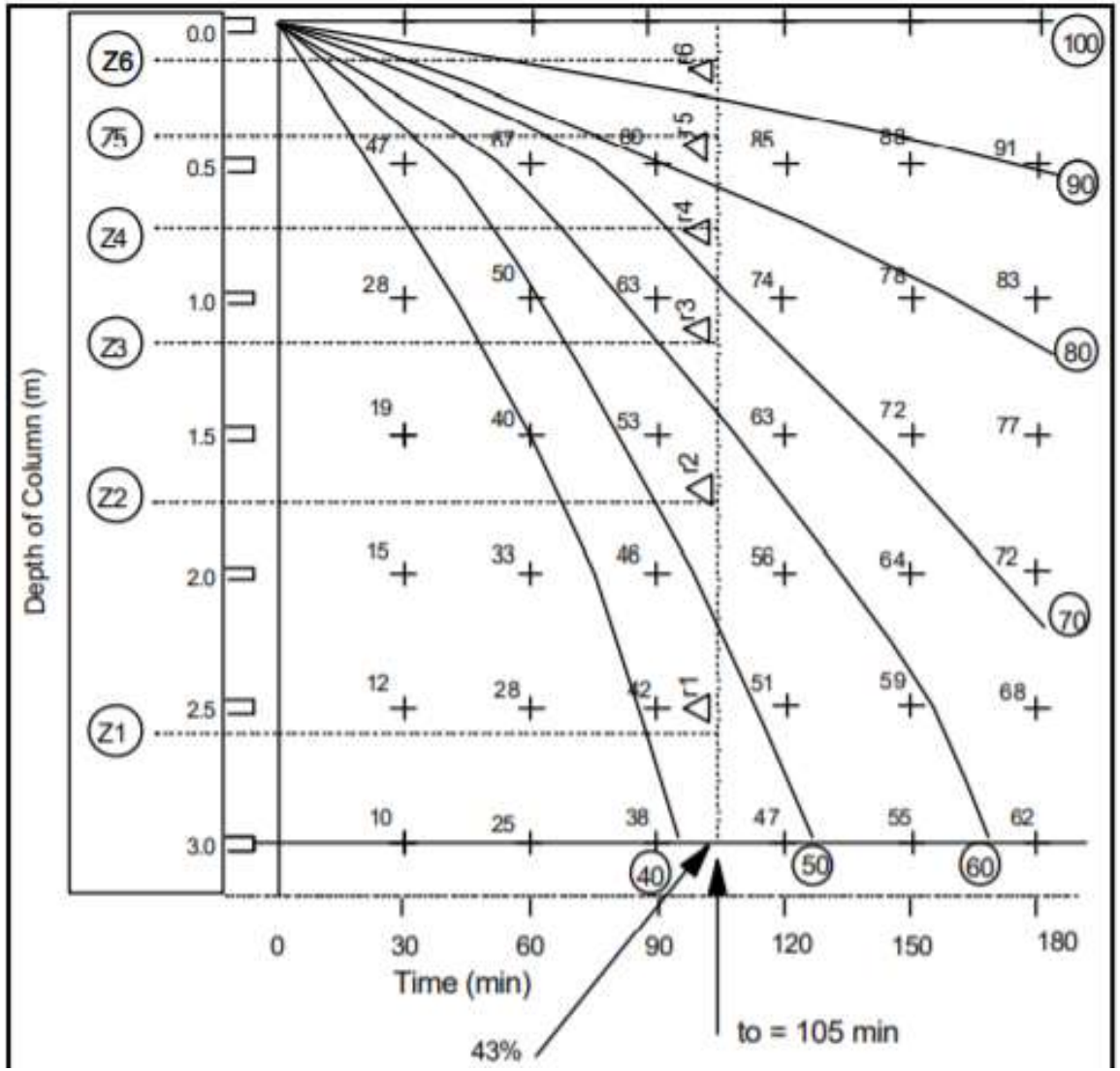
Primary Sedimentation

Long tube settling tests can be performed in order to estimate specific value of surface loading and detention time for desired efficiency of clarification.



a - calculated with xij, where i is depth and j is time

Primary Sedimentation



$$R = R_{intercept} + \frac{1}{H} \sum (Z_i \Delta R)$$

where, $R_{intercept} = 43\%$

Safety factors: 1.25 to 1.75 for the overflow rate, and 1.5 to 2.0 for detention time when converting laboratory results to the prototype design.

Primary Sedimentation Tank: Design Parameters

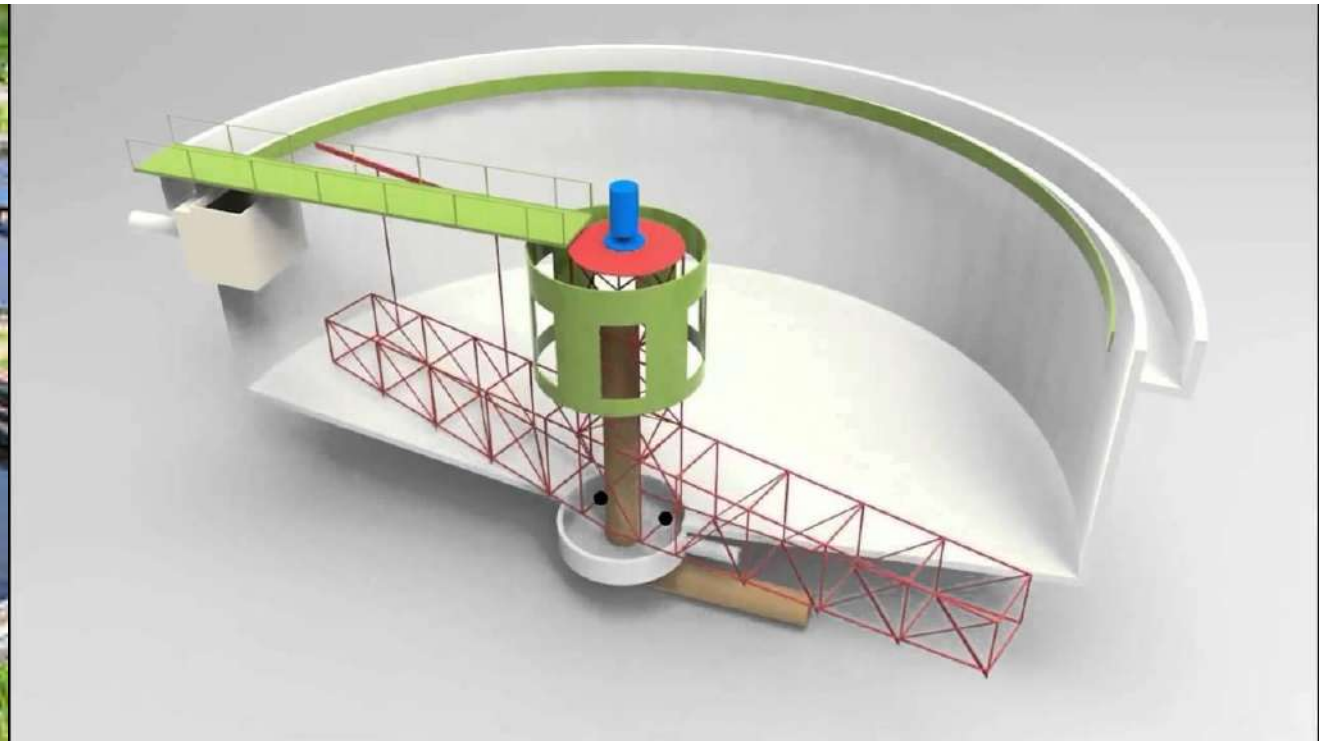
- For primary settling tanks treating municipal or domestic sewage, laboratory tests are generally not necessary, and recommended design values given in table may be used.

Types of settling	Overflow rate m^3m^2/day		Solids loading $kg/m^2/day$		Depth	Detention time
	Average	Peak	Average	Peak		
Primary settling only	25-30	50-60	-	-	2.5-3.5	2.0-2.5
Primary settling followed by secondary	35-50	60-120	-	-	2.5-3.5	2.0-2.5

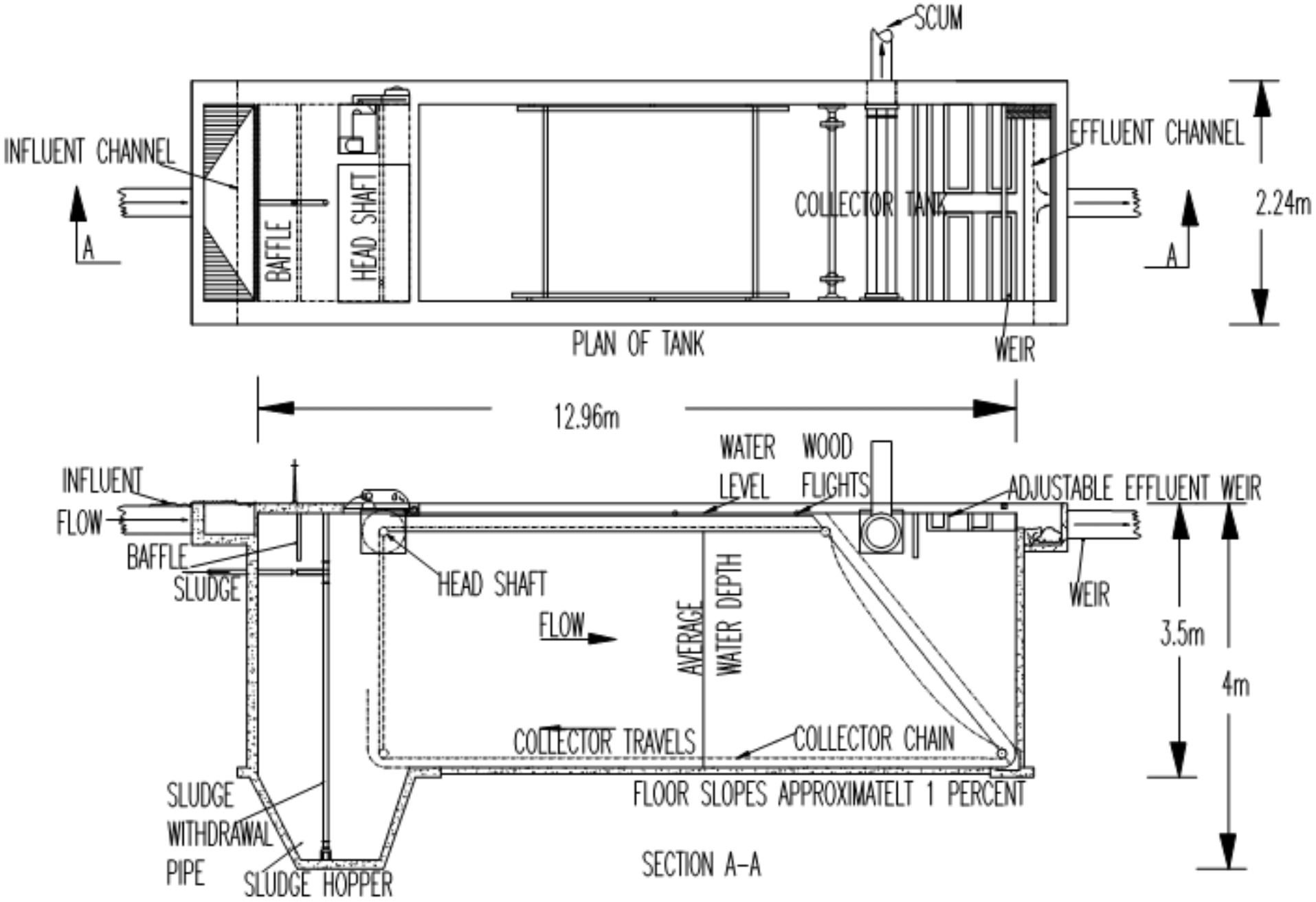
Primary Sedimentation

- Using an appropriate value of surface loading from table, the required tank area is computed.
- Knowing the average depth, the detention time is then computed.
- Excessively high detention time (longer than 2.5 h) must be avoided especially in warm climates where anaerobicity can be quickly induced.

Circular Sedimentation Tank



Rectangular Sedimentation Tank



Biological Treatment process

Objectives of Biological Process

- **Primary**: Oxidize Organic materials present in the wastewater stream and form the flocs (solids)
- **Secondary**: Form flocs, enmesh fine and colloidal not removed in primary settling tank

Finally, separate flocs from wastewater stream in Secondary Clarifier

Principles of Biological Treatment process

Oxidation and Synthesis

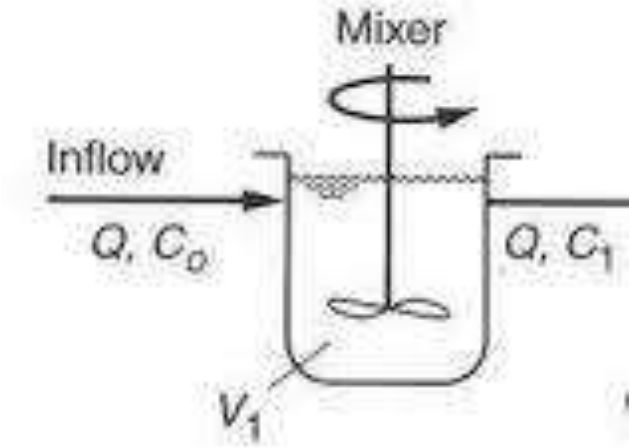
$$\underset{\text{(Organic matter)}}{COHNS} + O_2 + \text{Nutrients} \xrightarrow{\text{Bacteria}} CO_2 + NH_3 + \underset{\text{(New bacterial cells)}}{C_5H_7NO_2} + \text{Other end products}$$

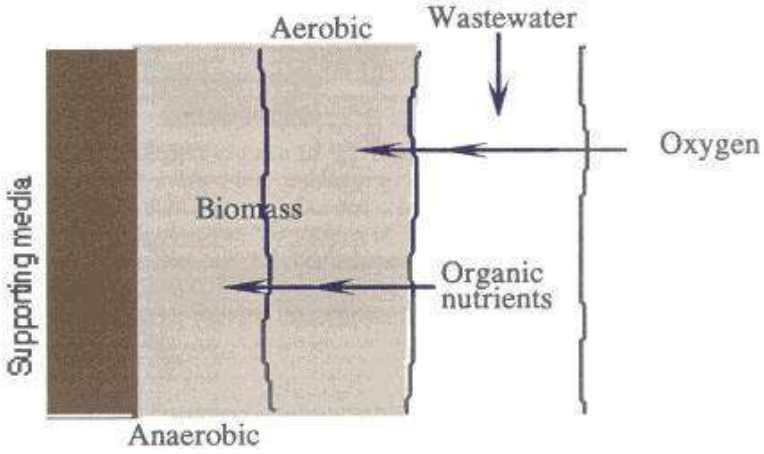
Endogenous Respiration

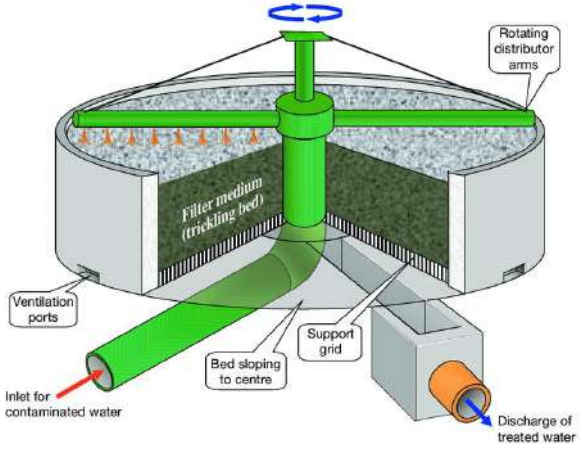
$$\underset{\text{(Cells)}}{C_5H_7NO_2} + 5O_2 \xrightarrow{\text{Bacteria}} 5CO_2 + 2H_2O + NH_3 + \text{Energy}$$

Biological Treatment process

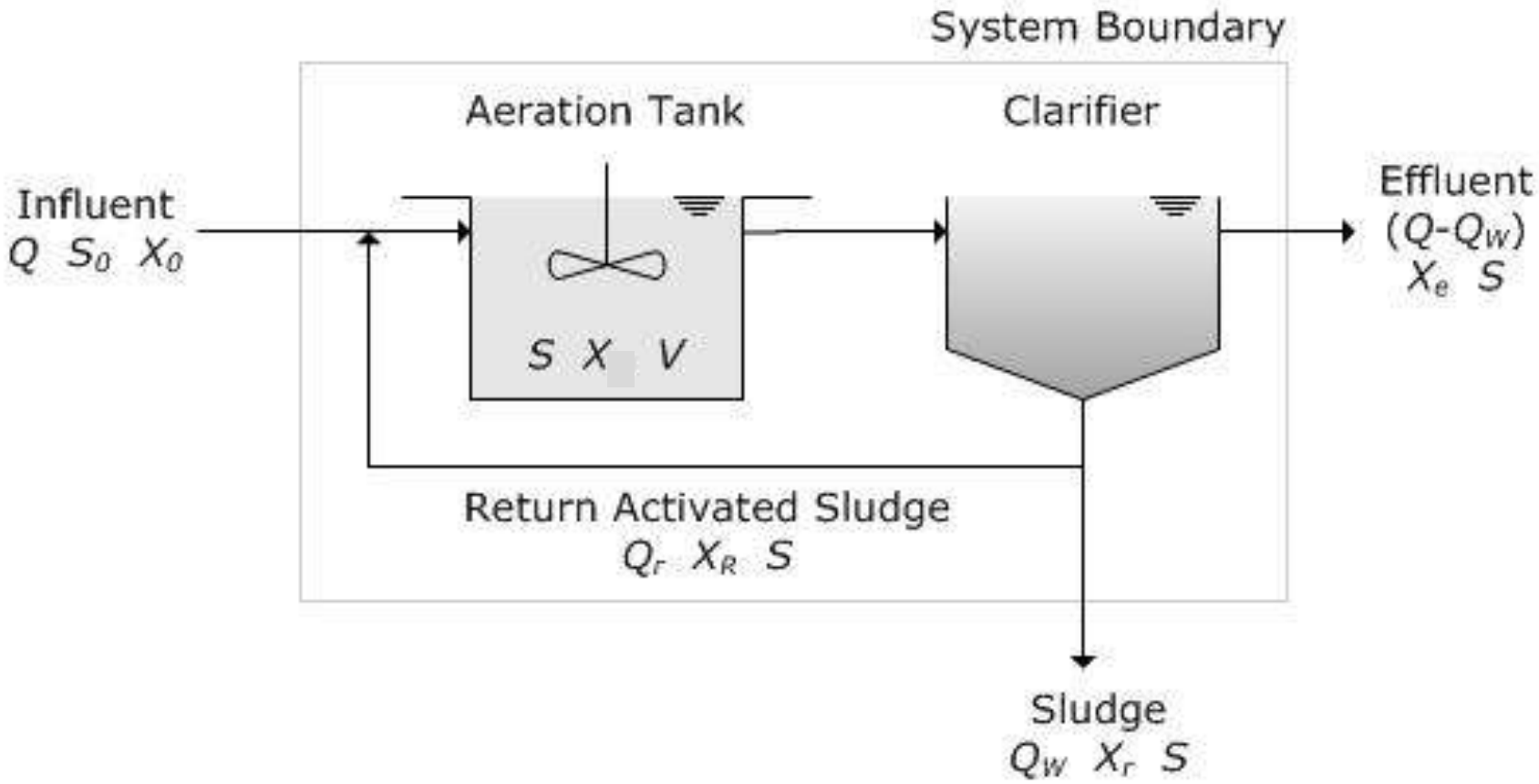
1. Suspended Growth Process: In which, microorganisms (bacteria) are grown in suspension and the Oxidation of organic materials takes place in the suspension
2. Attached Growth Process: Microorganisms are attached in a solid surface; they grow in attached condition and oxidize organic materials at same







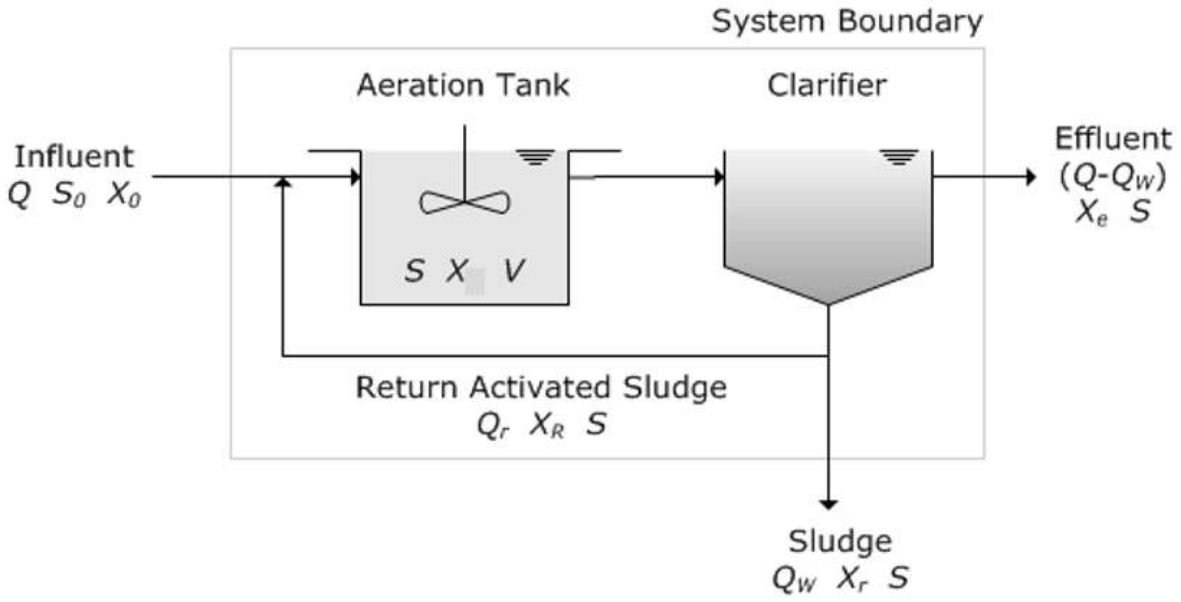
Activated Sludge Process



Activated Sludge Process

<u>ASP Involves</u>

- wastewater aeration in the presence of a microbial suspension,
- solid-liquid separation following aeration,
- discharge of clarified effluent,
- return of required biomass to the aeration tank, and
- wasting of excess biomass.



Activated Sludge Process

- In ASP wastewater containing organic matter is aerated in an aeration basin in which micro-organisms metabolize the suspended and soluble organic matter.
- Part of organic matter is synthesized into new cells and part is oxidized to CO_2 and water

Oxidation and Synthesis

$$\underset{\text{(Organic matter)}}{COHNS + O_2 + \text{Nutrients}} \xrightarrow{\text{Bacteria}} \underset{\text{(New bacterial cells)}}{CO_2 + NH_3 + C_5H_7NO_2} + \text{Other end products}$$

- In activated sludge systems the new cells formed in the reaction are removed from the liquid stream in the form of a flocculent sludge in settling tanks.
- A part of this settled biomass, described as activated sludge is returned to the aeration tank and the remaining forms waste or excess sludge.

ASP Loading Criteria

1. Hydraulic Retention Time (HRT), $\theta(hours) = \frac{V}{Q}$x24

Where, V = volume of aeration tank (m^3), Q = Sewage inflow (m^3/day)

HRT Range (θ) = 4 to 8 hours

2. Volumetric BOD_5 loading Rate

$$Vloumetric\ loading\ rate\ \left({}^{kg\ BOD_5}/_{m^3}\right) = \frac{QS_0}{V}$$

Where, S_0 = influent BOD_5 to aeration tank (mg/L)

Volumetric loading Rate $\left({}^{kg\ BOD_5}/_{m^3}\right)$ =0.3 to 0.7

ASP Loading Criteria

3. Sludge age (Solid Retention time or Mean Cell Residence time), θ_C (day)

$$\theta_C = \frac{VX}{Q_w X_r + Q_e X_e} = \frac{VX}{Q_W X_r}$$

Where, X = VSS concentration in aeration tank (mg/L), Q_W= Sludge wasted from the system (m^3/d), X_r = VSS concentration in return sludge (mg/L), Q_e = Effluent flow rate (m^3/d), X_e = VSS concentration in effluent (mg/L)

SRT (θ_C) = 5 to 15 day

4. Mix Liquor Suspended Solids (MLSS) = ***1500 to 3000 mg/L***

ASP Loading Criteria

5. MLVSS/MLSS = ***0.8*** where, MLVSS = Mix Liquor Volatile Suspended solids

6. Food/Microorganism $\frac{F}{M} = \frac{QS_0}{XV}$ ***(0.4 to 0.2 day^{-1})***

7. Sludge Volume Index

$$SVI = \frac{V_S}{X} \text{ (mL/mg)}$$

$$SVI\left(\frac{L}{mg}\right) = \frac{SVI\ (\frac{mL}{mg})}{10^6}$$

where, Vs = settled solid in mL after 30 minutes of settling in a 1L graduated cylinder, X = MLSS mg/L

Values of SVI between 100 and 150 ml/g indicate good settling of suspended solids

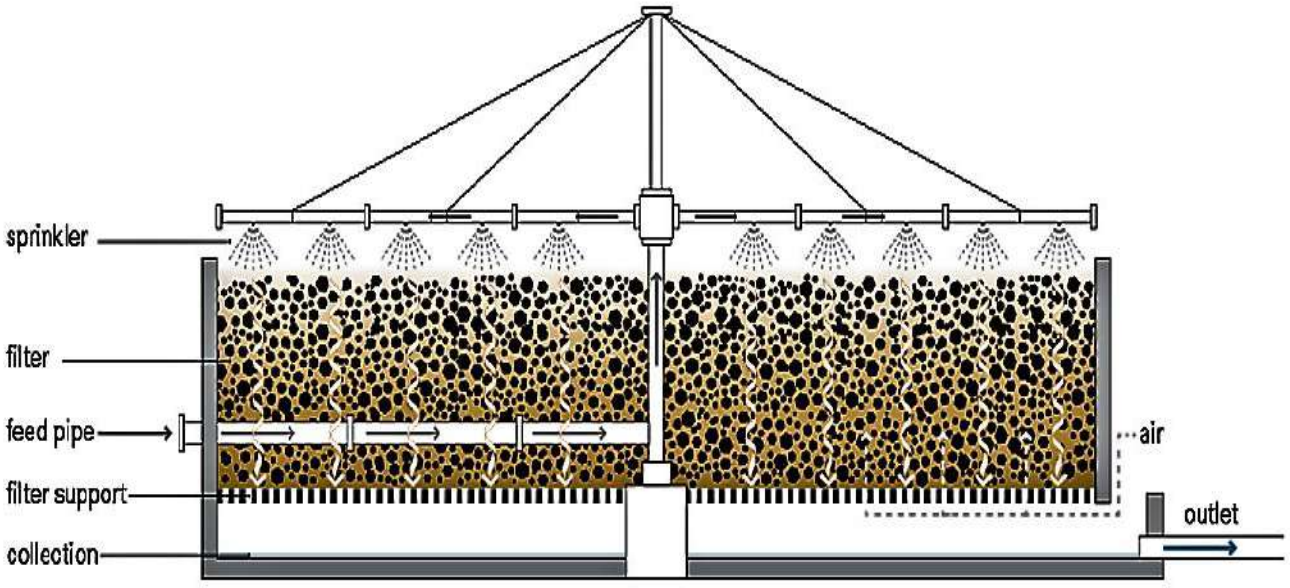
Sewage Filtration: Trickling Filters

Trickling filter is an ***attached growth process*** i.e. process in which microorganisms responsible for treatment are attached to an inert packing material.

- Packing material used in attached growth processes include rock, gravel, slag, sand, redwood, and a wide range of plastic and other synthetic materials.

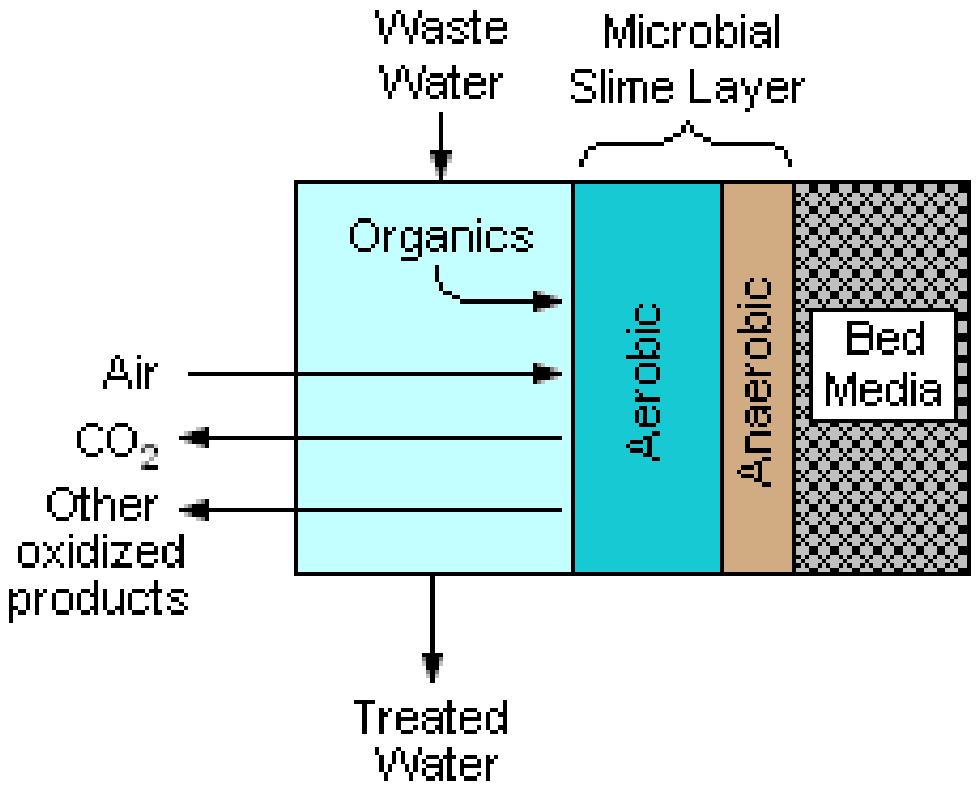
Trickling Filters: Process Description

- The wastewater in trickling filter is distributed over the top area of a vessel containing non-submerged packing material.
- Air circulation in the void space, by either natural draft or blowers, provides oxygen for the microorganisms growing as an attached biofilm.



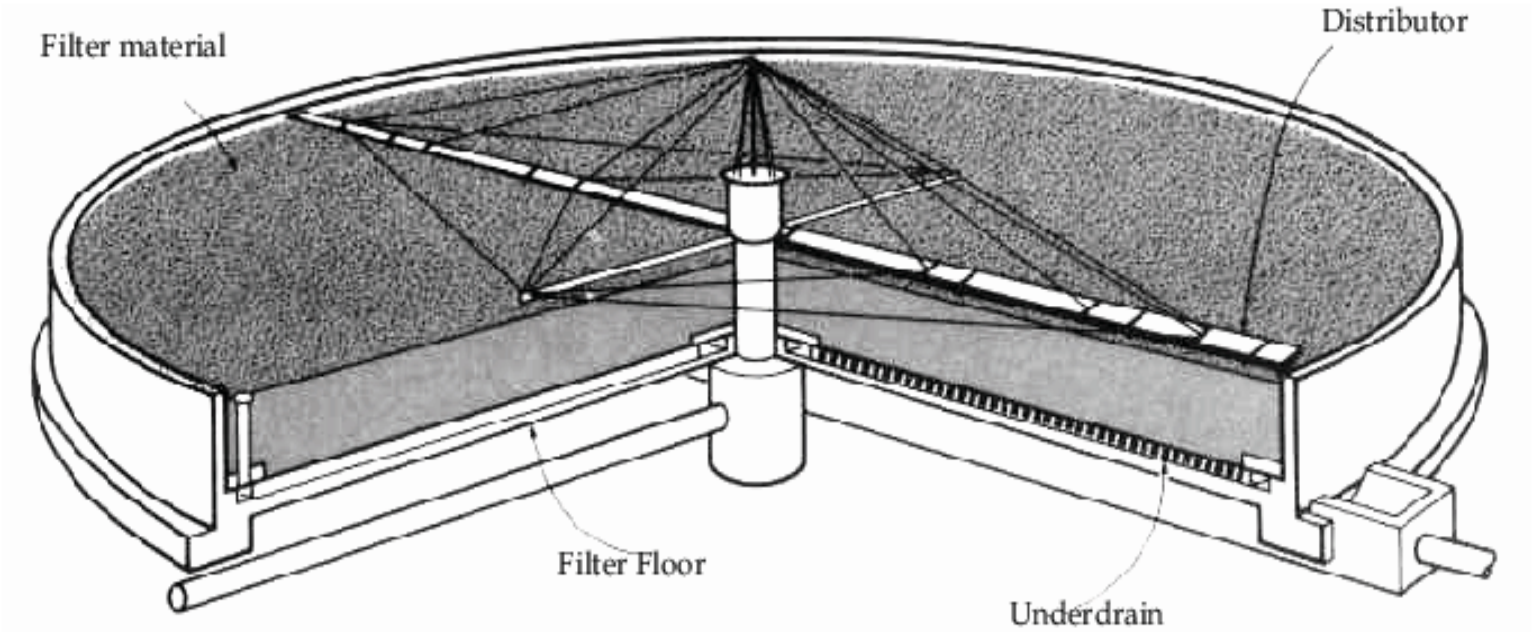
Trickling Filters: Process Description

- During operation, the organic material present in the wastewater is metabolized by the biomass attached to the medium. The biological slime grows in thickness as the organic matter abstracted from the flowing wastewater is synthesized into new cellular material.
- The thickness of the aerobic layer is limited by the depth of penetration of oxygen into the microbial layer



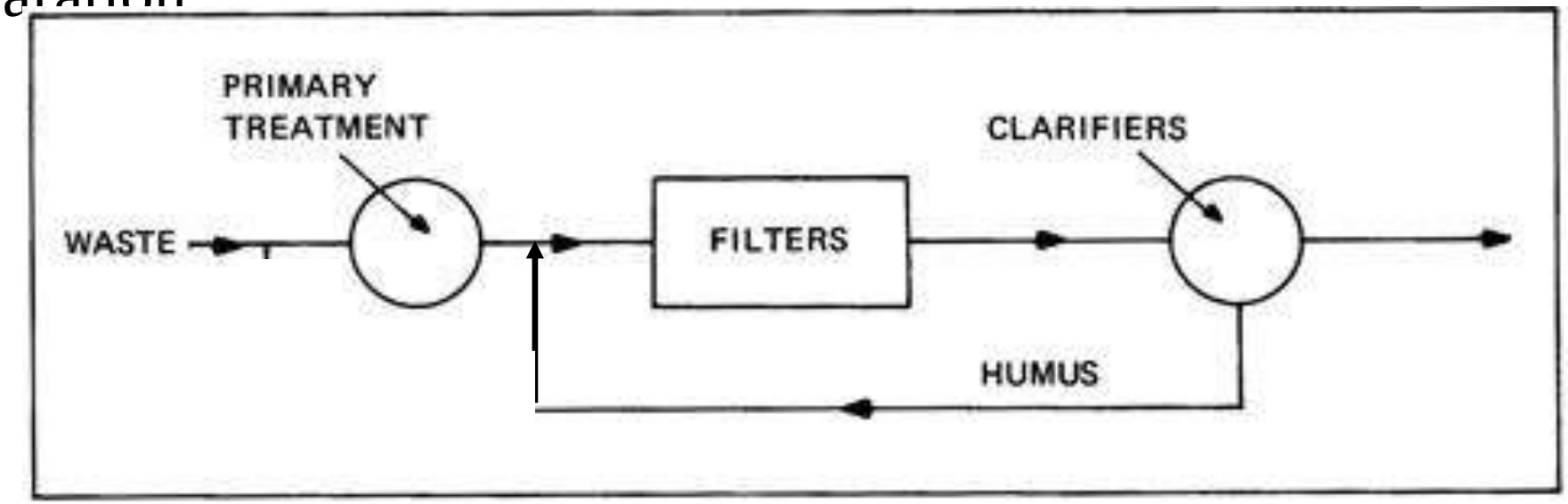
Trickling Filters: Process Description

- The micro-organisms near the medium face enter the endogenous phase as the substrate is metabolized before it can reach the micro-organisms near the medium face as a result of increased thickness of the slime layer and loose their ability to cling to the media surface. The liquid then washes the slime off the medium and a new slime layer starts to grow. This phenomenon of losing the slime layer is called



Trickling Filters: Process Description

- The sloughed off film and treated wastewater are collected by an underdrainage which also allows circulation of air through filter. The collected liquid is passed to a settling tank used for solid- liquid separation



Standard-rate trickling filters.

Trickling Filter Loading Rate

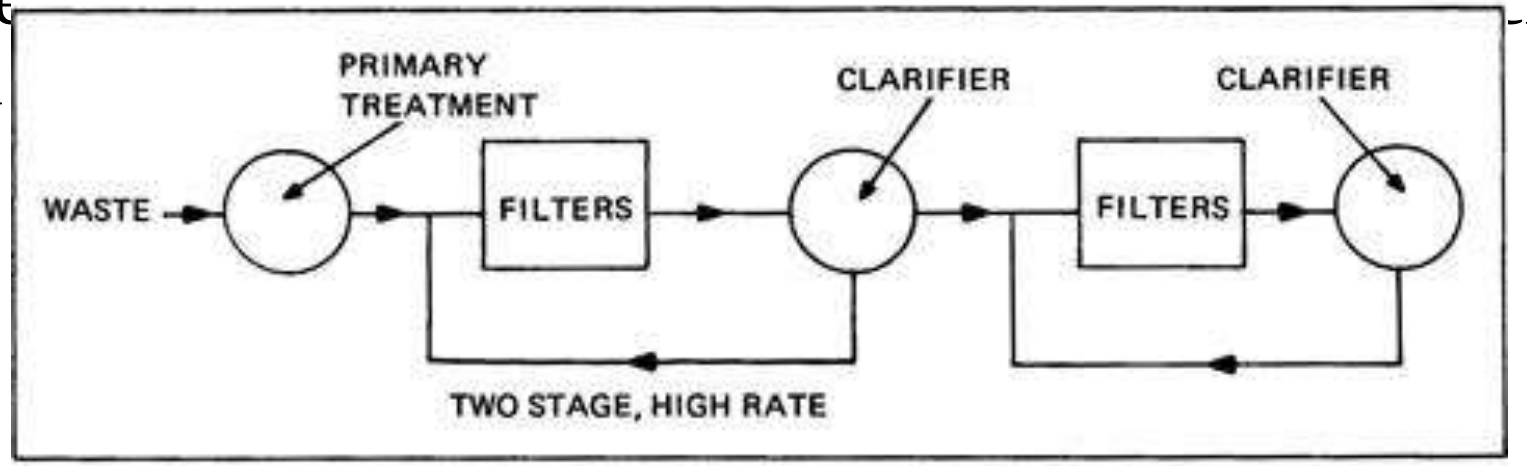
S. No.	Design Parameters	Low Rate Filter	High Rate Filter
1.	Hydraulic loading ($m^3/m^2.d$)	1 - 4	10 - 40
2.	Organic loading (kg BOD / m^3.d)	0.08 - 0.32	0.32 - 1.0
3.	Depth (m)	1.8 - 3.0	0.9 - 2.5
4.	Recirculation ratio	0	0.5 - 3.0 (domestic wastewater)

Trickling Filter Loading Rate

- The hydraulic loading rate is the total flow including recirculation applied on unit area of the filter in a day, while the organic loading rate is the 5 day 20°C BOD, excluding the BOD of the recirculate, applied per unit volume in a day.
- Recirculation is generally not adopted in low rate filters.
- A well operated low rate trickling filter in combination with secondary settling tank may remove 75 to 90% BOD and produce highly nitrified effluent. It is suitable for treatment of low to medium strength domestic wastewaters.

Trickling Filter Loading Rate

- The high rate trickling filter, single stage or two stage are recommended for medium to relatively high strength domestic wastewater. The BOD removal efficiency is around 75 to 90% but the effluent is only partially nitrified.
- Single stage unit consists of a filter, secondary settling tank and facilities for recirculation of the effluent. Two stage filters consist of two filte ch may be omitted



High-rate trickling filters.

Trickling Filter Design

Generally trickling filter design is based on empirical relationships to find the required filter volume for a designed degree of wastewater treatment. Types of equations:

- NRC equations (National Research Council of USA)
- Rankins equation
- Eckenfilder equation
- Galler and Gotaas equation

NRC and Rankin's equations are commonly used. NRC equations give satisfactory values when there is no re-circulation, the seasonal variations in temperature are not large and fluctuations with high organic loading. Rankin's equation is used for high rate filters.

NRC equations: Stone Media

$$E_1 = \frac{100}{1 + 0.4432\sqrt{\frac{W_1}{VF}}}$$ Single Stage Filter $$F = \frac{1 + R}{\left(1 + \frac{R}{10}\right)^2}$$

$$E_2 = \frac{100}{1 + \frac{0.4432}{1 - E_1}\sqrt{\frac{W_2}{V_2 F}}}$$ Second Stage Filter $$R = \frac{Q_r}{Q}$$

Where, E_1 and E_2 are efficiencies of BOD removal for First (or single) stage and second stage filters at 20^oC including recirculation and sedimentation respectively, %

W_1 and W_2 are the BOD loadings to first (single) stage and second stage filters respectively, kg/d

V and V_2 are volumes of first (single) stage and second stage filters respectively, m^3

Design Criteria for Trickling Filters

Typical Design Criteria for Trickling Filters

Item	Low-rate filter	High-rate filter	Super-rate filter
Hydraulic loading (m^3/m^2-d)	1 - 4	10 - 40	40 - 200
Organic loading (kg BOD_5/m^3-d)	0.08 - 0.32	0.32 - 1.0	0.8 - 6.0
Depth (m)	1.5 - 3.0	1.0 - 2.0	4.5 - 12.0
Recirculation ratio	0	1 - 3	1 - 4
Filter media	Rock, slag, etc.	Rock, slag, synthetics	
Filter flies	Many	Few, larvae are washed away	Few or none
Sloughing	Intermittent	Continuous	Continuous
Dosing intervals	< 5 min	< 15 s	Continuous
Effluent	Usually fully nitrified	Nitrified at low loadings	Nitrified at low loadings

Sludge Treatment and Disposal

Sources of sludge

- Grit Chamber (may or may not be included in the sludge stream, generally ***Not***)
  - Specific gravity~2.6, diameter: 0.15 or 0.21 mm
- Primary Sedimentation Tank
  - Fine and colloidal solids, organic and inorganic, solid content: 2-8% (typically 5%), Specific gravity of solids: 1.4, Specific gravity of sludge: 1.02
- Secondary Sedimentation Tank
  - waste activated sludge: either from aeration tank or from recirculation line: Primarily organic solids, Solids: 0.5 to 1.5% (typically 0.8%), Specific gravity of solids: 1.25, Specific gravity of sludge: 1.005
  - Trickling filter sludge: Primarily organic solids, Solids: 0.5 to 1.5% (typically 0.8%), Specific gravity of solids: 1.45, Specific gravity of sludge: 1.025

Sludge Treatment and Disposal

Necessity of sludge treatment

- Sludge contains very high moisture content
- Organic solids has potential to decay- causes odor problems, BOD demand and in water bodies depletes DO
- Contains pathogens

Characteristics of sludge (***previous slide***)

Sludge Treatment and Disposal

Determination of sludge volume, Volume-Moisture relations

$$\frac{W_{sl}}{S_{sl}\rho_w} = \frac{W_s}{S_s\rho_w} + \frac{W_w}{S_w\rho_w}$$

Where, W_{sl} = weight of sludge, W_s = weight of solids, W_w = weight of water, S_{sl} = Sp. Gr. of sludge, S_s = Sp. Gr. of solid, S_w = Sp. Gr. of water, ρ_w = density of water

$$V = \frac{W_S}{\rho_w S_{sl} P_s}$$

V = volume of sludge, W_S = weight of dry solids (kg), P_s = percent solids expressed as decimal, S_{sl} = Sp. Gr. of sludge, ρ_w = density of water

$$\frac{V_1}{V_2} = \frac{P_2}{P_1} \ (approximate)$$

V_1 and V_2 = sludge volumes
P_1 and P_2 = percent of solid matter

- mnop

Sludge Treatment Methods

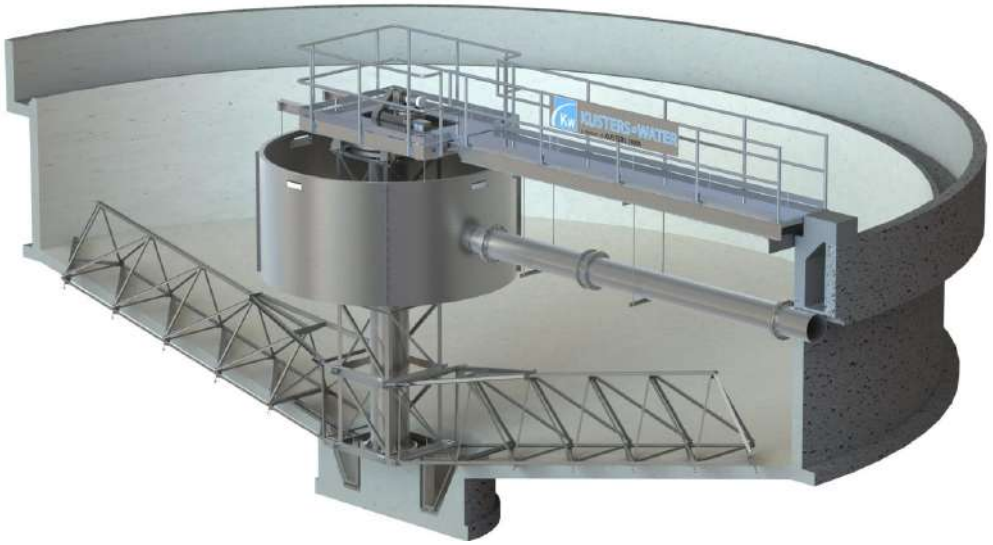
Grinding and Blending

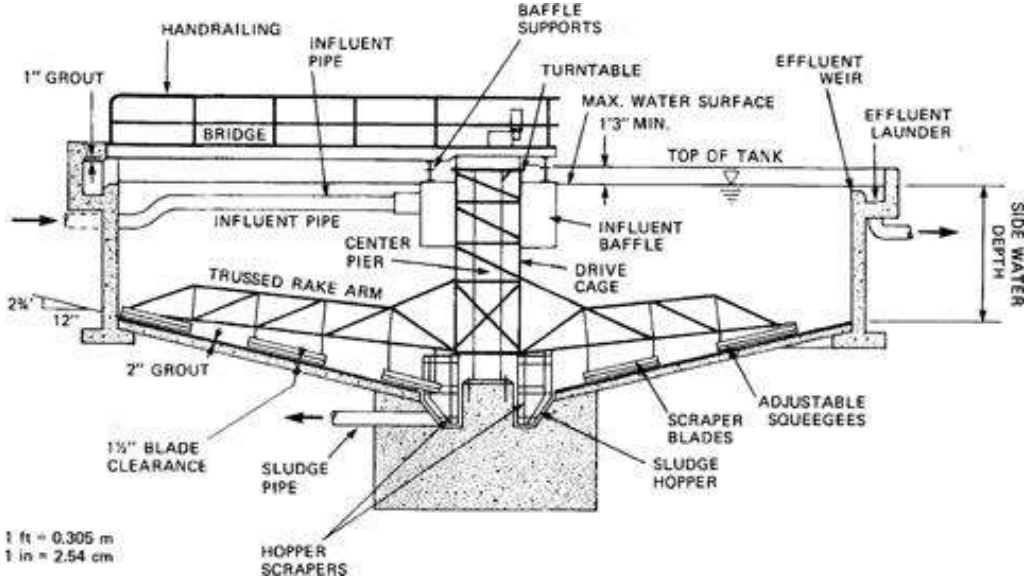
- Grinding is used to grind Grit if it is to be mixed with sludge from primary and secondary sedimentation tank
- Grinding is the crushing of the grit to reduce its ability to clog and abrade the pumps and pipes
- Blending means mixing of sludges produced at different units
- Blending is required as the characteristics of sludge produced at different units are different. To ensure sludge of uniform characteristic into sludge treatment units blending is required.
- Blending can be done in the sludge pipes, sludge thickener, *primary settling tank or with an additional sludge blending unit*- not commonly practiced.

Sludge Treatment Methods

Thickening-Gravity thickener, purpose, construction and loading criteria

- Thickening is a procedure used to increase the solids content of sludge by removing a portion of the liquid fraction
- Gravity thickening- is accomplished in a tank similar in design to a conventional sedimentation tank.
- Generally, circular tank is used
- Loading rate for combined sludge (primary and secondary)- 48 to 78 kg/m^2/d
- Result:
  - Unthickend: primary+ activated sludge- 2 to 5%





Sludge Treatment Methods

Digestion-Aerobic and Anaerobic Digestion, Digestion process, Control of digestion,, Construction and design criteria of digester

- Digestion is one of the methods used to stabilize the sludge
- Stabilization is used to
  - inhibit, reduce, or eliminate the potential for putrefaction,
  - eliminate offensive odors, and
  - reduce pathogens.
- Aerobic stabilization process is similar to the Activated Sludge Process used to treat wastewater stream

Sludge Treatment Methods

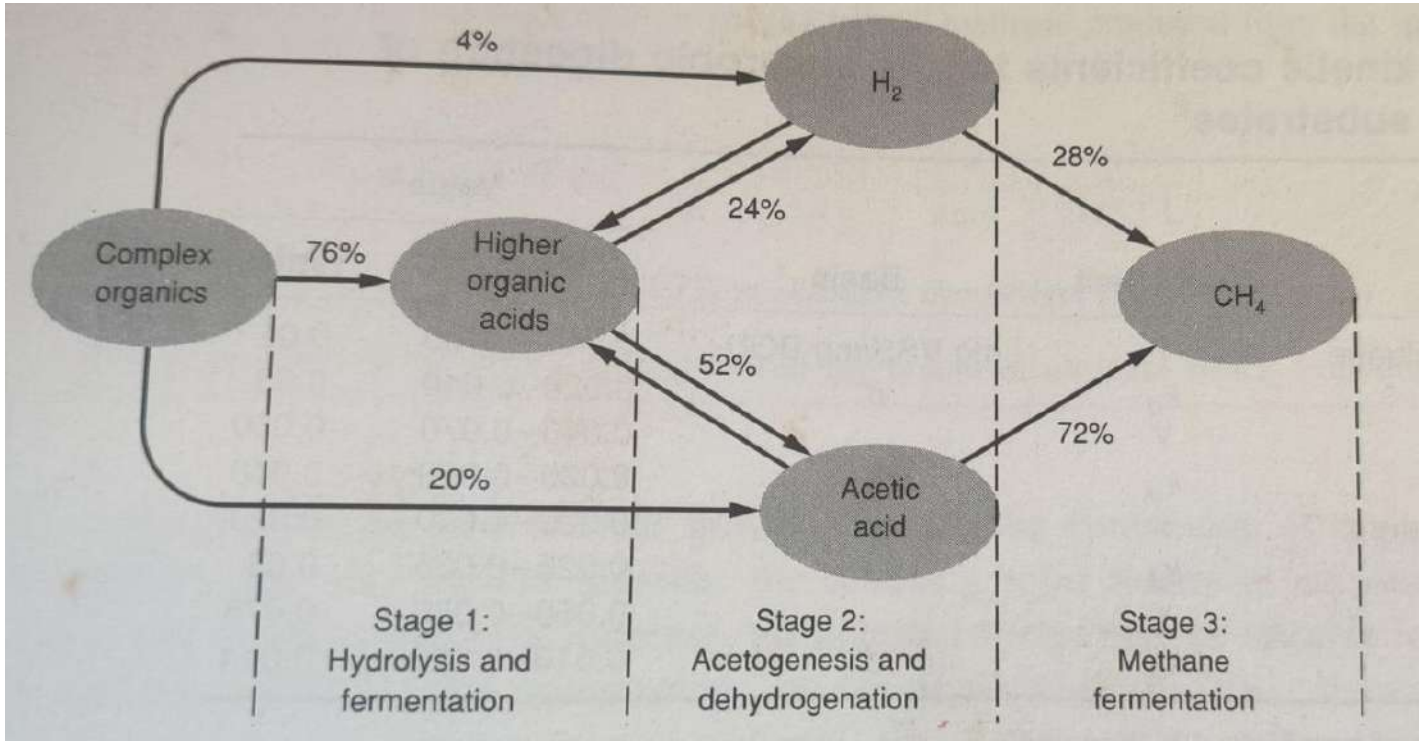
Anaerobic Digestion, Digestion process, Control of digestion, Construction and design criteria of digester

- The anaerobic treatment has several advantages over aerobic treatment process, namely,
  - the energy input of the system is low as no energy is required for oxygenation,
  - lower production of excess sludge (biological synthesis) per unit mass of organic matter utilized, and
  - degradation leads to production of biogas which is a valuable source of energy.

Anaerobic Digestion, Digestion process, Control of digestion, Construction and design criteria of digester

Microbiological Process

- End products of the anaerobic treatment process are carbon dioxide and methane.
- Process involves three distinct stages
  - Hydrolysis and fermentation: breakdown of complex organic compounds to simple organics and higher organic acids
  - Acetogenesis: Formation of acetic acid from higher organic acids
  - Methanogenesis or Methane



Anaerobic Digestion, Digestion process, Control of digestion, Construction and design criteria of digester

Microbiological Process

Acetic acid:

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

Propionic acid:

Ist Step:

$$CH_3CH_2COOH + 0.5\ H_2O \longrightarrow CH_3COOH + 0.75CH_4 + 0.25CO_2$$

IInd Step:

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

Overall:

$$CH_3CH_2COOH + 0.5\ H_2O \longrightarrow 1.75CH_4 + 1.25CO_2$$

Environmental Condition

- pH: 6.6 to 7.6
- Sufficient alkalinity 1000 to 5000 mg/L should be present not to allow pH to drop below 6.2
- Sufficient amount of nutrient such as Nitrogen and Phosphorous should be present
- Temperature:
  - Mesophilic- 30 to 380C
  - Thermophilic: 49 to 570C

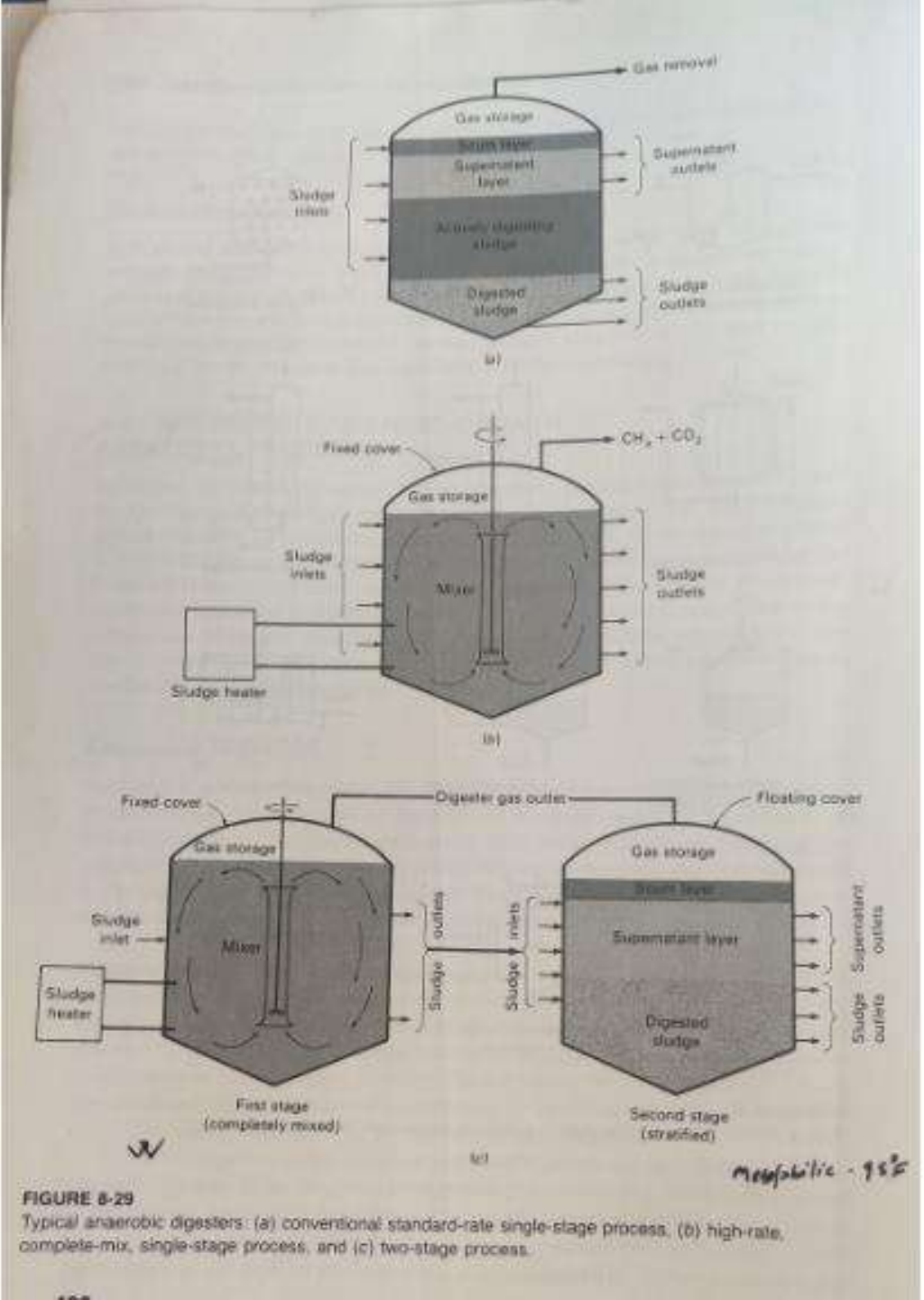


FIGURE 8-29
Typical anaerobic digesters: (a) conventional standard-rate single-stage process, (b) high-rate, complete-mix, single-stage process, and (c) two-stage process.

Types of Digester

- Standard Rate:
  - Loading rate: 0.65 to 1.6 kg VSS/m^3/d or 0.11 to 0.17 m^3/capita
  - Detention time: 30 to 60 days
  - Stratified: active digestion volume is about 50 to 60%
  - Generally not heated
- High Rate: 1.6 to 3.2 kg VSS/m^3/d or 0.07 to 0.11 m^3/capita
  - Loading rate:
  - Detention time: 15 to 20 days
  - No stratification
  - Heating required
- Two stage
  - High rate as the first digester followed by low rate

Anaerobic Digestion, Digestion process, Control of digestion, Construction and design criteria of digester

Sizing of Anaerobic Digester

$$V = \left[V_f - \frac{2}{3}\left(V_f - V_d\right)\right] \mathrm{t}$$

Where,

V = volume of digester, m^3

V_f = volume of fresh sludge added per day, m^3/d

V_d = volume of digested sludge removed per day, m^3/d

t = digestion time, day

Sludge Treatment Methods (***Remaining***)

- Dewatering-Vacuum filtration: purpose and construction
- Drying-Sludge drying beds: purpose and construction
- Composting-purpose, principles, types (windrows and mechanical)
- Incineration-purpose and construction

Numerical on sludge-volume determination and design of digester

Sludge Disposal Methods

- Dumping
- Land filling
- Lagooning
- Spreading on land