OLVER ASSOCIATES INC.
ENVIRONMENTAL ENGINEERS
290 MAIN STREET WINTERPORT, MAINE

ACTIVATED SLUDGE 101…. and then some

PRESENTED TO:

UNITED SOUTH & EASTERN TRIBES (USET) UTILITY SUMMIT
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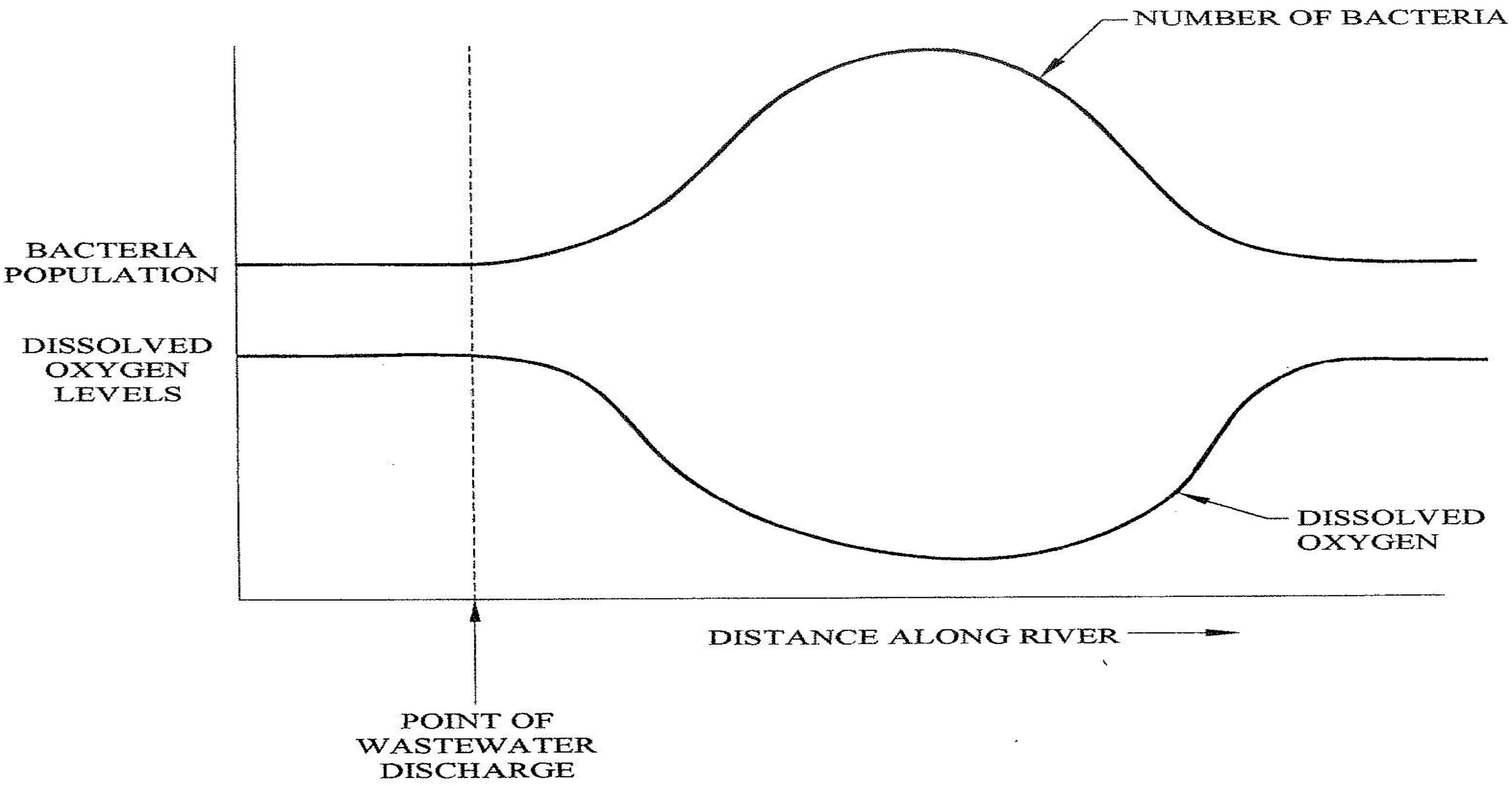
Surface Waters Previously Served As Receiving Waters For Raw Wastewater and Stormwater Discharges

Effects of Wastewater Discharge

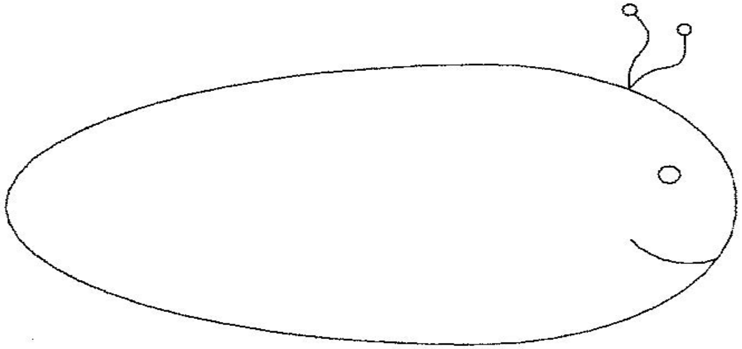
- Discharge of organic wastes causes surge in bacteria population.
- Increased bacteria cause increased oxygen depletion.



What is Significance of Biodegradable Organic Volatile Solids?

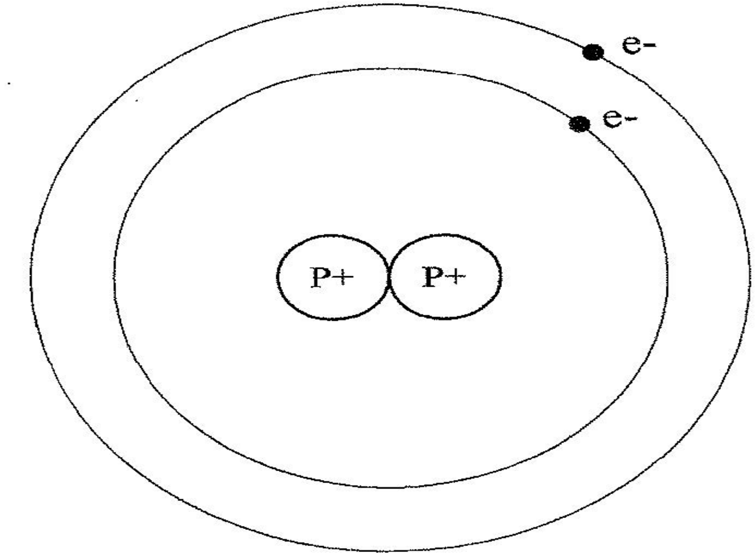
- Naturally occurring bacteria utilize biodegradable organic solids as food source.

- Typical bacterial cell.



FORMULA = $C_5H_7O_2NP$

How Do Bacteria Obtain Energy?



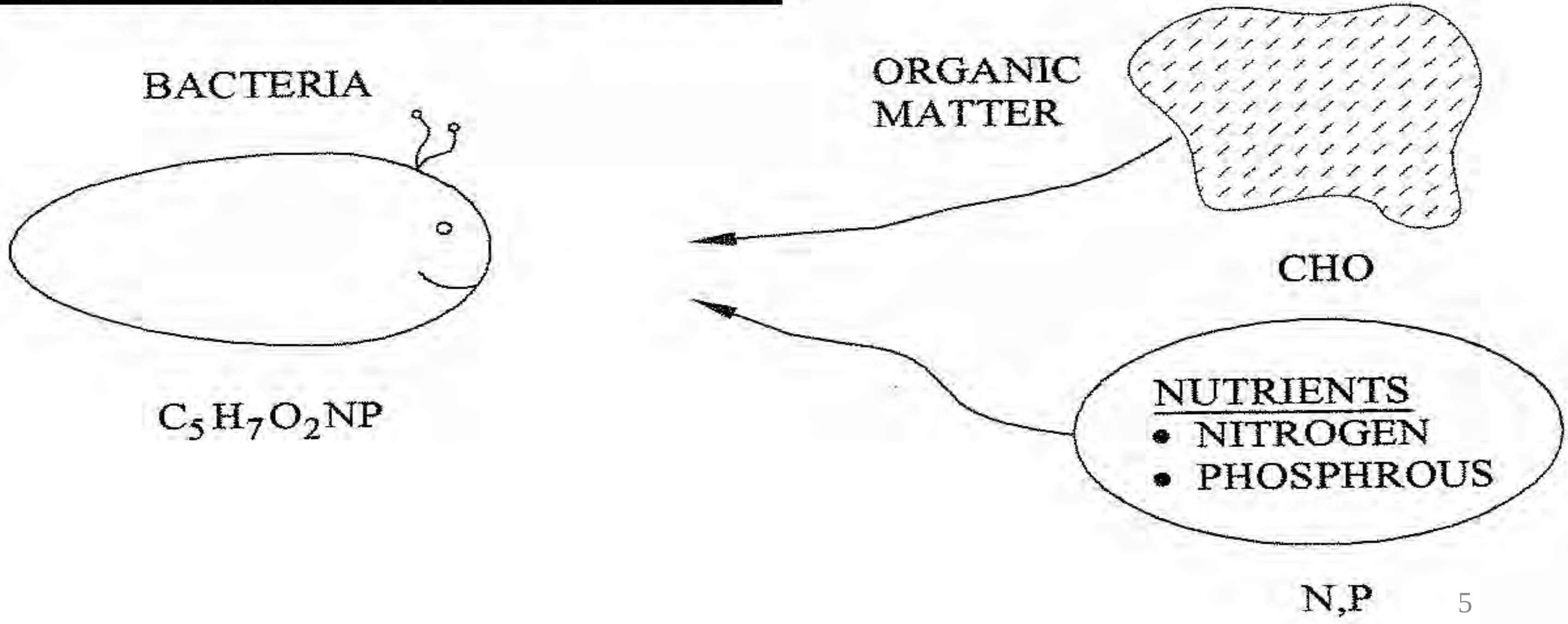
- All matter is made up of atoms.
- Atoms contain positively charged (+) center with protons.
- Atoms contain negatively charged (-) outer rings of electrons that circle protons.
- Energy is released by transfer of electrons from one compound to another during biodegradation.

Overall Microbial Biodegradation Reactions

Bacteria + Biodegradable Organics + Nutrients + Electron Acceptor

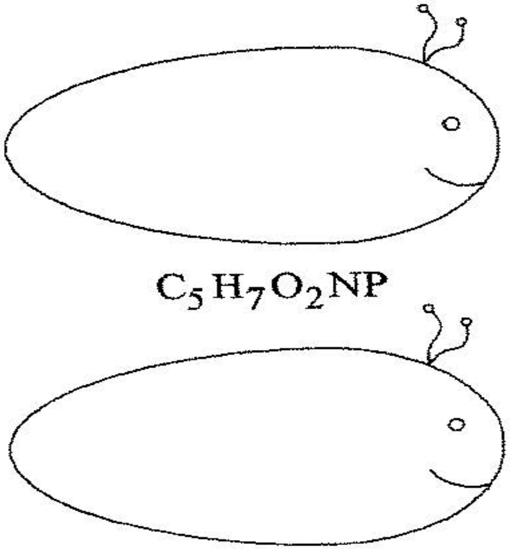
⟶ New Bacteria Cells + By-Products

If these components are present:



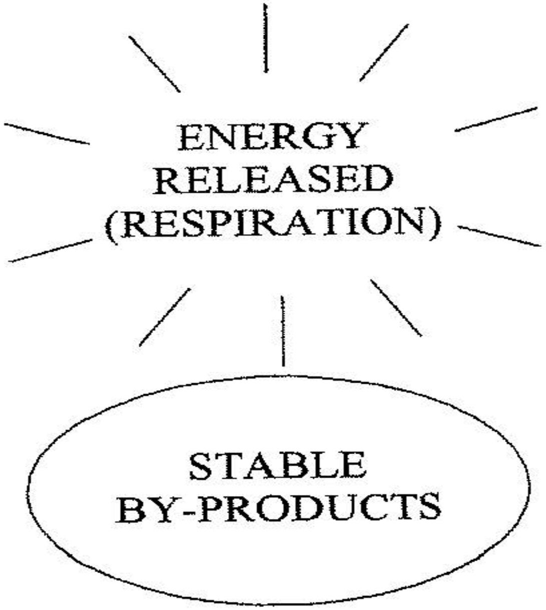
Overall Microbial Biodegradation Reactions

These results will occur:

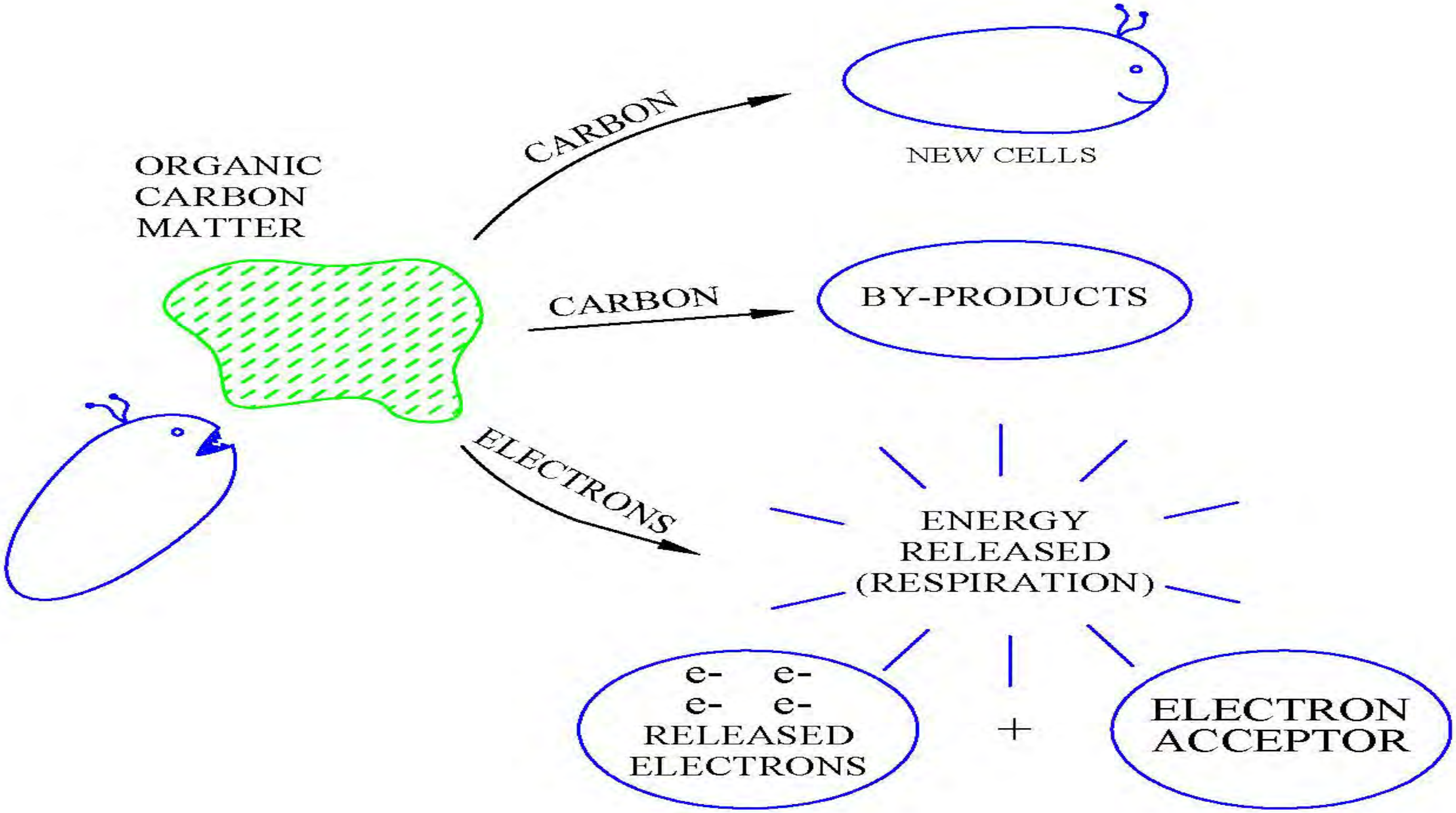


$C_5H_7O_2NP$

NEW CELLS MADE OF CARBON (SYNTHESIS)



What Is The Role of Electron Acceptors?



Different Compounds Can Serve As Electron Acceptors:

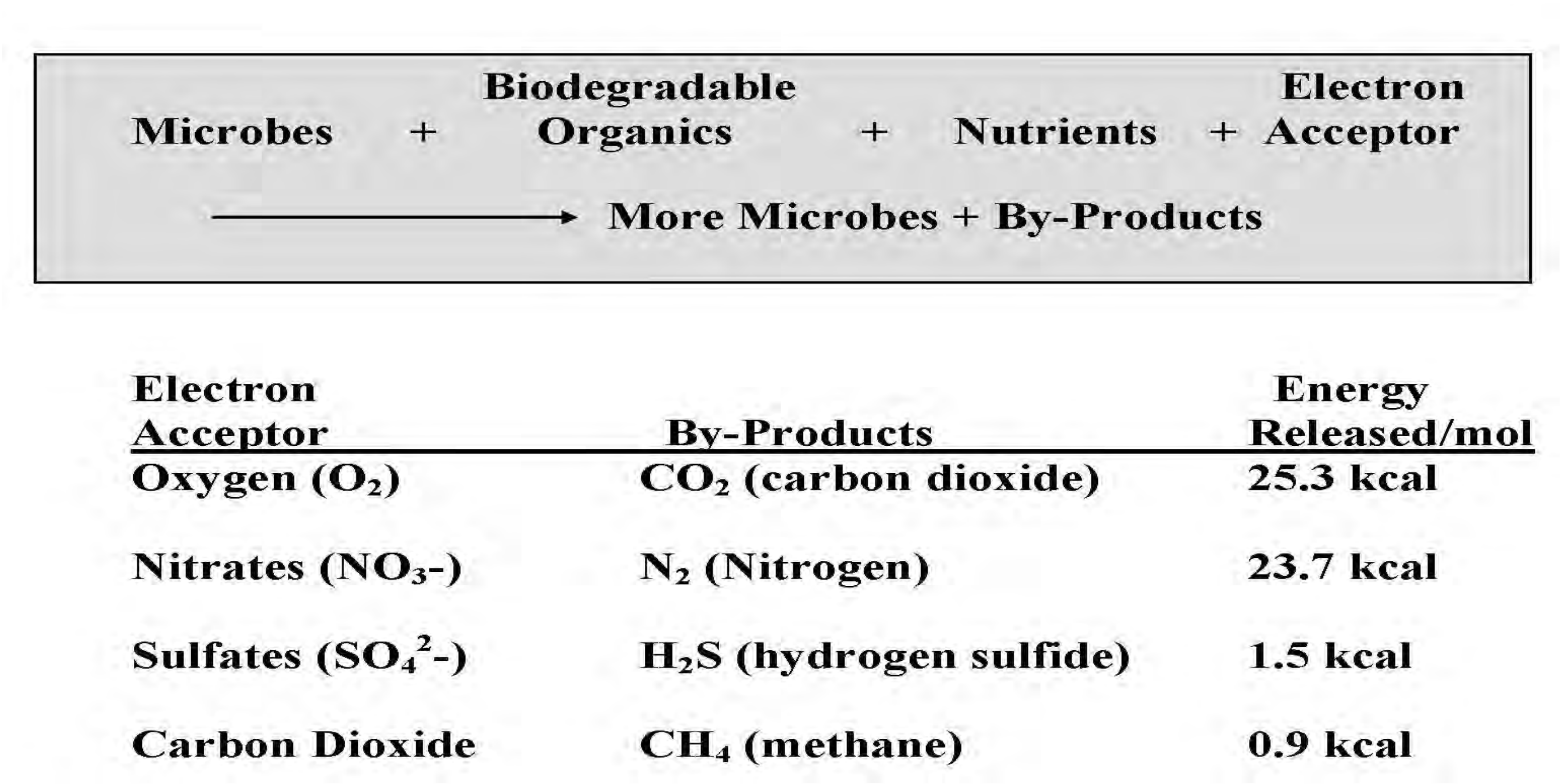
- Typical electron acceptors:

    - Oxygen
    - Nitrate
    - Sulfate
    - Carbon dioxide

- Some electron acceptors give off more energy than others.

- Different by-products are formed depending on which electron acceptor is used.

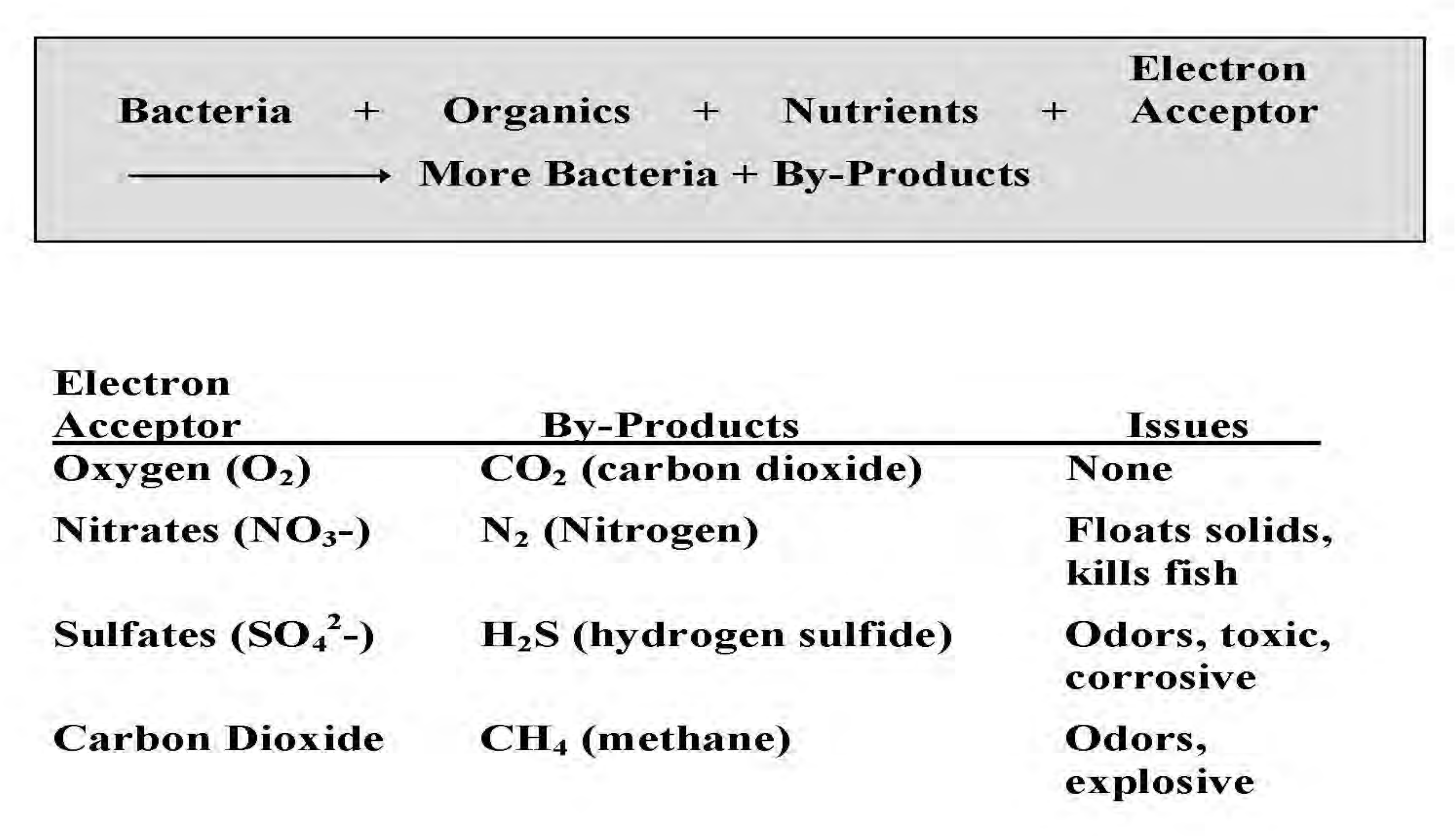
Potential Biodegradation Reactions



Microbes + Biodegradable Organics + Nutrients + Electron Acceptor $\longrightarrow$ More Microbes + By-Products

Electron Acceptor	By-Products	Energy Released/mol
Oxygen (O_2)	CO_2 (carbon dioxide)	25.3 kcal
Nitrates (NO_3-)	N_2 (Nitrogen)	23.7 kcal
Sulfates (SO_4^2-)	H_2S (hydrogen sulfide)	1.5 kcal
Carbon Dioxide	CH_4 (methane)	0.9 kcal

Some By-Products Have Adverse Environmental Effects



Bacteria + Organics + Nutrients + Electron Acceptor

→ More Bacteria + By-Products

Electron Acceptor	By-Products	Issues
Oxygen (O_2)	CO_2 (carbon dioxide)	None
Nitrates (NO_3-)	N_2 (Nitrogen)	Floats solids, kills fish
Sulfates (SO_4^{2}-)	H_2S (hydrogen sulfide)	Odors, toxic, corrosive
Carbon Dioxide	CH_4 (methane)	Odors, explosive

Oxygen Is the Electron Acceptor of Choice

- **Highest energy yield to bacteria.**
- **Fastest biodegradation reaction rate.**

Excessive organic loads to rivers are a concern because:

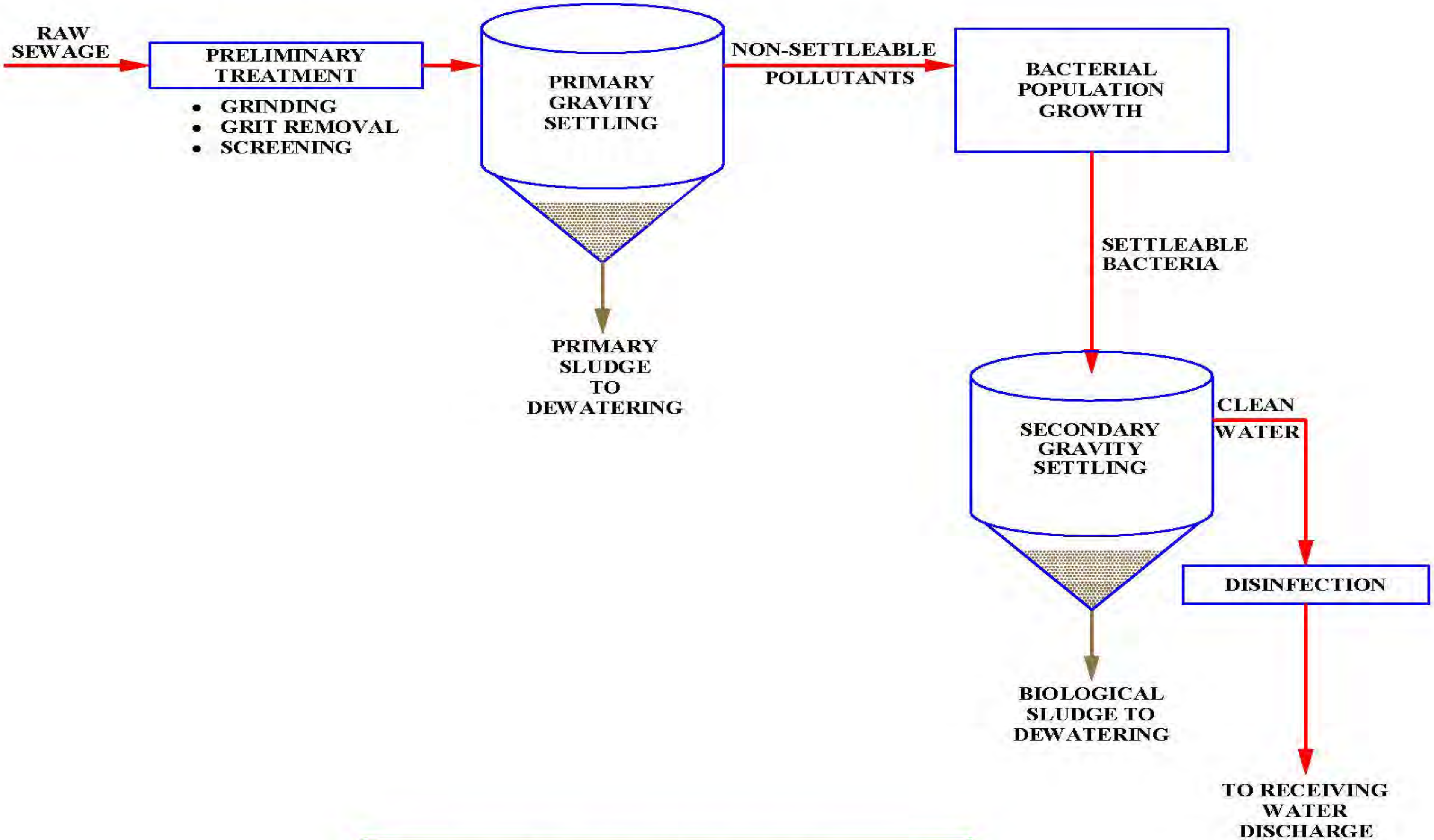
- **Bacteria will use up oxygen first as they biodegrade organic wastes.**
- **Depletion of dissolved oxygen may result.**
- **Fish kills occur at D.O. < 5.0 mg/l.**
- **Septic conditions (anaerobic) occur at D.O. <0.0 mg/l.**
- **Undesirable by-product formation occurs with septic electron acceptors.**

Major Goals of Conventional Wastewater Treatment

1. **Maintain aerobic conditions in river by removing organics that would otherwise cause oxygen depletion during bacterial stabilization.**

2. **Improve water quality by disinfection, pH control, turbidity removal, etc.**

All Wastewater Treatment Plants Utilize Similar Process Principles



RAW SEWAGE

PRELIMINARY TREATMENT

- GRINDING
- GRIT REMOVAL
- SCREENING

PRIMARY GRAVITY SETTLING

PRIMARY SLUDGE TO DEWATERING

NON-SETTLEABLE POLLUTANTS

BACTERIAL POPULATION GROWTH

SETTLEABLE BACTERIA

SECONDARY GRAVITY SETTLING

BIOLOGICAL SLUDGE TO DEWATERING

CLEAN WATER

DISINFECTION

TO RECEIVING WATER DISCHARGE

BACTERIA + SEWAGE + OXYGEN + NUTRIENTS $\xrightarrow{\text{YIELDS}}$ MORE BACTERIA + CARBON DIOXIDE

SEAL HARBOR WASTEWATER TREATMENT PLANT

PLEASANT POINT WASTEWATER TREATMENT PLANT

WASHBURN WASTEWATER TREATMENT PLANT

CORINNA WASTEWATER TREATMENT PLANT

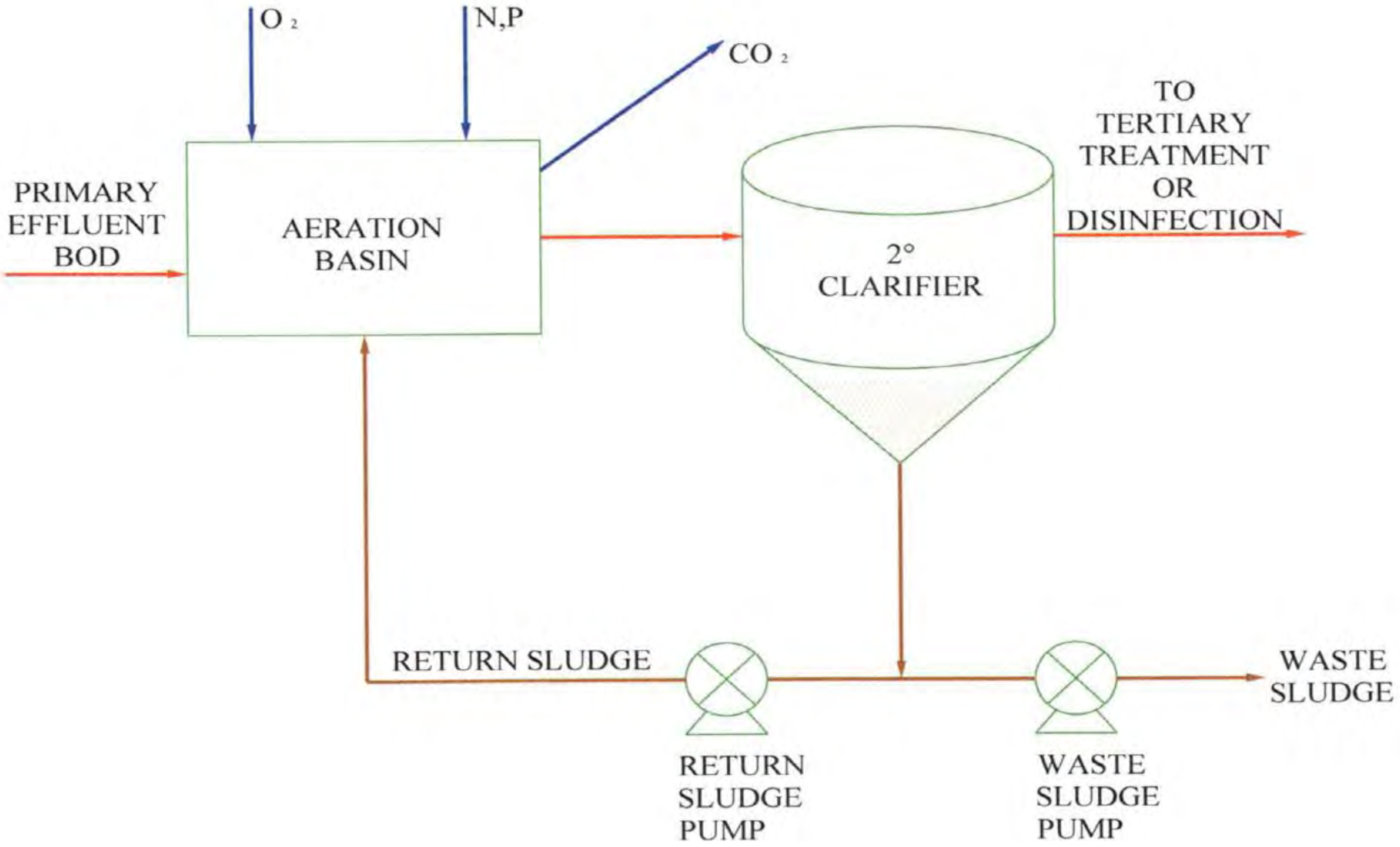
Trickling Filters Utilize Fixed Film Approach

- **Microbes grown on rock, wood, or plastic media.**
- **BOD trickled down through media.**

Rotating Biological Contactors (RBC) Also Utilize Fixed Film Processes

- **Media attached to shaft rotates through tank of wastewater.**
- **Microbes feed when submerged.**
- **Microbes are aerated at surface.**

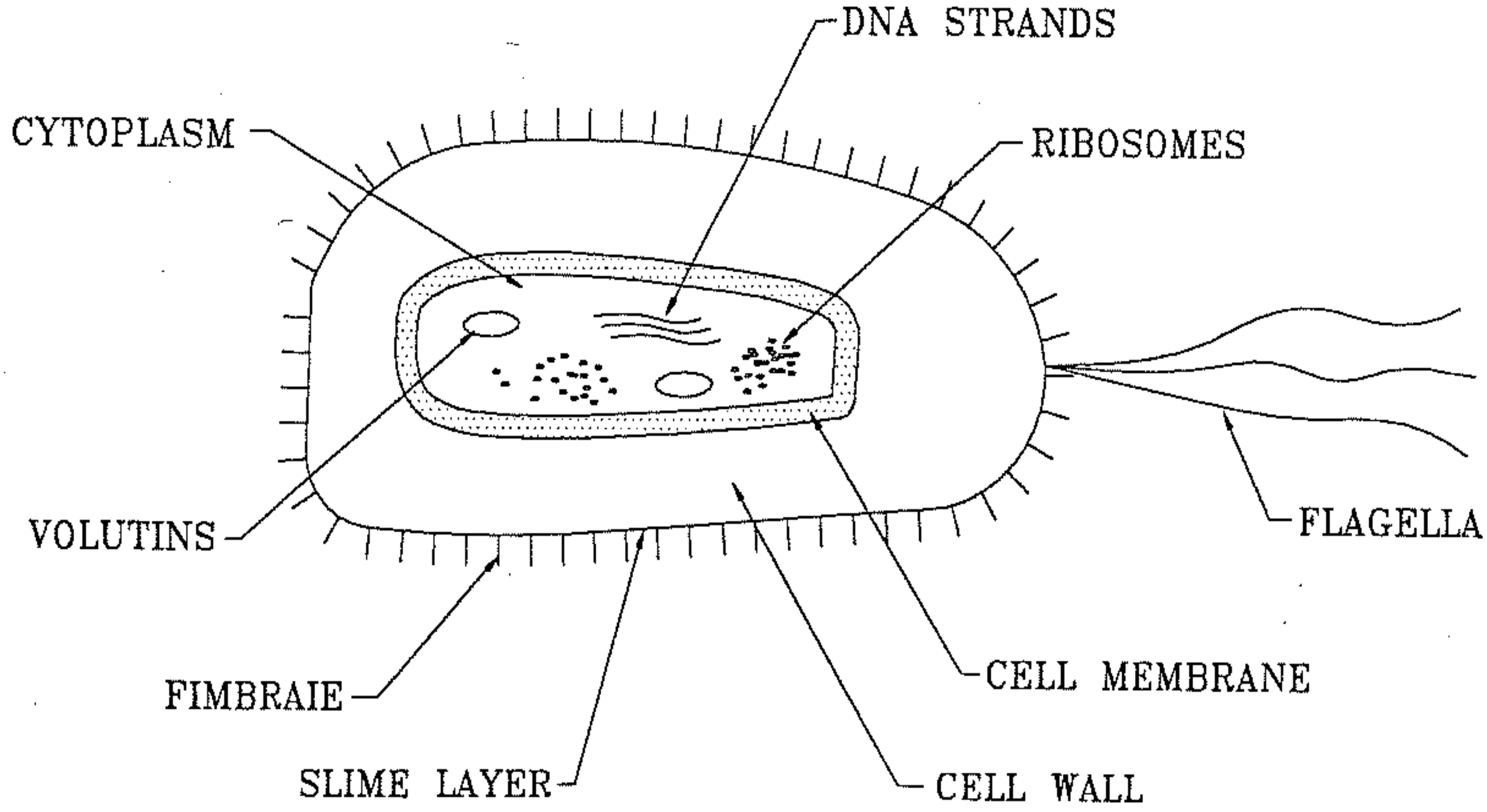
Activated Sludge Process – Most Common Form of 2º Treatment



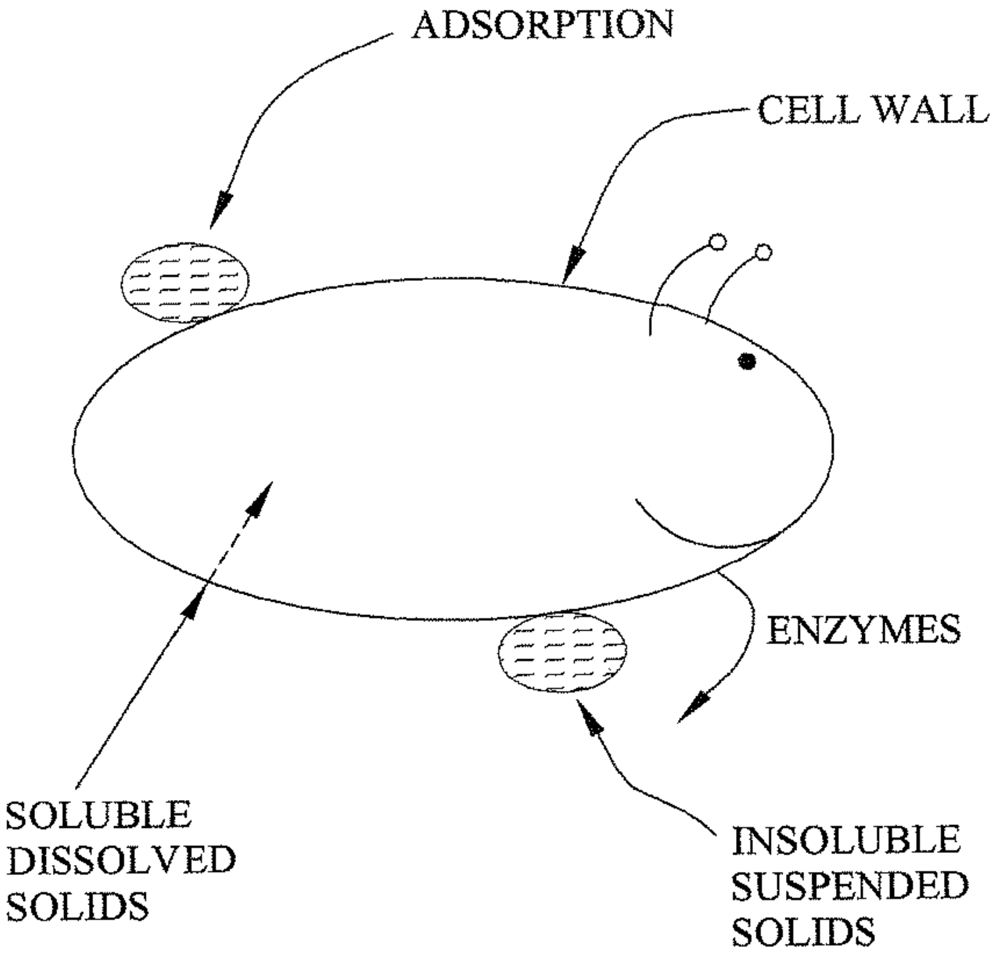
Four Parts to Activated Sludge Process

1. **Aeration Basin – Where bacteria grow to treat incoming wastes.**
2. **Final Clarifier – Where bacteria are settled to leave clean water behind.**
3. **Return Sludge Pump (RAS) – Allows settled bacteria to be recycled back to aeration basin from clarifier.**
4. **Waste Sludge Pump (WAS) – Periodically removes sludge to keep microbial population in balance.**

Bacteria Are Important Decomposers That Biodegrade Organics



How are Pollutants Removed in Reactors?



- **Some soluble dissolved solids can pass through cell wall rapidly by diffusion.**
- **Some insoluble solids must be solubilized by release of enzymes to allow pollutants to pass through cell walls.**
- **Some pollutants may be adsorbed onto cell wall and removed as bacteria settle.**

Microorganism Population Often Estimated By

- **Total TSS in aerator (mixed liquor suspended solids – MLSS).**
- **Total VSS in aerator (mixed liquor volatile suspended solids – MLVSS).**

Bacterial Growth Rates are Critical to Natural Biodegradation and Wastewater Treatment Processes

- Bacterial cells divide to form more cells.
- Rate of growth depends on:
    - - Availability of enzymes
    - - Accimilation to environment such that enzymes will be produced.
    - - Ratio of available food supply to microbial population (F/M).

$$\frac{F}{M} = \frac{\text{Mass of food (lbs)}}{\text{Mass of microbes (lbs)}}$$

Bacterial Growth Rates are Critical to Natural Biodegradation and Wastewater Treatment Processes

$$\frac{F}{M} = \text{Food/Microorganism Ratio}$$

$$= \frac{\text{BOD into reactor (lbs.)}}{\text{Microorganism mass in reactor (lbs.)}}$$

$$= \frac{\text{BOD (lbs)}}{\text{MLVSS (lbs)}}$$

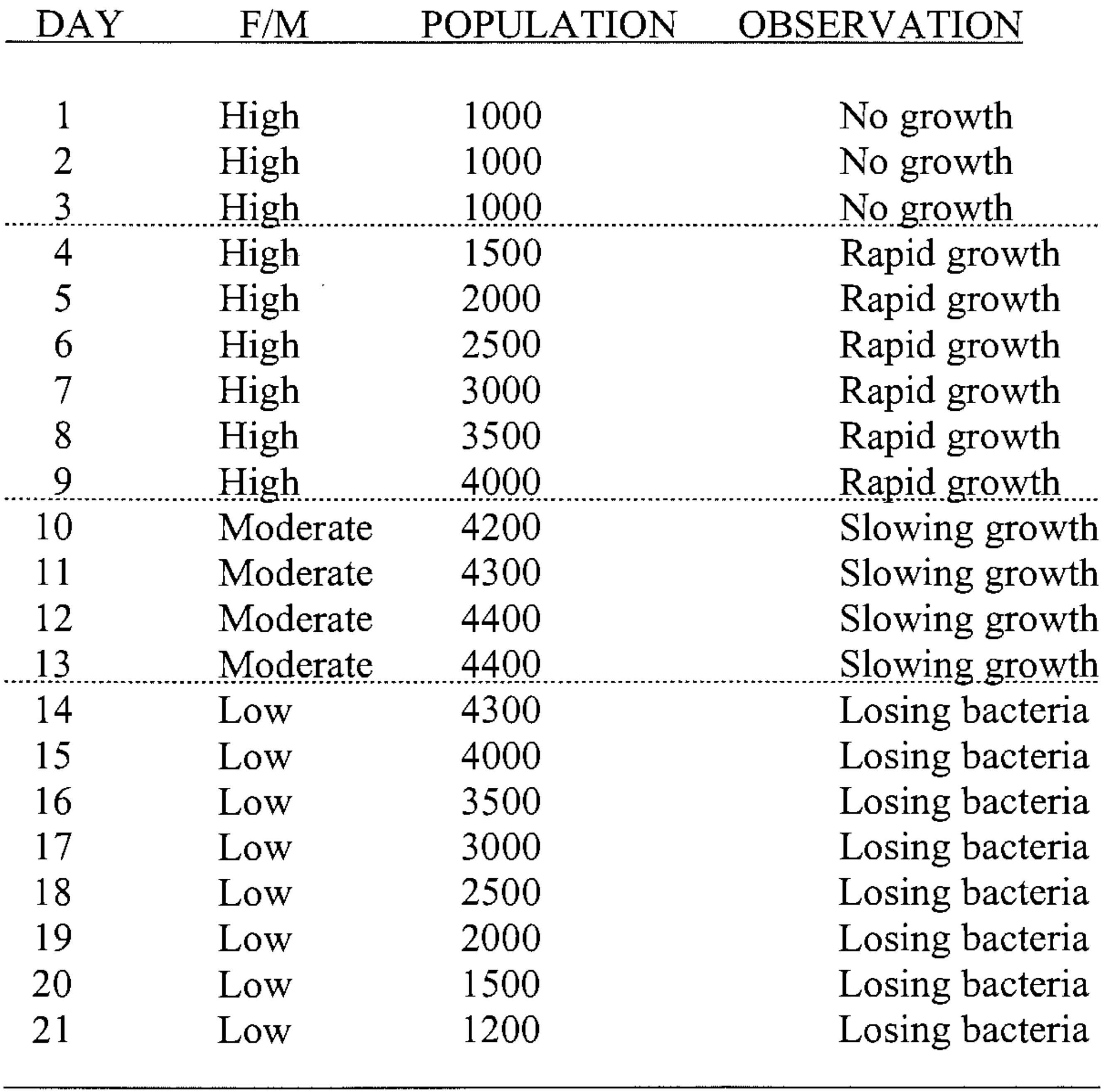
F/M Is A Key Factor In:

- **Bacteria growth rate.**
- **Development of slime layer.**
- **Ability of bacteria cells to flocculate and settle.**

Bacterial Growth Rates are Critical to Natural Biodegradation and Wastewater Treatment Processes

- **Suppose a 55 gallon drum was filled with wastewater, a packet of bacteria was added, and oxygen and nutrients were provided.**

- **If 1,000 colonies of bacteria were added on Day 1 and you measured the bacteria population each day for three weeks, what might be found?**



DAY	F/M	POPULATION	OBSERVATION
1	High	1000	No growth
2	High	1000	No growth
3	High	1000	No growth
4	High	1500	Rapid growth
5	High	2000	Rapid growth
6	High	2500	Rapid growth
7	High	3000	Rapid growth
8	High	3500	Rapid growth
9	High	4000	Rapid growth
10	Moderate	4200	Slowing growth
11	Moderate	4300	Slowing growth
12	Moderate	4400	Slowing growth
13	Moderate	4400	Slowing growth
14	Low	4300	Losing bacteria
15	Low	4000	Losing bacteria
16	Low	3500	Losing bacteria
17	Low	3000	Losing bacteria
18	Low	2500	Losing bacteria
19	Low	2000	Losing bacteria
20	Low	1500	Losing bacteria
21	Low	1200	Losing bacteria

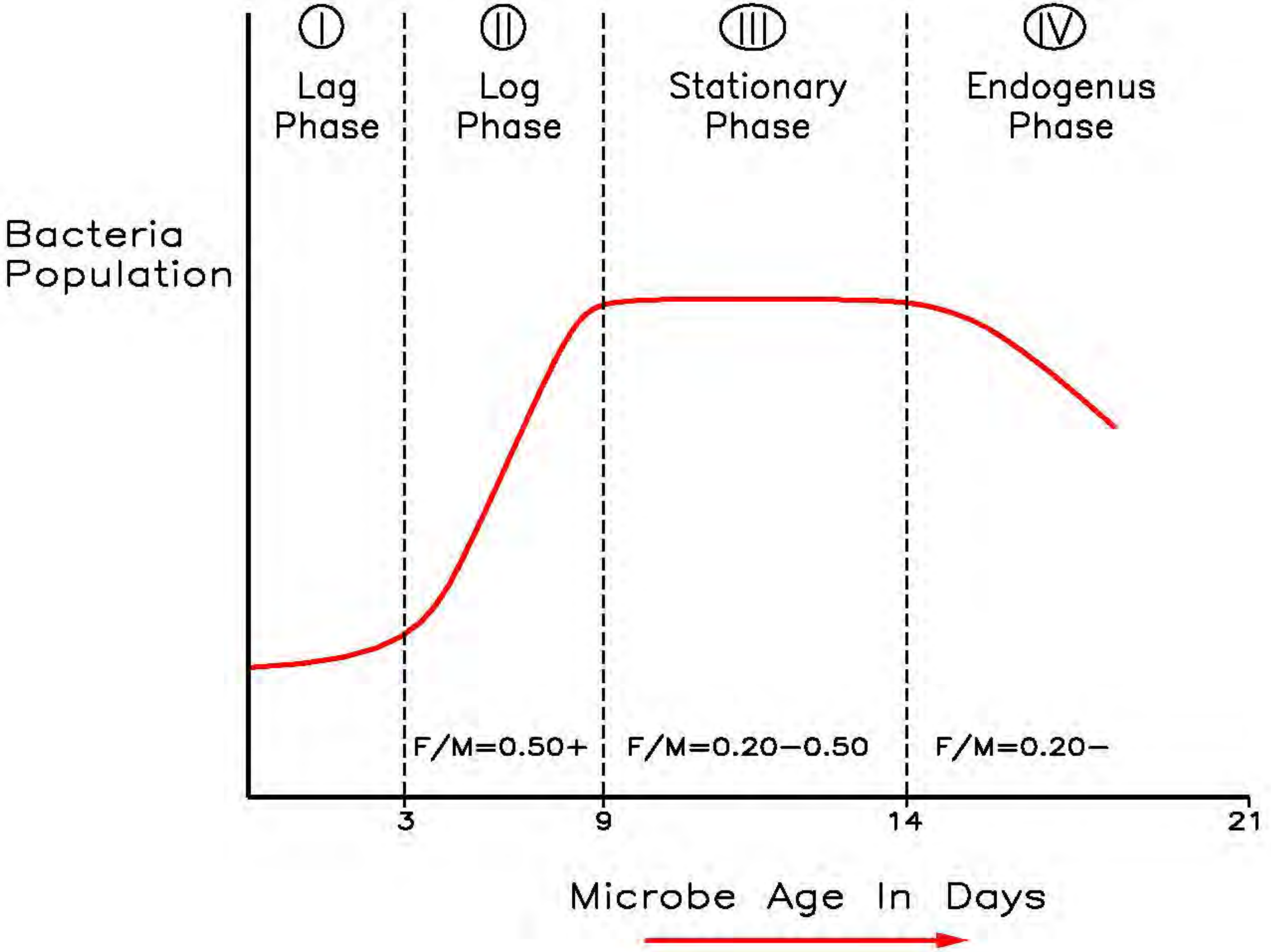
LAG GROWTH

LOG GROWTH

STATIONARY OR DECLINING GROWTH

ENDOGENUS DECAY (DEATH)

Impact of F/M on Bacteria Growth



Flocculation and Subsequent Settling of Biomass Depends On:

1. **Biomass growth rate (point on curve).**

2. **Age of sludge (detention time of cells as measured by MCRT).**

3. **Balance between food supply & biomass (F/M).**

Impact of F/M on Bacteria Growth

I. Lag Phase

- No growth after new food source added.
- Bacteria acclimating to waste (producing digestive enzymes).

Typical for new wastes, plant startup or rapidly changing waste conditions.

II. Log Phase – High F/M >0.50

- High food source, low population.
- Rapid growth at maximum rate, high cell formation.
- Poorly developed bacterial slime layer.
- Dispersed microbes (hard to flocculate).

Impact of F/M on Bacteria Growth

III. Stationary Phase

- Moderate F/M (0.20-0.50)
- Balanced food and microbes
- Population growth matches population death
- Slime layer fully developed
- Optimal flocculation, good settling, clear effluent

Impact of F/M on Bacteria Growth

IV. Endogenous Decay (Death Phase)

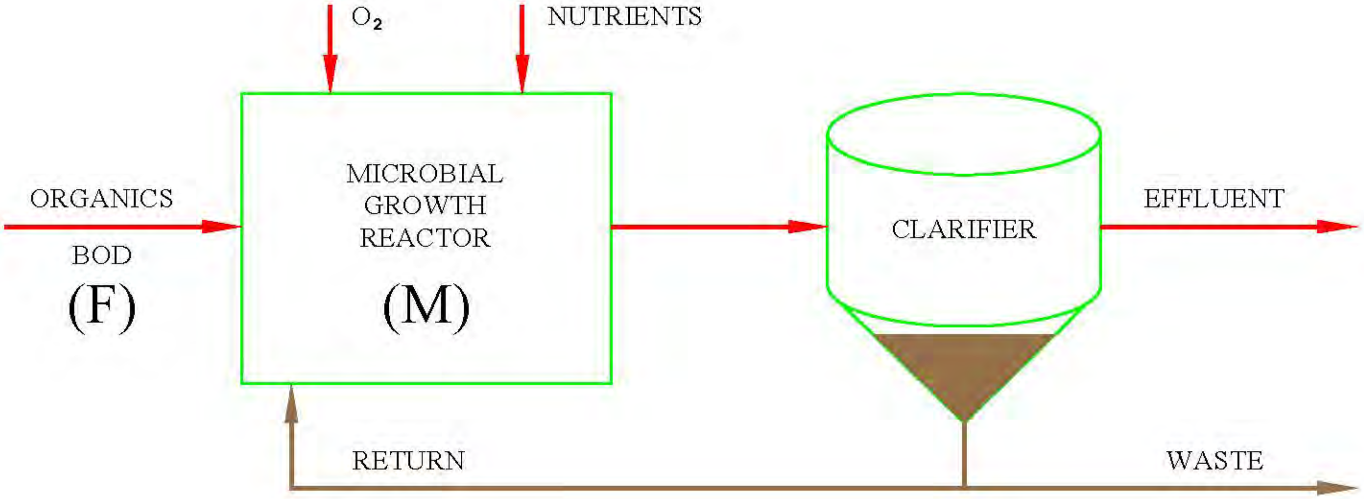
- Low F/M <0.20

- Low food, high microbial population

- Microbes starve, digest themselves and each other

- Leaves dead cell fragments, turbid effluent behind

Batch Bacteria Growth Results Can be Extrapolated To Continuous Feed Reactors



- **Continuous feed reactors reach a point on the batch growth curve at steady state.**

- **Keep in mind "steady state" is somewhat of a misnomer in a rapidly changing reactor.**

- **However, simulation of steady state is achieved by regulating F/M.**

- **This is done by using wasting to keep "M" in an acceptable range for "F".**

Optimization Of Biological Treatment Processes

- **Grow and maintain adequate microbial population (M) in reactor.**
- **Keep population in balance to influent organic wastewater loading (F).**
- **Achieve desired settling results by F/M manipulation and wasting.**
- **Remove microbes by settling in clarifiers.**
- **Balanced F/M in stationary phase produces the best effluent due to optimal settleability of sludge.**
- **Not all plants designed or operated in stationary F/M mode for various reasons.**

Age of Sludge Can Be Correlated to F/M

- **F/M is good predictor of sludge settleability.**
- **Takes five days to obtain the BOD data needed to calculate "F".**
- **Sludge age is often used to estimate the F/M range.**
- **Sludge age can be determined in a few hours using TSS tests.**
- **Sludge age is also called mean cell residence time (MCRT).**

Calculation of Sludge Age

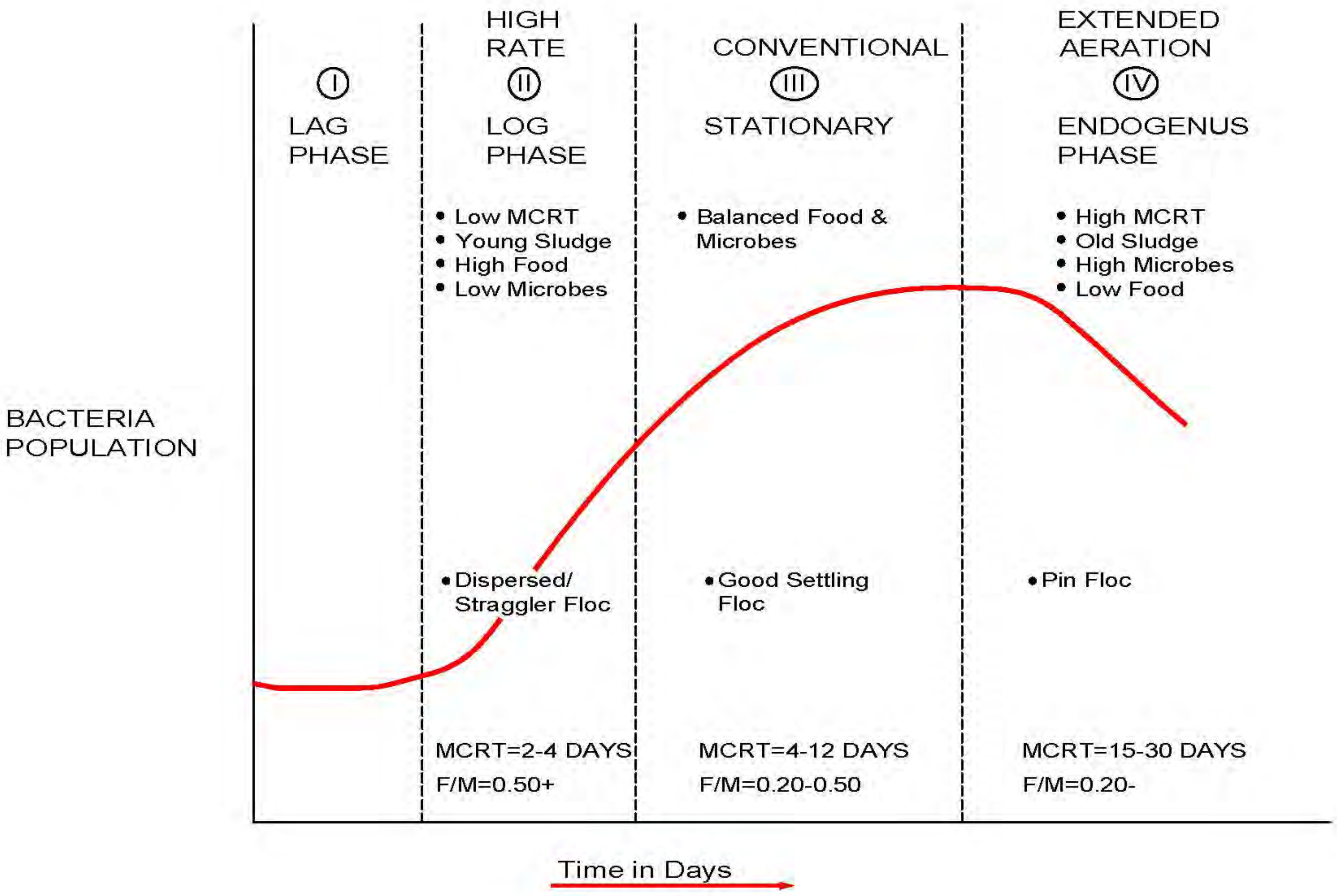
MCRT = MEAN CELL RESIDENCE TIME (SLUDGE AGE)

$$\text{MCRT} = \frac{\text{LBS OF BIOMASS IN AERATION REACTOR}}{\text{LBS/DAY OF BIOMASS LOST FROM AERATION}}$$

$$\text{MCRT} = \frac{\text{LBS MLSS}}{\text{(LBS/DAY WASTED) + LBS/DAY TSS IN EFFLUENT)}}$$

- **Units of MCRT are days.**

MCRT Relationship to F/M



MLSS Settleability Is Related To Plant Performance and Process Control

A. Dispersed Straggler Floc

- High F/M (0.50+)
- Low MCRT (2-4 Days)
- Young sludge (low biomass population)/Log Phase Growth
- High wasting rates
- High rate process

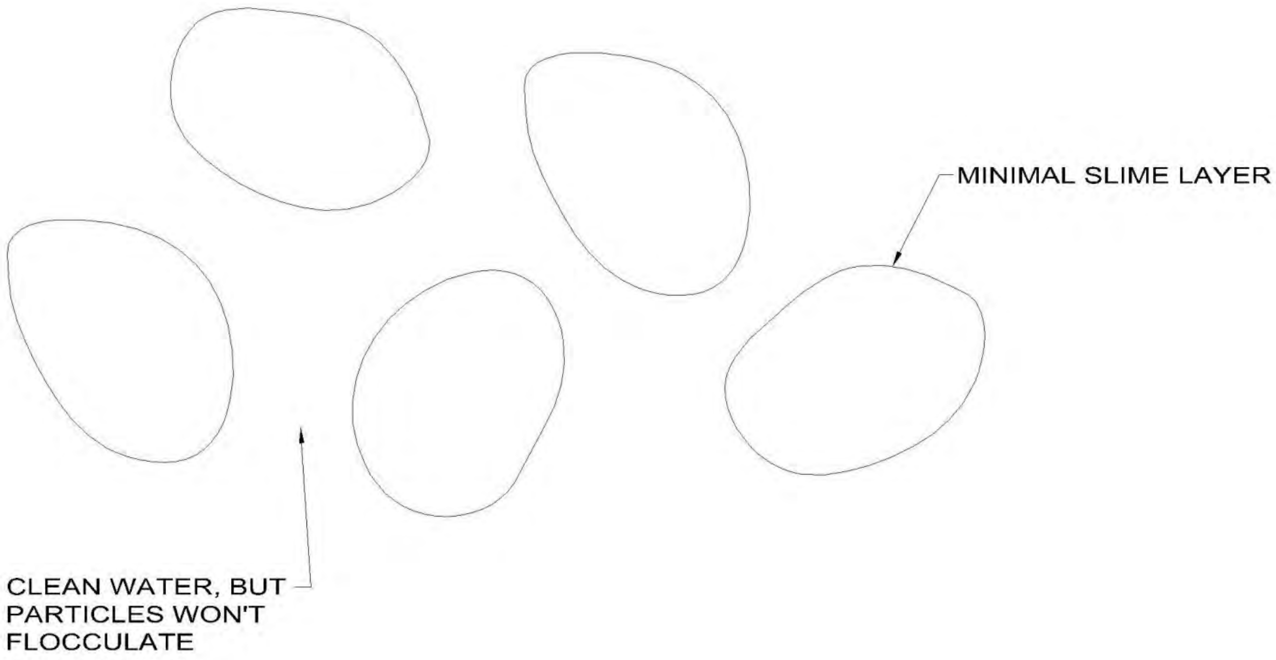
B. Good Settling Floc

- Balanced F/M (0.20-0.50), MCRT (4-12 Days), and wasting/(Stationary Phase Growth)
- Conventional process

C. Pin Floc

- Low F/M (0.20-)
- High MCRT (15-20 Days)
- Old sludge (high biomass population)/(Endogenous Phase Growth)
- Low wasting rates
- Extended aeration process

Dispersed Floc



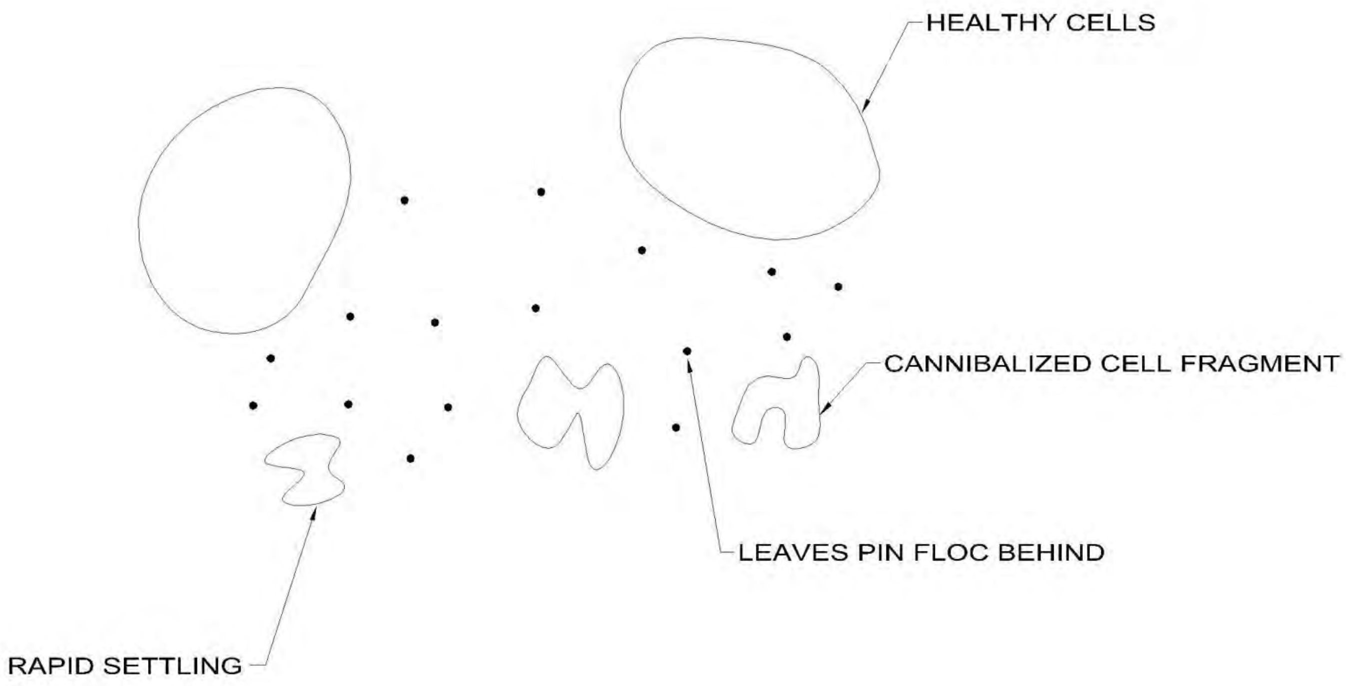
- Microbes remain suspended individually instead of agglomerating into a settleable floc
- In order to create settleable floc, need to discourage growing MLSS with only individual microbial cells

Dispersed Floc Often Caused by Log Phase Growth Condition

Operator Selects High Sludge Wasting Rates

- Aeration basin population will be low
- Excess food for a few microbes
- Means high F/M and low MCRT
- High food supply means a lot of bacteria will be present
- Animal form will be amoebas and flagellates
- Lack of predators means minimal slime layer on bacteria
- Large areas between flocs
- Causes poor settling dispersed floc

Pin Floc



- Caused by low F/M, high MCRT, insufficient sludge wasting
- Lack of structure promotes floc shearing under aeration
- Dense inert floc settles rapidly leaving pin floc (which is normally swept out) behind
- Settling test shows turbid supernatant without a distinct sludge interface

Low Sludge Wasting Rates Lead to Pin Floc

- **Aeration basin population is high**
- **Too many microbes for available food supply**
- **Means low F/M and high MCRT**
- **Depleted food supply means animal forms that need less bacteria will predominate (stalked ciliates/rotifers)**
- **Starving MLSS cannibalize each other leaving inert cell fragments behind**
- **Inerts settle rapidly but leave turbid effluent from unswept pin floc behind**

Uses of Various Process Modes

HIGH RATE PROCESSES

- Achieve initial level of treatment in short period.
- Applicable to industrial pretreatment system.
- Poorly settling dispersed flow and young sludge.

CONVENTIONAL PROCESSES

- Best treatment and settleability due to slime layer and healthiest microbes.
- Requires constant sludge wasting to maintain F/M.
- Carbon food source synthesized to cell mass.

EXTENDED AERATION PROCESSES

- Hold microbes long enough to cause starvation.
- Microbes digest each other as food source.
- Carbon cell mass used for respiration and converted to carbon dioxide.
- Pin floc formation needs special clarifier design considerations.
- Less sludge to process (good feature for small plants).

Wastewater Treatment Microorganisms

- **Bacteria members** – single celled microbes that feed on incoming biodegradable organics.

- **Animal members** – advanced life forms that feed on bacteria.

  - Amoebas
  - Flagellates
  - Free Swimming Ciliates
  - Stalked Ciliates
  - Rotifers
  - Nematodes

Amoebas

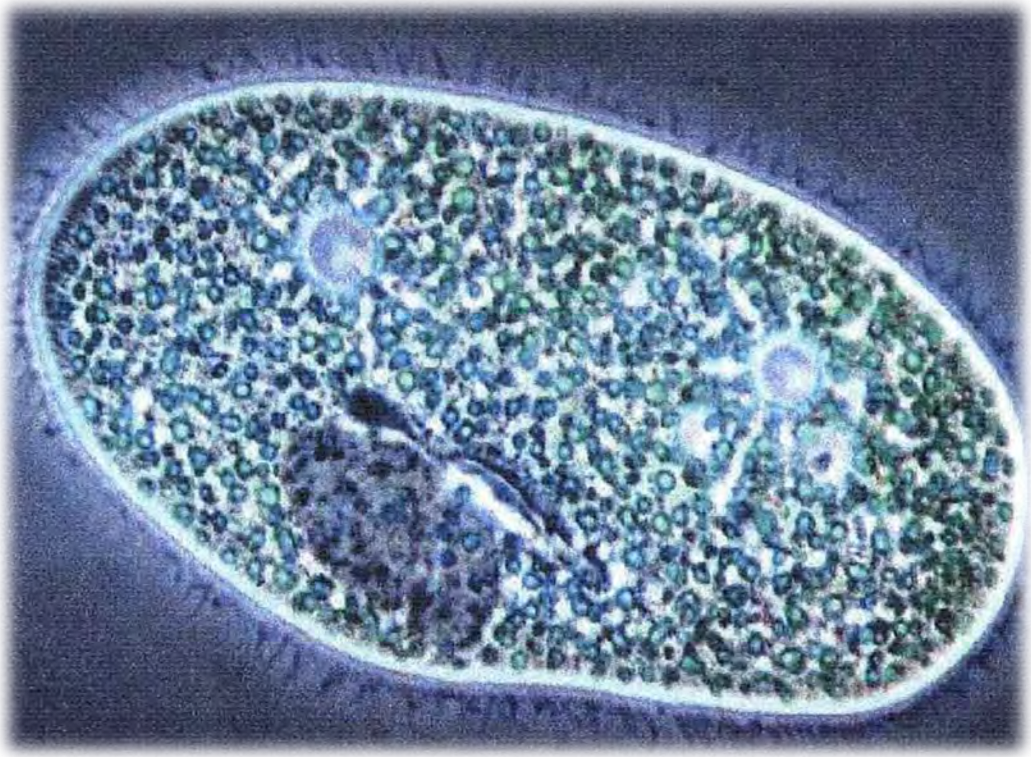
- Lowest animal form
- Non-rigid wall
- Move with “fake feet” called pseudopods (extensions of protoplasm).
- Pseudopods can reach out and entrap bacteria.
- Cannot swim for food so needs large bacteria population to survive.
- Large amoeba population implies high organic source to sustain bacteria (dirty water) (high F/M) (low MCRT).

Flagellates

- Moves through water with flagella.
- Allows some movement to seek food source.
- Need slightly smaller bacteria supply than amoebas because of mobility to reach food.

- Still need relatively large bacteria supply to sustain mobility.
- Large flagellate population is sign of high organic source to sustain bacteria (high F/M) (low MCRT).

Free Swimming Ciliates

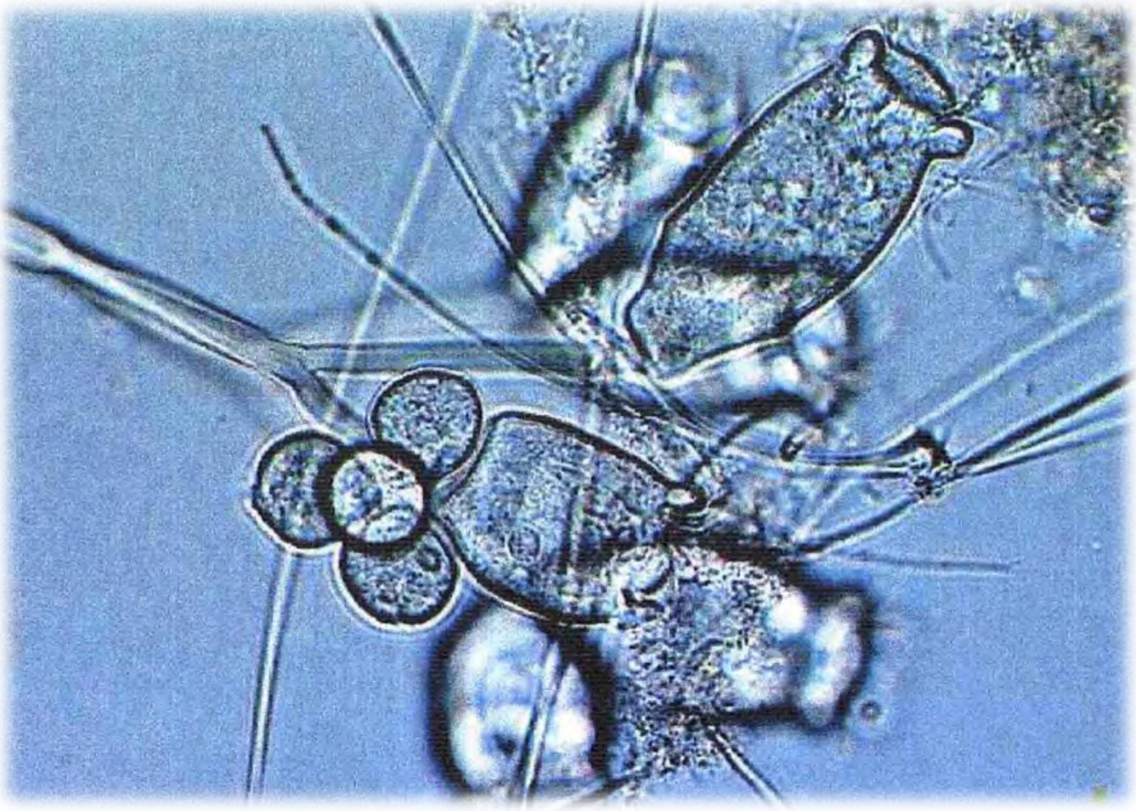


- Cilia around cell promote mobility.
- Swim in search of food.
- Need a lot of energy to swim.
- Higher, more advanced life form than amoebas and flagellates so less food is needed.
- Sign of water becoming cleaner (moderate F/M) (moderate MCRT).

Stalked Ciliates

- **Attach to surfaces with stalk.**
- **Not free swimming so less energy needed.**
- **Replace free swimmers as bacterial food supply declines.**
- **Sign of water becoming cleaner**

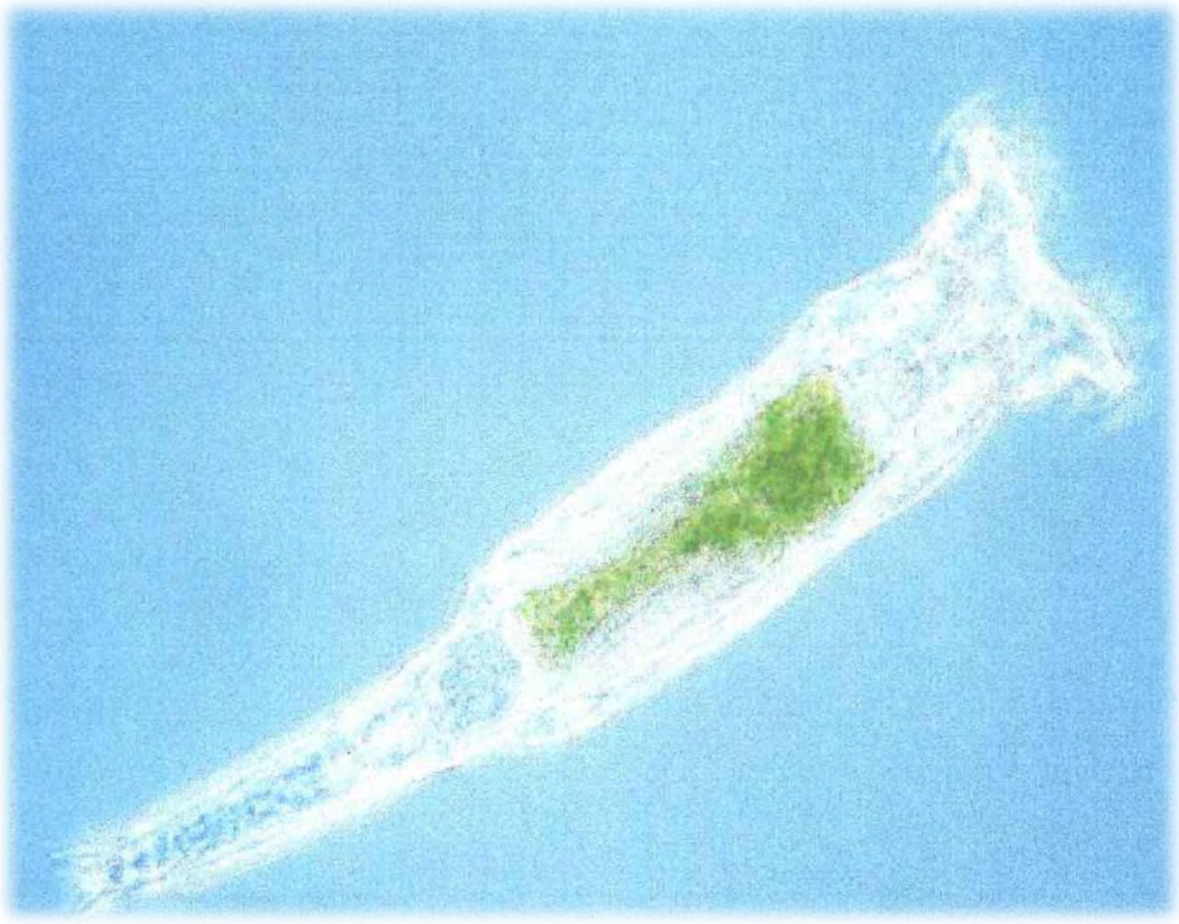
  (lowering F/M) (increasing MCRT).



Rotifers

- Advanced multicellular microorganisms.
- Sign of clean water.
- Don’t need a lot of food (bacteria)

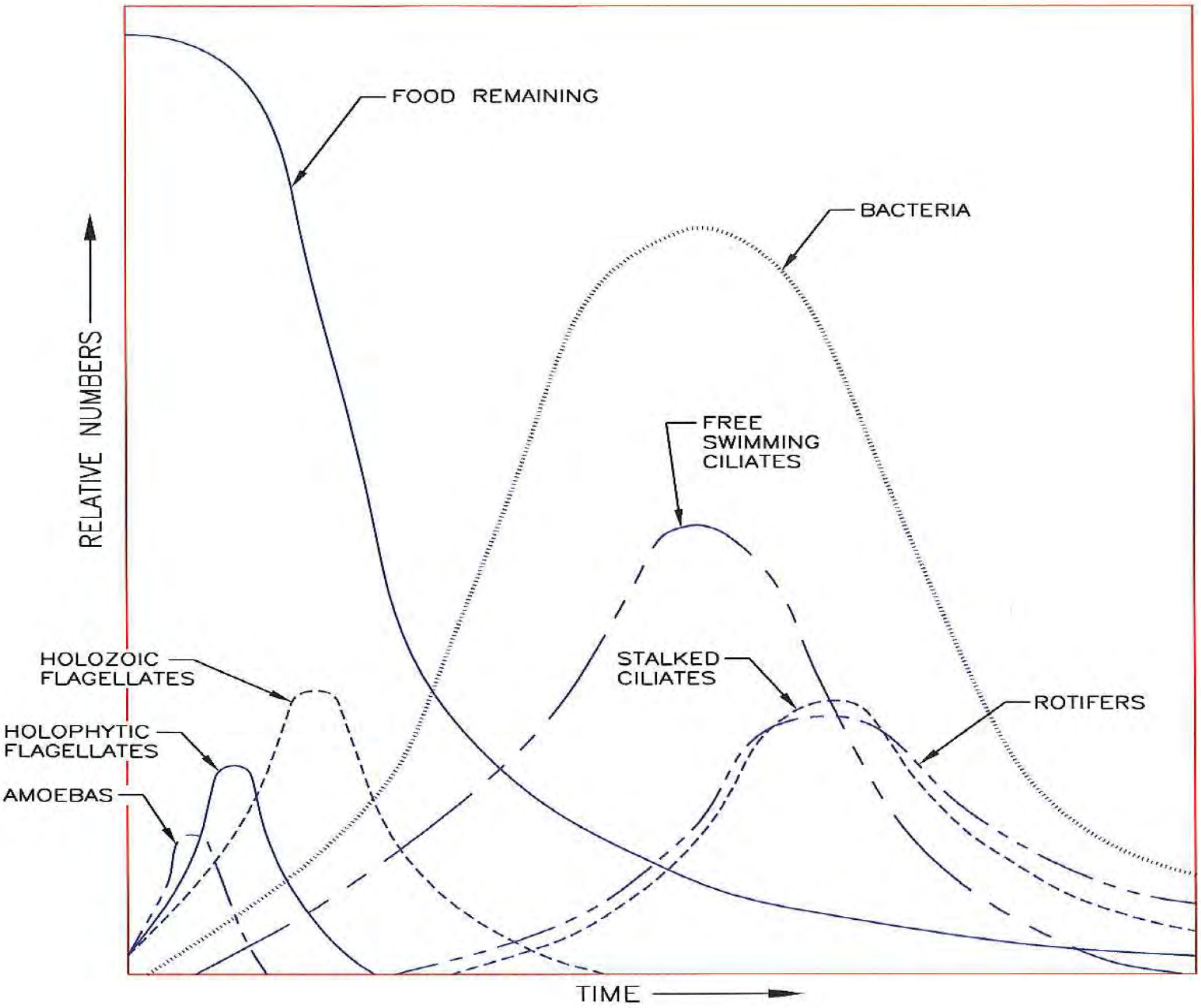
  (low F/M) (high MCRT).



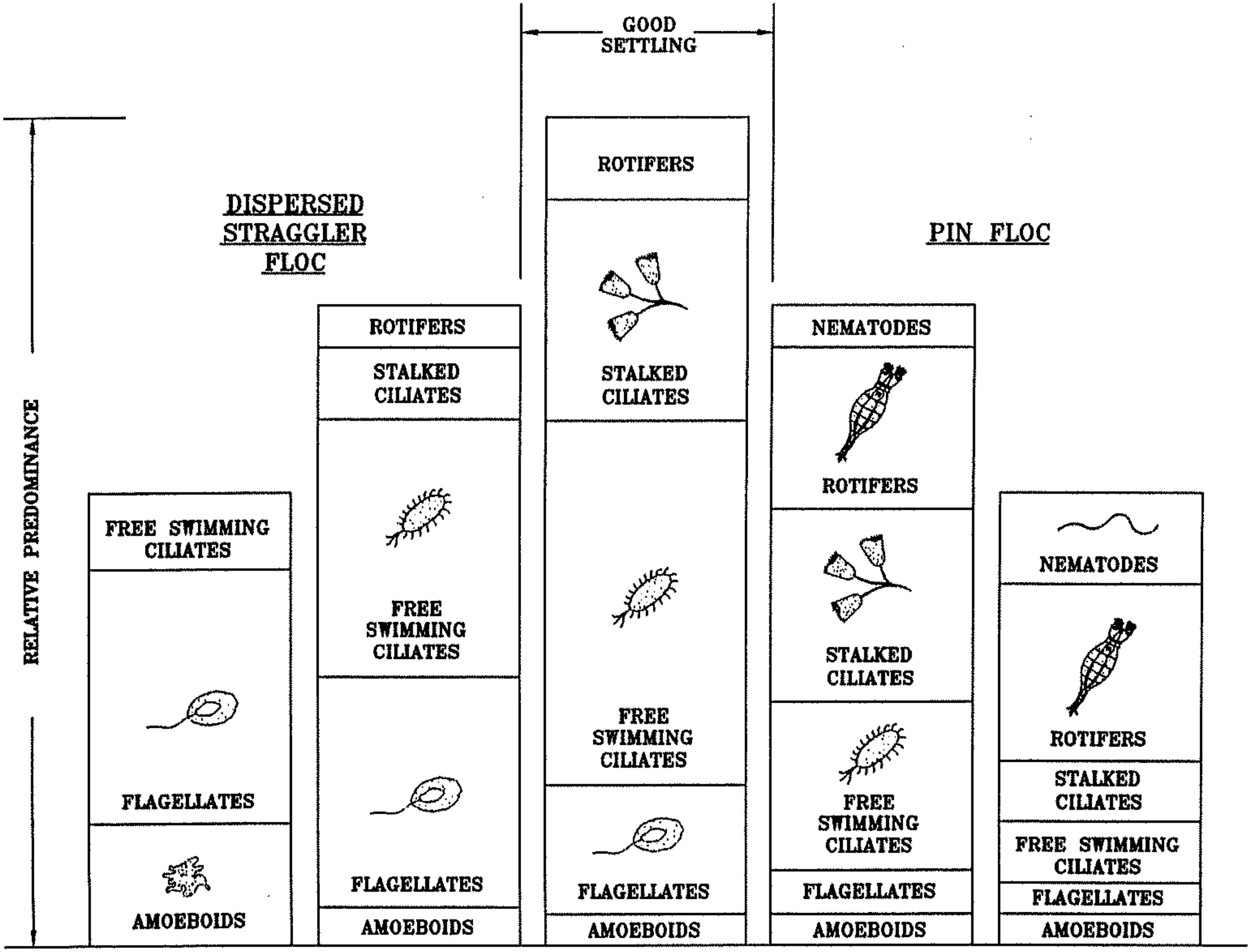
Nematodes

- **Worms**
- **Can harbor pathogens due to incomplete digestion.**
- **Sign of old sludge or sediments (low F/M) (high MCRT).**

Animal Population Shifts as Food Supply Dwindles



Relative Number of Microorganisms vs. Sludge Quality



Success of Wastewater Treatment Processes

Attract Microbes That Will

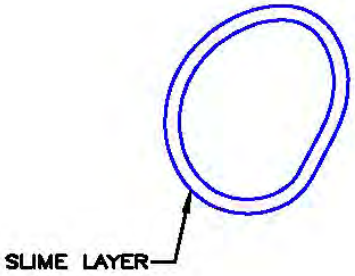
- **Assimilate the specific pollutants in the waste stream.**
- **Flocculate well together.**
- **Settle readily in final clarifier or quiescent zones.**

Other Microbes Can Also Thrive And Take Over Process Including

- **Filaments**

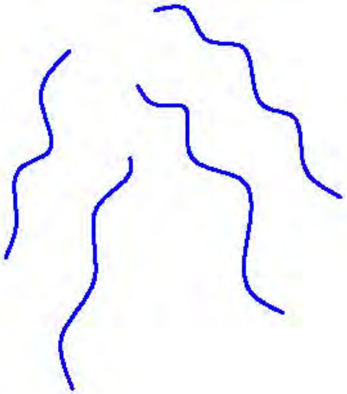
Two Groups of Wastewater Plant Bacteria

Floc-Formers



- Oval, spherical bacteria.
- Develop slime layer.
- Agglomerate and settle.
- Low area to volume ratio.

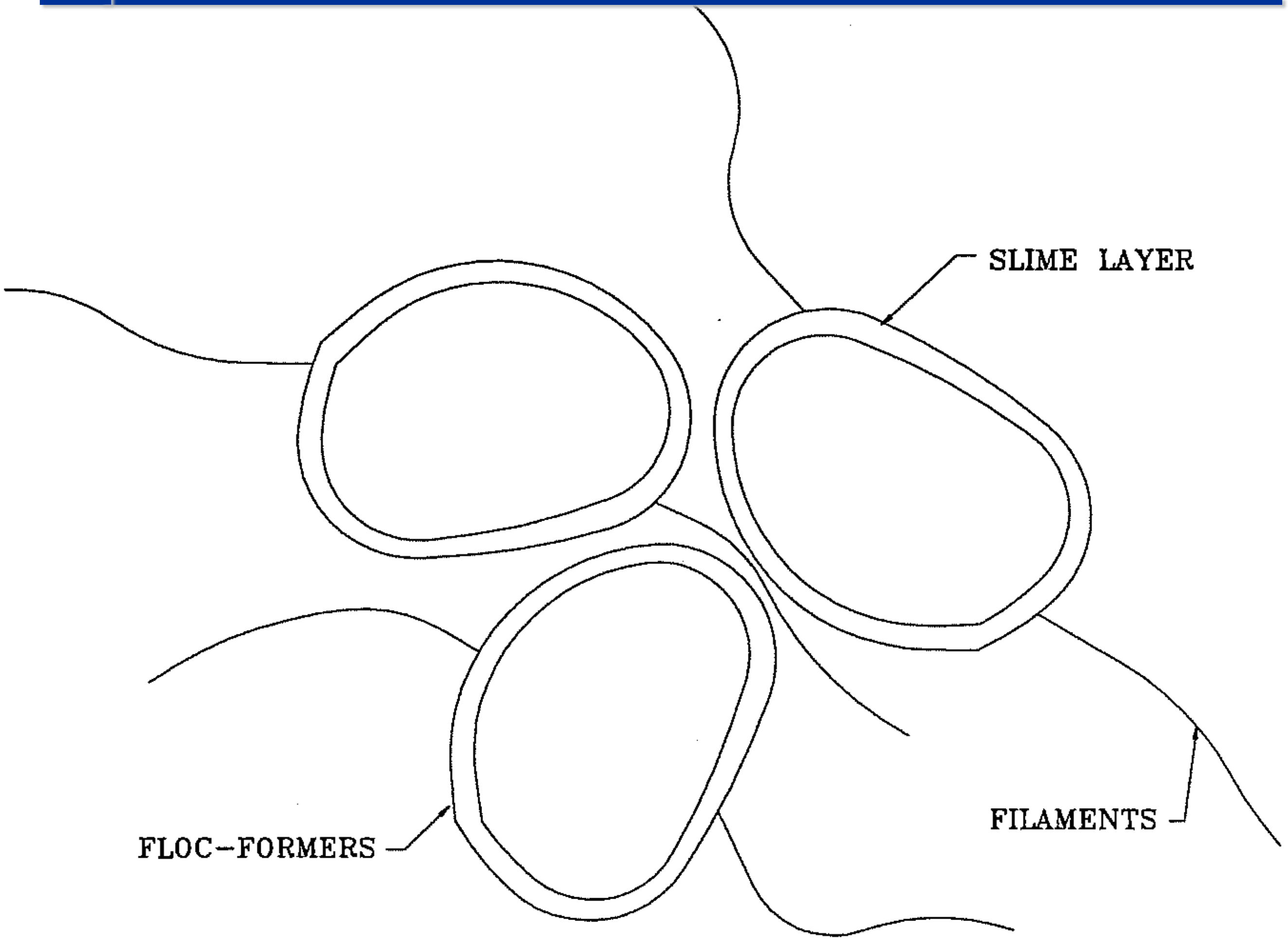
Filaments



- Long stringy bacteria.
- Do not agglomerate well.
- Hold each other apart.
- High area/to volume ratio.

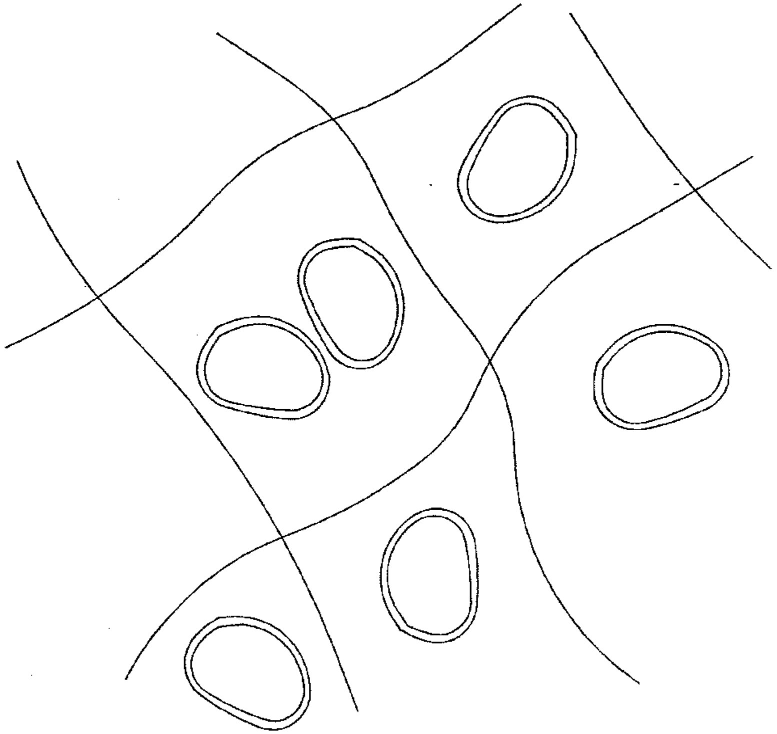
- Both floc formers and filaments are present in reactor.
- Relative predominance determines settleability.

Optimal Floc-Former Predomination



- Slime layer assists in cell flocculation.
- Filaments provide floc structure.
- Sludge settles/compacts well.

Filamentous Microorganism Predomination



- **Filaments hold floc-formers apart.**
- **Sludge will not flocculate.**
- **Sludge settles poorly and won’t compact.**
- **Called “sludge bulking”.**

Filamentous Microorganisms

- Can often decompose resistant wastes not readily biodegradable by floc-forming bacteria.
- Filament grow in environments not conducive to floc-forming bacteria:
    - - Low pH
    - - Low D.O.
    - - Low Nutrients
    - - Low F/M
    - - High sulfur
    - - High Septicity
    - - Very Old MLSS
- Can often take over activated sludge plants and cause poor settling.

Filaments Can Cause Significant Process Problems

- **Thrive in conditions unsuitable for floc formers.**

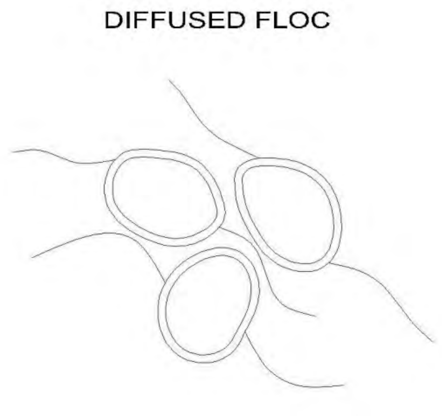
- **Have wastewater assimilation advantage over floc formers due to their superior A/V ratio. (More surface area for food diffusion).**

- **Create bulking, poorly settling sludges.**

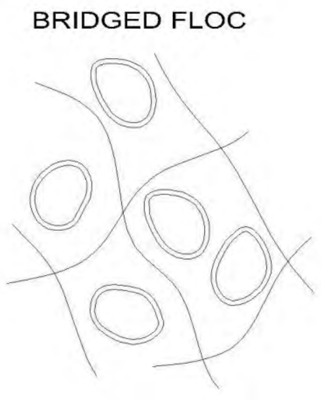
- **Result in poor effluent quality and solids carryover.**

Filamentous Sludge Bulking

- **Caused by floc structure failure due to excessive filament formation**
- **Excess filaments produce clear water due to excellent pollutant removal (high cell area to volume ratio)**
- **Unfortunately, filaments will not settle or compact well in final clarifier due to two mechanisms:**



Filaments within floc cause it to spread out making it difficult to compact



Filaments extend beyond floc preventing floc agglomeration

Sludge Volume Index (SVI) Indicates Bulking

$$\text{SVI} = \frac{\text{(30 Minute Cone Test (ml) (1000))}}{\text{(MLSS In mg/l)}}$$

SVI Value	Indicates
100 or Less	Rapid Settling
100	Good Settling
150	Incipient Bulking
150 or More	Bulking Problem

Monitor SVI as an Indicator of Filaments

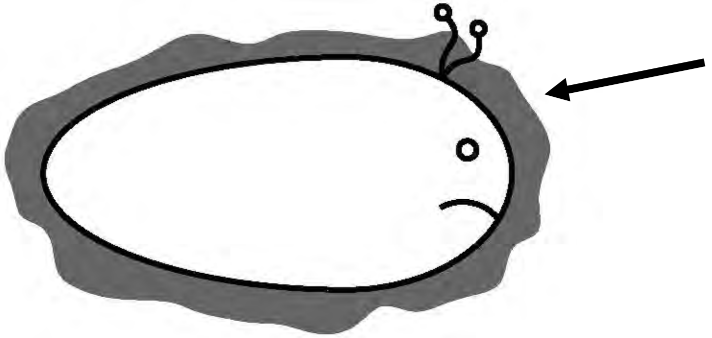
SVI Range	Filament Status
50-100	Lacking Filaments
100-150	Balanced Filaments
150+	Excessive Filaments

- Too few filaments leads to rapid floc settling, pin floc and turbid effluent.
- Balanced filaments adds strength to floc.
- Excessive filaments leads to sludge bulking and hindered, slow settling.

Identification of Filament Types

- **One of most valuable process control tests available to operator**
- **Conduct microscopic evaluation of floc**
- **Identify predominant filament types**
- **Assess aeration basin or plant conditions that promote predominant filaments**
- **Eliminate or control that condition to bring bulking under control**

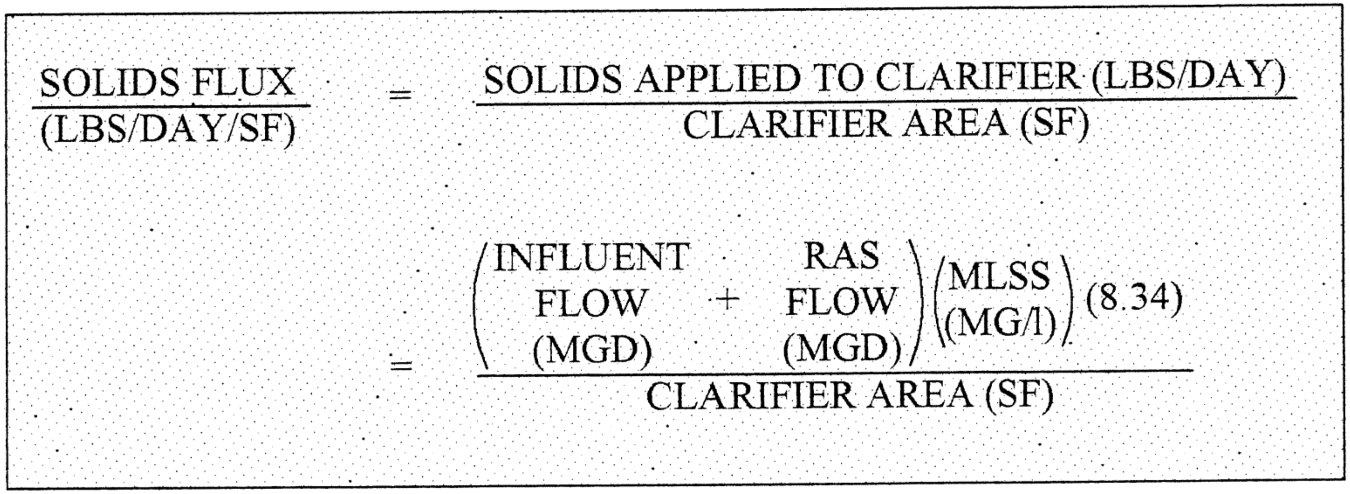
Viscous (Non-Filamentous) Bulking



excessive slime layer
around cell

- Excessive gelatinous slime layer around cell wall hinders flocculation and settling.
- Caused by either/or high soluble organic load or lack of nutrients to build cell mass.
- Cell growth is overstimulated by soluble sugars, milk or alcohols (dairy, ice cream or brewery waste).
- Low nutrients in waste or nutrients get tied up in carbon and are not available for microbes.
- Microbes cannot build healthy cells, so they shift excess protoplasm to slime layer.

Final Clarifier Solids Flux is Often The Cause of Poor Process Performance



$$\frac{\text{SOLIDS FLUX}}{\text{(LBS/DAY/SF)}} = \frac{\text{SOLIDS APPLIED TO CLARIFIER (LBS/DAY)}}{\text{CLARIFIER AREA (SF)}}$$

$$= \frac{\left(\begin{matrix}\text{INFLUENT}\\ \text{FLOW}\\ \text{(MGD)}\end{matrix} + \begin{matrix}\text{RAS}\\ \text{FLOW}\\ \text{(MGD)}\end{matrix}\right)\left(\begin{matrix}\text{MLSS}\\ \text{(MG/l)}\end{matrix}\right)(8.34)}{\text{CLARIFIER AREA (SF)}}$$

- **Maximum Solids Flux for Typical Municipal MLSS:**

  - **At average daily flows – 24 lbs/day/sf**
  - **At peak hourly flows – 48 lbs/day/sf**

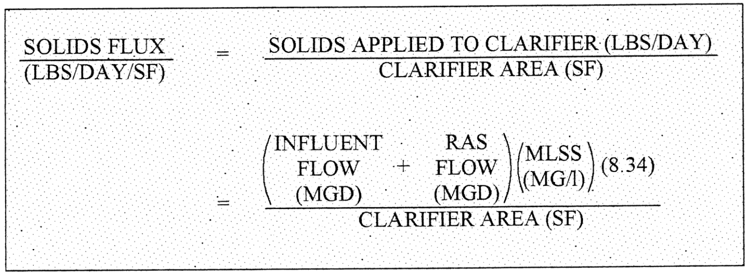
Relationship of Applied Clarifier Solids Flux to Sludge Settleability and Filament Population

SVI (ml/g)	Avg. Daily Flux (Lbs/Day/SF	Peak Hourly Flux (Lbs/Day/SF
75	30	60
100	24	48
125	23	46
150	20	40
175	18	36
200	15	30

- **Typical allowable solids flux of 24 lbs/day/sf is valid only if good settling occurs (SVI = 100).**
- **During periods of bulking, allowable solids flux is reduced.**

Manipulating Solids Flux to Maximize Clarifier Performance

- **To reduce the solids flux, the operator can do one or all of the following during high flow periods:**
  - **Reduce the return sludge rate.**
  - **Reduce the MLSS concentration.**
  - **Increase the clarifier surface area by bringing another clarifier on-line.**



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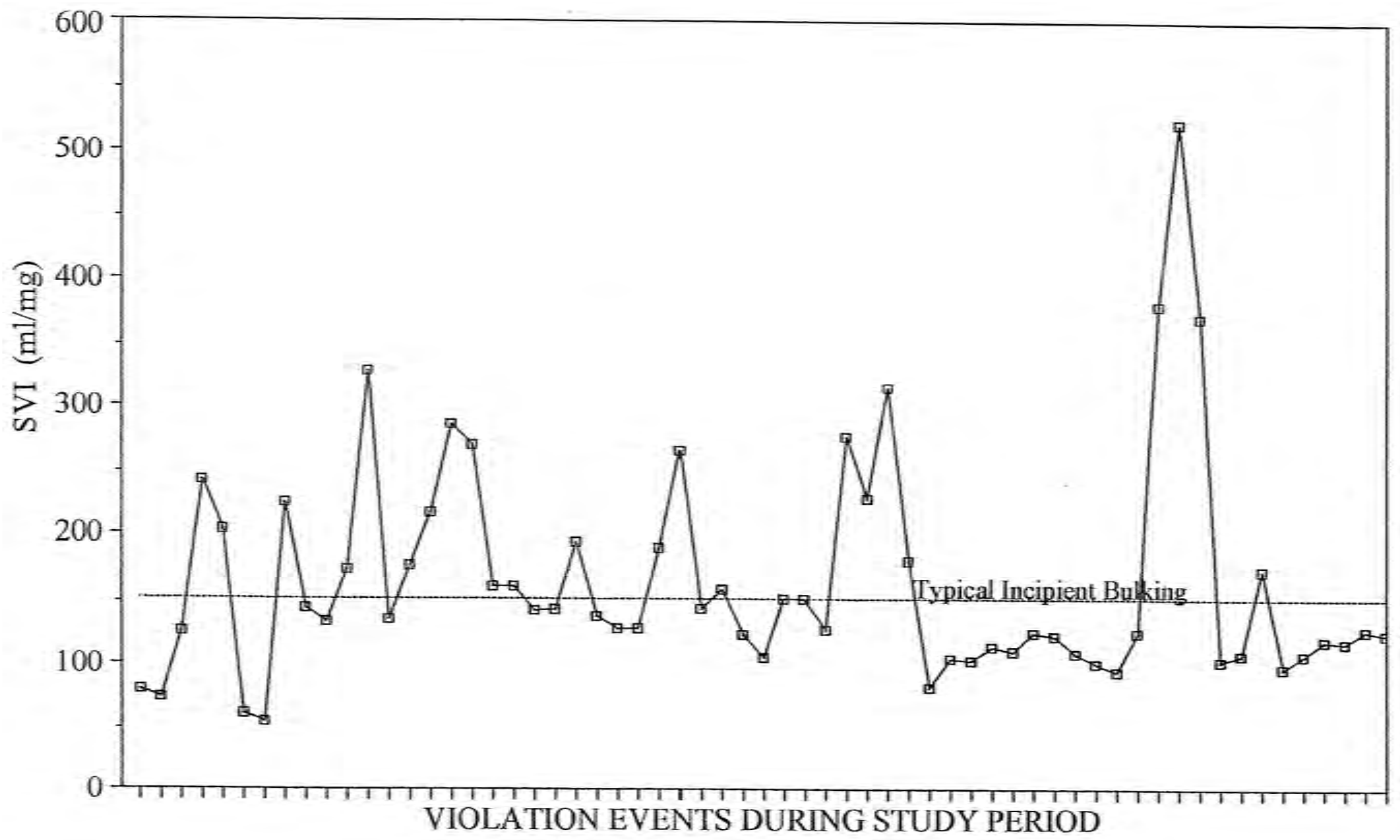
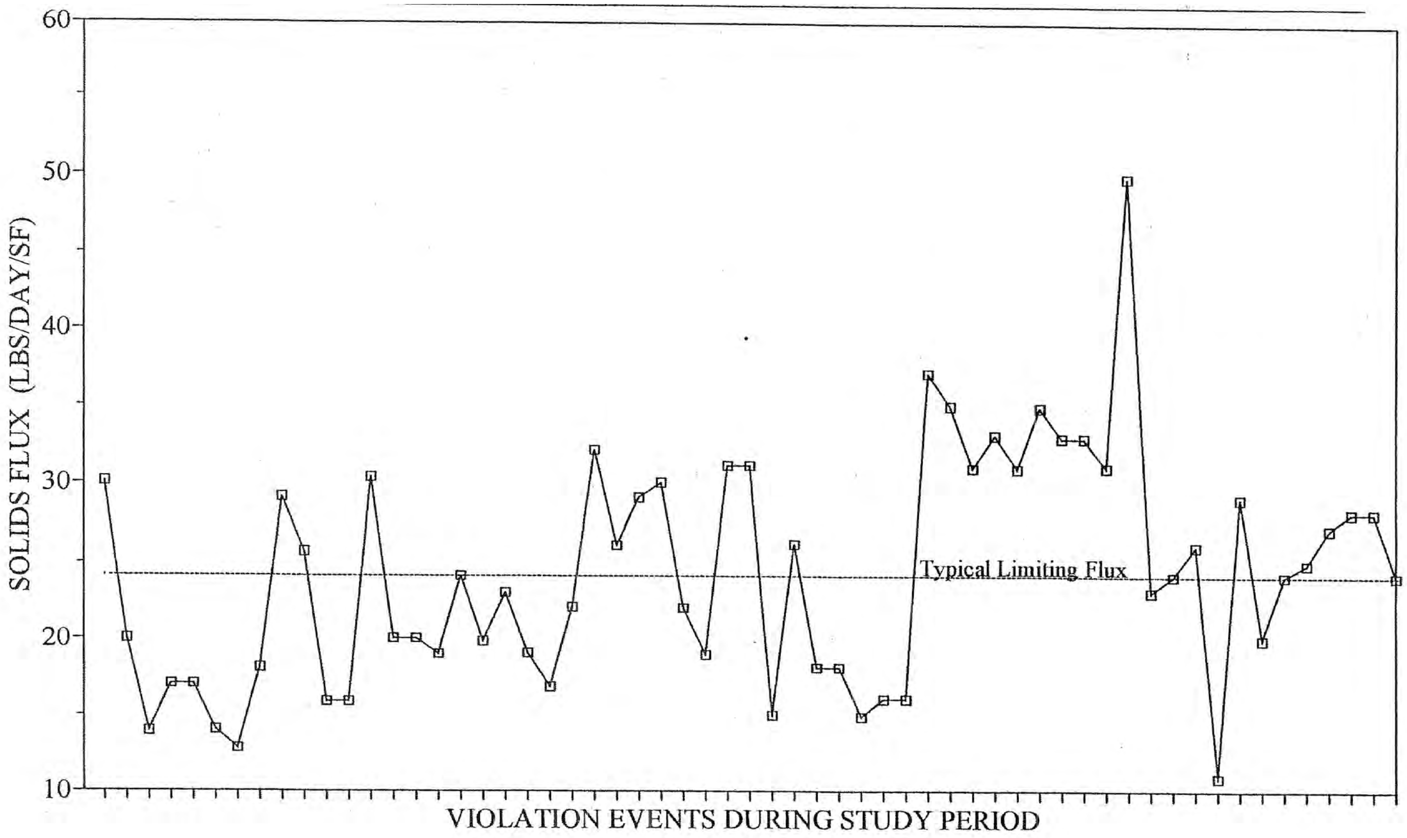
- **To maximize solids flux capacity, need to minimize SVI and filament proliferation.**

Poor Process Performance Often is Associated With Sludge Bulking and Filament Proliferation



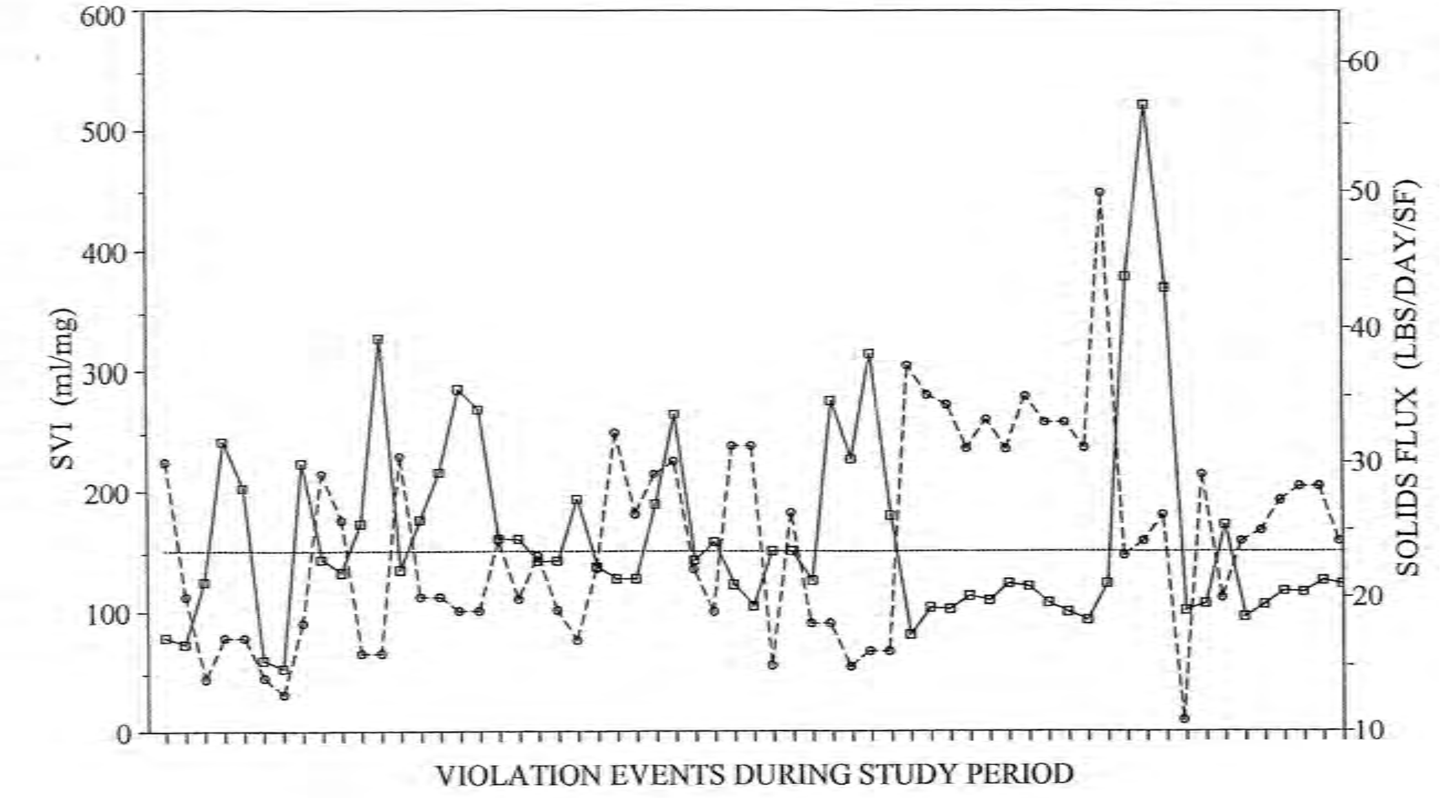
- Sludge bulking with high SVI values is often associated with poor effluent quality.
- SVI is a measure of how many filaments are in the MLSS.
- SVI should be monitored daily.
- If filaments present in excess, identify type and address cause of filaments.

Solids Flux Is Often Elevated on Plant Upset Days



- **IF SOLIDS FLUX IS TOO HIGH, IT CAN BE REDUCED BY:**
  - **Lower RAS rate during high flow.**
  - **Reduce MLSS by more wasting.**
  - **Bring additional clarifier on-line.**

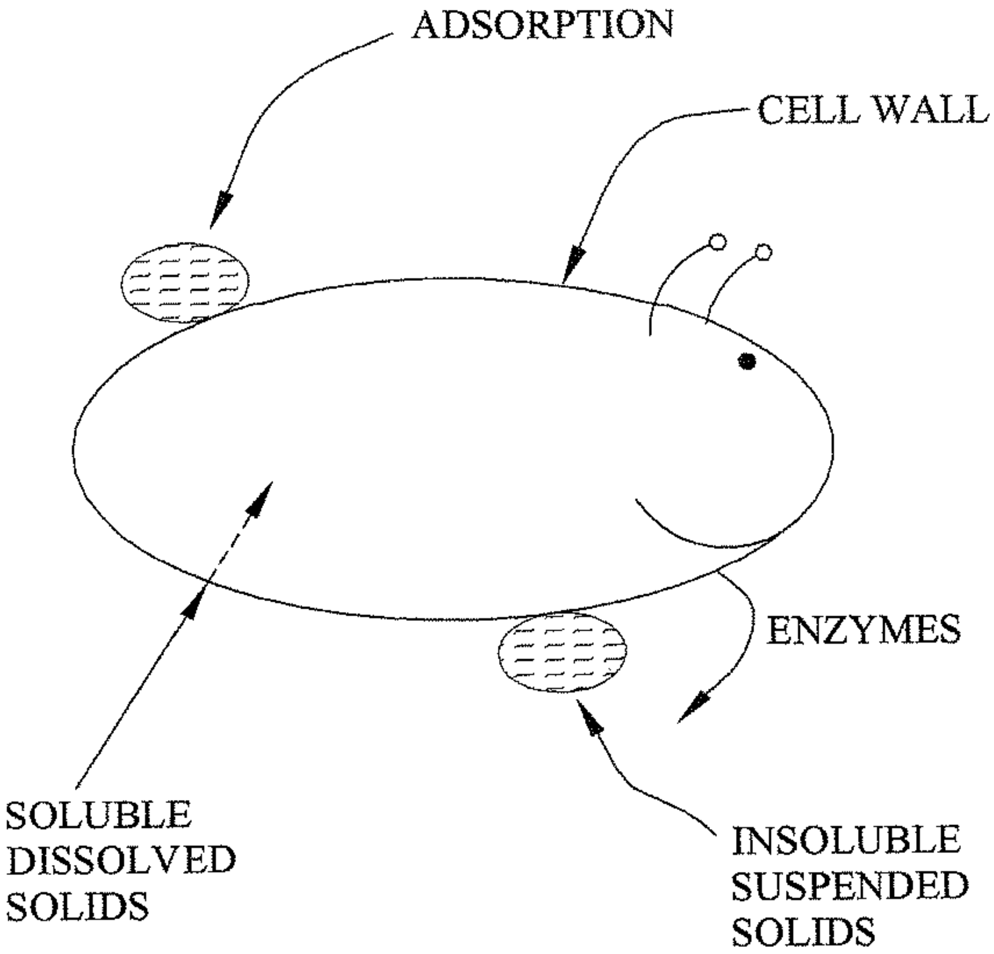
Combined Impacts of Filaments and Solids Flux on Plant Performance Often Overlooked



- **Majority of effluent violations shown were result of solids flux or sludge bulking issues.**

Activated Sludge Aeration Tank

Waste Transfer Step

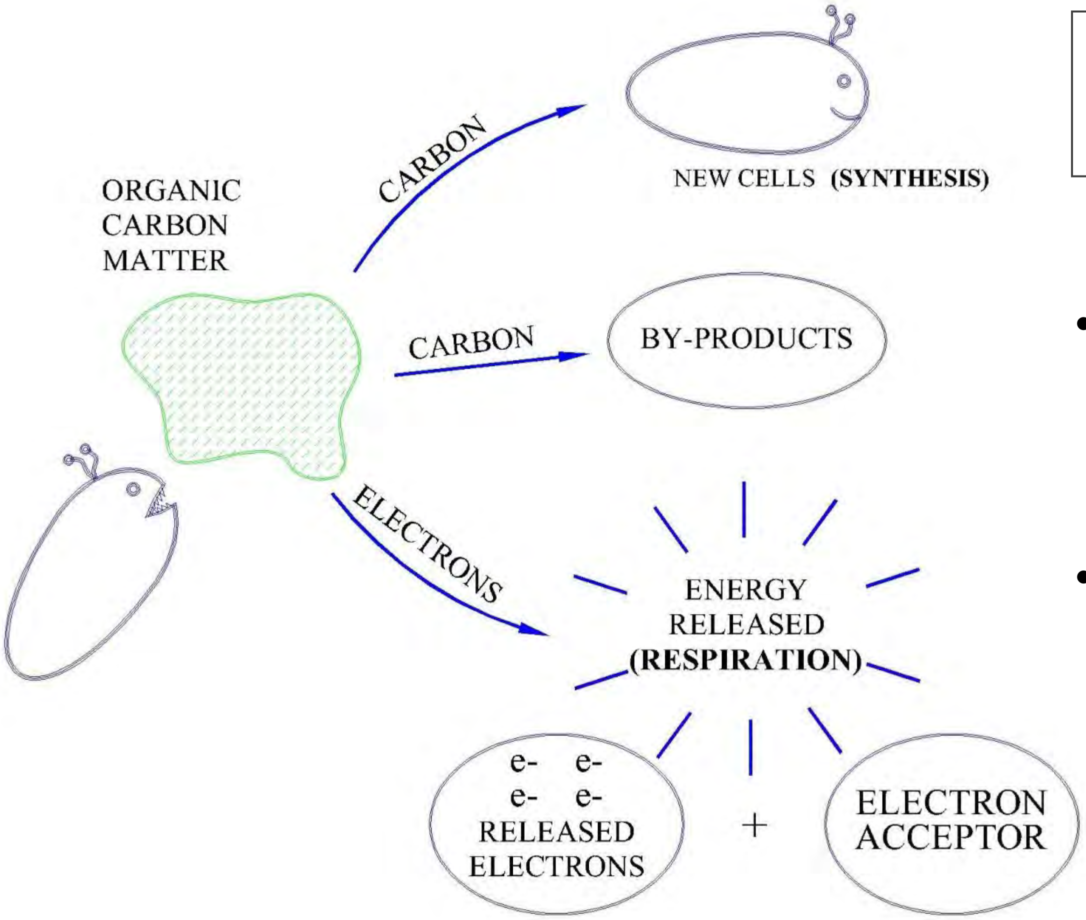


- **TYPICAL REACTION TIME**

  15-60 minutes depending on solubility

- **Some hard to degrade industrial wastes could take hours or days.**

Waste Transformation Conversion Step



- **TYPICAL TIME**

  4 to 6 hours

- **Much beyond this time, microbes begin to starve and digest each other.**
- **Industrial wastes can take longer.**

Hydraulic Detention Time Measures Length of Time That Influent Flow Is Held Under Aeration

$$\text{HRT} = \frac{\text{Aeration Basin Volume (MG)}}{\text{Influent Flow (MGD)}}$$

- **As flow increases, HRT decreases**
- **If HRT is too low, some BOD could pass through reactor untreated**
- **Typical Hydraulic Detention Times:**

- High rate	**2-4 hours**
- Conventional	**4-8 hours**
- Extended aeration	**12-24 hours**

Organic Loading Rate Compares BOD Loading To Available Aeration Volume

$$\text{Volumetric Organic Loading} = \frac{\text{LBS/Day of BOD into Aeration}}{\text{Aeration Basin Volume (1000 CF)}}$$

- **Excessive BOD loadings may result in BOD breakthrough in effluent.**

- **Typical Volumetric BOD Loading Rates:**

  - High rate 100-1000 LBS/DAY/1000 CF

  - Conventional 20-40 LBS/DAY/1000 CF

  - Extended aeration 10-25 LBS/DAY/1000 CF

Adequate Dissolved Oxygen Is Critical To Proper Process Control

- Typical minimum D.O. levels = 1.0 to 2.0 mg/l
- Varies seasonally:
- Warm weather
  - Water temperature rises
  - Saturation D.O. drops
  - Bacterial activity increases
  - D.O. consumption increases

⟶ More oxygen supply needed

- Cold weather
  - Water temperature decreases
  - Saturation D.O. Rises
  - Bacterial activity declines
  - D.O. consumption decreases

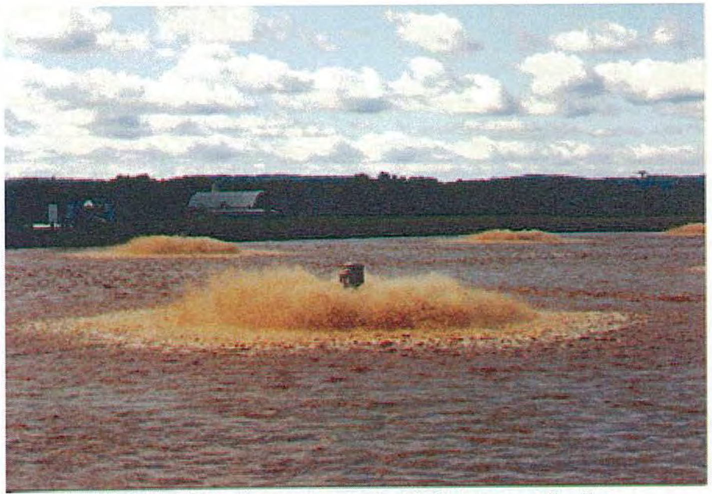
⟶ Less oxygen supply needed

- Low D.O. leads to filaments and odors

Different Approaches to Supply Oxygen As Electron Acceptor

- **Mechanical Aeration – Throw drops of water into air for O_2 diffusion.**
- **Coarse Bubble Aeration – Pipe large air bubbles through water.**
- **Fine Bubble Aeration – Pipe small air bubbles through water.**

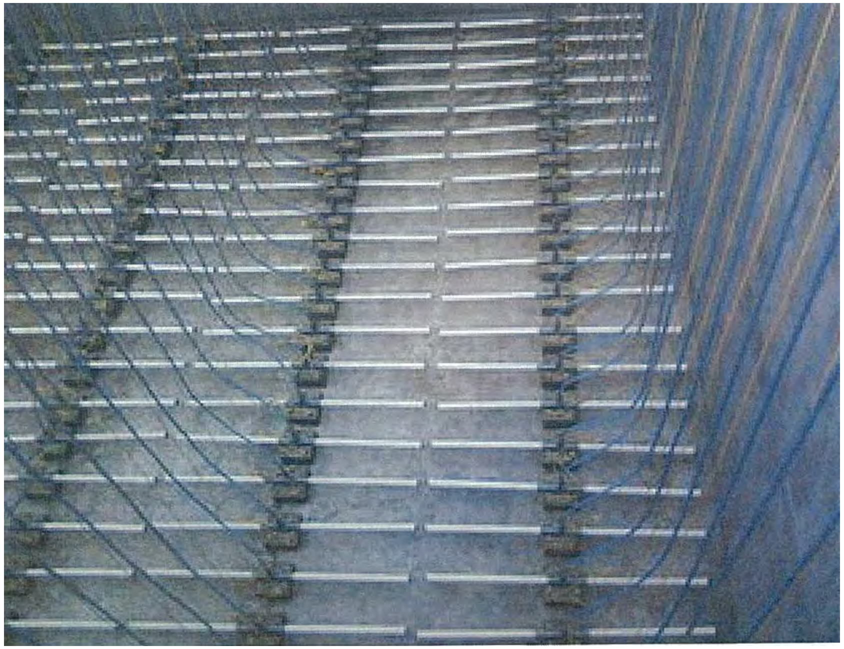
Mechanical Coarse Bubble Aeration



Aqua-Jet® Aerators in an industrial lagoon application.

- **Can use floating aerators on surface.**
- **Can use fixed platform aerators.**

Coarse Bubble Diffusion Technology



- **Creates coarse bubbles by forcing air flow through large holes in stainless steel tube.**
- **Oxygen transfer efficiency about 10%.**
- **Very low maintenance, non-clog feature.**

Fine Bubble Diffusion Technology

- **Creates fine bubbles by forcing air flow through perforated plastic membrane.**
- **Fine bubbles with high area to volume ratio give high oxygen transfer efficiency (25%).**
- **Less air volume and horsepower needed than coarse bubble.**
- **Current trend in plant retrofits due to energy savings.**

Typical Oxygen Requirements for BOD Removal

DIFFUSED AERATION

High Rate	650-850 SCF/#BOD
Conventional	750-1200 SCF/#BOD
Extended Aeration	2000-3500 SCF/#BOD

MECHANICAL AERATION

High Rate	0.7-0.9 #O_2/#BOD
Conventional	0.8-1.1 #O_2/#BOD
Extended Aeration	1.4-1.6 #O_2/#BOD

Aeration Requirements for Mixing

- **Prevents bacteria from settling out and creating septic conditions.**
- **Allows full aerator volume to be used.**
- **Minimizes aerator short-circuiting.**
- **Poor mixing can cause incomplete treatment.**

Typical mixing requirements:

– **Coarse Diffused Aeration**	**20-30 SCFM/1000 CF of basin**
– **Fine Diffused Aeration**	**0.12 SCFM/SF of basin**
– **Mechanical**	**1.0 hp/1000 CF of basin**

- **Turning aeration system down below minimum mixing level will cause process failure even if D.O. appears high.**
- **Mixing often governs design.**

Final Clarifiers Are Utilized to Settle Microbes and to Create Clear Effluent

Flocculation Step Occurs in Clarifier

- **Healthy biomass develops slime layer.**
- **Acts as natural coagulant.**
- **Biomass cells flocculate and settle.**
- **Clear water left behind as effluent.**

SECONDARY CLARIFIER OBJECTIVES

1. **CLARIFY** - Provide clear effluent
   - Separate cells from water
   - Cells = activated sludge

2. **THICKEN** - Concentrate thickened cells (2-3x optimal)
   - MLSS = 3000 MG/L (0.3%)
   - RAS = 6000-9000 MG/L (0.6-0.9%)

Optimization Of Final Clarifier Performance Minimizes Effluent Violations

KEYS TO OPTIMAL CLARIFIER PERFORMANCE

1. Minimize sludge holding time and blanket depth
2. Do not violate clarifier hydraulic loading rates
3. Monitor SVI to control bulking from filaments
4. Do not violate solids flux loadings onto clarifiers

Most clarifier performance failures occur when one of four above rules are violated

Do Not Violate Clarifier Hydraulic Loading Rates

- **Surface overflow rate = SOR in GPD/SF**

$$\underset{\text{(GPD/SF)}}{\text{SOR}} = \frac{\text{Flow to clarifier in GPD}}{\text{Clarifier area in SF}}$$

Allowable SOR Limits:

Type of Process	At Average Daily Flows	At Peak Hourly Flows
Conventional Plant	400-800	1000-1200
Extended Aeration Plant	200-400	600-800

- Extended aeration pin floc requires lower loading rate.

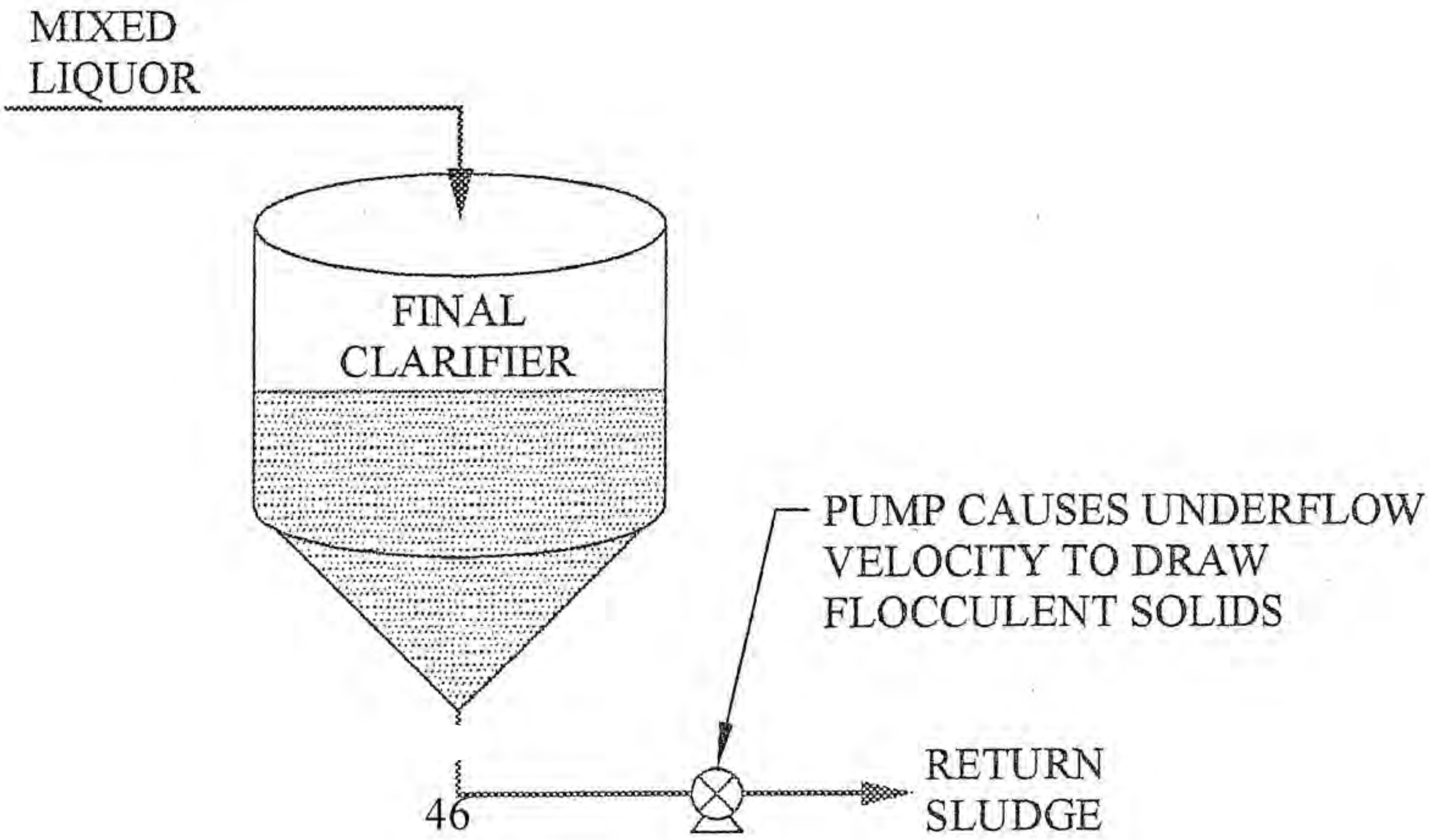
Minimize Sludge Holding Time and Blanket Depth

- 2^{o} clarifier not a solids reservoir
- Maximum blanket depth 1 – 3 feet
- Maximum holding time 1 hour
- Use RAS pumping rate to control sludge blanket

Denitrification Leads to “Rising Sludge”

- Microbes originally settle well in clarifier
- Septic conditions occur in sludge blanket
- Nitrate is converted to nitrogen gas in anoxic conditions (nitrate serves as electron acceptor instead of oxygen)
- Small nitrogen gas bubbles form within the floc particles causing them to float to surface
- Results in thick surface foaming and possible effluent violations

Activated Sludge Relies on Return Sludge Pump To Pull Sludge Blanket Down



RETURN ACTIVATED SLUDGE (RAS)

1. **RAS pumps control clarifier blanket depth, sludge holding time, sludge withdrawal rate, and sludge thickening.**

2. **RAS sends biomass back to aeration basin and impacts MLSS in reactor.**

3. **RAS helps to increase MLSS concentration.**

Empirical Targets For RAS Pump Rate Determination

High rate plant	15-30% Q_{INF}
Conventional plant	25-75% Q_{INF}
Extended aeration plant	75-150% Q_{INF}

- Plants that recycle more waste less and vice versa.

SLUDGE WASTING (WAS)

1. **Waste sludge to control MLSS, F/M and MCRT.**

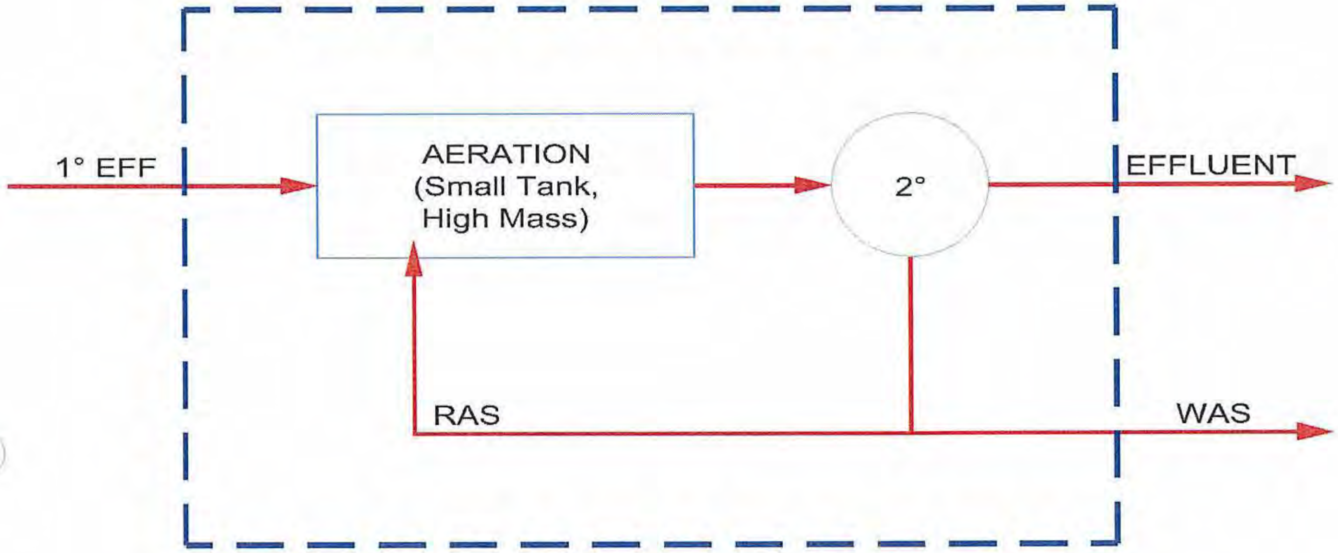
2. **Solids accumulate in system from:**
    1. **Synthesis of new biomass cells from BOD conversion.**

    2. **Accumulation of non-biodegradable inert portion of dead cells.**

    3. **Accumulation of refractory non-biodegradable organic solids from primary clarifier effluent carry over or raw influent.**

    4. **Accumulation of inert solids from primary clarifier effluent or raw influent.**

WAS KEEPS SYSTEM IN BALANCE



- Mass balance boundary has one input and two outputs.

- Since MLSS is increasing over time, solids must either be automatically wasted, or they will waste themselves out effluent.

Typical Microbial Population as MLSS

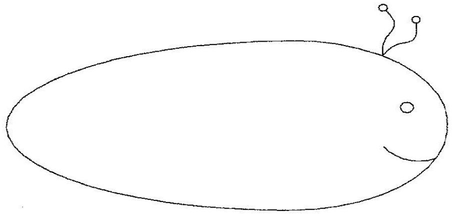
High Rate	**<1000 mg/l MLSS**
Conventional	**1500-4000 mgl MLSS**
Extended Aeration	**3000-6000 mgl MLSS**

VARIES SEASONALLY:

Higher in winter
Lower in summer

Nutrients

- Nitrogen and phosphorus are key nutrients
- Required for biomass cell growth
- Part of cell structure
- Industrial wastes often low in nutrients
- Some filaments thrive in low nitrogen environment
- Provide BOD/N/P of 100/5/1 (for every 100 pounds of BOD removed, provide 5 pounds of nitrogen and 1 pound of phosphorus



FORMULA = $C_5H_7O_2NP$

pH

- **Extreme pH range for biomass = 5.0 to 10.0**
- **Optimal pH range for biomass = 6.5 to 8.5**
- **Low pH can cause filaments to bloom**
- **High pH can cause nutrients to precipitate out of water**

Temperature

- Optimal range = 80° to 90°F
- Maximum limit = 105°F
- Bacterial growth doubles or halves for each 10° temperature change

Warm temperatures

- Warm water causes higher reaction rates
- Microbes work faster
- Lower MLSS concentration needed

Cold temperatures

- Cold water reduces reaction rates
- Microbes works slower
- Higher MLSS needed

Color of MLSS

Should be moderately dark brown

Symptom: **MLSS goes from normal light/dark brown to gray/black**

Cause: **Septic conditions developing**

Corrective Action: **Check aerator D.O. and MLSS levels**

Symptom: **MLSS goes form normal light/dark brown to dilute brown**

Cause: **Insufficient MLSS from washout or excessive wasting**

Corrective Action: **Check peak flow and reactor detention times**

Odors In Aeration Basin

Should have musty, earthen smell without odors

Symptom: Any deviation from the musty earthy smell of a healthy basin

Cause: Low pH, low D.O., poor mixing

Corrective action: Control pH, D.O. and mixing, check for overloading or excessive solids

EXCESSIVE FOAM IN AERATORS

a)Symptoms: Aerators covered with excessive white or dark foam

b) Causes

1) White foam

- **a) Over aeration of MLSS**
- **b) Young sludge not using D.O. supplied**
- **c) Toxic shock to biomass**

2) Dark foam

- **a) Excessive solids under aeration**
- **b) Nocardia filament infestation**
- **c) Analysis: check D.O., and MLSS levels, check for nocardia**

d) **Corrective Action**

1) **White foam**
    - a) Reduce air supply
    - b) Increase MLSS by lowering wasting
    - c) Identify toxic loadings

2) **Dark foam**
    - a) Reduce MLSS by increasing wasting
    - b) Identify nocardia filament causes

TREATMENT PROCESS TROUBLESHOOTING REQUIRES DETAILED DATA BASE TRACKING

ESSENTIAL DATA:

- Flows
- MLSS
- MLVSS
- F/M
- SVI
- MCRT
- D.O.
- pH
- Temperature
- Nutrients
- BOD
- TSS
- Microscopic Evaluation

COMMON OPERATIONAL PROBLEMS

- MIXED LIQUOR SOLIDS WASHOUT
- BOD LOSS IN EFFLUENT
- DISPERSED STRAGGLER FLOC IN EFFLUENT
- PIN FLOC IN EFFLUENT
- RISING SLUDGE IN CLARIFIER
- BULKING SLUDGE
- TOXIC SHOCK LOADS
- EXCESSIVE FOAMING IN AERATORS
- ODORS IN AERATION BASIN
- COLOR CHANGES
- FILAMENTS

1) MIXED LIQUOR SOLIDS WASHOUT

a) SYMPTOM: High TSS lost in clarifier effluent.

b) CAUSE: Excessive hydraulic loadings through plant or solids flux overloading of clarifier.

c) ANALYSIS:

1) Check clarifier detention time ($\Theta = V/Q$).

2) Check clarifier surface loading rates (SOR = FLOW/AREA).

3) Make sure flow is evenly distributed to all clarifiers.

4) Make sure effluent weirs are level.

5) Check solids flux onto clarifier.

$$\left(\text{FLUX} = \frac{\text{SOLIDS APPLIED}}{\text{AREA}}\right)$$

d) IMMEDIATE REMEDIES

1) Lower return sludge pumping rates to reduce clarifier loading.

2) Reduce MLSS levels in aerator.

e) CORRECTIVE ACTION

1) Locate peak flow sources.

2) Correct inflow/infiltration problems in sewer system.

3) Add clarifier capacity if available.

4) Determine optimal MLSS based on F/M.

2) BOD LOSS IN EFFLUENT

  a) SYMPTOM: Increasing Effluent BOD

  b) CAUSE: Incomplete oxidation in aeration basin or correlated to TSS loss.

  c) CORRECTIVE ACTION:

    1) If due to incomplete oxidation, there will be high soluble BOD component.

      - Measure soluble BOD
      - Check aeration basin detention time
      - Check volumetric BOD loadings
      - Check oxygen supply and D.O.

    2) If due to solids loss, resolve solids loss issues

3) DISPERSED FLOC IN 2° EFFLUENT

a) SYMPTOM: Secondary clarifier has bulking sludge which won’t settle well. The secondary effluent is fairly clear, but large clumps of MLSS FLOC can be seen flowing over the effluent weirs.

b) CAUSE: Young sludge from high F/M and low MCRT.

c) CORRECTIVE ACTION: Decrease waste rate to allow:

1) Increase sludge age

2) Increase MCRT

3) Decrease F/M

4) PIN FLOC IN 2˚ EFFLUENT

a) SYMPTOM: The secondary effluent is turbid and contains a lot of dense, inert fine materials.

b) CAUSE: Excessive inert MLSS from endogenous decay leads to a rapidly settling FLOC which fails to sweep out fine MLSS solids in clarifiers.

c) ANALYSIS: Check plant F/M, MCRT, MLSS and MLVSS levels, and sludge wasting rates.

d) IMMEDIATE REMEDIES: Add polymers to clarifiers.

e) CORRECTIVE ACTION: Increase waste rate to allow:

1) Decreased sludge age

2) Decreased MCRT

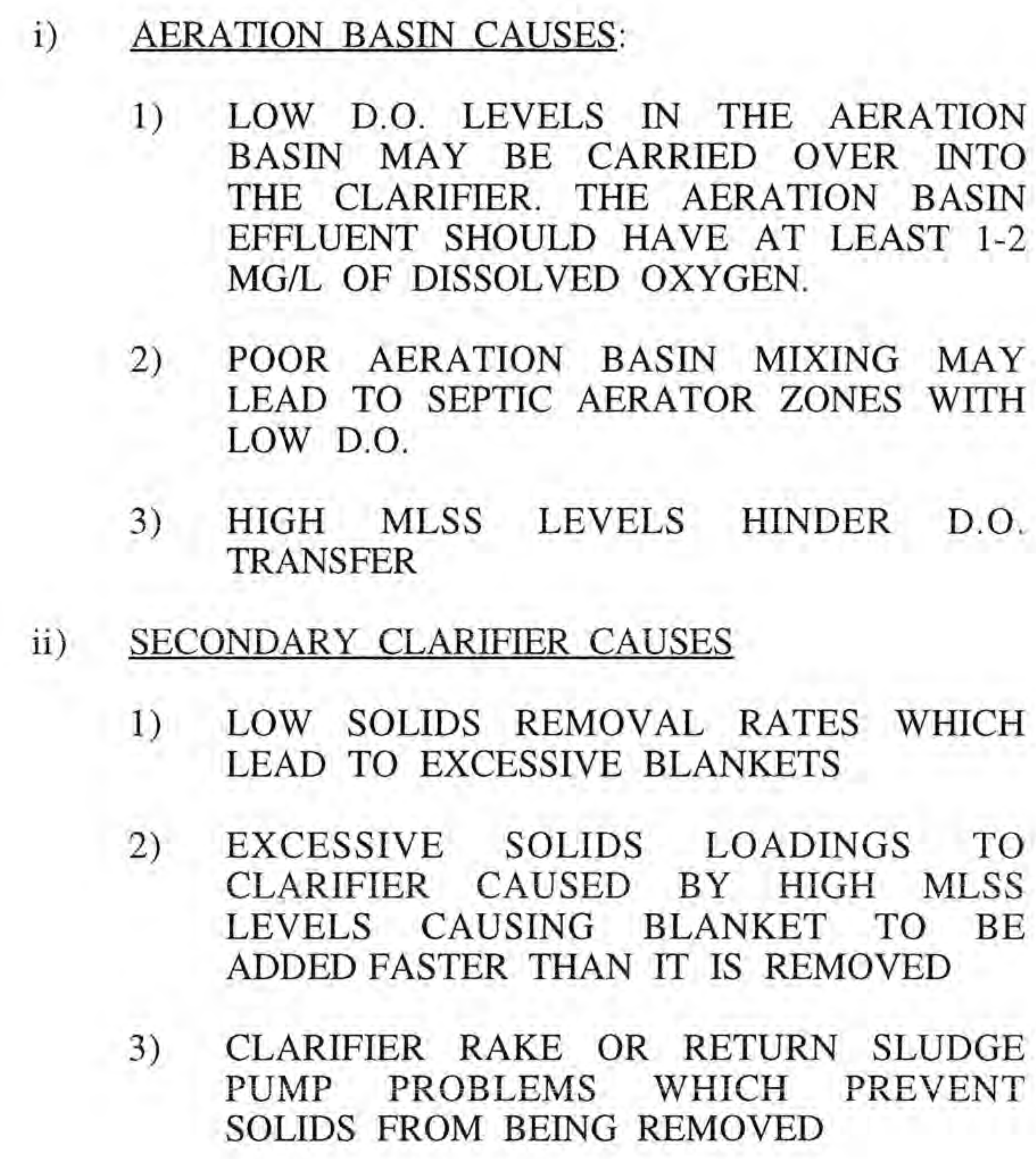
3) Increased F/M

5) RISING SLUDGE IN 2˚ CLARIFIER

a) SYMPTOM: Rising sludge is not the same as bulking sludge. Bulking sludge will not settle well. Rising sludge settles well, but comes to the clarifier surface later.

b) CAUSE: Oxygen is used up in sludge blanket and nitrates are then used as electron acceptor. This leads to the release of Nitrogen gas bubbles (Denitrification) which floats the sludge blanket.

c) ANALYSIS: Two potential process upsets may lead to rising sludge namely either problems in the aeration basin or problems in the secondary clarifiers:



i) AERATION BASIN CAUSES:

1) LOW D.O. LEVELS IN THE AERATION BASIN MAY BE CARRIED OVER INTO THE CLARIFIER. THE AERATION BASIN EFFLUENT SHOULD HAVE AT LEAST 1-2 MG/L OF DISSOLVED OXYGEN.

2) POOR AERATION BASIN MIXING MAY LEAD TO SEPTIC AERATOR ZONES WITH LOW D.O.

3) HIGH MLSS LEVELS HINDER D.O. TRANSFER

ii) SECONDARY CLARIFIER CAUSES

1) LOW SOLIDS REMOVAL RATES WHICH LEAD TO EXCESSIVE BLANKETS

2) EXCESSIVE SOLIDS LOADINGS TO CLARIFIER CAUSED BY HIGH MLSS LEVELS CAUSING BLANKET TO BE ADDED FASTER THAN IT IS REMOVED

3) CLARIFIER RAKE OR RETURN SLUDGE PUMP PROBLEMS WHICH PREVENT SOLIDS FROM BEING REMOVED

d) CORRECTIVE ACTION

1) AERATION BASIN

   a) INCREASE D.O. TO 1-2 MG/L AT EFFLUENT

   b) MAKE SURE BASIN IS WELL MIXED

   c) CHECK FOR HIGH MLSS LEVELS AND REDUCE IF NECESSARY

   d) DURING HIGH BASIN TEMPERATURE, MAY NEED LOWER MLSS LEVEL

2) RETURN SLUDGE RATES - INCREASE SUCH THAT THERE IS:

   a) NO RISING SLUDGE

   b) ONE TO THREE FOOT BLANKET

   c) SLUDGE HELD ONE HOUR MAXIMUM

3) SLUDGE WITHDRAWAL SYSTEM - CHECK SYSTEM FOR:

   a) PLUGGED LINES

   b) BROKEN RAKES

   c) RETURN PUMP MALFUNCTION

6) BULKING SLUDGE

a) SYMPTOM: SLUDGE WON'T SETTLE WELL OR COMPACT. THE EFFLUENT MAY BE CLEAR WITH CLUMPS OF RISING SOLIDS. THE BLANKET SETTLES SLOWLY, WON'T COMPACT, AND MAY REACH WEIRS.

b) ANALYSIS

1) MEASURE SVI OF THE MLSS:

$$\text{SVI} = \frac{(1000)\ (30\ \text{MIN. CONE})}{\text{MLSS IN MG/L}}$$

SVI	MLSS SETTLEABILITY
50 - 100	GOOD
100	AVERAGE
100 - 150	POOR
150+	BULKING

2) MEASURE NUTRIENTS, AERATOR D.O., DETENTION TIME IN AERATOR

3) LOOK FOR FILAMENTS UNDER MICROSCOPE

4) CHECK F/M

c) <u>CAUSES</u>

1) Filamentous Organisms

2) Dispersed FLOC

3) Short MLSS Aeration Period

d) <u>IMMEDIATE REMEDIES</u>

1) Add polymer to 2° clarifiers.

2) Chlorinate return sludge if filaments are present.

e) <u>CORRECTIVE ACTION</u>

1) <u>FILAMENTS</u>: Caused by aeration basin having low D.O., low pH, low Nitrogen, high sulfides, high MCRT, low F/M, etc. Identify filaments and their cause.

2) <u>DISPERSED FLOC</u>: Caused by high F/M or low MCRT. Lower F/M and increase MCRT by reducing waste.

3) <u>AERATION PERIOD</u>: Check detention time. Increase detention period in aerator by reducing RAS rate.

7) TOXIC SHOCK LOADS

a) SYMPTOMS: MLSS biomass dies quickly. Aeration basin D.O. rises sharply since biomass is dead and not consuming D.O. After D.O. increase, massive washout of MLSS may occur.

b) CAUSE: Toxic dump of chlorine, acid, heavy metals, toxic organics, etc.

c) ANALYSIS: Check D.O. levels, pH, toxic organic levels, heavy metals, and oxygen uptake rate.

d) IMMEDIATE REMEDIES

   1) Reduce waste rate to preserve MLSS

e) CORRECTIVE ACTION

   1) Locate source of toxics

   2) Reseed aeration basins

SPECIFIC FILAMENT CAUSES

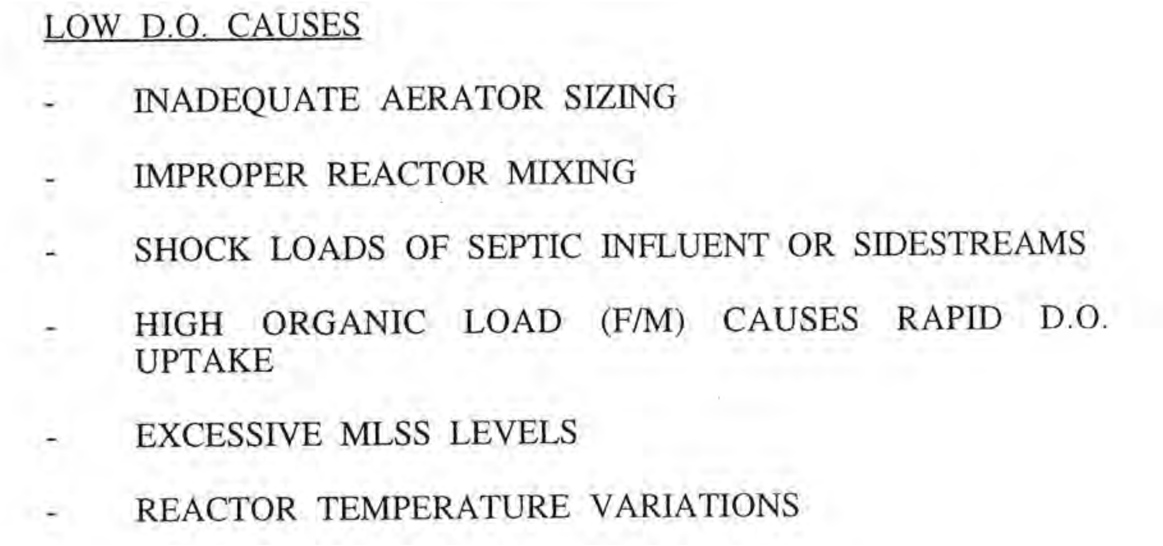
1. LOW D.O.

A. AT LOW TO MODERATE MCRT

- Type 1701
- S. Natans
- H. Hydrossis

B. AT HIGH MCRT

- M. Parvicella



LOW D.O. CAUSES

- INADEQUATE AERATOR SIZING
- IMPROPER REACTOR MIXING
- SHOCK LOADS OF SEPTIC INFLUENT OR SIDESTREAMS
- HIGH ORGANIC LOAD (F/M) CAUSES RAPID D.O. UPTAKE
- EXCESSIVE MLSS LEVELS
- REACTOR TEMPERATURE VARIATIONS

2. NUTRIENT DEFICIENCES

- Type 021N
- Thiothrix Spp.
- Type 0041
- Type 0675

NUTRIENT DEFICIENCY CAUSES

- Typical industrial waste issue
- Pollutant source may be low protein wastes
- Pollutant source may be high carbohydrate waste (Dairy, Brewery)
- Available nutrients may be chemically bound and not available for metabolism

3. LOW pH

- HIGH FUNGI LEVELS
- NOCARDIA

pH VARIATION CAUSES

- BACKGROUND WATER SUPPLY ACIDITY OR ALKALINITY
- LOW ALKALINITY WASTEWATERS POORLY BUFFERED
- INTERNAL PROCESS REACTION THAT CAUSES pH DROP (i.e.: NITRIFICATION)
- STRONG ACID OR BASE IN POLLUTANT LOAD

(NOTE THAT LOW pH IS GREATER PROBLEM WITH FILAMENT PROLIFERATION THAN HIGH pH)

4. SULFIDES

- THIOTHRIX SPP.
- TYPE 021N
- BEGGIATOA SPP.
- TYPE 0914

SULFIDE CAUSES

- INDUSTRIAL DISCHARGE OF SULFUR COMPOUNDS
- UPSTREAM SEWER SYSTEM SEPTICITY FROM:
  - LONG FORCE MAINS AND SEWER
  - EXCESSIVE PUMP STATION WET WELL VOLUMES
  - OVERSIZED SEWERS WITH POOR VELOCITY
  - PRIVATE PUMPING STATIONS TO REACH SEWER
- INTERNAL PROCESS ISSUES
  - SEPTIC AERATION POCKETS FROM POOR MIXING
  - INADEQUATE D.O. LEVELS
  - EXCESSIVE SLUDGE HOLDING TIMES
  - SEPTIC PROCESS SIDESTREAMS
  - LOW pH THAT CAUSES SULFIDE RELEASE

5. READILY SOLUBLE WASTES

- S. Natans
- Type 021N
- Thiothrix Spp.
- H. Hydrossis
- N. Limicola
- Type 1851

WASTE SOLUBILITY ISSUES

- Highly soluble wastes cause filament selection due to rapid food availability.
- Filaments have adsorption advantage over FLOC formers due to their high A/V.
- Common problem for high sugar and starch wastes from food processing.

6. SLOWLY METABOLIZED WASTES (LOW BIODEGRADABILITY)

- Type 0041
- Type 0675
- Type 0092
- M. Parvicella

BIODEGRADABILITY ISSUES

- If BOD not readily available, same condition as creating low F/M.
- FLOC formers selected against at low F/M.
- Common industrial waste issue (Papermills/Textiles/Tanneries).

7. OLD SLUDGES (HIGH MCRT)

- Nocardia
- M. Parvicella
- Type 0092
- Type 1891
- Type 0675
- May also see with low F/M wastes

OLD SLUDGE ISSUES

- High MCRT associated with low F/M.
- Older sludge less vital and more susceptible to filament competition.

FILAMENTOUS CONTROL

- Add systems that prevent favorable filamentous environments.

- Regulate industrial loadings through pretreatment permits to control filamentous causing pollutants.

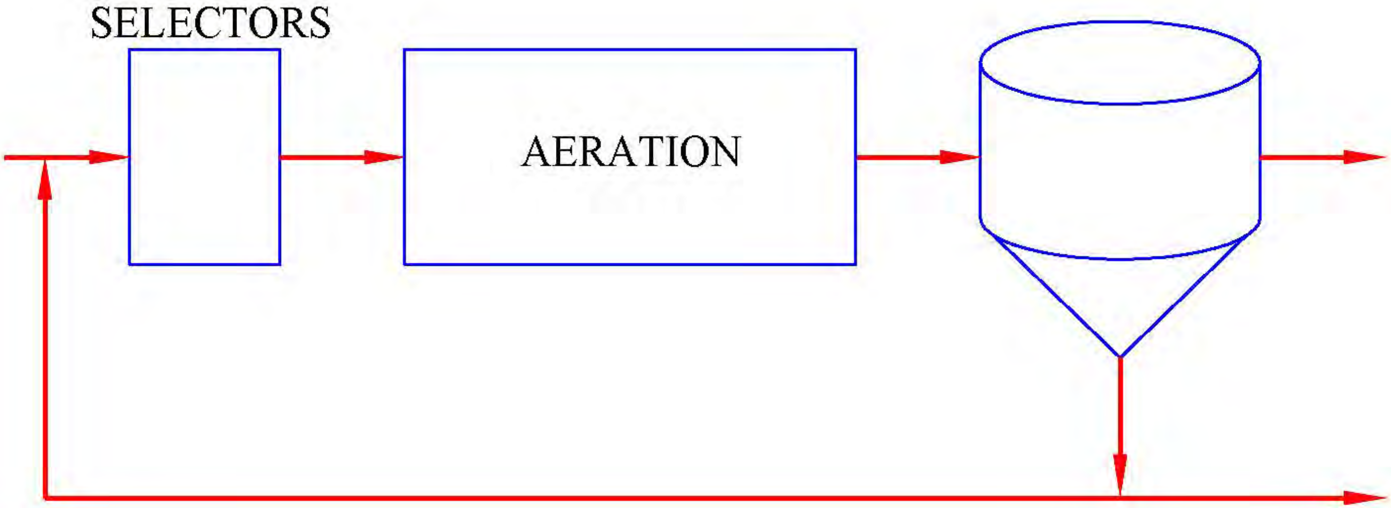
- Operate facilities using frequent microscopic examinations and SVI tracking.

- Provide short or long term filamentous control with RAS or MLSS chlorination.

- Possibly provide coagulant addition to final clarifiers.

SELECTORS

- Provide brief high F/M for 15-30 min.
- Promote floc formers.



TWO TYPES OF SELECTORS

1. KINETIC
   - Expose settled RAS to high food concertation before aeration basin.
   - Floc formers get exposed to food source first and are “selected” over filaments.
2. METABOLIC
   - Force electron acceptor change in selector.
   - Make it anoxic versus aerobic by mixing, but adding no oxygen.
   - Some filaments that are strict aerobes cannot tolerate anoxic conditions and die off.

ANOXIC SELECTOR BASIN

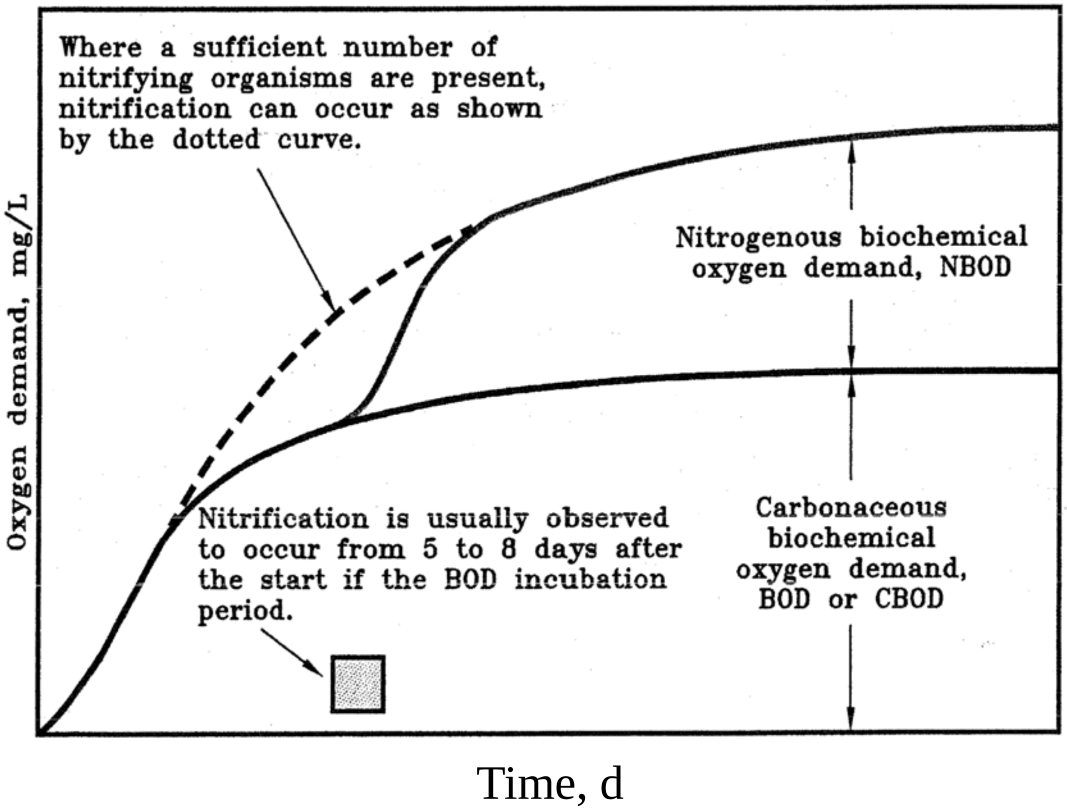
Oxygen Depletion Issues

- **Conventional wastewater treatment has focused on removing biodegradable organics and solids that deplete oxygen in receiving water.**

- **Nutrients can also deplete oxygen.**

- **Nitrogen removes oxygen from water as it changes its form.**

- **Nitrogen oxygen demand (NOD) and sediment oxygen demand (SOD) are not measured in typical effluent oxygen demand test (BOD), but can be significant.**



Initial Nitrogen Degradation

1. **Protein + urea ----> raw sewage**

2. **Raw sewage ----> organic N (ORG-N)**

3. **ORG-N + bacteria -----> NH^+_4 (ammonia)**
   (aerobic/
   anaerobic)

4. **(Organic-N is released as ammonia as the organic compounds bonded to nitrogen are biodegraded)**

Nitrification Process

- **Two groups of microbes are responsible for nitrification.**

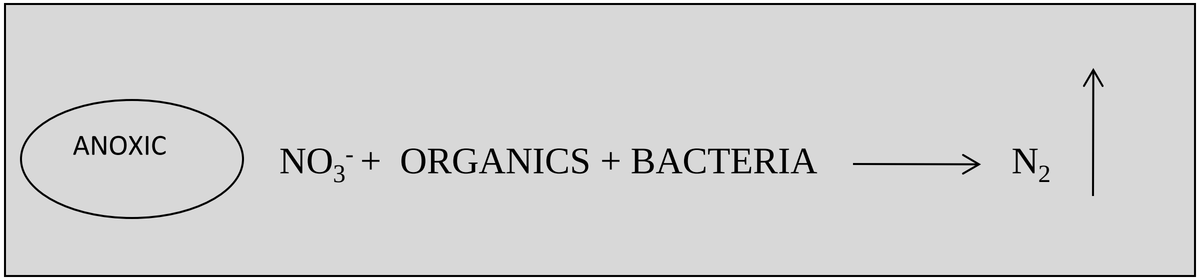
NITROSOMONAS + NH^{+}_{4} + O_2 $\longrightarrow$ NO_2^- (NITRITE UNSTABLE)

AEROBIC

NITROBACTER + NO_2^- + O_2 $\longrightarrow$ NO_3^- (NITRATE STABLE)

- **No conversion of ammonia in sewers due to lack of oxygen.**
- **Consumes oxygen in aeration basin.**
- **Removes nitrogen from aeration basin.**
- **Can remove 20-25% of nitrogen, not enough to meet license.**
- **Effluent still has 70-75% of influent nitrogen (now in NO^-_3 form).**

Denitrification Process



ANOXIC

$NO_3^- + \text{ ORGANICS} + \text{BACTERIA} \longrightarrow N_2 \uparrow$

- **Requires septic conditions devoid of oxygen (such as sludge blanket).**
- **Microbes utilize nitrate (NO_3^-) as electron acceptor.**
- **Rising N_2 gas bubbles lead to poor settleability in final clarifier.**
- **Only occurs if sludge is septic and if nitrate present.**
- **Plants that nitrify in aeration basin are prone to rising sludge in clarifier.**

Optimizing Process For Conventional BOD Removal Will Not Remove Nitrogen

- At best, conventional plant will convert most of ORG-N and NH_4^+ to NO_3^-.

- Clarifier effluent will be high in nitrate.

- Operator will take measures to avoid denitrification in clarifiers.

- If we want to remove nitrate, need to modify process to encourage nitrification and denitrification without allowing rising sludge in clarifier.

Creation of Anoxic Zone Ahead of Aeration Basin Promotes Nitrogen Removal

- **IN AEROBIC ZONE**

Bacteria remove organic carbon as always.

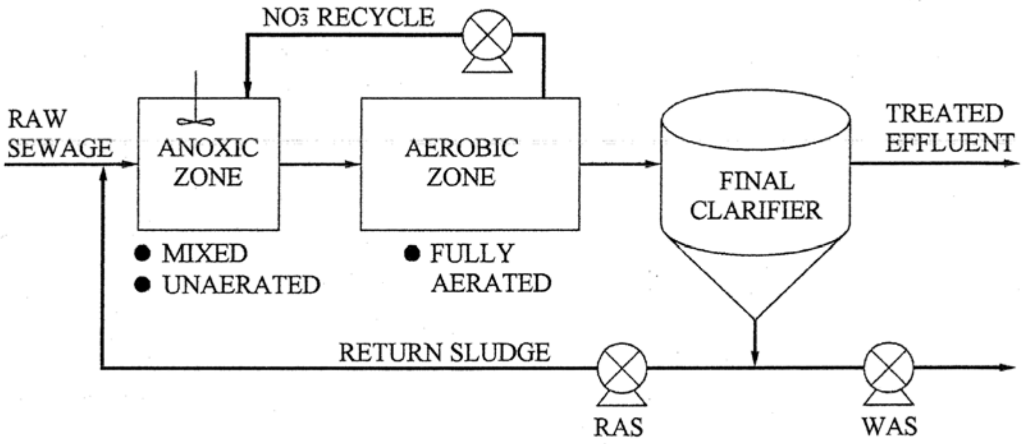
MLVSS MICROBES + ORGANICS + O_2 ⟶ MORE MLVSS + CO_2

NO_3^- is recycled from aeration basin back to anoxic zone.

- **IN ANOXIC ZONE**

Bacteria use NO_3^- as electron acceptor and produce N_2 gas which is stripped.

MLVSS MICROBES + NO_3^- ⟶ MORE MLVSS + N_2



Nitrification Process Requires Optimization of Microbes That Utilize Nitrogen

- **Principal microbes of interest are:**

  - **Nitrosomonas ($NH_4^+ \rightarrow NO_2^-$)**
  - **Nitrobacter ($NO_2^- \rightarrow NO_3^-$)**

- **In typical activated sludge aeration basin:**

  - **90% of MLVSS microbes are carbon (BOD) converters.**
  - **10% of MLVSS are nitrifiers.**

- **Activated sludge process is not an ideal reactor for nitrification because BOD microbes in MLVSS make it difficult for nitrifiers to compete.**

- **Biggest issue is nitrifiers have different environmental requirements than BOD microbes.**

Promoting Nitrification In Aeration Basin Through Longer MCRT

- **Nitrifiers grow at a slower rate than BOD microbes.**

- **Typical cell growth yield rates**

– **BOD microbes**	**0.50# cells/#BOD**
– **Nitrosomonas**	**0.03# cells/# NH_4^+**
– **Nitrobacter**	**0.01# cells/# NO_2^-**

- **BOD microbes reproduce every 15-30 min, but nitrifiers take 48-72 hours to reproduce.**

- **Need MCRT of at least 8-10 days for nitrifiers to take hold.**

- **To achieve longer MCRT, need to hold MLVSS longer at higher MLSS concentration.**

- **Need to make sure that plant has sufficient aeration and clarifier capacity to handle higher MLSS.**

Temperature Has Significant Impact on Rate of Nitrification

- Reaction rate increases at high temperatures and decreases at low temperatures.

MCRT VARIES DEPENDING ON TEMPERATURE

TEMPERATURE (˚C)	MCRT (DAYS)
10	30
15	20
20	15
25	10
30	7

- At 5˚C, nitrification ceases.

- Need long MCRT in winter to nitrify (most plants do not have enough aeration basin volume capacity to achieve winter MCRT).

- These long MCRT times may promote other process problems, such as low F/M filaments or high MCRT filaments.

Temperature Has Significant Impact on Rate of Nitrification

- Foaming is big problem in nitrifying plants.
- Some states are issuing seasonal nitrogen limits to take temperature effects into account.
- Nitrobacter are more impacted by temperature than nitrosomonas, so nitrite (NO_2^-) may accumulate in cold weather. (Partial nitrification)

Excess Aeration Capacity is Required for Nitrification

- **Need to maintain D.O. > 2.0 mg/l in aeration basin at all times.**
- **BOD microbes use 1.0 to 1.5 #O_2/#BOD.**
- **Nitrifiers use 4.33 # O_2/NH_4^+.**
- **Many older aeration systems were not sized properly to support nitrification. (Leads to D.O. deficits during unintentional nitrification)**
- **Since nitrification can occur even if not intended, conservative blower/aerator design practice is to include excess aeration capacity to accommodate nitrification.**
- **This may lead to high D.O. levels during non-nitrifying periods.**
- **Need to check aeration capacity if nitrification is to be promoted to remove nitrogen.**

pH/Alkalinity Control Is Critical To Nitrification

- **Alkalinity represents compounds in water that allow acids to be buffered without causing a pH drop.**

- **Nitrification reaction strips alkalinity out of water:**

$$NH_4 + O_2 + \text{ALKALINITY} \rightarrow NO_3^- + H^+ + \text{CELLS}$$

- **Every 1.0 # of NH_4^+ removed uses up 7.14# of alkalinity from water.**

- **Denitrification will bring back 50% of lost alkalinity, but still a net loss of 3.57# alkalinity/#NH_4^+.**

- **May need to add alkalinity back to process in form such as sodium bicarbonate to prevent pH drop.**

- **Need to keep at least 50 mg/l of alkalinity in aeration basin.**

- **Nitrification shuts down at pH <6.7 (optimal pH is 7.2-8.0).**

Indicators of Effective Nitrification

- Nitrification is occurring if NO_2^- and NO_3^- are increasing from inlet to outlet of aeration basin.

- Drop in NH_4^+ does not mean nitrification is occurring since other compounds react with NH_4^+ and remove it. (BOD microbes use NH_4^+ and some NH_4^+ is air stripped).

- Should test filtered MLSS for NO_3^- to check nitrification status.

- Growth of algae in clarifier launders may indicate nitrification (algae need NO_3^- instead of NH_4^+ like BOD microbes).

- Increase in D.O. demand in basin may mean nitrification is occurring.

- Drop in alkalinity or pH may be a sign of nitrification.

- If denitrification is occurring in clarifier with rising sludge, nitrification has had to have occurred first in aeration basin.

- Increase in chlorine demand to create total chlorine residual may occur since NH_4^+ will not be available to create chloramines.

Need to Promote Conditions That Sustain Nitrification In Aeration Basin While Still Treating BOD

- **Aeration basin microbes prefer NH_4^+ to build new cell mass.**
- **For nitrogen to pass thru cell wall, it must be in soluble form.**
- **Organic-N is not always soluble or readily available, because it is tied up with carbon.**
- **NH_4^+ is readily available to MLVSS and can pass through cell wall.**
- **If nitrification has converted a lot of NH_4^+ to NO_2^- or NO_3^-, microbes have ability to release enzymes to convert NO_2^-/NO_3^- back to NH_4^+.**
- **This conversion uses up energy that is no longer available for BOD treatment.**
- **This may result in incomplete BOD conversion in aeration tank.**
- **In nitrification process, need to make sure ample nutrients are present in aeration basin for BOD microbe so they will not remove NO_3^- to make NH_4^+.**
- **100/5/1 of BOD/N/P still applies.**

Unintentional Versus Intentional Nitrification

- **Nitrification occurs in all biological plants at various times of year if optimal conditions are there (even if it was not intended).**

- **As long as excess NH_4^+ is present after nutrient needs of BOD microbes are met, nitrification will occur if conditions are right to promote nitrifiers.**

- **For biological nutrient removal, we need to move from accidental, unintentional nitrification to controlled, intentional, complete nitrification.**

- **Operator should look for signs of complete versus incomplete nitrification.**

Signs of Complete Nitrification

- **NH_4^+ and NO_2^- will be less than 1.0 mg/l in settled MLSS effluent.**
- **NO_3^- will be greater than 10 mg/l in settled MLSS effluent.**
- **This means that most of influent nitrogen has been converted to nitrate.**
- **May want to leave some NH_4^+ in effluent to combine with chlorine in contact tank to form chloramines for disinfection. (in plants with complete nitrification and no NH_4^+, may need more Cl_2 to obtain residual.**

Signs of Complete Nitrification

- **WITH INCOMPLETE NITRIFICATION;**
  - **Not all NH_4^+ will convert to NO_2^-, or**
  - **NO_2^- is formed, but it does not convert to NO_3^- (nitrite accumulates).**
- **TYPICAL CAUSES OF PARTIAL NITRIFICATION**
  - **Cold or changing temperatures.**
  - **Nitrogen deficiencies (not enough nitrogen to support nitrifiers).**
  - **Excess influent ammonia at high pH (high pH puts NH_4^+ back to NH_3 which is toxic).**
  - **pH out of range.**
  - **Detention time too short.**
  - **Low dissolved oxygen.**
  - **High BOD slug load causes BOD microbes to grow rapidly and nitrifiers can't compete.**

Partial Nitrification Can Occur If Toxics Enter Plant

- **Small amount of toxics can inhibit nitrifiers.**

- **Nitrifiers are more sensitive than BOD microbes and will die or be inhibited by toxics first.**

- **Compounds that can inhibit nitrifiers:**
  - **Return sludge chlorination**
  - **Ammonia in NH_3 form**
  - **Heavy metals**
  - **Acidic wastes**

Nitrite Accumulation Can Cause Plant Process Upsets

- **Nitrobacter reaction ($NO_2^- \rightarrow NO_3^-$) will often shut down first.**

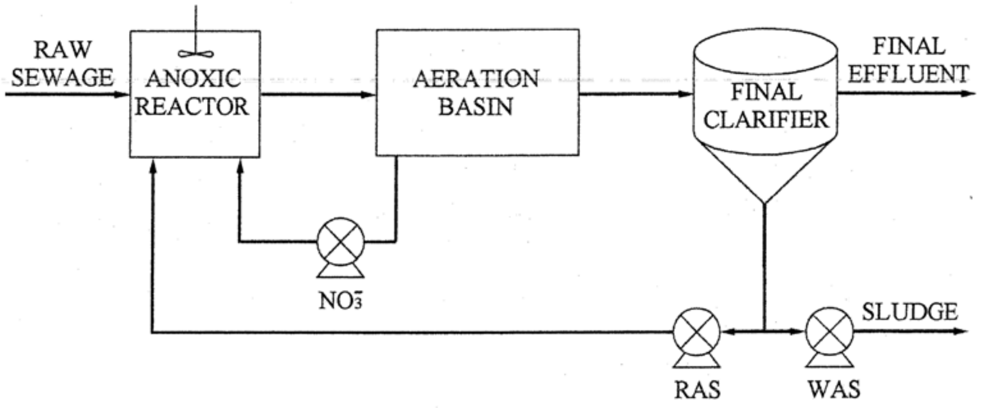
- **This causes nitrosomonas ($NH_4^+ \rightarrow NO_2^-$) to produce excess NO_2^- that will not be converted. (NO_2^- builds up in system).**

- **Excess NO_2^- can become toxic to BOD microbes and hinder BOD removal.**

- **NO_2^- will leave plant in effluent and react with chlorine. (Chlorine is a strong oxidant of nitrite).**

- **This may cause a large chlorine demand to be created (chlorine sponge).**

Better Approach Is To Place Anoxic Zone Ahead of Aeration Basin



- **Nitrification occurs in aeration basin to create NO_3^-.**
- **NO_3^- is recycled back to anoxic reactor which is mixed without oxygen.**
- **NO_3^- pump recirculation rate may approach 400% of Q_{AVG}.**
-
- **Raw sewage provides organic carbon to denitrifying microbes.**
- **Less organic carbon is sent to aeration basin, so less waste sludge is produced.**
- **No rising sludge issues in final clarifier because N_2 gas is stripped in aeration basin.**
- **This is called a “one-sludge system”.**

Summary of Presentation

- **Activated sludge process is very effective method to remove biodegradable organic matter from water.**

- **The key to its success is to consider what the microbes in the process need to grow.**

- **Good process control means the monitoring and manipulation of the microbial environment to create the desired effluent results.**