Wastewater Treatment Plants

Principles of Process, Operation & Troubleshooting

Learning Points

- Basic Type and Technologies of Activated Sludge Process
- List five key process control parameters and for each parameter, explain what it is, why it is used and how it is calculated.

Objective

To provide the basic knowledge on typical wastewater treatment process technologies, regulations limits, biological process operation control and troubleshooting

1. **Improve Basic Knowledge of Process Engineers**

2. **Help to supervise the assigned OEM Contractors Works**

3. **Control the Effluent Quality to meets the regulations and Environment Compliance**

WWTP Advance Technologies

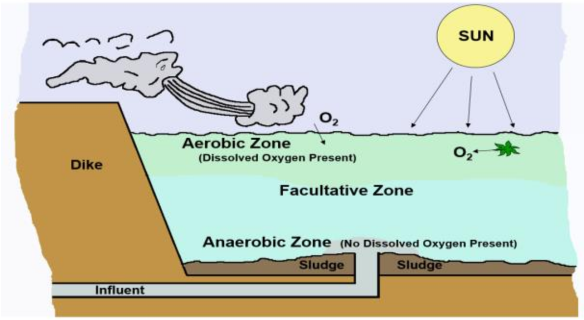
1. EXTENDED AERATION OXIDATION DITCH (Carrousel)

2. MOVING BED BIO REACTOR (MBBR)

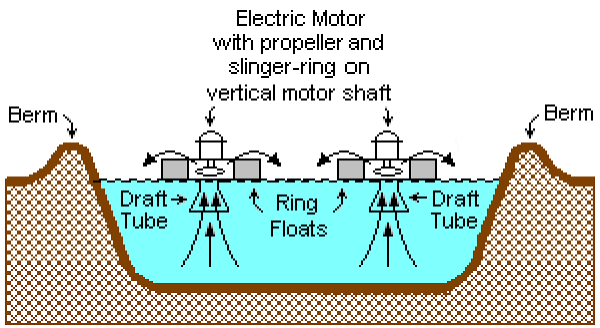
3. SEQUENTIAL BATCH REACTOR (SBR)

4. MEMBRANE BIO REACTOR (MBR)

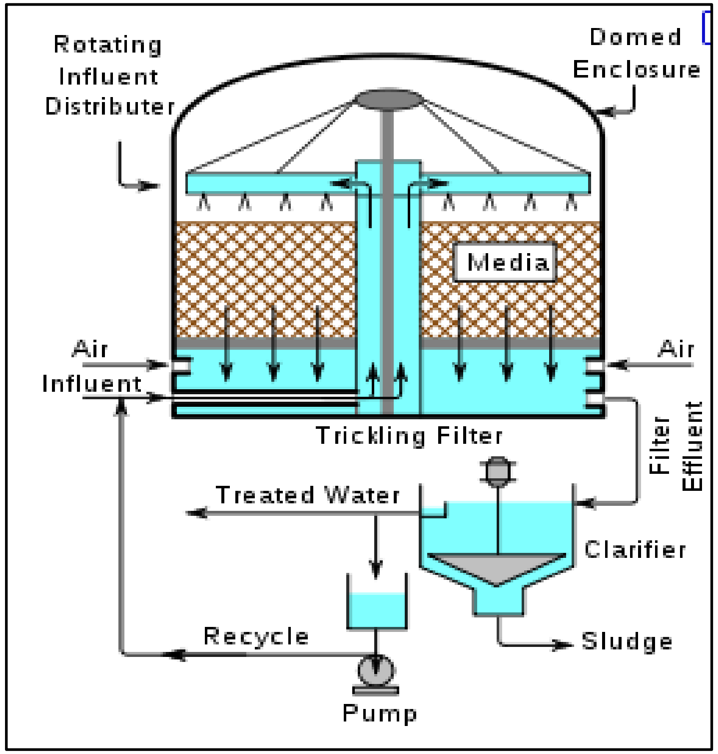
WWTP Conventional Old Technologies



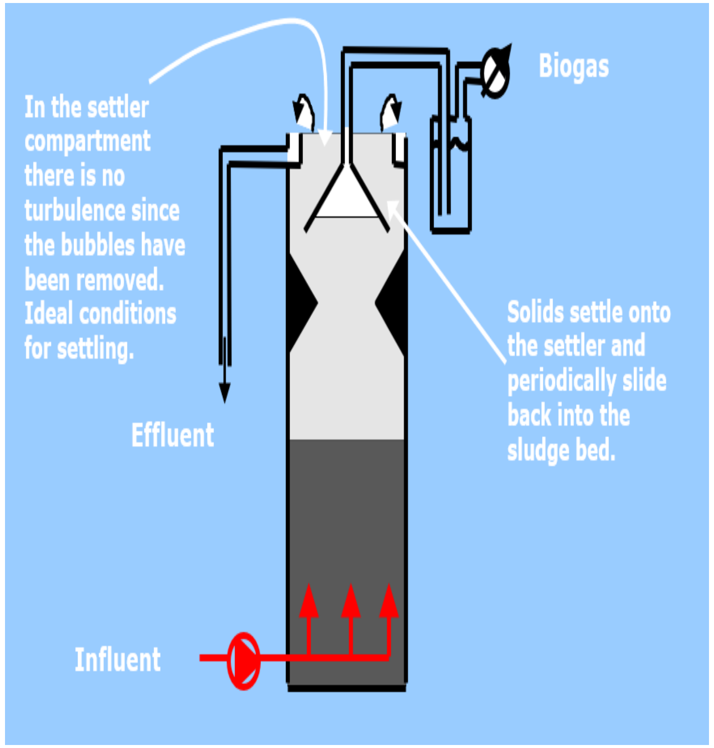
Oxidation Pond / Lagoon



Aerated Lagoon



Tricking Bio Filter

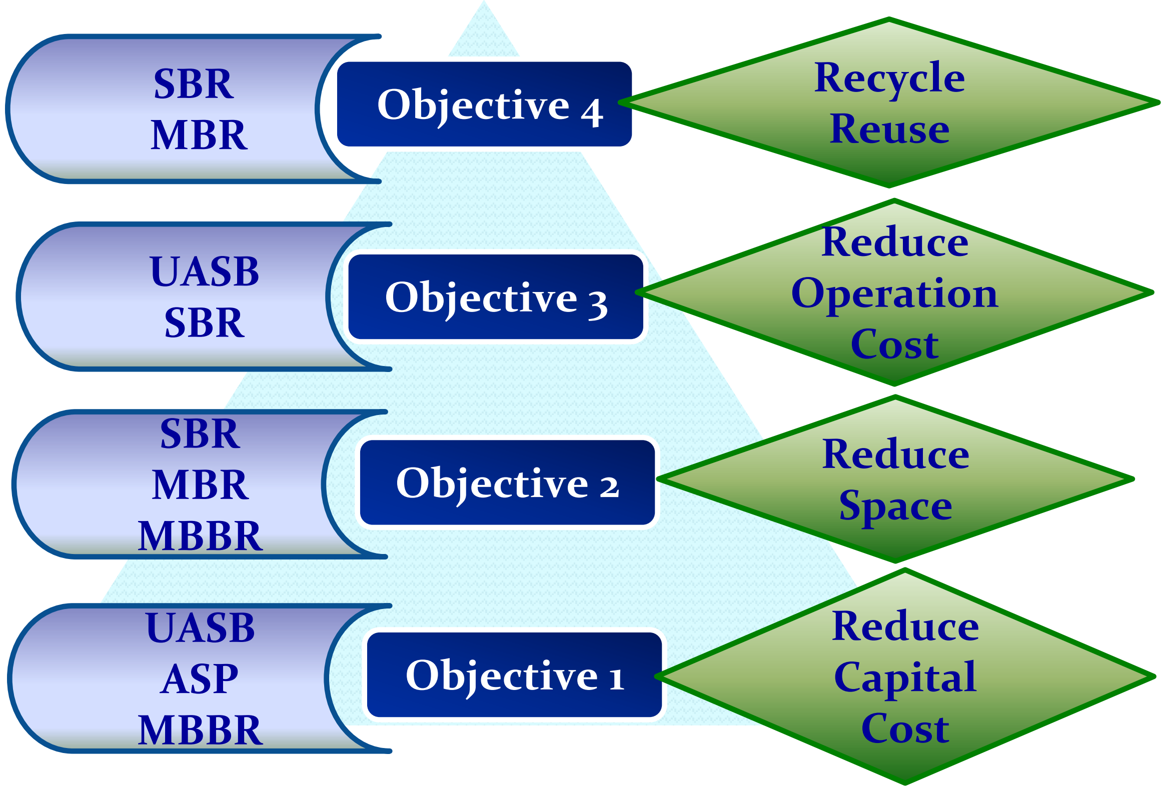


Up-flow anaerobic sludge blanket reactor (UASB)

Activated Sludge Principles & Selection Criteria

Activated Sludge Principles

- Wastewater is aerated in a tank
- Bacteria are encouraged to grow by providing
    - Oxygen
    - Food (BOD)
    - Nutrients
    - Correct temperature
    - Time
- As bacteria consume BOD, they grow and multiply
- Treated wastewater flows into secondary treatment
- Bacterial cells settle, removed from clarifier as sludge
- Part of sludge is recycled back to activated sludge tank, to maintain bacteria population
- Remainder of sludge is wasted



Video

Typical WWTP Process

- **In the case of domestic wastewater treatment, the objective of biological treatment is**
  - **To stabilize the organic content**
  - **To remove nutrients such as nitrogen and phosphorus**

Types:

✓Aerobic Processes
✓Anoxic Processes
✓Anaerobic Processes
✓Combined Aerobic-Anoxic-Anaerobic Processes

✓Attached Growth
✓Suspended Growth

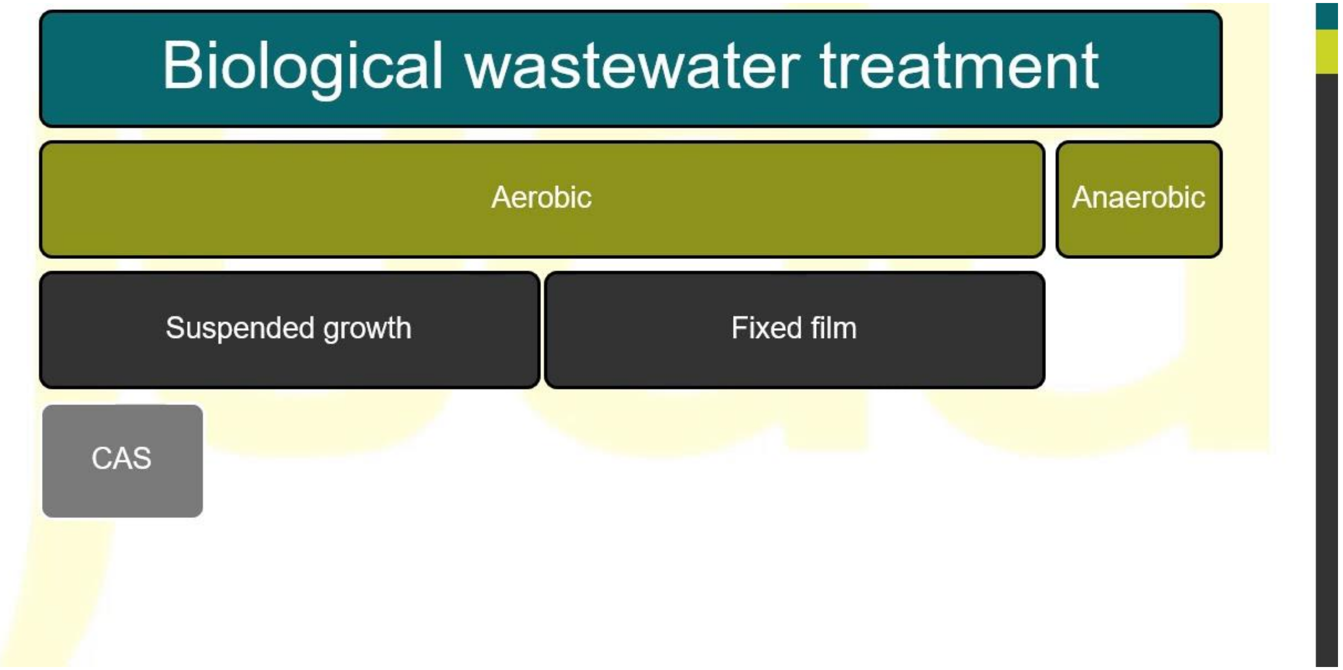
✓Pond Processes

✓Aerobic
✓Anaerobic

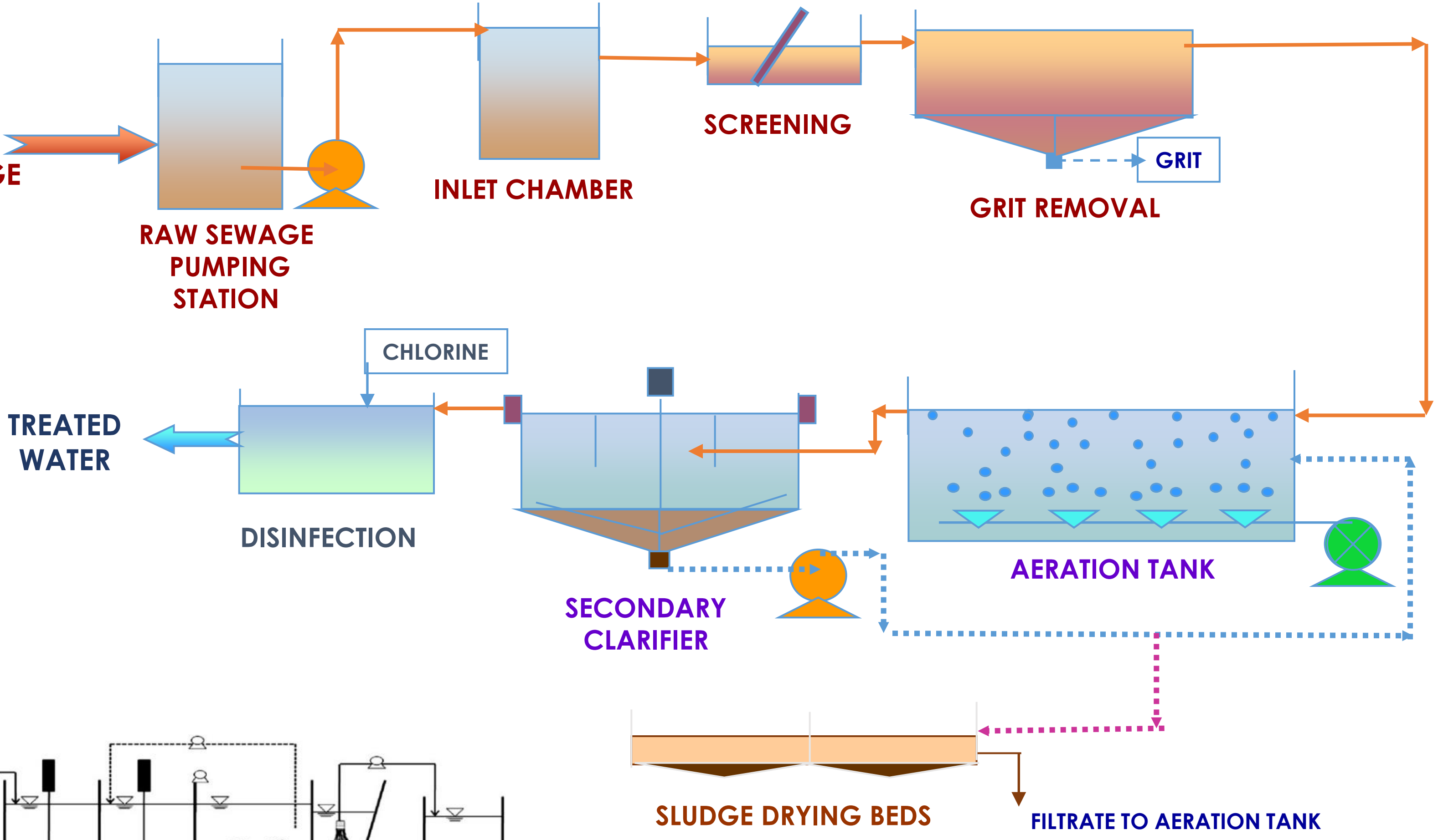
Typical WWTP Process

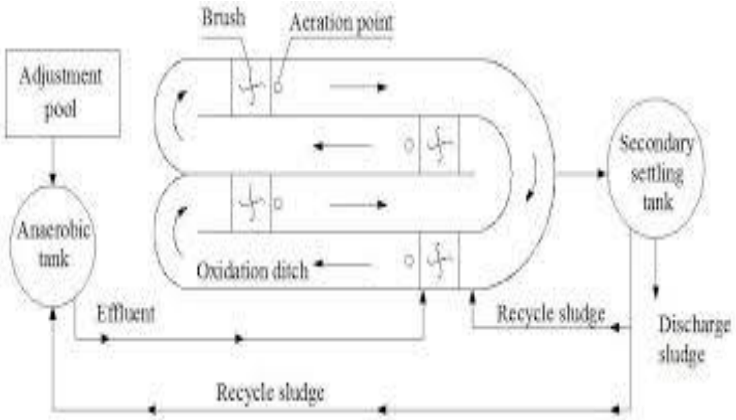
Treatment Process examples are:

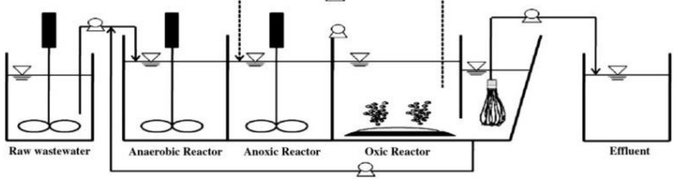
- aerobic processes - presence of dissolved oxygen
  - Activated sludge (EA-Oxidation Ditch, SBR, MBBR & MBR)
  - Trickling Filters
  - Aerated Lagoon
  - Aerobic Digestor
- anaerobic processes – absence of dissolved oxygen
  - Phosphorous Removal
  - Up flow anaerobic sludge blanket reactor (UASB)
  - Anaerobic Digestor



Typical Flow Chart –Extended Aeration Oxidation Ditch (Carrousel)

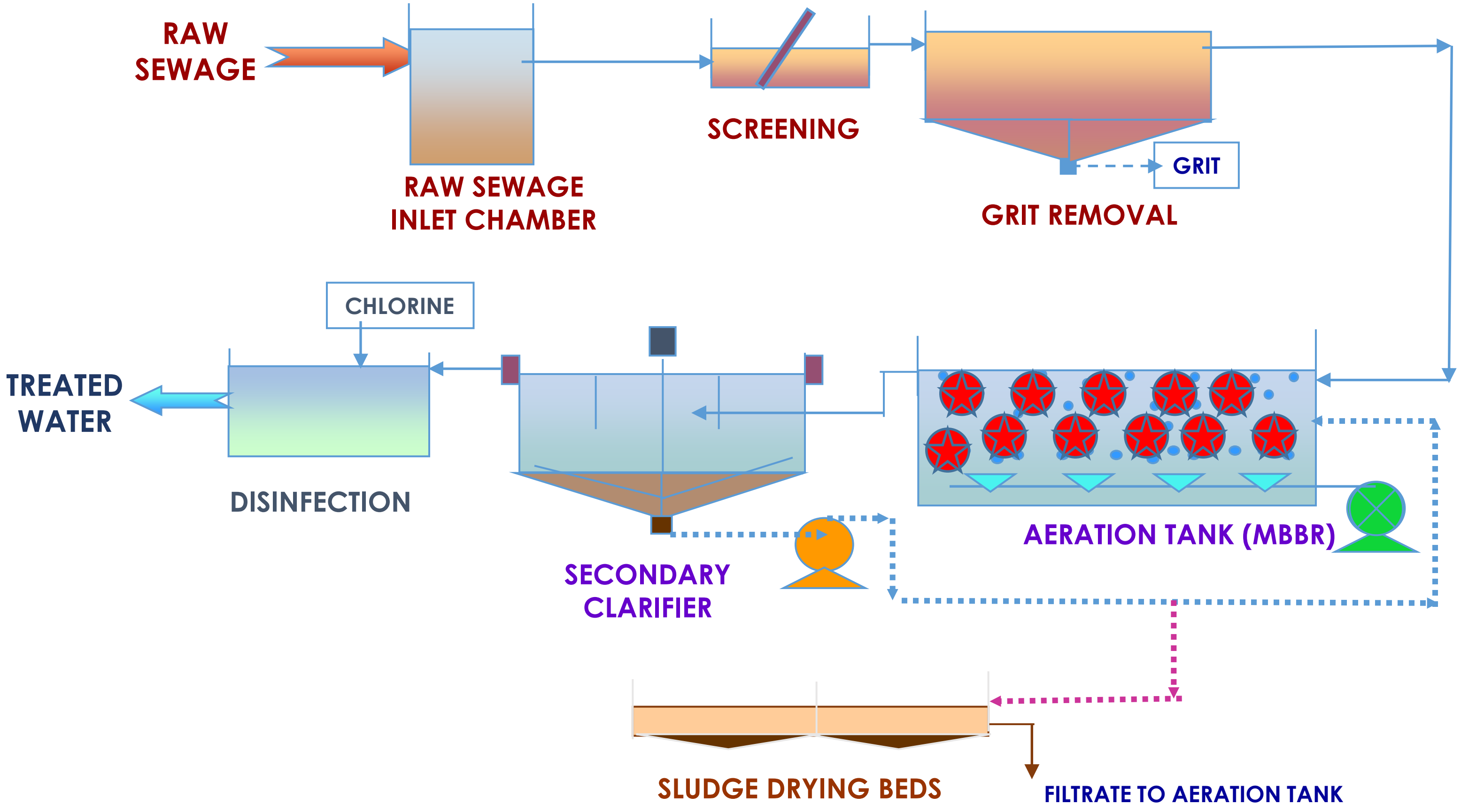


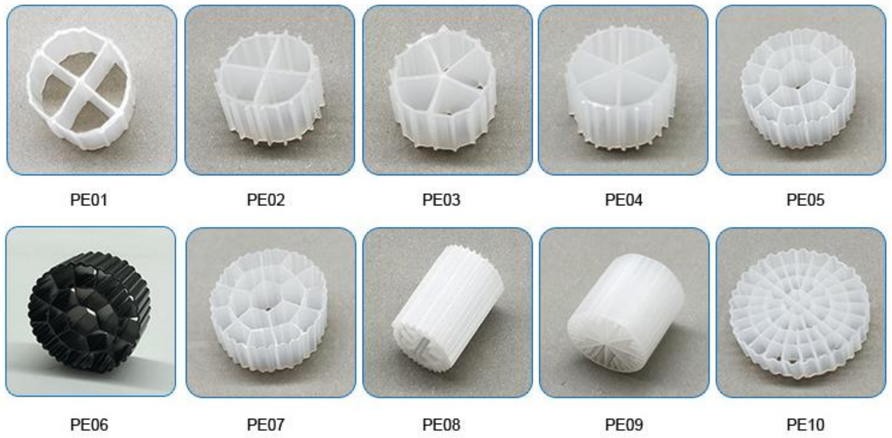


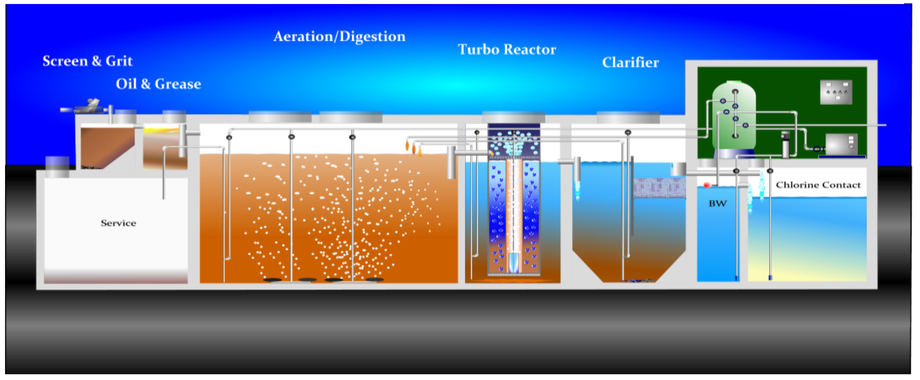


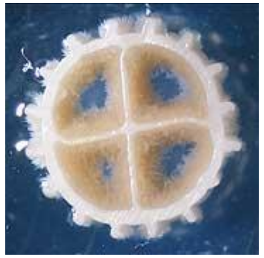
Anaerobic zone helps with BNR

Typical Flow Chart - MBBR

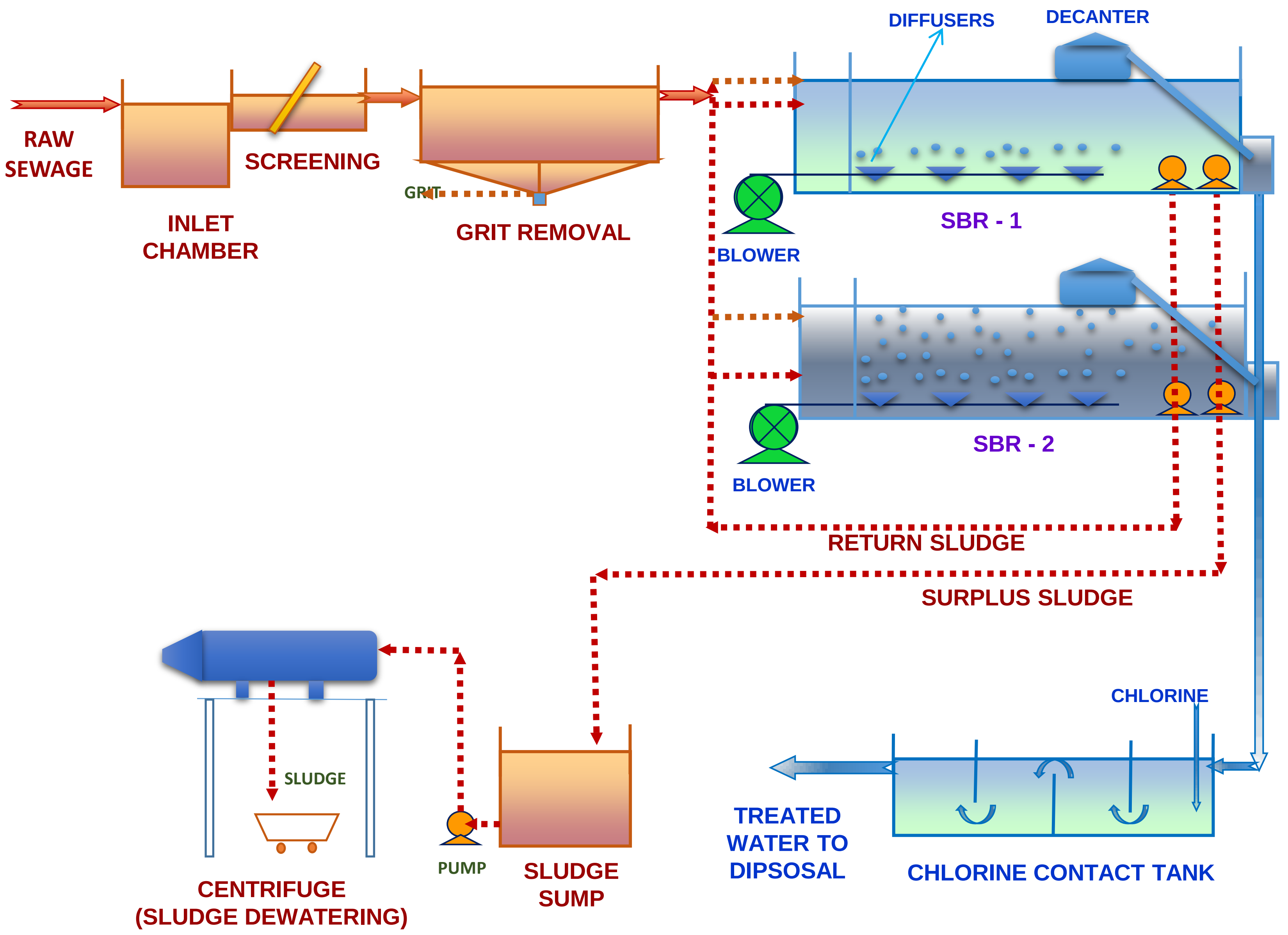


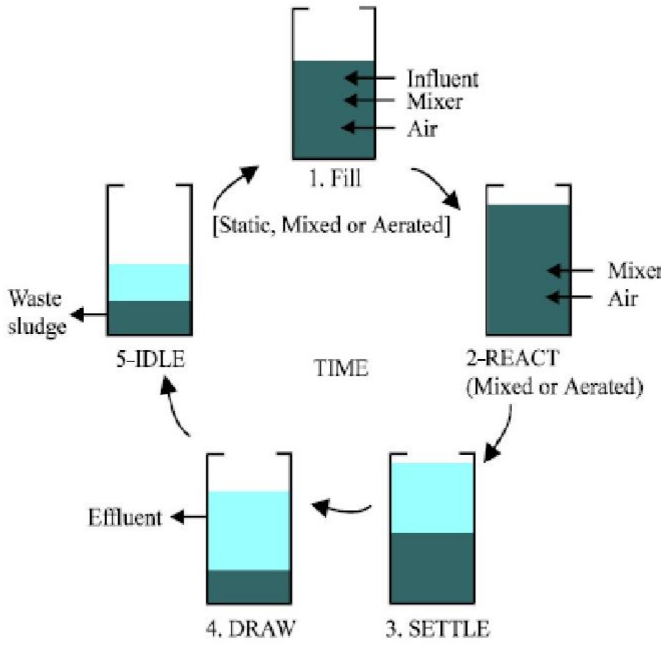




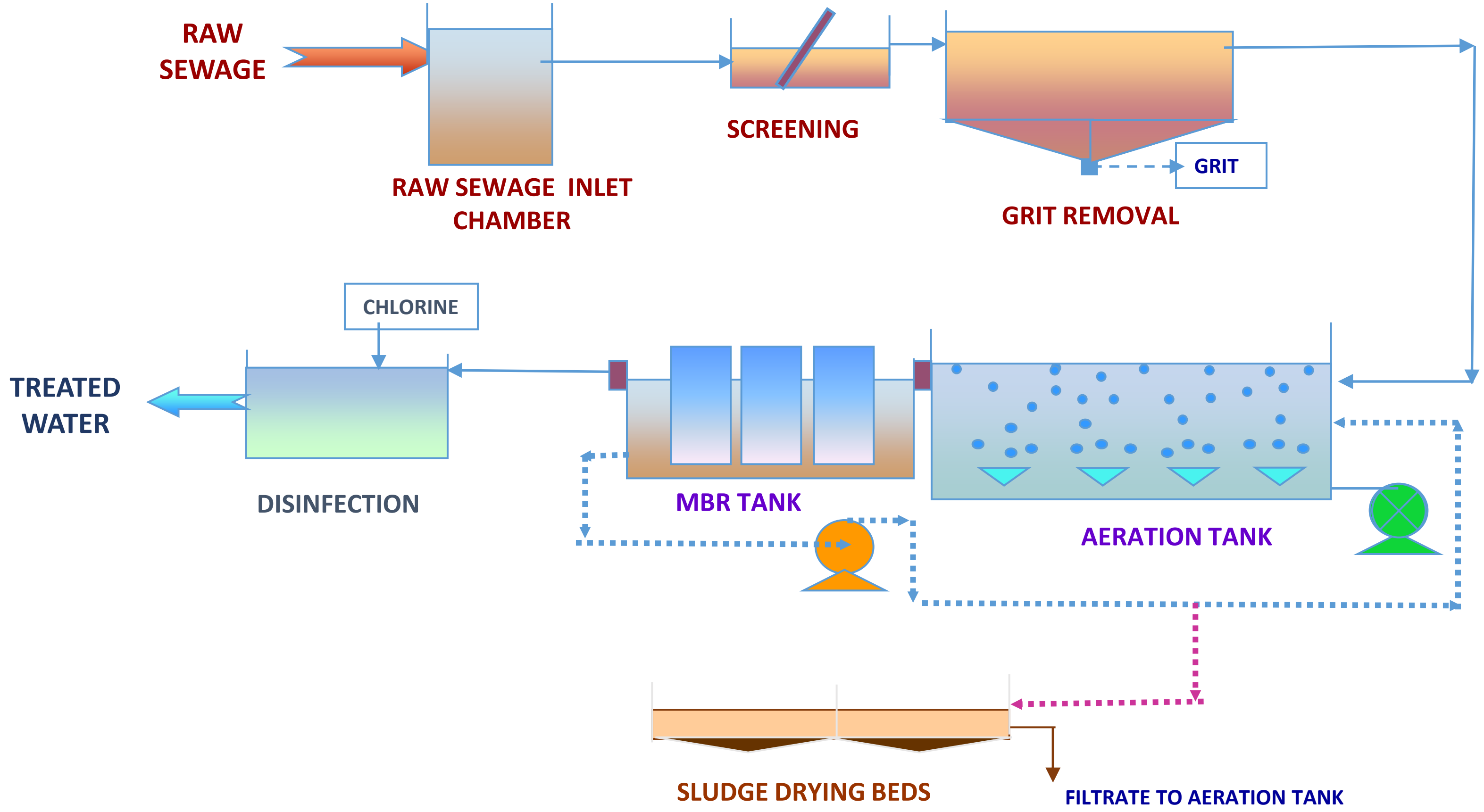


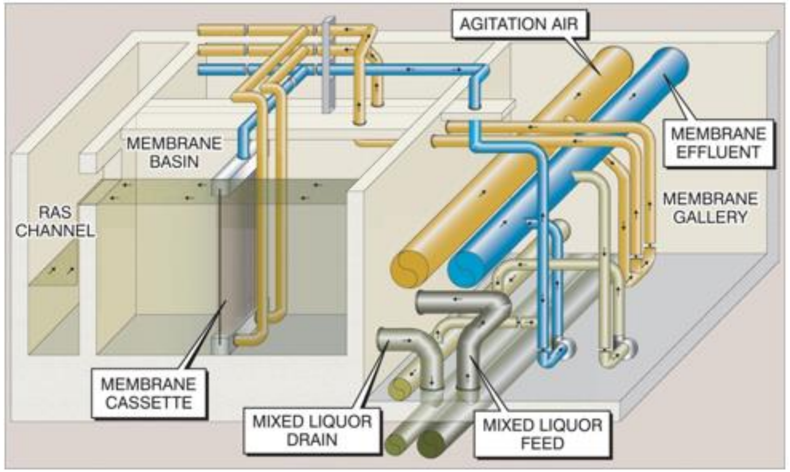
Typical Flow Chart - SBR





Typical Flow Chart - MBR





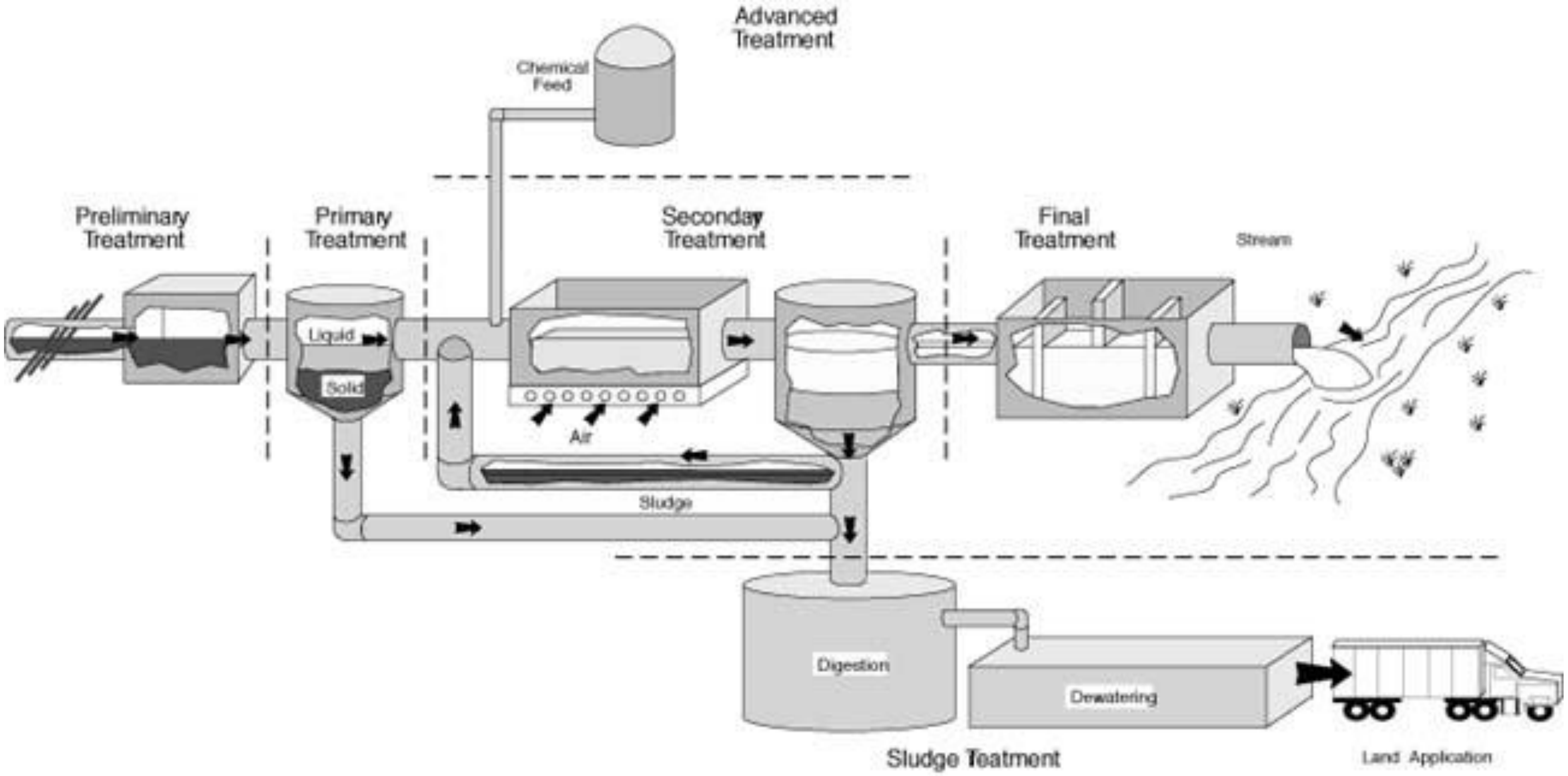
Typical Raw Wastewater Characteristics

Contaminant	Concentration mg/l		
	Strong	Medium	Weak
Total Suspended Solids - TSS	350	220	100
Biochemical Oxygen Demand - BOD	400	220	110
Chemical Oxygen Demand - COD	1000	500	250
Total Nitrogen – TN	85	40	20
Total Phosphorous – TP	15	8	4

Desired Treated Effluent Quality (GAMEP)

Contaminants	Concentration (mg/l)
Total Suspended Solid - TSS	5
Biochemical Oxygen Demand - BOD	10
Chemical Oxygen Demand - COD	25
Total Kjeldahl Nitrogen - TKN	3
Total Phosphorous - TP	0.5
Ammonia (free, as NH_3)	0.1
Oil & Grease	3

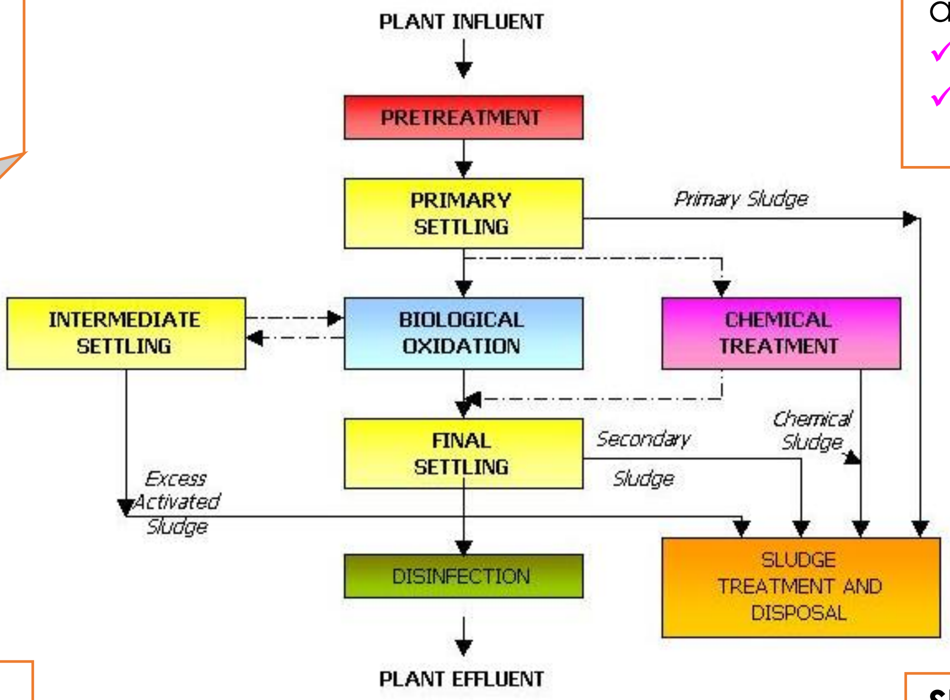
Typical Treatment Plant



Typical Treatment Stages

Pretreatment involves:
✓Screening
✓Grit Removal
✓Oil separation
✓Flow equalization

Chemical Treatment is used in conjunction with the physical and chemical processes:
✓Chemical precipitation
✓Adsorption



Odour Control is used meet the environment regulation compliance

Disinfection can use:
✓Chlorine compounds
✓Per oxide
✓Ozone
✓UV Radiation

Sludge Treatment and Disposal involves:
thickening, stabilization, conditioning, dewatering, heat drying, thermal reduction

Treatment Stages

Preliminary Stage

Screening and grit removal by physical action

Primary Stage

Primary Sedimentation of suspended organic material

Treatment Stages

Biological Stage

Conversion of soluble organic matter to stable end products

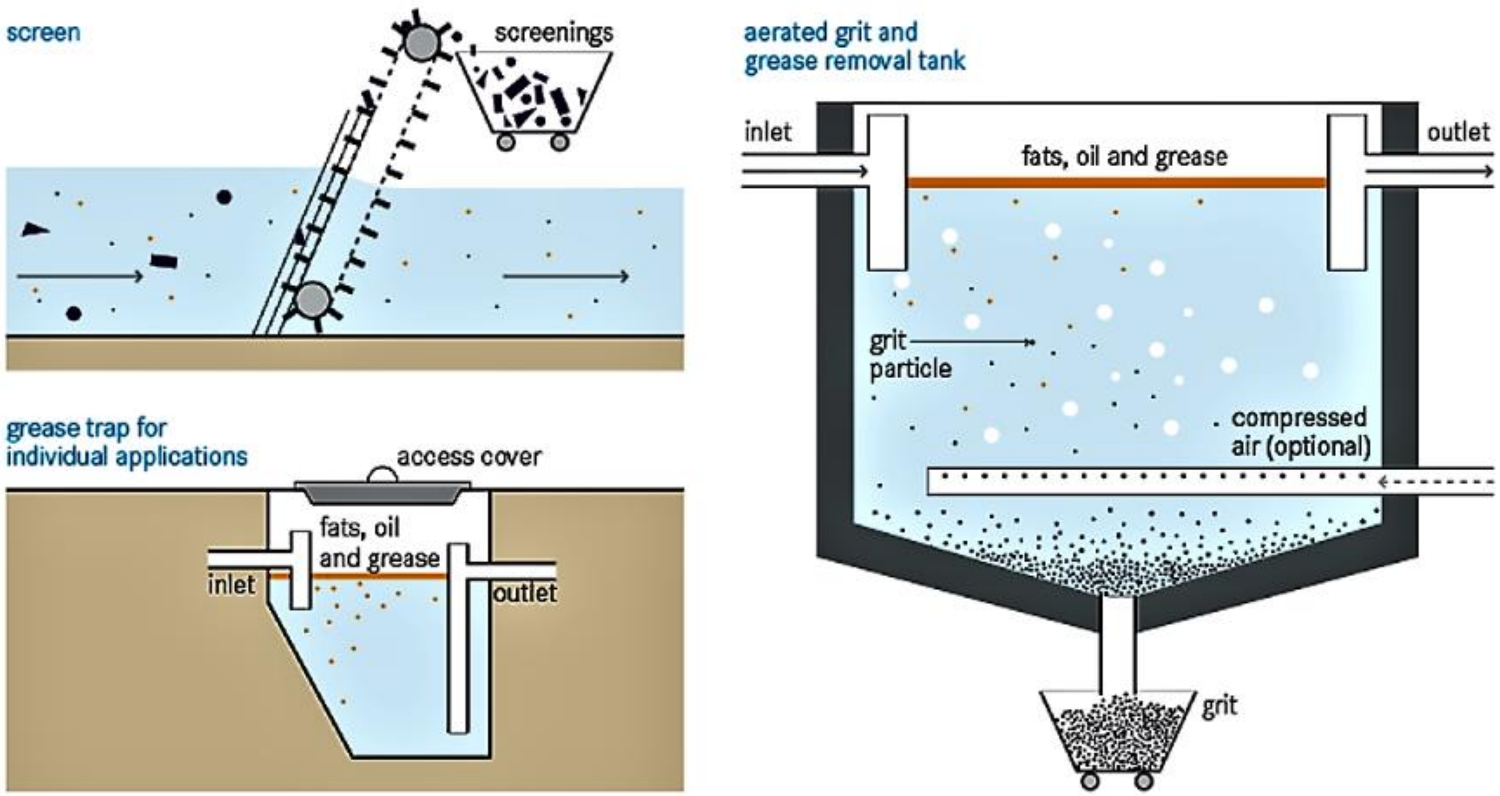
Tertiary Treatment Stage

Removal of particulate pollutant & Disinfection

Preliminary Treatment Stage

Typical materials that are removed during primary treatment include;

- Coarse Screens
- Fine Screens
- FOG Removal Unit



Primary Treatment Stage

Typical materials that are removed during primary treatment include;

- ✓ Equalization Tank – balance Peak flow, produce a homologous liquid for later biological treatment
- ✓ Primary Clarifier, applicable in industrial influent and anaerobic digestion
- ✓ Fecal sludge are pumped to sludge treatment plant

Secondary Treatment Stage

Typical materials that are removed during biological treatment include;

- ✓ **Aeration Tank**
- ✓ **Secondary Clarifier**

Biological Nutrient Removal

- ✓ **Aerobic (oxic)** - in the presence of molecular oxygen (O_2)
- ✓ **Anoxic** - very low concentration of molecular oxygen (O_2) significant levels of electron acceptors (NO3-, SO4-)
- ✓ **Anaerobic** - no oxygen, lack of electron acceptors (only CO_2)

Tertiary Treatment

The additional treatment required to remove suspended and dissolved substances* remaining in treated effluent after conventional secondary treatment.

➲ **Filtration – Sand Media or Disc etc.**

➲ **Disinfection by Chlorine, UV.**

- Coagulation-flocculation-settling followed by filtration and disinfection is generally recommended.
- Multiple disinfection process in the treatment chain may be adopted.
- Other processes could be selected on the basis of land availability, cost considerations. However, disinfection operation should invariably be included.

Sludge Treatment

Primary sludge usually have strong odors / Secondary sludge have high concentration of microorganism;

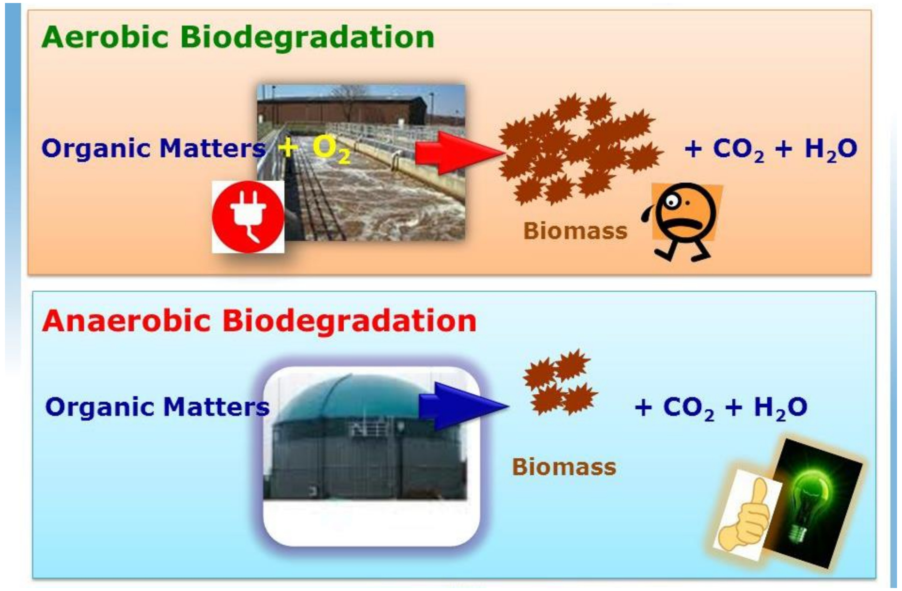
- Untreated sludge are about 97 percent water
- Settling can reduce about 92 to 96 percent of water
- dried sludge is called a sludge cake (20 % DS)

Goals of treatments are:

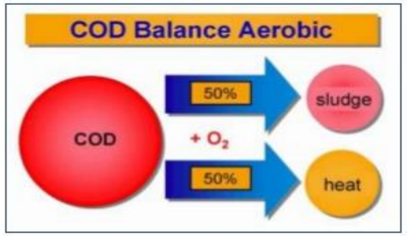
- Reduce odors
- Remove water reduce volume
- Decompose organic matter

Process of treatments are:

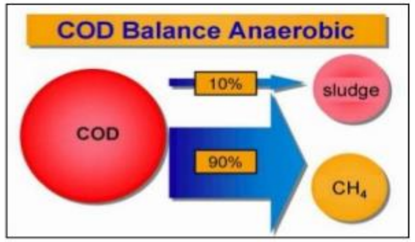
- Digestion – Aerobic or Anaerobic
- Dewatering – Filter Press / Centrifuge / Drying Bed etc.



COD Balance Aerobic Biodegradation



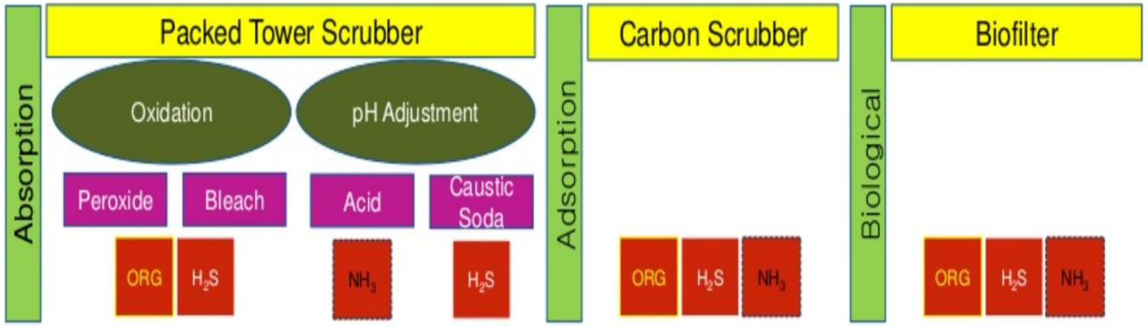
COD Balance Anaerobic Biodegradation



Odour Control

- 3 main technologies
  - Chemical scrubbing
  - Dry media (activated carbon)
  - Biological scrubbing

Sl. No	Parameter	Time-weighted average ($\mu g/Nm^3$)	Time-weighted average (ppm)	Averaging time	Number of allowable exceedances
1	Hydrogen Sulphide	150	0.1	24 hours	10 times per annum
		40	0.03	Annual	N/A



Bad Odour Gases are

- hydrogen sulfide (rotten egg gas),
- ammonia and
- organic odours (indoles, skatoles, mercaptans, inorganic acids, aldehydes, ketones and organic compounds containing nitrogen or sulfur atoms

Location

- Sewer collection system,
- Pumping station in primary treatment facilities
- in solids handling facilities

Odour Impacts

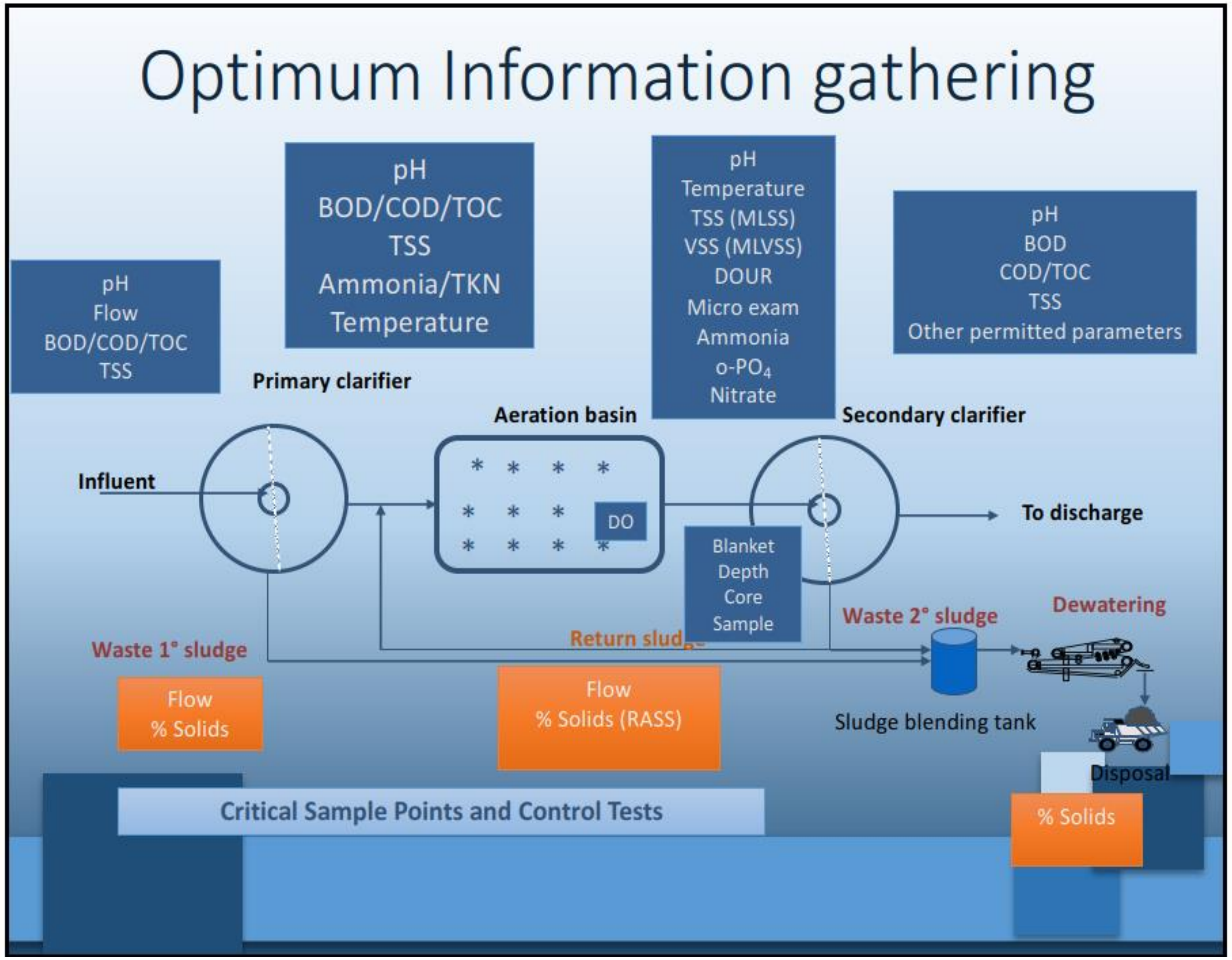
- the intensity of the odour;
- the distance from the odour source ;
- the weather conditions
- the geographical condition of the site plain, forest, mountains etc.
- the frequency of the exposure;

Learning Points

- ❑ List the key monitoring points within the activated sludge process and explain what to look for at those points.
- ❑ List major troubleshooting and its solution

Typical Biological Process Operation & Control

- **pH/Alkalinity/Salinity/ Temperature**
- **DO (2 mg/l is ideal for ASP)**
- **DOUR / SOUR**
- **F/M = Food/Micro organism ratio**
- **SVI: Sludge Volume Index (range: 80-120)**
- **SRT = Sludge Retention Time**
- **MLSS: Mixed Liquor Suspended Solids (WAS and RAS)**
- **MCRT = Mean Cell Residence Time and Sludge Age (SRT)**
- **Nitrate (De-nitrification)**
- **Ortho- Phosphate (Soluble)**
- **BOD / COD**
- **TSS**



Typical Biological Process Operation & Control

Table 8-22
Typical design parameters for commonly used nitrogen-removal processes

Design parameter/ process	SRT, d[a]	MLSS, mg/L	τ, h Total	Anoxic zone	Aerobic zone	RAS, % of influent	Internal recycle, % of influent
MLE	7–20	3000–4000	5–15	1–3	4–12	50–100	100–200
SBR	10–30	3000–5000	20–30	Variable	Variable		
Bardenpho (4-stage)	10–20	3000–4000	8–20	1–3 (1st stage) 2–4 (3rd stage)	4–12 (2nd stage) 0.5–1 (4th stage)	50–100	200–400
Oxidation ditch	20–30	2000–4000	18–30	Variable	Variable	50–100	
Bio-denitro™	20–40	3000–4000	20–30	Variable	Variable	50–100	
Orbal™	10–30	2000–4000	10–20	6–10	3–6 (1st stage) 2–3 (2nd stage)	50–100	Optional

Typical Biological Process Operation & Control

Typical design parameters for commonly used activated-sludge processes[a]

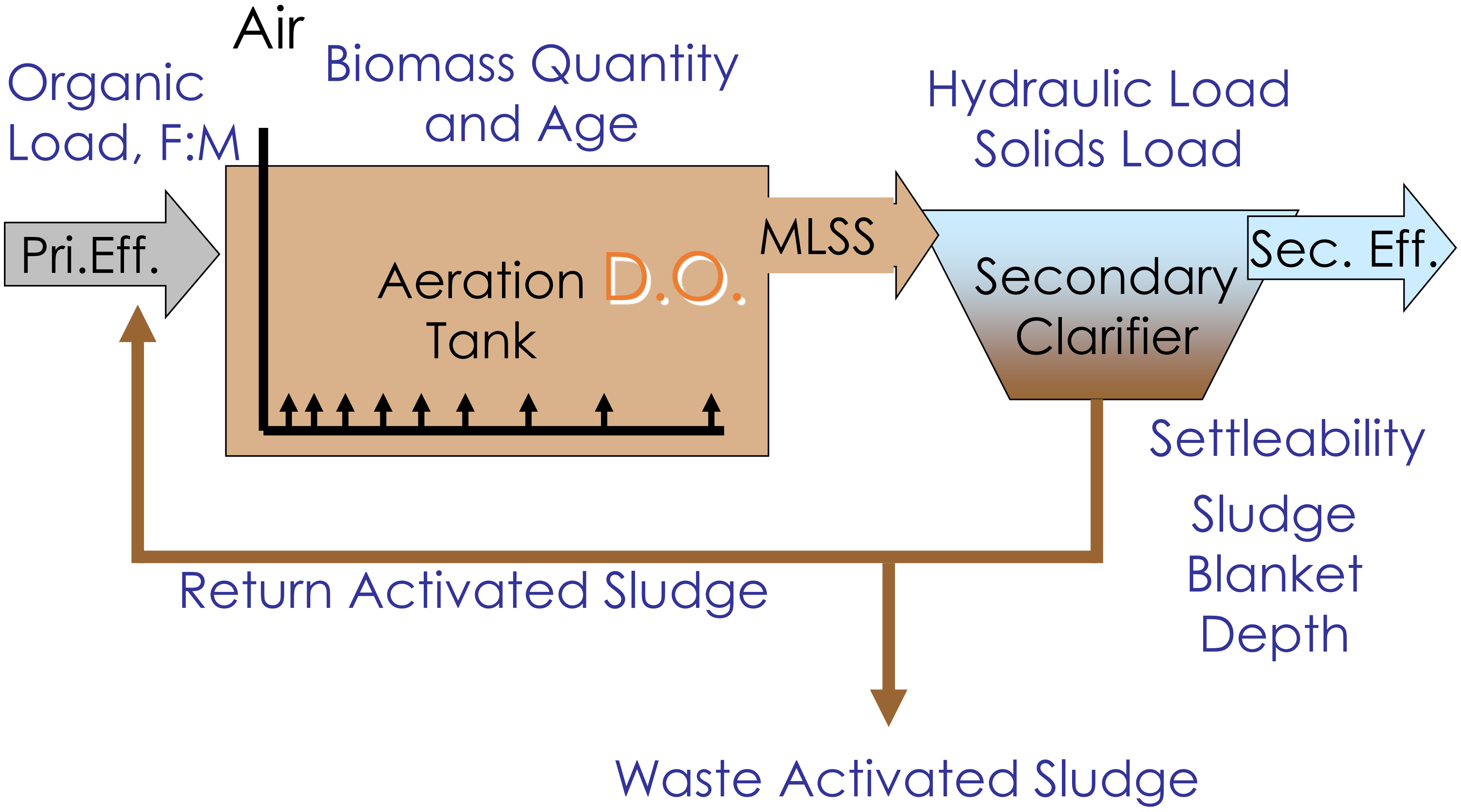
Process Name	Type of Reactor	SRT, days	F:M kg BOD/kg MLVSS-d	Volumetric Loading: lb BOD/1000 ft^3-d	Volumetric Loading: kg BOD/m^3-d	MLSS, mg/L	Hydraulic detention time, hrs	RAS % of Influent[e]
High-rate aeration	Plug flow	0.5 - 2	1.5 - 2.0	75 - 150	1.2 - 2.4	200 - 1000	1.5 - 3	100 - 150
Contact stabilization	Plug flow	5 - 10	0.2 - 0.6	60 - 75	1.0 - 1.3	1000 - 3000[b]	0.5 - 1[b]	50 - 150
						6000 - 10000[c]	2 - 4[c]	
High-purity oxygen	Plug flow	1 - 4	0.5 - 1.0	80 - 200	1.3 - 3.2	2000 - 5000	1 - 3	25 - 50
Conventional plug flow	Plug flow	3 - 15	0.2 - 0.4	20 - 40	0.3 - 0.7	1000 - 3000	4 - 8	25 - 75[f]
Step feed	Plug flow	3 - 15	0.2 - 0.4	40 - 60	0.7 - 1.0	1500 - 4000	3 - 5	25 - 75
Complete mix	CMAS	3 - 15	0.2 - 0.6	20 - 100	0.3 - 1.6	1500 - 4000	3 - 5	25 - 100[f]
Extended aeration	Plug flow	20 -40	0.04 - 0.10	5 - 15	0.1 - 0.3	2000 - 5000	20 - 30	50 -150
Oxidation ditch	Plug flow	15 - 30	0.04 - 0.10	5 - 15	0.1 - 0.3	3000 - 5000	15 - 30	75 - 150
Batch decant	Batch	12 - 25	0.04 - 0.10	5 - 15	0.1 - 0.3	2000 - 5000[d]	20 - 40	NA
Sequencing batch reactor	Batch	10 - 30	0.04 - 0.10	5 - 15	0.1 - 0.3	2000 - 5000[d]	15 - 40	NA
Countercurrent aeration system (CCAS)	Plug flow	10 - 30	0.04 - 0.10	5 - 10	0.1 - 0.3	2000 - 4000	15 - 40	25 - 75[f]

[a]Adapted from WEF (1998); Crites and Tchobanoglous (1998)
[b]MLSS and detention time in contact basin
[c]MLSS and detention time in stabilization basin
[d]Also used at intermediate SRTs
[e]Based on average flow
[f]For nitrification, rates may be increased by 25 to 50%
NA = not applicable

From Wastewater Engineering: Treatment and Reuse, 4th Edition, Metcalf & Eddy, pg. 747.

www.thewastewaterblog.com

Typical Biological Process Operation & Control



Video

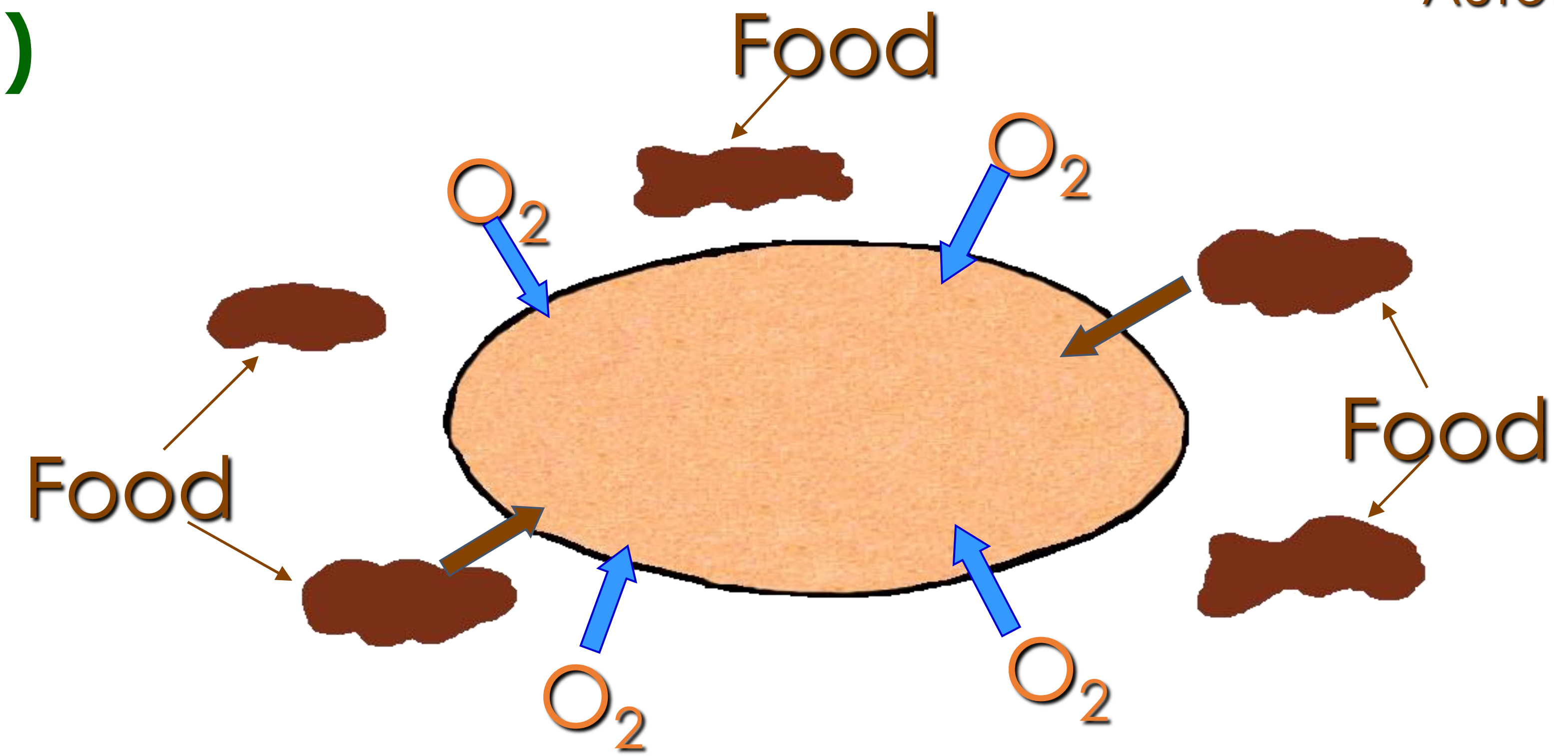
Control Factors – D.O

Dissolved Oxygen (D.O)

Biological

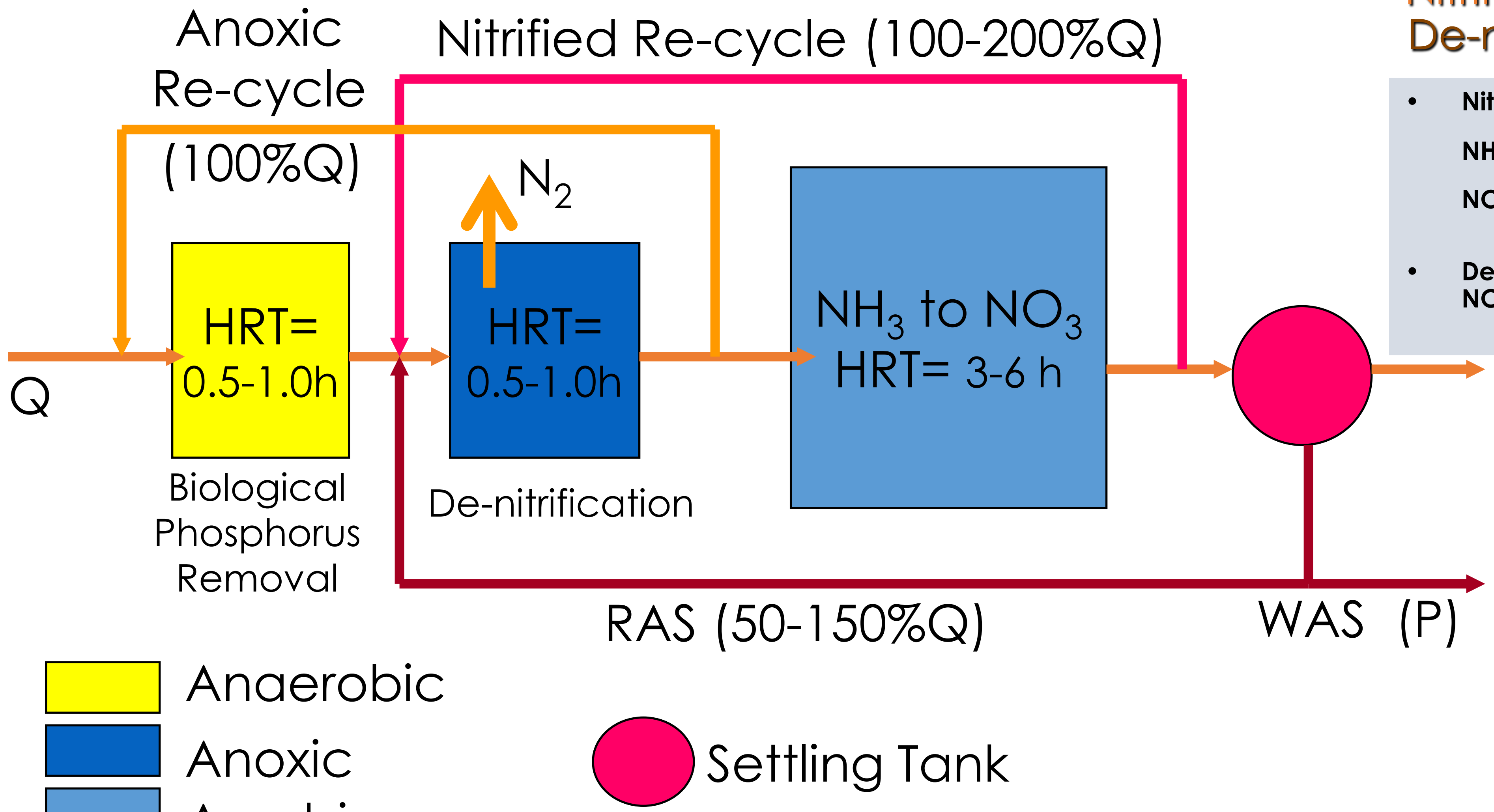
Heterotrophic Bacteria

Autotrophic Bacteria



Millions of aerobic and facultative micro-organisms remove pollutants thru living and growing process

Control Factors – Nitrate / Ortho - Phosphate



Nitrification
De-nitrification

- **Nitrification**

  $NH_4^+ + 1.5\ O_2 \longrightarrow NO_2^- + 2H^+ + H_2O$

  $NO_2^- + 0.5\ O_2 \longrightarrow NO_3^-$

- **Denitrification**

  $NO_3^- + CH_2 + H^+ \longrightarrow N_2\uparrow + CO_2 + H_2O$

(= 6% P)

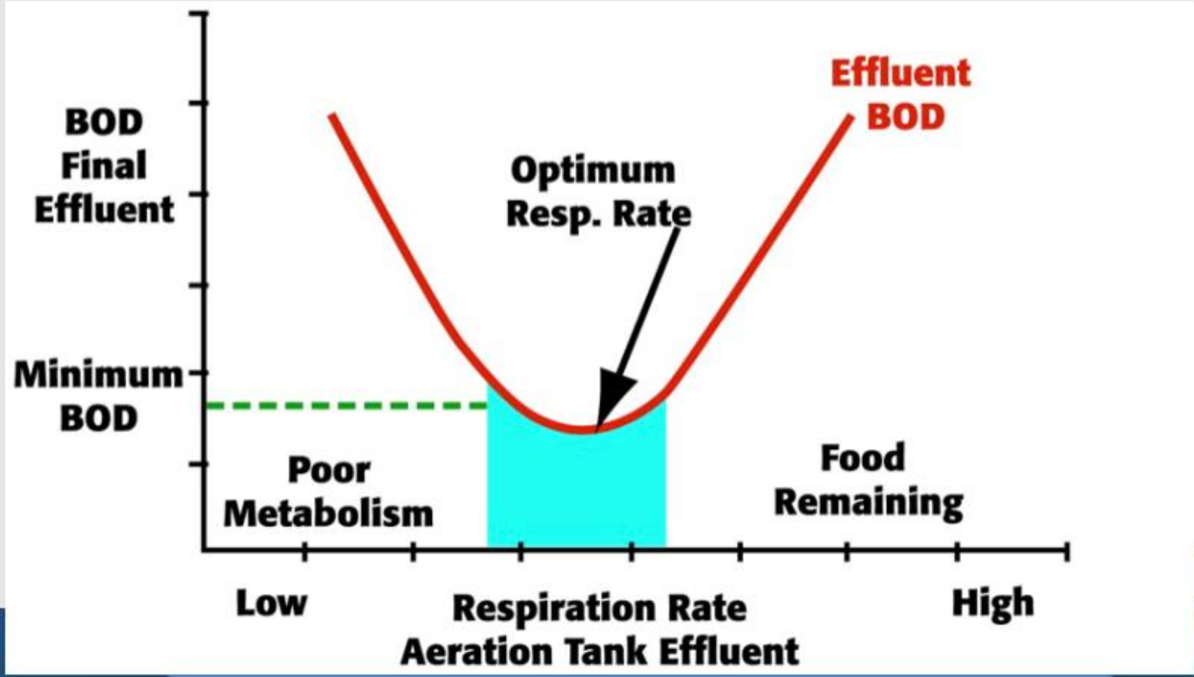
Video

Control Factors – SOUR

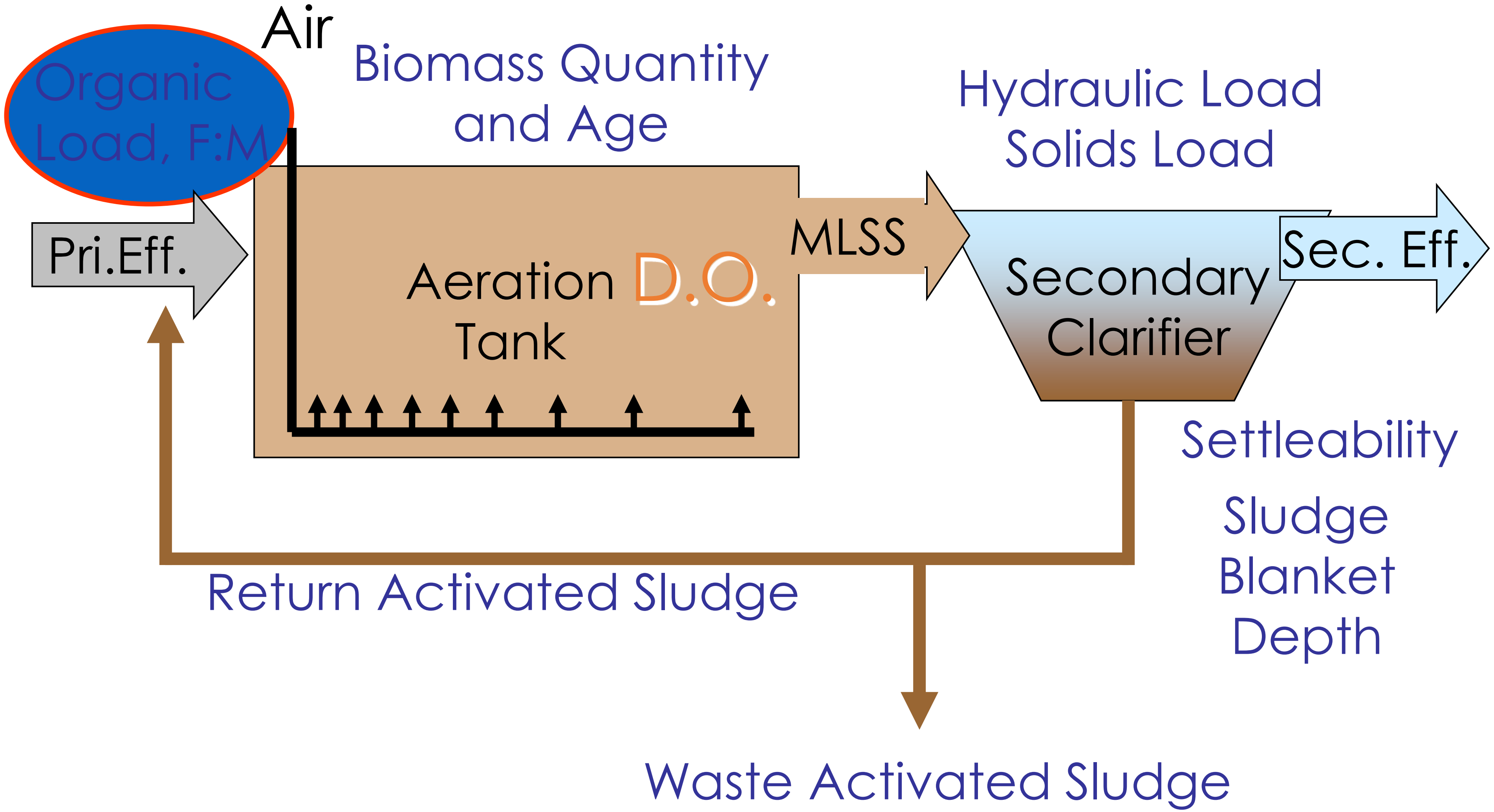
SOUR Guidelines - Activated Sludge

SOUR mg O_2/hr/g VSS	Indicates
>30	Possible BOD overload
10-20	Normal high rate
4-8	Normal operation - conventional A/S
2-4	Normal operation - Extended Aeration A/S or ASB
< 2	Low loading
< 1	Possible Toxicity. Verify with Micro, ATP

Using SOUR to Predict Final BOD

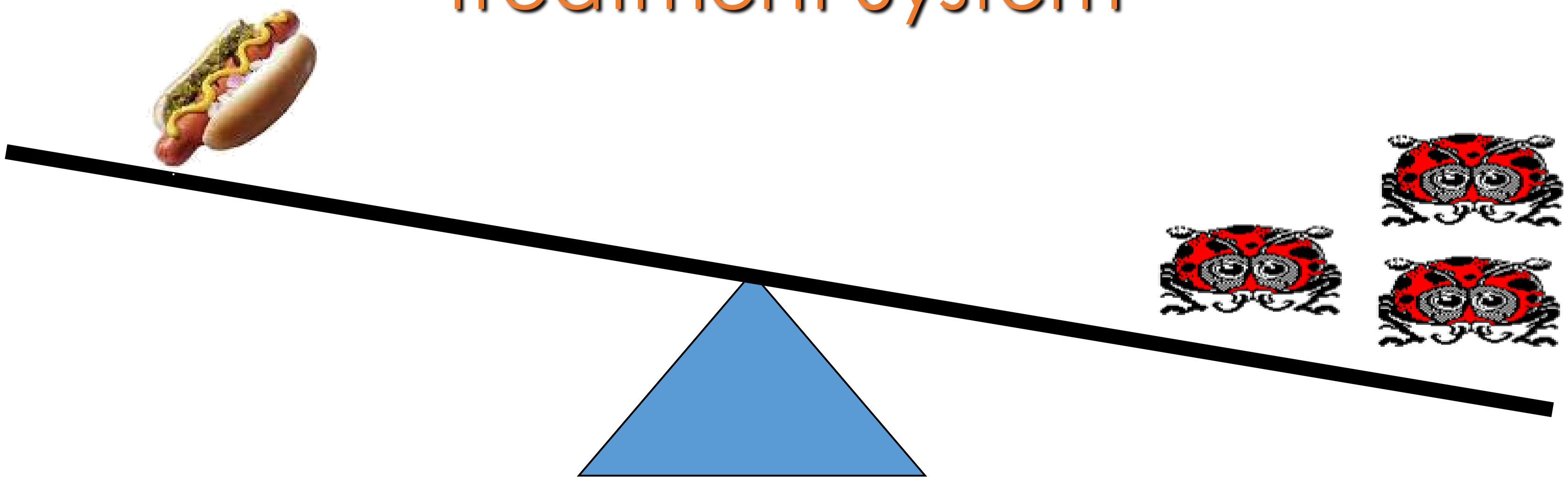


Control Factors – Organic Load, F/M Ratio



Control Factors – F/M Ratio

Need to Balance Organic Load (kgs BOD) With Number of Active Organisms in Treatment System



Food to Microorganism Ratio

F:M or $\frac{F}{M}$

Control Factors – MLSS /MLVSS

Mixed Liquor

Flocculation

A process of contact and adhesion whereby the particles of a dispersion form larger-size clusters.

Control Factors – Determine MLSS

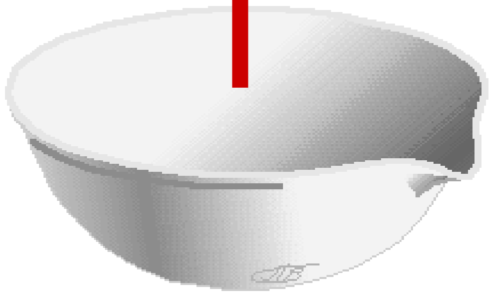
Solids

$$\text{Solids} = \frac{\text{Wt. of Solids + Paper, mg} - \text{Wt. of Paper, mg}}{\text{Wt. of Solids, mg}}$$

$$\frac{\text{Wt. of Solids, mg}}{\text{Volume of Sample, L}} \longrightarrow \text{MLSS, mg/L}$$

Control Factors – Determine MLVSS

Solids



Volatile Solids

550 °C

Wt. of Dish + Solids, mg

— Wt. of Dish + Ash, mg

Wt. of Volatile Solids, mg

$$\frac{\text{Wt. of Volatile Solids, mg}}{\text{Volume of Sample, L}} \longrightarrow \text{MLVSS, mg/L}$$

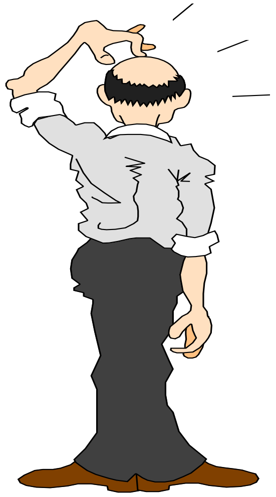
Control Factors – Determine F/M Ratio

F/M Ratio is Used to Determine the Kgs of MLVSS Needed at a Particular Loading Rate

$$F/M = \frac{\text{Kgs BOD}}{\text{Kgs MLVSS}} \qquad \frac{F}{F/M} = M \text{ (Kgs MLVSS)}$$

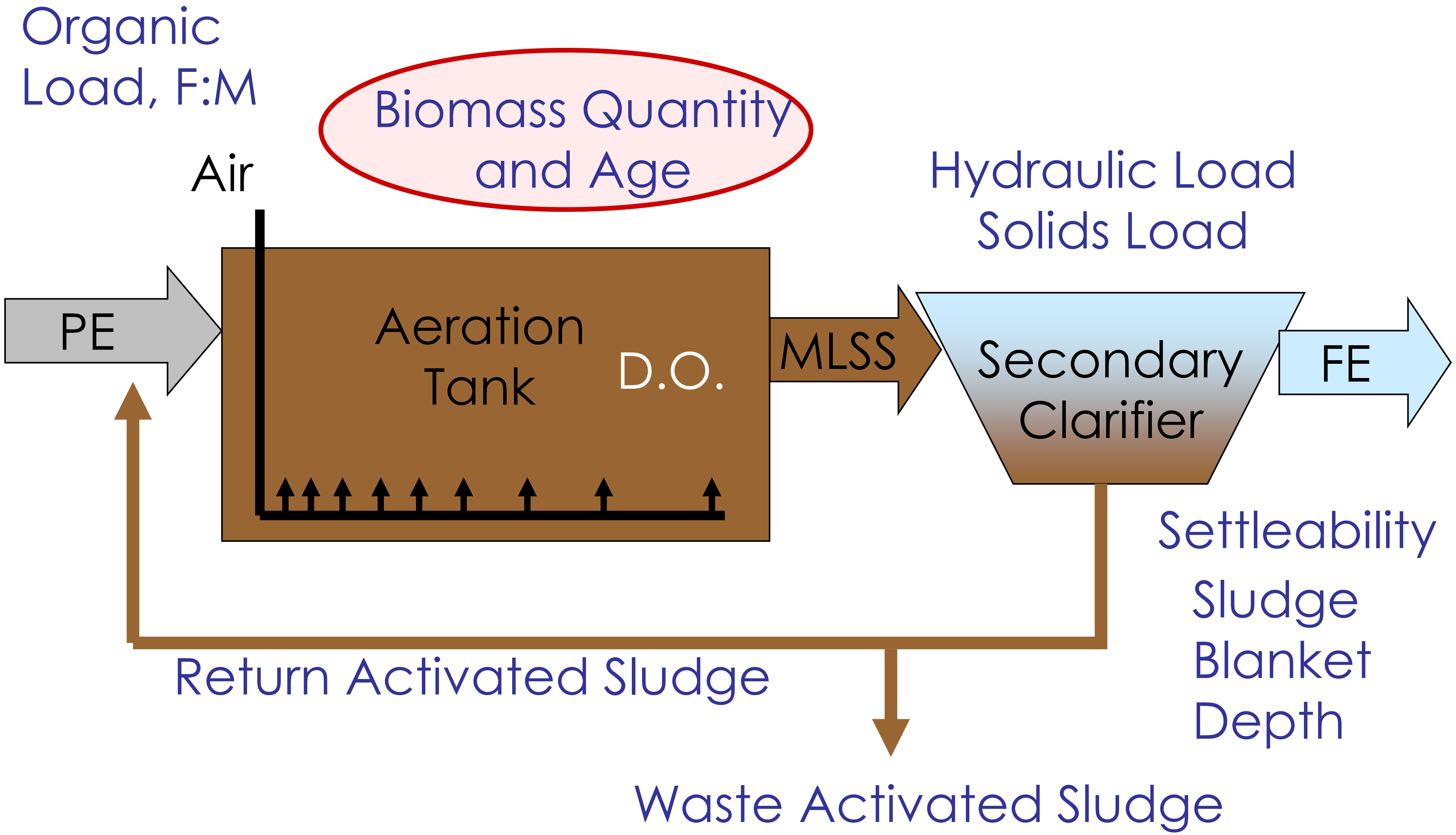
Can you Calculate the Kgs of MLVSS Needed for a Specific F/M

What Concentration That Would Be in an Aeration Tank?

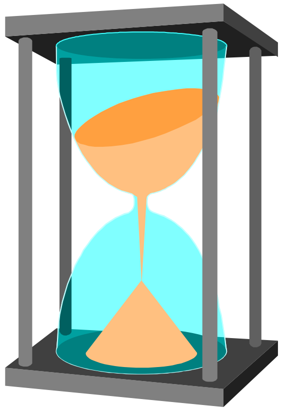


Prove It !

Control Factors - Biomass Quantity and Age



Control Factors - Biomass Quantity and Age



Cell Residence Time, CRT
Mean Cell Residence Time, MCRT
Sludge Age, SA

Biomass Age

The Average Length of Time in Days that an Organism Remains in the Secondary Treatment System

$$\text{SA, days} = \frac{\text{Suspended Solids in Aerator, kgs}}{\text{Suspended Solids in PE, kgs/day}}$$

$$\text{MCRT} = \frac{\text{Total MLVSS, kgs (Aerator + Clarifier)}}{\text{Total MLVSS Wasted + Effluent TSS, kgs/d}}$$

The SA and MCRT Calculations are Seldom Used
The Most Common (and Best for Most Processes) Is the Cell Residence Time

Control Factors - Biomass Quantity and Age

Young Sludge

- Start-up or High BOD Load
- Few Established Cells
- Log Growth
- High F:M
- Low CRT

White
Billowing
Foam

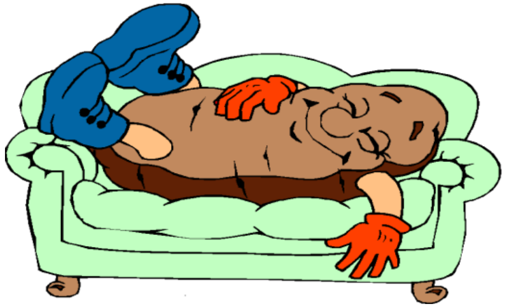
High O_2
Uptake Rate

Poor Flocculation
Poor Settleability
Turbid Effluent

Control Factors - Biomass Quantity and Age

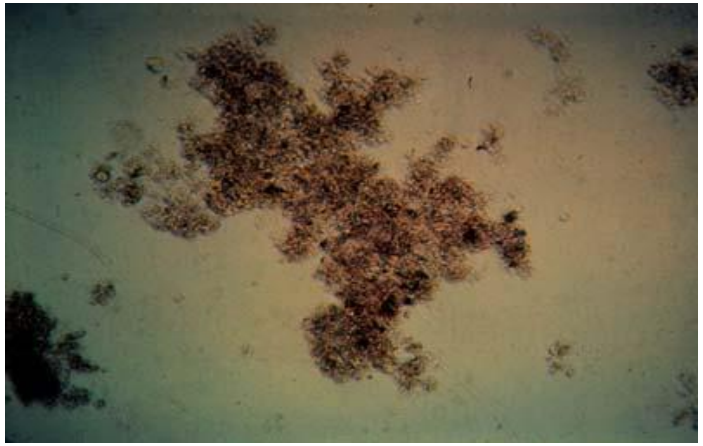
Old Sludge

- ❑ Slow Metabolism
- ❑ Decreased Food Intake
- ❑ Low Cell Production
- ❑ Oxidation of Stored Food
- ❑ Endogenous Respiration
- ❑ Low F:M
- ❑ High CRT
- ❑ High MLSS

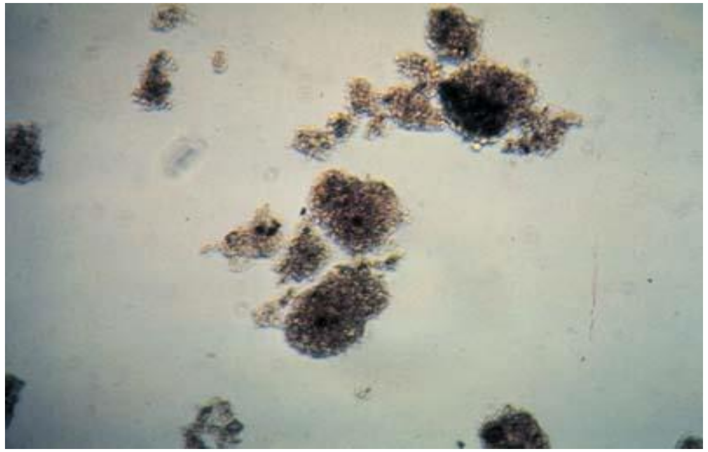


Dense, Compact Floc

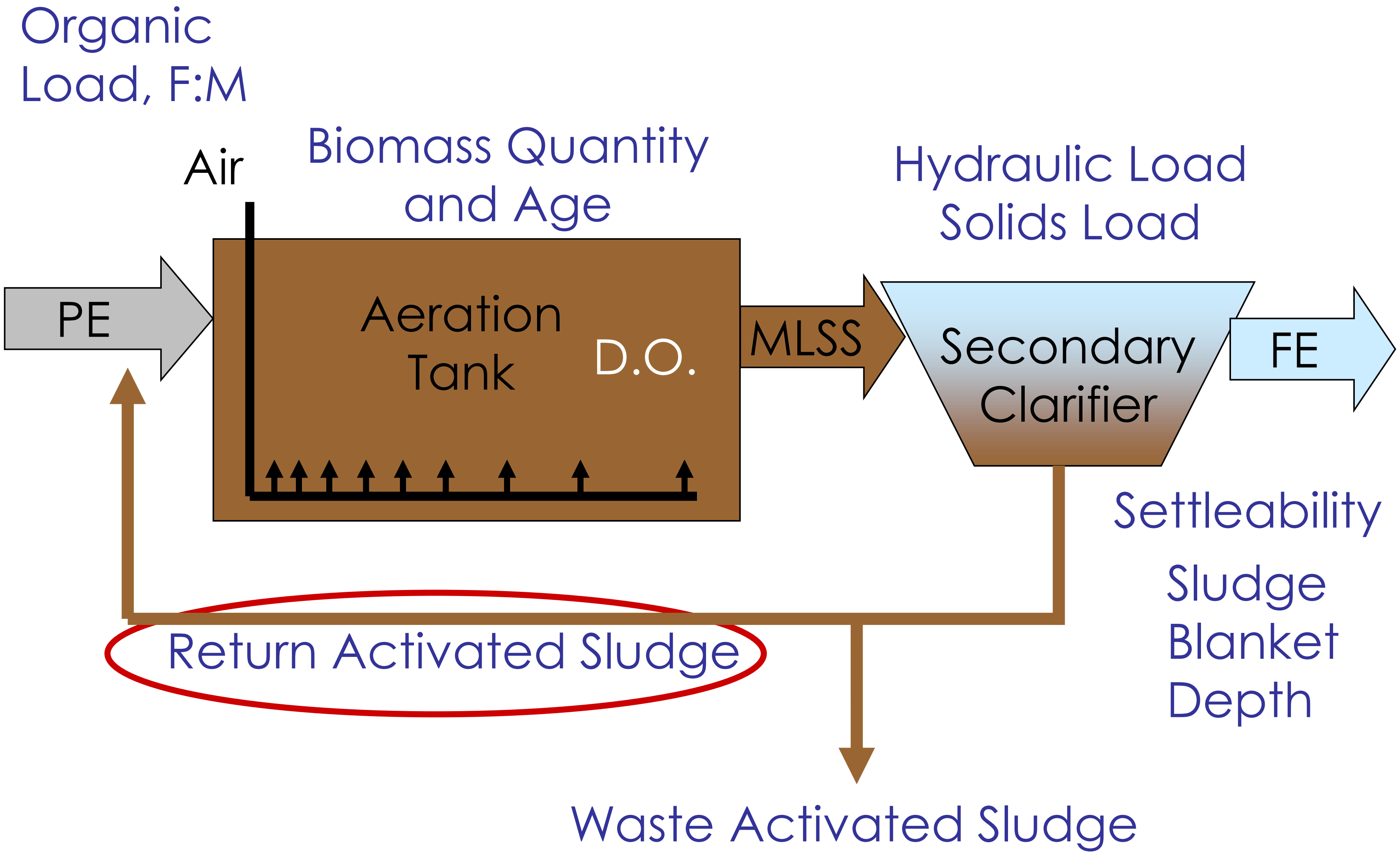
Fast Settling



Straggler Floc



Control Factors - Return Activated Sludge



Control Factors - Return Activated Sludge

Biological Solids (Mixed Liquor Solids) which have settled in the secondary clarifier, continuously returned to the aeration system.

Why:

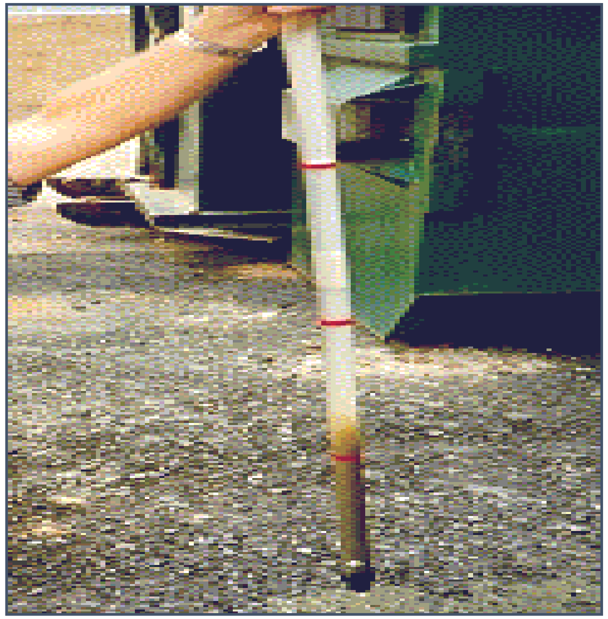
- Control sludge blanket in clarifier
- Maintain a sufficient population of active organisms in service

Control Factors - Return Activated Sludge

- Consistent Flow Rate
- % Influent Flow
- RAS Metering

- 1 – 3 Feet Depth
- Too Much – Solids Over Weir
- Too Little – Thin RAS Concentration

  (More Volume When Wasting)



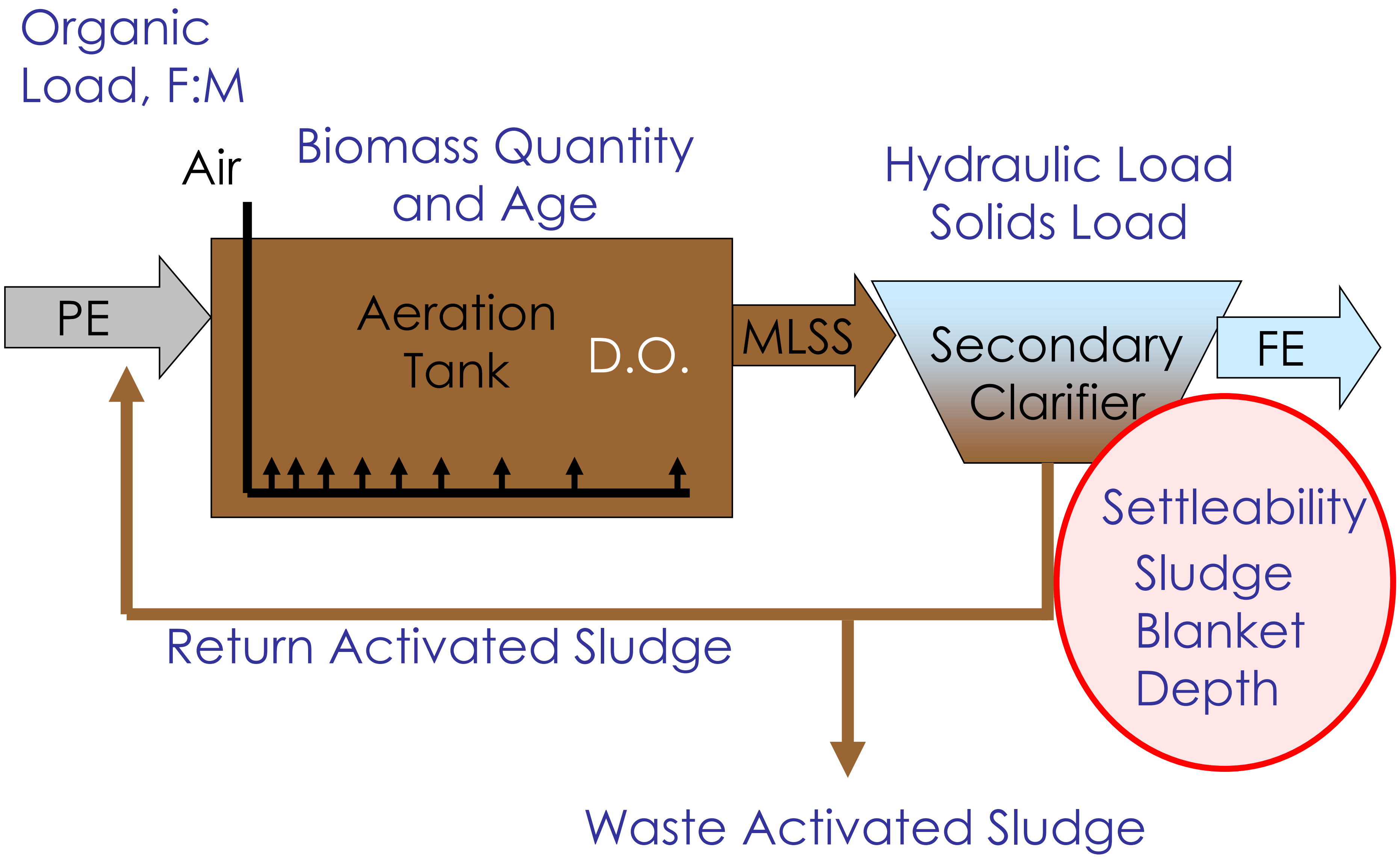
Setting the RAS Rate

How Much is Enough
(or Too Much)

Sludge Blanket Depth

Sludge Judging

Control Factors - Settleability



Settleometer Test

Collect Sample
Below Scum Line

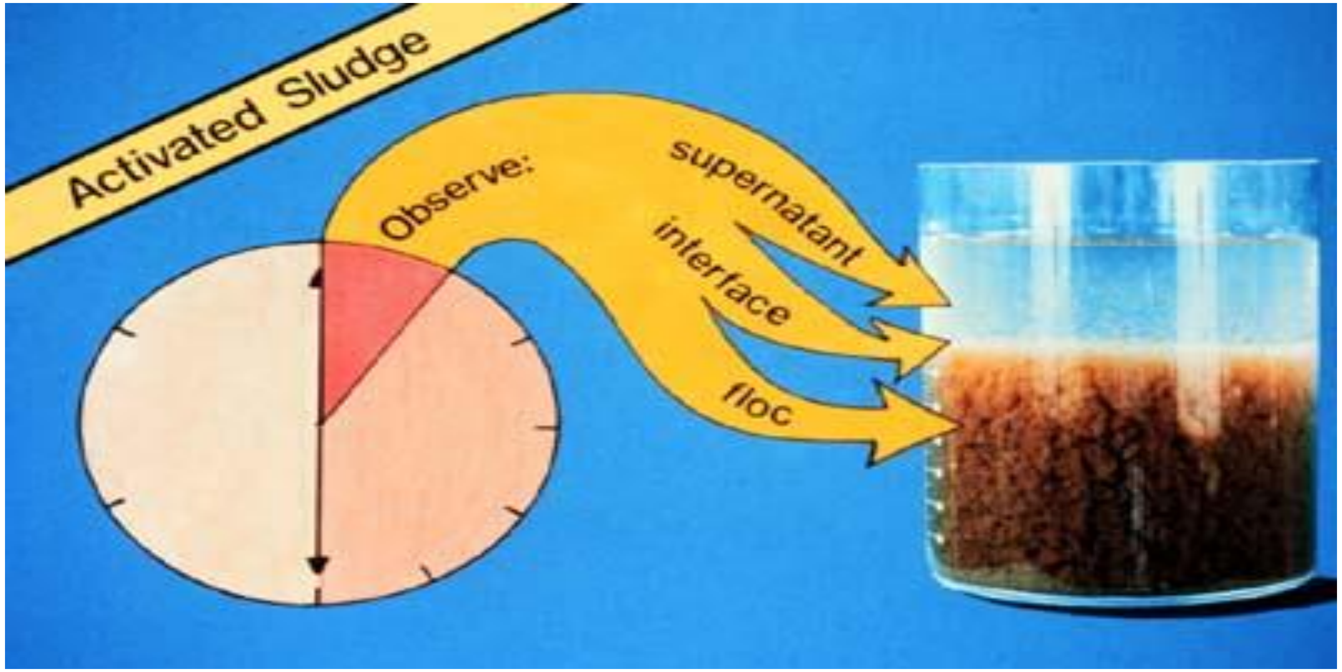
Set up Settling
Test Immediately

Also Determine MLSS, mg/L on a Portion of Same Sample

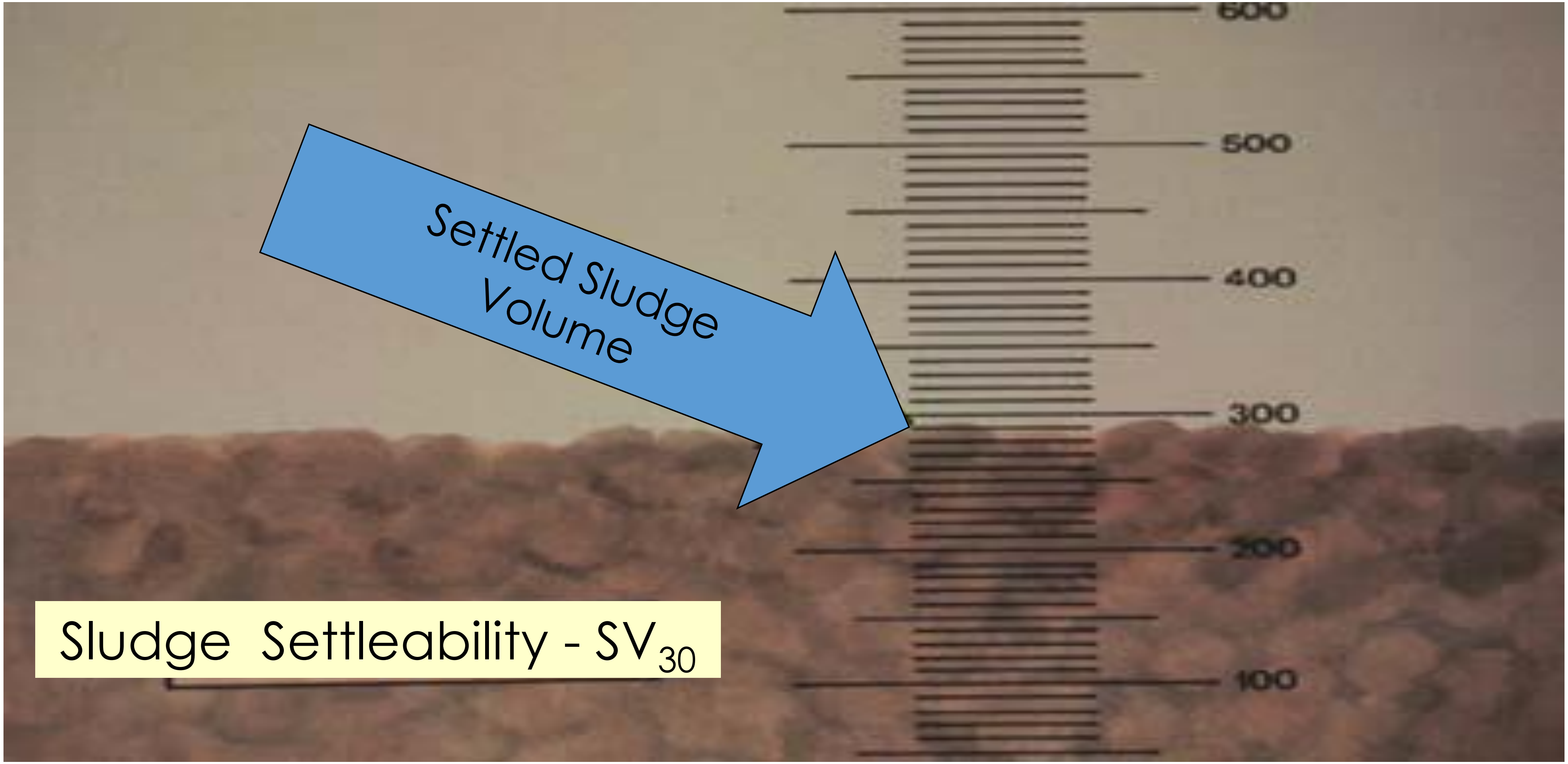
While Settling Observe:

Color of ML and Supernatant
Supernatant Turbidity
Straggler Floc

Record Settled Sludge Volume Every 5 Minutes for 30 Minutes



Control Factors - Settleability



Control Factors - Settleability

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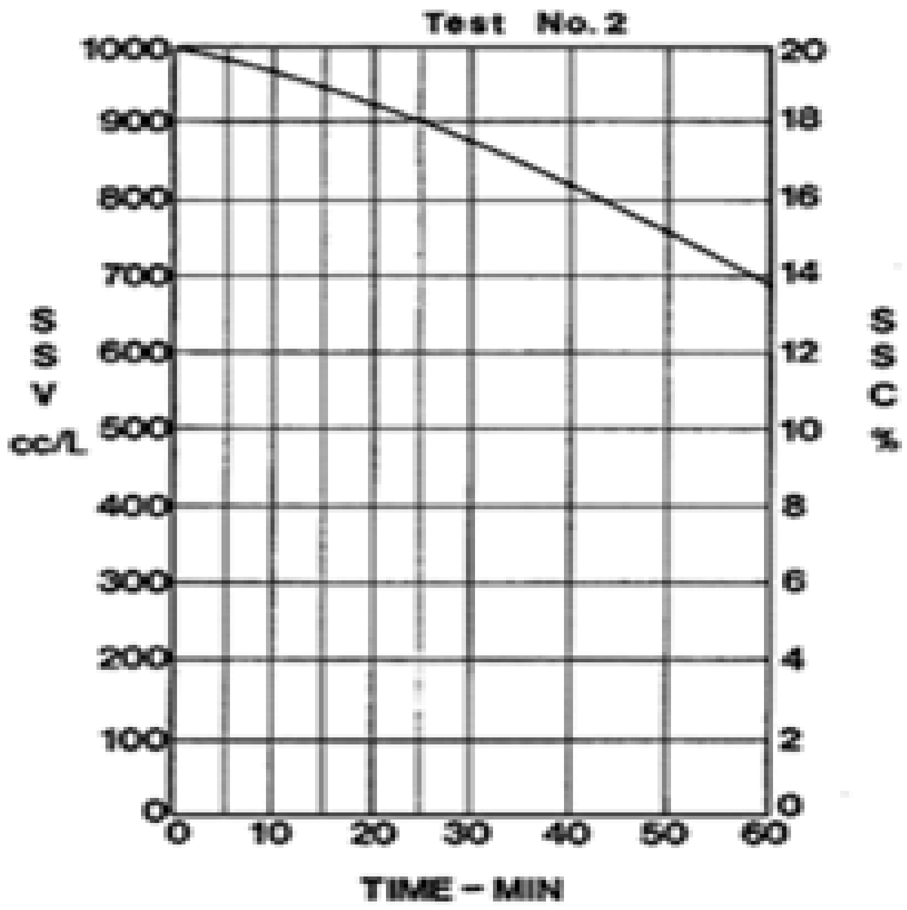
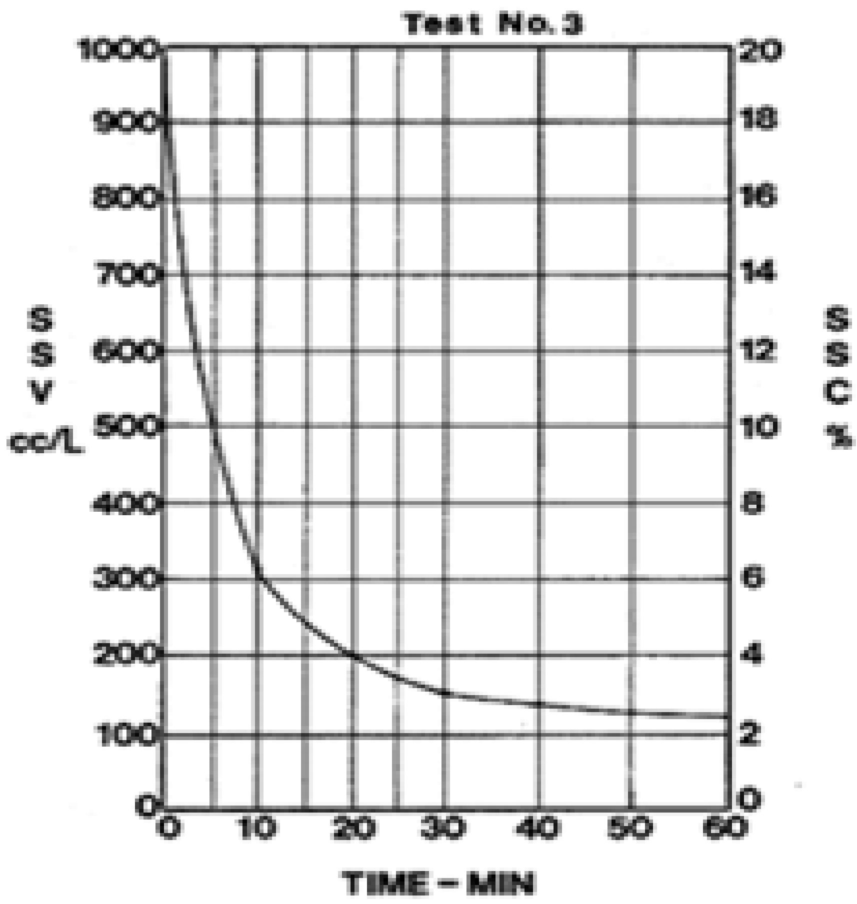


Not Compacting (Bulking)

Solids Washed Out
in High Flows



Indication of “Old” Sludge

Leaves Straggler Floc
in Effluent

Control Factors - Settleability

Sludge Volume Index (SVI)

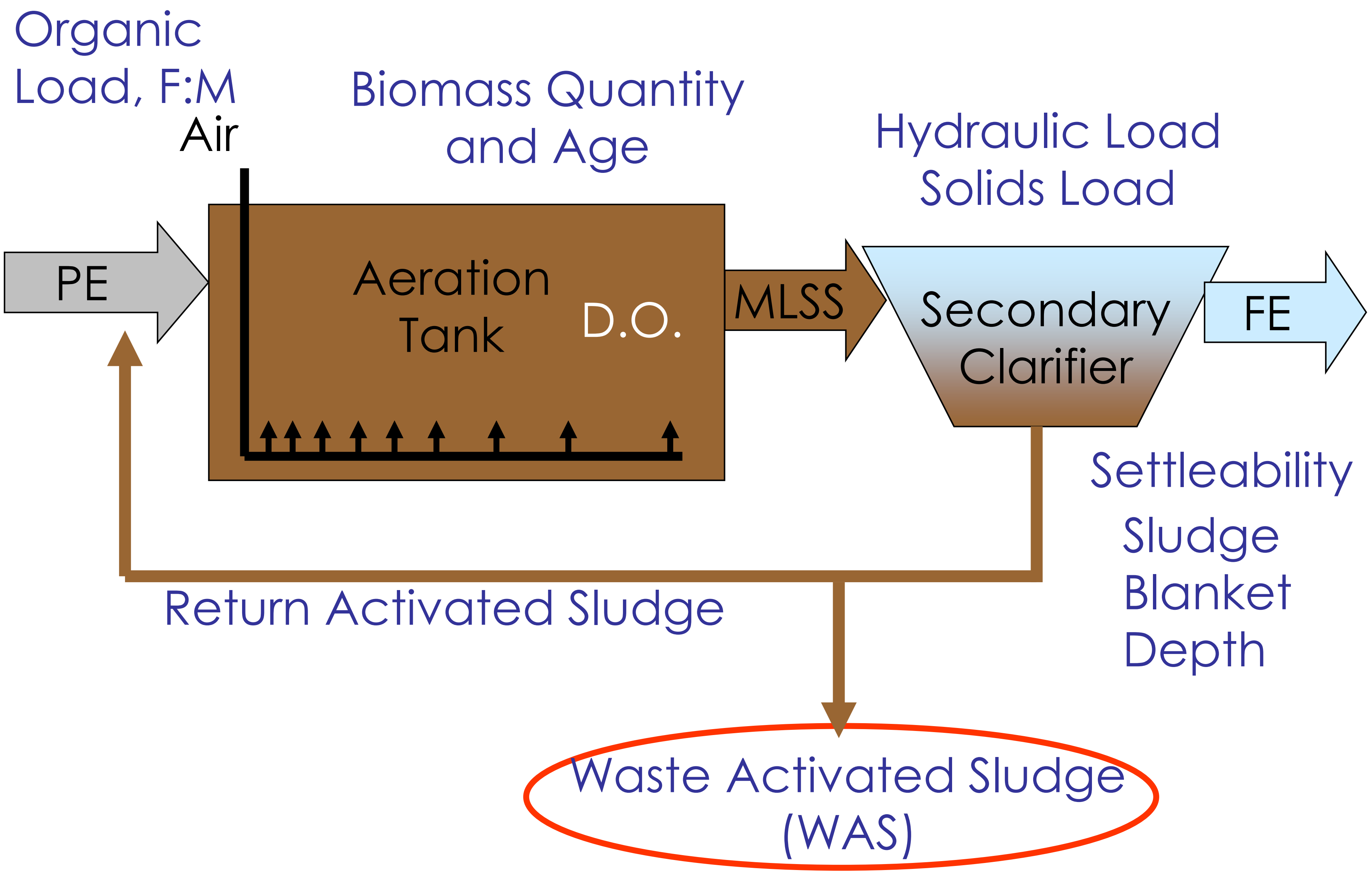
The volume in milliliters occupied by one gram of activated sludge which has settled for 30 min.

$$SVI = \frac{\text{mLs Settled in 30 min}}{\text{MLSS Conc, grams/L}} = \frac{SV_{30}\ \text{(mL Settled)}}{\dfrac{\text{MLSS, mg/L}}{1000}}$$

Typical Range for Good Settling 80 - 120

The higher the number, the less compact the sludge

Control Factors - Waste Activated Sludge



Growth Rate

Yield Coefficient (Y)

Y = Kgs of Biological Solids Produced
Per Kgs of COD Removed

How to Determine Y for a Facility?

Use Monthly Average of Kgs of Solids Wasted
Divided by
the Monthly Average of Kgs of COD Removed

Should be Monitored Regularly (Monthly) – **0.49** kg of SS/ kg of COD removed

Major Troubleshooting

Stiff, White Foam

- Activated sludge is not returned to the biological reactor;
- MLSS is low because the process is being started up;
- MLSS is low because of excessive sludge wasting or a high organic load from an industry (typically occurs after low-load periods, such as weekends and early mornings);
- Operations conditions are unfavorable (toxic or inhibiting materials are present, pH is less than 6.5 or more than 9.0, dissolved oxygen or nutrient concentrations are too low, or seasonal temperature changes have reduced microorganism activity and growth);
- Secondary clarifier effluent loses biomass unintentionally because of excessive (shock) hydraulic loads or biological upset;
- A high sludge blanket in the secondary clarifier because of leaking seals or open dewatering valves; or
- Wastewater or RAS is improperly distributed among multiple biological reactors.

Major Troubleshooting

Excessive Brown Foam

- The F : M ratio is low because of nitrification and denitrification;
- The MLSS concentration is high because of insufficient sludge wasting (can happen unintentionally when seasonal temperature changes increase microorganism activity and, therefore, sludge production);
- Sludge is re-aerated (especially if the F : M ratio is low); or
- The wasting controls are insufficient.

Very Dark & Black Foam

- Increase aeration;
- Investigate industrial waste sources for dyes or inks; and
- Reduce the MLSS concentration.

Major Troubleshooting

Bulking Sludge

- Add nutrients, such as nitrogen, phosphorus, and iron;
- Raise the dissolved oxygen concentration in the biological reactor; or
- Correct the pH (either raise or stabilize it).

Major Troubleshooting

Nitrification & Denitrification Facilities

Observations	Solutions
BOD < 25 mg/L, NH_4-N > 3 mg/L	Ensure MCRT is sufficient for design temperature
Effluent NH_4-N varies erratically, > 3 mg/L and < 2 mg/L, in a short period of time	Waste sludge operation not stabilized, stop wasting until NH_4-N is < 2 mg/L for 3 consecutive days; restart a careful sludge-wasting operation
Effluent NH_4-N > 3 mg/L, dark brown or black MLSS	Check aeration zone DO, should be > 2 mg/L; check MLSS solids balance; MCRT may be too high
Brown clumps of sludge floating on final clarifier surface; effluent NH_4-N < 2 mg/L, BOD < 30 mg/L	Nitrogen gas bubbles being produced in stagnant sludge in clarifier; check return sludge recycle rate, increase frequency of cleaning of clarifier walls and weirs
Effluent NH_4-N > 10 mg/L, BOD > 25 mg/L	Check MCRT, check mixed liquor DO, check MLSS; if all appear satisfactory, plant may be receiving inhibitor of of nitrification from industry; check pretreatment program
Effluent NO_3-N > 7 mg/L, NH_4-N < 2 mg/L	DO in anoxic zone, should be less than 0.2 mg/L

Major Troubleshooting

Phosphorous Removal Facilities

Observations	Solutions
Effluent SP > 1 mg/L, TP > 2 mg/L, BOD < 20 mg/L	Ensure DO in anaerobic zone is < 0.2 mg/L, NO_3-N in anaerobic zone is < 5 mg/L
Effluent SP < 1 mg/L, TP > 2 mg/L, BOD < 25 mg/L, SS > 30 mg/L	Check SS frequently, use polymer or metal salt to control SS; find reason for high SS, such as high flow rates, high return sludge recycle rate, or bulking
Effluent SP < 0.2 mg/L, TP < 1 mg/L, BOD > 30 mg/L	Plant may be organically overloaded; check F:M ratio
Effluent SP > 1 mg/L, TP > 2 mg/L, BOD < 15 mg/L	May not be enough low molecular weight acids in anaerobic zone; consider adding anaerobic digester supernatant to this zone
Thin-looking MLSS, effluent TP > 2 mg/L, BOD < 30 mg/L	Sludge may be forming a blanket in secondary clarifier, check sludge blanket depth, adjust recycle rate if necessary
Effluent TP > 2 mg/L, BOD < 25 mg/L, SS < 25 mg/L	Start or increase dose of metal salt to assist in precipitating TP

Major Troubleshooting

Nitrogen & Phosphorus Removal Facilities

Observations	Solutions
Effluent TP < 2 mg/L, NH_4-N < 2 mg/L, NO_3-N > 7 mg/L	Check recirculation rate between aerobic zone and anoxic zone, increase rate if necessary; check DO in anoxic zone, should be < 0.2 mg/L
Effluent TP < 2 mg/L, NH_4-N < 2 mg/L, NO_3-N < 2 mg/L, BOD > 30 mg/L	Check feed rate of optional chemical dosing pump for adding organics to second anoxic zone
Effluent TP < 2 mg/L, NH_4-N > 3 mg/L, NO_3-N < 5 mg/L, BOD < 25 mg/L	Check DO in aerobic zone, should be > 2 mg/L