Sewage sludge management in a circular economy: Exploring technologies applied in the Netherlands

Summary of MSc student group work report for Academic Consultancy Training, Wageningen University & Research

1 Introduction

1.1 Context of this document

This summary document provides an overview of the main findings reported by an interdisciplinary team of seven MSc students, in the framework of their Academic Consultancy Training at Wageningen University & Research (WUR). The research topic was commissioned by the Netherlands Water Partnership (NWP) for initiating and fostering collaborations between the Dutch and Western Balkan[1] water sectors. At present, the countries in the region are expanding their sewer networks and increasing the number of sewage treatment plants, which will lead to increased amounts of sludge that need to be properly managed. There is a pressing need to explore sustainable solutions for sewage and sludge management that can be adapted to the context of the region.

The students explored existing and innovative sewage sludge management technologies applied in the Netherlands, reviewing technical, economic, environmental, and socio-political aspects. The resulting non-exhaustive overview can be used by NWP to assist decision makers in the Western Balkan region in the selection of sludge treatment options that support the European Union's (EU) goal of a circular Europe by 2050. Given the many years of Dutch experience in sewage sludge management, an overview of the expertise located in the Netherlands could greatly contribute to the development of new sludge treatment facilities in the Western Balkan region.

> The MSc student project was executed by means of a literature review and interviews with experts of the Dutch sewage treatment sector. The original report is more detailed and contains the references to the information sources. See also page 11.

Wastewater treatment coverage in the Netherlands has been almost 100% since 2008, with around 350 sewage treatment plants. In the year 2016, approximately 345 thousand tons of sludge were produced in the country. In the Netherlands, the concept of transforming WWTPs into "Energy and Resources Factories" is being implemented. The transformation is led by a team of employees from water authorities that want to contribute to the transition of wastewater treatment to the recovery and reuse of energy and raw materials. Examples of recovered materials are cellulose, nutrients, bioplastics, fatty acids, Kaumera gum, water, biomass, and energy. Over the years, the Dutch water sector has been developing innovative sludge treatment techniques and has become a leader in implementing resource recovery. According to largest Dutch sludge treatment company SNB, over 95% of sludge treatment residues were employed as reusable raw materials.

1.2 Sustainability in sludge treatment

EU legislation on waste treatment is aiming to shift the perception of waste as an unwanted burden towards valuing it as a resource. Legislation and policy – on the European, national and local level – greatly influence the final destination of the sludge, and can stimulate or block certain choices with respect to options for e.g. energy or nutrient recovery options.

[1] *In this specific study, the Western Balkan region refers to the following countries: Albania, Bosnia and Herzegovina, Croatia, Kosovo, North Macedonia, Montenegro, Serbia, and Slovenia*

2 Sludge Treatment Chain

At most sewage treatment plants, sludge is separated in a primary and a secondary settling stage taking place before and after activated sludge processing. Sludge management can include different steps, depending on the desired end use. An overview of a typical sludge treatment chain employed in the Netherlands is given in Figure 1.

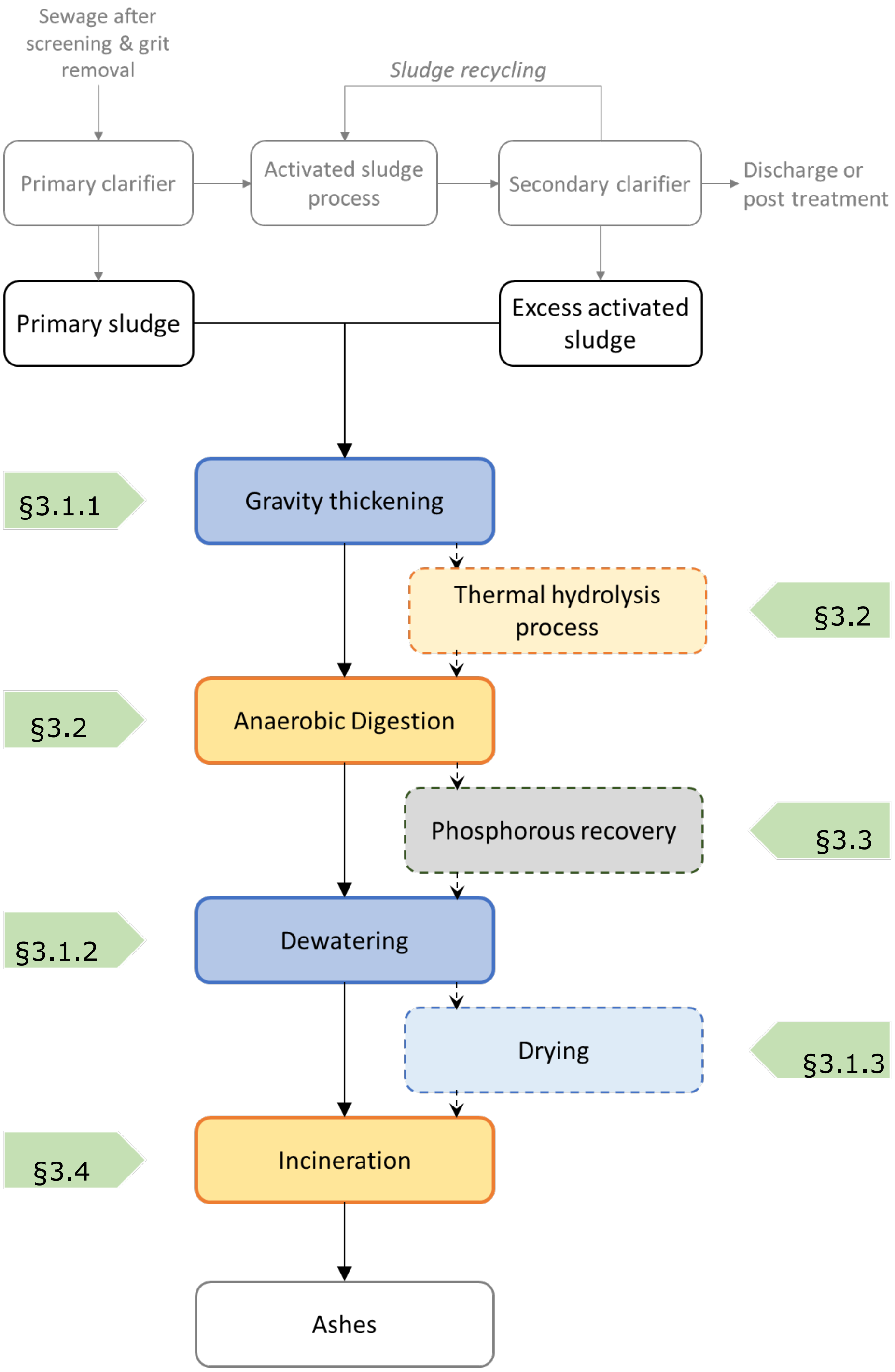

Figure 1: Common Dutch sludge treatment chain and additional options. ***BLUE*** *refers to volume reduction and stabilisation,* ***GREY*** *to nutrient recovery and* ***ORANGE*** *represents energy recovery options. Dotted lines represent treatment steps that are less commonly applied. Clicking on the green arrows takes you to the respective document section.*

3 Established Sludge Treatment Techniques

3.1 Volume Reduction & Stabilization

Sewage sludge typically has a high moisture content of over 95%. In order to lower the cost of treatment and transportation, thickening and dewatering processes are employed to reduce the sludge volume. These can be followed by composting or external heat drying to further reduce the volume and stabilise the sludge.

3.1.1 Thickening

Thickening is usually done on-site. Commonly large circular gravity settling tanks are used, in which the sludge is slowly stirred while allowing it to settle on the bottom of the tank where it is scraped towards the outlet. Belt filters are less commonly used.

- Reduces sludge volume.
- Low complexity.
- Resulting sludge concentration up to 15% depending on sludge type.

Comparing gravity and gravity belt thickening methods

Gravity thickening	Gravity belt thickening
Requires a much larger area. Consumes less energy. No chemical additives required.	Compact method. Needs more operator attention. Polyelectrolytes are used.

3.1.2 Dewatering

During dewatering, thickened sludge is separated in a sludge cake and rejection water. The achieved solids content depends on e.g. the applied technology, the composition of the mixed sludge and the use of flocculants. In the Netherlands, decanter centrifuges are most used. Other options are belt filter or membrane filter presses.

- Greatly reduces sludge volume.
- Input of energy and chemicals (coagulants / flocculants).
- Solids 10-50% depending on the applied technology.

Comparing decanter centrifuge, belt filter press and membrane filter press

Decanter centrifuge	Belt filter press	Membrane filter press
Continuous process, complex. Electricity input is higher. Most compact system, requires specialised maintenance. Solids concentration up to 30%	Continuous process. Least complex of the three. Lower capex and opex compared to the other two methods. Solids concentration up to 25%	Batch process, complex. Can achieve a twice higher solids concentration compared to the other two methods. Solids concentration up to 50%

3.1.3 Drying by composting

Composting is a biological process that converts organic matter into stable humic-like compounds. In the Netherlands the process is carried out in large closed tunnels. Dewatered sludge is mixed with a dry bulking agent, and receives a continuous supply of air. The aerobic degradation processes release heat, raising the temperature to 65-70℃. Ammonia is liberated from the sludge and stripped with the supplied air. Ammonium sulphate can be recovered from the exhaust air, absorbing it in a sulphuric acid solution. In the Netherlands, it is not allowed to use composted sludge in agriculture. However, sludge composting is a crucial part of the mono-incineration line: before incineration, dewatered and composted sludges are mixed, producing an optimal 45% dry solids.

- Relatively simple.
- Needs a large area.
- Release of odour and ammonia.
- Dry matter content up to 65%.
- Several countries allow the use of composted sludge in agriculture.

3.1.4 External heat drying

In sludge drying greenhouses, residual heat of 60-100°C is used to dry the sludge, resulting in a dry matter (DM) content of 60-70%.

Dried sludge is not biologically stable and cannot be stored for a longer period. Maintenance of the greenhouses is easy, and capex can be relatively low. Belt dryers operate at 80-120°C. Air is forced through the sludge, maximising evaporation.

- Energy intensive, it is more sustainable to use non-fossil energy sources such as residual heat from industries or biogas.
- Release of odour and ammonia.

Comparing sludge drying by composting, sludge drying greenhouses and belt driers.

Composting	Sludge drying greenhouses	Belt dryer
65-70°C. Internal heat source, cooling needed. Dry bulking material needed. Output is granulated sludge with 65% DM.	60-100°C. External heat source. Low complexity. Output is granulated sludge with >60% DM.	80-120°C. External heat source. Most complex of the three methods. Needs large investments. Low area requirement compared to the other two methods. Output DM>90%, risk of flammability.

3.2 Energy recovery: Anaerobic digestion

Anaerobic digestion (AD) converts degradable organic matter into biogas, a mix of mainly methane and carbon dioxide. It is one of the most widely used and technically mature sewage sludge treatment techniques. In the Netherlands, a major part of the thickened sludge is used for biogas production.

- Biological process without oxygen.
- Produces biogas (energy source).
- N and P are released in recoverable form.
- No special pre-treatment needed.
- Capex relatively low.

Due to the high water content of sewage sludge, even after thickening, large digester volumes are needed and a significant part of the biogas is used to maintain either mesophilic (around 35°) or thermophilic (around 55°) process temperatures.

Biogas generally contains around 60-70% methane and can be used for e.g. combined heat and power production (CHP), heat generation, vehicle fuel and as building block for the production of chemicals. Depending on the application certain components such as H_2S, CO_2 and water need to be removed from the biogas.

Comparing mesophilic (MAD) and thermophilic anaerobic digestion (TAD)

Mesophilic anaerobic digestion	Thermophilic anaerobic digestion
35-40 °C	55-60 °C Higher energy input
Larger reactor volume	Better pathogen inactivation
Process is more stable	Lower foam formation
Lower volatile solids removal	Lower dewaterability of digested sludge

Thermal Hydrolysis Process

The Thermal Hydrolysis Process (THP) can be applied to improve biogas production from sludge. At high temperature and pressure, complex molecules are hydrolysed, making organic matter better available for further conversion and increasing the biogas yield. Pathogens are inactivated.

THP also enhances the dewaterability, increasing DM content from 24-25% to 27-28%. When coupled with AD, the increase in biogas production will be sufficient to cover the THP energy demand. Capex and opex are relatively high.

During AD, organically bound N and P are released into the liquid as ammonia and phosphate, making them available for recovery. Biogas production is an integral part of the Dutch "Energy and Resources Factories" concept. Water authority Vallei & Veluwe is currently able to provide 80% of their energy needs of all their sixteen WWTPs with the obtained energy out of the biogas of two WWTPs.

3.3 Phosphate recovery from sludge liquor

Sewage sludge contains phosphorous (P) that can be recovered in mineral form as a replacement for mineral fertilisers. In the sludge treatment line, P recovery is done after anaerobic digestion, as during AD the organically bound P is liberated as recoverable orthophosphate.

- P recovery after AD.
- influent concentration >60 mg/l P
- Recovery rate: 80–90% of PO_4-P
- Producing slow-release fertiliser.
- Chemical input needed.

Struvite

At STPs in the Netherlands, the main applied phosphate recovery process is struvite precipitation from digested sludge liquor. Struvite, magnesium ammonium phosphate ($MgNH_4PO_4 \cdot 6H_2O$), is a slow-release fertiliser.

Different types of struvite reactors exist, each with their particular configuration. Three well-developed techniques are AirPrex®, PHOSPAQ® and ANPHOS®.

Calcium phosphate

Phosphate can also be recovered as calcium phosphate. The Crystalactor® is one of the possible technologies. It was developed in the early 1980s to remove calcium from drinking water as calcium phosphate.

Chemicals are required to precipitate P. Magnesium chloride ($MgCl_2$), Magnesium oxide (MgO) and Calcium hydroxide ($Ca(OH)_2$) are commonly used. Apart from recovering fertiliser products, removing P from the sludge liquor prevents operational problems due to spontaneous struvite precipitation downstream of the AD. The legal status of P fertiliser products recovered at WWTPs can vary per country.

3.4 Energy recovery: Incineration

Dewatered and dried sludge can be incinerated, recovering the calorific value of the biosolids. Incineration is the second predominant final sludge processing method in the EU, dealing with over 20% of produced sludge. It reduces the sludge volume by 90% and ensures that any organic pollutants are effectively inactivated.

- Final processing method.
- Energy recovery from the OM.
- Flue gases need special attention to prevent air pollution.

The ashes and flue gases contain heavy metals and other (in)organic pollutants and should be properly dealt with. The sludge water content influences the energy balance. There are two types of thermal energy at an incinerator: direct heat, which is used for sufficiently drying the incoming flow, and hot steam from flue gas cooling. If excess energy is produced it may be possible to use this for e.g. industries or district heating. In the Netherlands, all sludge is finally treated with incineration, as both agricultural application and landfilling are not legally possible.

Mono-incineration

In mono-incineration, sludge (dewatered or dried) is the only input. The sludge is transported to a fluidized bed chamber and heated to 850-950℃. Ash moves with the flue air and is collected in an electrostatic receptor, off-gases are cleaned. The bottom ashes have a high phosphorous content, and initiatives to recover P from the ashes are gaining interest (see §4.1). In the Netherlands there are two large mono-incineration plants.

Co-incineration

Co-incineration uses sludge as one of several fuels, for example adding sludge to coal-fired power plants. This is widely applied in the EU. Another common combination is to incinerate sludge with municipal solid waste. Depending on the exact configuration, either dewatered or dried sludge is used. Generally, sludge co-incineration is an add-on value, as it is done at an existing incineration plant and does not interfere with the normal waste incineration. However, the treated sludge volume is limited to about 7% of the plant's capacity. Under certain conditions, the bottom ashes can be used as construction material. The P-content of the ashes is too low for efficient recovery.

Comparing mono-incineration and co-incineration.

Mono-incineration	Co-incineration
Only for incineration of sludge. Can be energy-positive. Pure sludge ashes, suitable for P recovery.	Done in existing incineration plant, additional installations needed. Amount of sludge that can be processed limited. Required sludge DM content depending on exact configuration. Mixed ashes with lower nutrient contents.

Ashes

Bottom ashes from sludge incineration are in many countries still disposed of at landfills. The ashes can be used as raw material for bricks, road construction, and cement. Mono-incineration produces ashes that are high in phosphorous. Interest in P recovery is increasing, see §4.1. According to Dutch legislation, neither mono- nor co-incinerated sludge ashes can be landfilled. In 2020 the use of ashes as construction material has become mandatory in the Netherlands. Its use is regulated to prevent soil or groundwater pollution. Different ways to improve the ashes' quality are applied, to enhance and further enable reuse options. The ashes from Dutch sludge incineration are nowadays used as filler material in roads and bricks, or exported to Germany to support salt mines from collapsing.

3.5 Agricultural application

Agricultural application is the most circular option for sewage sludge management, as organic matter and plant macro- and micro-nutrients are recycled to the fields to produce crops. Sludge can be applied on the field in different forms: thickened, dewatered, dried, and with or without composting or anaerobic digestion.

- Circular solution for organic matter and nutrients.
- National legislation is a decisive factor.
- Seasonal activity, storage capacity needed.

However, sludge also contains organic and inorganic pollutants: e.g. pathogens, heavy metals, pharmaceutical residues, dioxins and microplastics. Some experts see sewage sludge as an ideal fertiliser in a circular society, whereas others fully support a ban on its soil application to protect human and environmental health. Legislation in some countries greatly limits or prohibits the use of sludge on land. In 2017, 40% of the sludge produced in the EU was applied in agriculture, with large differences between individual countries.

Consulted Dutch experts expressed that agricultural use is actually the most circular and sustainable option, and economically more attractive than incineration. The sludge treatment sector of the Netherlands is currently looking into different ways to improve sludge quality to meet the standards for agricultural use.

4 Recent developments in the Netherlands

In the Netherlands almost all of the sludge is finally incinerated. Alternative technologies are developed and tested to find circular applications for at least part of the resources contained in the sludge. In this subchapter, some of these are presented.

Phosphate recovery from mono-incineration ashes

Ashes from mono-incineration contain almost all of the phosphorous originally contained in the sludge, resulting in a high P content of around 27% that makes recovery interesting. Several pilots have resulted in proof of concept, with the wet chemical process as the most popular technology. Dutch mono-incinerator HVC plans to build a full scale installation.

Supercritical Water Gasification

Supercritical water gasification (SCWG) is a technique for the conversion of biomass containing high moisture contents into fuel gases, such as methane and hydrogen. The critical point for water is at a temperature and pressure of 374°C and 22.1 MPa. Since the gasification process takes place in water, sludge can be directly treated with the SCWG process, eliminating the need for drying. Also P recovery receives attention. The first demonstration plant of the Netherlands is being built in Alkmaar.

MID-MIX®

The MID-MIX® technology converts sewage sludge into a raw material by reacting with quicklime. When stabilising dehydrated sludge with quicklime, an exothermic reaction takes place. The temperature rises and water and ammonium are released. Organic matter is converted to CO_2 and subsequently to calcium carbonate ($CaCO_3$), 'encapsulating' heavy metals which means that they are strongly bound in the final product called Neutral. An essential difference between the MID-MIX® process and existing final sludge treatment techniques, is that there is no ash left after the MID-MIX® process. Recently, the company VSGM has built a the first full-scale plant in The Netherlands in Wilp.

Kaumera Nereda® Gum

Kaumera Nereda® Gum, a multi-purpose biobased raw material, can be extracted from the sludge granules that form during the Nereda® purification process. This technique is already implemented at the WWTP of Zutphen in the Netherlands. Sludge granules are broken at high temperature and high pH after which the polymers are separated and precipitated as Kaumera gum. The recovery of Kaumera from sludge has an important benefit for the water authorities of the Netherlands: a sludge reduction of 20-35%, which has positive effects on their energy use and CO_2-emissions.

Power to Protein

The Power to Protein (PtP) concept focuses on closing the nitrogen cycle by using ammonium from sludge digestion rejection water as building block for microbial protein. The PtP concept uses specific bacteria, that form single cell protein from hydrogen, carbon dioxide, oxygen and ammonium. Ammonium can be recovered from rejection water using air stripping or gas permeable membranes, for example the NutriTec-N® process by Dutch company Sustec. The PtP concept is still in the development phase, after pilot testing at WWTP Hengelo several points of improvement were identified that need to be solved before the technology can be successfully applied in practice.

TORWASH®

TORWASH® is a wet torrefaction process developed by the Energy Research Centre of the Netherlands (ECN). Biomass, such as sludge, is treated at high pressure and temperature during which the chemical structure is changed and solids partly dissolve. The resulting slurry is dewatered to cakes of 50% dry matter content that can be used as biofuel. The liquid fraction can be used for biogas production. After a successful pilot trial at WWTP Almere, work has begun to scale up the process.

ViviMag

At many WWTPs iron salts are dosed to remove phosphate by precipitation. During sludge AD an insoluble iron-phosphate mineral is formed, called vivianite ($Fe_3[PO_4]_2 \cdot 8H_2O$). Around 70 to 90% of the phosphate is bound in this form in iron-rich digested sludge. Vivianite becomes magnetic as soon a strong magnet is close by, a property used by magnetic separation technique ViviMag that is currently at pilot stage. The recovered vivianite can be used as iron-fertiliser for particular agricultural fields. Further research is being done on separating the iron and the phosphate to increase the use options, and also on using vivianite as a fire retardant or as raw material for lithium iron phosphate batteries.

About this summary document

This document summarises the main information of the report: "Exploring Sustainable Sludge Treatment Techniques in the Netherlands - Recommendations to implement Dutch practices and knowledge in the Western Balkan Region", written by a interdisciplinary group of MSc students as part of their work in the Academic Consultancy Training at Wageningen University. The assignment was commissioned by Darja Kragić Kok of the Netherlands Water Partnership and was conducted in May-June 2020. The full report contains more detailed information and the references to the information sources.

The student group, *Sustainable Sludge Wageningen*, consisted of the following members:

Hanchu Yu
Jara Bakx
Jiaoyi Qu
Laura de Gier
Milan Adriaenssens
Viktoria Hartan
Xiangyu Ji

The following Dutch companies and organisations provided information:

For more information about the full student report:

Darja Kragić Kok
Project Manager Central and Eastern Europe
Netherlands Water Partnership (NWP)
d.kragic@nwp.nl
www.netherlandswaterpartnership.com

This summary document was made possible by funding from the Partners for Water programme.