Activated sludge wastewater treatment

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• Since 20th century
• Secondary treatment
• Involves treating the liquid part of the wastewater biologically. It is carried out after primary treatment (which removes some of the solid material)
• The purpose of this process is to remove the organic matter (and N, P) from the wastewater by bacteria in suspension
• So far the mostly widely used biological process for the treatment of municipal and industrial wastewaters in developed countries
• Microbial community (activated sludge) is highly diverse and competitive

Liquid-solids separation, usually sedimentation tank
• A recycle system for returning solids removed from the liquid-solids separation unit back to the reactor to maintaining a high concentration of cells
• Formation of flocculent settleable solids that can be removed by gravity settling
Basic activated sludge process flow sheet

Advantages

- Adapted to any size of community (except very small ones)
- Good elimination of all the pollution parameters (SS, COD, N, P);
- Partially-stabilized sludge
- Small area required
Disadvantages

- Relatively high capital costs
- High energy consumption
- Requires skilled personnel and regular monitoring
- Sensitivity to hydraulic overloads
- Settling property of sludge is not always easy to control (bulking sludge)
- High production of sludge
Activated sludge performance

- BOD removal (%): 90-98
- Kjeldahl-N removal (%): 80-95
- Total N removal (%): 65-90
- Pathogen removal (orders of magnitude): 1-2
Key Characteristics and Terms

Mixed Liquor Suspended Solids (MLSS)
- Indication of microbial population
- Usually between 2000 and 4000 mg/L
- Maintained by adjusting waste flow

Food to Microorganism ratio F/M: load (kg.d)/microbial mass (kg)
- Also termed sludge loading rate/ organic loading rate
- F traditionally on BOD basis but now often on COD basis
- M fraction under aeration (MLSS)
Food to microorganisms ratio

- The higher the waste rate, the higher the ratio
- A low ratio means that the microbes are starving (mineralization)
- A high ratio will result in a high sludge production
- Typically 0.2-0.5 d⁻¹ (conventional plant)
Mean Cell Residence Time ($\theta_C$) or sludge age

- Cell residence time ($\theta_C$) is defined as:
  - $\theta_C = \frac{\text{mass of organisms in the reactor}}{\text{mass of organisms removed from the system each day}}$ (days)
F/M Ratio and $\theta_c$

- Both parameters are used to characterize the performance of the activated sludge process
  - A high F/M ratio and a low $\theta_c$ produce filamentous growth that have poor settling characteristics
  - A low F/M ratio and a high $\theta_c$ can cause the biological solids to undergo excessive endogenous degradation and cell dispersion

- For municipal wastewater
  - $\theta_c$ should be at least 3 to 4 days
  - If nitrification is required, $\theta_c$ should be at least 10 days
Other important Operating Parameters

- Oxygen supply
- Control and operation of the final settling tank

Functions settling tank
- Clarification
- Thickening

Sludge settleability is determined by sludge volume index (SVI)
<table>
<thead>
<tr>
<th>Process</th>
<th>$\theta$ (d)</th>
<th>$\theta$ (h)</th>
<th>F/M</th>
<th>Qr/Q</th>
<th>X (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>5-15</td>
<td>4-8</td>
<td>0.2-0.4</td>
<td>0.25-5</td>
<td>1,500-3,000</td>
</tr>
<tr>
<td>Complete-mix</td>
<td>5-15</td>
<td>3-5</td>
<td>0.2-0.6</td>
<td>0.25-1</td>
<td>3,000-6,000</td>
</tr>
<tr>
<td>Step-aeration</td>
<td>5-15</td>
<td>3-5</td>
<td>0.2-0.4</td>
<td>0.25-0.75</td>
<td>2,000-3,500</td>
</tr>
<tr>
<td>Modified-aeration</td>
<td>0.2-0.5</td>
<td>1.5-3</td>
<td>1.5-5.0</td>
<td>0.05-0.15</td>
<td>200 – 500</td>
</tr>
<tr>
<td>Contact-stabilization</td>
<td>5-15</td>
<td>0.5-1</td>
<td>0.2-0.6</td>
<td>0.25-1</td>
<td>1,000-3,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3-6</td>
<td></td>
<td></td>
<td>3,000-4,000-10,000</td>
</tr>
<tr>
<td>Extended-aeration</td>
<td>20-30</td>
<td>18-36</td>
<td>0.05-0.15</td>
<td>0.75-1.5</td>
<td>3,000-6,000</td>
</tr>
<tr>
<td>High-rate aeration</td>
<td>5-10</td>
<td>0.5-2</td>
<td>0.4-1.5</td>
<td>1-5</td>
<td>4,000-10,000</td>
</tr>
<tr>
<td>Pure-oxygen</td>
<td>8-20</td>
<td>1-3</td>
<td>0.25-1.0</td>
<td>0.25-0.5</td>
<td>6,000-8,000</td>
</tr>
</tbody>
</table>
SVI

- One-liter graduated cylinder, 30 minutes settling period

- SVI (ml/g) = settled sludge volume (mL/L) x 1000/MLSS (mg/L) = mL/g, i.e., volume occupied by one gram of settled solids

- A high SVI (>150 ml/g) indicates bulking
Settling Problem in Activated Sludge Processes

Settling WWTP in Greece facing operational problems due to excessive bulking and foaming of activated sludge

Source: www.hydro.ntua.gr/images/project/AndrBulking.jpg
Microorganisms in the activated sludge system

Activated sludge floc:

- Bacteria: major component
- Fungi: low pH, toxicity, N deficient waste
- Protozoa: grazing on bacteria
- Rotifers: multicellular organism (help in floc formation)
- Organic/ inorganic particles

Activated Sludge, Hoek van Holland, The Netherlands
Type of reactor

- Plug-flow reactors
- Completely-mixed reactors

Heiploeg WWTP, The Netherlands

Ecco WWTP, The Netherlands
Activated sludge process with chemical P removal

Source: Prof. H Kroiss, Institute for Water Quality, Resource and Waste Management Vienna University of Technology, 2008
Activated sludge process with biol. N removal

Source: Prof. H Kroiss, Institute for Water Quality, Resource and Waste Management Vienna University of Technology, 2008
Activated sludge process with biol. N and P removal

Source: Prof. H Kroiss, Institute for Water Quality, Resource and Waste Management Vienna University of Technology, 2008