Estonian sludge management strategy and possibilities for phosphorus recovery

Taavo Tenno
OÜ aqua consult Baltic
University of Tartu

Gdansk, 12.06.2018
Overview

• Definition of sludge and how to distinguish “good sludge” from “bad sludge”?

• Legislation and how Estonian sludge corresponds to the legislation?

• What is done with the sludge in Estonia?

• What should be done with the sludge?

• P – reuse in agriculture, greenery and recultivation.

• Possibilities for P – recycling.
Wastewater treatment and sludge management

Wastewater → WWTP → Effluent

Biowaste

Separate treatment

Primary sludge

Surplus sludge

SLUDGE

WASTE
**Composition**

**Composition of primary and secondary sludge as % dry weight of the organic sludge mass**

<table>
<thead>
<tr>
<th>Component</th>
<th>Primary sludge</th>
<th>Secondary sludge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Volatile fraction</td>
<td>79.7</td>
<td>73.5</td>
</tr>
<tr>
<td>Lipids</td>
<td>18.6</td>
<td>21.0</td>
</tr>
<tr>
<td>Cellulose</td>
<td>18.2</td>
<td>19.9</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>Proteins</td>
<td>17.2</td>
<td>28.7</td>
</tr>
</tbody>
</table>

Sources: (1) = O’Rourke (1968), (2) = Eastman and Ferguson (1981), (3) = Higgins et al. (1982), (4) = US EPA (1979) and (5) = Pavlostatis (1985)

van Haandel & van der Lubbe 2012
Phosphorous in sewage sludge

Wastewater

150-200 L/(PE•d)
C(P) 8-14 mg/L
P 100%
dissolved P

Primary sludge

WWTP

EELSETITI

Surplus sludge

JÄRELSETI

SLUDGE

Digester

Drying and incineration

Effluent

150-200 L/(PE•d)
C(P) 0,3-2 mg/L
P ~3-10 %
dissolved P

0.03 kg/(PE•d)
C(P) ~50 g/kg
P ~90-97%
chem bound P

Ash

0.15 kg/(PE•d)
C(P) ~ 10 g/kg
P ~90-97%
P ~2-3% of TS
bound P
Fate of sludge

FERTILIZER
- N, P, K, Mg, ..
- Organic fertilizer
- Cheap

WASTE
- Anthropogenic contamination
Sludge quality – how to evaluate?

- **Stabilisation**
  - Content of organics

- **Hygienisation**
  - Content of pathogens

- **Anthropogenic inorganic contaminantants**
  - Heavy metals (Cd, Hg, Ni, Zn, Cu, …)

- **Anthropogenic (toxic) non-biodegradable organics**
  - Drugs, antibiotics, hormones, PCB, …
Nondegradable organic pollutants

- Hormones
  - Estrogens
- Common drugs
  - Paracetamol
  - Diclofenac
- Antibiotics
  - Fluorokinones
  - Tetracycline
  - Sulphonamides
Sludge quality – what is it already in the legislation?

• Stabilisation
  – Content of organics

• Hygienisation
  – Content of pathogens

• Anthropogenic inorganic contaminants
  – Heavy metals (Cd, Hg, Ni, Zn, Cu, …)

• Anthropogenic (toxic) non-biodegradable organics
  – Drugs, antibiotics, hormones, PCB, …
Fate of sludge

**FERTILIZER**
- N, P, K, Mg, ..
- Organic fertilizer
- Cheap

**WASTE**
- Organics
- Pathogens
- Heavy metals
- Drugs, hormones

**LEGISLATION**
What are the quality requirements for direct reuse?

Agriculture
Greenery
Recultivation
Sludge quality – what is it already in the legislation?

• Stabilisation
  – Content of organics

• Hygienisation
  – Content of pathogens

• Anthropogenic inorganic contaminants
  – Heavy metals (Cd, Hg, Ni, Zn, Cu, …)

• Anthropogenic (toxic) non-biodegradable organics
  – Drugs, antibiotics, hormones, PCB, …
Stabilisation of sludge in the Estonian legislation

- **Oxygen demand**
  - $< 10 \text{ mg O}_2/\text{g DS 96-hour period}$

- **Content of organics – loss of ignition (VS)**
  - $\text{VS has decreased more than 38\%}$

- **Content of organics (VS/TS)**
  - $\text{VS/TS < 0,6}$

- **Biogas potential**
  - $< 0,25 \text{ l/g VS}$

- **Volatile fatty acids**
  - $< 0,43 \text{ g KHT/g VS}$
Sludge quality – what is it already in the legislation?

• Stabilisation
  – Content of organics

• Hygienisation
  – Content of pathogens

• Anthropogenic inorganic contaminants
  – Heavy metals (Cd, Hg, Ni, Zn, Cu, …)

• Anthropogenic (toxic) non-biodegradable organics
  – Drugs, antibiotics, hormones, PCB, …
Sludge hygienisation

COMMISSION REGULATION (EC) No 208/2006
of 7 February 2006
amending Annexes VI and VIII to Regulation (EC) No 1774/2002 of the European Parliament and of the Council as regards processing standards for biogas and composting plants and requirements for manure

- Content of pathogens
  - Digestion residues or compost taken during or immediately after processing at the biogas or composting plant must comply with the following standards:
    - *Escherichia coli*: 1 000 CFU/g;
    - *Enterococaceae*: 1 000 CFU/g;
Can hygienisation be achieved?

- Windrow composting in ambient conditions needs extended periods and unstabilized sludge
  - Problems in winter period
Study by: Estonian Central Lab

Development of strategy for wastewater sludge treatment, including assurance of safe reuse, application of chemical ana biological indicators and introduction of quality system. II STAGE
Pathogens in 6 Estonian WWTP with windrow composting

Escherichia coli

Log Escherichia coli (MPN/g)

RAW
TREATED
EU 208/2006

WWTP 1  WWTP 2  WWTP 3  WWTP 4  WWTP 5  WWTP 6
Can hygienisation be achieved?

- Windrow composting in ambient conditions needs extended periods and unstabilized sludge

- Reactor composting – properly controlled temperatures

$E\ coli: <10\ CFU/g$
Can hygienisation be achieved?

- Windrow composting in ambient conditions needs extended periods and unstabilized sludge

- Reactor composting – properly controlled temperatures

- Anaerobic digestion needs hygienisation
Sludge quality – what is it already in the legislation?

- **Stabilisation**
  - Content of organics

- **Hygienisation**
  - Content of pathogens

- **Anthropogenic inorganic contaminants**
  - Heavy metals (Cd, Hg, Ni, Zn, Cu, …)

- **Anthropogenic (toxic) non-biodegradable organics**
  - Drugs, antibiotics, hormones, PCB, …
Wastewater content of heavy metals Germany

- Heavy metals
- Heavy metals levels can be affected long term
- Means of influence
  - Legislations
  - Guidelines and practices
Heavy metals

- Limits for heavy metals in Estonian legislation are accordance with EC directive 86/278/EEC

<table>
<thead>
<tr>
<th></th>
<th>Estonian law SLUDGE [mg/kg TS]</th>
<th>HELCOM SLUDGE [mg/kg TS]</th>
<th>ECN-QAS COMPOST [mg/kg TS]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mercury (Hg)</strong></td>
<td>16</td>
<td>1</td>
<td>0.45</td>
</tr>
<tr>
<td><strong>Cadmium (Cd)</strong></td>
<td>20</td>
<td>1</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Lead (Pb)</strong></td>
<td>750</td>
<td>100</td>
<td>130</td>
</tr>
<tr>
<td><strong>Zinc (Zn)</strong></td>
<td>2 500</td>
<td>2 500</td>
<td>600</td>
</tr>
<tr>
<td><strong>Nickel (Ni)</strong></td>
<td>300</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td><strong>Chromium (Cr)</strong></td>
<td>1 000</td>
<td>300</td>
<td>60</td>
</tr>
<tr>
<td><strong>Copper (Cu)</strong></td>
<td>1 000</td>
<td>900</td>
<td>200</td>
</tr>
</tbody>
</table>
Heavy metals – levels in Estonia

- Study of Estonian wastewater sludge by Etonian Central Lab
- 8 wastewater treatment plants, total 80 sludge analyses
- Proportion of samples which are nonconforming with the respective limits

<table>
<thead>
<tr>
<th></th>
<th>Cd, mg/kg</th>
<th>Cr, mg/kg</th>
<th>Cu, mg/kg</th>
<th>Hg, mg/kg</th>
<th>Ni, mg/kg</th>
<th>Pb, mg/kg</th>
<th>Zn, mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limits in the Estonian legislation - 30.12.2002 nr 78</td>
<td>20</td>
<td>1000</td>
<td>1000</td>
<td>16</td>
<td>300</td>
<td>750</td>
<td>2500</td>
</tr>
<tr>
<td>- UNTREATED sludge - nonconforming analyses</td>
<td>0%</td>
<td>2%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
</tr>
<tr>
<td>- TREATED sludge - nonconforming analyses</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>
Sludge quality – what is it already in the legislation?

- **Stabilisation**
  - Content of organics

- **Hygienisation**
  - Content of pathogens

- **Anthropogenic inorganic contaminants**
  - Heavy metals (Cd, Hg, Ni, Zn, Cu, …)

- **Anthropogenic (toxic) non-biodegradable organics**
  - Drugs, antibiotics, hormones, PCB, …
Baltic Marine Environment Protection Commission  
Group on Sustainable Agricultural Practices  
Copenhagen, Denmark, 20-21 November 2014  

**Document title**: Drafting of HELCOM Recommendation on sewage sludge handling  
**Code**: 9-2  
**Category**: INF  
**Agenda Item**: 9 – Phosphorous recycling  
**Submission date**: 17.11.2014  
**Submitted by**: Sweden and Germany  
**Reference**: 2013 Ministerial Declaration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concentration (mg/ kg DS)</th>
<th>Concentration (mg/kg P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>Cu</td>
<td>900</td>
<td>21 400</td>
</tr>
<tr>
<td>Ni</td>
<td>50</td>
<td>1 400</td>
</tr>
<tr>
<td>Pb</td>
<td>100</td>
<td>1 600</td>
</tr>
<tr>
<td>Zn</td>
<td>2 500</td>
<td>800</td>
</tr>
<tr>
<td>Hg</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>Cr</td>
<td>300</td>
<td>2 100</td>
</tr>
<tr>
<td>Ag</td>
<td>5</td>
<td>180</td>
</tr>
<tr>
<td>As</td>
<td>18</td>
<td>-</td>
</tr>
<tr>
<td>Tl</td>
<td>1.5</td>
<td>-</td>
</tr>
<tr>
<td>U</td>
<td>50 mg Uran/ kg P2O5</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concentration (mg/ kg DS)</th>
<th>Concentration (mg/kg P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B(a)P (Benz(a)pyrene)</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>PCB (Polychlorinated Biphenyls)</td>
<td>0.1</td>
<td>2</td>
</tr>
</tbody>
</table>
Sludge quality – what is it already in the legislation?

- **Stabilisation**
  - Content of organics

- **Hygienisation**
  - Content of pathogens

- **Anthropogenic inorganic contaminants**
  - Heavy metals (Cd, Hg, Ni, Zn, Cu, …)

- **Anthropogenic (toxic) non-biodegradable organics**
  - Drugs, antibiotics, hormones, PCB, …
Which sludge treatment technologies should be used?

- **Stabilisation**
  - Content of organics

- **Hygienisation**
  - Content of pathogens

- **Anthropogenic inorganic contaminants**
  - Heavy metals (Cd, Hg, Ni, Zn, Cu, …)

- **Anthropogenic (toxic) non-biodegradable organics**
  - Drugs, antibiotics, hormones, PCB, …
Sewage sludge disposal in Europe 2012

Data: ec.europa.eu/eurostat
Disposal pathways of sewage sludge in Germany (municipal WWTP)

Disposal 2016 in total: 1,77 Mt
New German Sewage Sludge Ordinance: Consequences

Revision of the sewage sludge ordinance („Klär-schlammverordnung“) includes as main regulations:

- WWTPs with a capacity of more than 100,000 inhabitants have to recycle phosphorus after a transition period of 12 years.

- WWTPs with a capacity of more than 50,000 inhabitants have to recycle phosphorus after a transition period of 15 years.

- Direct use of sewage sludge as fertilizer is not allowed after the transition period of 12/15 years.

- Exemptions for small and medium WWTP - these WWTP can use sewage sludge even after the transition period as fertilizer.
What is done with sludge in Estonia?
The sludge study

- The Estonian Ministry of the Environment contract
- Investigation of the sludge management strategy in Estonia
- Development of the solutions for regional sludge treatment and elaboration of the waste discontinuation criteria for wastewater sludge
- 2014 – 2016
  - Stage I – Overview of the sludge management
  - Stage II – Sludge usage and clarification of the sludge potential users
  - Stage III – Discontinuation criteria
  - Stage IV – Financial and economic study for sludge management
Sludge usage in Estonia

- Greenery: 54%
- Agriculture: 16%
- Recultivation: 13%
- Accumulating: 11%
- Others: 6%
What should be done with sludge in Estonia?

Good sludge quality in regards to heavy metals

Unknown risks from anthropogenic organic contaminants
Sludge management concept for Estonia

Principles

- Sludge management has to be feasible
  - Minimise the effect on water price
- Sludge management centres
  - Sludge transportation from small WWTP to the centres
Sludge usage in Estonia

- Sewage sludge ordinance defines sludge usage as “waste”
- Starting from 2013 registration of sludge usage as waste final deposit is required
  - Sludge usage for real estate has been one of the major usage areas
  - Sludge usage for private usage (greenery, lawn) is ceased

Market competition

- End of waste has been legalised for biowaste compost (2013) and digestate (2016)
- There are two legalised products, which compete with sewage sludge (waste) at the market
Media

- Sludge usage in greenery is very vulnerable.
- Media publications can affect the strategy of water company and behaviour of the population.

Citations

- "The do not know what happens, if sludge-related antibiotics are introduced into the soil – all kinds of fungus and aborted bacteria can develop. "
Flexible sludge management concept for Estonia

A – Dewatering and sludge treatment centres

20 000…400 000 PE

2 000…20 000 PE

50…2 000 PE
Flexible sludge management concept for Estonia

B – Sludge treatment centres for high quality sludge

AGRICULTURE  GREENERY  RECULTIVATION

Local demand management
End of Waste
Compost as product
Flexible sludge management concept for Estonia

B – Sludge treatment centres for high quality sludge

Big potential

End of Waste

Quality normalised to P
Sludge management concept for Estonia

- Direct use of sludge should not be banned for good-quality sludge
  - Direct reuse of nutrients

- Gradual, demand-based adaption of drying and incineration

- Propagation of direct use of good quality sewage sludge by defining End of Waste (EoW) criteria for sewage sludge.

Ordinance

- Requirements for preparation of sewage sludge fertilizer product

Reoveesettest toote valmistamise nõuded

Vastu võetud 19.07.2017 nr 24
End-of-waste law in Estonia

2013 - EoW for **biowaste compost** (2013)
  –  https://www.riigiteataja.ee/akt/119122015010

2013 - **Certification body** in Estonia is *Foundation ‘Certification Centre of Recycled Materials’*

2014-2015 – development of certification documents

2015 Dec – Case 1 sertification

2016 Feb – National Accreditation Center issued sertificate

2016 – EoW for **biowaste digestate**
  –  https://www.riigiteataja.ee/akt/119052016009

2017 – EoW for **sewage sludge**
  –  https://www.riigiteataja.ee/akt/128072017004
  –  2017 first sertification process failed (excessive Cd)
  –  2018 several sertifications in progress
Estonian end of waste (EoW) legislation for sludge

**CERTIFICATION PROCESS**

**REQUIREMENTS**

- **Stability** (oxygen demand, biogas, VS/TS, …)
- **Hygienisation** (*Salmonella*, *E coli*, helminth eggs)
- **Other unwanted** (weed seeds)
- **Heavy metals**

<table>
<thead>
<tr>
<th>Substance</th>
<th>Agricultural usage [g/kg P]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead (Pb)</td>
<td>7,5</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>0,2</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>15,0</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>45,0</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>4,0</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>0,1</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>125</td>
</tr>
</tbody>
</table>
Flexible sludge management concept for Estonia

C – When sludge quality is not sufficient

- **AGRICULTURE**
- **GREENERY**
- **RECOLTIVATION**

Monoincineration preferred
Most expensive
Alternative C

Three sludge incineration centers

Region
- Harju
- Ida-Viru
- Tartu

Incineration center
Dewatering center

Approximately 600,000 PE
Approximately 200,000 PE
Approximately 200,000 PE

Step by step realisation only if:
- sludge quality is not sufficient;
- no usage could be found
- new information about the hazardous nature of sludge
P-recovery potential from a WWTP

REUSE

OR

RECOVERY
Potential of using sewage sludge as a agricultural fertilizer in Estonia
Total agricultural need for P-fertilizer in Estonia

- P from sewage sludge
- P mineral fertilizer used
Phosphorous recovery from sewage sludge

Wastewater

WWTP

Effluent

150-200 L/(PE•d)
1,8 g P/(PE•d)
dissolved P
Recovery ~ 45 %

1-10 L/(PE•d)
20-100 mg/L
dissolved P
Recovery ~ 45 %

0.15 L/(PE•d)
~ 10 mg/kg
bound P
Recovery ~ 85 %

Primary sludge

Surplus sludge

SLUDGE

Digester

Drying and incineration

Ash

0.03 kg/(PE•d)
~50 g/kg
chem bound P
Recovery ~ 85 %

150-200 L/(PE•d)
5-8 mg/L
dissolved P
Recovery 15-50 %
Phosphorous recovery methods

Wastewater → WWTP → Effluent

Primary sludge → Surplus sludge

Sludge with phosphorus

Cristallization and precipitation processes
- Phostrip
- DHV Crystalactor
- Ostara PEARL
- Unitika Phosnix
- Nishihara
- Kurita fixed bed reactor
- Ebara
- MAP crystallization Treviso
- CSIR fluidized bed reactor
- REPHOS

Ion exchange processes
- REM NUT
- PHOSIEDI

Combined and special processes
- RECYPHOS
- Magnetic separation

Digester → Drying and incineration → Ash
Phosphorous recovery methods

Wastewater → WWTP → Effluent

Primary sludge → Surplus sludge

Sludge water → Primary sludge

Cristallization processes
- AirPex MAP process
- PECO process (mikrobiell. Oxid.)
- FIX Phos

Acidulation processes
- Stuttgart process
- Seaborne process
- Kemira KEMICOND

Hydrothermal processes
- PHØXNAN LOPROX process
- Kemira KREPRO
- Aqua-Reci
- Cambi process

High temperature processes
- Mephrec
- ATZ iron bath reactor

Electrokinetic process
- EPHOS

Bioleaching process
- Inocre

Wet chemical extraction processes
- RÜPA/PASCH process
- SEPHOS process
- SESAL (enhancement of SEPHOS)
- BioCon
- Eberhard process

High temperature processes
- SUSAN
- Mephrec
- ATZ iron bath reactor

Ash
TECHNOLOGIES

Local dewatering and transport to bigger plant
Lime stabilisation
Extended aerobic
Sludge beds & humification
Reactor composting
Anaerobic digestion
Windrow composting
Drying / incineration

5 ... 50 ... 100 ... 500 ... 1000 ... 5000 ... 10 000 ... 50 000 ... 100 000 ... 500 000 PE
Cost of sludge treatment in Estonia

- Windrow composting: 25 €/m³
- Reactor composting: 48 €/m³
- Anaerobic digestion: 82 €/m³
- Sludge transport: 50 €/m³
Feasibility of technologies

• Biogas plant (anaerobic digestion)
  – Feasibility starts from 50 000…100 000 PE
  – Investment for 100 000 PE ~ 6 M€

• Drying plant
  – Feasibility starts from 100 000…200 000 PE
  – Investment for 200 000 PE ~ 6 - 8 M€

• Drying and incineration plant
  – Feasibility starts from 200 000…400 000 PE
  – Investment for 200 000 PE ~ 10 - 12 M€

• P – recovery plant ???
  – Only for regional centres
  – Possibly in conjunction with incineration
Conclusion

- Estonia has continued with direct usage of sewage sludge in agriculture, greenery and recultivation (N & P reuse).
- In order to facilitate reuse of quality sludge Estonia has legalised EoW for sewage sludge.
- Local sludge treatment centres for small WWTP-s is foreseen to manage quality and cut the costs.
- Step by step application of incineration and P recycling technologies for sewage sludge is postponed and realised on demand.
Thank you!

taavo.tenno@aquaconsult.ee
www.aquaconsult.ee