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




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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

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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

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2.1 Overview of the EXPOVAL research project

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

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

2.2 Project partners (1/2)

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

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2.2 Project partners (2/2)

Subgroup (SG)	Partners
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

Subgroup (SG)	Partners
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 dissemi-nation of results	German Association for Water, Wastewater and Waste (DWA)

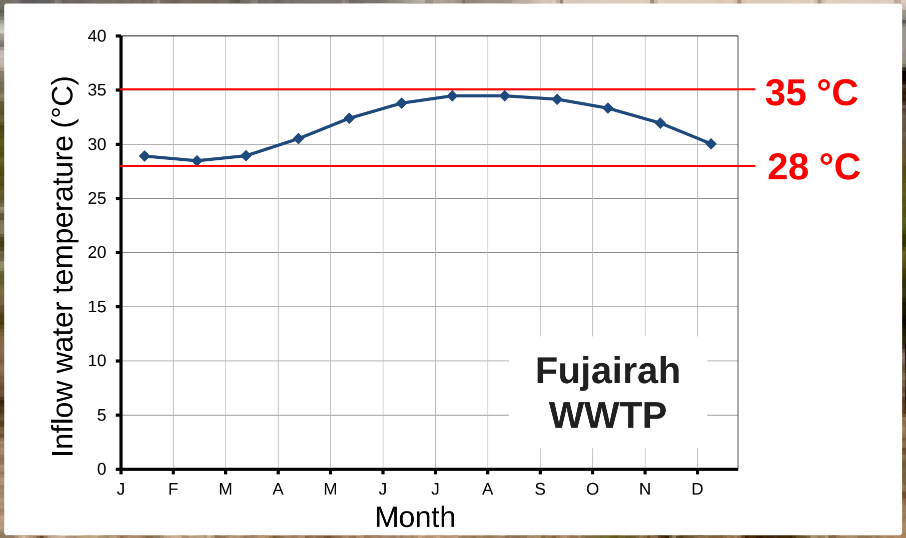
3.1 Influence factors on the WWTP's design: Specific conditions in different countries

- **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)**

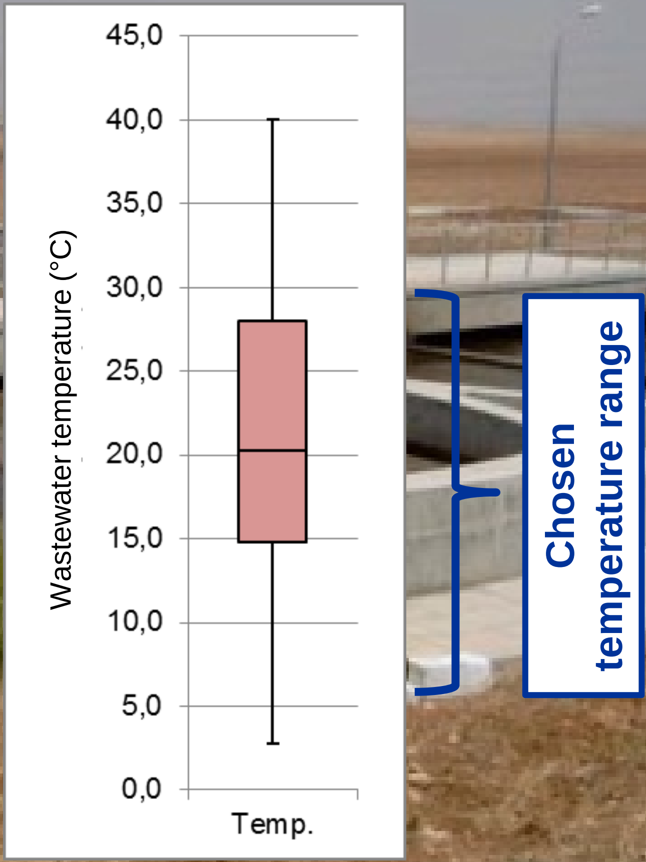
All those parameters influence the results of the WWTP design!

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

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

	CSB elimination	Nitrification	Denitrification
Activated sludge system	X	X	X
Trickling filter	X	X	(X)
Wastewater ponds	X	(X)	
Anaerobic reactors (e.g. UASB)	(X)		

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

Activated sludge system

Trickling filter (Photo credit: GEA 2H)

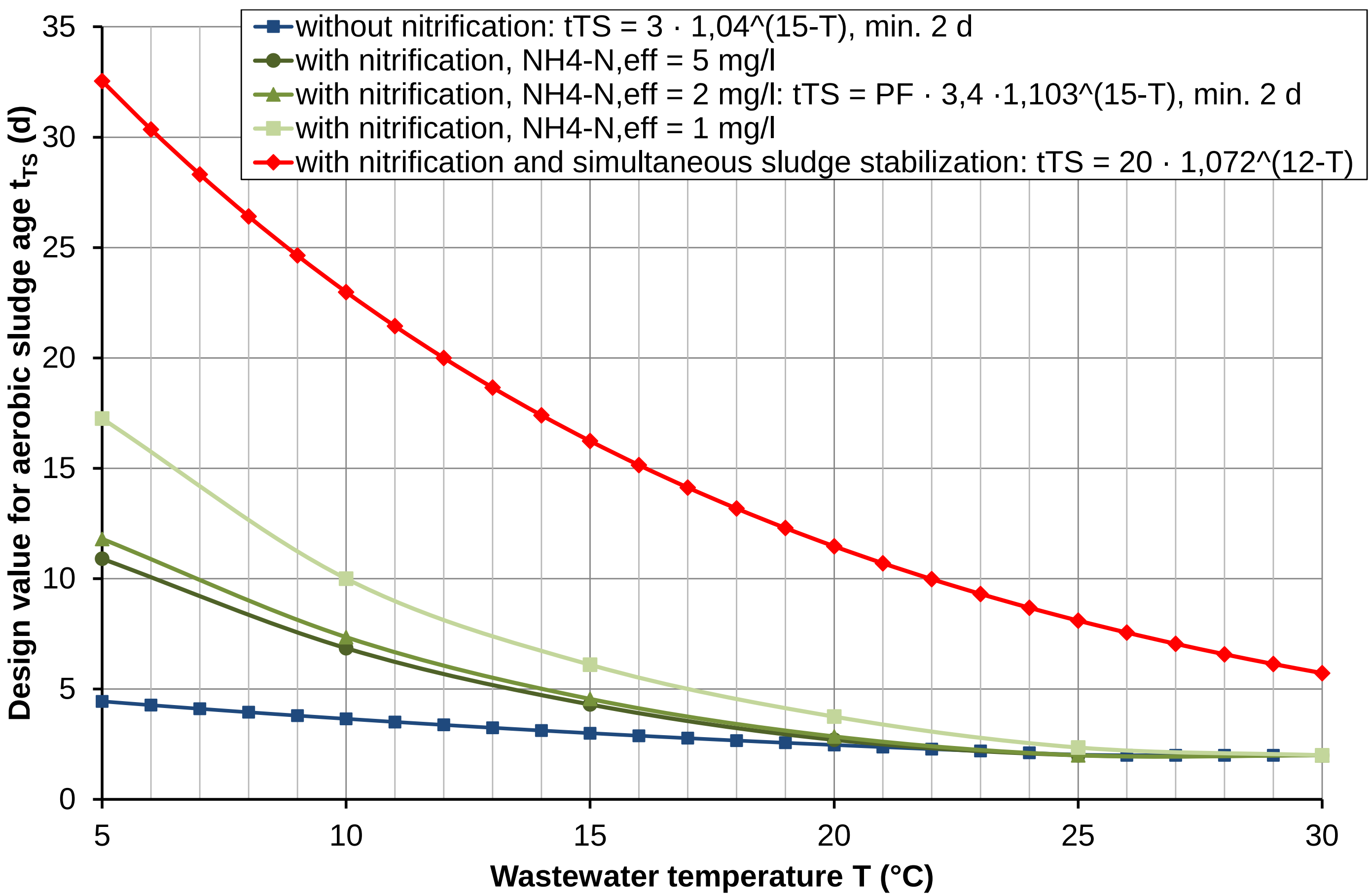
Wastewater pond

4.1 Activated sludge systems

RUB
EMSCHER WASSERTECHNIK GmbH
HACH

Advanced design of the aeration tank

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



Example Fujairah WWTP, VAE, average water temp.: 31°C

Example Tehran WWTP, Iran, average water temp.: 25°C

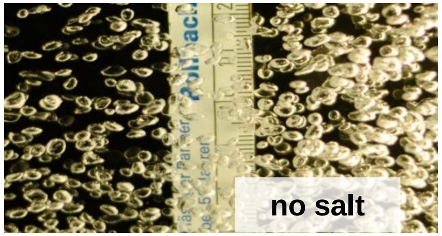
4.2 Aeration systems

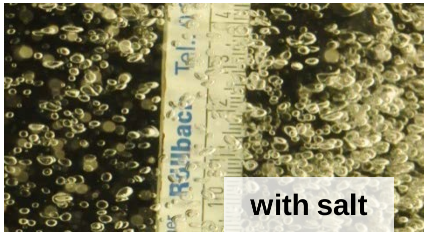
TECHNISCHE UNIVERSITÄT DARMSTADT

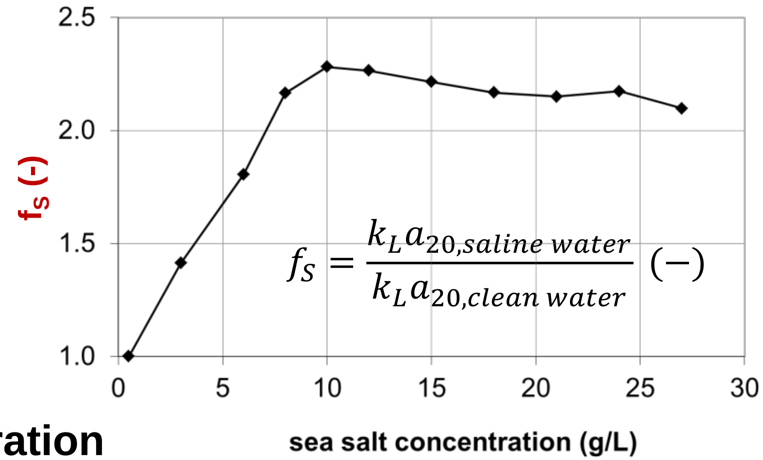
BILFINGER WATER TECHNOLOGIES

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):**

$$SOTR = \frac{f_d \cdot \beta_{St} \cdot C_{S,20} \cdot f_{S,St}}{(\alpha \cdot f_{S,\alpha}) \cdot \left(f_d \cdot \beta_\alpha \cdot C_{S,T} \cdot \frac{p_{atm}}{1.013} - C_X\right) \cdot \theta^{(T_W - 20)}} \cdot OV_h \qquad \left(\frac{kg\ O_2}{h}\right)$$

with: $f_{S,\alpha}$: under operational conditions; $f_{S,St}$: in tap water

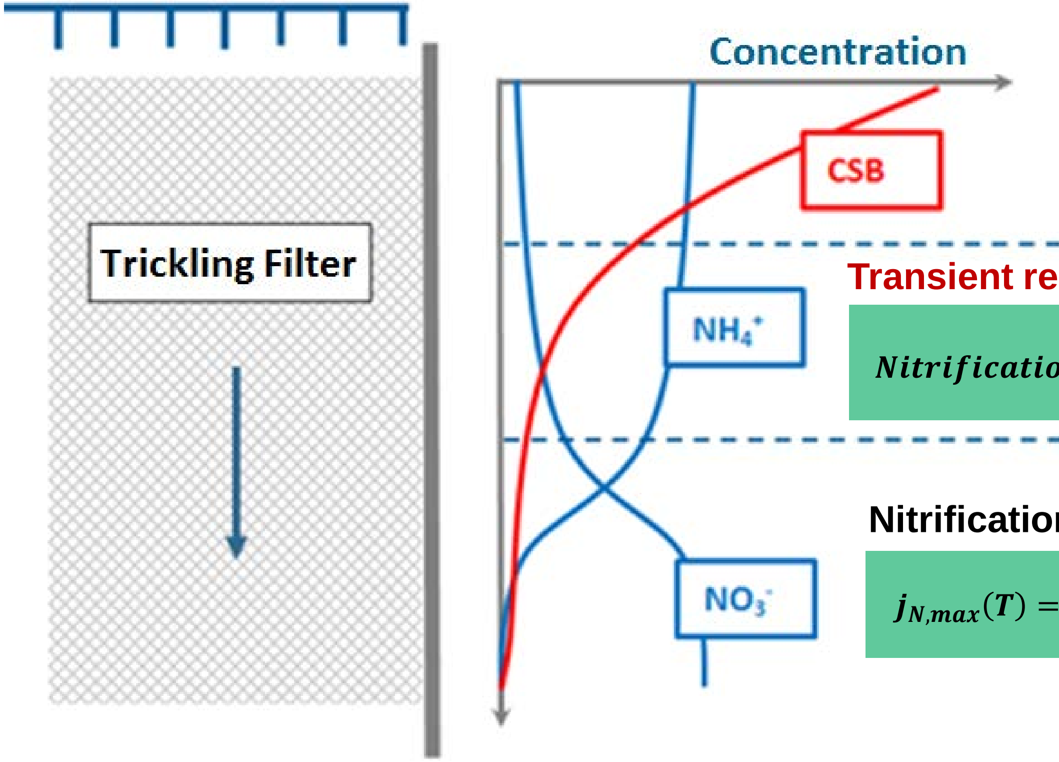
4.3 Trickling filters

Universität Stuttgart

ENEXIO

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.

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

Transient region (beginning of nitrification)

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

Nitrification: Gujer & Boller eq.

$$j_{N,max}(T) = -\frac{A_s}{q_A} \cdot j_{N,max}(10) \cdot 1{,}02^{\,(T-10)} \cdot \frac{S_N}{N + S_N} \cdot e^{(-k \cdot D)} \quad \left(\frac{\mathrm{gN}}{\mathrm{m^2 \cdot d}}\right)$$

4.4 Anaerobic wastewater treatment (UASB reactors)

Leibniz Universität Hannover

aqua & waste International GmbH

Internationally available design approaches

Brazilian standard ABNT (2011), DECOM Manual (1994), Lettinga et al. (1991), etc.

HRT → f (T)
v_{up} → f (Q_{daily} and $Q_{max,hourly}$) ⇒ Needed A, H, Vol ⇒ $\eta_{COD,hom}$ ≈ 50 to 80%
η_{TSS} ≈ 50 to 90%

Further development and validation of design approach in full scale plants

=> Advanced differentiation of parameters

$\eta_{COD,dissolved}$ and $\eta_{COD,particulate}$ → Differentiation between dissolved and particulate COD
η_{solids} → Estimation of hydrolysis and surplus sludge extraction
$Q_{CH4,available}$ → f ($\eta_{COD,total}$, η_{SO4} , $Q_{CH4,dissolved}$)

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

Institut für Umwelttechnik und Management an der universität Witten / Herdecke gGmbH

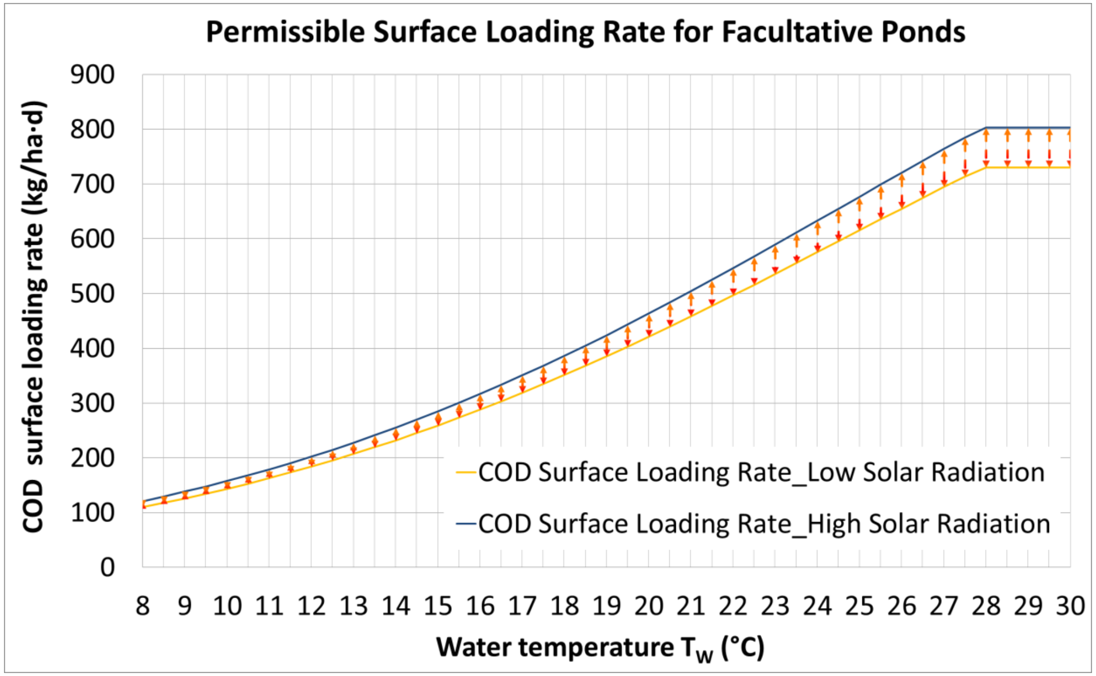
FUCHS Clean Solutions

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

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

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



IEEM-Pilot Plant, Seville in co-operation with Fuchs Enprotec GmbH (Photo credit: CENTA)

4.5 Wastewater ponds: Aerated ponds

Institut für Umwelttechnik und Management an der universität Witten / Herdecke gGmbH

FUCHS Clean Solutions

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

$$L_{V,COD} = 33{,}6 \cdot 1{,}0353^{Tw} \cdot k_1 \cdot k_2 \qquad (g/(m^3 \cdot d))$$

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

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

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

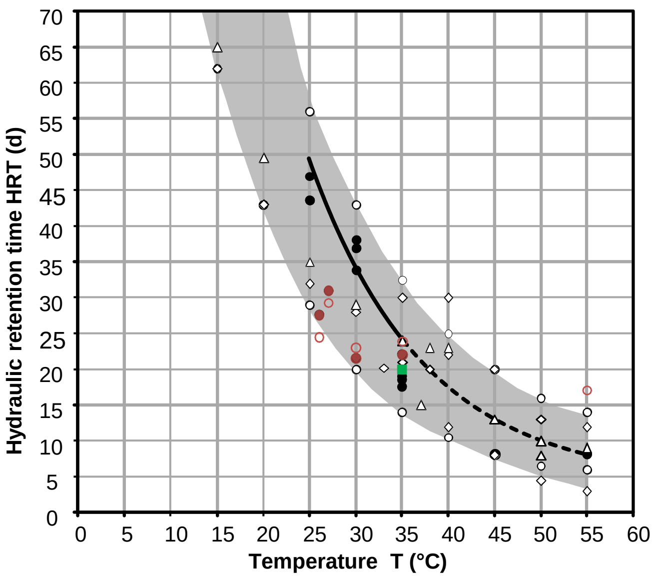
Klodzko WWTP (Photo: TU Braunschweig)

Bottrop WWTP (Photo credit: TU Braunschweig)

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



● 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
■ EXPOVAL data: nearly continuous operation PS+ES

Plant Size (PE)	< 50.000	50.000 – 100.000	> 100.000	
DWA-M 368				Digestion temperature (°C)
Safety factor	1,25	1,15	1,0	
HRT (d)	20 - 28	18 - 25	16 - 22	**35 – 40**
Advancement				Digestion temperature (°C)
Safty factor	1,5	1,2	1,0	
HRT (d)	32 - 37	25 - 30	21 - 25	**30 - 34**
	40 - 49	32 - 40	27 - 33	**25 - 29**
	53 - 73	42 - 58	not recommended	**20 - 24**

5.2 Solar sludge drying

Technische Universität Braunschweig

OSWALD SCHULZE Umwelttechnik GmbH

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

- **Including transmission of cover, external energy source and humidity**

$$E_{p,SKT} = \frac{(\alpha R_G + R_H)\cdot(T^* + 22)}{30 \cdot (T^* + 123)} \cdot \left(1 - \frac{\Phi}{100}\right) \quad \left[\frac{\text{kg H2O}}{\text{m}^2\cdot\text{a}}\right]$$

with: α transmission (-)

R_G energy input by global solar radiation (J/m²)

R_H energy input by additional hearting (J/m²)

T^* temperature inside the greenhouse (°C)

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

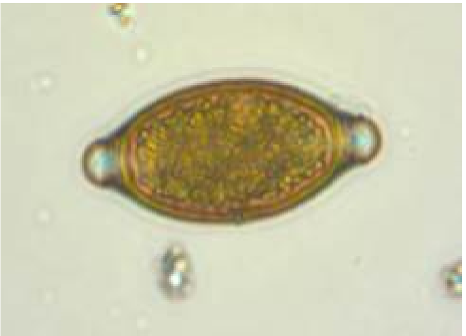
- **Operational aspects:**
  - o **Additional heating (R_H)**
  - o **Mixing interval**
  - o **Aeration**

Klodzko WWTP (Photo: TU Braunschweig)

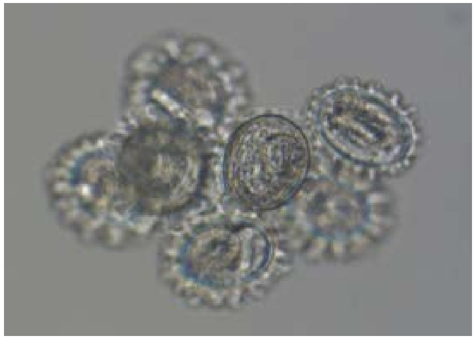
6. New design approaches for municipal WWTPs - Disinfection -

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)

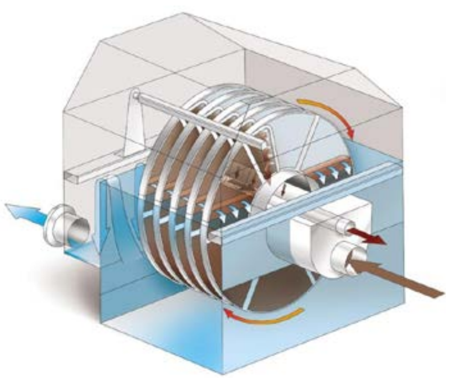
6.1 Removal of helminth eggs by disc filtration (micro-sieving)

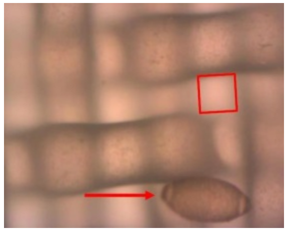
Constraints:

- **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

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