University of Zambia
School of Engineering
Department of Civil and Environmental Engineering

CEE 4412: Environmental Engineering I

WASTEWATER MANAGEMENT

JMT

OCTOBER 2020

UNZA

Definition

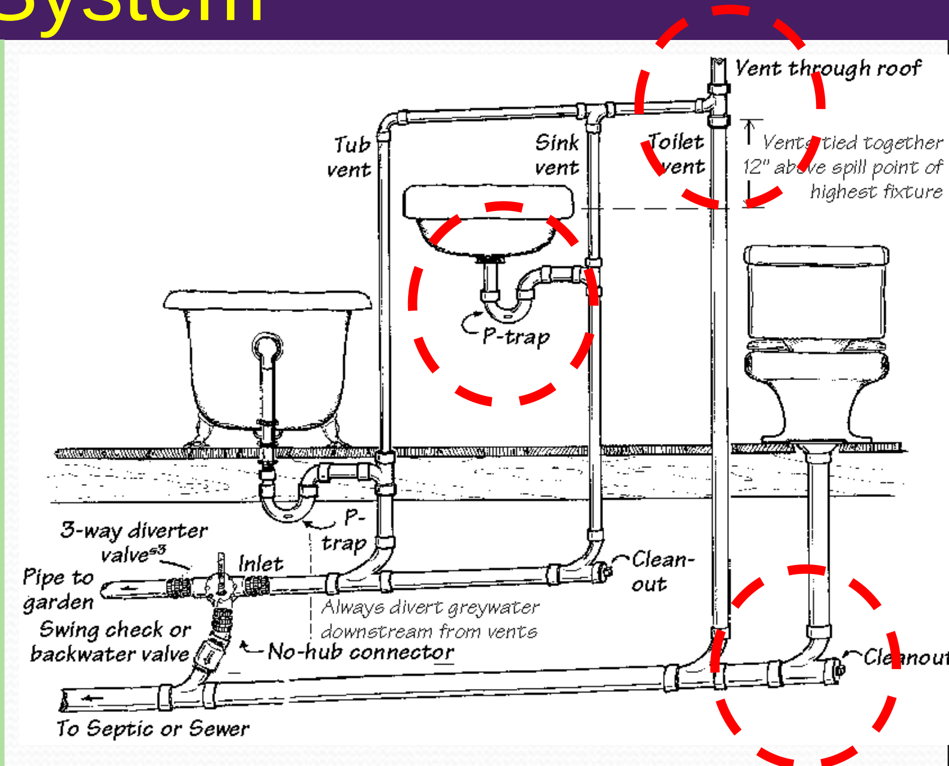
Off-site sanitation system

- System where wastewater is treated or/and disposed of on a site away from the point of generation
- In this case, wastewater is conveyed through a sewerage system which is the physical infrastructure for sewage conveyance (i.e. sewer pipes, pumps, force mains) to treatment/disposal site
- Off-site systems always require a sewerage systems

Elements of a Sewerage System

- Household or institutional plumbing systems (Plumbing fixtures)

- House connections to the community sewerage network (100-150mm pipes)



Elements of a Sewerage System

- Sewers and appurtenances such as manholes/inspection chambers and pumping stations

Elements of a Sewerage System

Types of Sewerage Systems

- Combined systems;
- Separate systems; and
- Small-bore sewers

Combined and Separate Sewerage systems

- Combined systems = Convey both wastewater and stormwater.

- Separate systems = Either convey stormwater or wastewater

Design Considerations

- Minimum velocity = 0.6m/s to promote self cleansing velocities in pipes

- Maximum velocity = 3m/s to avoid erosion of pipes – abrasion (due to grit)

- Q/Q_{full} = 0.5 – 0.7 to avoid pressurised flow characteristics

Small-bore Sewers

- Only transport the liquid constituent of the wastewater.
- Solids in a small-bore system are retained on site
- The liquid part is conveyed to the final point of discharge through small pipes which can be as small as 75mm.
- As there are no solids, there is no need for self-cleansing velocities. (0.3m/s is usually adopted; pipes gradient minimal (i.e., 1 in 200) thereby avoiding excessive excavations in most cases.

Small-bore Sewers Cont’

Small-bore sewers are appropriate:

- Where septic tanks already exist, but soakaways have failed or do not exist;
- Where pour-flush toilets are used, but on-site disposal of the effluent is impossible;
- Where sewerage is needed, but the normal conditions of sewer laying cannot be met without exceptional expense

O and M issues – Conventional and small bore sewers

- SB sewers designed to only carry the liquid part of the wastewater, therefore, there is need for efficient emptying of the septic tanks.
- In all systems, hydraulic jumps should be avoided
- Manholes to be provided at appropriate locations (Where connections are made and where direction is changing
- Minimum cover of 1m to be provided. Where too deep, concrete cover to be provided to withstand excessive pressure

Estimation of Flow Quantities

- Based on water supply. It is usually taken as 0.6 to 0.8 of water supplied

- Inflow from roofs and other sources are estimated based on local conditions

Quantification for Industrial Wastewater

- Dependant on processes

Wastewater Treatment

TREATMENT METHODS

- Conventional
  a) Trickling filters
  b) Activated sludge system

- Non – conventional
  c) Wastewater stabilisation ponds
  d) Oxidation ditches
  e) Aerated lagoons

Treatment Principles

- Physical
- Biological (aerobic vs anaerobic)
- Chemical (sometimes)

Sitting of Treatment Plants

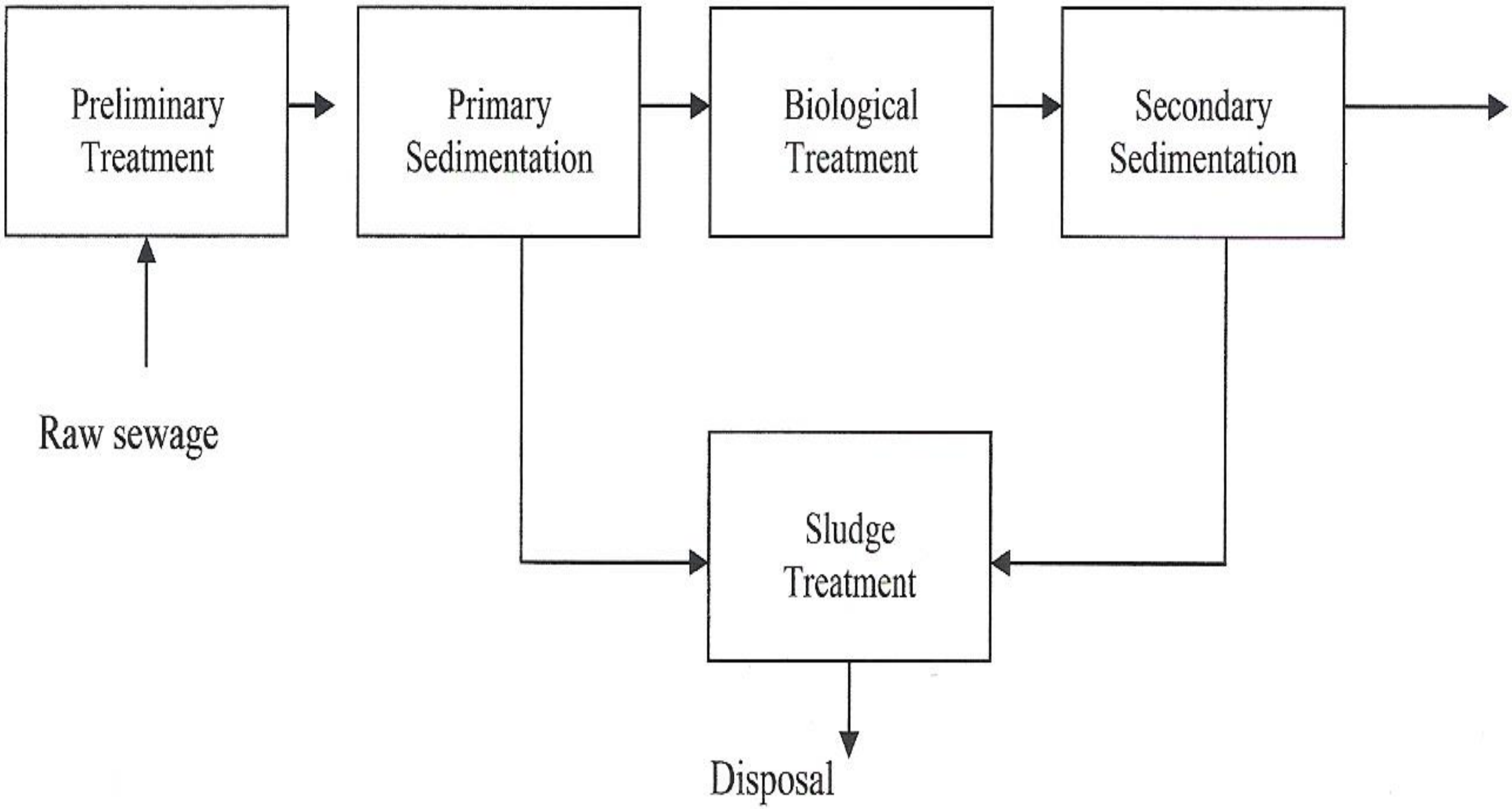
- ❖Free from floods
- ❖Suitable shape and gradient to permit gravitational flow
- ❖Sufficient land for future expansion
- ❖Leeward of prevailing winds
- ❖At least 500m from nearest dwellings

Conventional Treatment Systems

STAGES

- Preliminary treatment
- Primary sedimentation (Treatment)
- Biological treatment
- Secondary sedimentation
- Sludge treatment

Flow Diagram Of Conventional Treatment



Preliminary Treatment

- Screening
- Communition
- Grit removal

❖Screening

❖Screening is the process for the removal of bigger inorganic objects (Rugs, wood, metals, plastics etc) from the wastewater.

❖If absent or not effective, the following might occur:-

a. Blockages in sludge pipes
b. Damage to pumps
c. Formation of scum in digesters (Due to inorganics)
d. Complications to the ultimate disposal of sludge

Screens

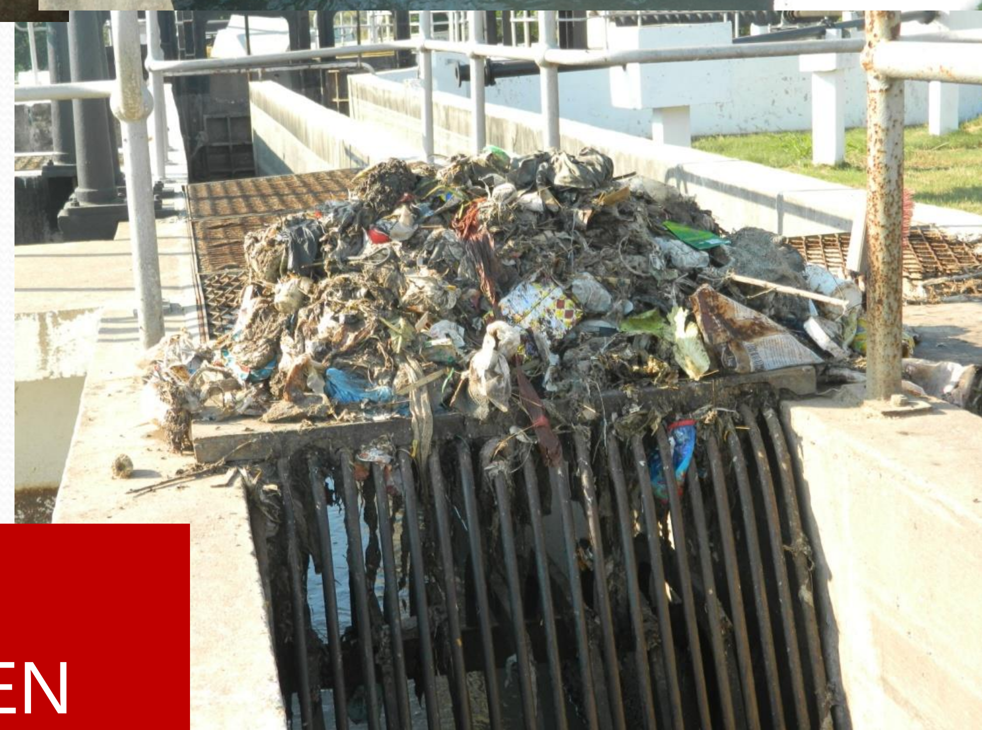
TYPES

- ❖ Hand raked – 20 to 40cm bars
- ❖ Mechanical raked

FOR EFFECTIVE OPERATION OF SCREENS

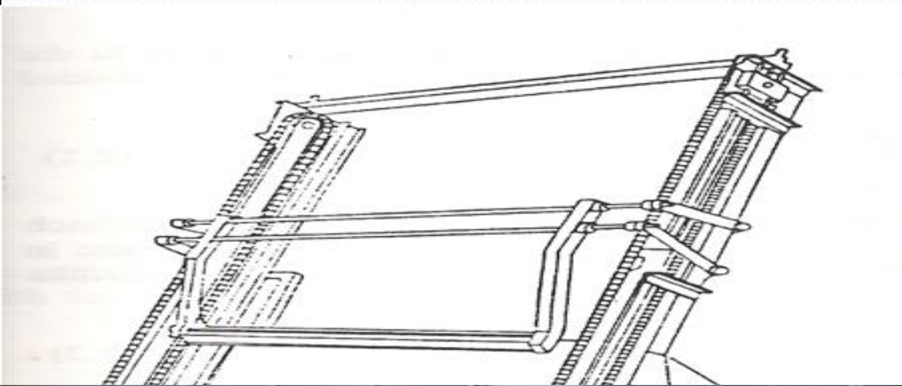
- ❖ Frequent removal of screenings
- ❖ Effective disposal of screenings
- ❖ The approach velocity (0.3 - 0.6m/s)

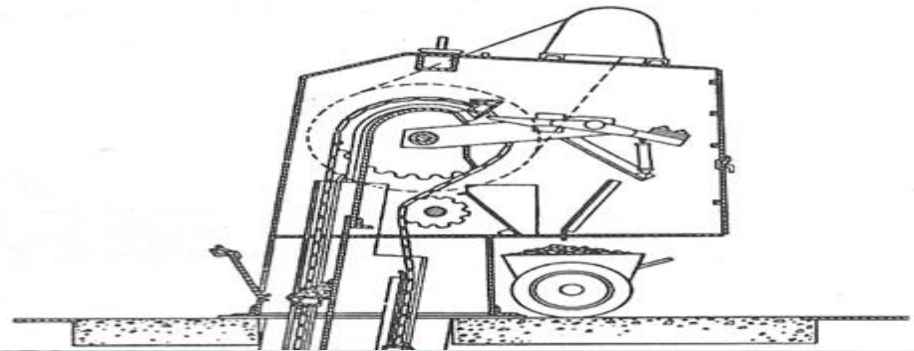


HAND RAKED BAR SCREEN

Mechanically/Automatically Raked Screens

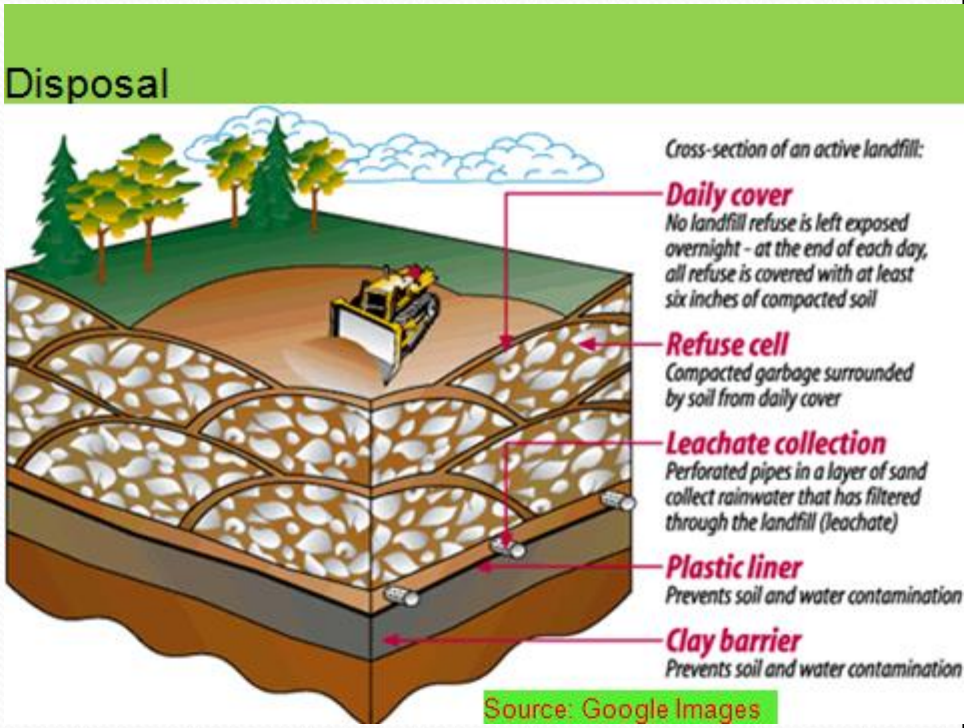




eening device (Metcalf and Eddy, 1991).

Disposal Of Screenings

❖Burying/incineration/Engineered Landfill.

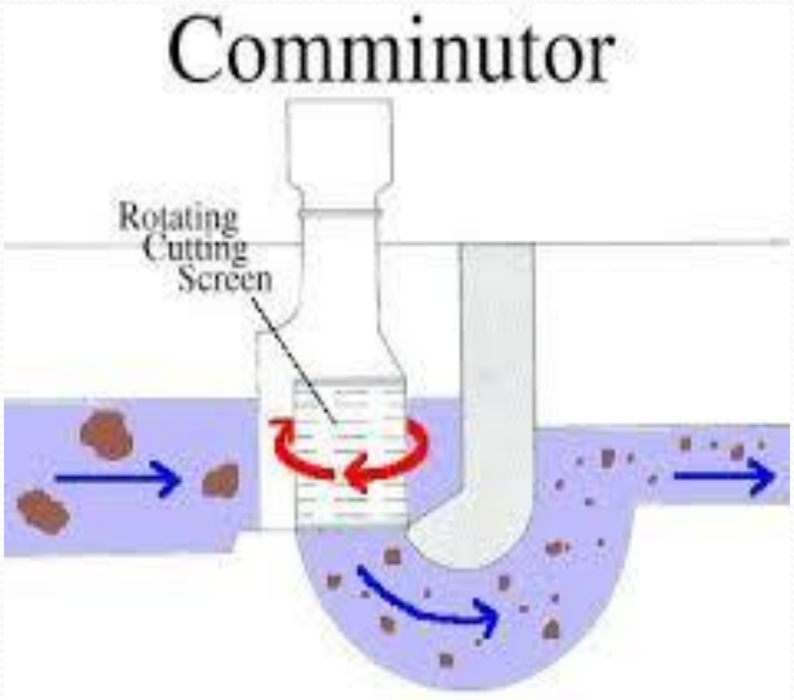


Communition

- ❖The cutting of bigger sewage solids into smaller pieces

- ❖Improves plant efficiency by increasing surface area of organics

- ❖Satisfactory performance depends on servicing of the machine especially the cutting teeth



Source: Google images

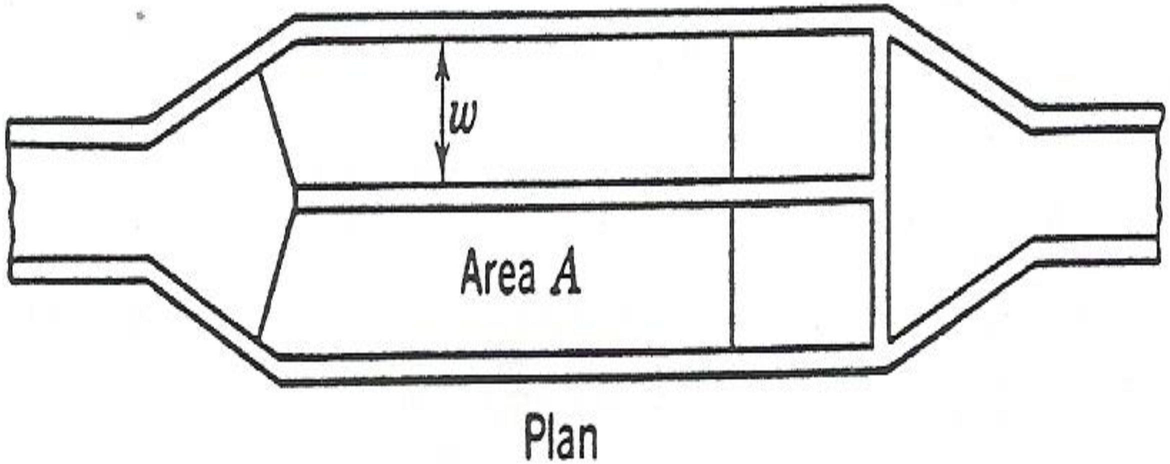
Grit Removal

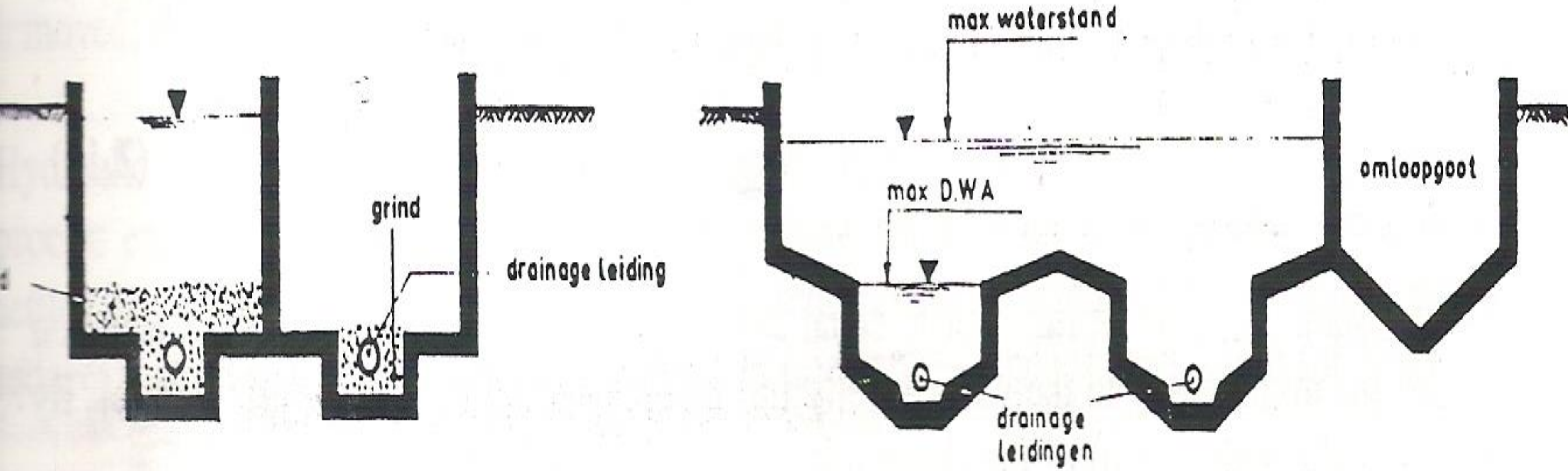
- The removal of dense inert particles from the sewage
- Grit should be removed early in the treatment process because it is:
  - Abrasive and will rapidly wear out pumps and other equipment
  - Settles in pipes and channels causing blockages/clogging
  - Settles in digesters and settling tanks resulting in more frequent cleaning and maintenance

Grit Channels

- Grit is removed in
  - Constant velocity channels
  - Tanks with spiral currents

Grit Channels - Examples





Effective Performance

- Effective performance of grit removal will depend on
  - ✓ Degritting Rate
  - ✓ Flow rate (about 0.3m/s)

Grit Disposal

- Washed, Buried or used in construction works

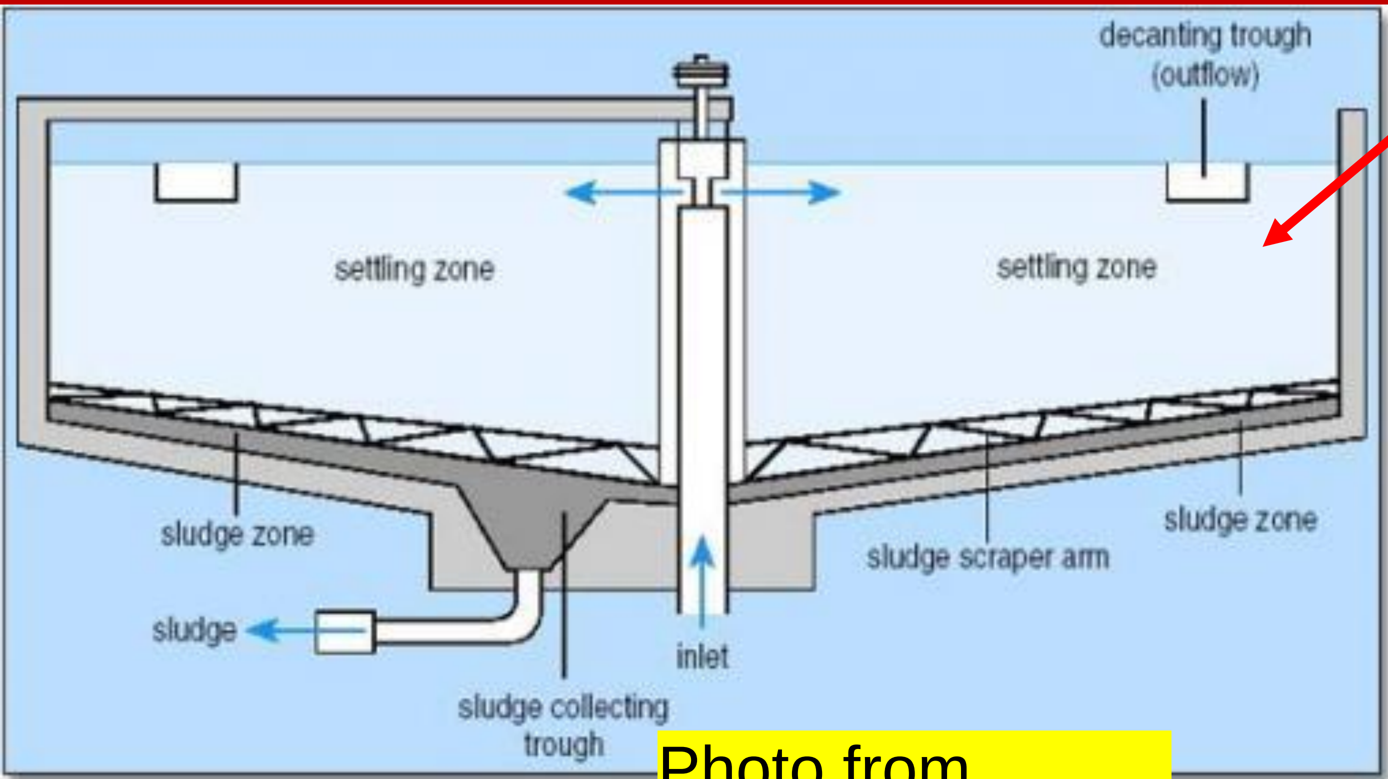
Primary Treatment

PRIMARY SEDIMENTATION

REASONS FOR PRIMARY SEDIMENTATION

- To reduce "Strength" of sewage
- To remove Solid organic matter (including some colloidal particles)
- To prevent the solids from blocking the biological filters (ponding)

Sedimentation tank Cross Section



Source: Google images

Photo from CWWTP

Primary Sedimentation Cont'

- EFFICIENCIES
  - ✓ Total suspended solids removal 50 -70%
  - ✓ BOD removal 25 - 40%

- PARAMETERS FOR ENHANCED OPERATION
  - Flow rates which affect
    - ✓ Retention times
    - ✓ Hydraulic surface loading rates upon which the efficient operation of the tanks is based (design parameters)

Design Considerations

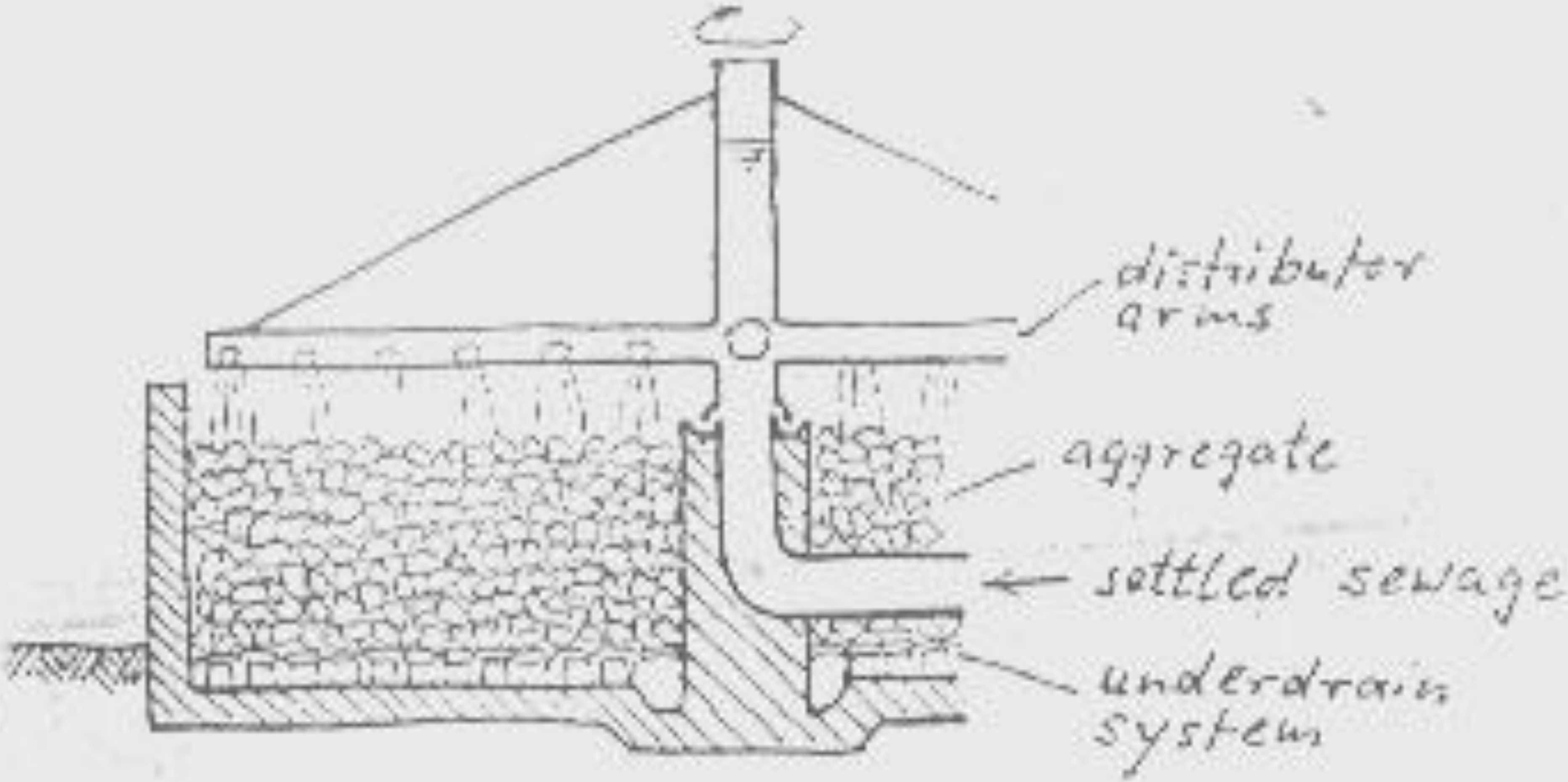
Design surface loading rates and retention times for clarifiers

TYPE	S.L.R(m/d)	RETENTION TIME(h)
PRIMARY	24 - 32	1.5 - 2.5
SECONDARY	32 - 40	1.0 - 1.5

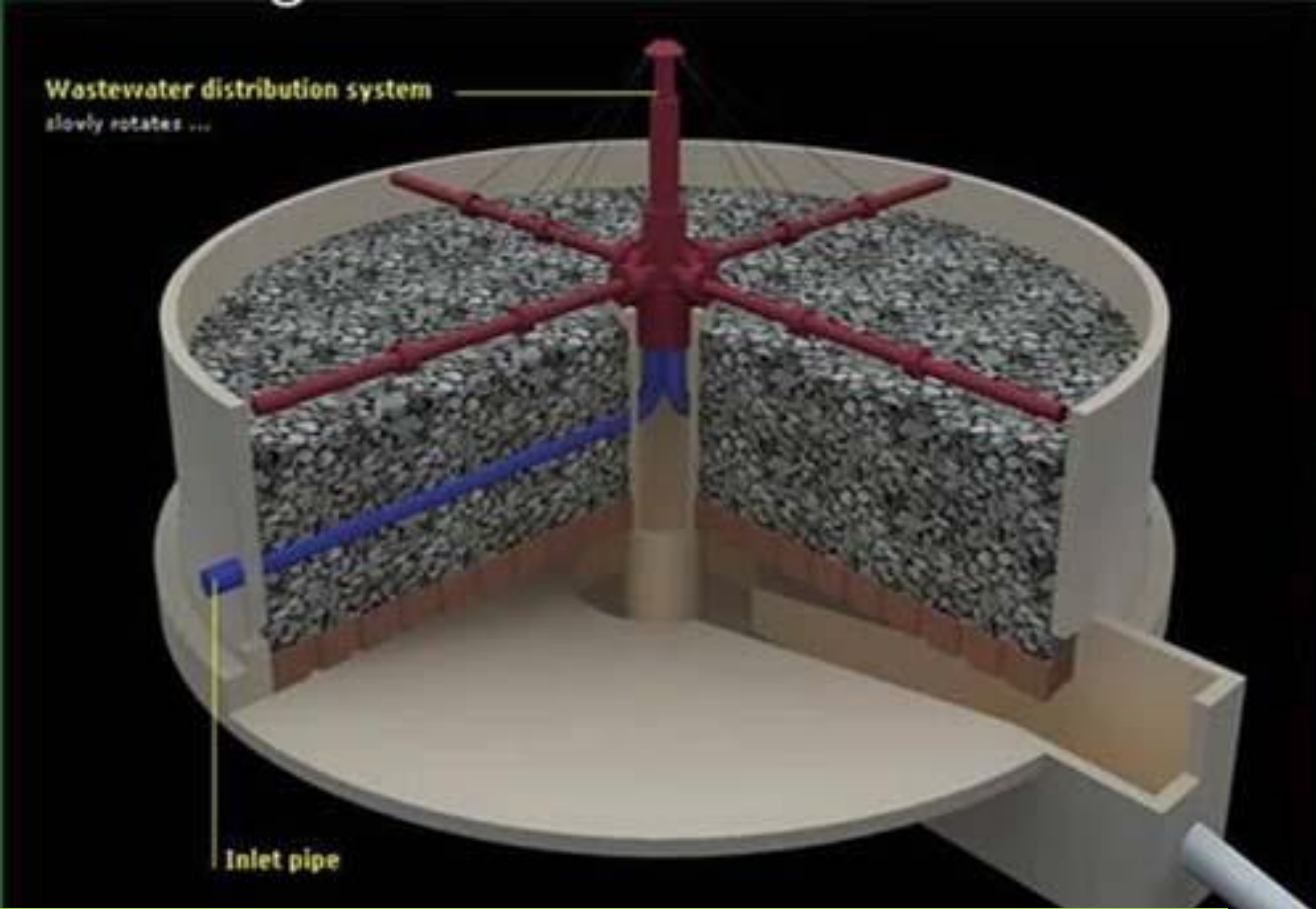
Biological Treatment

- Trickling Filters (fixed film process)
- Activated Sludge (Suspended film process)

What is a Trickling Filter (Percolating Or Bio -Filter)



Picture Of A Trickling Filter

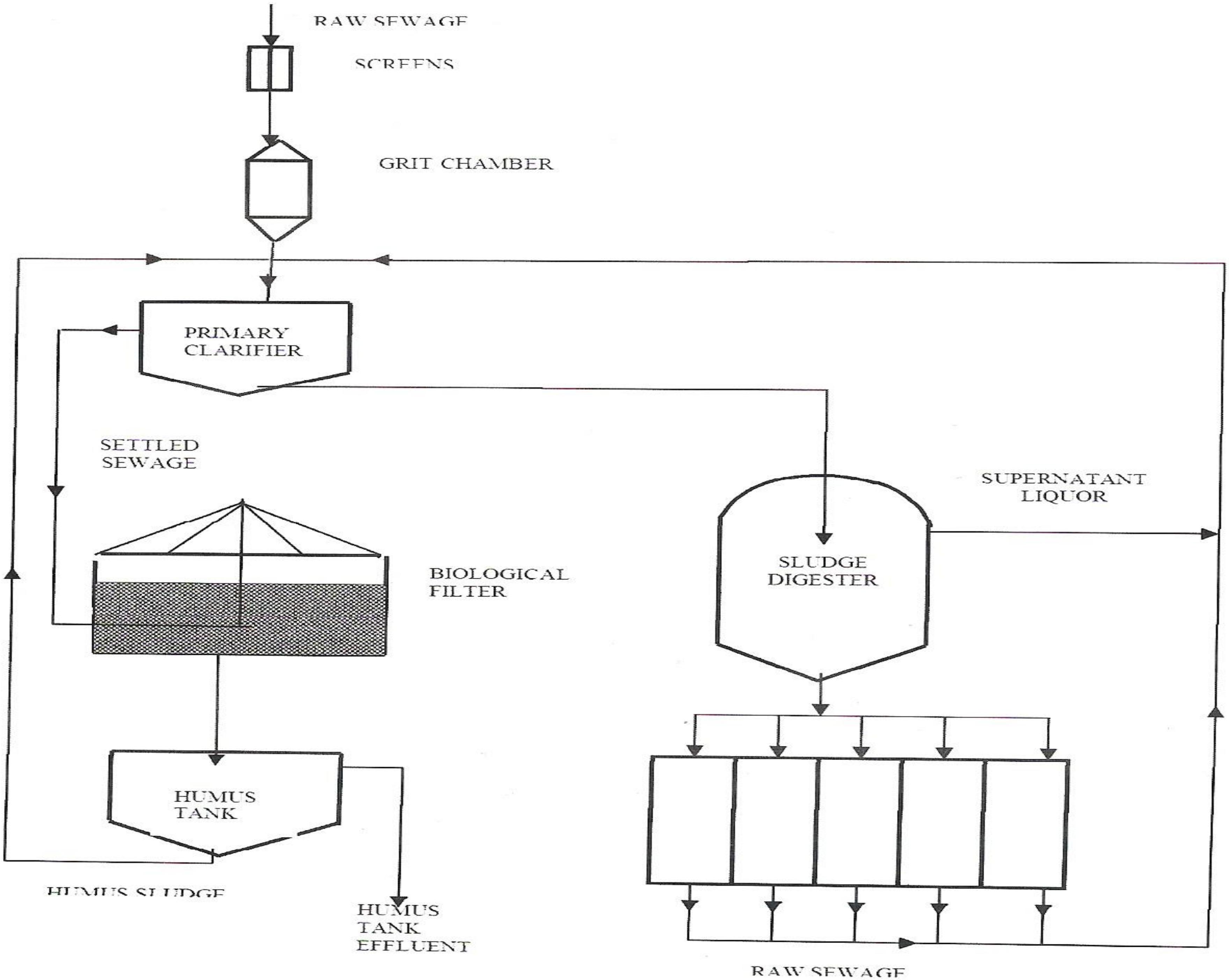


INSIDE A TRICKLING FILTER

Components

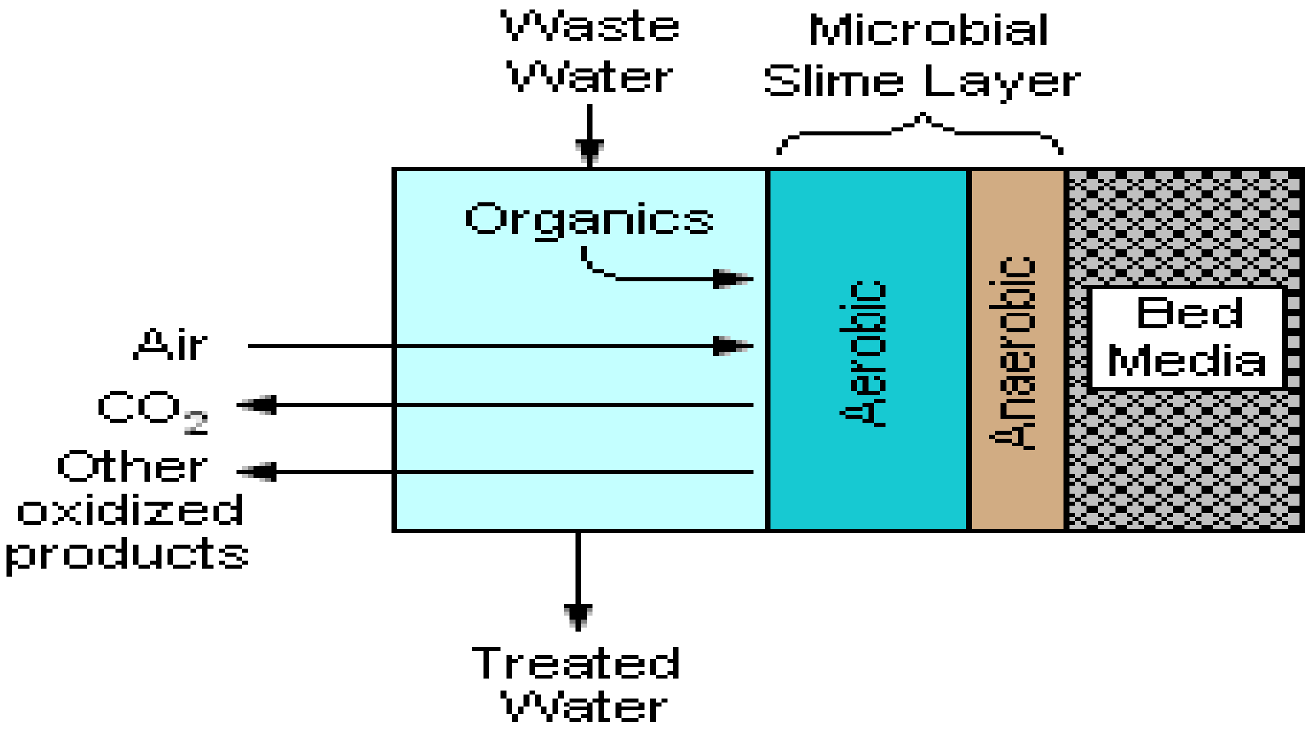
- ❖Containment structure
- ❖Media (Crushed stones 60mm dia or sythentic)
- ❖Underdrain system
  - ✓ to support the media,
  - ✓ to collect and transport the filter effluent, and
  - ✓ to convey the air through the filter
- ❖Filter feed (and recirculation system) and
- ❖Post filter clarifiers (Secondary sedimentation tanks)

Synthetic Media


RAW SEWAGE
SCREENS
GRIT CHAMBER
PRIMARY CLARIFIER
SETTLED SEWAGE
SUPERNATANT LIQUOR
SLUDGE DIGESTER
BIOLOGICAL FILTER
HUMUS TANK
HUMUS SLUDGE
HUMUS TANK EFFLUENT
RAW SEWAGE

Treatment Mechanism

Microorganism + soluble/Colloidal organic matter + O_2 = More microorganisms + energy + CO_2 + H_2O+ other waste products (e.g. Nitrates)



Treatment Mechanism Cont’

- SLOUGHING = In biological terms is shedding or casting off of dead skin

Important parameters in the design/operation of biofilters

- Volumetric (Organic) loading rate Lv
- Surface (Organic) loading rate SLR
- Hydraulic surface loading rate HSLR

Design Criteria

Volumetric Organic Loading Rate

$$L_v = \frac{Load(KgBOD/d)}{V_f(m^3)}(Kg/m^3.d)$$

Design Criteria Cont'

Organic Surface Loading Rate

$$SLR = \frac{Load(KgBOD/d)}{A_f(m^2)}(Kg/m^2.d)$$

Design Criteria Cont'

Hydraulic Surface Loading Rate

$$HSLR = \frac{Flowrate Q_i + Q_r}{A_f (m^2)} (m^3/d)$$

Design equations

Mostly based on empirical formulae

E.g. the Rumpf equation based on OSLR

BOD removal efficiency (%) = 93 – 1.1 OSLR

Design equations

Example: Design a trickling filter for a plant receiving $2400m^3$/day of wastewater with a BOD concentration of 300mg O_2/l.

1. There is a PST which will remove at least 25% BOD. Therefore Influent BOD to TF = 0.75*300 = 225mg
2. Know required effluent standard = 50mg/l
3. Compute required removal efficiency =(225-50/225) =78%
4. Find OSLR: 78=93-1.1OSLR (OSLR = 13.64kg/m^2.d
5. Use eqn for OSLR to compute required area
6. Depth is adopted from standards (usually 1.8m) Range is wide depending on means of ventilation

DESIGN EQUATION BASED ON Lv (National Research Council Equation)

$$E = \frac{100}{1 + a\sqrt{\left\{\frac{L}{A_f * D * F}\right\}}}$$

DESIGN EQUATION BASED ON Lv (National Research Council Equation) cont'

Where

- A_f = filter area
- D = Effective filter depth
- F = Correction factor for recirculation
- a = factor which depends on sewage temperature and strength

DESIGN EQUATION BASED ON Lv (National Research Council Equation)cont'

Correction factor for recirculation

$$F = \frac{1+R}{(1+0.1R)^2}$$

Recirculation ratio R = Qr/Q

DESIGN EQUATION BASED ON Lv (National Research Council Equation)cont'

Influent temperature	100 mg BOD/ l	150 mg BOD/ l	200 mg BOD/ l
12	0.50	0.46	0.42
16	0.44	0.40	0.36
20	0.38	0.34	0.30

Table: "a" values corresponding to temperature and sewage strength

CRITICAL PARAMETERS FOR OPERATIONS

- The dosing rate (Continuous and uniform or intermittent but still uniform flow to sustain the growth of the biofilm and provide enough sloughing to avoid excessive biofilm growth.)

- The type and physical characteristics of the filter media to be used (high surface area per unit of volume, cheap, high durability, higher void ratio, does not clog easily)

CRITICAL PARAMETERS FOR OPERATIONS CONT'

- Configuration of the under-drain system
  - to support the media,
  - to collect and transport the filter effluent, and
  - to convey the air through the filter.

- Ventilation in the filter (O_2 to be available throughout height of tank) and

- The design of the required secondary settling tanks

REMOVAL EFFICIENCIES

- BOD REMOVAL = 90%
- FC removal = 95% including both sedimentations

OPERATIONAL CHALLENGES

- **Unpleasant odours from the filter:**
- ANAEROBIC CONDITIONS IN THE FILTER DUE TO:
  - Organic overloading
  - Poor ventilation

- **Ponding on the filter media**
  - **Organic overloading**
  - **Hydraulic overloading**
  - **Poor media and**
  - **Poor house keeping.**

OPERATIONAL CHALLENGES CONT’

- **Filter flies (psychoda)**
  - Insufficient wetting of the filter media

- **Problems with the distribution arms**
  - Blockages
  - damages

OPERATIONAL CHALLENGES CONT'

- **Problems with sedimentation (i.e Increase of TSS in effluent from SC**
  - Clarifier hydraulically overloaded
  - Denitrification in the clarifier
  - Excessive sloughing from the filter because of changes in wastewater
  - Malfunctioning of equipment in secondary clarifier or
  - Short circuiting of flow in the sc.

ACTIVATED SLUDGE SYSTEMS

What are they?

- Suspended film processes

What happens?

- Microorganisms concentrated in a tank (Flocculent sludge form) where oxygen is supplied. Tank contents referred to as Mixed Liquor Suspended Solids (MLSS)

- The MLSS is a collection of live or active microorganisms hence "activated" and concentration should be 2 – 8Kg/m^3

ACTIVATED SLUDGE SYSTEMS

How they differ from Trickling filters

- Microorganisms are in suspension – not fixed
- Oxygen is artificially forced into the system and not through natural process (100m^3 of air per kg BOD)
- Hence more intensive

ACTIVATED SLUDGE TREATMENT

PROCESSES IN ACTIVATED SLUDGE PROCESSES

- Organic matter removal (aerobic zone)

NITROGEN REMOVAL

- Nitrification (aerobic zone)

- Step One: Ammonia (NH_4^+) to nitrites (NO_2) by *Nitrosomonas*

- Step Two: Nitrites (NO_2) to nitrates (NO_3) by *Nitrobacter.*

ACTIVATED SLUDGE TREATMENT

PROCESSES IN ACTIVATED SLUDGE PROCESSES

- Denitrification (anoxic zone)

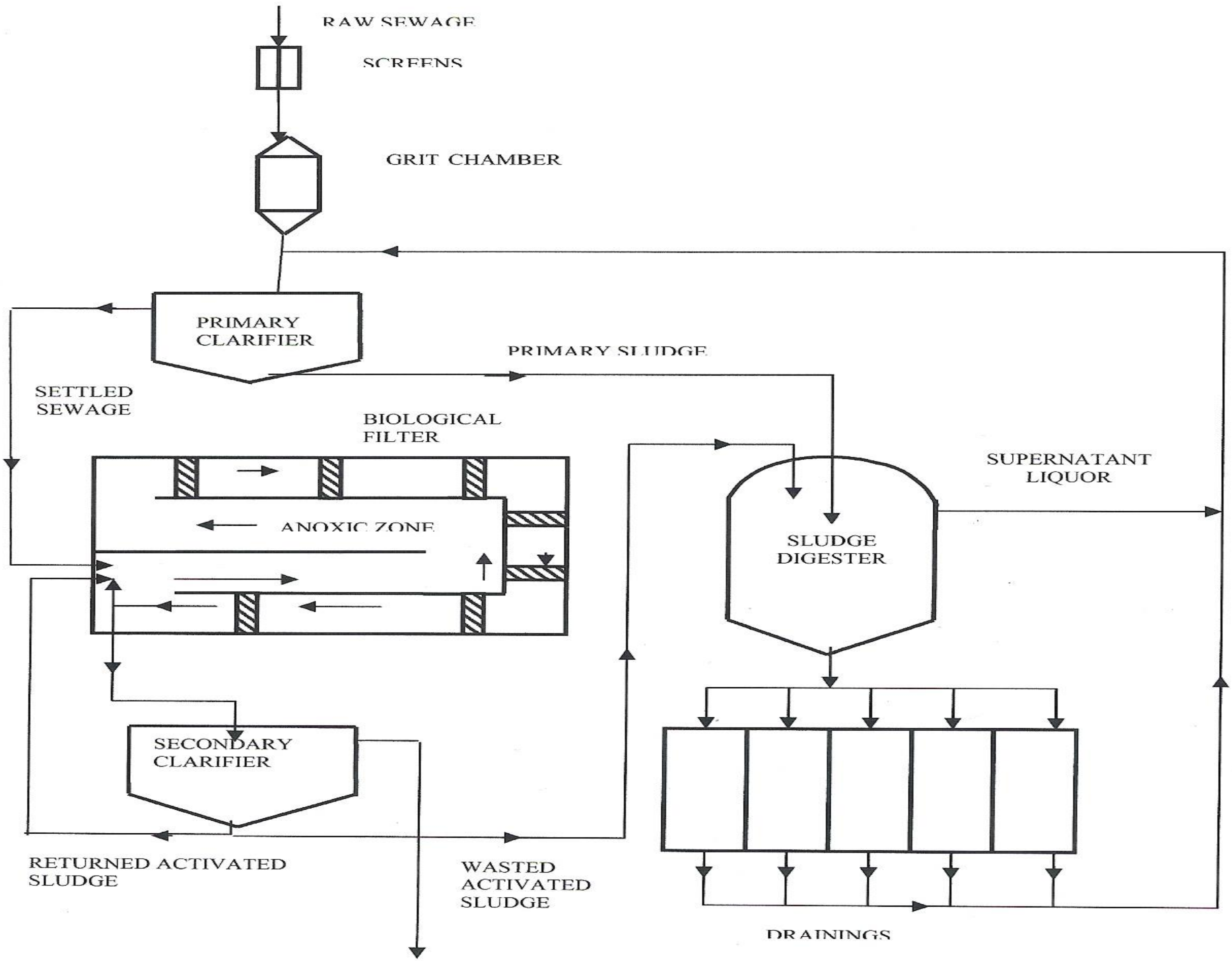
  By *Thiobacillus denitrificans*, *Micrococcus denitrificans*, species of *Serratia*, P*seudomonas*, and *Achromobacter*

- Phosphate removal (Anaerobic zone - Aerobic zone)
- By *Acinetobacter* bacteria

TREATMENT MECHANISM

Microorganism + soluble/Colloidal organic matter + O_2 = More microorganisms + energy + CO_2 + H_2O+ other waste products (e.g. Nitrates)

MASS BALANCE IN TERMS OF ORGANIC MATTER as for trickling filters


RAW SEWAGE
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SETTLED SEWAGE
BIOLOGICAL FILTER
ANOXIC ZONE
SUPERNATANT LIQUOR
SLUDGE DIGESTER
SECONDARY CLARIFIER
RETURNED ACTIVATED SLUDGE
WASTED ACTIVATED SLUDGE
DRAININGS

PHOSPHATE AND N REMOVAL

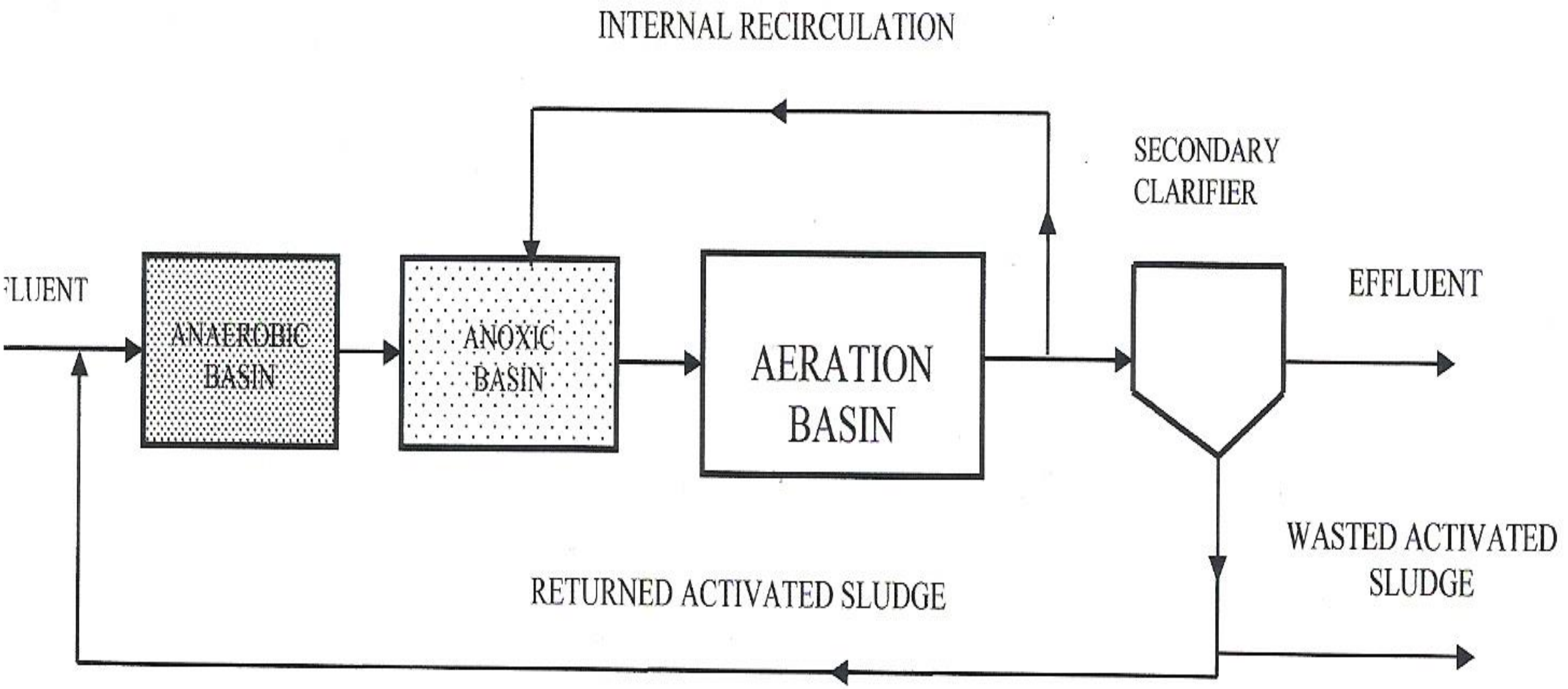

Figure 3: A Flow Diagram of an Activated Sludge Plant Incorporating Nitrogen and Phosphorus removal

PROCESSES EXPLAINED

- Removal of organic matter
- Removal of Nitrogen
- Removal of phosphates (Acinetobacter)

AERATION TANKS

- TYPES?
- Shapes (Usually circular and rectangular)
- Depth = 3 – 4m
- Retention time 8 to 12 hours
- Minimum of 2mg/l DO to be present in Aeration tank

AERATION TANKS

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AERATORS

- PURPOSE
  - Supply Oxygen
  - Help Keep the sludge in suspension

- TYPES
  - Air diffusers (Porous plate)
  - Mechanical Surface Aerators

DIFFUSER AERATORS: Source: Google images




REMOVAL EFFICIENCIES

- BOD = 85 – 90% (=Trickling filters)
- FC = 90%

METHODS OF CONTROLLING ACTIVATED SLUDGE PLANTS

Maintaining Mixed Liquor Suspended Solids (MLSS)

- What are they?
  - The dry mass of solids per unit of liquid volume in the aeration tank.
- What is their significance?
  - Give an indication on the number of microorganisms in the tank
- How are they measured?

METHODS OF CONTROLLING ACTIVATED SLUDGE PLANTS

- How do you measure their concentration
- Filtering the sludge from a certain volume of the mixed liquor,
- Drying the sludge at 103^{o}C
- The MLSS could then be expressed either as mg/l or as kg/m^3.

OTHER FACTORS AFFECTING EFFICIENCE

- HRT
- DO >2mg/l
- Ph 7 -9

SECONDARY SEDIMENTATION

- Removes microorganisms from the MLSS in AS plants and humus from effluent TF or BF plants.
- They go hand in hand with the biological unit

- PROBLEMS ASSOCIATED WITH SECONDARY SEDIMENTATION TANKS
  - Sludge re-suspension which can be due to
    - Increased Hydraulic loading
    - Longer than required sludge retention in the aeration tank
    - Denitrification

SLUDGE TREATMENT

WHAT IS SLUDGE

- Settleable organic matter from both the raw sewage (Primary) and treated (humus and MLSS)

CHARACTERISTICS

- High content of organic matter
- High content of microorganisms
- High content of wastewater constituents

TREATMENT

- ❖ Aerobic or anaerobic

TREATMENT

Aerobic Treatment

- Disadvantages:
  - Energy required;
  - More biomass generated – about 50%/ for each unit mass of organic matter resulting in sludge disposal challenges
  - Heat loss
- Advantages:
  - Faster
  - Higher effluent quality (88 – 90% removal efficiency)

TREATMENT

Anaerobic Treatment

- Advantages
  - No energy required;
  - Energy generated - a gCOD generates 0.28g CH_4 or o.35l CH_4 under STP;
  - Low biomass generation at about 0.5% for each unit mass of organic matter.
- Disadvantage
  - Process is very slow

Aanaerobic Digestion Process

DIGESTION PROCESSES

Organic solids → Fatty Acids by "acid formers in acidogenesis" → Methane "methane fermenters in methanogenesis"

TYPES OF ANAEROBIC DIGESTION

- Conventional digestion
- High rate digestion

CONVENTIONAL DIGESTION CONT’

CHARACTERISTICS

The digester is not heated and not mixed. Five zones develop:

- a scum layer on top
- a supernatant layer
- A layer with actively digesting sludge
- a sludge layer at the bottom

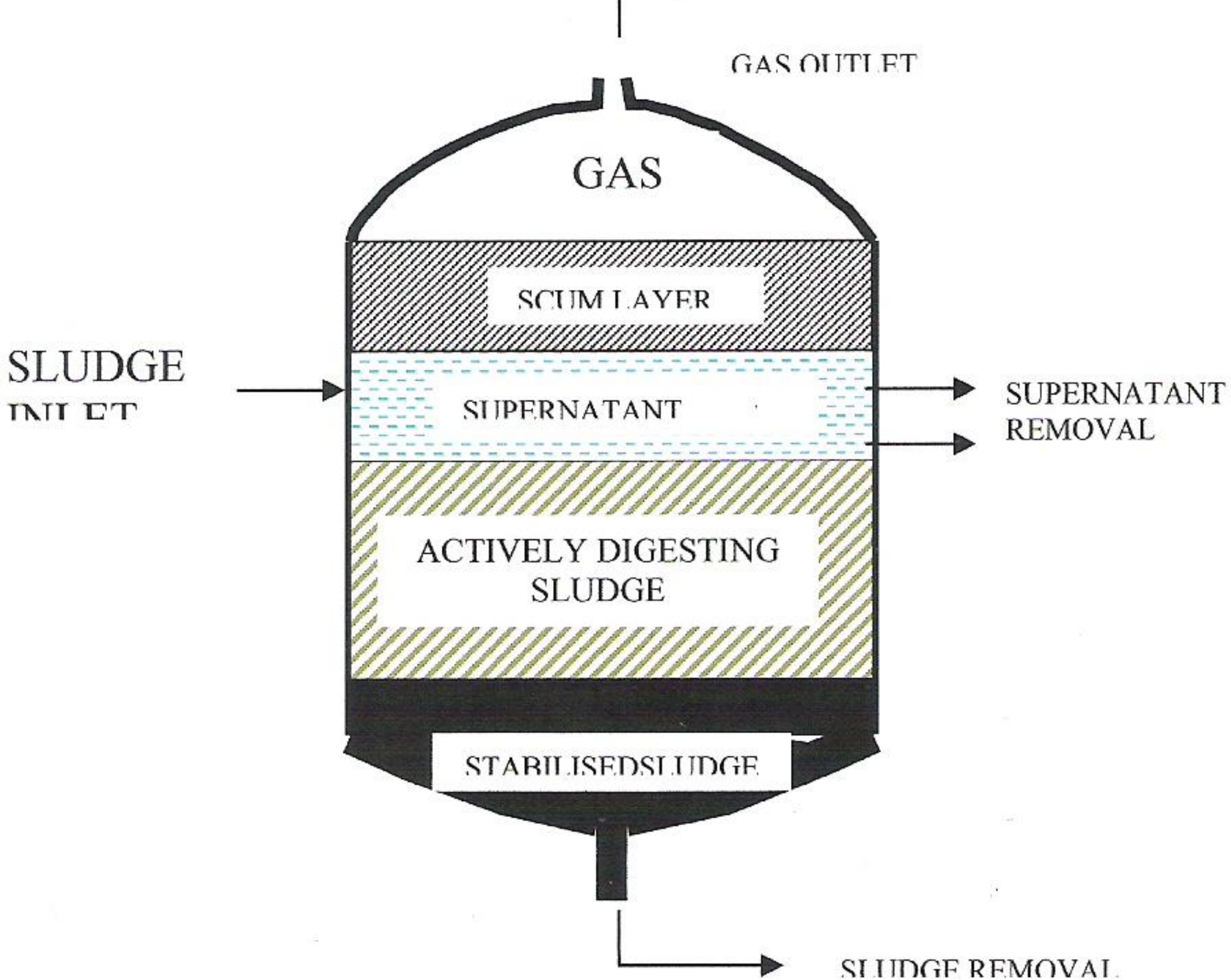

Figure 1: Conventional Rate Digester

CONVENTIONAL DIGESTION CONT'

CONDITIONS FOR CONVENTIONAL RATE DIGESTION

- Unheated
- Unmixed
- Retention time of 30 - 60days
- Loading of 0.5 - 1.0 Kg VS/m^3/day
- Intermittent feeding and withdraw
- Stratification

HIGH RATE DIGESTION

- Primary and secondary (digesters) needed

- Conditions for high rate primary digestion
  - Heated to 30 - 38^{O}C (May still not be necessary in tropical climate)
  - Retention time of 15 - 25 days
  - Loading 1.5 - 3.0 kg VSS/m^3/day
  - Continuous or intermittent feeding and withdrawal
  - Contents well mixed

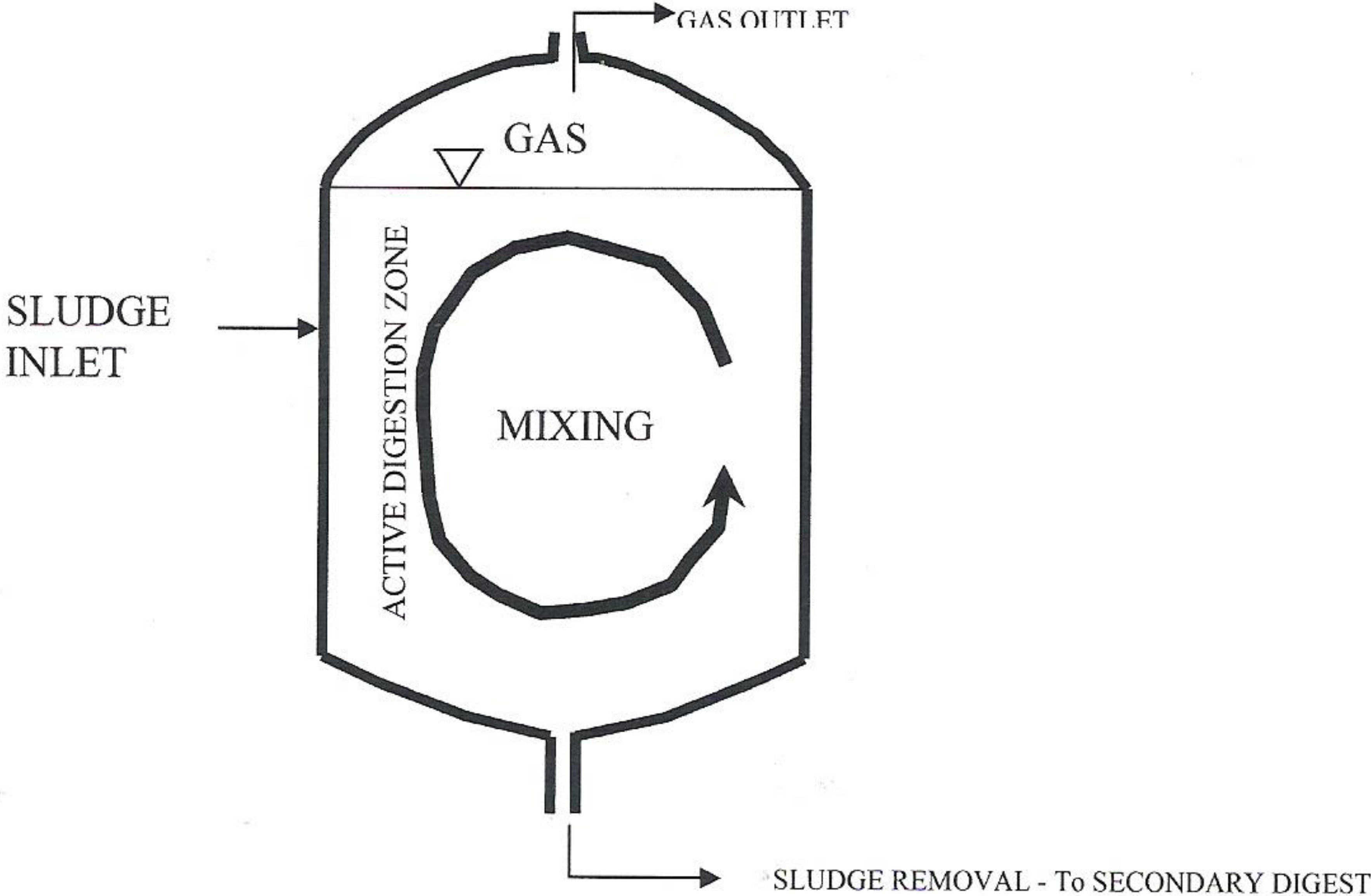

Figure 2.: High Rate Primary Digester

HIGH RATE DIGESTION CONT'

- Conditions and characteristics for high rate secondary digestion (thickening)
  - Unheated
  - Retention time of 15 - 60 days
  - Minimal gas production
  - Continuous or intermittent feeding
  - Intermitted withdrawal
  - Stratification

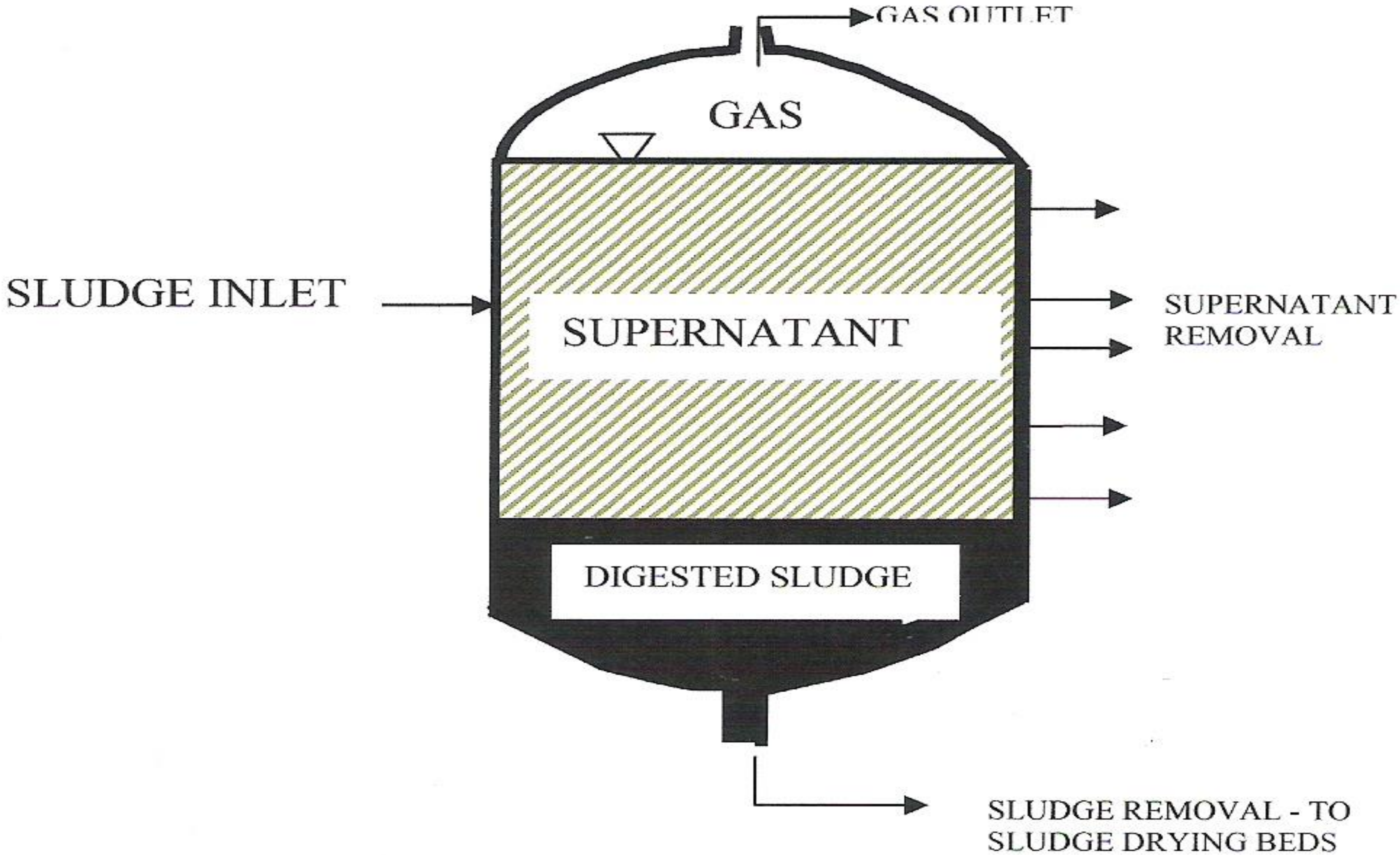

Figure 3: High Rate Secondary Digester (Thickener)

Sludge Digestion: Process Control

- PROCESS CONTROL
- Mainly by controlling feeding rate which is a direct control of the VSS loading into the digester
- What are volatile suspended solids?
- - Organic solids in the sewage

Sludge Digestion: Process Control

- How are they measured?
  - Get a known volume of sample
  - Dry over water bath
  - Then dry in oven at 103 - 105^oC to constant rate
  - Measure mass (say X mg)
  - Burn solids in muffle furnace at 550^oC to constant wt
  - Get mass of ash after cooling in dessicator (say Y mg)

    (ash is called fixed solids)
  - Volatile solids = X - Y
  - Percentage of volatile solids = (X - Y)/X

Sludge Drying -

- Through sludge drying beds
- Dimensions: 20x8
- Feeding Depth: 0.25-0.4 m
- Drying Period: Varies from 2 weeks

Challenges of Conventional Treatment Plants

- Operations
- Maintenance

Thiers and Ours

Ours and Thiers

END

THANK YOU