Introduction

- Introduction: P- and N-Removal in Multistage Processes
- WWTP Ratzeburg: Step-feed Denitrification
- WWTP Flensburg: Trickling Filter and Upflow Sludge Bed Reactor
- WWTP Lübeck: Combined Treatment with Biofiltration

All Topics: Description of Process Features, Remarks on Loads and Effluent Values
**Introduction**

**Biological Treatment:**

**Carbon Removal** (Activated Sludge)

- Primary settlement tank
- Aeration tank
- Clarifier
- Inlet
- Return sludge
- Effluent
- Excess sludge

+ further stages for advanced treatment

**Removal of Phosphorus**

- Biological
- Chemical

Why combining different precipitation stages?

- Early relief of the following process stages
- Economical use of chemicals
- Reducing flushing frequency of the filtration unit
**Introduction**

**Biological Nitrogen Removal**

- Aeration tank
- Clarifier

\[ \text{NH}_4 \rightarrow \text{NO}_3 \rightarrow \text{N}_2 \]

- Return sludge
- Excess sludge

Recirculation = 3 to 4 times inlet quantity

**Introduction**

**Pre-anoxic zone denitrification process**

- Denitrification
- Nitrification
- Internal recirculation \( Q_e \)
- Return sludge \( Q_{rs} \)
- Secondary settling tank

\[ Q_{rs} = x \times Q \]

**Introduction**

**Post denitrification process**

- Denitrification
- Nitrification
- Post aeration
**Introduction**

1. Stage of Treatment

   - Pre-anoxic zone denitrification process
   - Internal recirculation
   - Return sludge
   - Secondary settling tank

2. Stage

3. Stage

**Examples:**

- WWTP Ratzeburg: Step-feed Denitrification
- WWTP Flensburg: Post-Denitrification with an Upflow Sludge Bed Reactor
- WWTP Lübeck: Combined Treatment with Biofiltration

**WWTP Ratzeburg**

- Design Capacity:
  - Population Equivalents: 25,000 PE
  - Hydraulic Load: 4,700 m³/d
  - COD: 3,240 kg/d
  - Nₙ₅₀: 350 kg/d

WWTP Ratzeburg (2005): 25,000 PE
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Equalization Tank
Misch- und Ausgleichbecken, Zulauf 6.300 m³/d
Erforderliches Speichervolumen = 700 m³

Equalization tank
Substrate feeding
Mechanical pretreatment
(Screen, grit chamber, primary settlement tank)
Effluent
(D-Bio)-Filtration
Biogastank
Combined heat and power unit
Sludge dewatering

Dosing of precipitant

WWTP Ratzeburg

Activated Sludge Stage
Step-feed Denitrification
- No recirculation
- Higher MLSS in the upper tanks

### Technical Specifications:

- **Sludge Age** $t_{S,Lim}$
  - $T = 8 \, ^\circ C$
  - 11 d
- **Activated Sludge Volume**
  - 3.360 m³
- **Biofiltration**
  - **1st Stage, Nitrification**
    - 4 FBR each $A = 5 \, m^2$
  - **2nd Stage, Denitrification**
    - 6 Grit Filter each $A = 5 \, m^2$
- **Digester**
  - 1.200 m³

### Effluent Demands:

- COD $\leq 60 \, mg/l$
- BOD$_5$ $\leq 15 \, mg/l$
- NH$_4$N $\leq 3 \, mg/l$
- N$_{gas}$ $\leq 10 \, mg/l$
- P$_{gas}$ $\leq 0.3 \, mg/l$
- Susp. Sol. $\leq 5 \, mg/l$

* $T > 15 \, ^\circ C$
**Operational results: Phosphorus**

![Phosphorus graph](image)

**Operational results: Nitrogen**

![Nitrogen graph](image)

**Summary: Special Features WWTP Ratzeburg**

- Very strict effluent demands
- Step-feed Denitrification (no mixed liquor recirculation)
- Upgradable by diverse extra modules, according to future requirements

**WWTP Flensburg (1997 - 2005): 224,000 PE**

![Flensburg image](image)
**Design Capacity**

- **Population Equivalents**: 224,000 PE
- **Hydraulic Load**: 55,000 m³/d
- **COD**: 28,300 kg/d
- **N<sub>ges</sub>**: 2,125 kg/d

**Situation in 1985**

- **Inlet (from mechanical treatment)**
- **1st Lane**
- **2nd Lane**
- **3 Clarifiers**
- **Effluent**

**Flow Scheme, Concept 1997**

1. **Inlet (from mechanical treatment)**
2. **Low loaded biology**
3. **Clarifier**
4. **High loaded biology**
5. **SS as Substrate**
6. **TF 1**
7. **USBR 1**
8. **Clarifier**
9. **TF 2**
10. **USBR 2**
11. **TF 3**
12. **Effluent**

**Process Improvements**

- **1988-95**: Extension of carbon-removal facilities, simultaneous phosphorus-precipitation
- **1997**: Start of construction for nutrient removal: Existing studies by the TU Hamburg-Harburg, but lack of large-scale experience
  - Process survey and adjustment in parallel with stepwise upgrading the plant
- **1999**: Large-scale pilot operation and optimisation (by PIK together with TU Hamburg-Harburg)
- **2001**: Verification of the dimensioning of TF 1 and USBR 1 prior to start of construction of TF 2 and USBR 2
- **2004**: Start of operation TF 2
- **2005**: Start of operation USBR 2 and filtration unit
WWTP Flensburg

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Details high loaded lane

1st biological stage

Act. sludge (HL) PT Clar.

SS Me

TF USBR FBR FF

2nd biological stage

3rd biological stage (2-stage-filtration)

Effluent

Dosing of precipitant

Upflow Sludge Bed Reactor (Moving Bed Reactor)

Bubbling of N₂
**WWTP Flensburg**

- Inlet cylinder, diverting the flow
- Submerged outlet pipe
- Floating sludge removal

**Operating behaviour USBR:**
Inlet increase from 900 m³/h to 1.400 m³/h

**Technical Specifications:**

<table>
<thead>
<tr>
<th>Sludge Age ( t_{USLDNM} )</th>
<th>T = 12°C</th>
<th>9,5 d (LL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T = 12°C</td>
<td>1,5 - 2,0 d (HL)</td>
</tr>
</tbody>
</table>

- Activated Sludge Volume
  - 4.670 m³ (LL)
  - 2.700 m³ (HL)
- Trickling Filter
  - 2 TF
  - each 4.900 m³
- Upflow Sludge Bed Reactor
  - 2 USBR
  - each 3.350 m³
  - \( h_m = 7,40 \) m
- Biofiltration:
  - 1st Stage, Nitrification
    - 8 FBR
    - each \( A = 40 \) m²
  - (therfrom 2 for nitrification of sludge liquor)
  - 2nd Stage, Denitrification
    - 8 FBR
    - each \( A = 40 \) m²
**WWTP Flensburg**

Summary: Special Features WWTP Flensburg

- Strict effluent demands
- Biological process, 3 stages
  (no MLSS recirculation for denitrification):
  1) Carbon removal: Activated Sludge System
  2a) Nitrification: Trickling Filter
  2b) Post-Denitrification: Upflow Sludge Bed
  3) Biofiltration: 1st stage subsidiary nitrification
     2nd stage denitrification

**WWTP Lübeck**

- 1967 Mechanical-biological Treatment
- 1982 Aeration with refined oxygen
- 1990 New mechanical treatment
- 1990 / 1991 Pilot Plant
- 1992 Approval Planning (641.000 PE)
- 1996 Official Approval

**Design Capacity**

<table>
<thead>
<tr>
<th>Population Equivalents</th>
<th>640.000 PE&lt;sub&gt;eq&lt;/sub&gt;</th>
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<tbody>
<tr>
<td>Hydraulic Load</td>
<td>90.000 m³/d</td>
</tr>
<tr>
<td></td>
<td>15.100 m³/h</td>
</tr>
<tr>
<td>Inlet biological treatment</td>
<td>5.500 m³/h</td>
</tr>
<tr>
<td>BOD</td>
<td>&lt; 25.650 kg/d</td>
</tr>
<tr>
<td>BOD / N&lt;sub&gt;BOD&lt;/sub&gt;</td>
<td>&lt; 4,0</td>
</tr>
</tbody>
</table>

**WWTP Lübeck (2009): 640.000 PE**

**WWTP Lübeck: 1967-2007**
**Concept**

1. Stage: 2-stage step-feed denitrification, SVI 150 ml/g, actual suspended solids (2007) too low

Filtration:  
   a) **Higher MLSS in aeration tank**; then NH₃-N < 8 mg/l FBR used for denitrification  
   b) Alternative, needs a longer period for putting into operation: FBR for Nitrification, FF for Denitrification

**WWTP Lübeck**

**Inlet from mechanical pretreatment**

- Sewage Water Treatment Plant (WWTP) in Northern Germany
- Combined Wastewater Equalisation Tank (MWB)
- 50% Q₂
- Dosing of precipitant
- 2-stage biofiltration
- Effluent

**WWTP Lübeck: 1967-2007**

- 1996 / 1997 Verification of inlet data
- 1997 Start of overall completion
- 2000 Start of operation 5 new clarifiers
- 2001 Verification of inlet data
- 2003 Start of operation of new activated sludge stage, design biofiltration
- 2006 Verification of inlet data: declining biological load 370,000 PE, but disadvantageous CSB/BSB ratio 3.0 at weekends
- 2008 Start of operation biofiltration (in progress)
**Inlet Filtration (Effluent Secondary Clarifier)**

- \( \text{PO}_4^3- \leq 1.5 \text{ mg/l} \)
- \( \text{N}_{\text{tot}} \leq 20 \text{ mg/l} \)
- Suspended Solids \( \leq 75 \text{ mg/l} \)

**Construction:**

1. **Stage:** Upflow granular fixed bed reactor (FBR)
   - Fill: expanded clay

2. **Stage:** Sandfilter (FF)
   - Fill: anthracite / siliceous sand

**Diagram:**

- **Inlet chamber:** Water distribution
- **FBR:** Upflow granular fixed bed reactor
- **FF:** Sandfilter
- **RK:** Pipe channel 1, 2, 3

**Dosing Point Substrate, Precipitant**

- **C** from pump station
- **Fe** to Outlet channel

**Flow path filtration**

- **Inlet chamber:** Water distribution
- **FBR:** Upflow granular fixed bed reactor
- **FF:** Sandfilter
- **RK:** Pipe channel 1, 2, 3
Upflow granular fixed bed reactor, filled with Liaperl Ø 4-8 mm (expanded clay) height 5,00m

Fine filter, filled with anthracite (1,4-2,5 mm, height 1,5 m) and siliceous sand (0,7 - 1,2 mm, height 0,5 m)
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WWTP Lübeck

Technical Specifications:

<table>
<thead>
<tr>
<th>Sludge Age $t_{sys,Dim}$</th>
<th>$T = 12 ^\circ C$</th>
<th>12 - 16 d</th>
</tr>
</thead>
</table>

Activated Sludge Volume

- 22.400 m$^3$ + 17.340 m$^3$

Biofiltration (main function: removal of suspended solids):

1$^{st}$ Stage
- 12 FBR
- each $A = 36$ m$^2$
- (Denitrification, optional nitrification)

2$^{nd}$ Stage
- 12 FBR
- each $A = 36$ m$^2$
- (P-removal, optional denitrification)

Effluent Demands: GK 5

- COD $\leq$ 60 mg/l 75 mg/l
- $\text{BOD}_5$ $\leq$ 15 mg/l 15 mg/l
- $\text{NH}_4$-N $\leq$ 8 mg/l 10 mg/l
- $\text{NH}_3$-N $\leq$ 10 mg/l 13 mg/l
- $\text{PO}_4$-P $\leq$ 0,5 mg/l 1,0 mg/l
- Susp. Sol. $\leq$ 5,0 mg/l --

WWTP Lübeck

Inlet from primary treatment

- $\text{VKB}$
- $\text{MWB 1}$
- $\text{MWB 2}$

2-stage-biofiltration

$\text{S Clar.}$

Effluent

$\leq 5 \text{ mgNO}_3^-\text{N/l}$

$< 50 \% \text{ N}$

$50 - 80 \% \text{ DN}$

$< 20 \text{ mgNO}_3^-\text{N/l}$

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Operational results, 2-stage-biofiltration:

Phosphorus

WWTP Lübeck
Phosphorus Values, Test Operation 2008

Nitrogen

WWTP Lübeck
Nitrogen Values, Test Operation 2008
**Operational results, 2-stage-biofiltration:**

**Nitrogen**

**WWTP Lübeck: Biofiltration**
Denitrification Rate at T = 12°C (Test Operation 27 - 28.01.09)

**Summary: Special Features WWTP Lübeck**

- Strict effluent demands
- Biological process, 2 stages
  - Combined treatment
    1) Carbon removal, nitrification, partial denitrification: Activated Sludge System
    2) Biofiltration: 1st stage denitrification
       2nd stage fine filter (SS)

**Summary**

- Strict effluent demands, based on grab samples
- Different process designs proved to be applicable
- Different framework conditions require matched process designs
- New technologies may produce new operating challenges
- Take advantage from other operators experiences

**Thank you for your attention!**