Solutions of Sewage Sludge Mono-Combustion with an Integrated Rotary Kiln in an Existing Waste-to-Energy Plant

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1. Purpose of the system

1,8 Mio t/a dry material sewage sludge in Germany, Phosphor potential

Potential

- 100% Mono-Combustion
- 7-8% as P$_2$O$_5$

Actual

- 35% Farming/landscaping
- 35% Co-Combustion
- 40% Mono-Combustion existing

Actual amendments to:
- Klärschlammverordnung (AbfKlärV) 3. Oktober 2017
- Düngemittelverordnung (DüMV) 27. Mai 2015
- Düngeverordnung (DüV) 26. Mai 2017

Forces Mono-Combustion capacity increase

Future demand for Mono-Combustion capacity
app. 1.2 Mio t/a dm

59 kt/a Phosphor, existing potential
20 kt/a Phosphor, existing potential

Phosphor demand by fertilizer production
150 kt/a Phosphor

Other sources

All figures are approx. values
1. Purpose of the system

### Sewage sludge Mono Combustion technology

<table>
<thead>
<tr>
<th>Fluidized Bed</th>
<th>Rotary Kiln (alternative solution)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference: &gt; 20 plants in operation (Germany)</td>
<td>System connected to (existing) WtE plant using heat of flue-gas and existing AQCS, Reference: erzo Oftringen plant, in successful operation for 20 years</td>
</tr>
<tr>
<td>- Long permit procedures</td>
<td>- Short permit procedures</td>
</tr>
<tr>
<td>- Low TOC of ash</td>
<td>- Ash-TOC of approx. 10%, to be improved</td>
</tr>
<tr>
<td>- Invest Cost: 100 %</td>
<td>- Invest Cost: approx. 50%</td>
</tr>
</tbody>
</table>

**Actual project**

- Implementation of 2 x 40.000 t/a rotary kiln sewage sludge mono-combustion system at Energieversorgung Offenbach AG (EVO)
- With low Total Organic Content in ash (TOC < 5%)
- This requires additional measures like optimisation of kiln combustion process. Further TOC reduction by post combustion system is expected.
2. Description of the existing waste to energy plant

**Actual:**
Sewage sludge is co-incinerated at the roller grate combustion.

**Planned:**
New Mono-Combustion system connected to the existing plant

Firing rate: 28.1 MWth  
Live steam: 31.6 t/h

Sewage sludge  
1.1 t/h

Sewage sludge  
5.6 t/h

Mono-combustion system

Ash

Source figure: Bachelorarbeit zur Erlangung des Grades Bachelor of Engineering, Ressourcenschutz in der Abfallwirtschaft – MVA-Aschen als Sekundärrohstoffquelle für Metalle, Tilman Euler
3. Sewage sludge mono combustion

**Sludge and ash characteristic**

<table>
<thead>
<tr>
<th>Sludge</th>
<th>Design</th>
<th>Design range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash/Inert Material</td>
<td>11,25%</td>
<td>10 – 15%</td>
</tr>
<tr>
<td>Water</td>
<td>75,00%</td>
<td>70 – 80%</td>
</tr>
<tr>
<td>Dry Material</td>
<td>25,00%</td>
<td>20 – 30%</td>
</tr>
<tr>
<td>LHV at 80% Dry Material</td>
<td>10 – 12.5</td>
<td></td>
</tr>
</tbody>
</table>

**Expected ash properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOC [%]</td>
<td>9 – 11</td>
</tr>
<tr>
<td>Deformation temperature [°C]</td>
<td>1,120</td>
</tr>
<tr>
<td>P₂O₅ [%]</td>
<td>18</td>
</tr>
<tr>
<td>Residue 2 mm [%]</td>
<td>37</td>
</tr>
</tbody>
</table>

**Graphs:**
- Ash content vs. water content.
- HGI Value of different Fuels.

**Diagram:**
- Flowchart showing the process from Sludge to Ash through WtE Furnace and Rotary Kiln.
3. Sewage sludge mono combustion

Rotary kiln drying, combustion and burn out principle process

Counter-current combustion process

- flue gas, cold
- flue gas, hot
- sludge
- ash
4. Connection of WtE plant with Rotary Kiln

CFD to optimize flue gas extraction and process gas return points

Flue gas hot extraction

Flue gas cold return

to ensure sufficient combustion conditions in rotary kiln
5. Measures to reduce TOC at burn out zone

Ash volume flow equation*:

\[
\dot{V}_S = A_S \cdot v_S = \frac{2}{3} \omega R_i^3 \cdot \left( \frac{\tan \alpha}{\sin \beta} - \frac{\partial h_S}{\partial z} \cot \beta \right) \cdot \left( 2 \frac{h_S}{R_i} - \frac{h_S^2}{R_i^2} \right) \]

AB: Bed surface = reaction area

VB: Bed volume

\(\tau\): Mean residence time

Reaction number K:

\[ K = \frac{AB}{VB} \cdot \tau \]

Simplified estimation of \(\text{TOC}_\omega\):

\[ \text{TOC}_\omega = \text{TOC}_{\alpha,\text{Ref}} - \Delta\text{TOC}_{\text{Ref}} \cdot \frac{K}{K_{\text{Ref}}} \]

* Source: Dynamische Modellierung von Drehrohröfen, Dissertation RWTH Aachen, Fakultät für Maschinenwesen, Tobias Ginsberg, 26.11.2010
5. Measures to reduce TOC at burn out zone

Influence of rotational speed to residence time and TOC

- Rolling
- Slumping

TOC at beginning of burnout zone 15.5 %

- Effect of increased residence time by lowering rotational speed is limited
- Throughput influences the TOC

Source Figure: Rotary Kiln, Transport Phenomena and Transport Processes, Akwasi A. Boateng, BH 2008
5. Measures to reduce TOC at burn out zone

**Qualitative influence** of various parameters to reaction number $K$ respectively $\text{TOC}^\omega$, (at constant ash mass flow)

<table>
<thead>
<tr>
<th>Kiln Slope</th>
<th>Kiln diameter D</th>
<th>Kiln length $L$</th>
<th>Rotational Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Filling degree</th>
<th>Specific Surface $\text{AB} / \text{VB}$</th>
<th>Residence time $\tau$</th>
<th>Reaction Number $K$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

![Graph showing the qualitative influence of various parameters on TOC at burn out zone.](image-url)
5. Measures to reduce TOC at burn out zone

Segregation

- Improve ash mixing by lifters

Pour oxygen process gas layer

- Segregation
- Improve process gas mixing by rotating process gas
- Pour oxygen process gas layer

More ash particles get into contact with oxygen atmosphere

Particles get into contact with oxygen rich atmosphere

Effect can only be proven by tests at scale down kilns or by evaluation of operating data of a running facility.

While this is not available additional measures where developed to secure low TOC\(_{\omega}\) content.

⇒ post combustion of carbon in ash after leaving the kiln
6. Post Combustion system

- WtE Furnace
- Ash trap
- Shock blower
- Tempering Air
- Rotary Kiln
- Cyclone
- Post combustion
- Mill

Inputs:
- Sludge

Outputs:
- Ash

Components:
- WtE Furnace
- Ash trap
6. Post combustion system

Control diagram

- Fresh air
- Process gas
- Hot flue gas
- Cold flue gas
- Secondary air
- Sludge
- Ash
- WtE furnace
- Ash trap
- Post combustion
- Rotary Kiln
- Cyclone
- X mill
- Oxygen

Temperature points:
- $T_{FG}$
- $T_1$
- $T_{PG}$
- $T_2$
- $T_3$
6. Post combustion system

- Burn out is quick enough
- No reduction of Phosphor content in ash was observed
6. Post combustion system

Both types of ash could be removed (mechanical) easily from refractory. Sludge ash is more easy

Adhesion tests of waste incineration ash (light) and sludge ash after drop tube tests (dark) at oven temperature 1000°C

- Ash trap is foreseen to remove incineration ash as early and as much as possible in order to minimize slagging of downstream equipment
- Selection of suitable refractory material for cyclone, combustion chamber and ducts
6. Post combustion system

Arrangement

- Gas phase
- Sludge ash
- Rotary kiln
- Mill
- Ash trap
- Post combustion chamber
- Cyclone
6. Post combustion system

Arrangement

Gas phase

Rotary kiln

Mill

Ash trap

Cyclone

Post combustion chamber

Ash
7. Summary

- The presentation reveals that there are **more opportunities** for plant operators to **treat sewage sludge**. One of the **possibilities** to treat sewage sludge is to build a **mono-incineration** plant by using **FB** technology. This includes a long permit procedure as well as high investment costs.

- To avoid such complex effort **alternative solutions** are ready and proven in practice. One of those solutions is to combine a given WtE plant with a **rotary kiln** system by using the flue-gas of the WtE plant. This is practiced in Switzerland (plant erzo Oftringen) and has been in **successful operation for 20 years**.

- However, regulation of sewage sludge treatment and the requirement regarding limit value of **TOC** has to be fulfilled. Currently the **limit value cannot be proven by** only implementing a **rotary kiln** system.

- In order to meet this regulatory requirement MHPSE developed an advanced **upgrade** to the known technology by means of **post-combustion**. CFD calculation and drop tube tests of ash burnout shows very promising results for **lower TOC** content.

- Although it is expected that the **reduction of TOC** could be **improved** by adding **modified blades** and advanced **rotating gas flow** in the burn out area inside the rotary kiln to avoid phenomena like segregation.
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