Efficient aeration – oxygen transfer

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Structure

- **Introduction**
- **Oxygen transfer in waste**water
  - SOTR
  - General requirement
  - α-value
- **Dimensioning** an energy efficient aeration system
- New **design approach** and the **EXPOVAL project**
- **Conclusions**
- **References**

Energy demand for aeration/mixing

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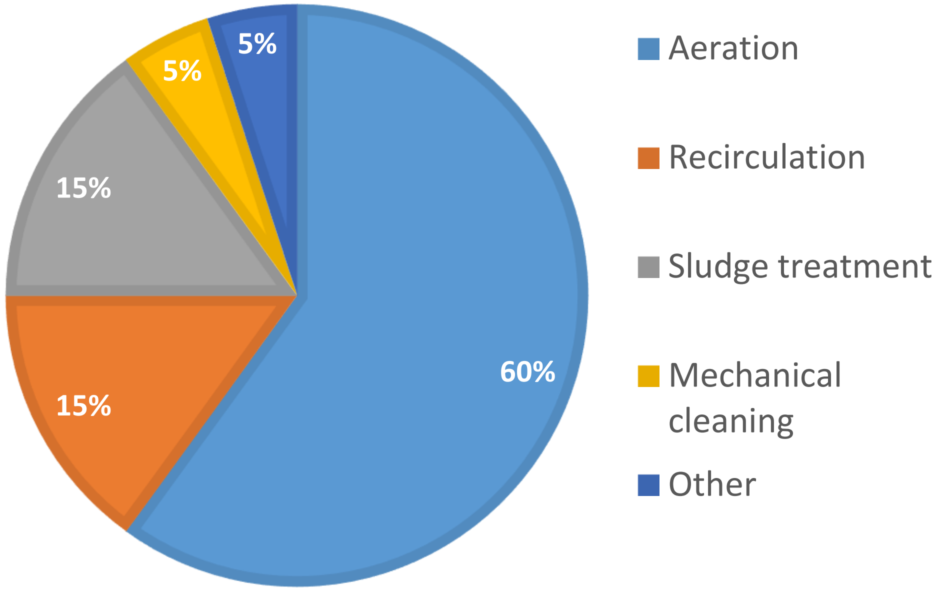
- **WWTP** consume large **amounts of energy**

  Consumer:

  - **Aeration**
  - **Mixing**
  - Pumps

  ...

- **Optimization** of the energy efficiency of a WWTP



[DWA(2008)]

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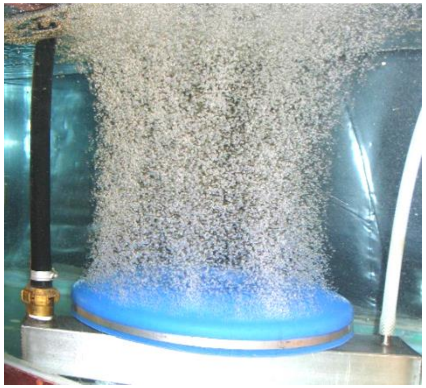
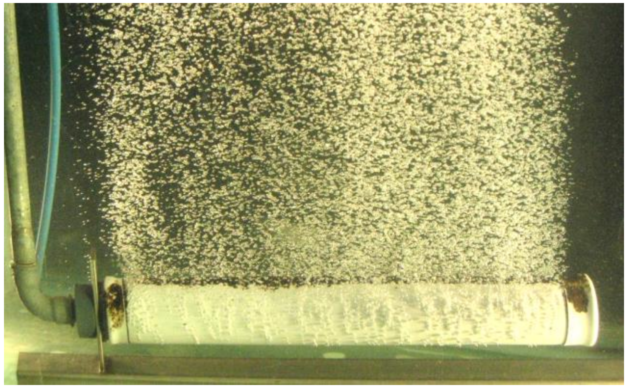
Objectives of Aeration

- **provide oxygen for carbon and nitrogen oxidation**
- maintaining minimum oxygen concentration:
  - without nitrification > 0 – 0.5 mg/l
  - nitrification 1.5 – 2.0 mg/l



Disc



Tube

Plate

Objectives of Aeration

Mixing of aeration tanks

- avoid settling of activated sludge
- provide nutrient transfer (BOD, N, P, O_2) to bacteria (-flocs)
- provide transport of metabolism products from bacteria (-flocs)
- provide stripping of gases
  - CO_2 → from BOD degradation (pH-value)
  - N_2 → denitrification

Aeration systems

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1. **Mechanical/Surface aeration**
   - Water drops in the air
   - O_2 Diffusion from air into water

2. **Fine bubble Aeration**
   - Gas-bubbles in the water
   - O_2 Diffusion from gas bubble into water

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Dimensioning an aeration system

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Standard Oxygen Transfer Rate SOTR [kg O_2/h]

- "SOTR is the mass [kg] of oxygen transferred by an aeration installation in one hour in a tank of certain size filled with clean water at DO of C = 0 mg/L, a water temperature of 20 °C and normal atmospheric pressure (1,013 mbar)."
  (ATV-M209E)
- Oxygen Transfer at **Standard Conditions**
  - atmospheric normal air pressure (1,013 mbar -> C_S)
  - TW = 20 °C -> c_S und k_La
  - oxygen concentration C = 0 mg/l

Dimensioning an aration system

- calculation of **Standard Clean Water Oxygen Transfer Rate (SOTR)** according to the DWA-M 229-1 (2013):

$$SOTR = \frac{f_d \cdot \beta \cdot C_{S,20}}{\alpha \cdot \left(f_d \cdot \beta \cdot C_{S,T} \cdot \frac{p_{atm}}{1{,}013} - C_X\right) \cdot \theta^{(T_W-20)}} \cdot OV_h$$

SOTR:	**S**tandard **O**xygen **T**ransfer **R**ate	[kgO_2/h]
OV_h:	Oxygen demand (OUR)	[kgO_2/h]
f_d:	depth factor	[-]
c_S:	O_2 saturation concentration	[mg/l]
β:	salt factor	[-]
f_S:	salt factor for α-value	[-]
α:	alpha-value	[-]

General requirements

source: www.stol.it www.merkur.de www.shutterstock.com

General requirements

Influence of salt:

Salt reduce O_2 saturation concentration:

$$c_{S,wastewater} = \beta \cdot c_S$$

β:	salt factor = 0,95 to 1,0 = 1 – 0,01 · TDS	[-]
TDS:	**T**otal **D**issolved **S**olids	[g/L]

e.g. North Sea: $\beta \approx 0,8$

Other effects by salt, where investigated in the **EXPOVAL** Project (later in this presentation)

General requirements

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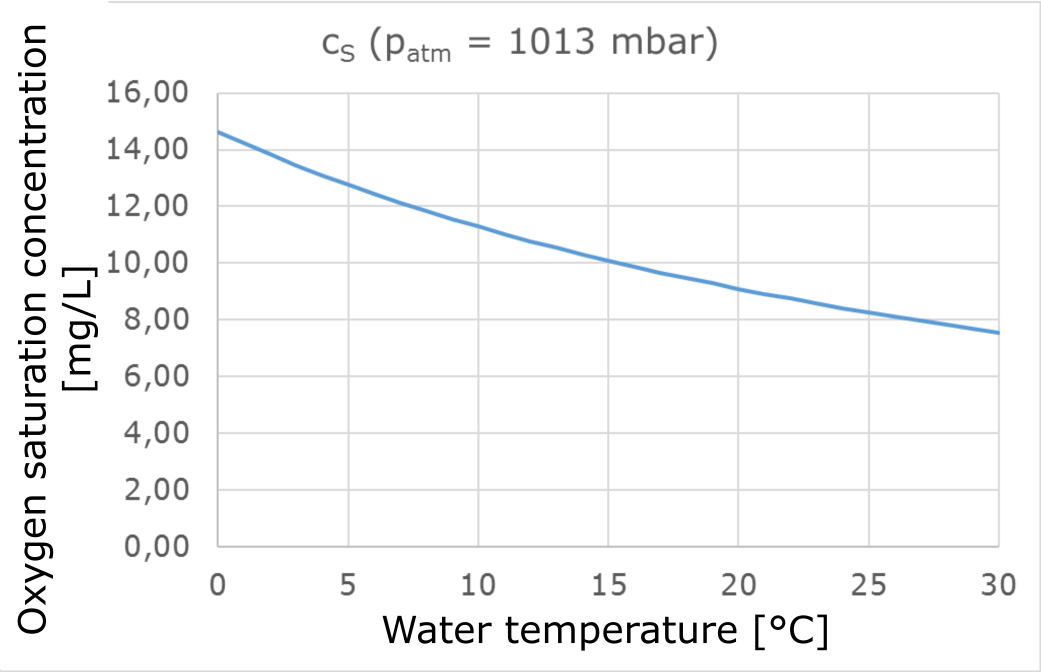
Influence of water temperature:



T [°*C*]	5	10	15	20	25	30
C_S [*mg/L*]	12,77	11,29	10,09	9,09	8,26	7,55

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General requirements

Influence of pressure:

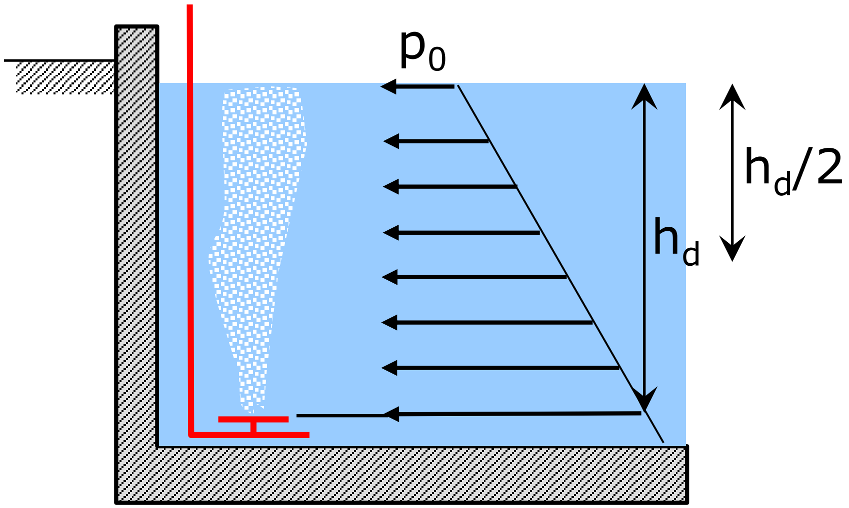
depth factor f_d

$$C_S = C_{S,p_0} \cdot \left(1 + \frac{h_D}{2 \cdot 10{,}35}\right) = C_{S,p_0} \cdot \underbrace{\left(1 + \frac{h_D}{20{,}7}\right)}_{\text{depth factor } f_d}$$

Depth factor f_d:

h_d: depth of submergence [m]

h_{BB}: depth of the tank [m]



General requirements

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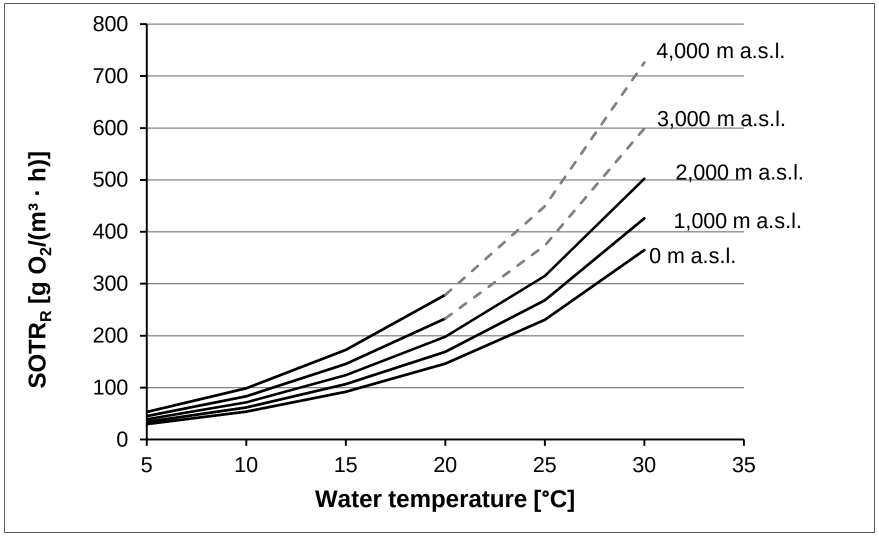
Atmospheric pressure:



city	height about NN	Inhabitants Mio.
Lhasa	3.650	0,5
La Paz	3.600	0,9
Quito	2.850	1,4
Bogota	2.640	6,8
Mexico-City	2.310	8,8
Sana'a	2.250	2,5
Johannesburg	1.753	3,9
Nairobi	1.650	2,7
Ulaanbaatar	1.350	1,0
Teheran	1.191	8,8

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The α-value

- various **substances** in **wastewater** (i.e. surfactants, MLSS): k_La at operation conditions is usually lower than in clean water.

$$k_La_{\text{service conditions}} = \alpha \cdot k_La_{\text{clean water}}$$

with

$k_La_{\text{service conditions}}$	calculated k_La for operation conditions	1/s; 1/h
α	α-value	-
$k_La_{\text{clean water}}$	k_La from clean water tests	1/s; 1/h

- **fine bubble aeration**: α = 0.2 to 0.9 (**average: 0.6**)
- surface/mechanical aeration: α = 0.7 to 1.8 (0.9)

The α-value – Influence of SRT

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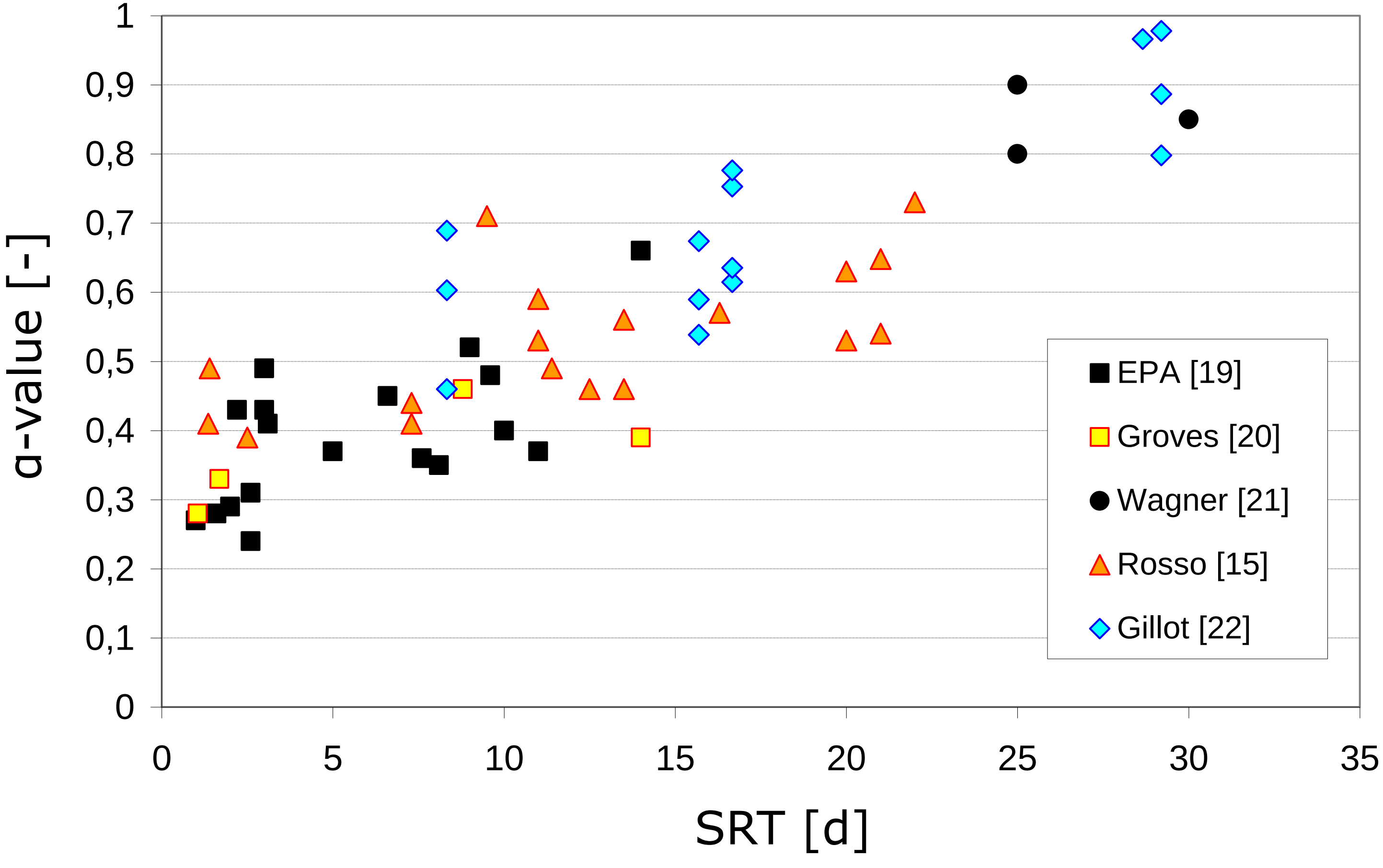
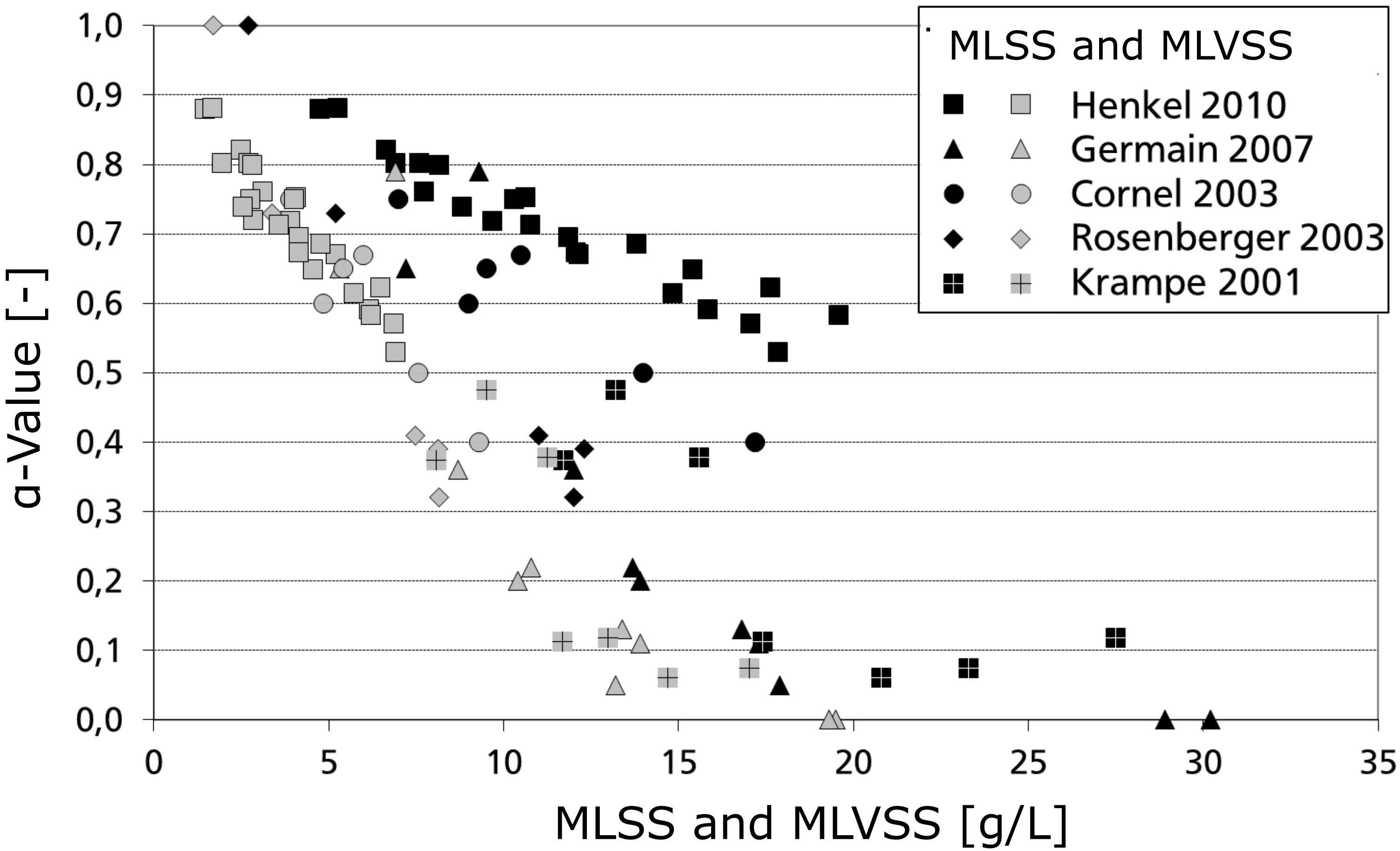


The α-value – Influence of MLSS/MLVSS



The α-value for different treatment processes and load cases

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The **α-values** depends on :

- treatment processes
- cleaning objectives

Treatment process	α_{min}	α_{medium}	α_{max}
Denitrification-Nitrification	0,60	0,75	0,85
SBR-reactor with N-Elimination	0,50	0,65	0,80
MBR (TS ~ 12 g/L, t_{TS} = 25 d)	0,50	0,60	0,70
aerobic stabilisation	0,70	0,80	0,90
C-Elimination	0,35	0,50	0,60

[Günkel-Lange 2012]

Dimensioning an aeration system

Many **aeration systems** are **oversized** because:

- optimistic assumptions were made of future loads
- sized using the same forecasting as the treatment plant structures
- sized for unfavorable conditions and for too high loads
- sized with too high, and overlapping safety factors

Dimensioning an aeration system

- Systems should be sized for a **range of load cases**
- **DWA – M 229-1 (2013)** give a new approach
- Determination of oxygen demand (OUR) for four different cases:

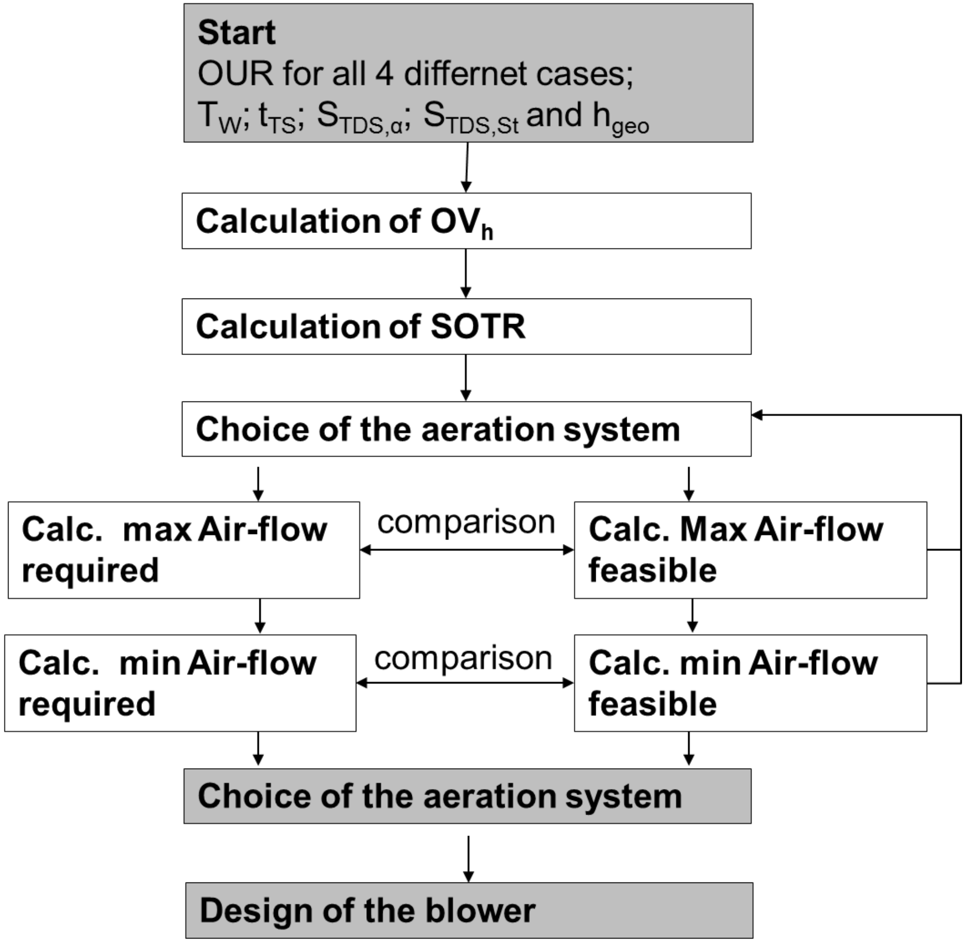
1. **average OUR**
2. **maximum OUR**
3. **minimum OUR**

(1.–3.) for the actual situation

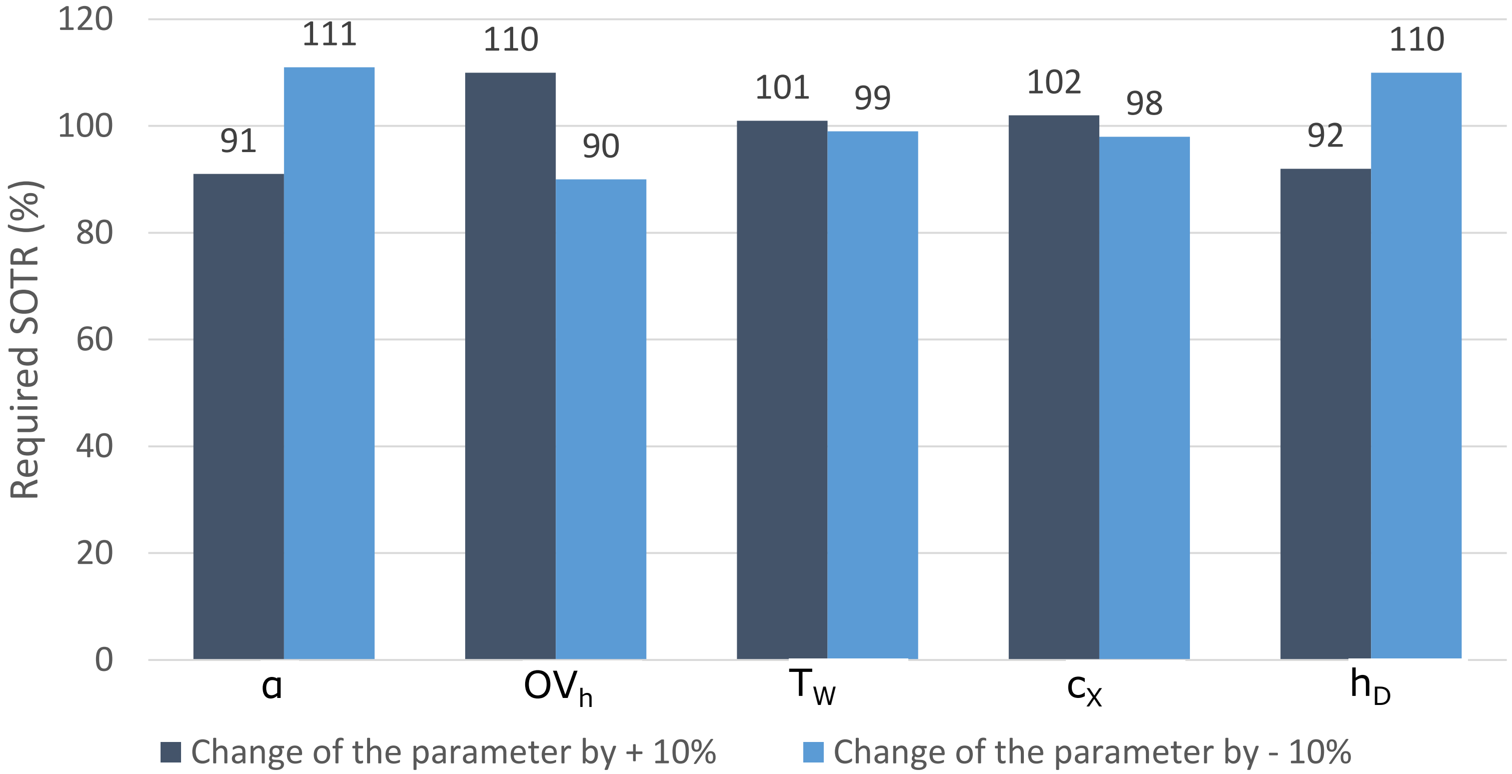
4. **OUR** for the **predicted situation** or expansion

Dimensioning an aeration system

- New procedure for design of a fine bubble aeration system according to **DWA-M 229 – 1 (2013)**
- Input Parameters are determined according to **DWA-A 131**
- New edition of DWA-M 229 are in progress and will be published in 09/2017



Sensitivity of the calculation of SOTR



[Günkel-Lange 2012]

α: Alpha-value (-); OV_h: Oxygen demand (OUR) (kg/d); T_W: wastewater temperature (°C); c_X: oxygen concentration in aeration tank (mg/L); h_D: depth of submergence (m)

General requirements

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High salt concentrations in wastewater

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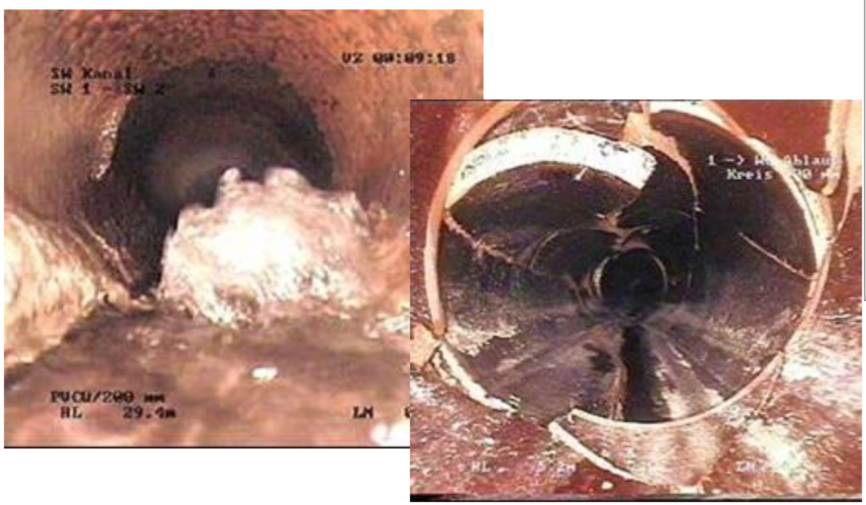
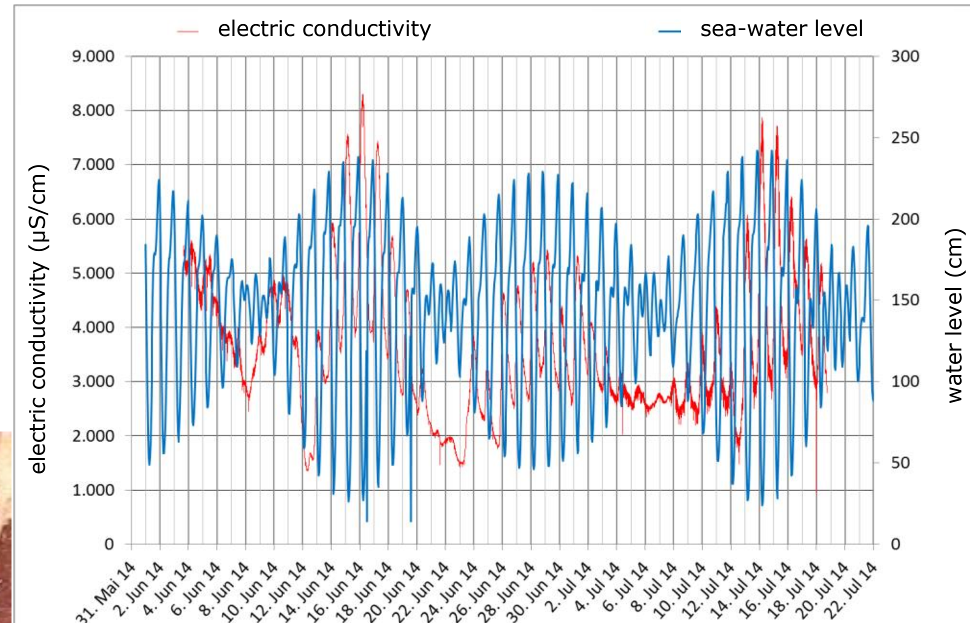
- Seawater for toilet flushing (Hong Kong 3.5-6.5 g/L Cl^-)
- Seawater intrusion into leaky sewers
- Industrial wastewater
- De-icing salt in winter





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The α-value – Influence of Salt

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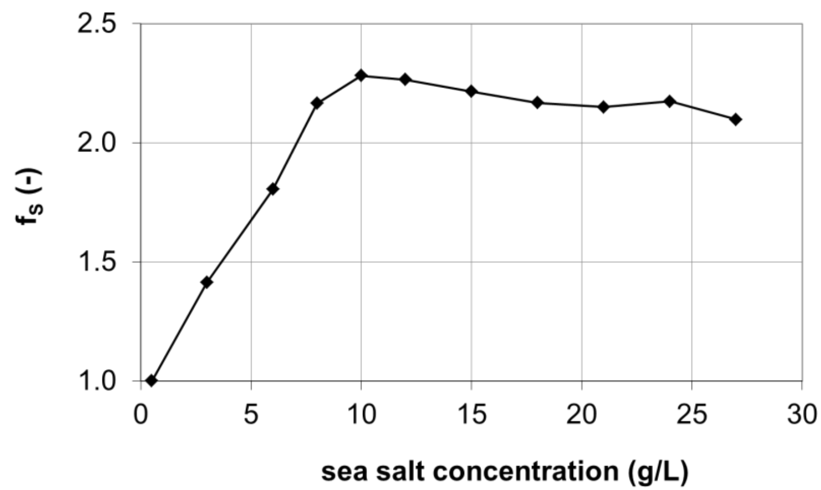
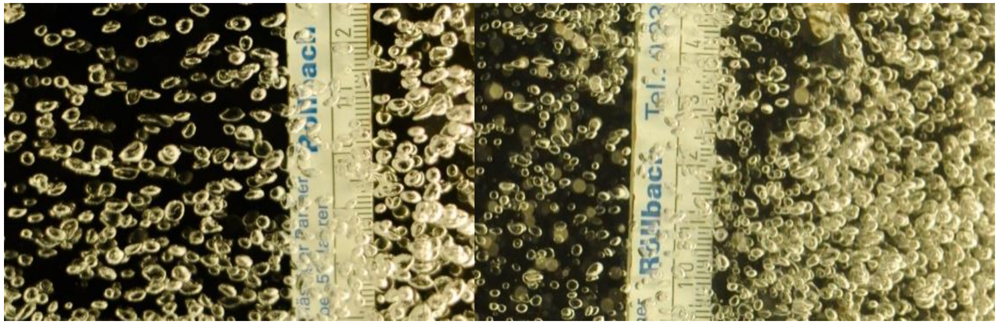
Effects of salt on oxygen transfer:

- Reduce the mass transfer (k_L)
- Increase the interfacial area (a)

Results in a net increase of the volumetric mass transfer ($k_L a$)





without salt   with salt

$$f_S = \frac{k_L a_{20,saline\,water}}{k_L a_{20,clean\,water}} \; (-)$$

Project EXPOVAL: Aeration under particular framework conditions

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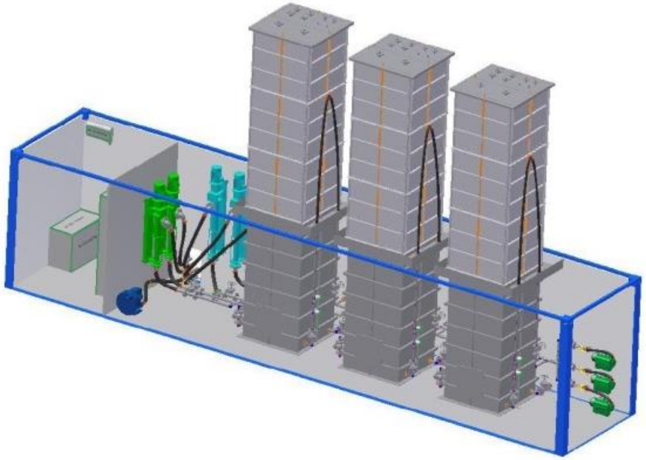
Influence of two parameters on oxygen transfer in WWTPs:

- Salt concentration
- Water temperature

Measurements from 2012 - 2015



EXPOVAL

NaWaM Nachhaltiges Wassermanagement

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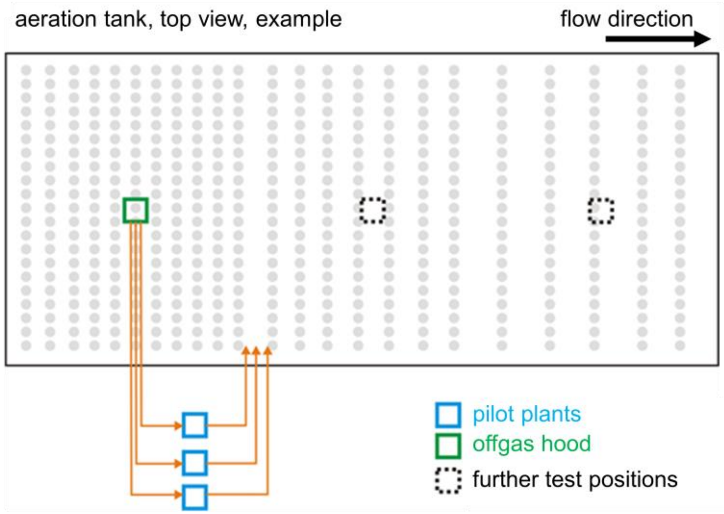
Project EXPOVAL: Aeration under particular framework conditions

- **Measurement of k_La-values** in clean, salty and wastewater
- **Dosage of salt** into the reactor (up to 28 g/L)
- **Fine bubble aeration system**
- **Depth of submergence** up to 6 m

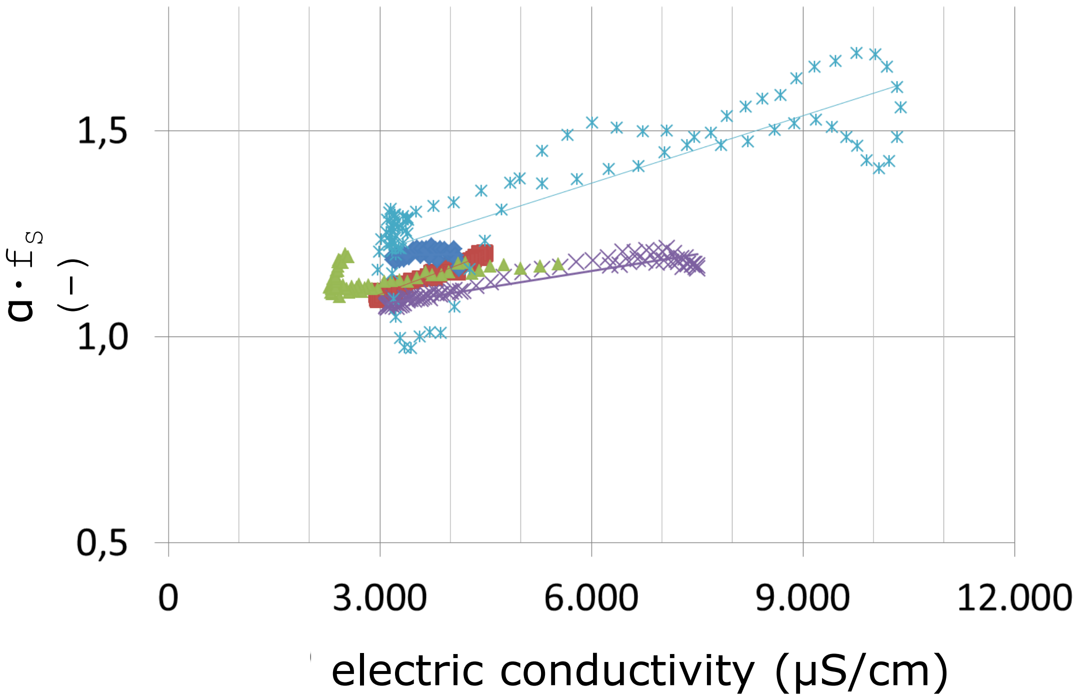


Project EXPOVAL: Aeration under particular framework conditions

- **$\alpha \cdot f_S$-value** describe the influence of salt and activated sludge in the aeration tank

- $\alpha \cdot f_S$-value obvious **higher than 1,0**

- there is an correlation between **electric conductivity** (salt-concentration) and **$\alpha \cdot f_S$-value**



New design approach from the results of EXPOVAL

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New equation for calculation of
standard clean water oxygen transfer rate (SOTR):

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

SOTR:	**S**tandard **O**xygen **T**ransfer **R**ate	[kgO_2/h]
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New design approach from the results of EXPOVAL

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Salt concentration (g/L)	$S_{TDS,St}$	$S_{TDS,\alpha}$
reduce C_S (-)	$\beta_{St} = 1 - 0{,}01 \cdot S_{TDS,St}$	$\beta_\alpha = 1 - 0{,}01 \cdot S_{TDS,\alpha}$
increase k_La (-)	$f_{S,St} = 1 + 0{,}08 \cdot S_{TDS,St}$	$f_{S,\alpha} = 1 + 0{,}08 \cdot S_{TDS,\alpha}$

New design approach from the results of EXPOVAL

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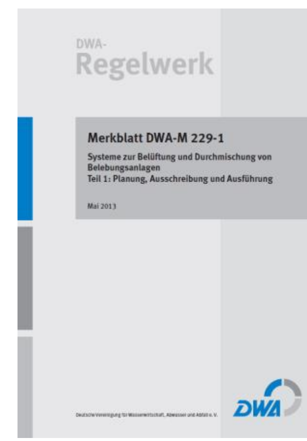
- **Validity of the new equation**:
  - Only for **municipal wastewater**
  - For wastewater with **high salt concentration as a consequence of sea water intrusion, predominant NaCl** (investigation about the influence of other salts are in progress)
  - Only **fine bubble aeration systems** (not for mechanical/surface aeration)
- Publishing of the **new DWA-M 229-1 in 09/2017**


DWA-
Regelwerk
Merkblatt DWA-M 229-1
Systeme zur Belüftung und Durchmischung von Belebungsanlagen
Teil 1: Planung, Ausschreibung und Ausführung
Mai 2013
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Conclusions

- aeration systems are **technically mature**
- fine bubble aeration systems are **state-of-the-art technology**
- **increasing electricity costs** demand also for optimizations of:
  - design of aeration system
  - diffuser technology
- Many **aeration systems** are **oversized**: with new design approaches, the efficiency of aeration systems increase
- additional **knowledge of oxygen transfer mechanisms** necessary to further improve the efficiency of aeration systems

Thanks you for your attention

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References

DWA-M 209, 2007: Messung der Sauerstoffzufuhr von Belüftungseinrichtungen in Belebungsanlagen in Reinwasser und in Belebtschlamm.

DWA-M 229-1, 2013: System zur Belüftung und Durchmischung von Belebungsanlagen Teil 1: Planung, Ausschreibung und Ausführung.

Henkel, 2010: Oxygen Transfer Phenomena in Activated Sludge; PhD Thesis; Institut IWAR TU Darmstadt

Wagner u. Stenstrom, 2014: Activated Sludge – 100 Years and Counting; IWA Publishing

References

Günkel-Lange, 2012: Sauerstoffzufuhr und α-Werte feinblasiger Belüftungssysteme beim Belebungsverfahren, PhD Thesis; Institut IWAR TU Darmstadt