Chapter 2: Conventional Wastewater Treatment (continue)
2.3 Biological treatment processes

1. Fundamentals of biological treatment

(1) Why biological treatment

- Transform (oxidize) dissolved and particulate biodegradable constituents into acceptable by-products
- Capture and incorporate suspended and nonsettleable colloidal solids into a biological floc or biofilm
- Transform or remove nutrients, such as nitrogen and phosphorous
- Remove specific trace organic constituents and compounds
(2) Role of microorganisms

- Microorganisms (principally bacteria) oxidize dissolved and particulate carbonaceous organic matter into simple end products \( \rightarrow \) e.g.,

\[
\text{Organic} + \text{O}_2 + \text{N} + \text{P} \xrightarrow{\text{microorganisms}} \text{CO}_2 + \text{H}_2\text{O} + \text{new cells}
\]

- The biotransformation (oxidation) \( \rightarrow \) need both electron acceptor and donor

- Organic molecules \( \rightarrow \) transformed by enzymes that reside within the cell walls of microorganisms \( \rightarrow \) Each transformation is carried out by a specific enzyme, often associated with a unique microorganism
Bacterial growth requires

- Carbon source ➔ to form cellular material of new cells
- Energy source ➔ to fuel synthesis of new cells ➔ Energy is created during the electron transfer from electron donor to electron acceptor
- Nutrient source ➔ to form cellular material
  ✓ Macronutrients ➔ N (e.g., NH₃) and P (e.g., PO₄³⁻)
  ✓ Other major nutrients ➔ S, K, Mg, Ca, Fe, Na, Cl
  ✓ Minor nutrients ➔ Zn, Mn, Mo, Se, Cu, Ni

Types of microbes based on electron acceptor

- Aerobic microbes ➔ use oxygen as an electron acceptor
- Anaerobic microbes ➔ use something other than oxygen as electron acceptor
Types of microbes based on carbon and energy sources

- Heterotrophic microbes ⇒ use organic carbon as energy and carbon source for growth of new cells
- Autotrophic microbes ⇒ use an inorganic source of carbon (e.g., CO\(_2\)) and light or inorganic chemical reactions as energy source
- Phototrophic microbes ⇒ get energy from light
  
  e.g., \( CO_2 + H_2O \) algae with sunlight \( O_2 + cells \)
- Chemotrophic microbes ⇒ get energy from chemical reactions
  
  ✓ Chemoautotroph ⇒ get energy from inorganic chemical reactions
  
  e.g., nitrifying bacteria use ammonia and nitrite:
  
  \[ 2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O \]
  
  \[ 2NO_2^- + O_2 \rightarrow 2NO_3^- \]
  
  ✓ Chemoheterotroph ⇒ get energy from oxidation of organics
- Bacteria reproduction rate
  - Bacteria grow rapidly
  - Bacteria reproduction rate (generation time) \( \Rightarrow < \) 20 min to several days
    e.g., one bacterium with 30 min generation time will reproduce to a number of
    \[ 2^{24} = 16.8 \text{ million within 12 hours} \]
    so that the total biomass generated will be
    \[ 16.8 \times 10^6 \times (5 \times 10^{-13}) = 8 \times 10^{-6} \text{ g} = 8\mu \text{g} \]
  \[\uparrow\]
    mass of one cell
- Biological wastewater treatment depends on balance between substrate and biomass \( \Rightarrow \) need to understand
  - How much substrate yields how much biomass \( \Rightarrow \) biomass yield
  - How quickly substrate is used \( \Rightarrow \) Biological kinetics
(3) Biomass yield (Y)

- \[ Y = \frac{\text{mass biomass produced}}{\text{mass substrate consumed}} \]
- Y can be determined from measurements
  - Organic matter in waste \( \rightarrow \) measured as BOD or COD
  - Biomass \( \rightarrow \) taken to be VSS (volatile suspended solids, mass of solids burned off at 500ºC)
- Y can be determined from stoichiometry
  - e.g., glucose \( \rightarrow \) cells
  - \[ 3\text{C}_6\text{H}_{12}\text{O}_6 + 8\text{O}_2 + 2\text{NH}_3 \rightarrow 2\text{C}_5\text{H}_7\text{NO}_2 \text{ (cells)} + 8\text{CO}_2 + 14 \text{H}_2\text{O} \]
  - MW: \( 3(180) \quad 8(32) \quad 2(113) \)
  - \[ Y = \frac{2\text{moles}(113\text{g/mol})}{3\text{moles}(180\text{g/mol})} = 0.42 \frac{\text{g cells}}{\text{g glucose}} \]
(4) Biological kinetics

- Growth kinetics of pure bacterial cultures
  - In batch cultures ➔ fixed quantity of biodegradable organics and nutrients with no inflow ➔ Bacterial growth looks like

![Graph of bacterial growth kinetics](image)

- Exponential growth phase
- Declining growth phase
- Stationary phase
- Endogenous phase

(Viessman et al., Water Supply and Pollution Control, 2009)
Goal of wastewater treatment is not to grow cells but for the microbiological culture to utilize substrate in the form of organic matter in wastewater.

Substrate utilization rate for the exponential and declining phases is closely related to biological growth and follows Monod-type equation

\[ \mu = \mu_m \left( \frac{S}{K_s + S} \right) \]

Where
\( \mu = \) specific growth rate, time\(^{-1}\)
\( \mu_m = \) maximum specific growth rate, time\(^{-1}\)
\( S = \) concentration of growth-limiting substrate in solution, mass/unit volume
\( K_s = \) saturation constant = limiting substrate concentration at half the \( \mu_m \), mass/unit volume
Monod observed that the microbial growth is represented by

\[
\frac{dX}{dt}_g = \mu X \quad \rightarrow \quad \frac{dX}{dt}_g = \frac{\mu_m X S}{K_s + S}
\]

Where \((dX/dt)_g\) = biomass growth rate, mass/unit volume*sec

\(X\) = concentration of biomass, mass/unit volume

\(\mu = \mu_m \left( \frac{S}{K_s + S} \right)\)

\(\mu\) vs \(S\) for the exponential and declining phases

(Viessman et al., Water Supply and Pollution Control, 2009)
Biomass growth yield \( Y = \frac{\text{mass biomass produced}}{\text{mass substrate consumed}} \)

\[
Y = \frac{X_m - X_0}{S_0} \Rightarrow X_m - X_0 = YS_0
\]

Where \( (dS/dt)_u \) = substrate utilization rate, time\(^{-1} \)

(Viessman et al., Water Supply and Pollution Control, 2009)
Factors affecting growth

- Temperature

<table>
<thead>
<tr>
<th></th>
<th>Overall range (°C)</th>
<th>Optimal range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychrophilic (cold-loving)</td>
<td>10-30</td>
<td>12-18</td>
</tr>
<tr>
<td>bacteria</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesophilic (middle-loving)</td>
<td>20-50</td>
<td>25-40</td>
</tr>
<tr>
<td>bacteria</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermophilic (heat-loving)</td>
<td>35-75</td>
<td>55-65</td>
</tr>
<tr>
<td>bacteria</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Arrhenius relationship

\[
\frac{k}{T_2} = \frac{k}{T_1} = \theta (T_2 - T_1)
\]
- **pH**: 4 to 9 → ok
  - 6.5 to 7.5 → best

- **DO**: Aerobic → DO > 1.5 to 2.0 mg/l
  - Anaerobic → DO << 0.1 mg/l
(5) Types of biological processes

- **Suspended growth processes**
  - Microorganism are maintained in suspension by appropriate mixing methods
  - Many of the processes are operated aerobically
  - The most common process used in domestic wastewater ➔ the activated sludge process

- **Attached growth (biofilm) processes**
  - Microorganism are attached to an inert packing material
  - Operate as aerobic and anaerobic processes
  - The most common process ➔ the trickling filter

Biomass (new cells) has a specific gravity that is larger than that of water ➔ It can be removed from liquid by gravity settling as bacteria flocs
2. Activated Sludge (AS) Treatment

(1) Definitions and treatment process

- Activated sludge can be represented by $C_5H_7O_2N \rightarrow$ has a molecular weight of 113

- The basic AS process consists of
  - A aeration tank in which the microorganisms (activated sludge) responsible for treatment of wastewater are kept in suspension and aerated
  - Liquid-solids separation, usually sedimentation tank
  - A recycle system for returning solids removed from the liquid-solids separation unit back to the reactor
Primary and secondary wastewater treatment

(Al-Malack, Water Supply and Wastewater Engineering, 2007)
- Microorganisms ➔ Use organic materials in wastewater as substrates ➔ remove organic materials by microbial respiration and synthesis
- A aeration tank ➔ contains mixed liquor (combination of influent wastewater and return/recycled activated sludge)
- **Mixed liquor suspended solids (MLSS)**
  - Concentration of suspended solids in the reactor
  - Ranges between 2000 and 4000 mg/l, typical value $\Rightarrow$ 2500 mg/l
  - A key component in AST $\Rightarrow$ MLSS rapidly (20-45 min) adsorbs organic matter in wastewater influent $\Rightarrow$ Bacteria
    - then solubilize and oxidize organic matter
  - MLSS includes
    - ✓ volatile suspended solids (MLVSS)
    - ✓ Inert suspended solids or fixed suspended solids (FSS)
    - ✓ Non-organic solids (e.g., clay particles)

- **volatile suspended solids (MLVSS)**
  - Concentration of volatile suspended solids
  - Used to indicate the mass of microorganisms in wastewater
  - Ranges between 80-90% of MLSS, typical value $\Rightarrow$ 2000 mg/l
F/M → Food to Microorganism Ratio

- State of bacteria controls nature of floc → F/M can dictates character of bacteria and floc
- At high F/M ratio
  - There is excess food → bacteria are growing fast → bacteria have energy to swim to food + food is plentiful → favors motile bacteria → result in small floc (“pin floc”) that does not settle well in final clarifier
  - Excess food carries into effluent → treatment efficiency is poor
- At low F/M ratio
  - Limited food → cells are starved → undergoing endogenous respiration
  - Nearly all substrate is consumed → high treatment efficiency
  - Cells are mostly attached to flocs → resulting in good settling floc → good efficiency in final clarifier
Favorable F/M ratio $\Rightarrow$ 0.2 to 0.4 Kg BOD$_5$/kg MLSS-day
0.3 to 0.6 Kg COD/kg MLSS-day
- **Sludge Density Index (SDI)**
  - Place 1 liter of the MLSS in 1-liter graduate cylinder
  - Settle the sludge for 30 minutes
  - SDI = TSS of settled sludge

- **Sludge Volume Index (SVI) = 1/ SDI**
  - The volume in ml occupied by 1 gram of settled activated sludge
  - Usually 50-200 ml/g
  - Low SVI ➔ good settling sludge
(2) Design parameters

- **BOD loading**
  - BOD loading on an aeration tank → calculated using the BOD in the influent in terms of
    - pounds of BOD applied per day per 1000 ft$^3$ of liquid volume in the aeration tank, and
    - pound of BOD applied per day per pound of MLSS in the aeration tank
  
  Pound of BOD applied per day per pound of MLVSS? → F/M

- **Aeration period**
  - It is the detention time of the raw-wastewater flow in the aeration tank expressed in hours
  - It is calculated by dividing the tank volume by the daily average flow without regarding the return sludge
Sludge age ➔ Mean cell residence time ($\theta_C$)

- It is the average time a cell remains in the system, days
- It is the retention time of the activated sludge in the aeration tank ➔ is defined as

$$\theta_C = \frac{\text{mass of organisms in the reactor}}{\text{mass of organisms removed from the system each day}}$$

$$\theta_C = \frac{MLSS \times V}{SS_e \times Q_e + SS_w \times Q_w}$$

Where
MLSS = mixed-liquor suspended solids, mg/l
$V = \text{volume of the aeration tank, mil-gal (m}^3\text{)}$
$SS_e = \text{suspended solids in effluent, mg/l}$
$SS_w = \text{suspended solids in waste sludge, mg/l}$
$Q_e = \text{quantity of effluent wastewater, mgd (m}^3/\text{d)}$
$Q_w = \text{quantity of waste sludge, mgd (m}^3/\text{d)}$
☐ Return sludge rates (%) $\Rightarrow$ a percentage of the raw wastewater flow (e.g., $Q = 10 \text{ mgd}$ and $R:Q = 20\% \Rightarrow$ the return sludge = 2 mgd)

(Shanahan, Water and Wastewater Treatment Engineering, 2006)
<table>
<thead>
<tr>
<th>Process</th>
<th>BOD Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb BOD/1000 ft³/day</td>
</tr>
<tr>
<td>Step aeration</td>
<td>30–50</td>
</tr>
<tr>
<td>Conventional (tapered aeration)</td>
<td>30–40</td>
</tr>
<tr>
<td>Contact stabilization</td>
<td>30–50</td>
</tr>
<tr>
<td>Extended aeration</td>
<td>10–30</td>
</tr>
<tr>
<td>High-purity oxygen</td>
<td>120+</td>
</tr>
</tbody>
</table>

*1.0 lb/1000 ft³/day = 16 g/m³·d.*

(Viessman et al., Water Supply and Pollution Control, 2009)
Example 2-8 Data from a field study on a step-aeration activated-sludge treatment are as follows:

Aeration tank volume = 120,000 ft$^3$ = 0.898 mil-gal
Settled wastewater flow = 3.67 mgd
Return sludge flow = 1.27 mgd
Waste sludge flow = 18,900 gpd = 0.0189 mgd
MLSS in aeration tank = 2350 mg/l
SS in waste sludge = 11,000 mg/l
Influent wastewater BOD = 128 mg/l
Effluent wastewater BOD = 22 mg/l
Effluent SS = 26 mg/l

Using these data, calculate the loading and operational parameters listed in the table of last slide and the excess sludge production in pounds of excess suspended solids per pound of BOD applied.
(3) AST systems

- Conventional AS treatment
  - Rectangular aeration tank
  - F/M = 0.2 to 0.4 (kg BOD5/kg MLVSS-day)
  - \( \theta_c = 5 \) to 15 (days)
  - Retention time (aeration period) = 6 to 7.5 (hours)
  - MLSS = 1500 to 3000 (mg/l)
  - R: Q = 0.25 to 1.0
  - BOD removal = 85 to 95 (%)
- Step-aeration AS treatment
- A modification of the conventional process
- F/M = 0.2 to 0.4 (kg BOD5/kg MLVSS-day)
- θc = 5 to 15 (days)
- Retention time (aeration period) = 5 to 7 (hours)
- MLSS = 1500 to 3000 (mg/l)
- R: Q = 0.25 to 1.0
- BOD removal = 85 to 95 (%)
Quarter of Reactor | $O_2$ Demand/total $O_2$ for entire reactor (%)
--- | ---
1st | 35
2nd | 26
3rd | 20
4th | 19

(Al-Malack, Water Supply and Wastewater Engineering, 2007)
Extended-aeration AS treatment

- Designed to minimize waste activated sludge production by providing a large endogenous decay of the sludge mass
- To make net sludge production nearly zero ➔ cell production is equal to cell decay during design
- Rectangular tank or racetrack layout (Oxidation ditch)

(Viessman et al., Water Supply and Pollution Control, 2009)
(Viessman et al., Water Supply and Pollution Control, 2009)
(4) Other suspended growth processes

- Stabilization ponds
  - Also known as oxidation ponds or lagoons ➔ one of the most ancient wastewater treatment methods known to humans
  - They're often found in small rural areas where land is available and cheap
  - Such ponds tend to be only a meter to a meter and a half deep, but vary in size and depth, and may be three or more meters deep
  - They utilize natural processes to "treat" waste materials, relying on algae, bacteria, and zooplankton to reduce the organic content of the wastewater

(Al-Malack, Water Supply and Wastewater Engineering, 2007)
- Septic tanks

- Also known as a septic system → a small scale sewage treatment system common in areas with no connection to main sewerage pipes

- A type of on-site sewage facility

- In North America approximately 25% of the population relies on septic tanks → this can include suburbs and small towns as well as rural areas

- Generally consists of a tank of between 1,000 and 1,500 gallons which is connected to an inlet wastewater pipe at one end and to a septic drain field at the other

(Al-Malack, Water Supply and Wastewater Engineering, 2007)
3. Trickling filters

(1) Definition and treatment process

- a biological process in which the microorganisms are attached to the filter media ➔ not actually “filters”
a biological slime layer formed on filter media (microbial film or biofilm) ➜ consist of bacteria, protozoans and fungi

(Viessman et al., Water Supply and Pollution Control, 2009)
- Wastewater is sprayed on top of packing and trickles down getting biofilm treatment in the process
- Trickling filters are composed of:
  - Influent pipe (feed pipe)
  - Rotary distribution
  - Filter bed
  - Underdrain system
  - Effluent pipe

(Viessman et al., Water Supply and Pollution Control, 2009)
Filter medium ➔ crushed stone (historical), plastic (now more common), large gravel, slag, and redwood
At downstream, a final settling tank is used to remove microbial growth that sloughs from the medium.

Sludge is usually mixed with the raw wastewater sent to primary settling tank for re-settling and disposal.

Recirculation is used during low-flow periods (nighttime) to ensure biofilms don’t dry out.

Classification of trickling filters:
- Single-stage trickling-filter plant
- Two-stage trickling-filter plant
Single-stage trickling-filter plant

(a) Recirculation and sludge return

(b) Direct recirculation

Sludge return with or without recirculation

(Viessman et al., Water Supply and Pollution Control, 2009)
Two-stage trickling-filter plant

(Viessman et al., Water Supply and Pollution Control, 2009)
The treatment procedures

- Tank is filled with solid media (rocks or plastic)
- Bacteria grow on surface of media
- Wastewater is trickled over media, at top of tank
- As water trickles through media, bacteria degrade BOD
- Bacteria eventually die, fall off of media surface
- Filter is open to atmosphere, air flows naturally through media
- Treated water leaves bottom of tank, flows into final clarifier
- Bacterial cells settle, removed from clarifier as sludge
- Some water is recycled to the filter, to maintain moist conditions
(2) Efficiency equations for stone-media trickling filters

For a single-stage trickling-filter plant

\[
E = \frac{100}{1 + 0.0561(\omega/VF)^{0.5}} \quad \text{and} \quad F = \frac{1 + R}{(1 + 0.1R)^2}
\]

Where
- \(E\) = BOD removal efficiency at 20°C, %
- \(\omega\) = BOD load applied, b/day
- \(V\) = volume of filter media, ft\(^3\) \times 10\(^{-3}\)
- \(F\) = recirculation factor
- \(\omega/V\) = BOD loading, b/1000ft\(^3\)/day
- \(R\) = recirculation ratio (ratio of recirculation flow to raw wastewater flow)
For a two-stage trickling-filter plant

\[
e_2 = \frac{100}{1 + \left[0.0561/(1 - e_1)\right] \left(\omega_2 / VF\right)^{0.5}}
\]

Where
E\(_2\) = BOD removal efficiency of the second stage at 20ºC, %
E\(_1\) = fraction of BOD removed in the first stage
\(\omega_2\) = BOD load applied to the second stage, b/day
\(\omega_2 / V\) = BOD loading, b/1000ft\(^3\)/day

E at different temperature

\[
e = e_{20} \times 1.035^{T-20}
\]

Where E= BOD removal efficiency at temperature T in ºC
Example 2-9: Calculate the BOD loading, hydraulic loading, BOD removal efficiency and effluent BOD concentration of a single-stage trickling filter based on the following data:

Average raw wastewater flow = 280gpm
Recirculation ratio = 0.5
Settled wastewater BOD (primary effluent) = 130 mg/l
Diameter of filter = 18.0m
Depth of media = 2.1m
Wastewater temperature = 18ºC
(3) Efficiency equations for plastic-media trickling filters

The mean contact time, $t$, for a filter is given by

$$t = \frac{CD}{Q^n}$$

Where

$t = \text{mean resident time, min}$

$D = \text{depth of filter media, ft (m)}$

$Q = \text{hydraulic loading}$

$C, n = \text{constants related to specific surface and configuration of media}$
Based on first-order kinetics, the removal of soluble BOD in a plastic-media trickling filter:

\[
\ln \frac{S_0}{S_e} = \frac{K_{20} A_s D \theta^{T-20}}{Q^n}
\]

Where

- \( S_e \) = soluble (filtered) BOD in effluent, mg/l
- \( S_0 \) = soluble (filtered) BOD in influent, mg/l
- \( K_{20} \) = reaction-rate constant at 20ºC, (gpm/ft\(^2\))^n
- \( A_s \) = specific surface area of media, ft\(^2\)/ft\(^3\)
- \( D \) = depth of filter media, ft
- \( \theta \) = temperature coefficient, normally selected as 1.035
- \( Q \) = hydraulic loading, gpm/ft\(^2\)
- \( n \) = constant, often selected as 0.5
(4) Advantages/disadvantages of trickling filters

- Advantages over Activated Sludge Treatment
  - less energy needed
  - simpler operation
  - no bulking sludge problems
  - better sludge thickening
  - withstands shock toxic loads

- Disadvantages
  - poorer effluent quality
  - sensitive to low temperature
  - produces odors
  - sloughing events can create lots of sludge in short time
  - nitrogen removal is difficult
(5) Another attached growth (biofilm) processes: rotating biological contractor (RBC)

- Plastic discs rotated through tank of wastewater serve as medium for biofilm growth.

Return of settled solids

Influent

Primary clarifier

Waste sludge

A

Four-stage RBC process  
(Viessman et al., Water Supply and Pollution Control, 2009)

Final clarifier

Effluent

2.4 Processing of sludges

1. Type of sludges

- Primary sludge ➔ solid concentration ≈ 4-6% and VSS ≈ 60-80%
- Secondary sludge (waste AT sludge) ➔ active microbial mass + dark brown suspension ➔ solid concentration ≈ 0.5-1.5% and VSS ≈ 70-80%
- Secondary sludge (trickling filter sludge) ➔ similar components to those in waste AT sludge ➔ solid concentration ≈ 4-5% and VSS ≈ 45-70%
- Anaerobically digested sludge ➔ dark brown thick slurry ➔ solid concentration ≈ 3-12% and VSS ≈ 30-60%
- Aerobically digested sludge ➔ dark brown ➔ solid concentration ≈ 1-2% and VSS ≈ 35-40%
2. Anaerobic digestion

raw sludge (from primary tanks) biological sludge (from final tanks) \[ \rightarrow \] concentrated and stabilized (by aerobic or anaerobic digestion) \[ \downarrow \] Disposal

- Two phases ➔
  - Stage 1: hydrolysis of organics and their biological conversion to organic acids
  - Stage 2: slow-growing methane bacteria use organic acids to produce gas

\[ \Rightarrow \] 2/3 methane + 1/3 CO\textsubscript{2} + traces of H\textsubscript{2}S
Microbiological Pathway of Anaerobic Digestion

- Complex Organics
  - Extracellular Enzymes
  - Hydrolysis
- Soluble Organics
  - Acid Producers
- Organic Acids
  - Methanogens
- Methane CO₂

Carbohydrates
- Proteins
- Lipids
- Phosphorylated Organics

Glucose
- Amino Acids
- Fatty Acids
- $\text{PO}_4^{-3}$

Acetic
- Propionic
- Lactic + Cell

Cells
- Stabilized Organics

(Shanahan, Water and Wastewater Treatment Engineering, 2006)
Primary and secondary wastewater treatment

(Al-Malack, Water Supply and Wastewater Engineering, 2007)
Control factors

- excess acid
- toxic matter
- temperature

Process

- mixing → promote digestion
- settling → sludge separation and thickening
- storage

If all three processes are together → conventional digestion
If mixing is separated from settling/storage → higher efficiency (high-rate digestion)

- low energy requirement
- reduce VSS by 50%
Mixing and digestion

Settling

(Shanahan, Water and Wastewater Treatment Engineering, 2006)
3. Land application of sludge

- Land application = sludge utilization
  - tank trucks (4-8 m capacity) with piping manifold ➔ spread sludge on agricultural land
  - not for heavy metals

4. Sludge dewatering and incineration

- environmental regulations: low heavy-metal content for land disposal of sludge
  
  - if cannot meet the requirement ➔ on-site incineration
    - problems: fuel consumption + air pollution
      
      - belt filters: compress sludge between moving porous belts ➔ force water out
      - plate/frame filters: use high pressure force water through a fixed porous medium

- Landfill
2.5 Limitations of conventional treatment

- Components reduced through conventional treatment processes
  - BOD
  - Suspended solids
  - Pathogens

- Components left/expected for further treatment
  - 300 mg/l of total solids
  - 200 mg/l of volatile solids
  - 30 mg/l of suspended solids
  - 30 mg/l of BOD
  - 26 mg/l of nitrogen
  - 5 mg/l of phosphorus
  - Organic chemicals/heavy metals/excreted pathogens
2.6 Selection of advanced wastewater treatment processes

- Advanced wastewater treatment for
  - Nitrogen removal
  - Phosphorous removal
  - Suspended solids removal
  - Carbon removal
  - Pathogen removal
  - Toxic substance removal