100 Years of Biological Wastewater Treatment Practice: A Perspective

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The Outline

- Re-look at WWTPs on an 100-year scale
- Current biological wastewater treatment
- Promising R&D focus
- Future R&D directions: a shift in concept?
- Concluding remarks
In ancient Rome...
Microbial Biofilms: Sticking Together for Success

Waiting to grow
Bacteria can shrink to a spore-like state to wait in water, soil—even rock or tissue—until conditions are right for active growth.

Meeting the challenge
While undetected damage occurs, cell layers, the biofilm community can survive.

Finding a niche
Chemical gradients create micro-environments for different microbial species or levels of activity.

Changing their spots
Active bacteria will attach to virtually any surface. Within minutes, changes in gene expression transform “swimmers” to “stickers.”

Getting breakfast in bed
Nutrients diffuse into the matrix as they flow by.

Building houses of slime
Attached bacteria multiply and encase their colonies with a slimy matrix.

Going with the flow
Propelled by shear forces, aggregated cells can break loose, roll, or ripple along a surface in sheets and remain in their protected biofilm state.

Sending the right signals
Close proximity of cells facilitates the exchange of molecular signals that regulate behavior.

“Persisters”
“Wall formers”
“Dispersers”

Peg Dirckx, Center for Biofilm Engineering
Zhengzhou University
Re-look at WWTPs worldwide

- Fixed film
- Nature

IMAGE CREDITS: Henry Aldrich
Email: haldrich@micro.ifas.ufl.edu

Zhengzhou University
May 1914, Ardern and Lockett introduced a recycle of suspension (activated sludge).

Re-look at WWTPs worldwide

Aeration Basin
Secondary Clarifier
Screening
Degritting Primary Clarifier

Start Here

dP
dN

Disinfection
Discharge

NaClO

Na₂(SO₃)

Belt Thickener

Blending Tank

Polyer Boiler Flare

Gas Generator

Centrifuge

Biosolids Final Disposal

Zhengzhou University
Re-look at WWTPs worldwide

Wastewater

Point Source
- Industrial: >80%
- Domestic: 100%

Non-point Source
- Other: >80%
- Agricultural: 100%

Zhengzhou University
Re-look at WWTPs worldwide

Wastewater as mgCOD/L

- Low strength
  e.g. <1000 mgCOD/L
- High strength
  e.g. >1000 mgCOD/L

Aerobic *
Anaerobic + Aerobic
For aerobic processes:

- Demand of oxygen → Energy high
- Excess sludge → Disposal difficult

Major breakthrough:

- Membrane bioreactor
Current biological wastewater treatment
Current biological wastewater treatment

< 50,000 m³/d

and more...
Current biological wastewater treatment

- Significantly reduced energy consumption
- Minimized excess sludge production
- Integrated N & P removals
- Extended filtration time

MBR G3
When $\text{SRT} \to \infty$, \( \lim_{\text{SRT} \to \infty} \text{MLVSS} = \frac{Y}{k_d} \left( \frac{C_i - C_e}{HRT} \right) \)
Zero excess sludge MBR

$$\text{MBR at } \frac{Y}{k_d} \left( \frac{C_i - C_e}{HRT} \right), \text{ gMLVSS/L}$$
The highest MLSS in practice

- **5-Year Dutch MBR experience (2000-2005):** preferably up to 10g/L while 20g/L unfavorable

- **Japan recommendations:** 10g/L~20g/L

Current biological wastewater treatment
Current biological wastewater treatment

Yamamoto and Xing (2005)
Zero Excess Sludge MBR,
US Patent No. 11/070,134
<table>
<thead>
<tr>
<th></th>
<th>Removal Average, %</th>
<th>Permeate Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>92.1%</td>
<td>12.6mg/L</td>
</tr>
<tr>
<td>Nitrification</td>
<td>93%</td>
<td>1.3 as mgNH₃-N/L</td>
</tr>
<tr>
<td>deNitrification*</td>
<td>71.7% at R=300%</td>
<td>8.86 as mgTN/L</td>
</tr>
<tr>
<td>Turbidity</td>
<td>99.9%</td>
<td>0.01NTU</td>
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</tbody>
</table>
Case I: Tanzhou WWTP, Beijing (45,000m³/d in operation)
Case II: Wenyuhe Reclamation Plant, Beijing (100,000 m³/d)
For anaerobic processes:

- Insufficient mixing
- Limited 3-phase separation

Major breakthrough:

- IC Reactor
Current biological wastewater treatment
Current biological wastewater treatment

IC Reactor

Membrane (PP)

Pukang Lincomycin Wastewater Treatment, Nanyang China (4,500 m³/d)

COD: 6000~10000 mg/L

COD: 1200~2500 mg/L

COD < 300 mg/L
Promising R&D focuses

UASB (G2) + IC (G3) + MBR (G1) + MBR (G2) + MBR (G3)
Promising R&D focus

Anaerobic Reactor (G4)

1. Enhanced mixing
2. Improved 3-phase separation
3. Lowered influent strength
Promising R&D focus

1. Significantly reduced kWh/m³ treated
2. Preferably zero excess sludge
3. Integrated N and P removals
4. Extended filtration time

MBR (G3)
Biogas, O_2 depleted air

- Fouling control
- Mixing effect

Anaerobic MBR (II)?

Promising R&D focus
Currently,

- Nutrient removals (\textit{i.e.} N\textregistered{} P)
- Excess sludge disposal
- Water reclamation & Reuse

Future,

- Energy recovery
- Sludge production
- Water-mining
Future R&D: a shift in concept?

- Wastewater
- Concentrator
- Anaerobic Reactor
- Biogas mining
- Membrane 1
- Water mining
- Membrane 2
- Aerobic Reactor
- Water mining
- Sludge mining
- Dual Membrane bioreactor?
Concluding remarks

UASB (G2)
IC (G3)
(UASB (G2) + MBR (G1))
MBR (G2)
MBR (G3)
MBR (G1)
Digester (G1)