Biological Wastewater Treatment (BOD & N removal)

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Contents

- Wastewater treatment Importance
- Type of Pollutants
- Methods of Treatment
- Biological process as Wastewater Treatment
- Microorganisms (Type, Applications and Working)
- BOD removal
- Nitrogen removal (Type of Microbes, Environment condition & Operational parameter)
- Activated sludge process (Components, Monitoring & Operation)

Wastewater Treatment

Why Treat ?

- Environmental Effects
  - Image
- Reuse Implications
  - Potable
  - Industrial
- Regulatory Requirements

Types of Pollutants

1) Suspended Solids
2) Dissolved Solids
3) Colloidal Solids

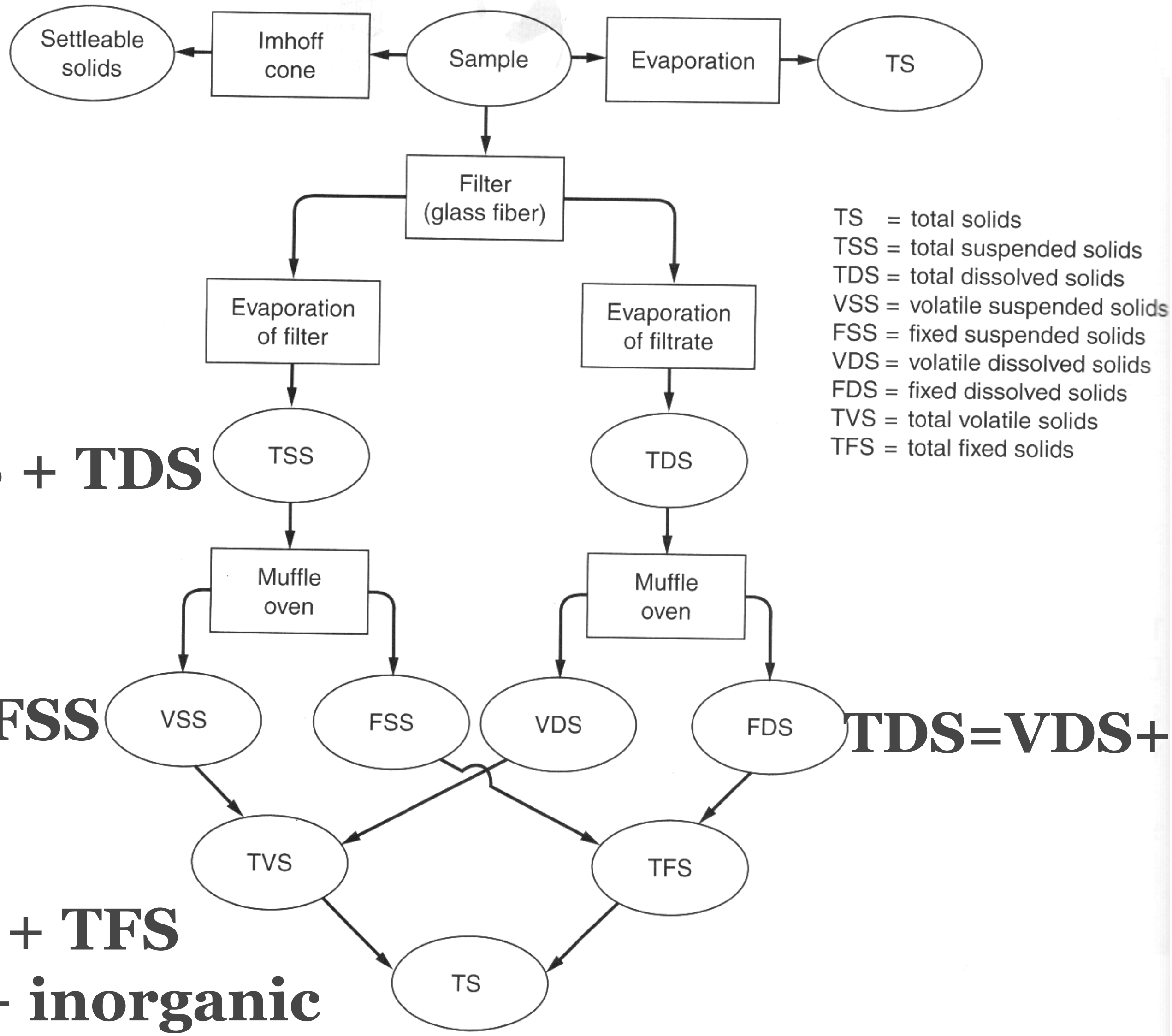
- Solids may be organic (eg. Phenol, oil, bacteria) or inorganic (eg. Salts, Ca, Mg, silt) in nature

The "Conventional" Pollutant Measures:

- Oxygen (BOD, COD, DO)
- Solids content (TS)
- Nutrients (phosphorus, nitrogen)
- Acidity (pH)
- Bacteria (e.g., fecal coliform)
- Temperature

Figure 2–3

Interrelationships of solids found in water and wastewater. In much of the water quality literature, the solids passing through the filter are called dissolved solids. *(Tchobanoglous and Schroeder, 1985.)*



TS = TSS + TDS

TSS=VSS+FSS

TDS=VDS+FDS

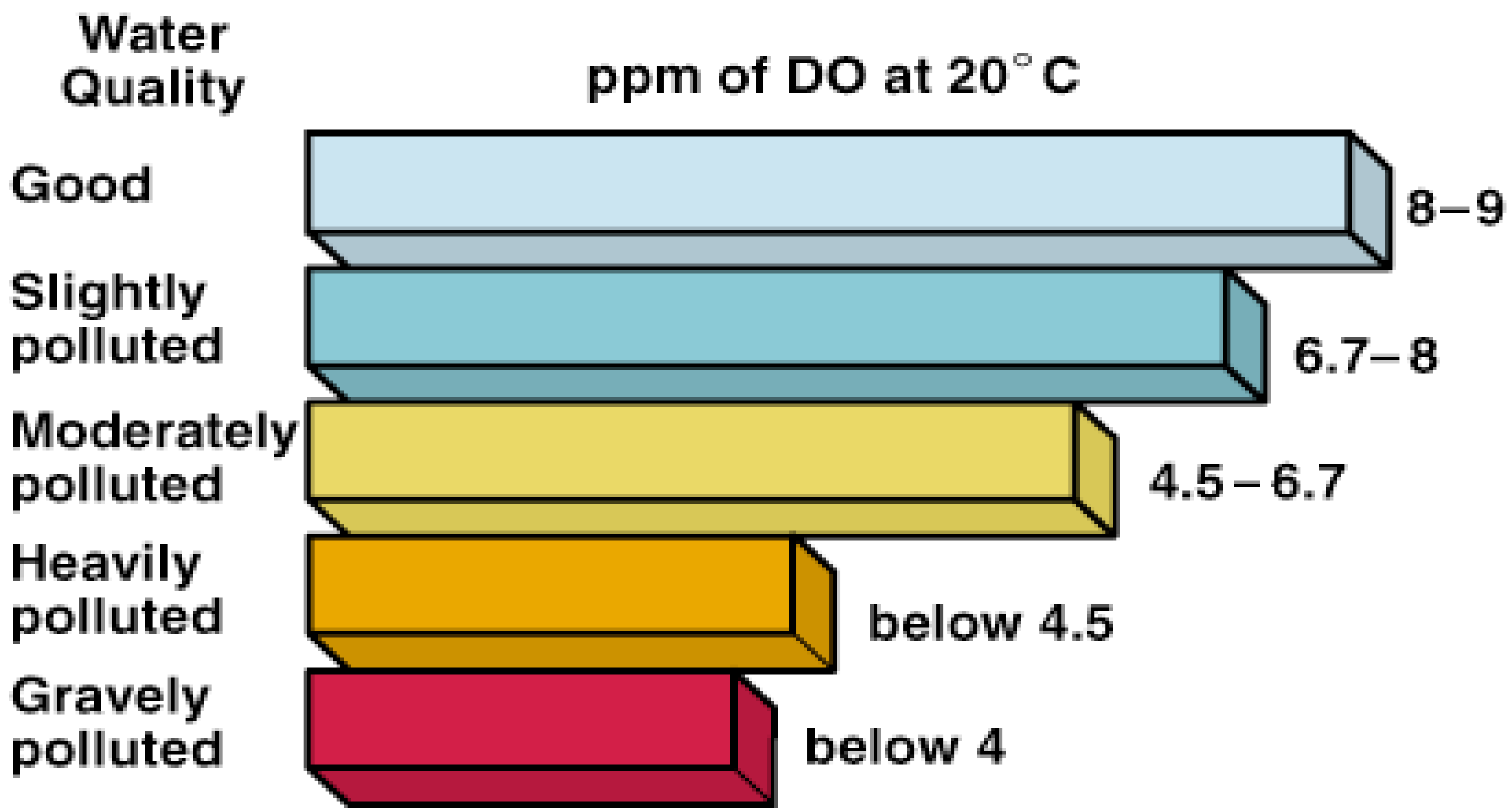
TS = TVS + TFS

TS = organic + inorganic

Metcalf & Eddy

Measurements of Gross Organic Content

- Dissolved Oxygen (DO)
- Biochemical oxygen demand (BOD)
- Chemical oxygen demand (COD)
- Total organic carbon (TOC)
- Theoretical oxygen demand (ThOD)


Water Quality
ppm of DO at 20° C
Good
8–9
Slightly polluted
6.7–8
Moderately polluted
4.5–6.7
Heavily polluted
below 4.5
Gravely polluted
below 4

Biological Oxygen Demand (BOD)

- BOD: Oxygen is removed from water when organic matter is consumed by bacteria
- Low oxygen conditions may kill fish and other organisms

http://www.lcusd.net/lchs/mewoldsen/Water_Pollution_LCHS.ppt

Chemical Oxygen Demand

- The quantity of oxygen used in biological and non-biological oxidation of materials in wastewater

- The determination of chemical oxygen demand (COD) is used in municipal and industrial laboratories to measure the overall level of organic contamination in wastewater. The contamination level is determined by measuring the equivalent amount of oxygen required to oxidize organic matter in the sample

- BOD/COD ratio – the greater the ratio, the more oxidizable (biologically treatable) the waste. Ratios rarely exceed 0.8-0.9.

Total Organic Carbon (TOC)

- Measure of WW pollution characteristics
- Based on the chemical formula
- Test methods use heat and oxygen, UV radiation, and/or chemical oxidants to convert organic carbon to carbon dioxide, which can then be measured
- Can be assessed in 5 to 10 minutes
- Theoretical > Measured

Theoretical Oxygen Demand (ThOD)

- WW generally contains a mixture of carbon, hydrogen, oxygen, and nitrogen
- Calculated using stoichiometric equations
- Considers both carbonaceous and nitrogenous oxygen demand
  - Main difference from COD

Methods of Treatment

1) Clarification, Sedimentation, Flocculation are used for suspended and/ or colloidal pollutants

2) Evaporation, Reverse Osmosis etc, are used for dissolved inorganic pollutants

3) Oxidation/ Synthesis by Micro-organisms is carried out (Biological Treatment) for Dissolved Organic Pollutant

Biological Processes…

- cell: derives energy from oxidation of reduced food sources (carbohydrate, protein & fats)

Requires…..

- microbes with the ability to degrade the waste organics
  - contact time with the organics
  - favorable conditions for growth

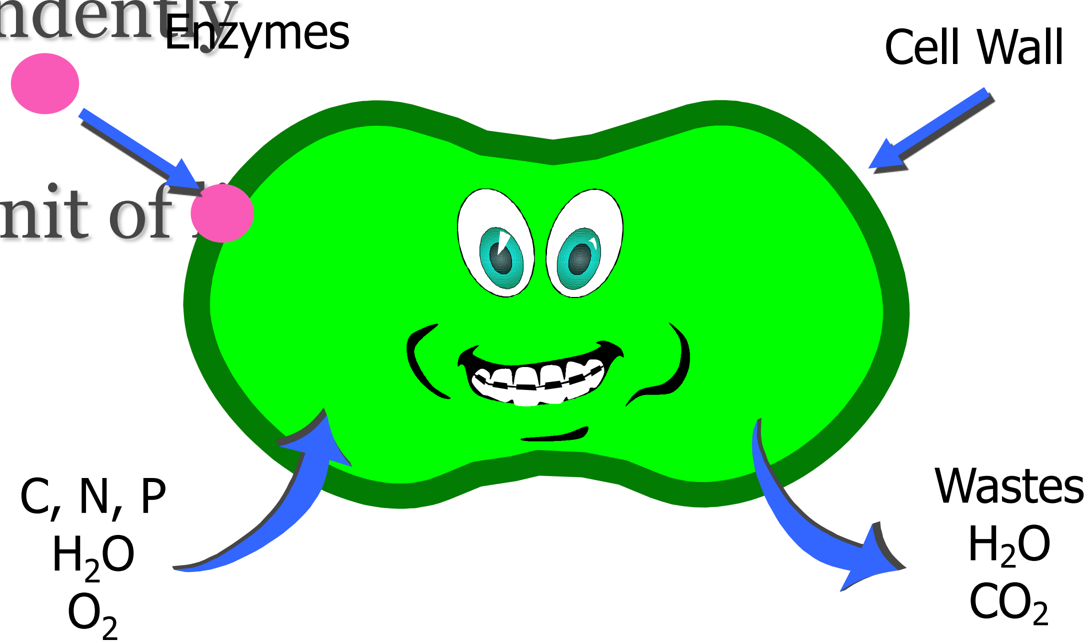
Objective of Biological Wastewater Treatment

- To stabilize the organic matter (Soluble and none settleble)

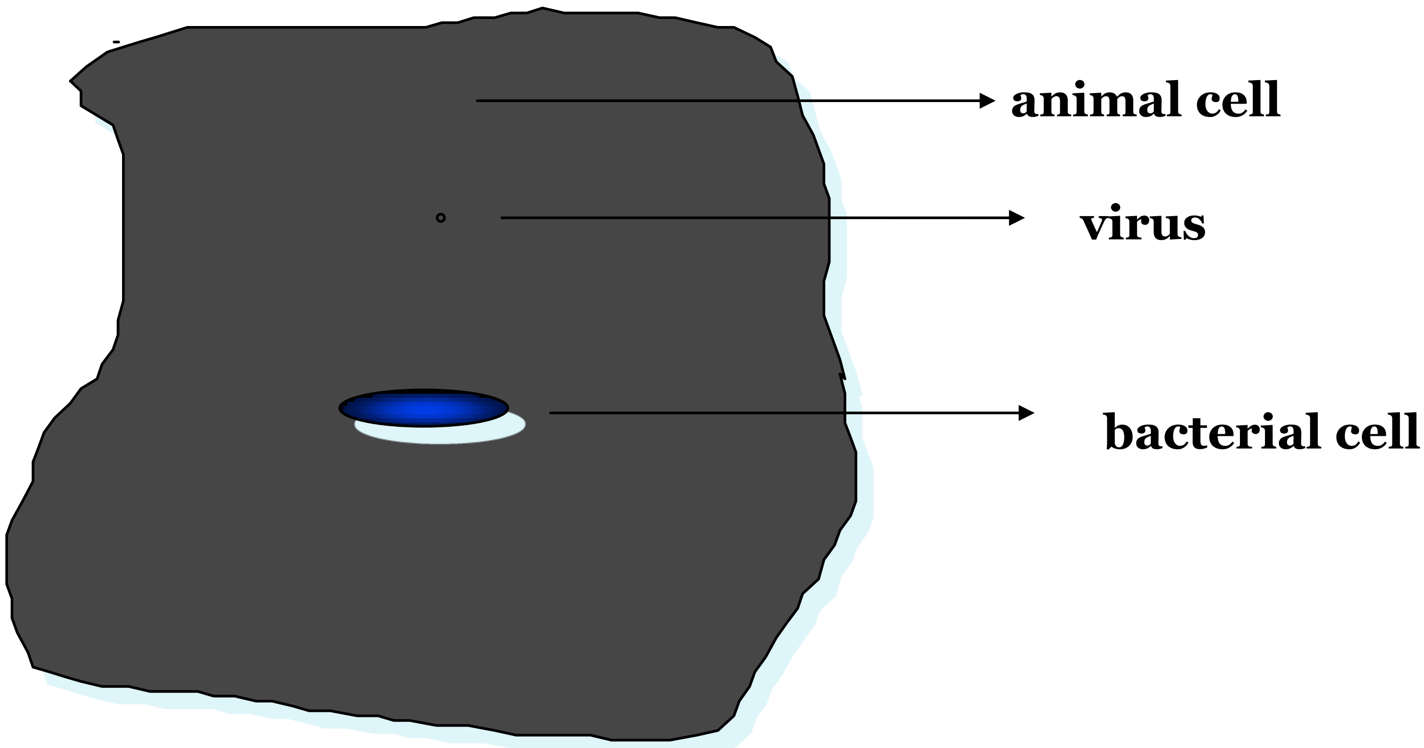
- To reduce the amount of dissolved phosphorus and nitrogen in the final effluent

Microorganisms

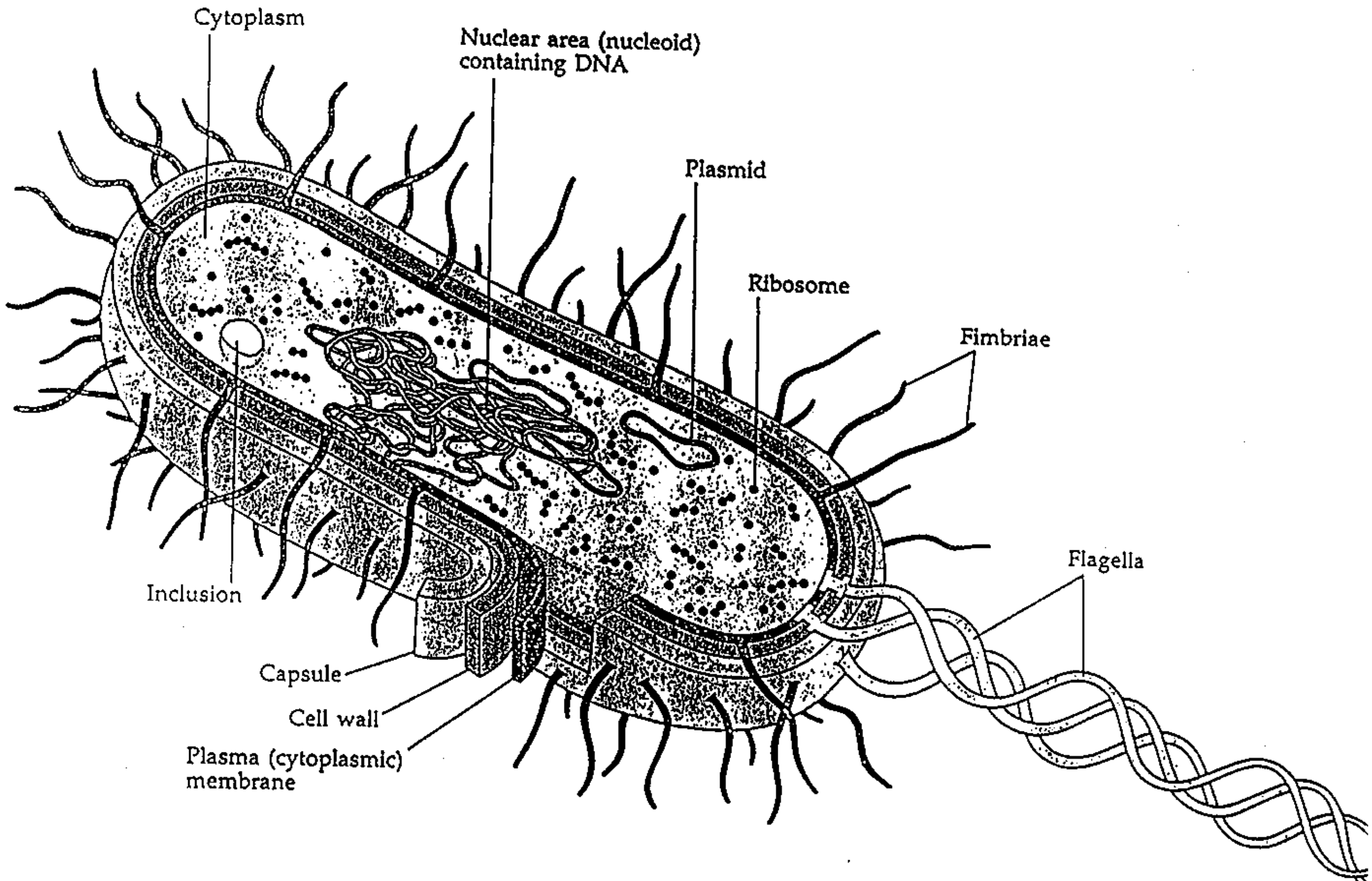
- Microorganisms = single-celled organism capable of performing all life functions independently
- Basic unit of



Typical animal cell:



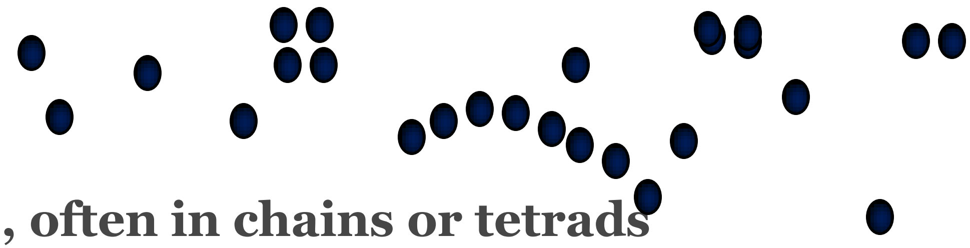
Bacterial Cell



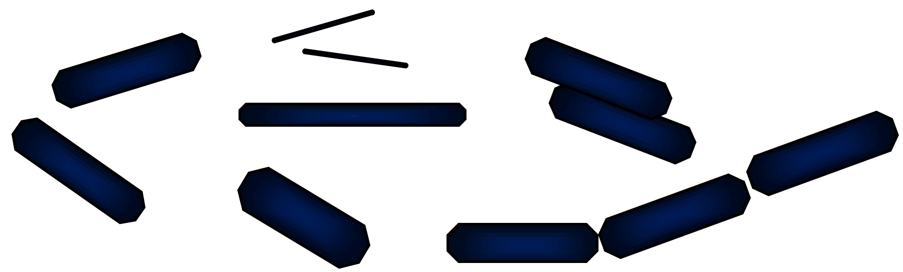
Type of microorganisms

Shape of Bacteria

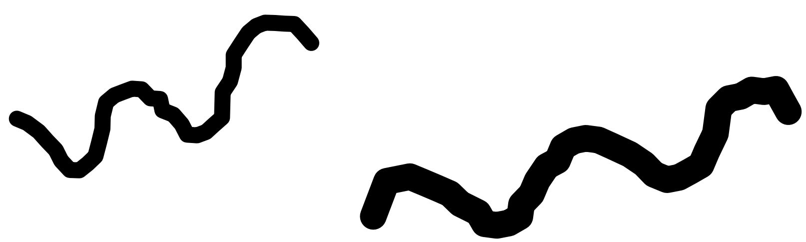
- **Cocci**
  - spherical cells, often in chains or tetrads



- **Rods**
  - most common shape
  - vary in shape & size



- **Spiral Rod**
  - curved rods



Growth

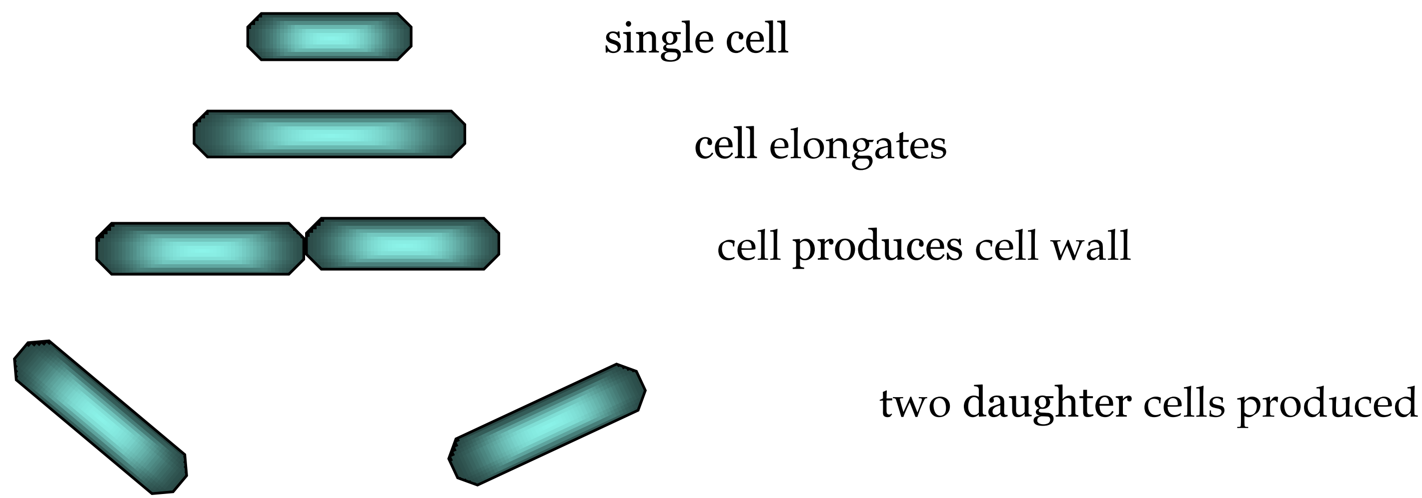
- **Growth = cell division**

  one cell divides to produce two equal daughter cells

- **Generation time**

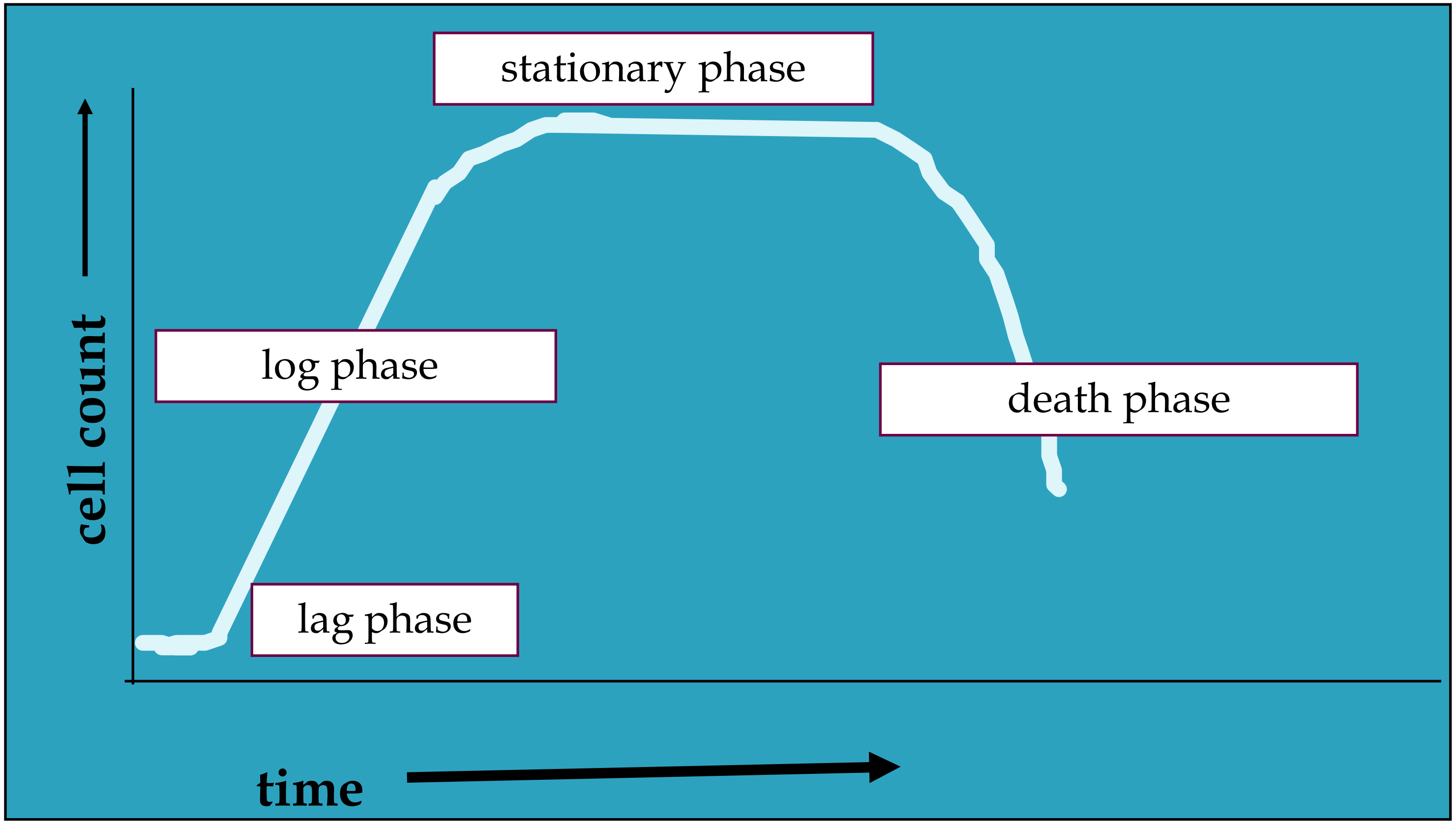
  length of time required for bacterial population to double

Bacterial Growth: cell division



The cell replicates all its components, reorganizes it into two cells, forms a cell wall, and separates.

Growth curve (typical phases of growth)



Composition of bacterial cell:

Percentage by weight

Carbon	50
Oxygen	20
Nitrogen	14
Hydrogen	8
Phosphorus	3
Sulfur	1
Potassium	1
Sodium	1
Calcium	0.5
Magnesium	0.5
Iron	0.2
All other elements	0.3

Cell Formula $C_{60}H_{84}N_{12}O_{24}P$

Requirements for Bacterial Growth

- Nutritional
  - Carbon source (waste to be degraded)
  - N & P (100:5:1;C:N:P)
  - Trace minerals
- Environmental
  - Oxygen (terminal electron acceptor)
  - Temperature
  - Water
  - pH
  - Non-toxic

Microorganisms

Classification:

- Heterotrophic- obtain energy from oxidation of organic matter (organic Carbon)
- Autotrophic- obtain energy from oxidation of inorganic matter (CO_2, NH_4, H^+)
- Phototrophic- obtain energy from sunlight

Biochemical Environments

Three Major Ones

- Aerobic - oxygen
- Anoxic - nitrate
- Anaerobic - strict and facultative

Biological Treatment

- 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
- ✓Combined Systems

- ✓Pond Processes

- ✓Aerobic
- ✓Maturation
- ✓Facultative
- ✓Anaerobic

Major Aerobic Biological Processes

Type of Growth	Common Name	Use
Suspended Growth	Activated Sludge (AS)	Carbonaceous BOD removal (nitrification)
	Aerated Lagoons	Carbonaceous BOD removal (nitrification)
Attached Growth	Trickling Filters	Carbonaceous BOD removal. nitrification
	Roughing Filters (trickling filters with high hydraulic loading rates)	Carbonaceous BOD removal
	Rotating Biological Contactors	Carbonaceous BOD removal (nitrification)
	Packed-bed reactors	Carbonaceous BOD removal (nitrification)
Combined Suspended & Attached Growth	Activated Biofilter Process ✓Trickling filter-solids contact process ✓Biofilter-AS process ✓Series trickling filter-AS process	Carbonaceous BOD removal (nitrification)

C
Removal

Biological Carbonaceous Removal

aerobic

- oxidation

$$\text{CHONS (organic matter)} + O_2 + \text{Nutrients} \xrightarrow{\text{bacteria}} CO_2 + NH_3 + \underset{\text{(new bacterial cells)}}{C_5H_7NO_2} + \text{other end products}$$

- endogenous respiration

$$C_5H_7NO_2 + 5O_2 \xrightarrow{\text{bacteria}} 5CO_2 + 2H_2O + NH_3 + \text{energy} \quad \text{(cells)}$$

N
Removal

What are the forms of nitrogen found in wastewater?

- **Forms of nitrogen:**

TKN	***Organic N***	Total N
	Ammonia	
	Nitrite	
	Nitrate	

Why is it necessary to treat the forms of nitrogen?

- **Improve receiving stream quality**
- **Increase chlorination efficiency**
- **Minimize pH changes in plant**
- **Increase suitability for reuse**
- **Prevent NH_4 toxicity**
- **Protect groundwater from nitrate contamination**
- **Increases aquatic growth (algae)**
- **Increases DO depletion**

How is N removed or altered by secondary (biological) treatment?

- **Biological assimilation**
  BUG = $C_{60}H_{86}O_{23}N_{12}P$

- **0.13 lb N/lb of bug mass**

- **Biological conversion by nitrification and denitrification**

Nitrification

- NH_4^+ → *Nitrosomonas* → NO_2^-
- NO_2^- → *Nitrobacter* → NO_3^-

- **Notes:**
  - Aerobic process
  - Control by SRT (4 + days)
  - Uses oxygen → 1 mg of NH_4^+ uses 4.6 mg O_2
  - Depletes alkalinity → 1 mg NH_4^+ consumes 7.14 mg alkalinity
  - Low oxygen and temperature = difficult to operate

Denitrification

- NO_3^- → denitrifiers (facultative bacteria) → N_2 gas + CO_2 gas

- **Notes:**
  - **Anoxic process**
  - **Control by volume and oxic MLSS recycle to anoxic zone**
  - **N used as O_2 source = 1 mg NO_3^- yields 2.85 mg O_2 equivalent**
  - **Adds alkalinity → 1 mg NO_3^- restores 3.57 mg alkalinity**
  - **High BOD and NO_3^- load and low temperature = difficult to operate**

Biological Nitrogen Removal

Nitrification

-energy

$$NH_4^+ + 1.5\,O_2 \xrightarrow{\textit{Nitrosomonas}} NO_2^- + H_2O + 2\,H^+ + (240\text{-}350\ kJ) \qquad (1)$$

$$NO_2^- + 0.5\,O_2 \xrightarrow{\textit{Nitrobacter}} NO_3^- + (65\text{-}90\ kJ) \qquad (2)$$

-assimilation

$$15\,CO_2 + 13\,NH_4^+ \xrightarrow{\textit{Nitrosomonas}} 10\,NO_2^- + 3\,C_5H_7NO_2 + 23\,H^+ + 4\,H_2O \qquad (3)$$

$$5\,CO_2 + NH_4^+ + 10\,NO_2^- + 2\,H_2O \xrightarrow{\textit{Nitrobacter}} 10\,NO_3^- + C_5H_7NO_2 + H^+ \qquad (4)$$

- **overall reaction**

$$NH_4^+ + 1.83\,O_2 + 1.98\,H\,CO_3^- \rightarrow 0.021\,C_5H_7NO_2 + 0.98\,NO_3^- + 1.04\,1H_2O + 1.88H_2CO_3$$

Biological Nitrogen Removal

- factors affecting nitrification
  - temperature
  - substrate concentration
  - dissolved oxygen
  - pH
  - toxic and inhibitory substances

$$\mu = \mu_m \left[\frac{NH_4 - N}{K_N + NH_4 - N} \right] \cdot \left[\frac{DO}{K_O + DO} \right] \left(e^{0.095(T-15)} \right) \left[1 - 0.83(7.2 - pH) \right]$$

Biological Nitrogen Removal

- Denitrification
  - Nitrate is used instead of oxygen as terminal electron acceptor
  - Denitrifiers require reduced carbon source for energy and cell synthesis
  - Denitrifiers can use variety of organic carbon source - methanol, ethanol and acetic acid

$$NO_3^- \longrightarrow NO_2^- \longrightarrow NO \longrightarrow N_2O \longrightarrow N_2$$

$$NO_3^- + 1.08CH_3OH + H^+ \longrightarrow 0.065C_5H_7O_2N + 0.47N_2 + 0.76CO_2 + 2.44H_2O$$

Biological Nitrogen Removal

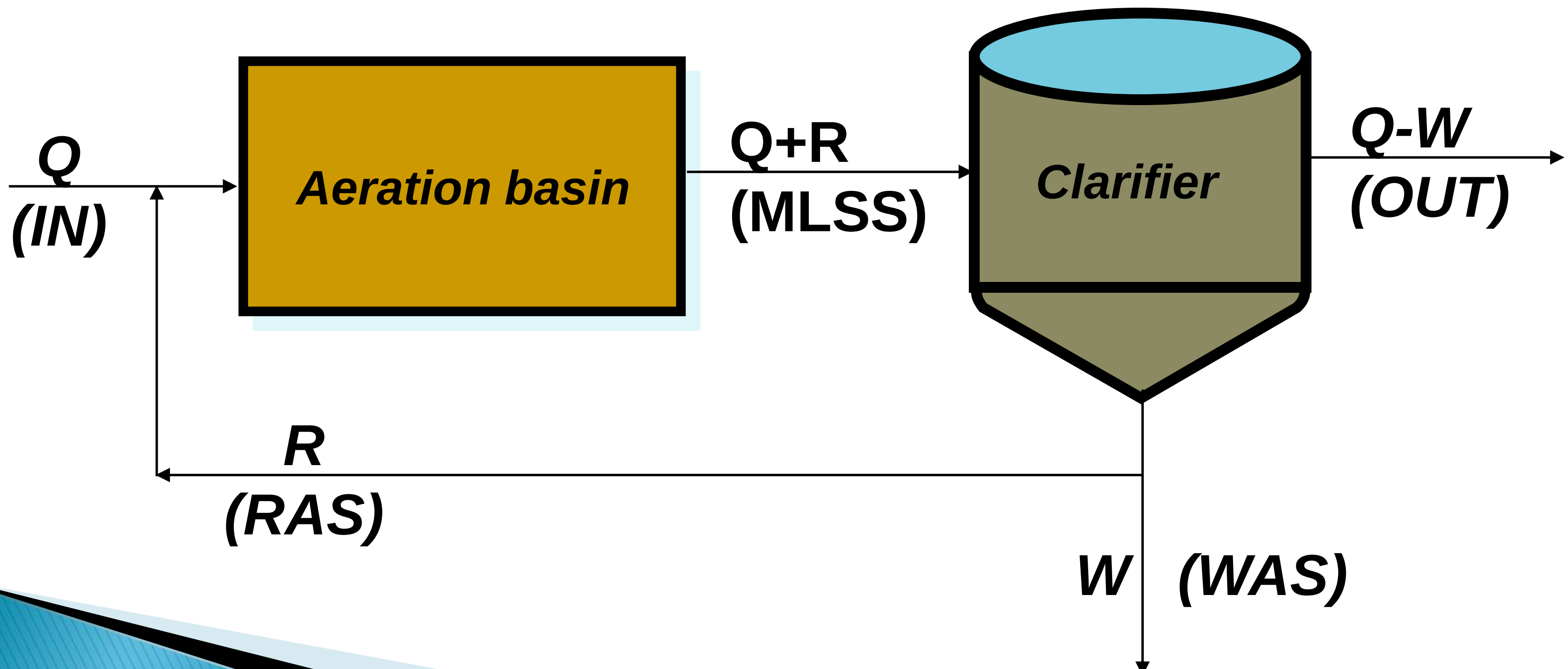
- factors affecting denitrification
  - temperature
  - dissolved oxygen
  - pH

Activated Sludge Process

Activated Sludge Process

- There are two phases to biological treatment
  - "Mineralization" of the waste organics producing CO_2 + H_2O + microbes
  - Separation of the microbes and water

Activated Sludge Process



Definitions: (measurement & control)

- MLSS / MLVSS (*active microbes*)
- F / M (*food to mass*)
- RAS / WAS (*recycle & waste*)
- MCRT (sludge *age*)
- DOUR / SOUR (how *active*?)
- SVI / SSV_{30} (*settleability*)

MLSS

Mixed Liquor Suspended Solids

The suspended solids in the totally mixed aeration basin liquid

MLVSS
Mixed Liquor Volatile Suspended Solids

- The part of MLSS which will combust.

- A good approximation of the active biological portion of the MLSS (75 - 85%)

- In a well oxidised sample,

$$\text{MLVSS} = \text{biomass}$$

Food to Mass Ratio

$$F + M + O_2 \longrightarrow M + CO_2 + H_2O$$

$$F/M = \frac{\text{kg/day } BOD_5}{\text{kg MLVSS}}$$

Concept: Microorganisms work best with an optimum amount of food

Recycle (RAS)

- Recycle converts once-through system into Activated Sludge
- Clarifier separates solids (biomass), thickens and allows return of microorganisms (RAS)
- Recycle or clarifier underflow influences thickening and mass balances
- Retention Time of Biomass no longer limited by Hydraulic Retention time

Wasting (WAS)

- Biomass is created as the microorganisms grow = Sludge Yield (kg/kg-deltaBOD)
- Sludge Yield varies by type of waste and operating conditions (e.g. growth rate)
- For Equilibrium conditions, Yield, or Excess Sludge must be removed or Wasted
- Excess sludge can involve significant influent inert TSS

Sludge Age or MCRT

- MCRT = Mean Cell Residence Time
- System level, or Gross parameter
- One definition is "average time biomass stays in the system"
- Calculated by Total Solids in System / Total Solids being Wasted
- Mathematically = 1/net growth rate

MCRT =

$$\frac{[\text{MLVSS (ppm)} * \text{Aeration Vol. } (m^3)]}{[\text{TSS(ppm)} * \text{Eff } (m^3/d)] + [\text{RAS MLVSS (ppm)} * \text{WAS } (m^3/d)]}$$

or MCRT = Total Solids/ Wasted Solids

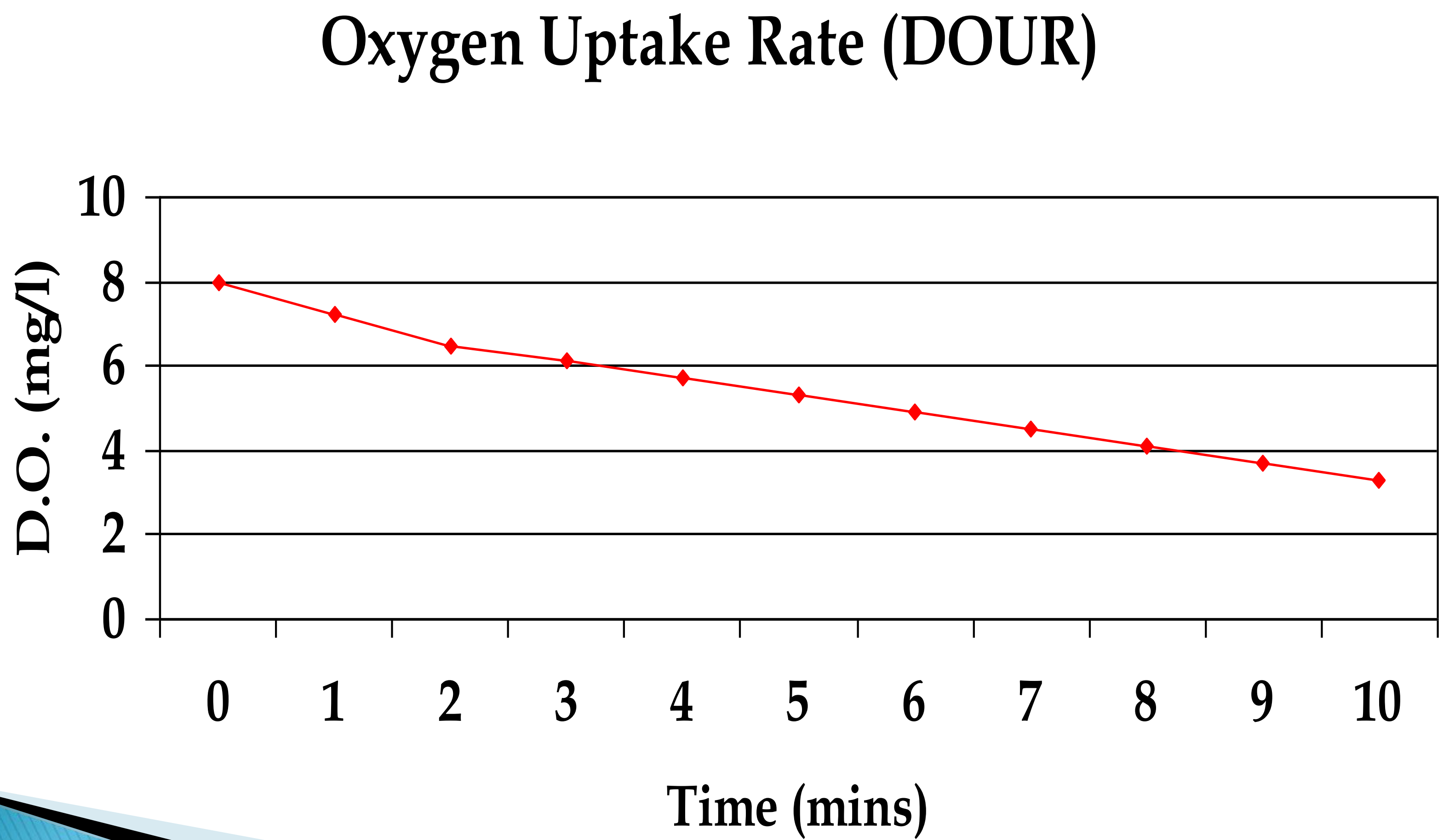
In practice, MLSS usually used

Oxygen Uptake

- DOUR and SOUR or Respiration Rate (RR) can provide useful information on health of biomass compared to normal operation
- High F/M operation = high growth rate = High RR (e.g. 20+ mg/l/hr/g/VSS)
- Extended Aeration ("old" sludge) = Low F/M = "Low" RR (e.g. 3- 12)
- Do not confuse RR with total O_2 demand

DOUR = (6.5-3.3)/(10-2) = 3.2/8 = 0.4 mg/l/min
= 24 mg/l/hr

SOUR-- *Specific Oxygen Uptake Rate or DOUR/ppm MLVSS*



SOUR-- Why do it?

- Indicates the health of the bugs
- Can show if there is a toxin the basin
- Has been shown to be correlated to the final effluent COD so it can be used as an indication of the effluent quality during an upset or change in operating conditions.

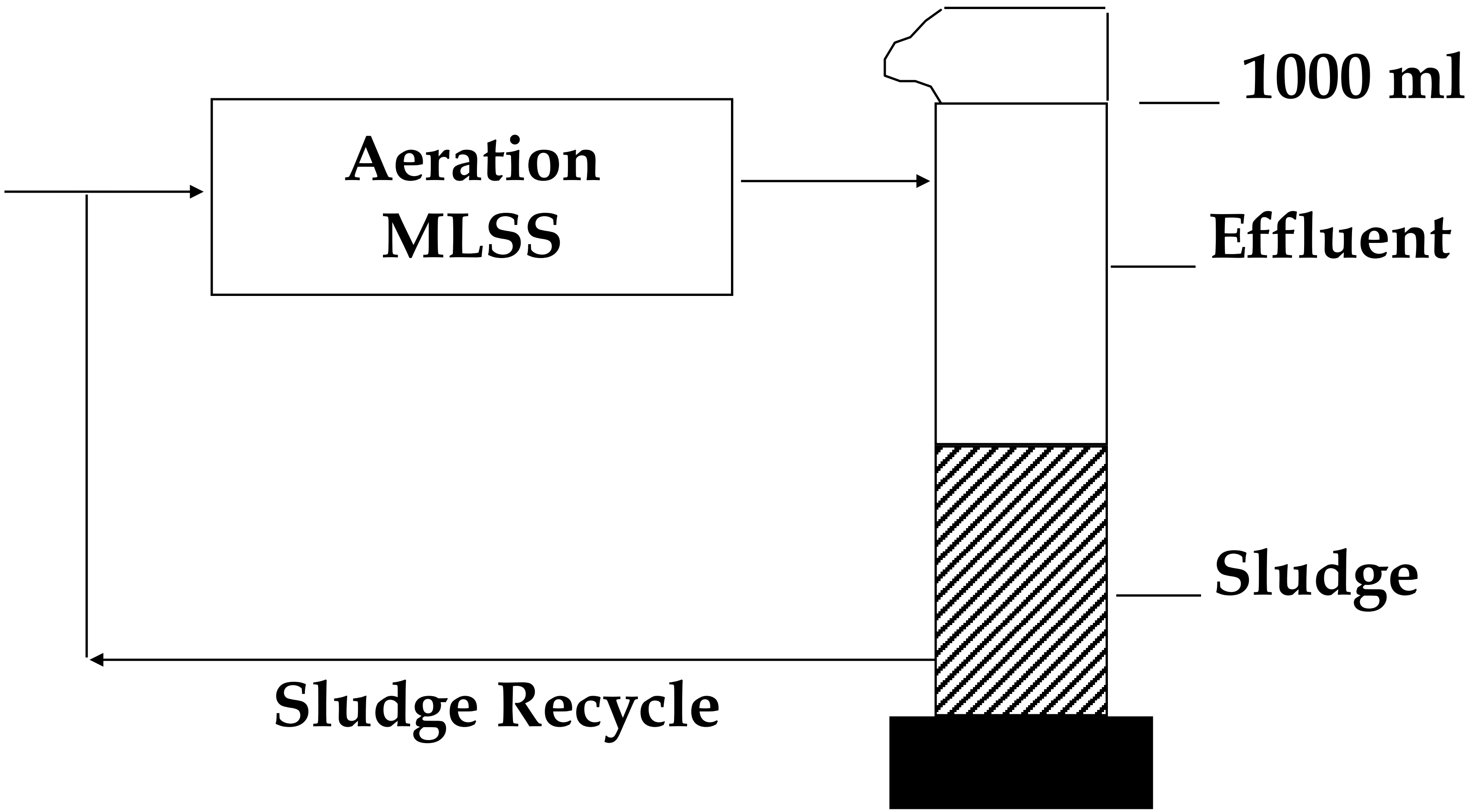
SVI

$$SVI = \frac{SSV_{30}(ml) \ *1000}{MLSS\ (mg/L)}$$

= Volume occupied by 1 gm of MLSS after 30 min of settling (usually 1 L sample)

SSV_{30} = Sludge settled volume after 30 minutes in ml/L

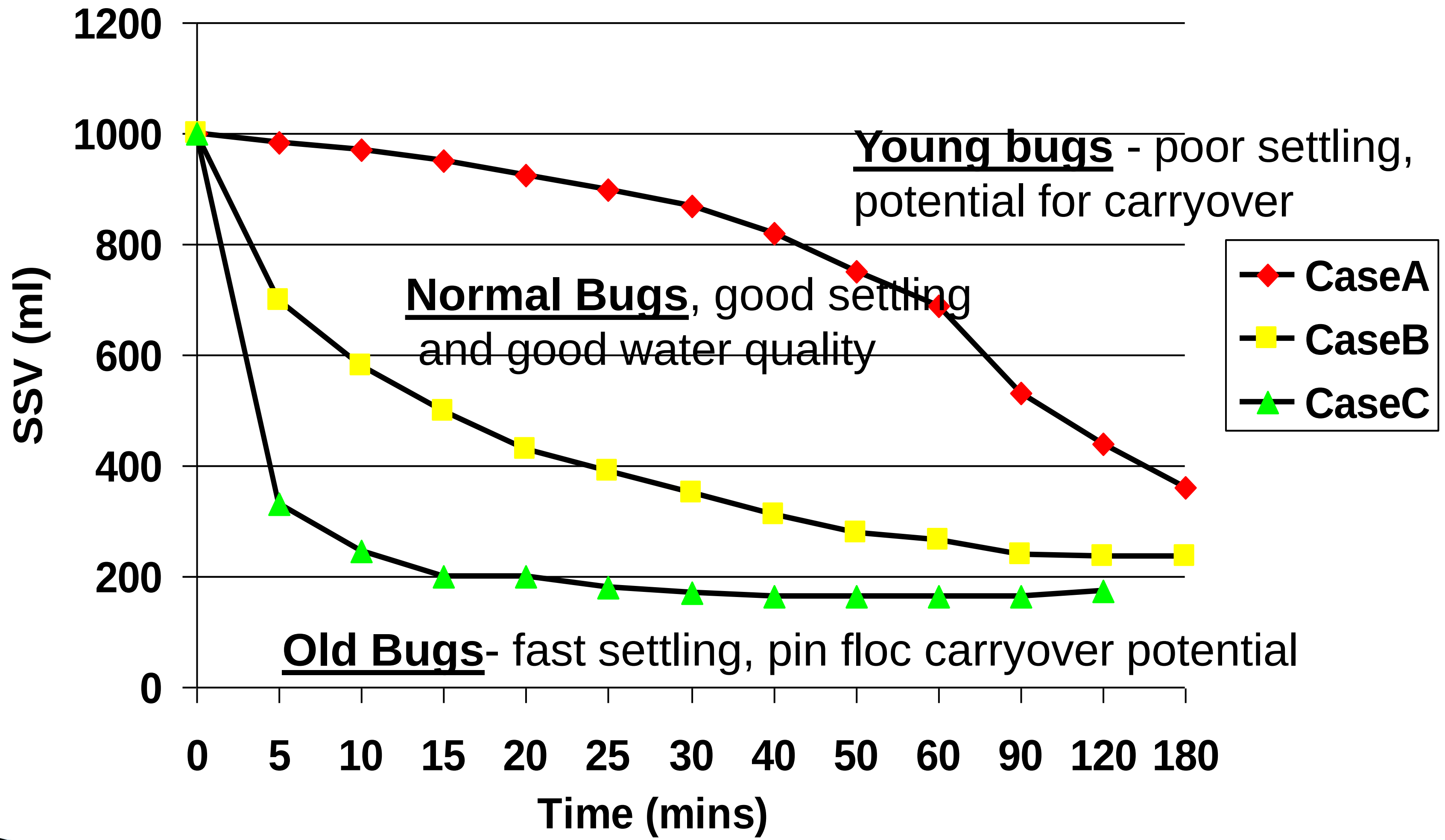
SVI target → 50 - 150



Information from Settling Tests (SVI)

- Graph of Rate of Settling = age of sludge
- Supernatant Condition = cloudy, ash, pin floc
- Production of Gas after 1- 2+ hr = denitrification
- Floating material, SVI = Filamentous Bulking
- Colour of Sludge e.g. brown or gray
- Shape of curve and Expected RAS concentration

Example of Settling Data



Operational Parameters in Activated Sludge Process

- Nature of substrate
- F/M ratio
- Dissolved Oxygen
- RAS
- Reactor Configuration
- pH
- Reaction kinetics
- Reactor Hydraulics
- Nutrients

Activated Sludge Process

- **Monitoring**
  - Flows
  - Organic Concentrations and Loadings
  - Solids concentrations
  - Settleability data
  - Oxygen
    - Dissolved oxygen (DO) in aeration basin
    - DOUR (Dissolved oxygen uptake rate (mg/L/hr)

Thank You