The EXPOVAL joint research project: Design of wastewater treatment plants for country-specific boundary conditions

Prof. Dr. Norbert Dichtl, Braunschweig University of Technology

in cooperation with the EXPOVAL coordinator Emscher Wassertechnik GmbH (Essen, Germany)
Prof. Dr. Holger Scheer, Dr. Tim Fuhrmann, Peter Wulf

IE expo, Shanghai, 6th May 2016
Content

1. Introduction
2. Overview of the EXPOVAL structure
3. Influence factors on the WWTP’s design
4. New design approaches – biological treatment
5. New design approaches – sludge treatment
6. New design approaches – disinfection
7. Publication of the new design approaches in a DWA Topic
8. Further information
1. Introduction

Increasing problems with – on a global scale – insufficient wastewater treatment (comparable with the problems caused by the climate change)

Demand for reliable and internationally applicable design approaches

Existing international design equations requires adaption

Further development and validation of German and other international rules by EXPOVAL joint project
2.1 Overview of the EXPOVAL research project

- 7 topical subgroups
- Focus on municipal wastewater treatment
- Project team of:
  - 6 universities
  - 11 consultants and suppliers
  - DWA

Scientific-technical supervision and overall coordination

1: Activated sludge systems
2: Aeration systems
3: Trickling filters
4: Anaerobic reactors
5: Wastewater ponds
6: Sewage sludge management
7: Disinfection and water reuse

Dissemination of results by DWA
## 2.2 Project partners (1/2)

<table>
<thead>
<tr>
<th>Subgroup (SG)</th>
<th>Partners</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SG 1: Activated sludge systems</strong></td>
<td>Ruhr-Universität Bochum (Prof. Dr. M. Wichern)</td>
</tr>
<tr>
<td></td>
<td>Emscher Wassertechnik GmbH</td>
</tr>
<tr>
<td></td>
<td>Hach-Lange GmbH</td>
</tr>
<tr>
<td><strong>SG 2: Aeration systems</strong></td>
<td>Technische Universität Darmstadt (Prof. Dr. M. Wagner)</td>
</tr>
<tr>
<td></td>
<td>Bilfinger Water Technologies GmbH</td>
</tr>
<tr>
<td><strong>SG 3: Trickling filters</strong></td>
<td>Universität Stuttgart (Prof. Dr. H. Steinmetz)</td>
</tr>
<tr>
<td></td>
<td>ENEXIO Water Technologies GmbH</td>
</tr>
<tr>
<td><strong>SG 4: Anaerobic reactors (UASB)</strong></td>
<td>Universität Hannover (Prof. Dr. K.-H. Rosenwinkel)</td>
</tr>
<tr>
<td></td>
<td>aqua &amp; waste International GmbH</td>
</tr>
<tr>
<td></td>
<td>Hach-Lange GmbH</td>
</tr>
<tr>
<td><strong>SG 5: Wastewater ponds</strong></td>
<td>IEEM gGmbH – Institute of Environmental Engineering and Management at the Witten/Herdecke University (Prof. Dr. mult. K.-U. Rudolph)</td>
</tr>
<tr>
<td></td>
<td>FUCHS Enprotec GmbH</td>
</tr>
<tr>
<td></td>
<td>Ultrawaves Wasser- und Umwelttechnologien GmbH</td>
</tr>
<tr>
<td></td>
<td>Xylem Water Solutions Herford GmbH (associated partner)</td>
</tr>
</tbody>
</table>
## 2.2 Project partners (2/2)

<table>
<thead>
<tr>
<th>Subgroup (SG)</th>
<th>Partners</th>
</tr>
</thead>
</table>
| SG 6: Sludge treatment | Technische Universität Braunschweig (Prof. Dr. N. Dichtl)  
Huber SE  
Oswald Schulze Umwelttechnik GmbH |
| SG 7: Disinfection and water reuse | Technische Universität Darmstadt (Prof. Dr. P. Cornel)  
Huber SE |

<table>
<thead>
<tr>
<th>Subgroup (SG)</th>
<th>Partners</th>
</tr>
</thead>
</table>
| Overall co-ordination and scientific/technological assistance | Emscher Wassertechnik GmbH (Prof. Dr. H. Scheer und Dr. T. Fuhrmann)  
Technische Universität Darmstadt, Institut IWAR (Prof. Dr. P. Cornel und Prof. Dr. M. Wagner)  
Leibniz Universität Hannover, Institut ISAH (Prof. Dr. K.-H. Rosenwinkel und Frau Dr. M. Beier) |
| PR and dissemination of results | German Association for Water, Wastewater and Waste (DWA) |
3.1 Influence factors on the WWTP‘s design: Specific conditions in different countries

- Measurement of wastewater constituents urgently necessary
  → rough estimations of loads and flows not sufficient
  → data from literature only complementary

- Close analysis and plausibility check of the existing data base is essential

- Local specifics of the inflow have to be investigated and taken into consideration (e.g. large loads of sand or settable constituents like pumpkinseeds)

All those parameters influence the results of the WWTP design!
3.2 Influence factors on the WWTP’s design: Design bases / ranges of inputs data

- Wastewater temperature: 5 – 30 °C
- Salt content (TDS) up to 10 g/l
- Daily averages of water parameters in the WWTP effluent

Example of graph of average water temperatures throughout the year

Range of water temperatures at the experimental sites

Chosen temperature range
3.3 Influence factors on the WWTP’s design: Selection of the treatment technology

Throughout the world there are varying effluent requirements regarding CSB and N elimination → basis for the selection and combination of the biological treatment system

<table>
<thead>
<tr>
<th>Treatment Technology</th>
<th>CSB elimination</th>
<th>Nitrification</th>
<th>Denitrification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activated sludge system</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Trickling filter</td>
<td>X</td>
<td>X</td>
<td>(X)</td>
</tr>
<tr>
<td>Wastewater ponds</td>
<td>X</td>
<td>(X)</td>
<td></td>
</tr>
<tr>
<td>Anaerobic reactors (e.g. UASB)</td>
<td>(X)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. New design approaches for municipal WWTPs
- Biological treatment -

Advanced design approaches for biological treatment systems:

4.1 Activated sludge systems

4.2 Aeration systems

4.3 Trickling filters

4.4 Anaerobic reactors

4.5 Wastewater ponds
### 4.1 Activated sludge systems

**Advanced design of the aeration tank**

- **New design approach for sludge age depending on wastewater temperature**

![Graph showing design value for aerobic sludge age vs. wastewater temperature]

- **Without nitrification:**
  \[ t_{TS} = 3 \cdot 1,04^{(15-T)}, \text{min. } 2 \text{ d} \]

- **With nitrification, NH4-N,eff = 5 mg/l:**
  \[ t_{TS} = PF \cdot 3,4 \cdot 1,103^{(15-T)}, \text{min. } 2 \text{ d} \]

- **With nitrification, NH4-N,eff = 2 mg/l:**
  \[ t_{TS} = 20 \cdot 1,072^{(12-T)} \]

- **With nitrification, NH4-N,eff = 1 mg/l:**
  \[ t_{TS} \]

- **With nitrification and simultaneous sludge stabilization:**
  \[ t_{TS} = 20 \cdot 1,072^{(12-T)} \]
4.2 Aeration systems

Design of aeration systems at WWTP’s with elevated salt contents

- Decrease of air bubble diameter with rising content of (most) salts
- Increase of the mass transfer coefficient \( k_L a_{20} \) by a factor > 2
- Resulting in a reduced energy demand for aeration
- => Incorporation of new salt correction factors \( f_S \) for salinity of 2 to 10 g/l into the DWA design rules for standard mass transfer rate (SOTR):

\[
SOTR = \frac{f_d \cdot \beta_{st} \cdot C_{S,20} \cdot f_{S,St}}{(\alpha \cdot f_{S,\alpha}) \left( f_d \cdot \beta_{\alpha} \cdot C_{S,r} \cdot \frac{p_{atm}}{1.013} - C_X \right) \cdot \theta (T_{W-20})} \cdot 0V_h \left( \frac{kg \: O_2}{h} \right)
\]

with: \( f_{S,\alpha} \): under operational conditions; \( f_{S,St} \): in tap water
4.3 Trickling filters

Adjustment and validation of established design approaches (Velz equation and Gujer & Boller equation)

Implementation of transition zone for beginning of nitrification

Carbon removal: Modified Velz eq.

$$S_{COD, bio,e} = \frac{S_{COD, bio,in}}{\exp \left( \frac{k_{20, COD, bio} \cdot A_s \cdot D \cdot \theta T - 20}{q_A n} \right)} \left( \frac{mg}{l} \right)$$

Transient region (beginning of nitrification)

Nitrification rate = (Guer & Boller eq.) \( \cdot \left( \frac{100 - S_{COD, bio}}{80} \right)^3 \) (-)

Nitrification: Gujer & Boller eq.

$$j_{N,max}(T) = -\frac{A_s}{q_A} \cdot j_{N,max}(10) \cdot 1.02^{(T-10)} \cdot \frac{S_N}{N + S_N} \cdot e^{(-k \cdot D)} \left( \frac{gN}{m^2 \cdot d} \right)$$
4.4 Anaerobic wastewater treatment (UASB reactors)

Internationally available design approaches


HRT $\rightarrow f (T)$

$v_{up}$ $\rightarrow f (Q_{\text{daily}}$ and $Q_{\text{max, hourly}})$ $\rightarrow$ Needed A, H, Vol $\rightarrow$ $\eta_{\text{COD, hom}} \approx 50$ to 80%

$\eta_{\text{TSS}} \approx 50$ to 90%

Further development and validation of design approach in full scale plants

$\Rightarrow$ Advanced differentiation of parameters

$\eta_{\text{COD, dissolved}}$ and $\eta_{\text{COD, particulate}}$ $\rightarrow$ Differentiation between dissolved and particulate COD

$\eta_{\text{solids}}$ $\rightarrow$ Estimation of hydrolysis and surplus sludge extraction

$Q_{\text{CH4, available}}$ $\rightarrow f (\eta_{\text{COD, total}}, \eta_{\text{SO4}}, Q_{\text{CH4, dissolved}})$

Controlled biogas recovery in the UASB effluent for energy recovery or neutralisation

Development of “DiMeR reactor” concept (Dissolved Methane Recovery)
4.5 Wastewater ponds: Facultative ponds

New design equation for the permissible COD surface loading rate as base for calculation of the required surface area of the pond

\[ L_{A,COD} = 615 \cdot (1,125 - 0,0023 \cdot T_W)^{(T_w-25)} \cdot f_{Sol} \]  
(kg/ha·d)

Conversion to COD surface loading rate

New factor \( f_{Sol} \) to consider influence of solar radiation with a range of 1.0 to 1.1
4.5 Wastewater ponds: Aerated ponds

New design equation for the permissible COD volumetric loading rate as base for calculation of the required volume of the pond

\[ L_{V,\text{COD}} = 33.6 \cdot 1.0353^{T_w} \cdot k_1 \cdot k_2 \] \(\text{g/(m}^3\cdot\text{d})\)

New factors to consider number of ponds and roughness of the slope material

<table>
<thead>
<tr>
<th>Factor</th>
<th>Value (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(k_1) for number of aerated</td>
<td>0.75 for one aerated unit</td>
</tr>
<tr>
<td>ponds in series</td>
<td>(1.0) for two aerated units</td>
</tr>
<tr>
<td></td>
<td>(1.2) for three aerated units</td>
</tr>
<tr>
<td>(k_2) for roughness of slope</td>
<td>0.8 for plastic lining</td>
</tr>
<tr>
<td>material</td>
<td>(1.0) for natural lining (adobe)</td>
</tr>
<tr>
<td></td>
<td>(1.2) for rough surface such as textured geomembrane or gravel</td>
</tr>
</tbody>
</table>

Wastewater pond in Algeria, 275.000 PE (Photo credit: FUCHS)
4.6 Conclusions regarding biological treatment

- Further development and validation of German and international design equations
- Conversion from BOD$_5$ to COD as standard design parameter
- Introduction of temperature terms into the design equations → cost-effective reduction of biological reactors at high temperatures
- High contents of dissolved solids (salinity) have no influence on biological processes at continuously high contents after adaption of bacteria
5. New design approaches for municipal WWTPs - Sludge treatment -

Advanced design approaches for sludge treatment systems:

5.1 Anaerobic sludge stabilisation

5.2 Solar sludge drying
5.1 Anaerobic sewage stabilisation

Advanced design approaches for digesters

- Rated sludge age at selected digestion temperature between 20 and 35 °C
- Estimation of biogas production
- Recommendations for different types of operation depending on the digestion temperature

![Graph showing relationship between temperature and HRT](image)

<table>
<thead>
<tr>
<th>Plant Size (PE)</th>
<th>&lt; 50,000</th>
<th>50,000 – 100,000</th>
<th>&gt; 100,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWA-M 368</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety factor</td>
<td>1,25</td>
<td>1,15</td>
<td>1,0</td>
</tr>
<tr>
<td>HRT (d)</td>
<td>20 – 28</td>
<td>18 – 25</td>
<td>16 – 22</td>
</tr>
<tr>
<td>Advancement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety factor</td>
<td>1,5</td>
<td>1,2</td>
<td>1,0</td>
</tr>
<tr>
<td>HRT (d)</td>
<td>32 – 37</td>
<td>25 – 30</td>
<td>21 – 25</td>
</tr>
</tbody>
</table>

- **EXPO data:** batch test
- **Literature data:** not indicated method of operation
- **Literature data:** discontinuous operation
- **Literature data:** batch test
- **EXPOVAL data:** nearly continuous operation PS
- **EXPOVAL data:** nearly continuous operation PS+ES

<table>
<thead>
<tr>
<th>Digestion temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 – 40</td>
</tr>
<tr>
<td>30 – 34</td>
</tr>
<tr>
<td>25 – 29</td>
</tr>
<tr>
<td>20 – 24</td>
</tr>
</tbody>
</table>
5.2 Solar sludge drying

Advancement of evaporation equations taken from agriculture (evaporation from soil and plants)

- Including transmission of cover, external energy source and humidity

\[ E_{p,SKT} = \frac{(\alpha R_G + R_H) \cdot (T^* + 22)}{30 \cdot (T^* + 123)} \cdot \left( 1 - \frac{\Phi}{100} \right) \]  

[kg H2O/m².a]

with:
- \( \alpha \) transmission (-)
- \( R_G \) energy input by global solar radiation (J/m²)
- \( R_H \) energy input by additional heating (J/m²)
- \( T^* \) temperature inside the greenhouse (°C)

- Dimension of drying area as ratio of necessary evaporation (sludge) and possible evaporation (climate)

- Operational aspects:
  - Additional heating (\( R_H \))
  - Mixing interval
  - Aeration
6. New design approaches for municipal WWTPs - Disinfection -

Advanced design approaches for disinfection technologies:

6.1 Removal of helminth eggs by disc filtration

Helminth eggs of *Trichuris trichiura* (size: 22-27 μm x 50-58 μm)

Ascaris lumbricoides (size: 35-50 μm x 45-75 μm)
6.1 Removal of helminth eggs by disc filtration (micro-sieving)

Constraints:

- 10 – 100 (1000) eggs/l in raw wastewater of endemic areas,
- ≤ 10 (100) eggs/l in the effluent of e.g. activated sludge systems → no safe reduction with contents below 1 egg/l (WHO, 2006)
- Almost no effect of convent. disinfection (UV radiation, ozonisation, chlorination) → sedimentation and filtration steps required → reduction of helminth eggs by size and specific density

Research on disc filtration with different mesh sizes

- Mesh sizes ≤ 15 µm (PET, woven): > 1 to 2 log decline of helminth eggs
- Mesh sizes of 10 µm (PET, woven): almost no eggs could pass in large-scale plants
- Sealing of the sieving elements and avoiding leakages are of capital importance

Egg of *Trichuris sp.* on 20 µm PET-mesh (Düppenbecker et al., 2013)
7. Publication of the new design approaches in DWA Topic

In October 2016 the new design approaches will be published in the DWA Topic „Design of wastewater treatment plants in warm and cold climatic zones“ (initially as German version; English version is planned)

Concrete design algorithms for:

- Activated sludge systems
- Aeration systems
- Trickling filters
- Anaerobic reactors (UASB)
- Wastewater ponds
- Anaerobic sludge stabilisation
- Solar sludge drying
- Removal of Helminth eggs
8. Further information

Project website:
www.expoval.de

Contact through project coordinator:

- Prof. Dr. Holger Scheer, scheer@ewlw.de
- Dr. Tim Fuhrmann, fuhrmann@ewlw.de
- Peter Wulf, wulf@ewlw.de
Acknowledgement:

The realisation of the EXPOVAL joint research project has been enabled only by funding of BMBF (project no. 02WA1252A ff.).