Overview of sludge treatment and disposal

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Comparison of the sludge amount in Europe

Stand 2003: Fachtagung Klärschlamm, Bonn, 6./7.12.06

Emscher-Lippe
Input for the sludge production

Yearly menu:
650 kg per family and year

Input for the sludge production: 
650 kg per family and year

* Inhaltstabelle einer durchschnittlichen Familie mit zwei Kindern unter 18 Jahren für die wichtigsten Lebensmittel.
Wastewater treatment plant
State of the art

Primary settling tank:
Removal of settleable solids (30-40 g/(PE·d))

Grit chamber:
Removal of sand and grit; 4 kg/(PE·a)

Grease trap (partially integrated):
Removal of oil and grease

Biological stage:
Removal of COD, BOD, N, P (30-45 g/(PE·d))

Screens, sieves: 2 kg/(PE·a)
Removal of solids, fibrous material, plastics

Results according DWA-benchmarking 2010

- Organic matters (COD): inflow KA 530 mg/l → outflow KA 28 mg/l
- Nitrogen: inflow KA 49 mg/l → outflow KA 9,5 mg/l
- Phosphorus: inflow KA 8 mg/l → outflow KA 0,75 mg/l
### Amount of sludge according „Sludge list“

**Raw sludge**

<table>
<thead>
<tr>
<th>Treatment technology/ condition</th>
<th>Type of sludge</th>
<th>Amount of sludge and condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DS-Content [% TR]</td>
</tr>
<tr>
<td><strong>Primary settler:</strong></td>
<td>Primay-Sludge</td>
<td></td>
</tr>
<tr>
<td>- ( t_{A,VK} = 0,5 ) h (^{1a)})</td>
<td>PS</td>
<td>2 .. 8</td>
</tr>
<tr>
<td>- ( t_{A,VK} = 1,0 ) h (^{1b)})</td>
<td></td>
<td>2 .. 8</td>
</tr>
<tr>
<td>- ( t_{A,VK} = 2,0 ) h (^{1c)})</td>
<td></td>
<td>2 .. 8</td>
</tr>
<tr>
<td><strong>Activated sludge system (T = 15 °C)</strong></td>
<td>Surplus-Sludge</td>
<td></td>
</tr>
<tr>
<td>- C-Elimination (BOD(_5)+ggf. Denitrification)</td>
<td>( \bar{U}_B )</td>
<td>0,7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0,7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0,7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0,7</td>
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<tr>
<td></td>
<td></td>
<td>0,7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0,7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0,7</td>
</tr>
<tr>
<td>- Nitrification</td>
<td></td>
<td>practical no additional sludge production to be realized</td>
</tr>
<tr>
<td>- Denitrification adding external C-Source</td>
<td>( \bar{U}_D,ECQ )</td>
<td>1,0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,0</td>
</tr>
<tr>
<td>- Biol. P-Elimination</td>
<td>( \bar{U}_B,IO,P )</td>
<td>2,88 (^{7)})</td>
</tr>
<tr>
<td><strong>Biofilm technologies</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Trickling filter (C-Elimination/Nitrifikation)</td>
<td>( \bar{U}_BF )</td>
<td></td>
</tr>
<tr>
<td>- Submerged Bed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Moving bed reactor</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

1. \(^{1)}\) \( t_{DS} = 5d, t_{A,VK} = 0,5 \) h
2. \(^{2)}\) \( t_{DS} = 5d, t_{A,VK} = 2,0 \) h
3. \(^{3)}\) \( t_{DS} = 10d, t_{A,VK} = 0,5 \) h
4. \(^{4)}\) \( t_{DS} = 10d, t_{A,VK} = 2,0 \) h
5. \(^{5)}\) \( t_{DS} = 15d, t_{A,VK} = 0,5 \) h
6. \(^{6)}\) \( t_{DS} = 15d, t_{A,VK} = 2,0 \) h
7. \(^{7)}\) \( t_{DS} = 25d \) (Stabilisierungsanlage o. VK)
8. \(^{8)}\) Practical no additional sludge production to be realized

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Note: The table above provides an overview of the amount of sludge for different treatment technologies and conditions, including primary settlement and activated sludge systems. Each entry specifies the type of sludge, the time of settlement, the sludge volume, and the load and content of the sludge. The table also categorizes the treatment technologies used, such as primary settlement, activated sludge systems, and biofilm technologies. The operational circumstances for each technology are specified with regards to the sludge production and condition, along with the sludge quality and volume.
## Typical condition of sludge

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Raw primary sludge</th>
<th>Secondary sludge</th>
<th>Very good Stabilized sludge</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>-</td>
<td>5.0 – 7.0</td>
<td>6.0 – 7.0</td>
<td>7.4 – 7.8</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>mg/l</td>
<td>500 – 1,000</td>
<td>500 – 1,000</td>
<td>4,000 – 5,000</td>
</tr>
<tr>
<td>Dry solids</td>
<td>%</td>
<td>5 - 10</td>
<td>4 - 8</td>
<td>4 - 12</td>
</tr>
<tr>
<td>Volatile solids</td>
<td>%</td>
<td>60 - 75</td>
<td>55 - 80</td>
<td>30 - 45</td>
</tr>
<tr>
<td>Volatile acids</td>
<td>mg/l</td>
<td>1,800-3,600</td>
<td>1,800-3,600</td>
<td>120 -200</td>
</tr>
<tr>
<td>CST</td>
<td>m/kg</td>
<td>$10^{11}$</td>
<td>$10^{12}$</td>
<td>$10^{10}$</td>
</tr>
<tr>
<td>Calorific value</td>
<td>kJ/gm&lt;sub&gt;DS&lt;/sub&gt;</td>
<td>16 - 20</td>
<td>15 - 21</td>
<td>6 - 10</td>
</tr>
</tbody>
</table>
Benefits and risks of sludge (bio-solids)

- **May be valuable:**
  Nutrients, nitrogen, phosphorus, organic fertilizer, improvement of the solid conditions (erosion, water storage capacity, etc.)

  ➔ *Agricultural use or re-cultivation brings advantages*
  Good control of the industrial dischargers!

- **Can be harmful:**
  Hygienic, Heavy metals
  not degradable organic substances (e.g. AOX, PCB)
  Pharmaceutical, endocrine disruptors, micro-pollutants
  „BSE-pathogen“ ➔ PFT ➔?

  ➔ Thermal treatment (disposal)

- **Attitude of food companies, psychology**
Main objectives of sludge treatment

- **Stabilisation**
  - Reduction of smelling substances
  - Reduction of the organic matters
  - Improvement of the dewaterability
  - Decreasing the amount of pathogens

- **Hygienisation (pasteurisation)** (in Germany still the exception)
  - Often applied regarding hygienic aspects
  - Avoidance the spreading of pathogen germs (e.g., helmet eggs, pathogenics)

- **Separation of sludge water**
  - Decreasing the water content
  - Reduction of the amount of sludge
  - Low volume for transport and storage (costs)

- **Storage**
  - De-coupling of the time of appearance and the time of application

- **Sewage sludge disposal and reclamation**
  - Agricultural sludge use, land use, re-cultivation
  - Landfill (in Germany forbidden),
  - Thermal use (incineration)
WTTP Rostock, typical sludge treatment in
Capacity: 400,000 PE; 65,000 m³/d
Build in 1994
Distribution of the types of water in the sludge suspension

A: Free (volatile) water
- No binding to the sludge particles

B: Intermediate water
- Bounded by capillary forces
- Both A + B = about 70%

C: Surface water
- Bounded by adhesion forces about 22%

D: Internal water of the cells
- Bounded in the cell about 8%
Processes auf sludge thickening, dewatering and drying

Thickening
- Mechanical
- Gravity
- Through flow
- Batch
- Mechanical
- Flotation

Dewatering
- Mechanical
- By machines
- Natural

Drying
- Thermal
- By machines
- Natural (Solar)
Principle of a Thickener

Input

Scum collector

Sewage works

Sludge liquor outlet

Sludge outlet
Pressure Flotation

Example for thickening of excess sludge

Dimensioning:

- Surface application \( (q_A = Q/A) \):
  \[ q_A = 3 \text{ – } 6 \text{ m/h} \]

- Air-solid-ratio:
  \[ L_{TS} = 40 \text{ – } 100 \text{ gO}_2/\text{kg TS} \]

- Time of passage:
  \[ t_R = 0.5 \text{ – } 1.0 \text{ h} \]
Thickening by machine

Seihtisch bzw. Seihband

Fa. Huber, Berching
Hygienization of raw sludge

- Storage tank
- Heater/Heat exchange
- Digester
- Storage tank
- Dewatering

Raw sludge

Energy

Digest sludge

Agricultural use

Fachtagung, Klärschlamm, Bonn, 6./7.12.06; EmscherLippe
If in Germany hygienisation would be demanded, the costs will double (thermal raw sludge treatment or lime).
Objectives of sludge stabilisation

- Reduction of organic matter and the total amount of sludge
- Decreasing of odour
- Reduction of pathogenic organisms
- Improvement of dewaterability of the sludge
- Production of energy (Biogas) by using anaerobic treatment
Stabilisation processes

- **Aerobic Stabilisation**
  - Simultaneous aerobic stabilisation
  - Separate aerobic stabilisation at normal temperature
  - Separate aerobic-thermophilic Stabilisation (at liquid environment)
  - Separate two-stage aerobic-thermophilic stabilisation (at liquid environment) composting of sludge

- **Anaerobic Digestion**
  - “Cold” digestion (e.g. Emscher tank; 15-20 C)
    \[ t_D \text{ ca. 60 d (}>20 \text{ l/PE}) \]
  - Mesophilic digestion (30-35 )
    \[ t_D \text{ ca. 20 d (16-25 l/PE}) \]
  - Thermophilic digestion (50-55 C)
    \[ t_D \text{ ca. 10 d (}\approx 12 \text{ l/PE}) \]
Stabilisation processes

related to number of WWTP‘s:

- 17% single-level
- 31% double-level
- 40% anaerobic digestion

related to connection size of WWTP‘s:

- 12% simultaneous aerobic
- 60% anaerobic digestion, single-level
- 16% anaerobic digestion, double-level
- 1% composting
- 1% ATS
- 1% other
- 9% no

ca. 1.200 plants ca. 97 Mio. PE

with anaerobic digestion (2006)

(DWA 2003)
Aerobic thermophilic sludge stabilisation
Building up a digester and Technical equipment
Digester Tanks as Architecture
Ideal operation of digestion

- time of digestion and temperature
- constant inflow
- mixing (complete and constant)
- high amounts of solids in raw sludge
  - longer time of digestion
  - higher gas production
- drop of temperature
  - gas reduction with 1-2°C variation

**additional activation**

- Co-fermentation (external substances e.g. fats)
- Pretreatment of sludge (desintegration)
Specific Gas Production against Digestion Time

Gas production in m³ kg⁻¹ organic solids at the inflow

Digestion time [days]

Gas production against Digestion Time

- 30°C
- 25°C
- 20°C
- 15°C
- 10°C

usual digestion time
Utilization of sewage gas in Germany 2008

Combined heat power station (CHP)

- Power generation: 75%
- Loss / gas flare: 6%
- To network: 3%
- Heating/operation: 15%

Gas storage

(StBA 2009)
Stabilisation criteria

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Aerobic</th>
<th>Anaerobic</th>
<th>Partly stabilised</th>
<th>Fully stabilised</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatile solids [%]</td>
<td>x</td>
<td>x</td>
<td>45..55</td>
<td>≤ 45</td>
</tr>
<tr>
<td>Sludge age [d]</td>
<td>x</td>
<td></td>
<td></td>
<td>≥ 25 1)</td>
</tr>
<tr>
<td>BOD$_5$/COD</td>
<td>x</td>
<td>x</td>
<td>0,15 – 0,18</td>
<td>≤ 0,15</td>
</tr>
<tr>
<td>Oxygen consumption [kg O$_2$/ kg oDS·d]</td>
<td>x</td>
<td></td>
<td></td>
<td>≤ 0,1</td>
</tr>
<tr>
<td>Reductase activity [mg Formazan/g oDS]</td>
<td>x</td>
<td></td>
<td>≤10</td>
<td>≤ 5</td>
</tr>
<tr>
<td>VOA [mg CH$_3$COOH/l]</td>
<td>x</td>
<td></td>
<td>100-1000</td>
<td>≤100</td>
</tr>
</tbody>
</table>

1) dependent on different requirements
Comparison of raw sludge to stabilized sludge

Raw sludge

- 66.3% Organic fraction (VS) 53 g DS/PE·d
- 33.7% Mineralic Fraction 27 g DS/PE·d
- 80 g DS/PE·d

Aerobic or anaerobic stabilized sludge

- 57% oTR Abbau 55% (50 g DS/PE·d)
- 38% TR Verring. 45% (23 g DS/PE·d)

Aerobic: CO₂
Anaerobic: Biogas
Sludge water

Organic fraction (VS)

Mineralic Fraction
Mechanical Dewatering

Filter press

Decanting centrifuge

Belt filter press

Sludge press
Sludge drying beds (Korba, Tunesien)

Independence of the climate
Sewage Sludge mineralisation

- With reed or grass seed
  - *sequential* sludge accumulation
    - Distance 6-10 month
    - about 40 cm thickness of layer
    - After a specific drainage level – seed of ryegrass
    - After sagging down to 10 cm new layer
    - after 3 layers removal
  - Charge: 30-40 kg TS/m²
  - After on cycle - 40% TR
  - Operating time about 6 years plus one neutral year
  - *Phenomenon*: no increase of pollutant concentration?
Solar sludge drying process

- anaerobic or aerobic stabilized sludge
- in „glasshouse“
- Steam pressure difference between sludge/air
- tendency of air to water saturation
- in summer DS 90% / in winter 45% DS
- Mixing with the electronic “pig”
Belt dryer
System Stela
Dried sludge
Belt dryer (about 95% DS)
Sludge disposal
Thermal utilisation (pros and cons)

**Pros**
- Durable destruction of the pollutants and pathogens
- Utilisation of slag and ashes e.g. as construction material
- Reduction of the offgas pollutants by technical measures
- Advanced immobilisation of all residual
- Economically calculable

**Cons**
- „uncontrolled“ distributions of the pollutants by the air pathway
  - Human food chain
- Health risks by offgases spec. Hg
- Thermal utilisation or thermal disposal?
- Irreversible destruction of the nutrients
- Higher global warming potential

**Assumption:**
- Construction of the required capacities
- Proper off gas cleaning
Sludge combustion/ fluidized bed furnace

- Combustion chamber: 800 - 900°C
- Offgas and slag: 850°C
- Input of dried sludge
- Fluidized layer (sand)
- Additional burner
- Nozzle bottom
- Disturbed air
- Start-up burner
Agricultural use of sludge (pros and cons)

**Assumption:**
- Considering the agricultural demand
- Good technical practice (e.g. 3 t dry solids/(ha·3 years))

**Pros**
- Recirculation of nutrients (N, P, K, Mg, trace elements)
- Improvement of soil (erosion water storage capacity, etc.)
- Protection of natural resources (P-reserves; energy)
- Economical advantages for the farmers and the WTTP
- Precaution (Consulting; Sludge fond)

**Cons**
- Closed loops ➔ accumulation of pollutants
- Limited availability of nutrients (Fe/P-ratio)
- Specific toxicological risk potential (endocrine disruptor, pharmaceuticals etc.)
- Application of still unknown pollutants
- Non differentiated agricultural application may use risks

Heavy metals, other contaminants must be removed before the WTTP (indirect discharger control)
Sludge/biosolids as a fertilizer
Sludge application in agriculture

Distribution of wet sludge

Distribution of dewatered sludge
New German Sludge ordinance for agricultural use 2007

<table>
<thead>
<tr>
<th></th>
<th>Pb</th>
<th>Cd</th>
<th>Cr</th>
<th>Ni</th>
<th>Hg</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>EWG 86/278</td>
<td>750 - 1200</td>
<td>20 - 40</td>
<td>-</td>
<td>300 - 400</td>
<td>16 – 25</td>
<td>1000 - 1.750</td>
<td>2.500 – 4.000</td>
</tr>
<tr>
<td>AbfKlärV (1992)</td>
<td>900</td>
<td>10</td>
<td>900</td>
<td>200</td>
<td>8</td>
<td>800</td>
<td>2500</td>
</tr>
<tr>
<td>Proposal BMU 11/07</td>
<td>120</td>
<td>2,5</td>
<td>100</td>
<td>60</td>
<td>1,6</td>
<td>700</td>
<td>1500</td>
</tr>
<tr>
<td>Reduction zu 1992</td>
<td>87%</td>
<td>75%</td>
<td>89%</td>
<td>70%</td>
<td>80%</td>
<td>12,5%</td>
<td>40%</td>
</tr>
<tr>
<td>Actual content insludge (2006)</td>
<td>37,2</td>
<td>0,96</td>
<td>36,7</td>
<td>24,9</td>
<td>0,59</td>
<td>300,4</td>
<td>713,5</td>
</tr>
<tr>
<td>Proposal DWA 2008</td>
<td>300</td>
<td>3,0</td>
<td>250</td>
<td>100</td>
<td>2,5</td>
<td>700</td>
<td>1.500</td>
</tr>
</tbody>
</table>

Copper and zinc essential micro-fertilizer and should be regarded separately.
Ways of sludge disposal
Germany 2010; about 1,9 mio. t sludge/a

<table>
<thead>
<tr>
<th>Disposal path</th>
<th>2004</th>
<th>2007</th>
<th>2010</th>
<th>Prognosis 20015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landfill</td>
<td>4%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Agriculture</td>
<td>31%</td>
<td>29%</td>
<td>30%</td>
<td>25%</td>
</tr>
<tr>
<td>Combustion</td>
<td>35%</td>
<td>49%</td>
<td>53%</td>
<td>65%</td>
</tr>
<tr>
<td>Land use</td>
<td>27%</td>
<td>18%</td>
<td>14%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Nach Könneumann 2009
Conclusions

- Advanced wastewater treatment with
  - Carbon-removal, Nitrification/denitrification
  - Phosphorus removal
  provides a good water quality in the receiving water bodies

- Proper Sludge treatment and utilisation is required
  - High effective dewatering and storage
  - Anaerobic digestion
  - Intensive control of the industrial discharges
    - Agricultural application as fertilizer (regarding Good practice)
  - Heavily polluted sludge
    - Thermal utilisation (disposal)
  - Recovery of nutrients

- Optimisation
  - Effective bio-gas utilisation (enhanced CHP, fuel cell)
  - Dosage of additional C-sources (Co-fermentation)
  - Applying sludge disintegration
  - Biogas re-formation and various modes of use (external)